Appendix A

Sonic Boom and Noise Studies

MEMORANDUM

May 29, 2018

TO: Federal Aviation Administration, Office of Commercial Space Transportation

FROM: Space Exploration Technologies

SUBJECT: Sonic Boom Analysis

As described in the 2017 Supplemental Environmental Assessment (SEA) for SpaceX Vertical Landing of Falcon 9 at LC-13, Space Exploration Technologies (SpaceX) is currently returning Falcon first stages to LZ-1 and LZ-2 at Cape Canaveral Air Force Station (CCAFS). While it is SpaceX's goal to boost-back and land all first stage boosters for reuse, because some payloads require additional fuel to reach desired orbits or destinations (due to increased weight or extended trajectory), not all the launches projected would include boost-back and landing. For Falcon Heavy boost-back and landing (which involves three first stage boosters), each of the three boosters would be controlled separately so their approach and landing would be managed independently. Not all of the boosters would land at CCAFS. Some would land on one of SpaceX's droneships in the Atlantic Ocean. For purposes of environmental analysis, the discussion of environmental consequences assumes a maximum of 54 annual first stage boosters landing at CCAFS (LZ-1 and/or LZ-2) and 27 annual first stage boosters landing on a droneship.

An Environmental Assessment (EA) is being prepared for the Proposed Action. The EA is being prepared in accordance with the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.); as implemented by CEQ regulations (40 Code of Federal Regulations [CFR] Parts 1500- 1508); and 32 CFR Part 989.

In accordance with Federal Aviation Administration (FAA) Order 1050.1E, if a project involves commercial space launch vehicles reaching supersonic speeds, the potential for sonic boom impacts should be discussed.

As such, the EA must use applicable methodology and predictions for sonic boom levels of the Proposed Action. It should be noted that the sonic boom model described in 1050.1E FAA Order, PCBOOM, was originally developed to address high frequency lateral events such as airplane and jet take-offs and landings. Historical Environmental Assessments and Environmental Impact Statements for space vehicle launches which occur with much less regularity, acknowledged the 1050.1E FAA Order is not as applicable because of the lower frequency of "the action". Additionally, the Falcon first stage landings are vertical.

SpaceX has run the PCBOOM model in 2015 for Vandenberg landings in preparation of the 2017 Incidental Harassment Authorization Application Boost-Back and Landing of the Falcon 9 First Stage at SLC-4 West. PCBOOM was also run in the 2017 Sonic Boom Analysis for SpaceX Falcon 9 Flybacks to CCAFS and VAFB.

Sonic Boom Modeling

The results of the 2015 PCBOOM modeling underestimated the near-field overpressures based on the recorded data during a landing at CCAFS. In 2017, PCBOOM was used and predicted levels were compared to the overpressure measurements for two Falcon 9 landings at CCAFS. Factors including the physical characteristics of the vehicle, atmospheric conditions through which it propagates, and wind were included in the modeling analysis. The data used in the model for included winds, temperature, and pressure as a function of altitude as recorded by a weather balloon released prior to the launch and landing. Using real data collected during the landing missions, PCBOOM methodology showed similarities between the measured and modeled levels. The CCAFS modeling methodology was then used to model the sonic boom peak overpressures generated by landings at VAFB. Precise and real-time atmospheric factors are needed to provide accurate overpressure predictions for Falcon first stage booster landings.

SpaceX Sonic Boom Data and Modeling

To provide more accurate overpressure predictions, SpaceX and the U.S. Air Force (USAF) adapted the sonic boom modeling used in the NASA technical paper 1122 with modifications, including expansion of the geometry and simplifying relations to estimate the wave propagation to the ground. The SpaceX 1122 model assumes the focal point of the sonic boom is the landing pad (LZ-1 or LZ-2) and has been continuously optimized to match overall data from SpaceX landing missions. The model has been presented to the USAF and used in previous environmental consultations to predict overpressures for SpaceX land landings at Vandenberg, AFB. Prior to landing missions, SpaceX used the adapted 1122 model to predict overpressures across a 10-mile radius and compared the predictions to recorded overpressure levels during the landings of the Falcon first stage boosters. Four low frequency, omni-directional microphones located across a 10-mile radius and were used to record sonic booms for multiple landing missions including the Customer X, CRS-9, CRS-10, CRS-11, CRS-12, NRO L-76, Orbcomm-2, and Falcon Heavy missions. Figure 1 shows the SpaceX modeled overpressure predictions based on the flight trajectory with the measured overpressure levels for the corresponding mission.

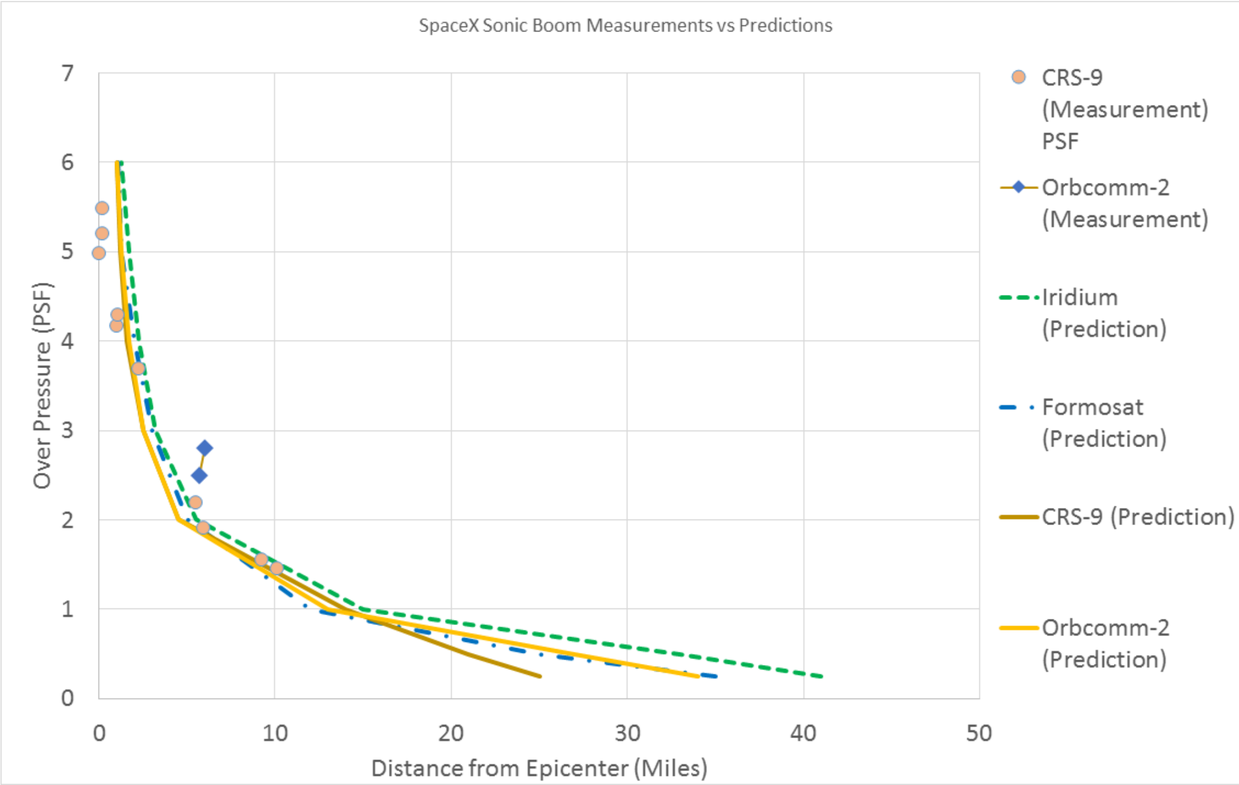

Figure 1

Overpressure measurements were in line with expectations. SpaceX 1122 model predicts mid-field and far-field (>1mile) measurements within 30% accuracy. Near-Field (<1mile) measurements are typically lower than predictions. SpaceX 1122 model over predicts close to the landing site.

Figure 2 compares the measured overpressures of several missions. Comparison of overpressure measurements for Falcon 9 land landings show high precision, with overpressures not exceeding 6 psf. Re-entry trajectories between the missions were similar.

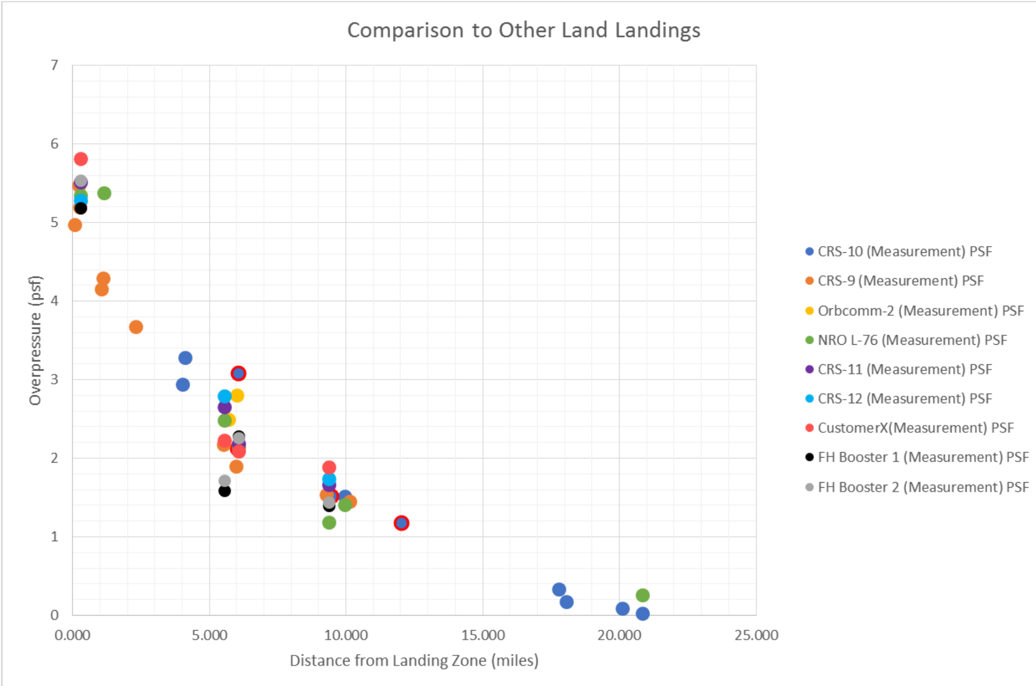

Figure 2: Falcon 9 First Stage

SpaceX also recorded data during the landing of the two Falcon Heavy first stage boosters (Table 1 and Figure 3). The data showed overpressure magnitudes as expected, the booms from each booster remained separate and did not coalesce into a single boom. Booms from each booster are similar in magnitude and remain below 6 psf, as recorded in previous landings.

Table 1: Measured Overpressures during Falcon Heavy First Stage Booster Landings

Microphone Name	Description	As Placed GPS Location	Booster 1 Measurement PSF	Booster 2 Measurement PSF	Distance from LZ-1 (miles)
LZ-1	Landing Zone Dynamics DAQ	28°29'11.07"N 80°32'51.00"W	5.185	5.537	0.28
LC-40	LC-40 Dynamics DAQ	28°33'37.60"N 80°34'37.40"W	1.589	1.713	5.55
LC-39A	LC-39A Dynamics DAQ	28°36'36.526"N 80°36'19.95"W	1.403	1.438	9.38
LCC	SpaceX LCC	28°25'2.00"N 80°36'20.00"W	2.277	2.2582	6.06

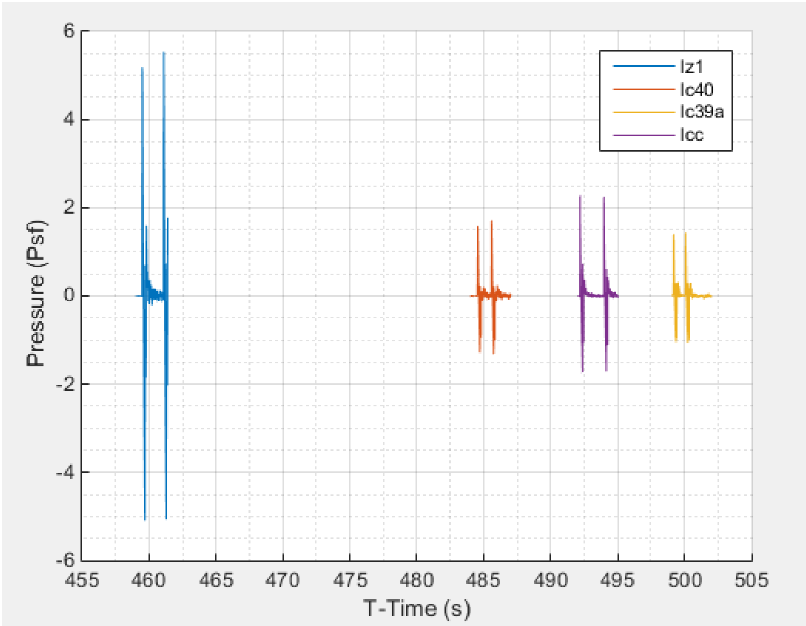

Figure 3

Conclusion

SpaceX has measured and analyzed land landing overpressure data since 2015 and continues to rigorously optimize their adapted 1122 Model to provide the most accurate and appropriate prediction for sonic boom data of a space craft vertical landing. PCBOOM has been used in several instances and unless calibrated to account for precise atmospheric factors, this model can under predict peak overpressures for Falcon first stage boosters. SpaceX believes the adapted 1122 model represents the most applicable overpressure predictions based on the accuracy of the results discussed above and the previous approved use in environmental consultations. SpaceX believes the precision would remain the same for the future Falcon 9 first stage booster landings, with the highest peak overpressure remaining between 6-7 psf. Based on the precision of the data presented, similar re-entry trajectories with the same vehicle would result in similar sonic boom magnitudes.

Blue Ridge Research and Consulting, LLC

Technical Memo

Sonic Boom Noise Analysis for the SpaceX Dragon Reentry

May 29, 2015

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1 Sonic Boom Modeling

SpaceX is proposing to land the Dragon capsule at two potential locations, Cape Canaveral Air Force Station (CCAFS), Florida and White Sands Missile Range (WSMR), New Mexico. This memo documents the sonic boom noise analysis for the two Dragon capsule reentry trajectories.

A vehicle creates sonic booms during supersonic flight. The potential for the boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. The sonic boom is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom. The noise is perceived as a deep double boom, with most of its energy concentrated in the low frequency range. Although sonic booms generally last less than one second, their potential for impact may be considerable.

The single-event prediction model, PCBoom4 (Plotkin, 1996; Plotkin, 1989; Plotkin, et al., 2002), is used to predict a sonic boom footprint. PCBoom4 calculates the magnitude and location of sonic boom overpressures on the ground from a vehicle in supersonic flight. Several inputs are required to calculate the sonic boom footprint, including the aircraft model, the trajectory path, the atmospheric conditions and the ground surface height. Predicted sonic boom footprints are generally presented as contours of constant peak overpressure (in terms of pounds per square foot, psf).

2 Noise Modeling Parameters

The PCBoom4 vehicle inputs include the vehicle length and vehicle weight. These parameters are summarized in Table 1 for the SpaceX Dragon capsule, specific to its reentry configuration. SpaceX personnel provided two reentry trajectories: one landing at CCAFS and the second at WSMR. The trajectory excel file provided, 'trajectories_for_blueridge_04282015.xlsx' contained the parameters time, latitude, longitude, altitude, Mach, heading, and flight path angle. Additional derivations required for PCBoom4 were calculated using the data provided. Site-specific atmospheric profiles were extended to the necessary altitudes and utilized for the following analysis.

Table 1. Vehicle parameters used in acoustic modeling

Vehicle	SpaceX Dragon
Length	14.2 ft
Total Weight	21,000 lbs

3 Results

The peak overpressure contours resulting from the nominal reentry trajectories of the Dragon capsule are shown in Figure 1 and Figure 2 for CCAFS and WSMR, respectively. The maximum predicted sonic boom overpressure is 0.41 psf for CCAFS and 0.37 psf for WSMR. The proposed operational tempo includes two nighttime landings and four daytime landings. The maximum noise exposure associated with the proposed operational tempo and max psf is predicted to be a C-weighted DNL of 33 dBC for CCAFS and 32 dBC for WSMR, which translates to an equivalent A-weighted DNL of 38.5 dBA for CCAFS and 37.5 dBA for WSMR, according to ANSI 12.9 Part 4 Annex B.

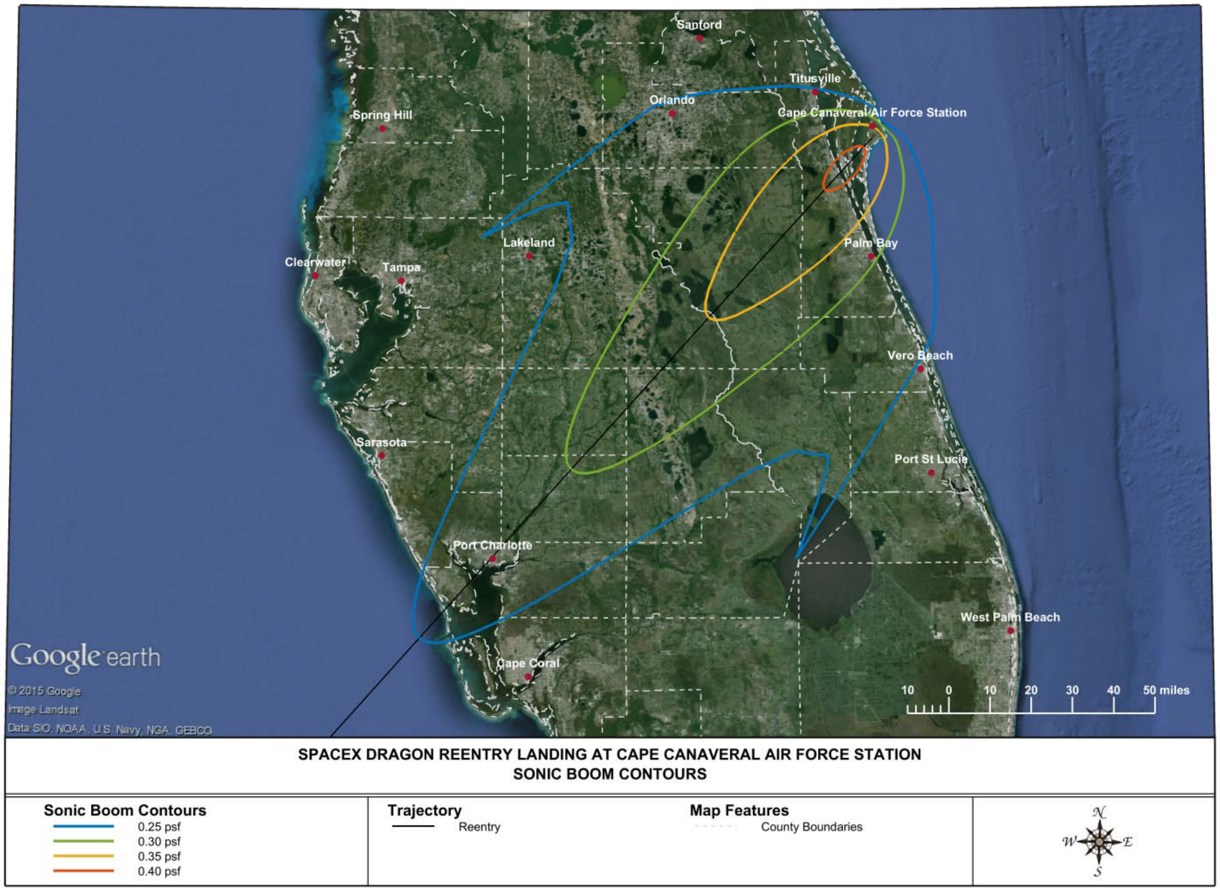

Figure 1. Sonic boom peak overpressure contours resulting from Dragon reentry to CCAFS

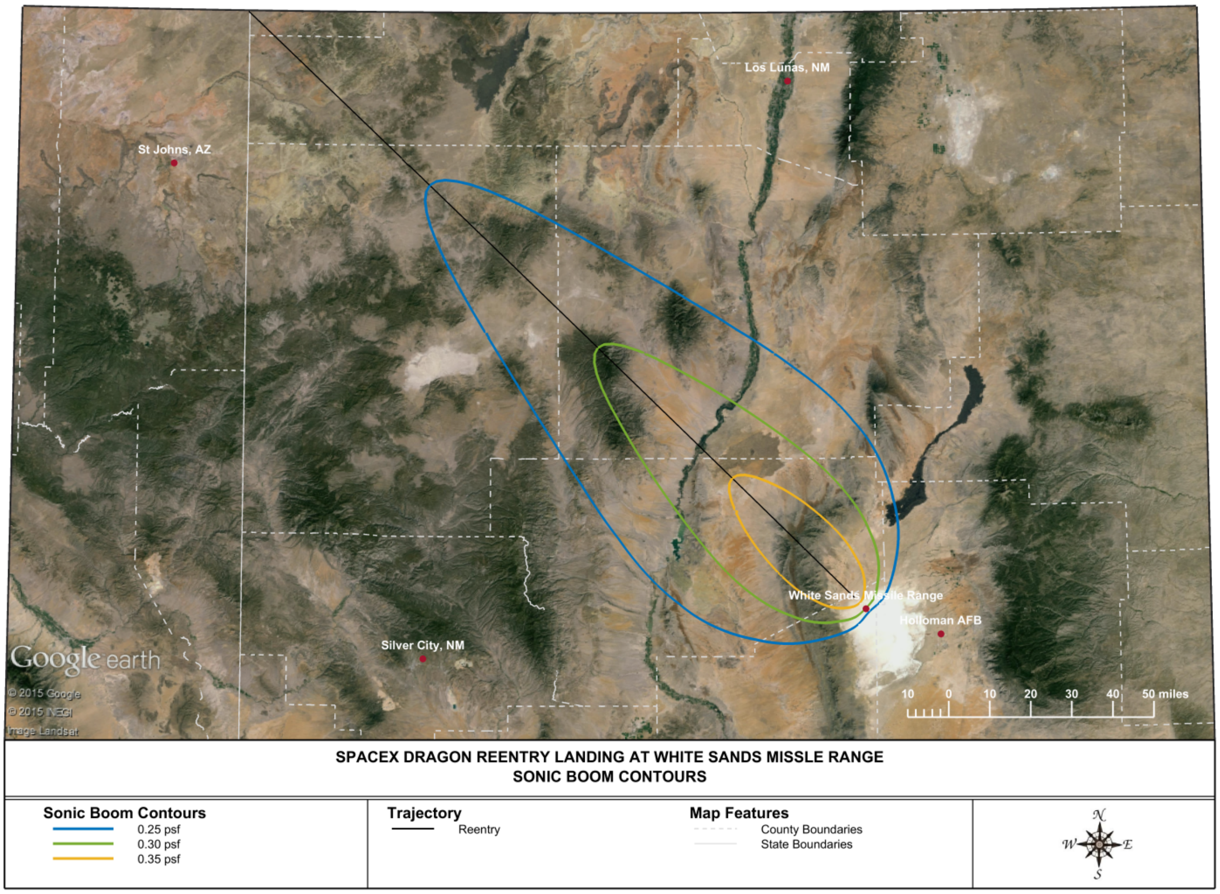

Figure 2. Sonic boom peak overpressure contours resulting from Dragon reentry to White Sands Missile Range

4 References

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Technical Memo

Sonic Boom Study for SpaceX Falcon 9 Flybacks to CCAFS and VAFB

March 2017

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1 Introduction

Sonic boom analysis has been completed for the SpaceX Falcon 9 reusable first stage flybacks to Cape Canaveral Air Force Station (CCAFS), Florida and Vandenberg Air Force Base (VAFB), CA. Recent sonic boom measurements collected by SpaceX personnel during the CRS-9 and CRS-10 missions from CCAFS present the opportunity to identify a PCBoom modeling methodology appropriate for modeling Falcon 9 flybacks. A comparison of measured and modeled results for the two CCAFS missions are presented along with modeled peak overpressure contours. Using the same PCBoom modeling methodology implemented for the CCAFS flybacks, the resulting sonic booms peak overpressure contours are also presented for Falcon 9 flybacks to VAFB.

2 Sonic Boom Modeling

A vehicle creates a sonic boom continuously during supersonic flight. The potential for a boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. A sonic boom waveform is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom heard on the ground. Sonic boom modeling and analysis utilized PCBoom4 software (1; 2), which includes the above factors. PCBoom4 calculates the magnitude and location of sonic boom overpressures on the ground from a vehicle in supersonic flight.

3 Cape Canaveral Air Force Station

The sonic boom peak overpressure measurements for two Falcon 9 flybacks to CCAFS, associated with the CRS-9 and CRS-10 missions, were compared to predicted levels generated using a number of PCBoom modeling methodologies to determine an appropriate modeling methodology based on optimal agreement between the measured and modeled levels. The modeling methodology identified uses PCBoom's mode 3, the Carlson F-function mode, and an axisymmetric shape factor of 0.084.

The trajectory and atmospheric profile data used to model the Falcon 9 flybacks to CCAFS were provided by SpaceX and summarized in Table 1. The CRS-9 and CRS-10 trajectory files include the supersonic portion of the Falcon 9's reusable first stage return to CCAFS. The CRS-9 and CRS-10 atmospheric data files include the winds, temperature, and pressure as a function of altitude as recorded by a weather balloon released prior to the launch and from a ground station approximately 1 mile from the landing site. The weather balloon data were provided for altitudes up to 11 miles. To extend the altitude range within the trajectory data, the temperature profile was extended using data obtained from the National Climatic Data Center (NCDC) Station 74794 at Cape Canaveral for altitudes up to 19 miles and the NASA Technical Memo 4511 and the "Handbook of Astronautical Engineering" (McGraw-Hill 1961) for altitudes up to 56 miles.

Table 1. Data provided by SpaceX

Mission	Trajectory Filename	Atmospheric Profile Filename	Date Received
CRS-9	CRS9_AsFlown.xlsx	F9_27_Boom_Atmospheric.xls	30 Jan 17
CRS-10	CRS10.txt	CRS_10_Boom_Atmospheric.xls	22 Mar 17

The CRS-9 and CRS-10 Falcon 9 flyback sonic boom peak overpressure levels are presented in Figure 1 along with the modeled levels. The peak overpressures are provided in pounds per square foot (psf) with the measured levels (green circles) compared to the modeled levels without wind (filled grey circles) and modeled with wind (outlined grey circles). Table 2 shows the measured levels compared to the predicted levels modeled without wind and with wind. The modeled levels for LZ-1 and Bldg 20185 locations are represented by a range of levels because the locations are within the highest modeled contour and are generated as the vehicles decelerate through Mach 1.0. The selected sonic boom modeling methodology results in predicted levels that compare favorably to measured levels, with a majority of the predictions within 0.5 psf of measured levels as shown in Table 2.

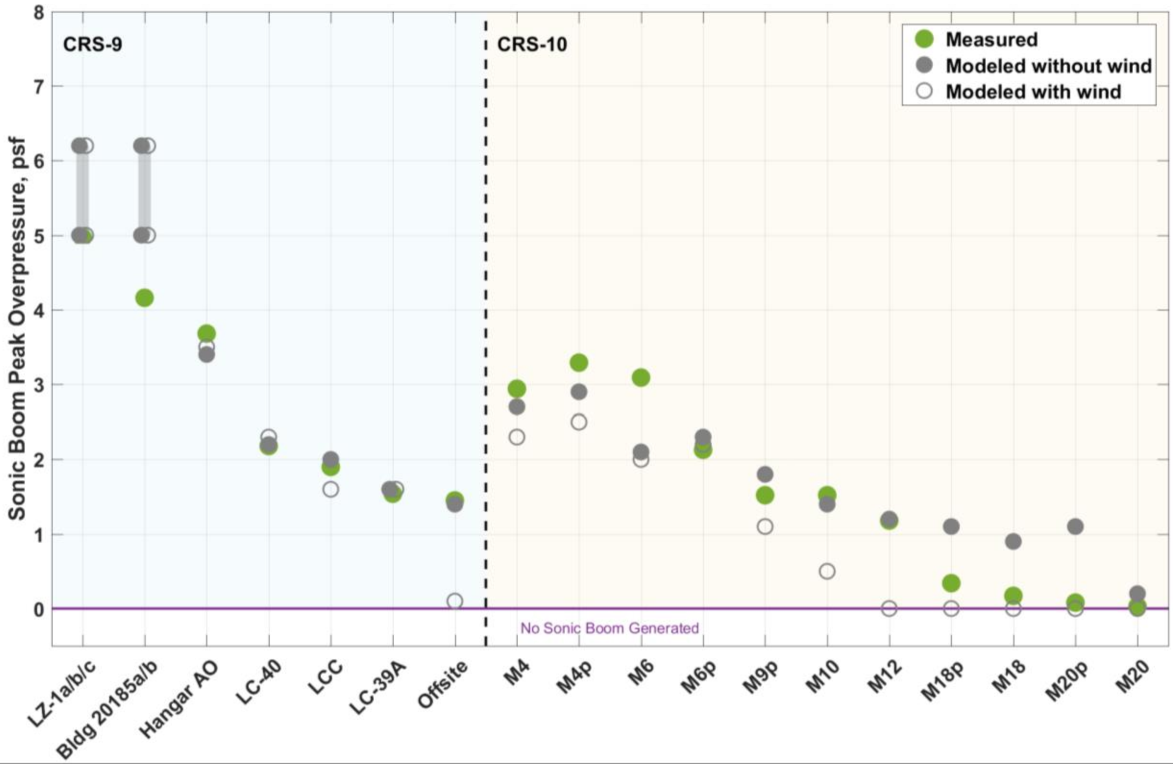

Figure 1. CRS-9 and CRS-10 measured vs. modeled peak overpressure levels comparison

The sonic boom peak overpressure contours are presented for CRS-9 in Figure 2 (without wind) and Figure 3 (with wind), and for CRS-10 in Figure 4 (without wind) and Figure 5 (with wind), along with the mission specific measurement locations (filled red circles). These figures demonstrate the effect wind has on the sonic boom footprint. For the cases with wind included, the sonic boom footprints are shifted and more complex because of the interaction of sonic boom propagation and wind speed profile. As the atmospheric profile was collected prior to the flyback operation, it is important to note that the actual sonic boom generated propagated through a similar but different wind speed profile. These figures provide a demonstration of the variation inherent in sonic boom propagating through a real atmosphere.

Overall, the comparison demonstrates great agreement between the measured and modeled data. Modeling results over-estimated levels for 12 of the 18 measurement locations (67%) when the wind data were not included and 9 measurement locations (50%) with wind included. Modeling without wind provided better estimates overall with levels within 0.1 psf for 14 of the 18 of the measurement locations (78%). The four sites in which modeling with wind results in a significantly smaller difference between measured and modeled are the four farthest CRS-10 measurement locations (M18p, M18, M20p, and M20). The estimated levels at these four sites is 0 psf (no sonic boom generated) because the CRS-10 winds effectively shifted the ground intercept of the sonic so that these last four sites were outside of the boom's footprint.

Table 2. Measured and modeled peak overpressure levels for CRS-9 and CRS-10 flybacks

				Atmosphere (without wind)		Atmosphere (with wind)	
	Location	Distance from LZ 1, miles	Measured psf	Predicted psf	Diff psf	Predicted psf	Diff psf
CRS 9	LZ-1a/b/c	0.2 - 0.3	5.0 - 5.5	5.0 - 6.2	0.0 - 1.2	5.0 - 6.2	0.0 - 1.2
	Bldg20185a/b	1.1 - 1.2	4.2 - 4.3	5.0 - 6.2	0.7 - 2.0	5.0 - 6.2	0.7 - 2.0
	Hanger AO	2.3	3.7	3.4	-0.3	3.5	-0.2
	LC-40	5.5	2.2	2.2	0.0	2.3	0.1
	LCC	6.0	1.9	2.0	0.1	1.6	-0.3
	LC-39A	9.3	1.5	1.6	0.1	1.6	0.1
	Offsite	10.1	1.5	1.4	-0.1	0.1	-1.4
CRS 10	M4	4.0	2.9	2.7	-0.2	2.3	-0.6
	M4p	4.1	3.3	2.9	-0.4	2.5	-0.8
	M6	6.0	3.1[a]	2.1	-1.0	2.0	-1.1
	M6p	6.0	2.1[a]	2.3	0.2	2.2	0.1
	M9p	9.5	1.5[b]	1.8	0.3	1.1	-0.4
	M10	9.9	1.5[a]	1.4	-0.1	0.5	-1.0
	M12	12.0	1.2[a]	1.2	0.0	0.0	1.2
	M18p	17.8	0.3	1.1	0.8	0.0	0.3
	M18	18.1	0.2	0.9	0.7	0.0	0.2
	M20p	20.1	0.1	1.1	1.0	0.0	0.1
	M20	20.8	0.03	0.2	0.17	0.0	0.03

[a] Value is estimated by SpaceX from Clipped Data.

[b] Data is from SpaceX Pad measurement and microphone has a 20 Hz – 20 kHz response.

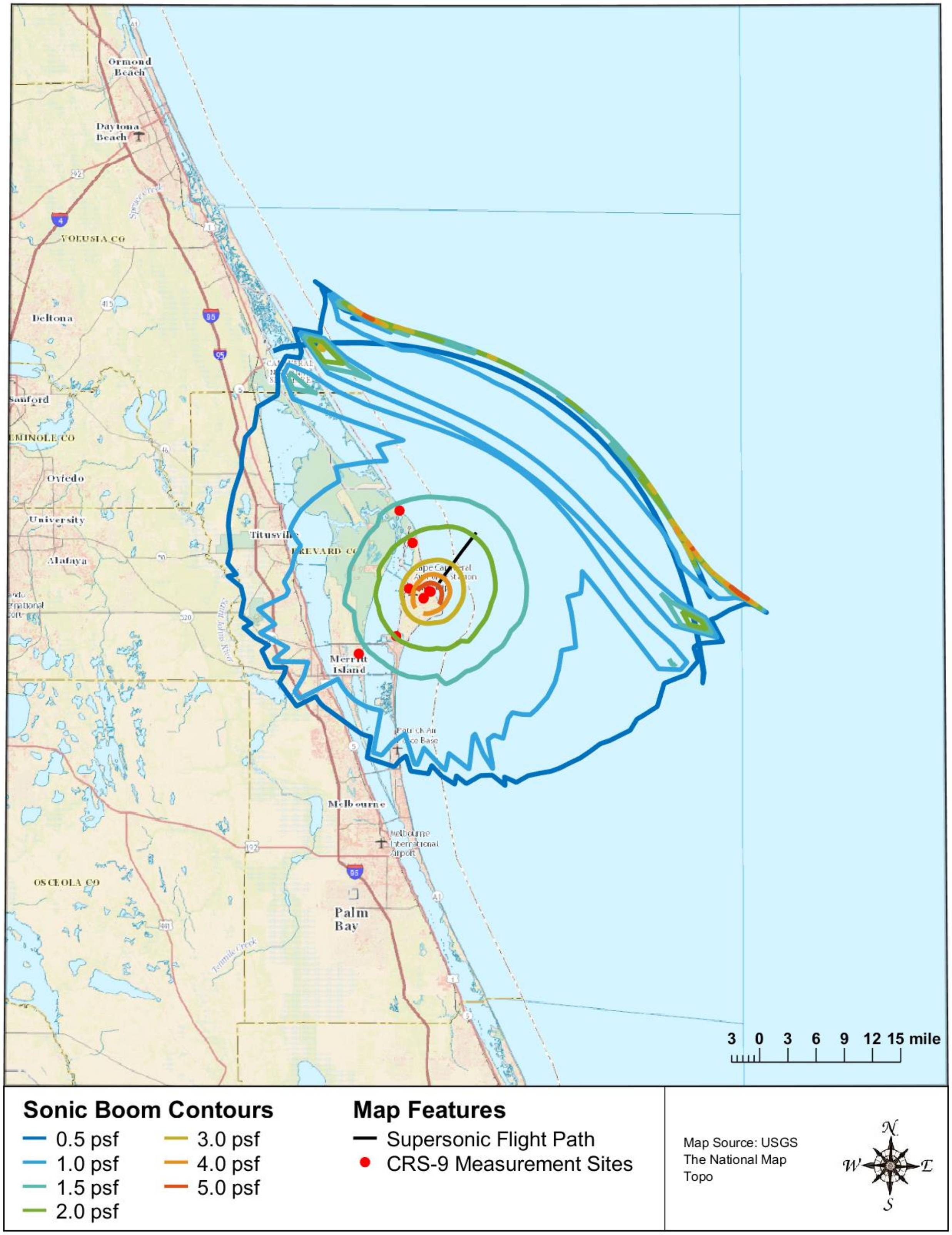

Figure 2. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled without wind

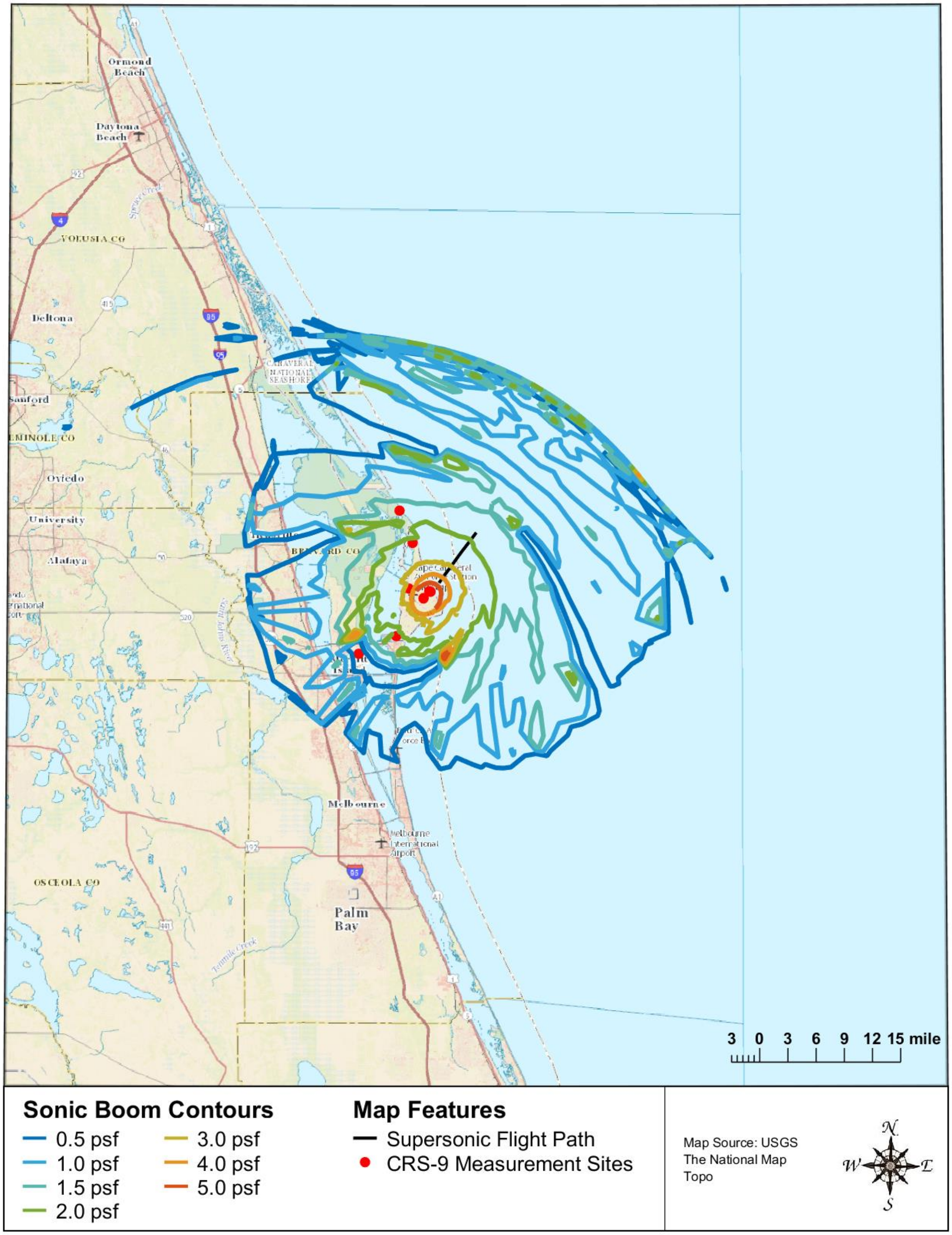

Figure 3. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled with wind

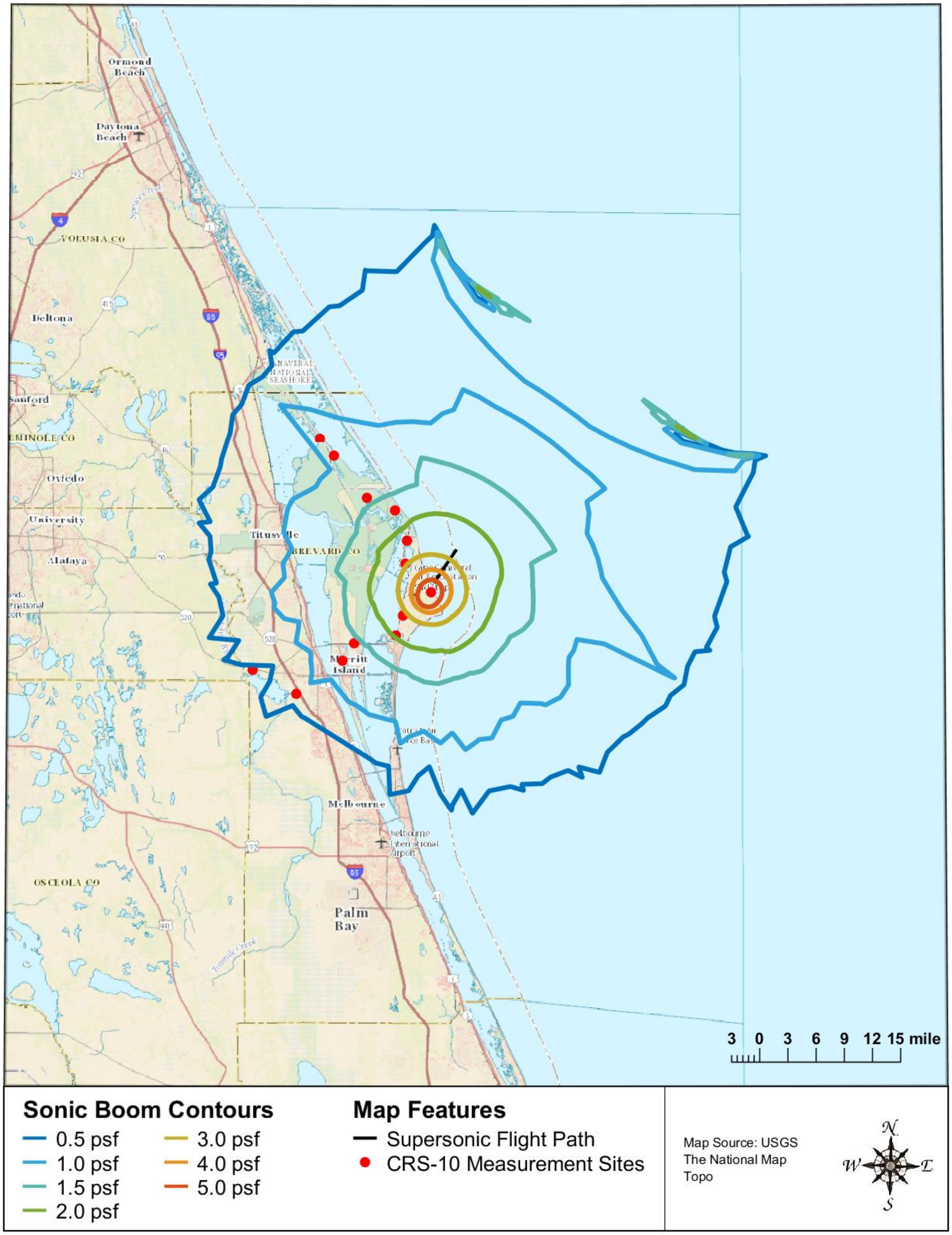

Figure 4. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled without wind

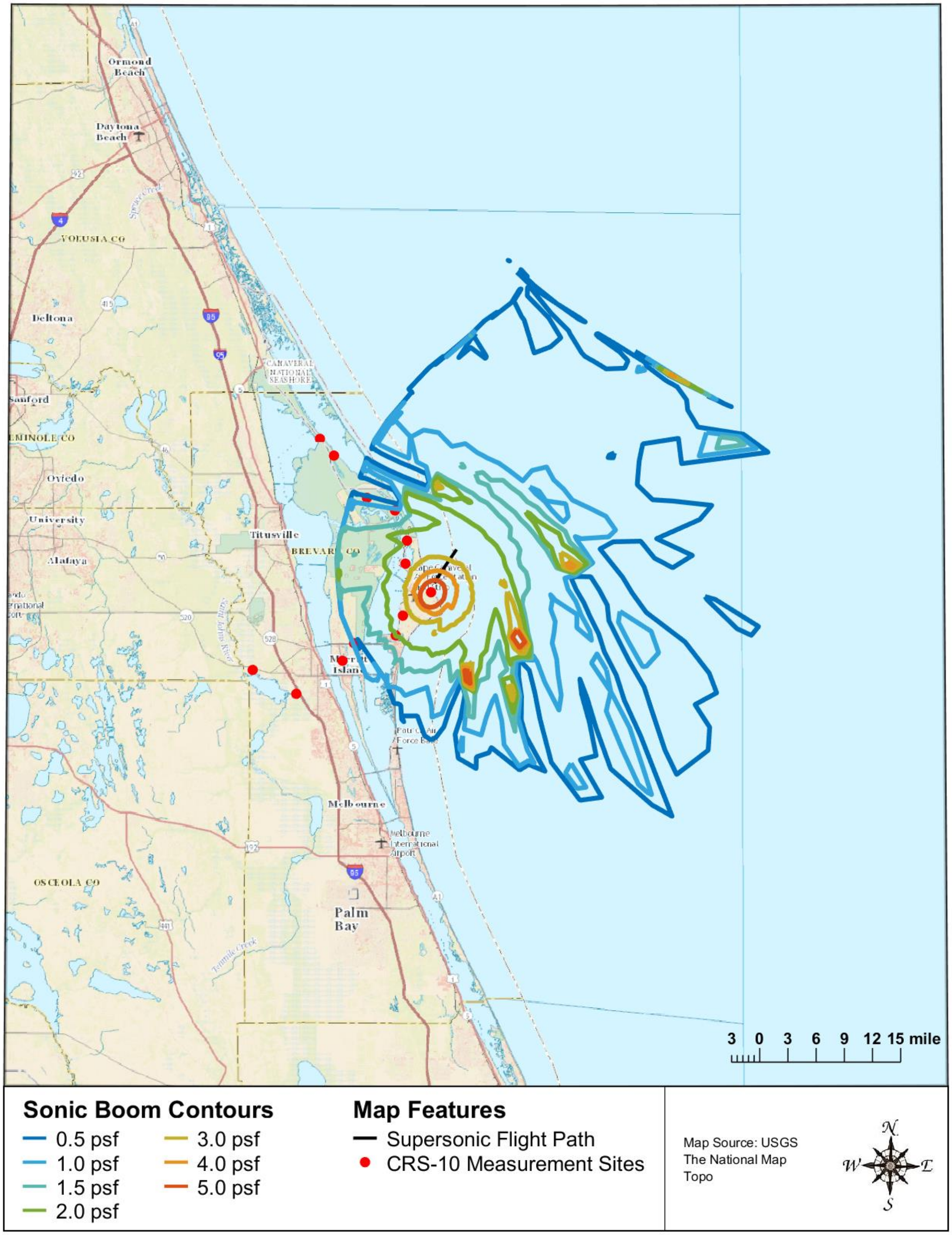

Figure 5. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled with wind

4 Vandenberg Air Force Base

The peak overpressure contours, in psf, resulting from the Falcon 9 first stage flyback at VAFB are shown in Figure 6, along with the ground track of the boom-producing portion of the trajectory. Sonic boom modeling of the VAFB flyback used a nominal trajectory provided by SpaceX ('Iridium_Prediction.xlsx') and a U.S. standard atmospheric profile.

As the vehicle descends below 32 miles, the sonic boom generates a forward-facing crescent shaped contour. As the vehicle descends further, the sonic boom generates oval shaped contours, which end when the vehicle's speed becomes subsonic. A summary of the modeled results are detailed below:

- An area of approximately 7.6 square miles surrounding the landing site may experience levels of 5 psf and above. In this region, the predicted levels are up to 7.8 psf, but they occur over significantly smaller areas. The sonic boom levels fall to 2 psf approximately 7.8 miles east of the landing site near the western edge of the city of Lompoc. The 0.5 psf contour is bounded by Hwy 101 to the east and Orcutt to the north.
- The broad and narrow crescent shaped contour includes land area on Santa Rosa Island and the tip of Santa Cruz Island. The predicted overpressure levels in these areas are less than 2 psf. Note that the location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions at the time of flight. Therefore, it is unlikely that any given location will experience the focus more than once over multiple events.

Note, although the maximum peak overpressure level is predicted to be 7.8 psf (located adjacent to the landing site), it should be noted that levels measured adjacent to the CCAFS landing site during the CRS-9 mission did not exceed 5.5 psf (3).

The maximum modeled overpressure levels for the vast majority of the community surrounding VAFB are predicted to be less than 2 psf. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures (4). Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair (4). The land area between 2 psf and 3 psf surrounding VAFB is largely uninhabited (based on GoogleEarth satellite imagery), with the exception of farm land to the northeast of the landing site between VAFB and Lompoc. The 3 psf contour area over land falls entirely within the VAFB property boundary, with the expectation of approximately 2.5 uninhabited acres.

A large degree of variability exists in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. The probability of a window breaking at 1 psf ranges from one in a billion (5) to one in a million (6). These damage rates are associated with a combination of boom load and glass condition. At 10 psf, the probability of breakage is between one in 100 and one in 1,000. Laboratory tests involving glass (7) have shown that properly installed window glass will not break at overpressures below 10 psf, even when subjected to repeated booms. However, in the real world, glass is not always in pristine condition.

At peak overpressure levels between 2 to 4 psf, there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels between 4 to 10 psf (4). The potential for hearing damage (with regards to humans) is negligible outside of the area adjacent to the landing site, as the modeled sonic boom overpressure levels in the community are substantially lower than the ~4 psf impulsive hearing conservation noise criteria.

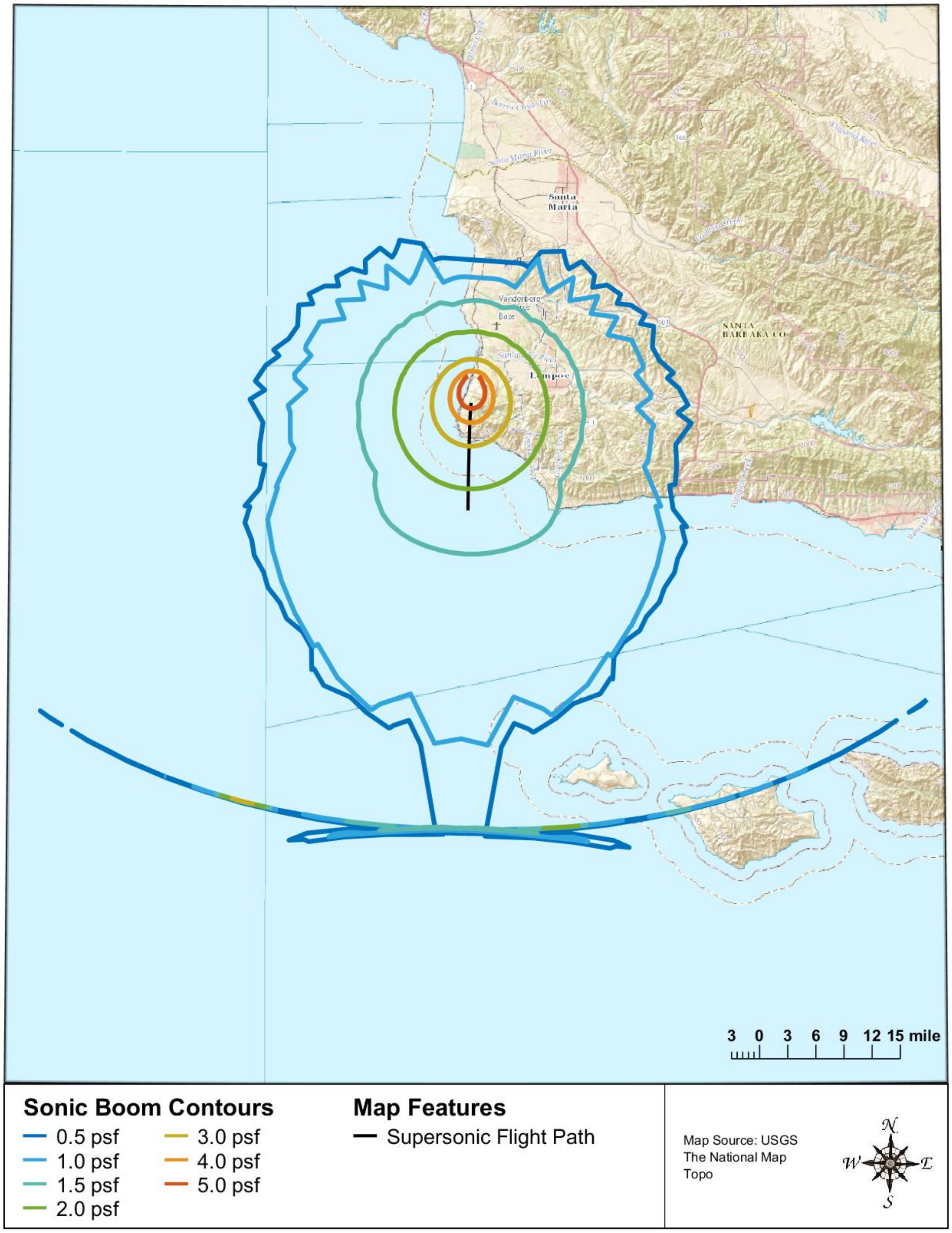

Figure 6. Sonic boom contours generated by the VAFB Falcon 9 Landing

5 Summary

Sonic boom analysis has been completed for the SpaceX Falcon 9 reusable first stage flybacks to CCAFS and VAFB. Recent sonic boom measurements collected by SpaceX personnel during the CRS-9 and CRS-10 missions from CCAFS were used to identify an appropriate PCBoom modeling methodology for Falcon 9 flybacks. The sonic boom peak overpressure measurements for the two Falcon 9 flybacks to CCAFS were compared to predicted levels generated using the selected modeling methodology and resulted in favorable agreement between the measured and modeled levels. The CCAFS modeling methodology was then used to model the sonic boom peak overpressures generated by flybacks to VAFB. A discussion of the VAFB sonic boom contours describes the potential impacts to the surrounding community.

6 References

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Technical Report

Sonic Boom Analysis for SpaceX's Falcon 9 Polar Launch and Lading Operations from CCAFS

March 1, 2019

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Acronyms and Abbreviations

The following acronyms and abbreviations are used in the report:

BRRC	Blue Ridge Research and Consulting, LLC
CCAFS	Cape Canaveral Air Force Station
dB	Decibel
dBA	A-weighted Decibel Level
DNL	Day-Night Average Sound Level
DOD	Department of Defense
FAA	Federal Aviation Administration
ft	Foot/Feet
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
P_k	Peak Pressure
psf	Pounds per Square Foot
SEL	Sound Exposure Level in decibels
SLC	Space Launch Complex
SpaceX	Space Exploration Technologies Corp.

1 Introduction

This report documents the sonic boom analysis performed as part of Space Exploration Technologies Corp.'s (SpaceX's) environmental analysis for the proposed Falcon 9 polar launch and landing operations from Cape Canaveral Air Force Station (CCAFS). SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS Space Launch Complex 40 (SLC-40). The largest configuration, Falcon 9 with composite fairing as shown in Figure 1, will be modeled to determine the potential for sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts will be evaluated for a nominal trajectory for up to five annual launches per year. Potential sonic boom impacts are evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

This noise study describes the sonic booms associated with the proposed Falcon 9 polar operations. Section 2 describes the proposed Falcon 9 polar operations; Section 3 summarizes the basics of sound and describes the noise metrics and impact criteria discussed throughout this report; Section 4 describes the general methodology of the sonic boom modeling; and Section 5 presents the sonic boom modeling results. A summary is provided in Section 6 to document the notable findings of this sonic boom analysis.

Figure 1. SpaceX's Falcon 9 with composite fairing (left), launch of Falcon 9 (middle), and droneship landing of the Falcon 9's first stage (right) (image credit: SpaceX)

2 Falcon 9 Polar Operations

SpaceX's Falcon 9 is a two-stage rocket that delivers payloads to space inside a composite fairing or aboard the Dragon spacecraft. The Falcon 9 with composite fairing will be modeled to determine the potential extent of sonic boom impacts from Falcon 9 launches. The vehicle parameters are presented in Table 1.

Table 1. Vehicle modeling parameters

Modeling Parameters	Values
Manufacturer	SpaceX
Name	Falcon 9
Length	272 ft (launch w/fairing) 154 ft (1st stage landing)
Diameter	12 ft
Gross Vehicle Weight	1,200,000 lbs (launch w/fairing) 97,000 lbs (1st stage landing)

Falcon 9 polar trajectories flown from CCAFS SLC-40 will be unique to the vehicle configuration, mission, and environmental conditions. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. For the purposes of this study, the sonic boom modelling utilizes a nominal launch trajectory provided by SpaceX [1] and shown in Figure 2 to model the sonic booms generated from Falcon 9 polar operations. The nominal launch trajectory follows an azimuth of approximately 160° for most of the trajectory.

The proposed action includes a total of five annual launch operations, four of which are planned to occur during acoustic daytime hours (0700 - 2200), and one during acoustic nighttime hours (2200 – 0700).

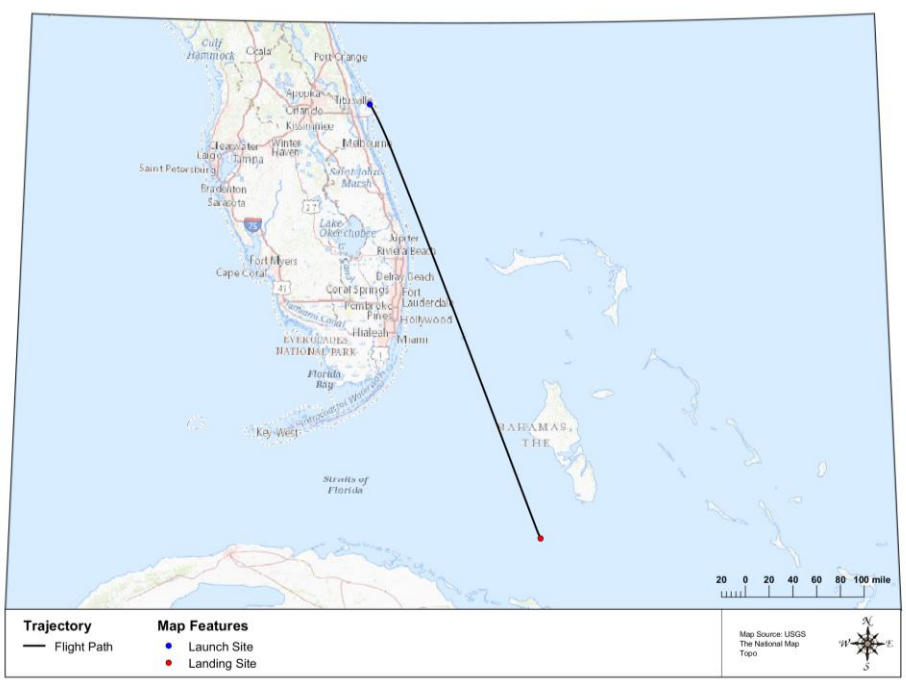

Figure 2. Falcon 9 polar trajectory

3 Acoustics Overview

An overview of sound-related terms, metrics, and effects, which are pertinent to this study, is provided to assist the reader in understanding the terminology used in this noise study.

3.1 Fundamentals of Sound

Any unwanted sound that interferes with normal activities or the natural environment is defined as noise. Three principal physical characteristics are involved in the measurement and human perception of sound: intensity, frequency, and duration [2].

- **Intensity** is a measure of a sound's acoustic energy and is related to sound pressure. The greater the sound pressure, the more energy is carried by the sound and the louder the perception of that sound.
- **Frequency** determines how the pitch of the sound is perceived. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.
- **Duration** is the length of time the sound can be detected.

The loudest sounds that can be comfortably detected by the human ear have intensities a trillion times higher than those of sounds barely audible. Because of this vast range, using a linear scale to represent the intensity of sound can become cumbersome. As a result, a logarithmic unit known as the decibel (abbreviated dB) is often used to represent sound levels. A sound level of 0 dB approximates the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level around 60 dB. Sound levels above 120 dB begin to be felt inside the human ear as discomfort. Sound levels between 130 and 140 dB are experienced as pain [3].

The intensity of sonic booms is quantified with physical pressure units rather than levels. Intensities of sonic booms are traditionally described by the amplitude of the front shock wave, referred to as the peak overpressure. The peak overpressure is normally described in units of pounds per square foot (psf). The amplitude is particularly relevant when assessing structural effects as opposed to loudness or cumulative community response. In this study, sonic booms are quantified by either psf or dB, as appropriate for the particular impact being assessed [4]. A chart of typical impulsive events along with their corresponding peak overpressures in terms of psf and peak dB values are shown in Figure 3. For example, thunder overpressure resulting from lightning strikes at a distance of one kilometer (0.6 miles) is estimated to be near two psf, which is equivalent to 134 dB [5].

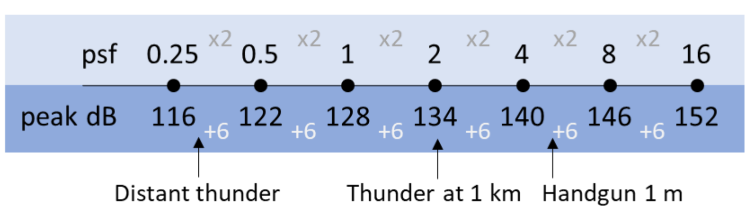

Figure 3. Typical impulsive event levels [5]

Sound frequency is measured in terms of cycles per second or hertz (Hz). Human hearing ranges in frequency from 20 Hz to 20,000 Hz, although perception of these frequencies is not equivalent across this range. Human hearing is most sensitive to frequencies in the 1,000 to 4,000 Hz range. Most sounds are not simple pure tones, but contain a mix, or spectrum, of many frequencies. Sounds with different spectra are perceived differently even if the sound levels are the same. Weighting curves have been developed to correspond to the sensitivity and perception of different types of sound. A-weighting and C-weighting are the two most common weightings. These two curves, shown in Figure 4, are adequate to quantify most environmental noises. A-weighting puts emphasis on the 1,000 to 4,000 Hz range to match the reduced sensitivity of human hearing for moderate sound levels. For this reason, the A-weighted decibel level (dBA) is commonly used to assess community sound.

Very loud or impulsive sounds, such as explosions or sonic booms, can sometimes be felt, and they can cause secondary effects, such as shaking of a structure or rattling of windows. These types of sounds can add to annoyance and are best measured by C-weighted sound levels, denoted dBC. C-weighting is nearly flat throughout the audible frequency range and includes low frequencies that may not be heard but cause shaking or rattling. C-weighting approximates the human ear's sensitivity to higher intensity sounds.

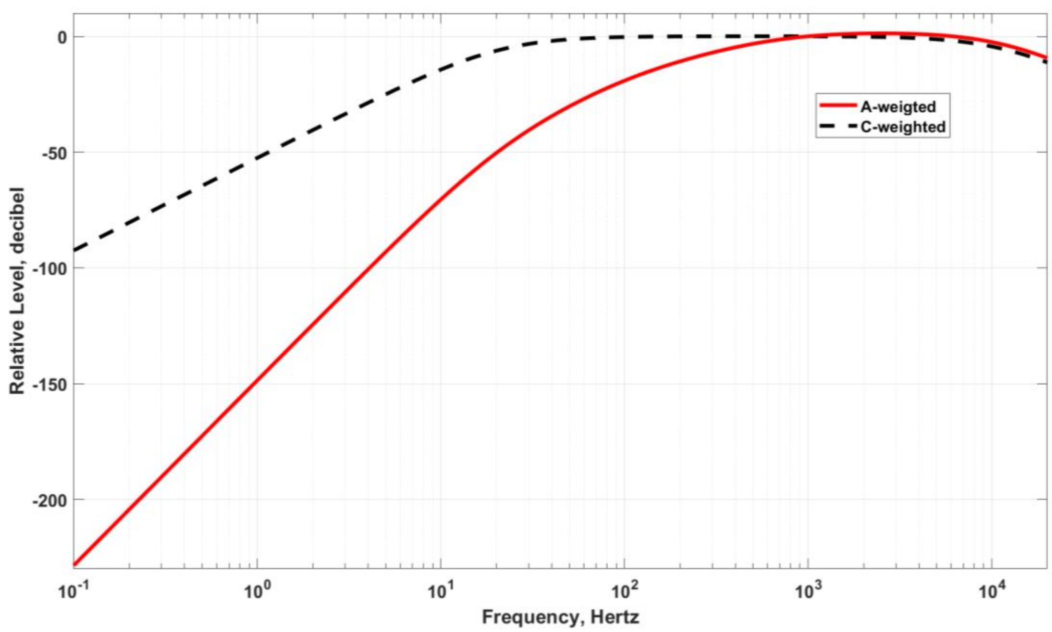

Figure 4. Frequency adjustments for A-weighting and C-weighting [6]

Sound sources can contain a wide range of frequency (pitch) content as well as variations in extent from short-durations to continuous, such as back-up alarms and ventilation systems, respectively. Sonic booms are considered low-frequency impulsive noise events with durations lasting a fraction of a second.

3.2 Noise Metrics

A variety of acoustical metrics have been developed to describe sound events and to identify any potential impacts to receptors within the environment. These metrics are based on the nature of the event and who or what is affected by the sound. A brief description of the noise metrics used in this noise study are provided below.

Peak Sound Level (L_{pk})

For impulsive sounds, the true instantaneous peak sound pressure level, which lasts for only a fraction of a second, is important in determining impacts. The peak pressure of the front shock wave is used to describe sonic booms, and it is usually presented in psf. Peak sound levels are not frequency weighted.

Day-Night Average Sound Level (DNL)

Day-Night Average Sound Level is a cumulative metric that accounts for all noise events in a 24-hour period. To account for our increased sensitivity to noise at night, DNL applies an additional 10 dB adjustment to events during the acoustical nighttime period, defined as 10:00 PM to 7:00 AM. The notations DNL and L_{dn} are both used for Day-Night Average Sound Level and are equivalent. DNL represents the average sound level exposure for annual average daily events. DNL does not represent a level heard at any given time but represents long term exposure to noise.

3.3 Noise Effects

Noise criteria have been developed to protect the public health and welfare of the surrounding communities. The impacts of launch vehicle sonic booms are evaluated on a cumulative basis in terms of human annoyance. In addition, the launch vehicle sonic boom impacts are evaluated on a single-event basis in relation to hearing conservation and potential structural damage. Although FAA Order 1050.1F does not have guidance on hearing conservation or structural damage criteria, it recognizes the use of supplemental noise analysis to describe the noise impact and assist the public's understanding of the potential noise impact.

3.3.1 Human Annoyance

A significant noise impact would occur if the "action would increase noise by DNL 1.5 dB[A] or more for a noise sensitive area that is exposed to noise at or above the DNL 65 dB[A] noise exposure level, or that will be exposed at or above this level due to the increase, when compared to the No Action Alternative for the same timeframe" [7]. A-weighted DNL is based on long-term cumulative noise exposure and has been found to correlate well with long-term community annoyance for regularly occurring events including aircraft, rail, and road noise [8, 9]. For impulsive noise sources with significant low-frequency content such as sonic booms, C-weighted DNL (CDNL) is preferred over A-weighted DNL [10]. In terms of percent highly annoyed, DNL 65 dBA is equivalent to CDNL 60 dBC [11]. Additionally, it has been noted that the DNL "threshold does not adequately address the effects of noise on visitors to areas within a national park or national wildlife refuge where other noise is very low and a quiet setting is a generally recognized purpose and attribute" [7]. DNL contours are provided as the most widely accepted metric to estimate the changes in long-term community annoyance.

3.3.2 Hearing Conservation

Multiple federal government agencies have provided guidelines on permissible noise exposure limits on impulsive noise such as a sonic boom. These documented guidelines are in place to protect one's hearing from exposures to high noise levels and aid in the prevention of noise-induced hearing loss (NIHL). In terms of upper limits on impulsive noise levels; National Institute for Occupational Safety and Health (NIOSH) [12], Occupational Safety and Health Administration (OSHA) [13], and the Department of Defense (DOD) [14] have stated that levels should not exceed 140 dB peak sound pressure level, which equates to a sonic boom level of approximately 4 psf.

3.3.3 Structural Damage

Sonic booms are also commonly associated with structural damage. Most damage claims are for brittle objects, such as glass and plaster. Table 2 summarizes the threshold of damage that may be expected at various overpressures [15]. A large degree of variability exists in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. The probability of a window breaking at 1 psf ranges from one in a billion [16] to one in a million [17]. These damage rates are associated with a combination of boom load and window pane condition. At 10 psf, the probability of breakage is between one in 100 and one in 1,000. Laboratory tests involving glass [18] have shown that properly installed window glass will not break at overpressures below 10 psf even when subjected to repeated booms. However, in the real world, installed window glass is not always in pristine condition.

Damage to plaster occurs at similar ranges to glass damage. Plaster has a compounding issue in that it will often crack due to shrinkage while curing or from stresses as a structure settles, even in the absence of outside loads. Sonic boom damage to plaster often occurs when internal stresses are high as a result of these factors. In general, for well-maintained structures, the threshold for potential damage from sonic booms is 2 psf [15]; below 2 psf, damage is unlikely.

Table 2. Possible damage to structures from sonic booms [15]

***Nominal* Level *and* *Comparative* Events**	**Damage Type**	**Item Affected**
0.5 – 2 psf *Compares to piledriver at construction site*	Plaster	Fine cracks; extension of existing cracks; more in ceilings; over doorframes; between some plasterboards.
	Glass	Rarely shattered; either partial or extension of existing.
	Roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Those carefully balanced or on edges can fall; fine glass, such as large goblets, can fall and break.
	Other	Dust falls in chimneys.
2 – 4 psf *Compares to cap gun or firecracker near ear*	Glass, plaster, roofs, ceilings	Failures show that would have been difficult to forecast in terms of their existing localized condition. Nominally in good condition.
4 – 10 psf *Compares to handgun at shooter's ear*	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, in fairly good condition can collapse.
	Walls (in)	Inside ("party") walls known to move at 10 psf.
> 10 psf *Compares to fireworks display from viewing stand*	Glass	Some good glass will fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plasterboards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gale-end and will-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Internal party walls can move even if carrying fittings such as hand basins or taps; secondary damage due to water leakage.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

4 Sonic Boom Modeling

A vehicle creates sonic booms during supersonic flight. The potential for the boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. The sonic boom is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom. The noise is perceived as a deep boom, with most of its energy concentrated in the low frequency range. Although sonic booms generally last less than one second, their potential for impact may be considerable.

When a vehicle moves through the air, it pushes the air out of its way. At subsonic speeds, the displaced air forms a pressure wave that disperses rapidly. At supersonic speeds, the vehicle is moving too quickly for the wave to disperse, so it remains as a coherent wave. This wave is a sonic boom. When heard at ground level, a sonic boom consists of two shock waves (one associated with the forward part of the vehicle, the other with the rear part) of approximately equal strength and (for fighter aircraft) separated by 100 to 200 milliseconds. When plotted, this pair of shock waves and the expanding flow between them has the appearance of a capital letter "N," so a sonic boom pressure wave is usually called an "N-wave." An N-wave has a characteristic "bang-bang" sound that can be startling. Figure 5 shows the generation and evolution of a sonic boom N-wave under the vehicle.

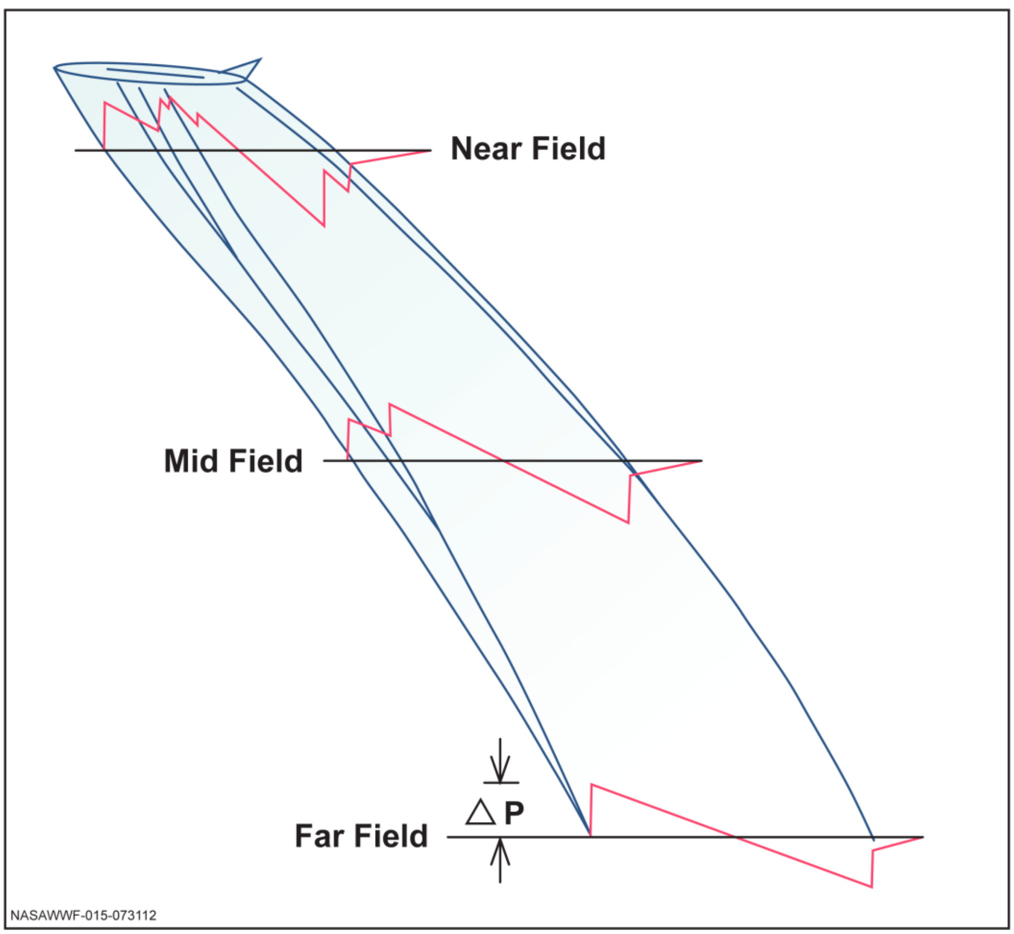

Figure 5. Sonic boom generation and evolution to N-wave [19]

Figure 6 shows the sonic boom pattern for a vehicle in steady, level supersonic flight. The boom forms a cone that is said to sweep out a "carpet" under the flight track. The boom levels vary along the lateral extent of the "carpet" with the highest levels directly underneath the flight track and decreasing levels as the lateral distance increases to the cut-off edge of the "carpet." When the vehicle is maneuvering, the sonic boom energy can be focused in highly localized areas on the ground.

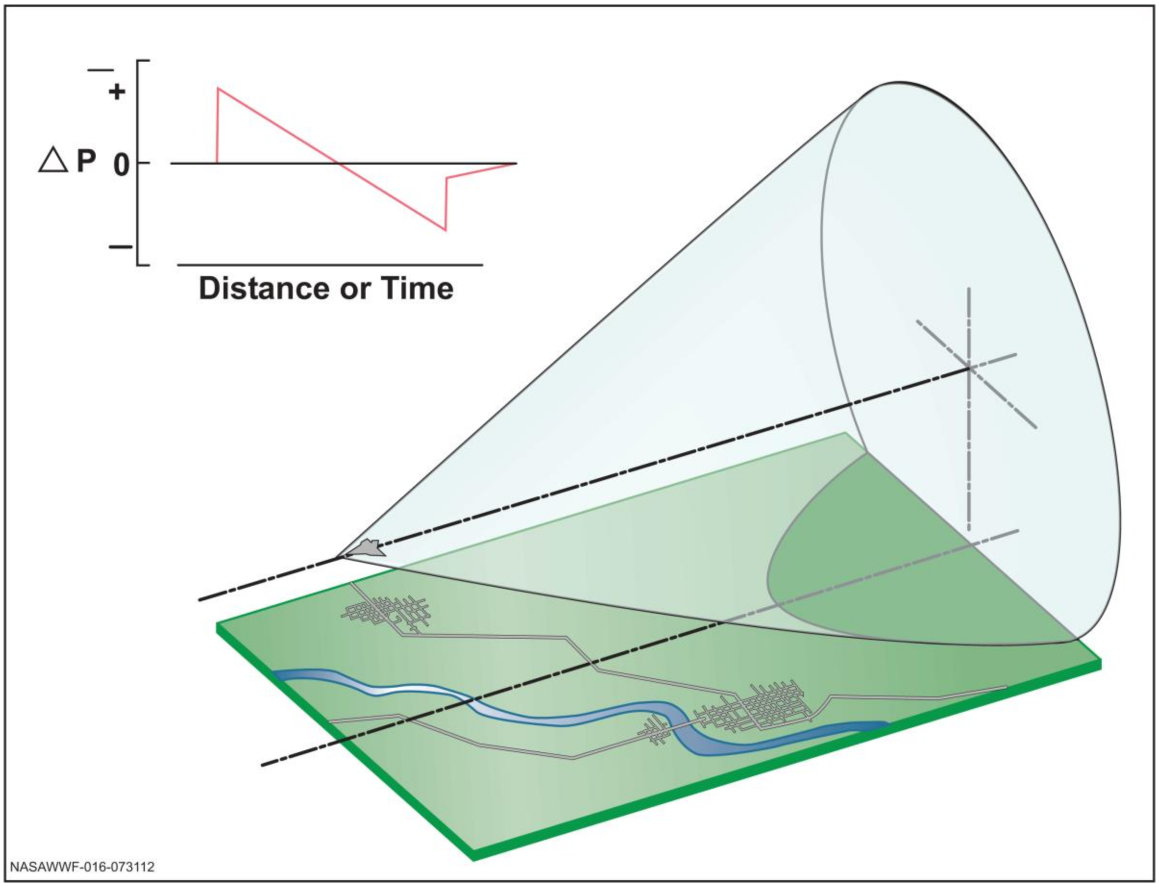

Figure 6. Sonic boom carpet for a vehicle in steady flight [20]

The complete ground pattern of a sonic boom depends on the size, weight, shape, speed, and trajectory of the vehicle. Since aircraft fly supersonically with relatively low horizontal angles, the boom is directed toward the ground. However, for rocket trajectories, the boom is directed upward and laterally until the rocket rotates significantly away from vertical, as shown in Figure 7. This difference causes a sonic boom from a rocket to propagate much further downrange compared to aircraft sonic booms. This extended propagation usually results in relatively lower sonic boom levels from rocket launches. For aircraft, the front and rear shock are generally the same magnitude. However, for rockets, in addition to the two shock waves generated from the vehicle body, the plume itself acts as a large supersonic body, and it generates two additional shock waves (one associated with the forward part of the plume, the other with the rear part) and extends the waveform duration to as large as one second. The sonic boom generated by the plume is stronger since the plume volume is significantly larger than the rocket.

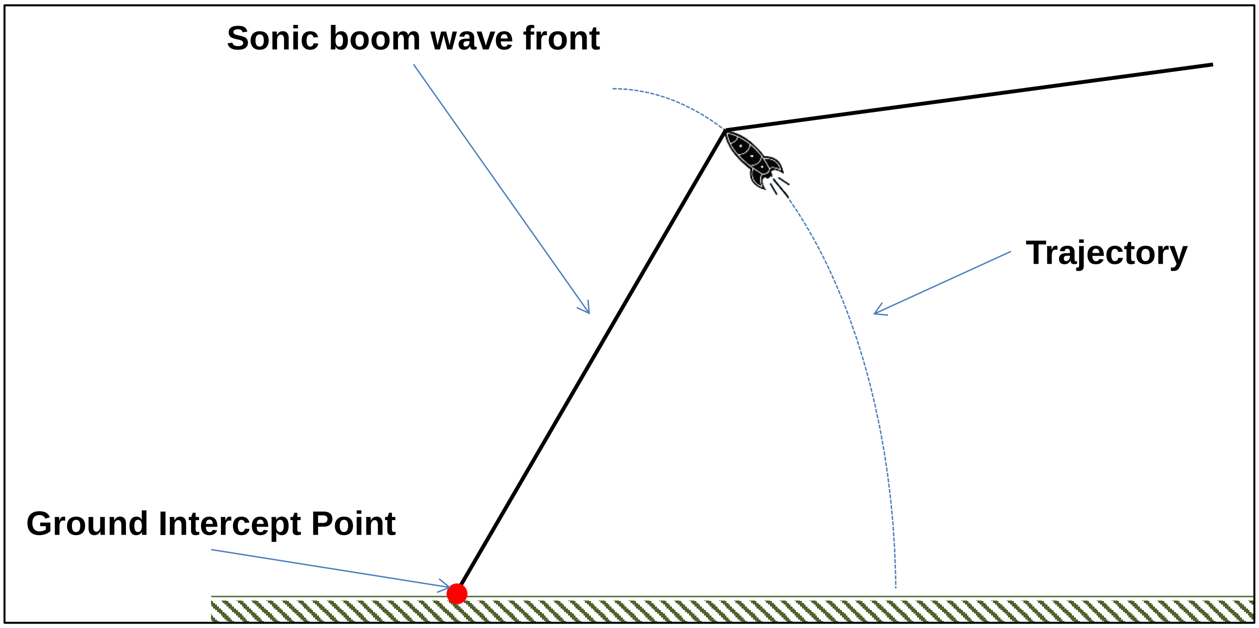

Figure 7. Sonic boom propagation for rocket launch

The single-event prediction model, PCBoom [21, 22, 23] is used to predict the sonic boom footprint from a supersonic vehicle trajectory. PCBoom is a full ray trace sonic boom program that calculates the magnitude, waveform, and location of sonic boom overpressures on the ground from supersonic flight operations. The model computes detailed ground signature shapes from a variety of near-field signature definitions. Additionally, PCBoom accounts for the effect of underexpanded rocket exhaust plumes on the boom [24]. Several inputs are required to calculate the sonic boom impact, including the aircraft 3-dimensional model, the trajectory path, the atmospheric conditions and the ground surface height. Predicted sonic boom footprints are presented in the form of equal pressure contours.

5 Results

The following section presents the results of the environmental sonic boom impacts associated with the proposed Falcon 9 polar operations. Site-specific atmospheric profiles including temperature and wind were used to model the sonic boom impacts. The modeled sonic boom contours associated with the polar launch and droneship landing of the Falcon 9 are presented in Figure 8 and Figure 9, respectively. In addition to the contours, the black ground path represents the portion of supersonic flight that is below the edge of space and generates sonic boom footprints that intercept the ground.

Falcon 9 Polar Launch

The sonic boom wavefront for a vertical rocket launch is directed upward and laterally during the initial portion of the launch, and thus it does not intercept the ground. As the vehicle rotates away from the vertical and its velocity increases, the sonic boom wavefront starts to be directed toward the ground. At this point the sonic boom will begin to intercept the ground. The Falcon 9 polar launch generates a sonic boom over a long, narrow, forward-facing crescent shaped focus boom region as shown in Figure 8. As the vehicle continues to ascend, the sonic boom levels generated decrease and the crescent shape becomes slightly longer and wider. A summary of the modeled results is detailed below:

- The sonic boom is modeled to intercept the southern Florida Atlantic coastal region including the communities of Vero Beach, Fort Pierce, and Port St Lucie along the coast; as well as inland communities near Okeechobee. The contours extend approximately 30 miles along the coast and reach up to approximately 75 miles west of the coast. The vast-majority of this region will experience peak overpressures of less than 1 psf. Areas south of Port St. Lucie and Okeechobee may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.
- A narrow focus boom region north of Vero Beach, with land area less than 3 square miles, is modeled to receive levels greater than 2 psf. In this region, the modeled peak overpressure may reach 4.6 psf, but these levels occur over significantly smaller areas (less than 0.01 square miles). Note, the location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions at the time of flight. Therefore, it is unlikely that any given location will experience the focus more than once over multiple events.

The maximum modeled overpressure levels are predicted to be less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region that experience sonic booms from Falcon 9 polar launches. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels between 2 to 4 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf (less than 0.01 square miles). The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

A modeled maximum peak overpressure of 4.6 psf translates to an equivalent CDNL of 51 dBC for the maximum projected reentry operation tempo. Therefore, the proposed Falcon 9 polar launch operation does not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA).

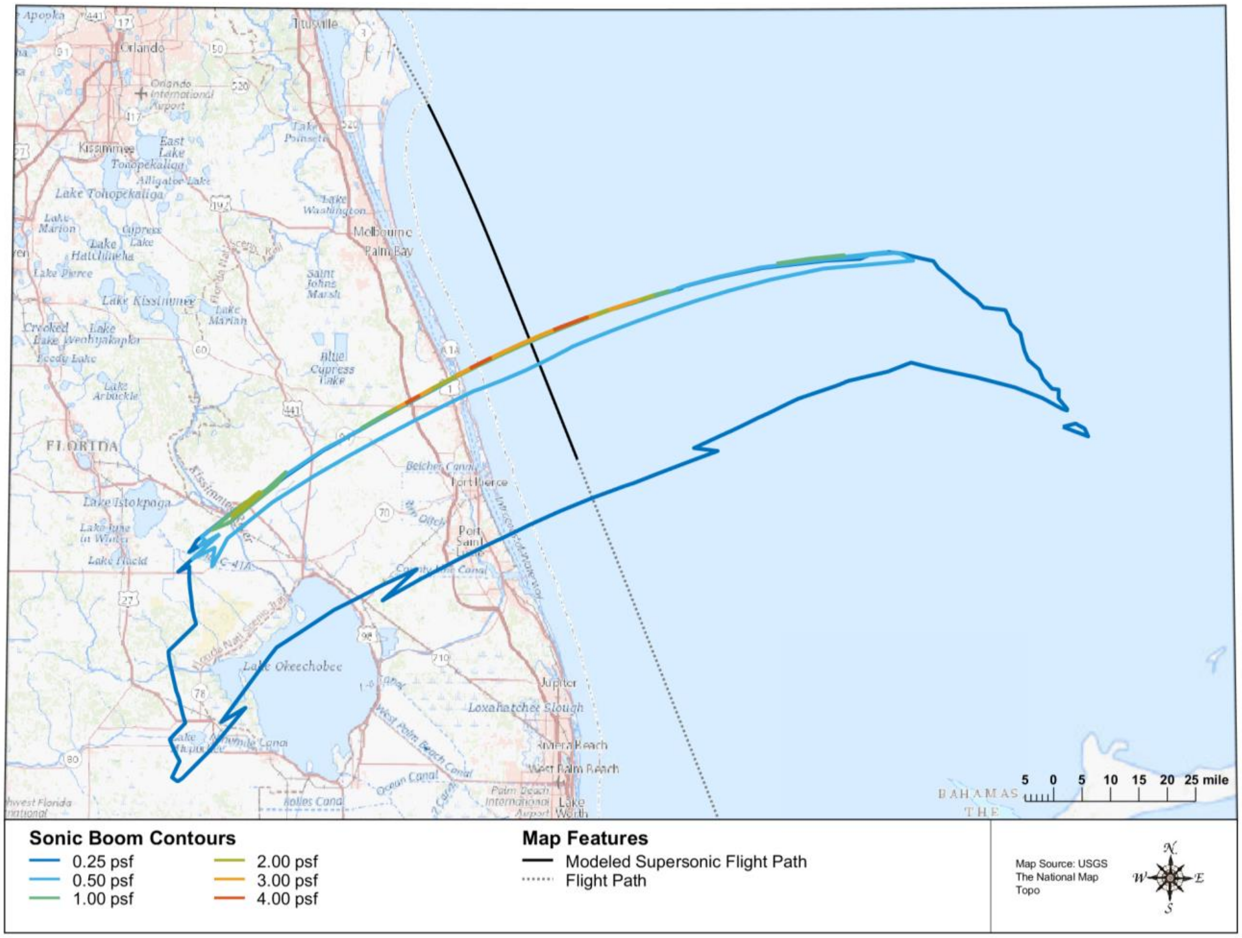

Figure 8. Sonic boom peak overpressure contours for the Falcon 9 polar launch

Note, sonic booms have previously impacted mainland Florida during shuttle orbiter reentries, with measured levels ranging from about 0.6 psf from the vehicle at higher altitudes to a maximum of 2.3 psf just prior to landing [25].

Falcon 9 Polar Droneship Landing

The Falcon 9 polar droneship landing modeled sonic boom contours are presented in Figure 9. After the first stage separates and the vehicle descends, the sonic boom will intercept the ground. As the vehicle descends further, the sonic boom contours become smaller and end when the vehicle's speed becomes subsonic. A summary of the modeled results is detailed below:

- The crescent shaped portion of the contours includes land area on the southern part of Andros Island within the Bahamas, the majority of which is part of West Side National Park but also includes small settlements along the eastern coast near Kemp's Bay. The predicted overpressure levels for a vast majority of this area is less than 0.5 psf. North Andros Island and as far north as New Providence Island may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.

- An area of approximately 18 square miles of ocean surrounding the droneship landing site may experience levels of 3 psf and above. In this region, the predicted levels are up to 4 psf, but they occur over significantly smaller areas.

Although the maximum peak overpressure level is predicted to be 4 psf (located adjacent to the droneship landing site), it should be noted that the maximum level measured adjacent to the CCAFS landing site during the July 18, 2016 landing event was 5.48 psf [26].

The potential for structural damage is unlikely as the modeled sonic boom overpressure levels over land are less than 2 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are substantially lower than the ~4 psf impulsive hearing conservation noise criteria. For the maximum projected reentry operation tempo, peak overpressures of approximately 0.5 psf translate to an equivalent CDNL that is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA). Therefore, the proposed Falcon 9 polar landing operation does not pose a significant impact with regards to human annoyance.

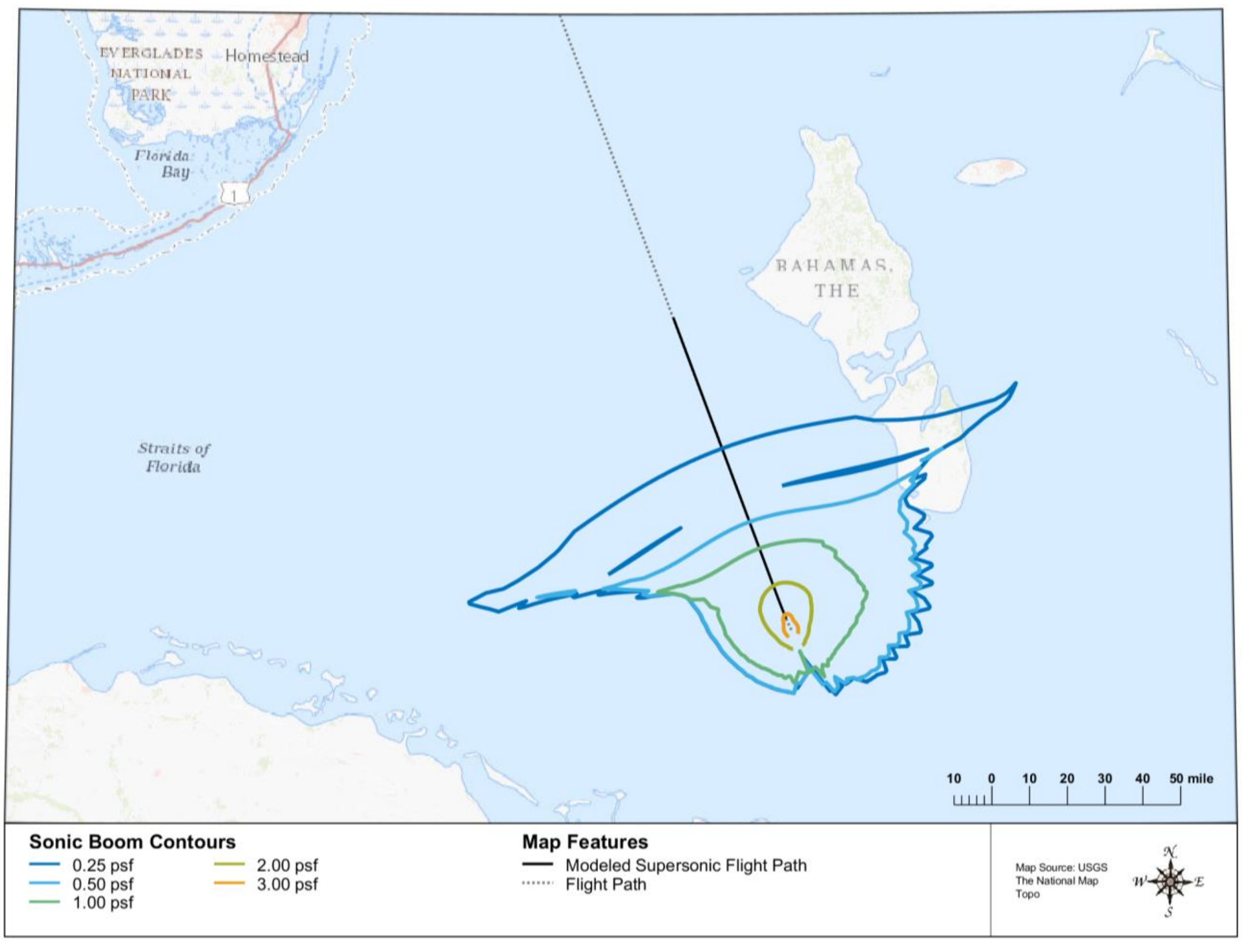

Figure 9. Sonic boom peak overpressure contours for the Falcon 9 polar droneship landing

Although the proposed polar operations do not pose significant impacts in relation to human annoyance, hearing conservation, or structural damage; the unexpected, loud impulsive noise of sonic booms tend to cause a startle effect in people. However, when humans are exposed to impulse noises with similar characteristics on a regular basis, they tend to become conditioned to the stimulus and the resulting startle reaction is generally not displayed. The physiological effects of single sonic booms on humans [27] for the levels produced by the proposed operations can be grouped as presented in Table 3.

Table 3. Physiological effects of single sonic booms on humans [27]

Sonic boom overpressure	Behavioral effects
< 0.3 psf	Orienting, but no startle response; eyeblink response in 10% of subjects; no arm/hand movement.
0.6 – 2.3 psf	Mixed pattern of orienting and startle responses; eyeblink in about half of subjects; arm/hand movements in about a fourth of subjects, but not gross bodily movements.
2.7 – 6.5 psf	Predominant pattern of startle responses; eyeblink response in 90 percent of subjects; arm/hand movements in more than 50 percent of subjects with gross body flexion in about a fourth of subjects.

6 Summary

This report documents the sonic boom analysis performed as part of SpaceX's efforts on the environmental analysis for the proposed Falcon 9 polar launch and landing operations from CCAFS. SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS SLC-40. The largest configuration, Falcon 9 with composite fairing, was modeled to determine potential sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts were evaluated for a nominal launch trajectory for up to five annual launches per year. The potential sonic boom impacts were evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

The representative Falcon 9 polar launch generated sonic boom peak overpressures of less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region the sonic boom is modeled to intercept. A narrow focus boom region north of Vero Beach with land area less than 3 square miles is modeled to receive levels greater than 2 psf, with a maximum peak overpressure of approximately 4.6 psf. Note, focus regions are highly localized and dependent on the mission specific trajectory and atmospheric conditions during the launch event.

The proposed launch operations do not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels above 2 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

The representative Falcon 9 droneship landing generates peak overpressures over land of less than approximately 0.5 psf. Therefore, the proposed landing operations do not pose a significant impact with regards to human annoyance, structural damage, or hearing damage (with regards to humans).

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ROCKET NOISE STUDY FOR SPACEX FLIGHT AND STATIC TEST OPERATIONS AT CAPE CANAVERAL AIR FORCE STATION AND KENNEDY SPACE CENTER

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We Deliver

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1 Introduction

Noise levels have been estimated for SpaceX Falcon 9 Block 5 and Falcon Heavy Block 5 launches, booster landings, and static fire tests at Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC). The Falcon 9 Block 5 succeeds the Falcon 9 Block 4 with changes that include 7-8% more thrust by uprating the engines, improvements on landing legs, and modifications to increase the efficiency of recovery and reusability of first-stage boosters. The Falcon 9 Block 5 has uprated Merlin 1D (M1D) engines that each provide sea-level thrust of 190 Klbf. Falcon 9 Block 5 launches and static fire tests occur at Kennedy Space Center Launch Complex 39 (LC-39A) and Cape Canaveral Air Force Station Space Launch Complex 40 (LC-40). Falcon Heavy Block 5 launches and static fire tests occur at LC-39A. Dragon static fire tests occur at LZ-1. Booster landings occur at LZ-1 and LZ-2. This assessment was conducted to estimate the single event and cumulative noise levels in the vicinity of CCAFS and KSC due to all of these rocket operations.

SpaceX provided the following data for noise modeling:

- Vehicle launch trajectories for the Falcon 9 and Falcon Heavy from liftoff to main engine cutoff (MECO).
- Falcon 9 Block 5 engine operating data and nominal ascent thrust profile per engine (Figure 1).
- Side booster landing trajectories from separation to landing with descent thrust profiles.
- Static fire test parameters for the Falcon 9, Falcon Heavy, and Dragon.
- Projected launch and static fire test operations at CCAFS and KSC from 2018 through 2024.

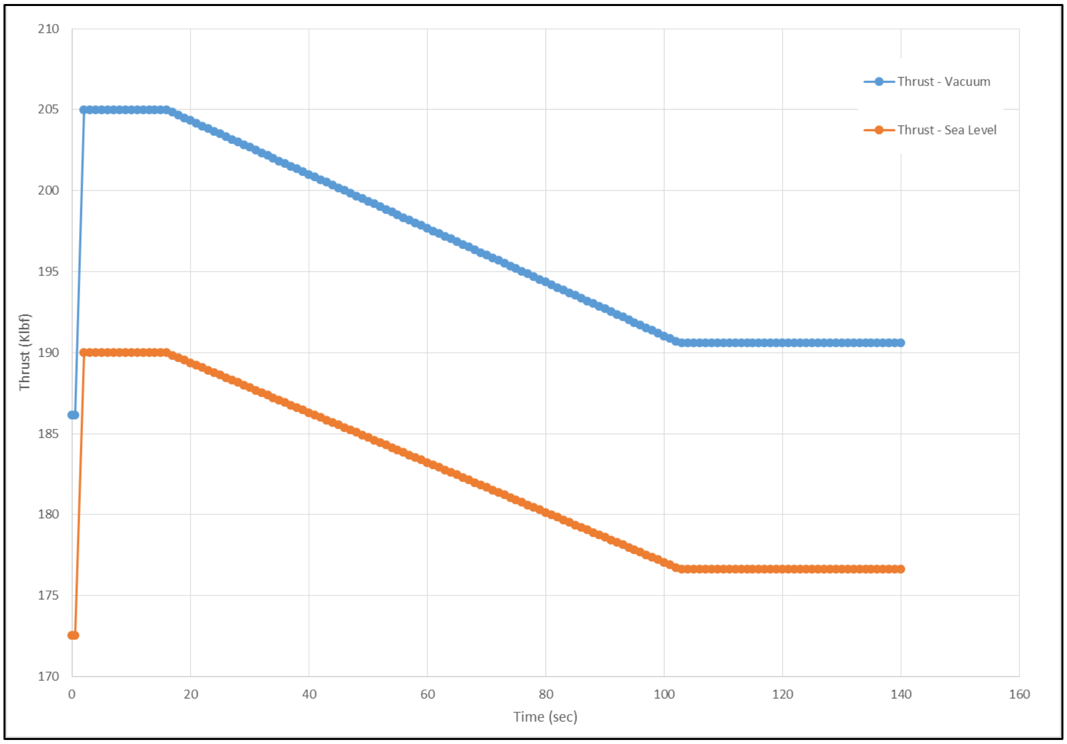

Figure 1. Falcon 9 Block 5 Nominal Ascent Thrust Profile (Per Engine)

To estimate the noise levels around LC-39A, LC-40, and LZ-1 and LZ-2, rocket noise from the Falcon 9 Block 5 and Falcon Heavy Block 5 was computed by Wyle's RNOISE model. RNOISE[1,2] is a far-field (distances beyond several hundred feet) community noise model for launch noise assessment. A description of rocket noise fundamentals and noise metrics are provided in Section 2. Estimates of Falcon 9 and Falcon Heavy launch noise levels around LC-39A and LC-40 are provided in Section 3. Estimates of booster landing noise levels around LZ-1 and LZ-2 are provided in Section 4. Static fire test noise levels for Falcon 9, Falcon Heavy, and Dragon are presented in Section 5. Cumulative noise levels for existing launches and projected future year 2024 launches, static firings, and booster landings are presented in Section 6.

2 Rocket Noise

2.1 Background

Rockets generate significant noise from the combustion process and turbulent mixing of the exhaust flow with the surrounding air. Figure 2 is a sketch of rocket noise. There is a supersonic potential core of exhaust flow, surrounded by mixing region. Noise is generated in this flow. It is directional, with the highest noise levels at an angle of 40 to 50 degrees from the direction of the exhaust flow. The fundamentals of predicting rocket noise were established by Wilhold et al.[3] for moving rockets and by Eldred et al.[4] for static firing. Sutherland[5] has refined modeling of rocket source noise, improving its consistency relative to jet noise theory. Based on those fundamentals, Wyle has developed the PAD model for near field rocket noise[6] and the RNOISE model for far field noise in the community. RNOISE was used for the current analysis.

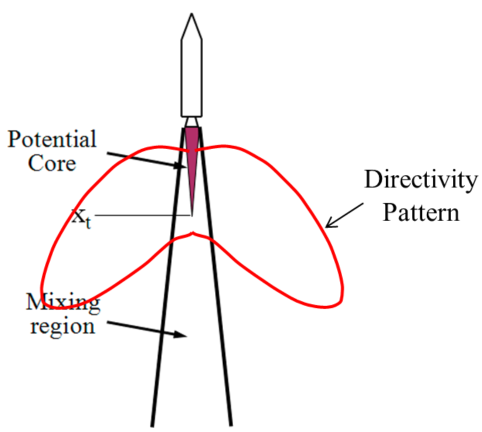

Figure 2. Rocket Noise Source

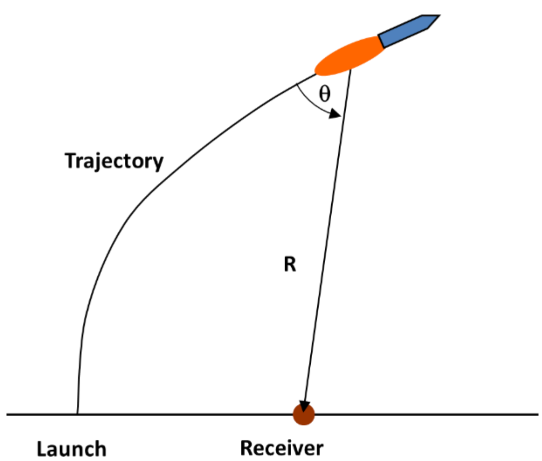

Figure 3. Modeling Rocket Noise at the Ground

Figure 3 is a sketch of far field rocket noise as treated by RNOISE. The vehicle position and attitude is known from the trajectory. Rocket noise source characteristics are known from the engine properties, with thrust and exhaust velocity being the most important parameters. The emission angle and distance to the receiver are known from the flight path and receiver position. Noise at the ground is computed accounting for distance, ground impedance,[7] and atmospheric absorption of sound.[8] RNOISE propagates the full spectrum to the ground, accounting for Doppler shift from vehicle motion. It is a time simulation model, computing the noise at individual points or on a regular grid for every time point in the trajectory. Propagation time from the vehicle to the receiver is accounted for, yielding a spectral time history at the ground. A variety of noise metrics can be computed from the full calculated noise field and the metrics commonly used to assess rocket noise are described in the following section.

2.2 Noise Metrics

FAA Order 1050.1E specifies Day-Night Average Sound Level (DNL) as the standard metric for community noise impact analysis, but also specifies that other supplemental metrics may be used as appropriate for the circumstances. DNL is appropriate for continuous noise sources, such as airport noise and road traffic noise. It is not appropriate for irregularly occurring noise events such as rocket launches or static tests.

The noise metrics used for rocket noise analysis are:

- DNL, as defined by FAA Order 1050.1E;
- SEL, the Sound Exposure Level, for individual events;
- L_{Amax}, the maximum A-weighted level, for individual events;
- OASPL, the maximum overall sound pressure level, for individual events; and
- One third octave spectra at particular sensitive receptors.

As mentioned, DNL is necessary for policy. The next two metrics (L_{Amax} and SEL) are A-weighted and provide a measure of the impact of individual events. Loud individual events can pose a hearing damage hazard to people, and can also cause adverse reactions by animals. Adverse animal reactions can include flight, nest abandonment, and interference with reproductive activities. The last two metrics, OASPL and spectra, may be needed to assess potential damage to structures and adverse reaction of species whose hearing response is not similar to that of humans. The estimated noise results presented in section 3 will be L_{Amax} and SEL contours for single event noise assessment over the study area.

L_{Amax} is appropriate for community noise assessment of a single event, such as a rocket launch or static fire test. This metric represents the highest A-weighted integrated sound level for the event in which the sound level changes value with time. The L_{Amax} metric indicates the maximum sound level occurring for a fraction of a second. Slowly varying or steady sounds are generally integrated over a period of one second. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleep, or other common activities. Although it provides some measure of the intrusiveness of the event, it does not completely describe the total event, because it does not include the period of time that the sound is heard.

SEL is a composite metric that represents both the intensity of a sound and its duration. Individual time-varying noise events (e.g., aircraft overflights) have two main characteristics: a sound level that changes throughout the event and a period of time during which the event is heard. SEL provides a measure of the net impact of the entire acoustic event, but it does not directly represent the sound level heard at any given time. For example, during an aircraft flyover, SEL would include both the maximum noise level and the lower noise levels produced during onset and recess periods of the overflight. SEL is a logarithmic measure of the total acoustic energy transmitted to the listener during the event. Mathematically, it represents the sound level of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For a rocket launch, the SEL is expected to be greater than the L_{Amax} because the launch noise event is up to several minutes in duration whereas the maximum sound level (L_{Amax}) occurs instantaneously.

Sections 3 through 5 present the single event noise levels, including L_{Amax} and SEL contours, for rocket launches, booster reentry/landings, and static fire tests, respectively. In Section 6, cumulative noise levels are presented for these operations, individually and combined, in terms of DNL.

3 Rocket Launch Noise Levels

3.1 Falcon 9 Launches at LC-39A and LC-40

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon 9 Block 5 Launches at LC-39A and LC-40 using trajectory data, from liftoff to MECO, provided by SpaceX in file 'Falcon_9_Full_Thrust_Block5_Representative_Cape_Trajectory.asc'. The L_{Amax} contours indicate the maximum sound level at each location over the duration of the launch, from liftoff to MECO, where engine thrust varies according to the ascent thrust profile (Figure 1). Both launch events were modeled with a duration of 161 seconds, SEL values are higher than L_{Amax} values.

RNOISE computations were done using a radial grid consisting of 128 azimuths and 100 intervals out to 300,000 feet from the launch point. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. As will be shown in the resulting noise contour maps (Figures 4 through 11), the shape of the innermost contours is approximately circular. The shape of the outermost contours is due to rocket noise directivity and the difference between acoustically hard water and acoustically soft ground. The launch pad locations at LC-39A and LC-40 are indicated in the map legends as are the CCAFS and KSC properties. SLC-40 is located about four miles southeast, along the coast, from LC-39A.

The L_{Amax} 70 dB through 110 dB contours shown in Figures 4 and 5 represent the maximum levels estimated for the Falcon 9 Block 5 launch at LC-39A; Figure 5 shows these contours using a zoomed in map scale to better show the extent of the noise exposure relative to cities located around LC-39A. The higher L_{Amax} contours (90, 100, and 110 dB) are located entirely within both the CCAFS and KSC properties. If a Falcon 9 Block 5 launch occurs during the day, when background levels are in the 50 dB to 60 dB range, residents of Titusville, Merritt Island, and Cape Canaveral may notice launch noise levels above 70 dB. If the same launch occurs during the night, when background levels are lower than during the day (e.g., below 40 dB to 50 dB range), these residents may notice launch noise levels that exceed 60 dB. A prevailing on-shore or off-shore breeze may also strongly influence noise levels in these communities.

SEL contour levels of 80, 90, 100, and 110 dB are shown in Figures 6 for the Falcon 9 Block 5 launch at LC-39A with Figure 7 showing a zoomed in map scale. As mentioned previously, SEL is an integrated metric and is expected to be greater than the L_{Amax} because the launch event is up to several minutes in duration whereas the maximum sound level (L_{Amax}) occurs instantaneously. Figure 7 indicates that the 100 and 110 dB SEL contours are expected to remain almost entirely within the CCAFS and KSC properties.

The L_{Amax}, and SEL contours estimated for Falcon 9 Block 5 Launches at LC-40 are shown in Figures 8 through 11 in the same sequence as the figures presented for LC-39A. In general, the estimated noise exposure from Falcon 9 Block 5 launches at LC-40 is similar to the estimated noise exposure for launches at LC-39A, except the noise contours are shifted southeast, along the coast, by about four miles.

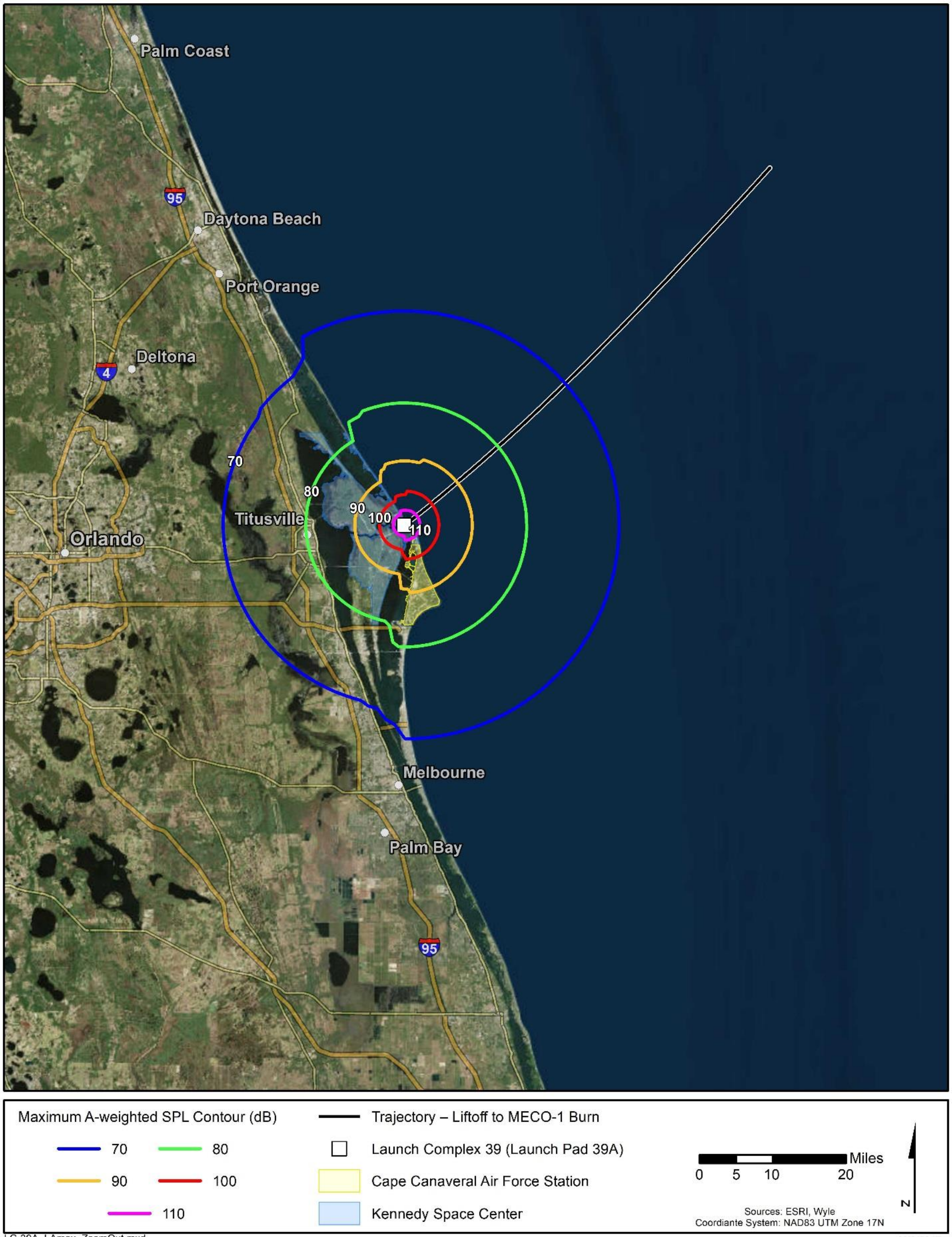

Figure 4. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-39A

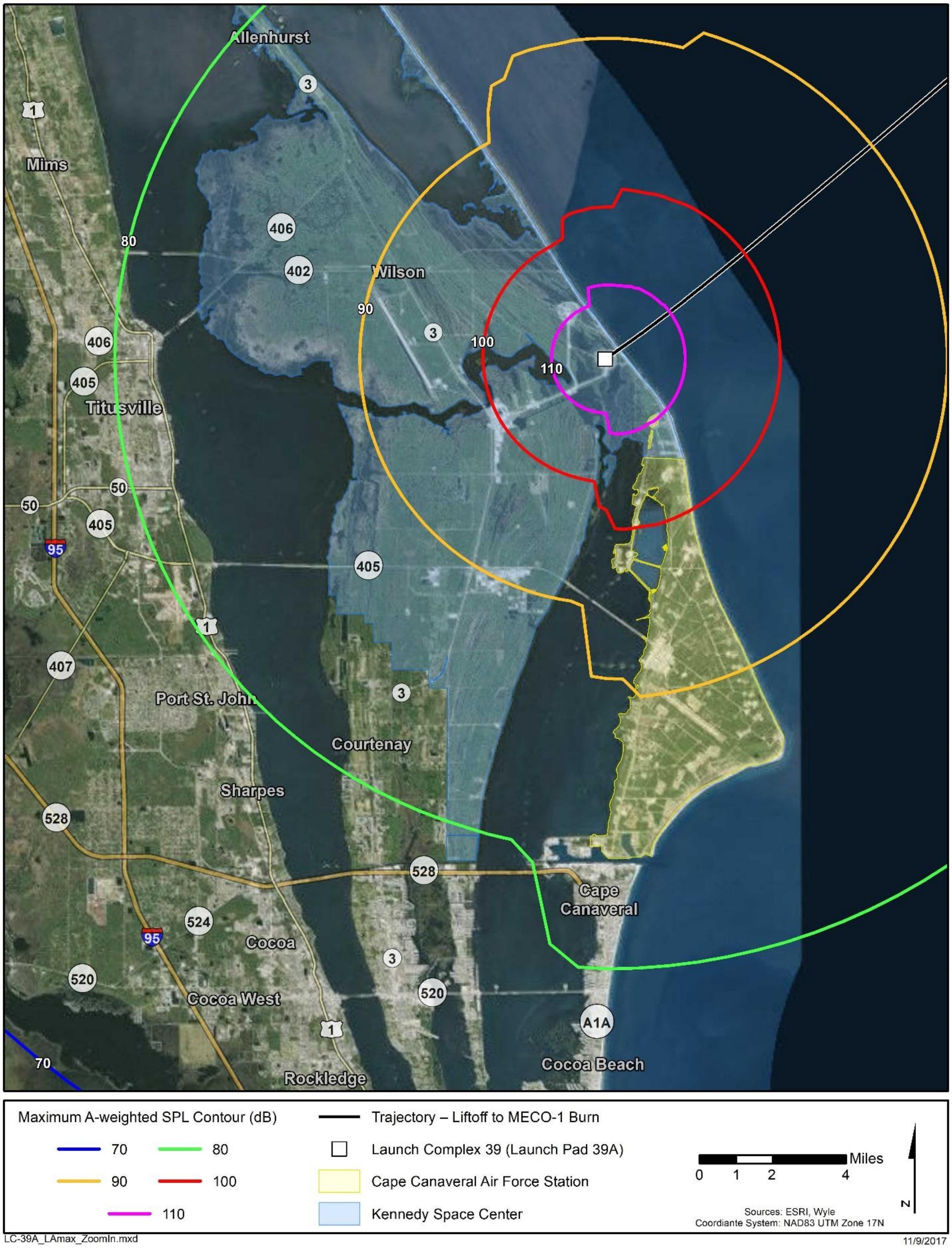

Figure 5. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-39A (Zoomed in)

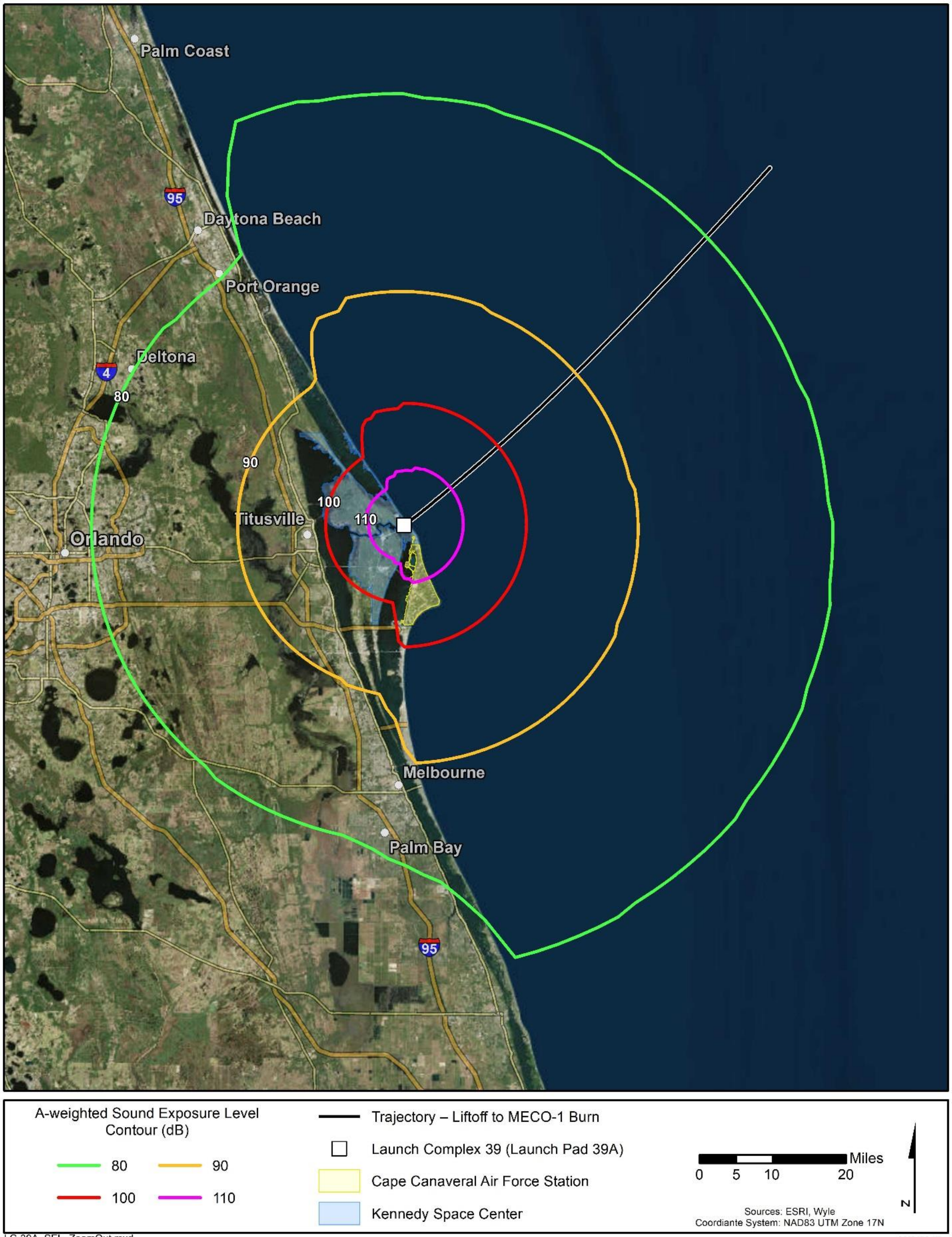

Figure 6. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-39A

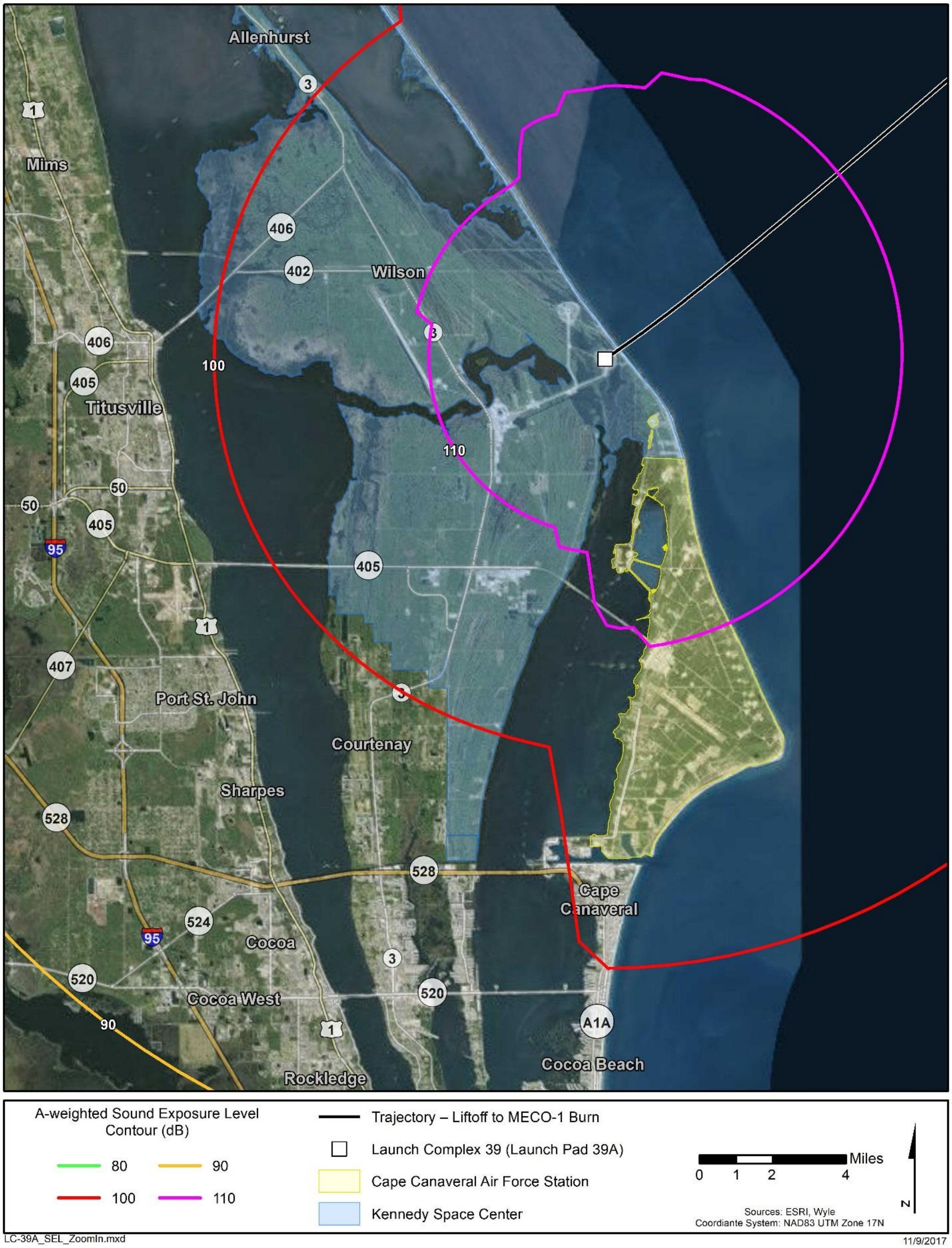

Figure 7. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-39A (Zoomed In)

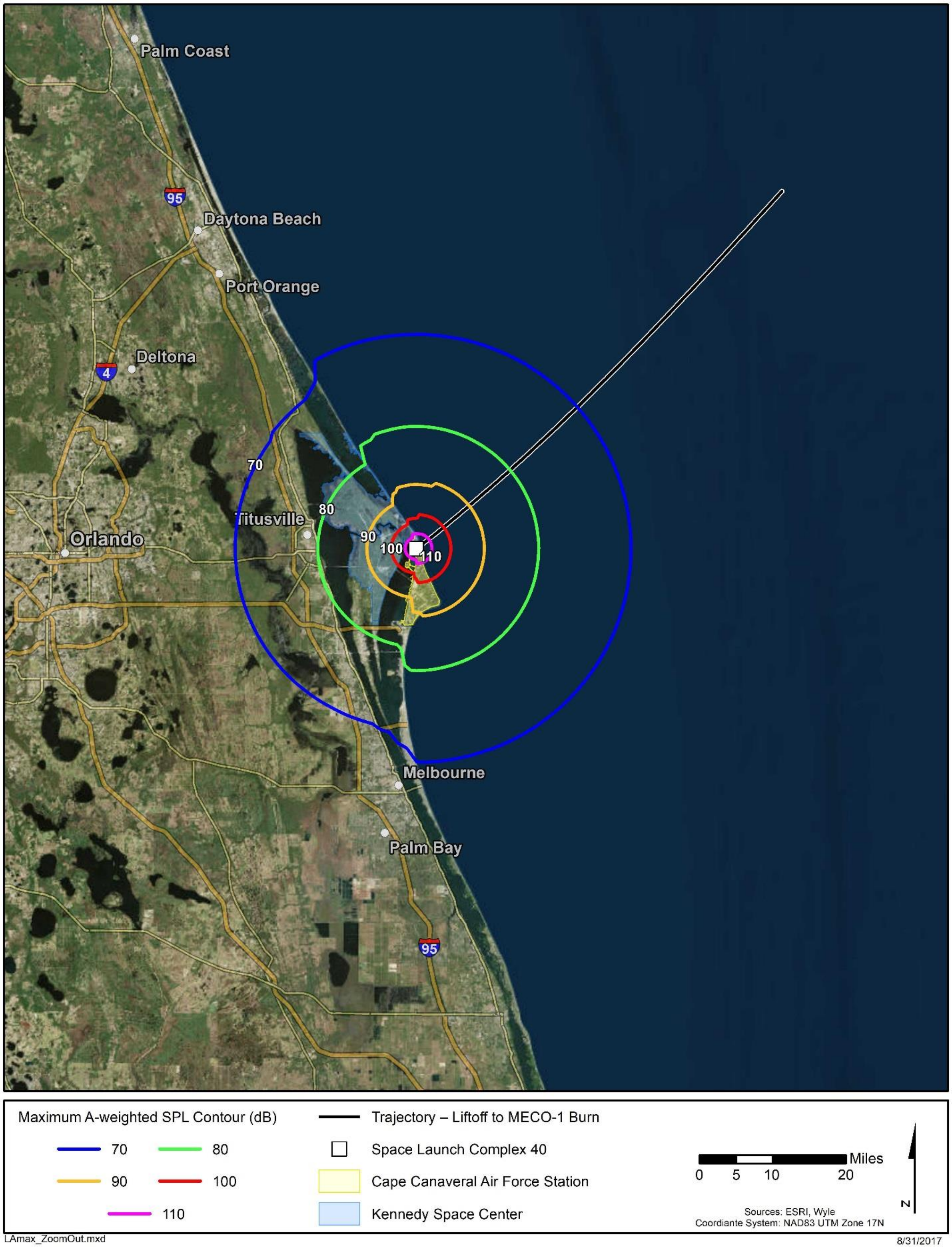

Figure 8. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-40

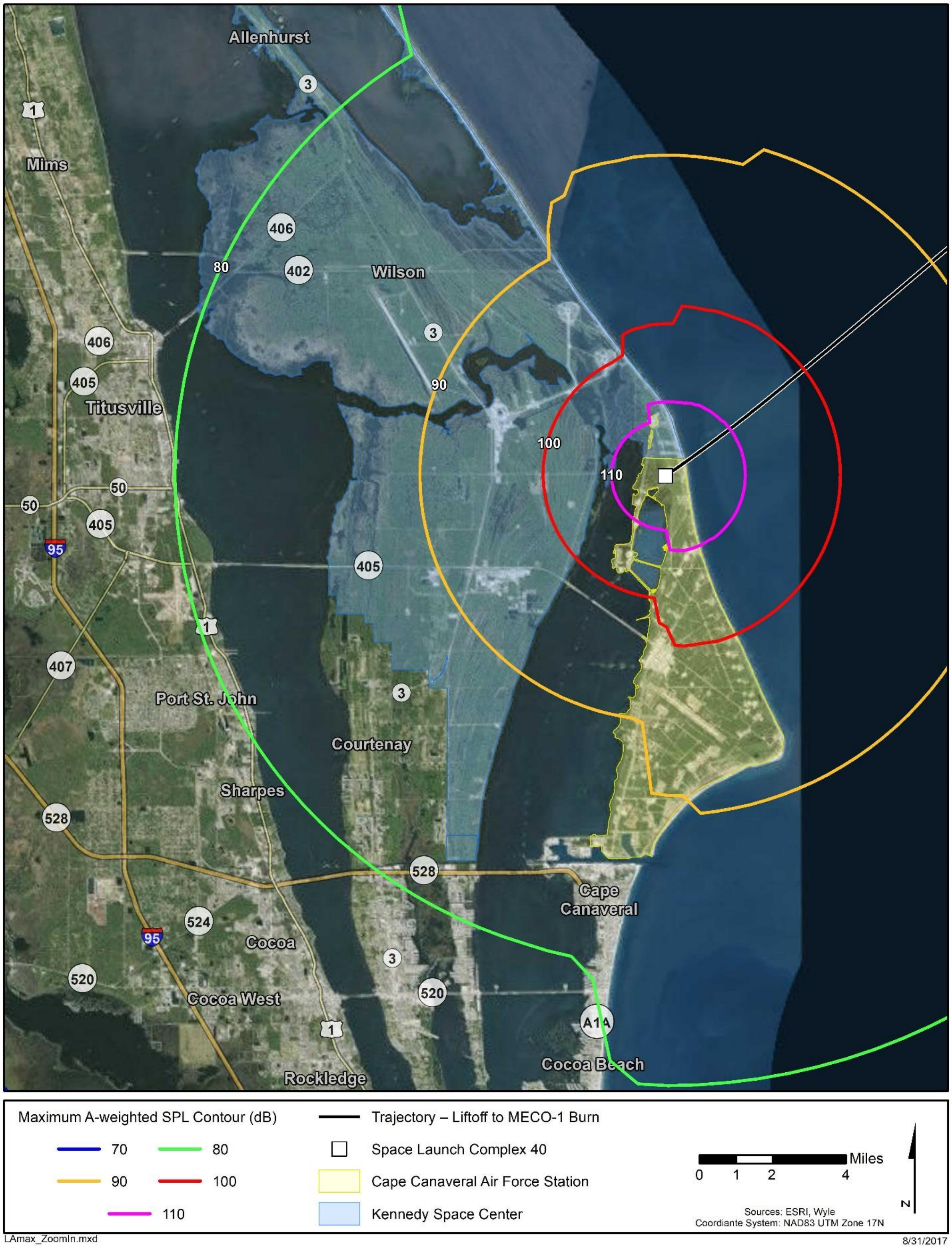

Figure 9. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-40 (Zoomed in)

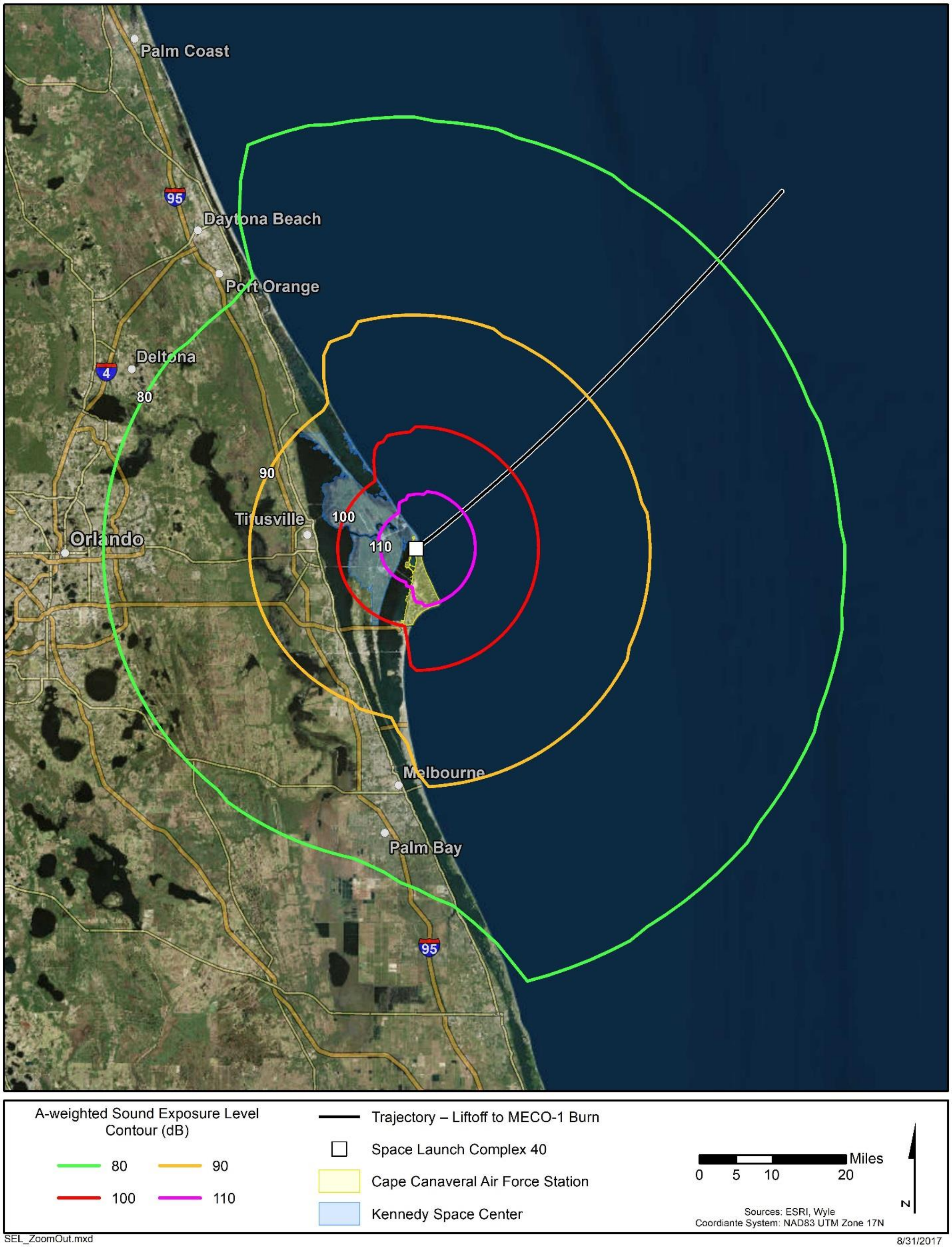

Figure 10. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-40

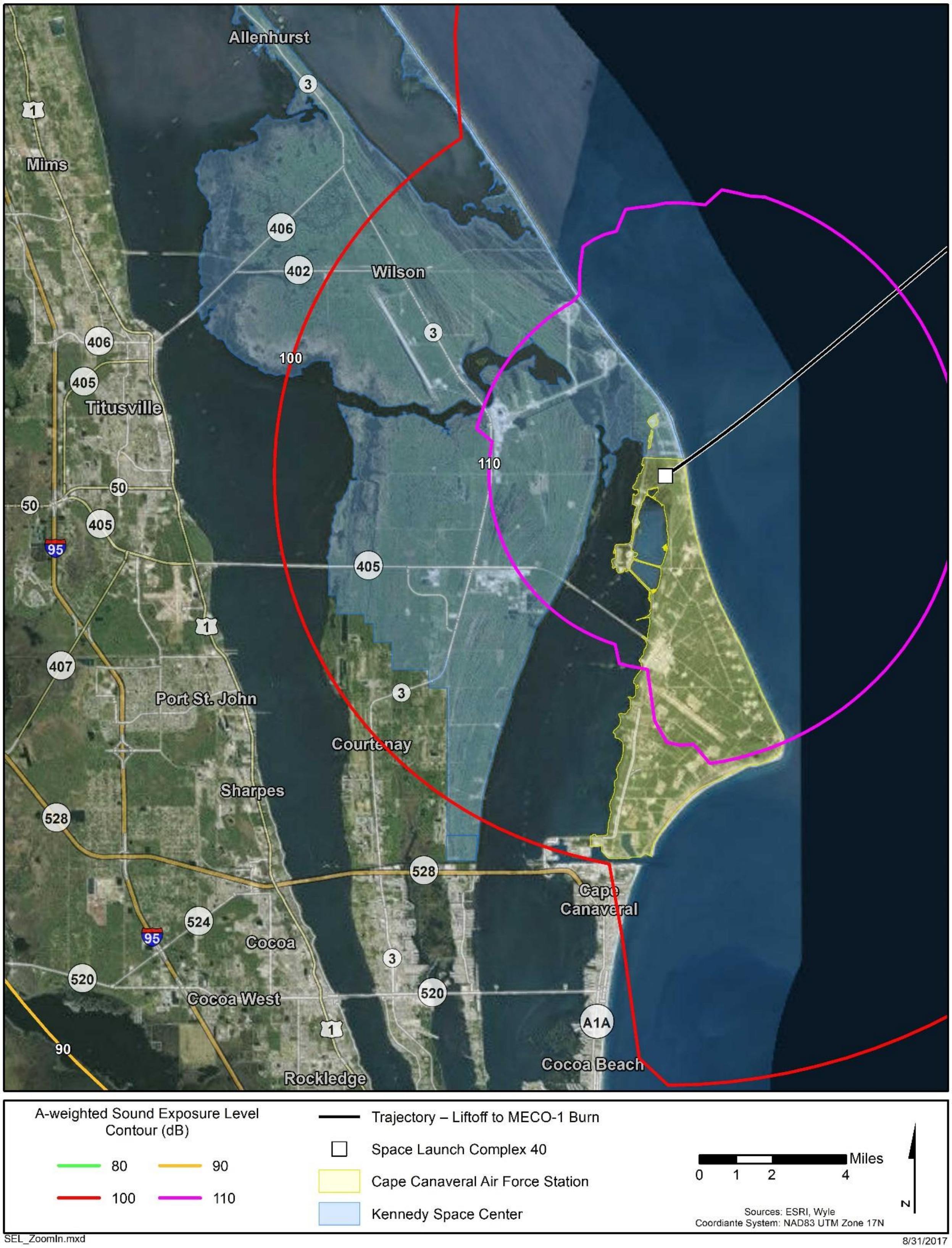

Figure 11. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-40 (Zoomed In)

3.2 Falcon Heavy Launches at LC-39A

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon Heavy Block 5 Launches at LC-39A using trajectory data, from liftoff to MECO, provided by SpaceX in file 'FH_REPRESENTATIVE_ASCENT_80_12.asc'. The L_{Amax} contours indicate the maximum sound level at each location over the duration of the launch, from liftoff to MECO, where engine thrust varies according to the ascent thrust profile provided with the trajectory data.

RNOISE computations were done using a radial grid consisting of 128 azimuths and 100 intervals out to 300,000 feet from the launch point. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. As will be shown in the resulting noise contour maps (Figures 12 through 15), the shape of the innermost contours is approximately circular. The shape of the outermost contours is due to rocket noise directivity and the difference between acoustically hard water and acoustically soft ground. The launch pad location at LC-39A is indicated in the map legends as are the CCAFS and KSC properties.

The L_{Amax} 70 dB through 110 dB contours shown in Figures 12 and 13 represent the maximum levels estimated for the Falcon Heavy Block 5 launch at LC-39A; Figure 13 shows these contours using a zoomed in map scale to better show the extent of the noise exposure relative to cities located around LC-39A. The higher L_{Amax} contours (90, 100, and 110 dB) are located entirely within both the CCAFS and KSC properties. If a Falcon Heavy Block 5 launch occurs during the day, when background levels are in the 50 dB to 60 dB range, residents of Titusville, Merritt Island, and Cape Canaveral may notice launch noise levels above 70 dB. If the same launch occurs during the night, when background levels are lower than during the day (e.g., below 40 dB to 50 dB range), these residents may notice launch noise levels that exceed 60 dB. A prevailing on-shore or off-shore breeze may also strongly influence noise levels in these communities.

SEL contour levels of 90, 100, and 110 dB are shown in Figures 14 and 15 for the Falcon Heavy Block 5 launch at LC-39A with Figure 15 showing a zoomed in map scale. SEL is an integrated metric and is expected to be greater than the L_{Amax} for rocket launches. Figure 14 indicates that the 110 dB SEL contour is expected to remain within the CCAFS and KSC properties whereas Merritt Island and parts of Titusville are expected to be exposed to SELs higher than 100 dB.

The L_{Amax}, and SEL contours estimated for Falcon Heavy Block 5 Launches at LC-39A are shown in Figures 12 through 15 in the same sequence as Figures 4 through 7 presented for Falcon 9 Block 5 launches at LC-39A. In general, the estimated noise exposure from Falcon Heavy Block 5 launches at LC-39A is 4 to 5 dB higher than the estimated noise exposure for Falcon 9 Block 5 launches at LC-39A. This difference reflects the higher power of the Falcon Heavy Block 5 which has three times the number of Merlin 1D engines as the Falcon 9 Block 5. Two different trajectory data sets provided by SpaceX account for the differences in the Falcon Heavy Block 5 and Falcon 9 Block 5 noise contours which do not have the exact same delta (i.e. change in noise level) at all locations. The noise contours at LC-39A for the Falcon Heavy Block 5 and Falcon 9 Block 5 can be compared to see how the levels change at specific locations.

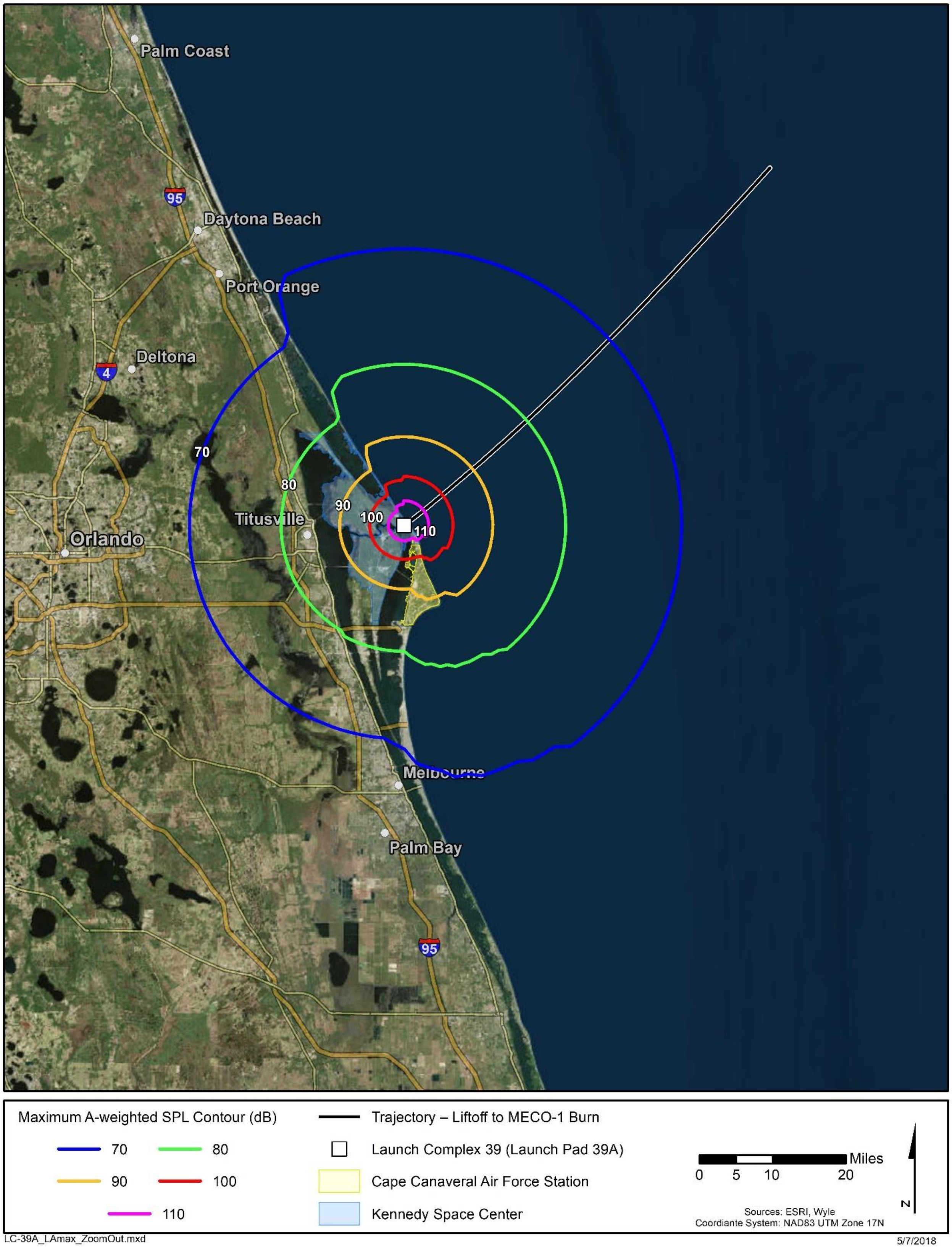

Figure 12. Maximum A-Weighted Sound Levels for Falcon Heavy Block 5 Launch from LC-39A

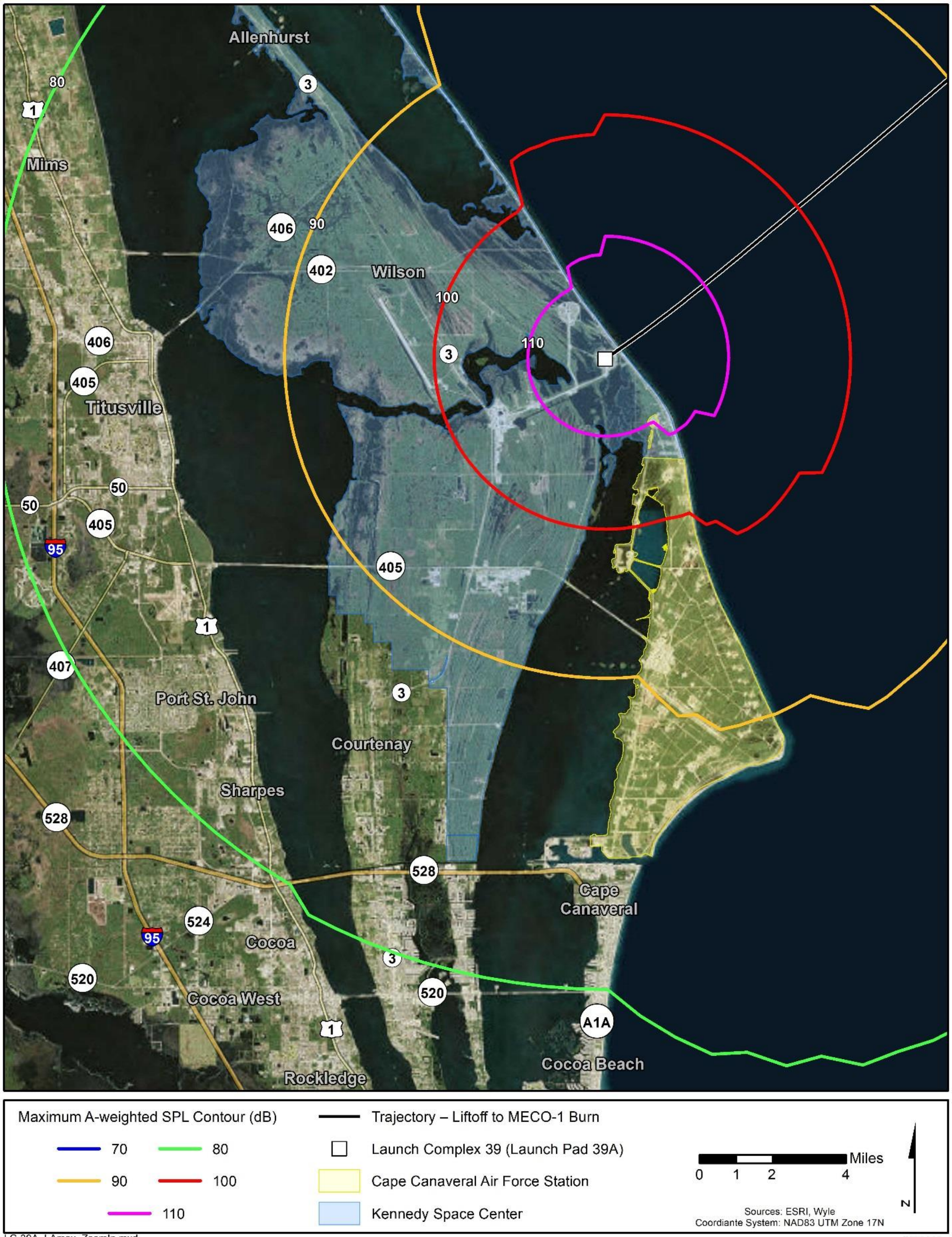

Figure 13. Maximum A-Weighted Sound Levels for Falcon Heavy Block 5 Launch from LC-39A (Zoomed in)

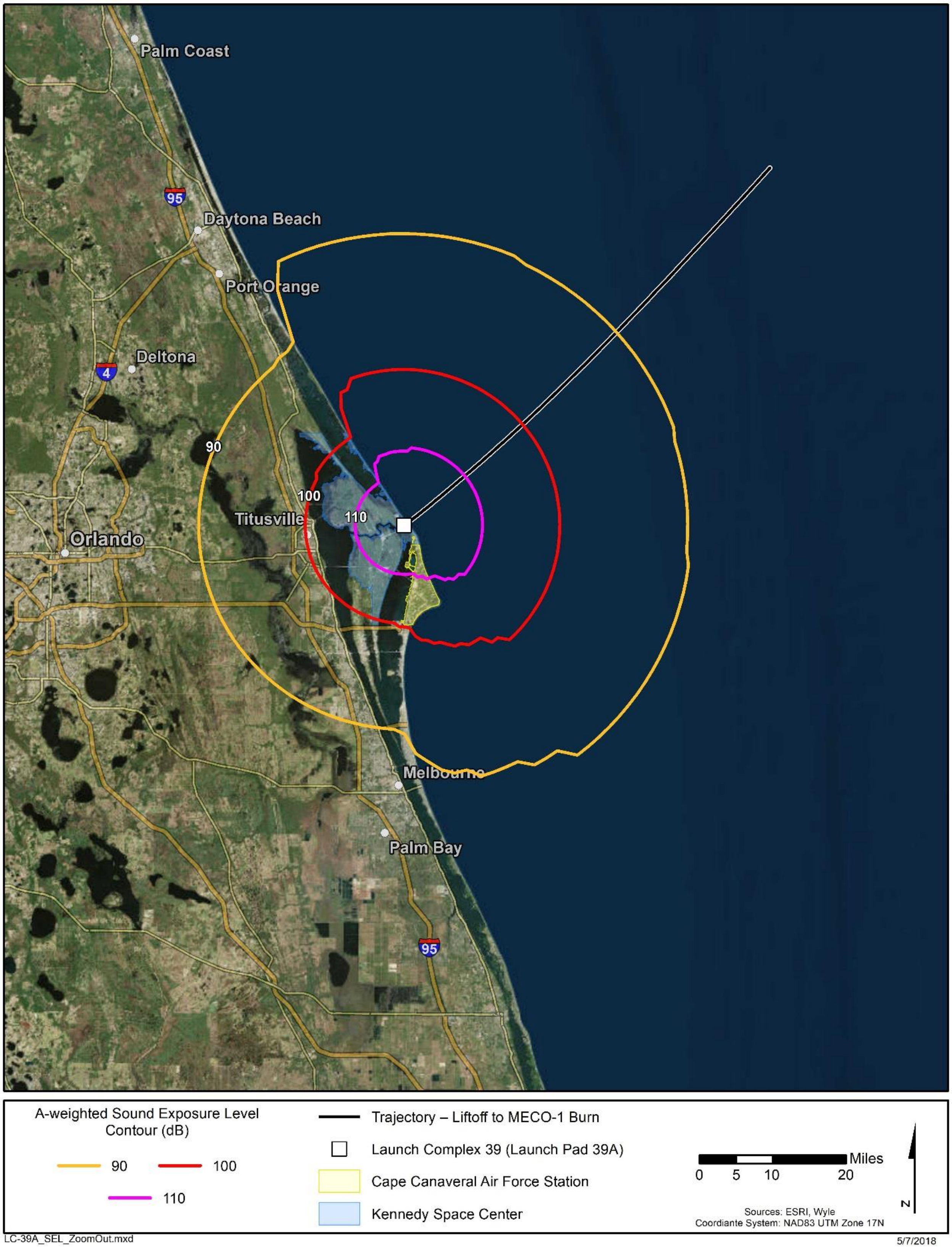

Figure 14. Sound Exposure Levels for Falcon Heavy Block 5 Launch from LC-39A

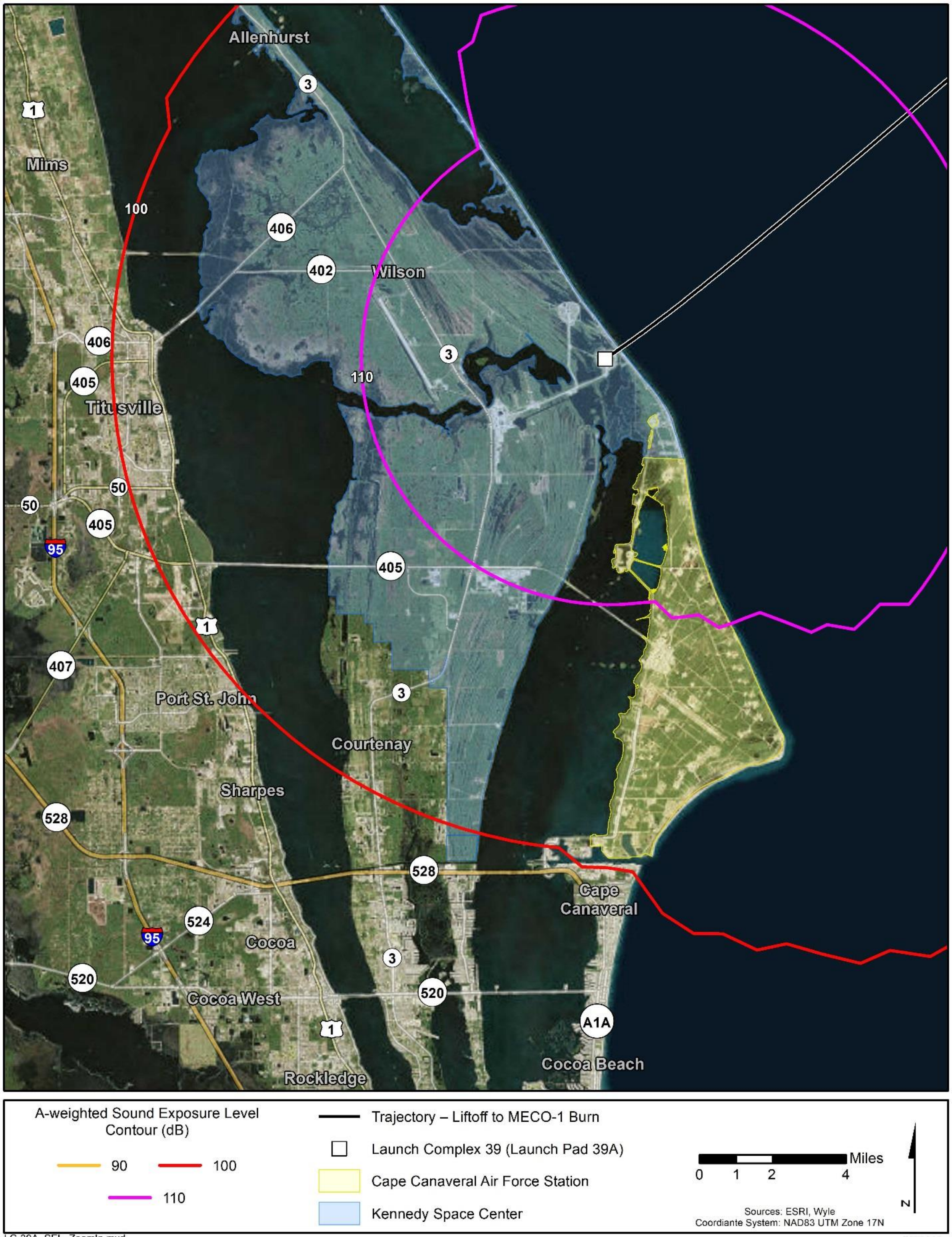

Figure 15. Sound Exposure Levels for Falcon Heavy Block 5 Launch from LC-39A (Zoomed In)

4 Booster Reentry/Landing Noise Levels

4.1 Booster Landings at LZ-1 and LZ-2

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon Heavy side booster (recovery) landings at LZ-1 and LZ-2. Booster fly back trajectories, from booster separation to landing, were provided by SpaceX in files 'FH-1_FH_DEMO_+Y_BOOSTER_NOM_BOOSTER_SEP_TO_LANDING_80_12.ASC' and 'FH-1_FH_DEMO_-Y_BOOSTER_NOM_BOOSTER_SEP_TO_LANDING_80_12.ASC'. These trajectory files represent two Falcon Heavy side boosters landing simultaneously with the +Y Booster landing at LZ-1 and the –Y Booster landing at LZ-2. L_{Amax} contours indicate the maximum sound level at each location over the duration of the landings where engine thrust varies according to the reentry/descent thrust profiles provided with the trajectory data.

RNOISE computations were performed as noted in Section 3.1. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. Figures 16 and 17 show the L_{Amax} and SEL contours for the booster landings at LZ-1 and Figures 18 and 19 show the L_{Amax} and SEL contours for the booster landings at LZ-2, respectively. The landing pad locations at LZ-1 and LZ-2 and landing trajectories are indicated in the map legends as are the CCAFS and KSC properties. Only the zoomed out map scale is used in this series of figures. In all four figures the 70 dB contour (L_{Amax} or SEL) extends to the west partly into the city of Titusville. Residents of Titusville may therefore notice the noise from booster landings at LZ-1 and LZ-2. Higher noise levels (90 to 110 dB L_{Amax} or SEL) are mostly within the CCAFS and KSC properties. Merritt Island and parts of the city of Cape Canaveral may be exposed to SELs higher than 100 dB.

Compared with the launch noise levels presented in Section 3, booster landing noise levels are considerably lower reflecting the much lower total engine thrust required for landing operations. Also of note in this series of figures is that the SEL contours for booster landings at LZ-1 (Figure 17) are noticeably larger (about 10 dB higher) than the SEL contours for booster landings at LZ-2 (Figure 19); whereas the L_{Amax} contours are about the same at both locations. This is due to the two booster landing trajectories having somewhat different thrust schedules during the landings, affecting SEL but not L_{Amax}. Both thrust schedules are similar in general, but have individual differences since these are actual flight trajectories.

While single booster landings can occur, the two booster fly back trajectories provided by SpaceX represent simultaneous booster landings at LZ-1 and LZ-2. Overall single event noise levels from these simultaneous landings are shown in Figure 20 (L_{Amax}) and Figure 21 (SEL). The Maximum A-Weighted Sound Levels are several dB higher for the combined, simultaneous landings than for either individual landing alone. The Sound Exposure Levels for the combined, simultaneous booster landings are only about 1 dB higher than the Sound Exposure Levels for the booster landing at LZ-1; since the levels at LZ-1 are about 10 dB higher than the levels at LZ-2; i.e., the Sound Exposure Levels from simultaneous landings at LZ-1 and LZ-2 is not much higher than the Sound Exposure Levels from the landing at LZ-1 alone.

The next section presents single event noise levels for four different SpaceX rocket static fire tests including the Falcon 9 at LC-39A and LC-40, Falcon Heavy at LC-39A, and Dragon at LZ-1.

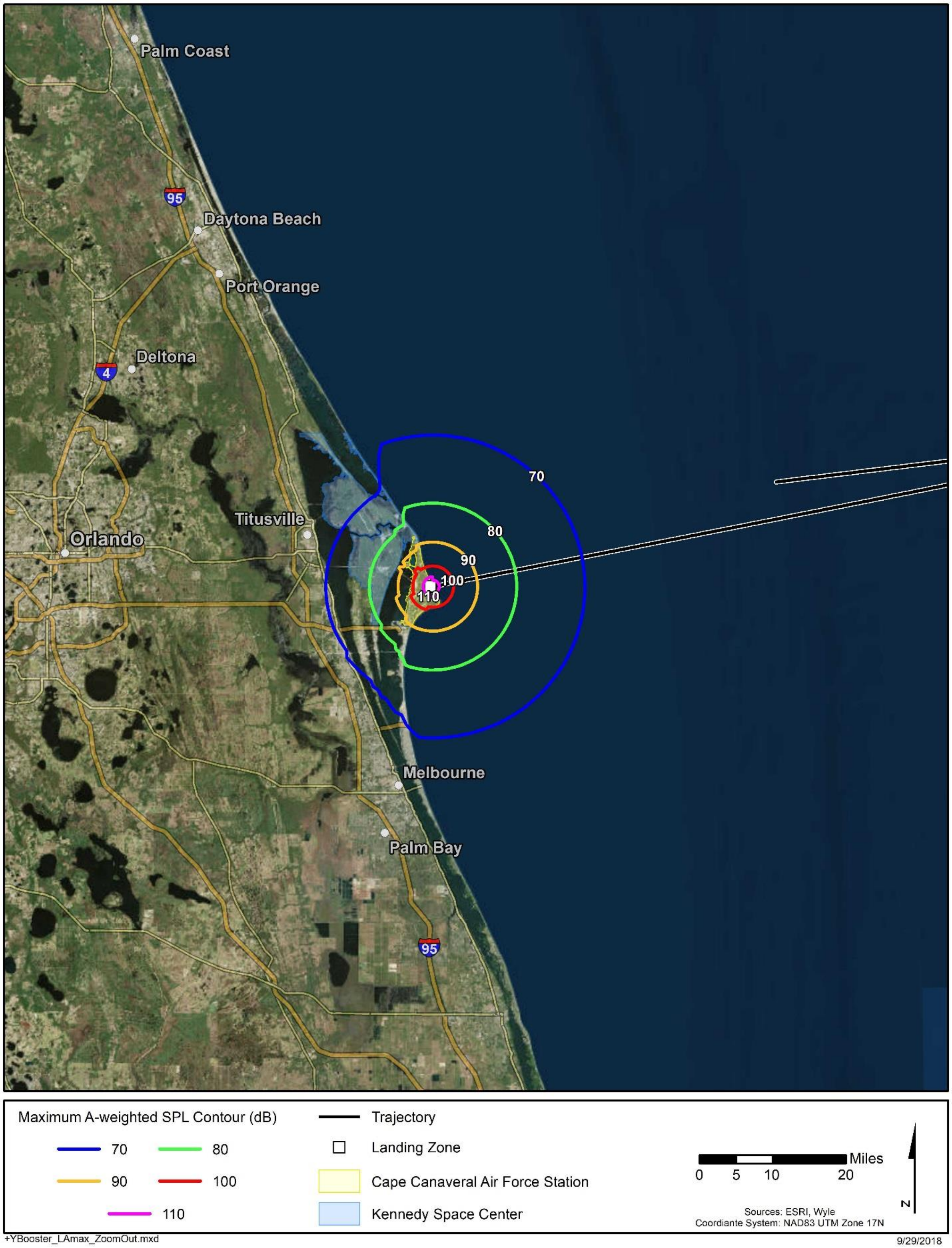

Figure 16. Maximum A-Weighted Sound Levels for Booster Landing at LZ-1

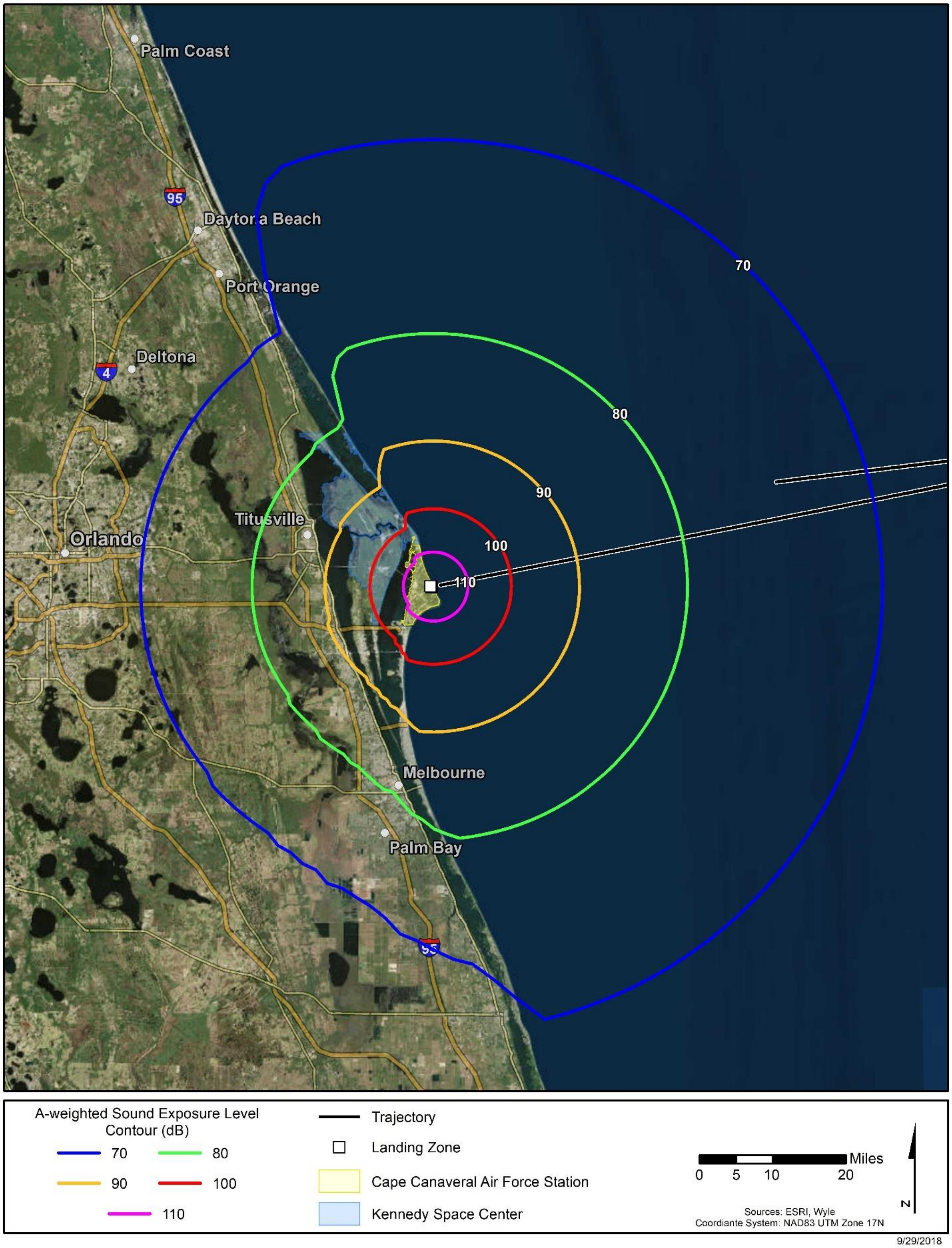

Figure 17. Sound Exposure Levels for Booster Landing at LZ-1

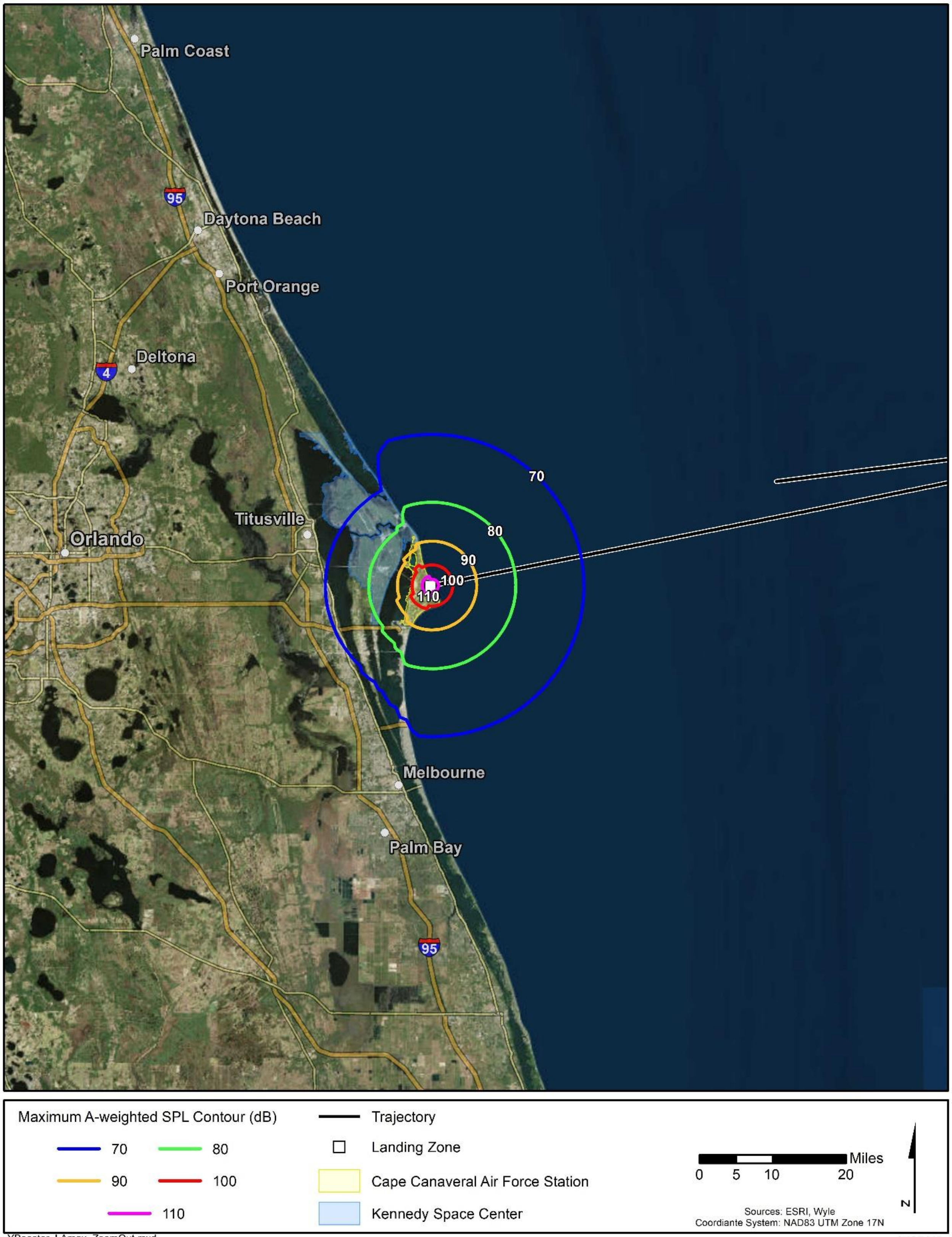

Figure 18. Maximum A-Weighted Sound Levels for Booster Landing at LZ-2

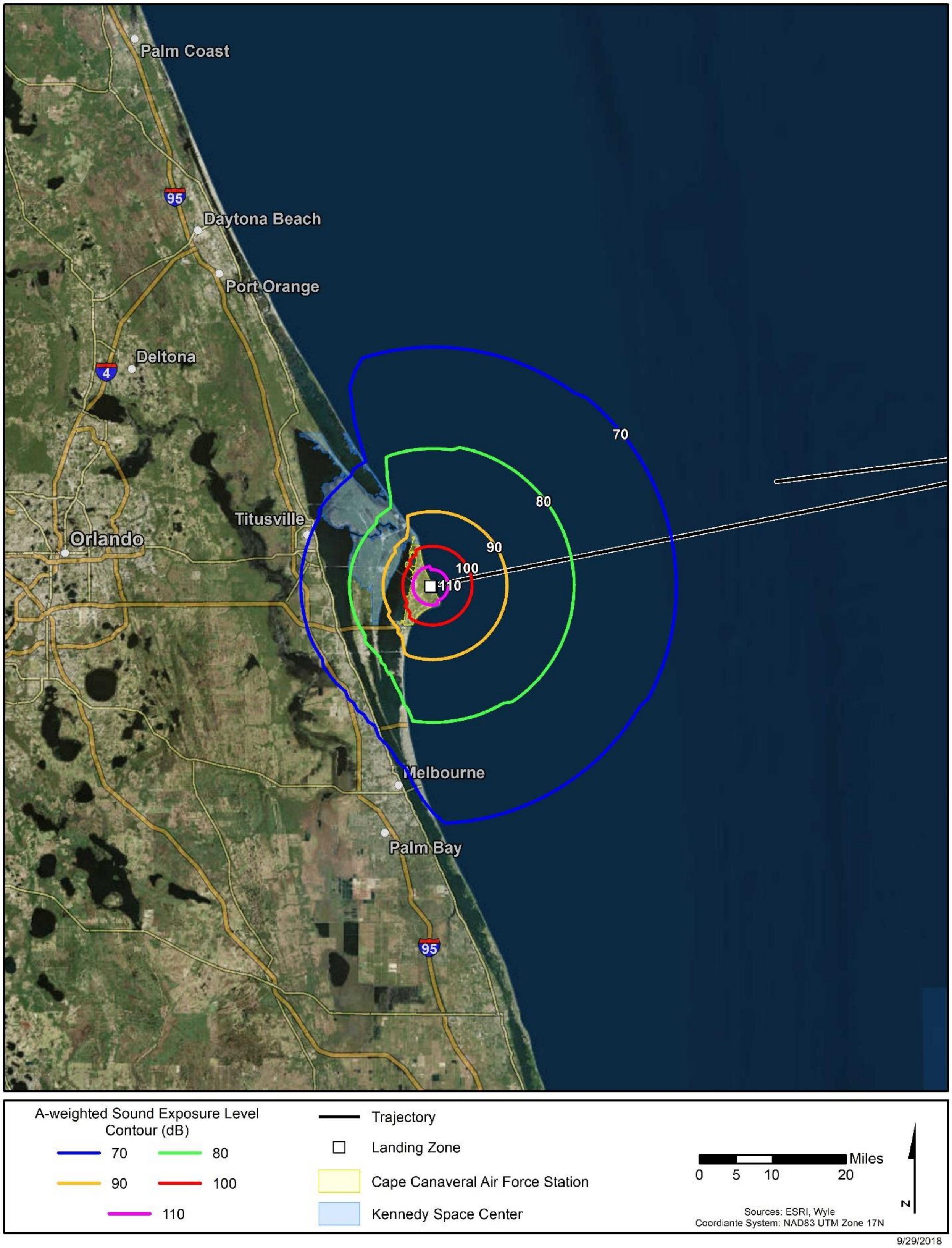

Figure 19. Sound Exposure Levels for Booster Landing at LZ-2

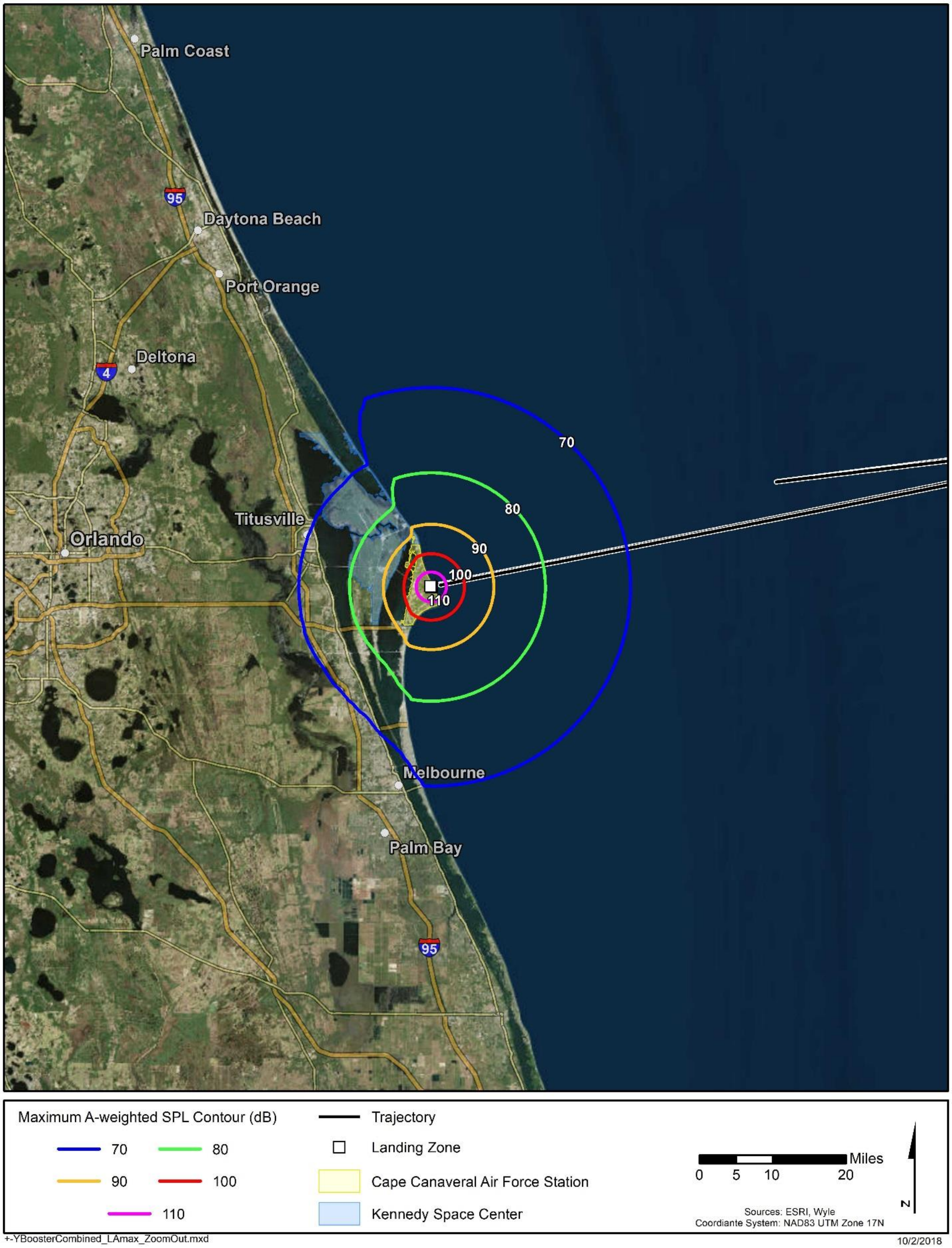

Figure 20. Maximum A-Weighted Sound Levels for Simultaneous Booster Landings at LZ-1 and LZ-2

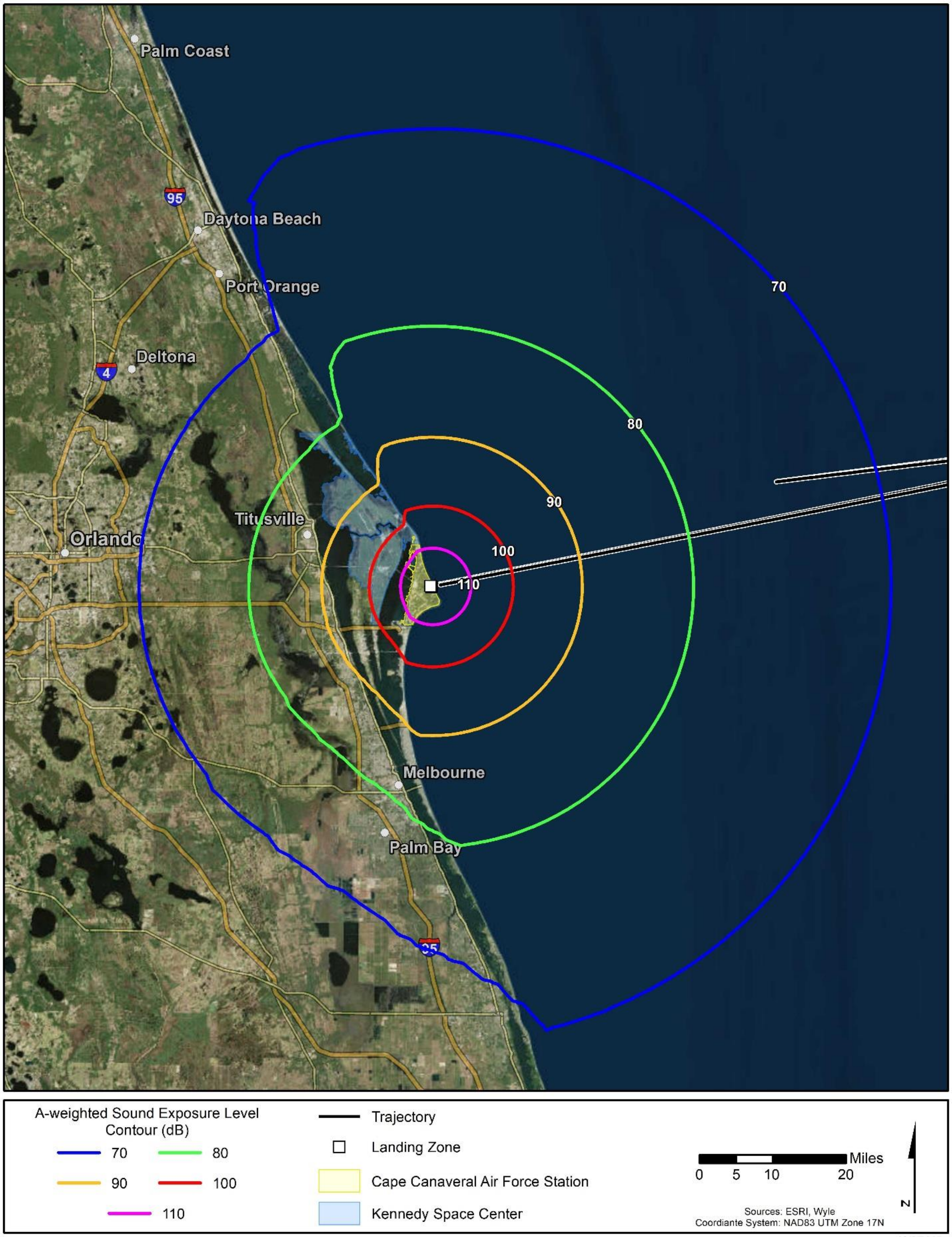

Figure 21. Sound Exposure Levels for Simultaneous Booster Landings at LZ-1 and LZ-2

5 Static Fire Test Noise Levels

5.1 Falcon 9 Static Tests at LC-39A and LC-40

Falcon 9 static fire tests occur at LC-39A and LC-40 where all engines (on vehicle, on mount) are fired for up to 12 seconds. Figures 22 and 23 show the estimated L_{Amax} and SEL contours, respectively, for a Falcon 9 static fire test at LC-39A. Figures 24 and 25 show similar L_{Amax} and SEL contours, respectively, for a Falcon 9 static fire test at LC-40. Falcon 9 static fire tests at both locations generate Sound Exposure Levels that are above 70 dB at the most eastern parts of Titusville. Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS and KSC properties.

5.2 Falcon Heavy Static Tests at LC-39A

Falcon Heavy static fire tests occur at LC-39A. Figures 26 and 27 show the estimated L_{Amax} and SEL contours, respectively, for a Falcon Heavy static fire test at LC-39A. All engines are fired for up to 12 seconds during these tests. Figure27, which shows a zoomed in map scale, indicates that Sound Exposure Levels will exceed 70 dB in nearby cities (Titusville, Cape Canaveral, Port St. John, and northern parts of Cocoa). Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS and KSC properties.

5.3 Dragon Static Tests at LZ-1

Dragon static fire tests occur at LZ-1 where all engines are fired for up to 12 seconds. Figures 28 and 29 show zoomed in maps of the L_{Amax} and SEL contours, respectively, for a Dragon static fire test at LZ-1. LZ-1 is located about six miles south, along the coastline, from LC-39A. In Figure 29, the 70 SEL contour extends south along the coast; residents of Cape Canaveral and Cocoa Beach may notice these tests, especially at night when background levels are lower. Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS property.

This concludes the analysis of single event levels for SpaceX rocket operations. L_{Amax} and SEL contours were shown for shown for single rocket launches (Section 3), booster landings (Section 4), and static fire tests (Section 5). In Section 6, cumulative noise levels are estimated, in terms of DNL, for these same rocket operations accounting for their projected annual operations from 2018 through 2024.

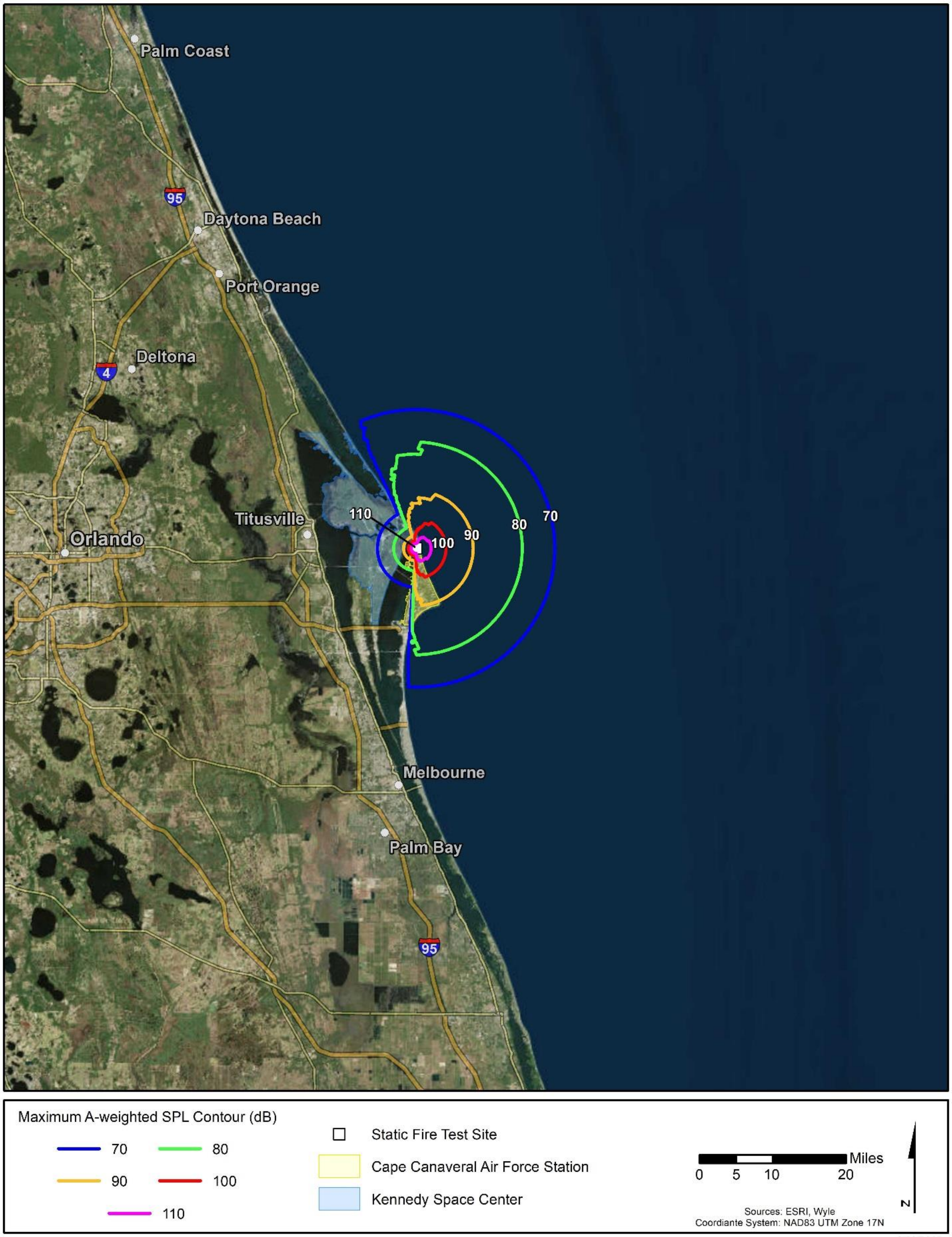

Figure 22. Maximum A-Weighted Sound Levels for Falcon 9 Static Fire Test at LC-39A

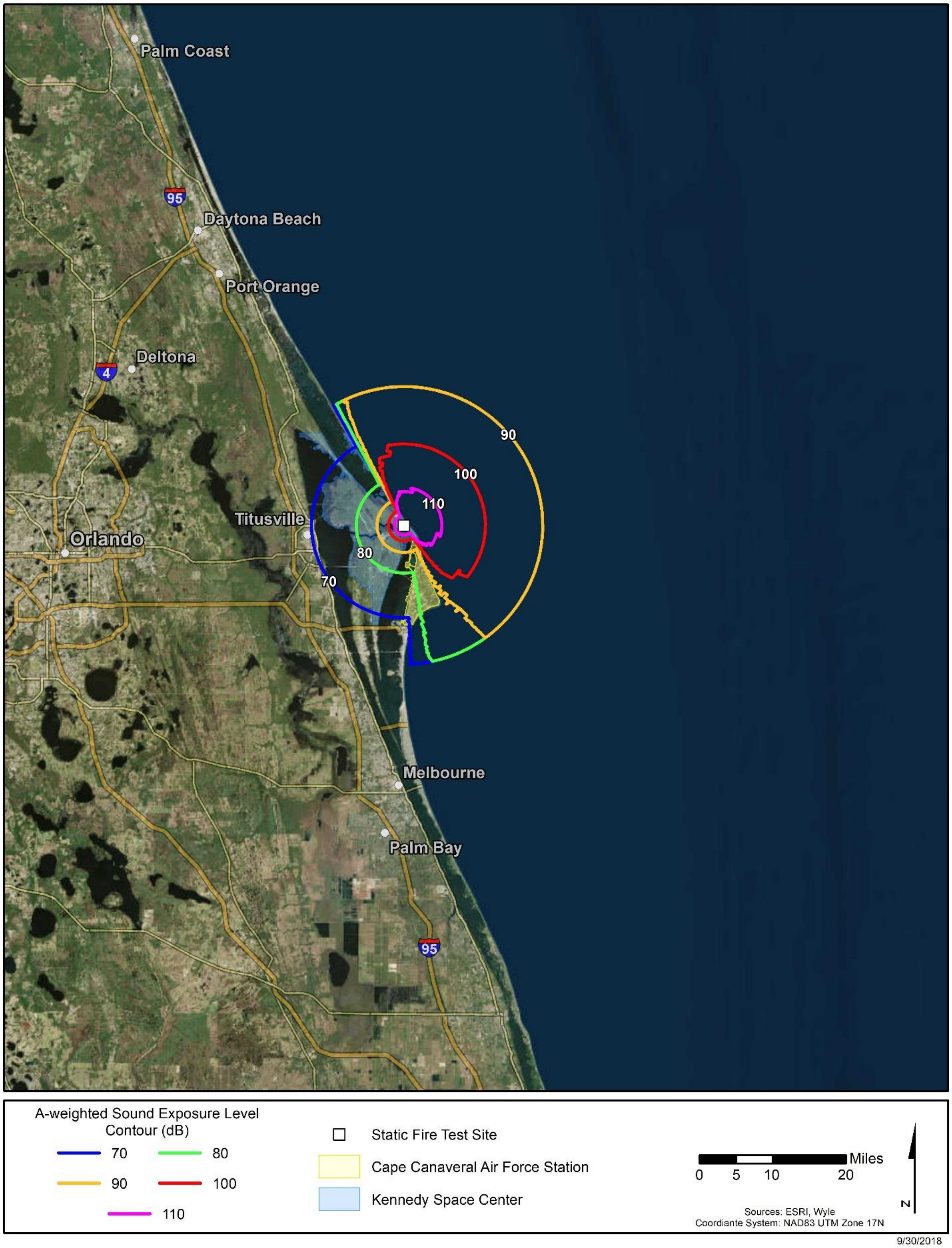

Figure 23. Sound Exposure Levels for Falcon 9 Static Fire Test at LC-39A

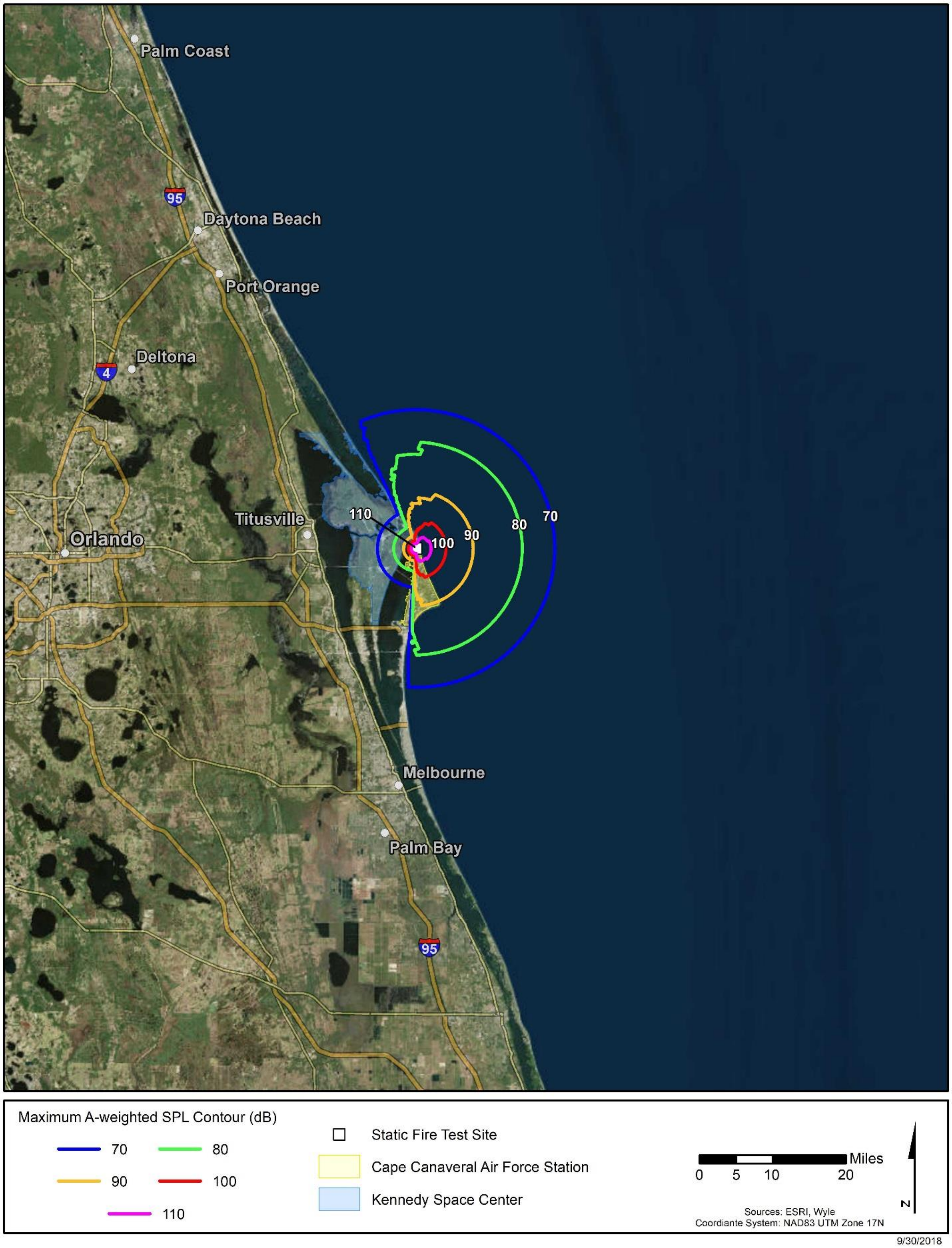

Figure 24. Maximum A-Weighted Sound Levels for Falcon 9 Static Fire Test at LC-40

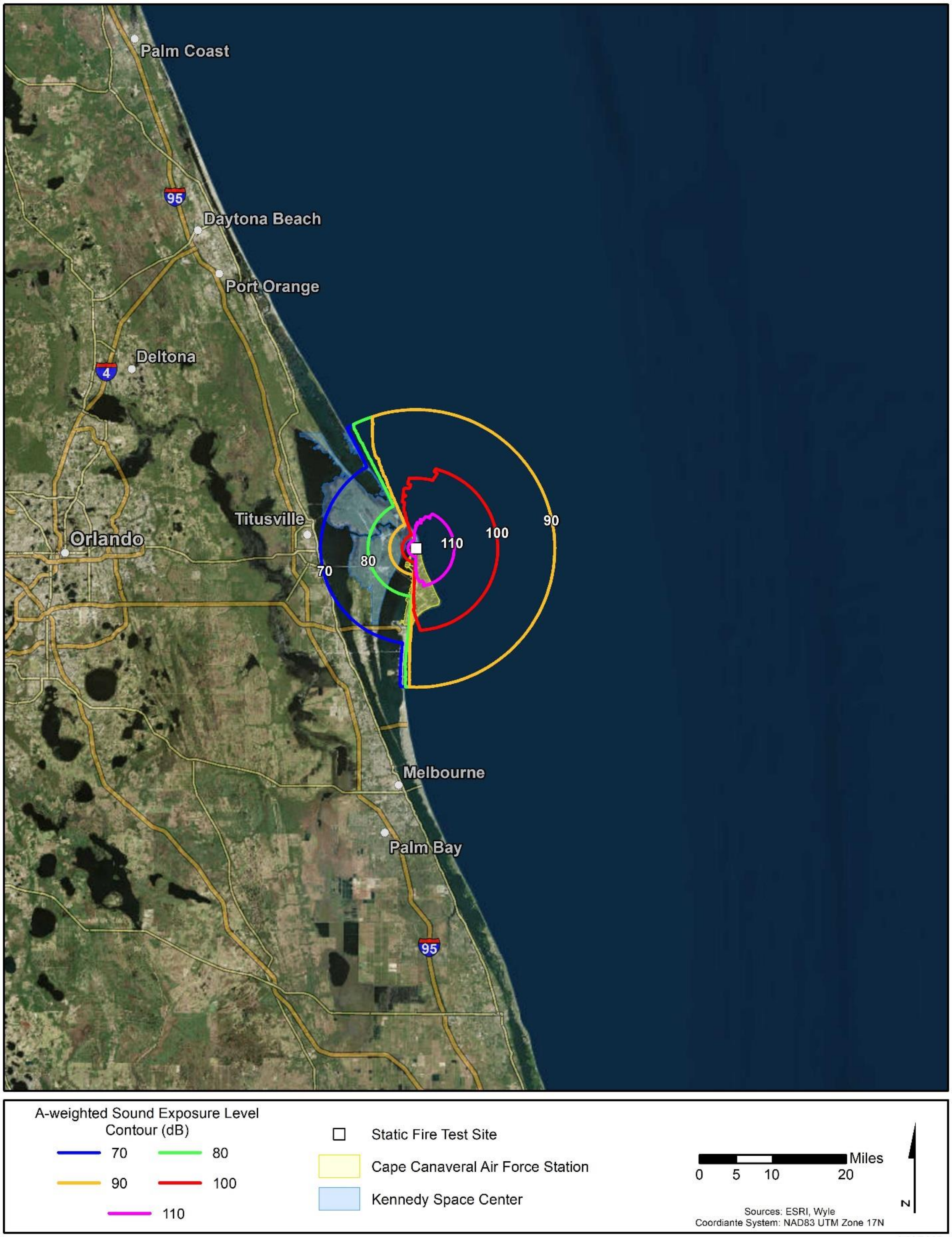

Figure 25. Sound Exposure Levels for Falcon 9 Static Fire Test at LC-40

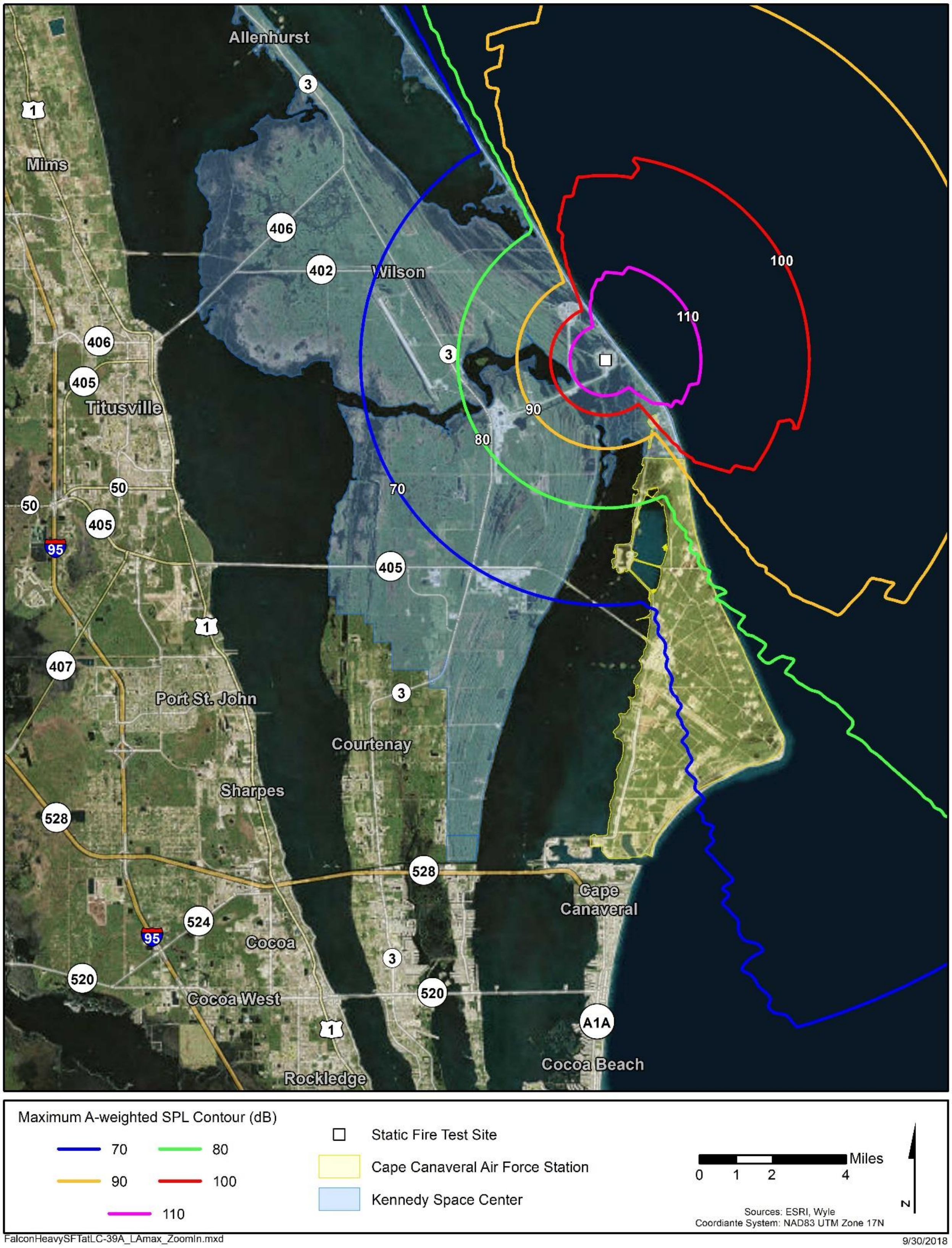

Figure 26. Maximum A-Weighted Sound Levels for Falcon Heavy Static Fire Test at LC-39A (Zoomed In)

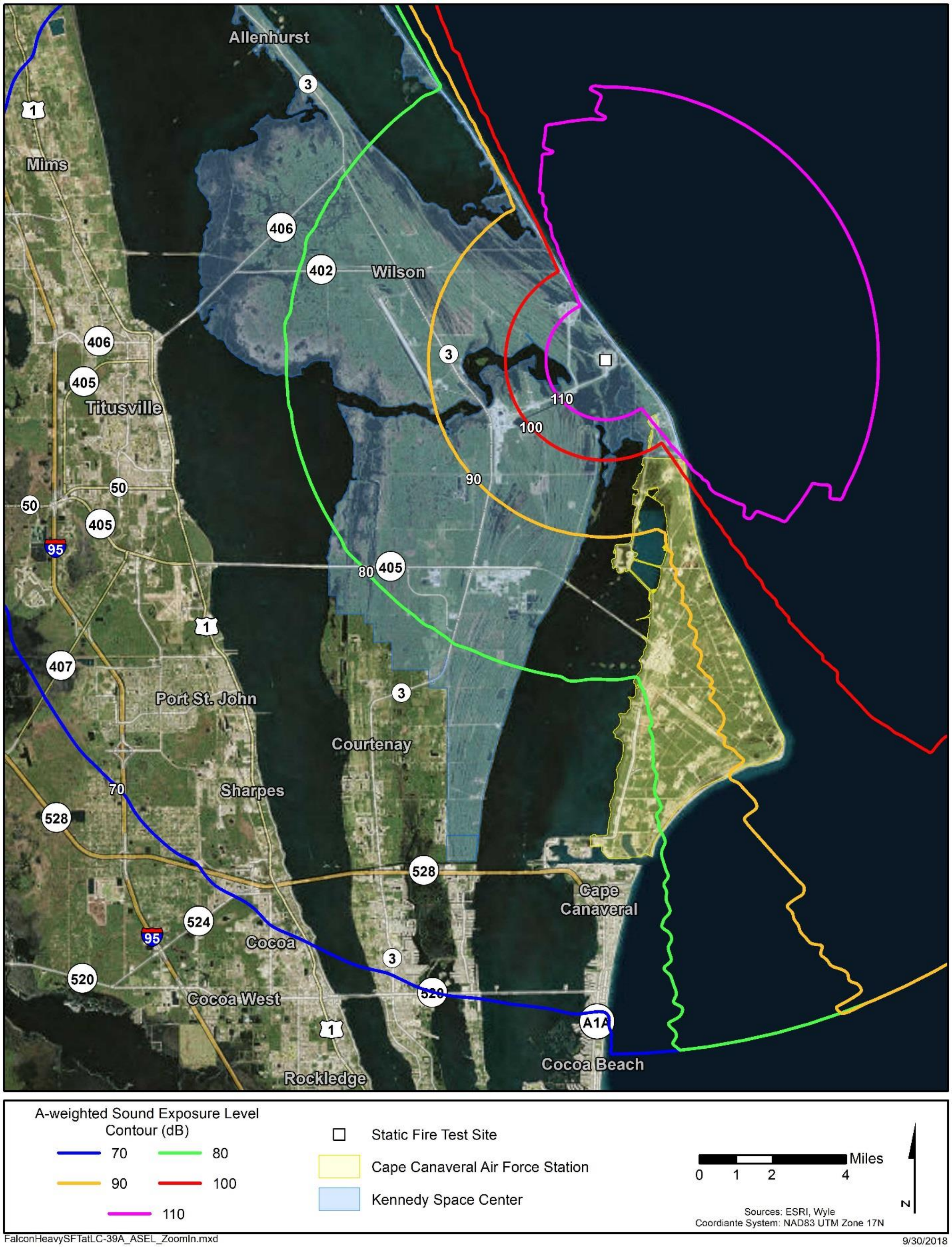

Figure 27. Sound Exposure Levels for Falcon Heavy Static Fire Test at LC-39A (Zoomed In)

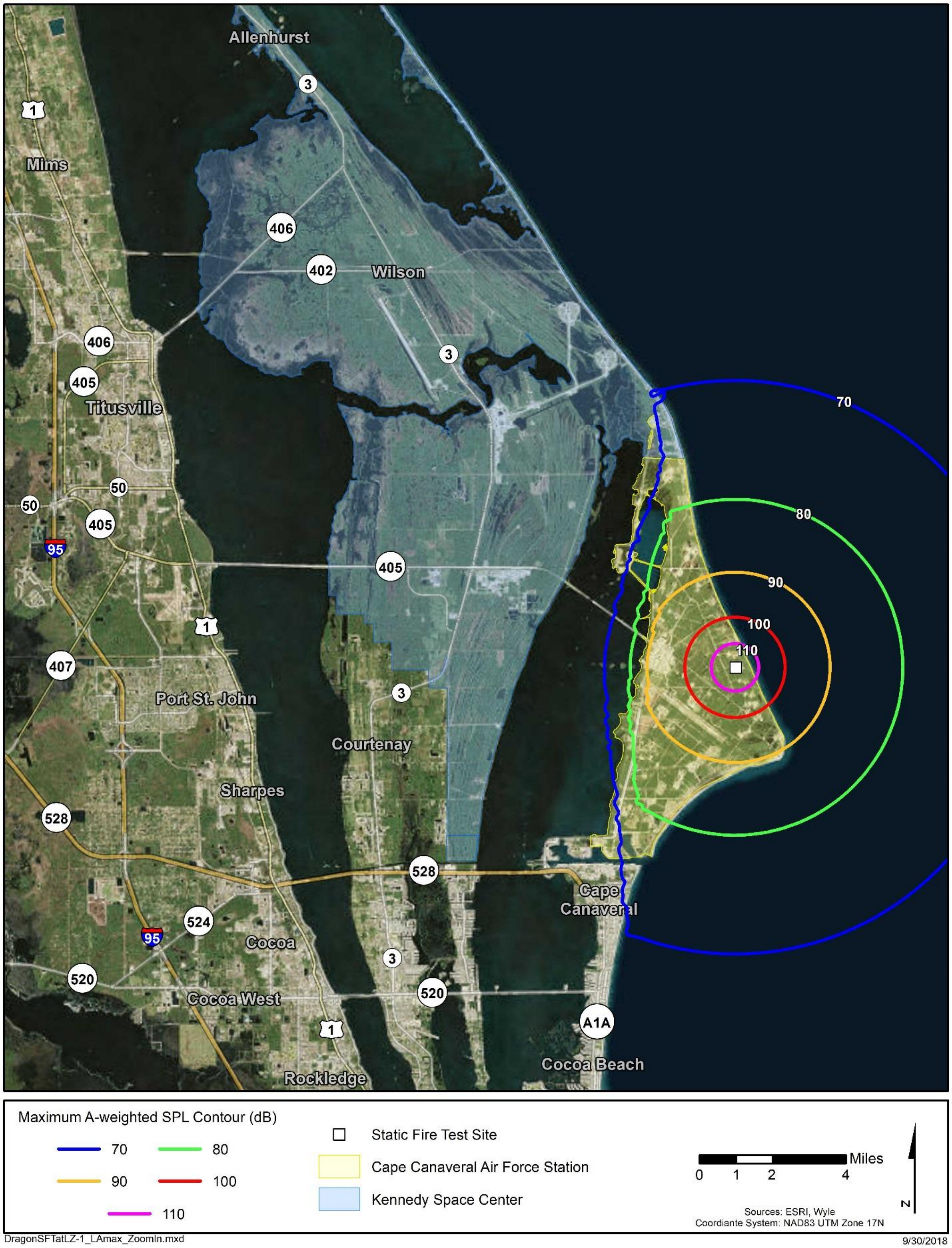

Figure 28. Maximum A-Weighted Sound Levels for Dragon Static Fire Test at LZ-1 (Zoomed In)

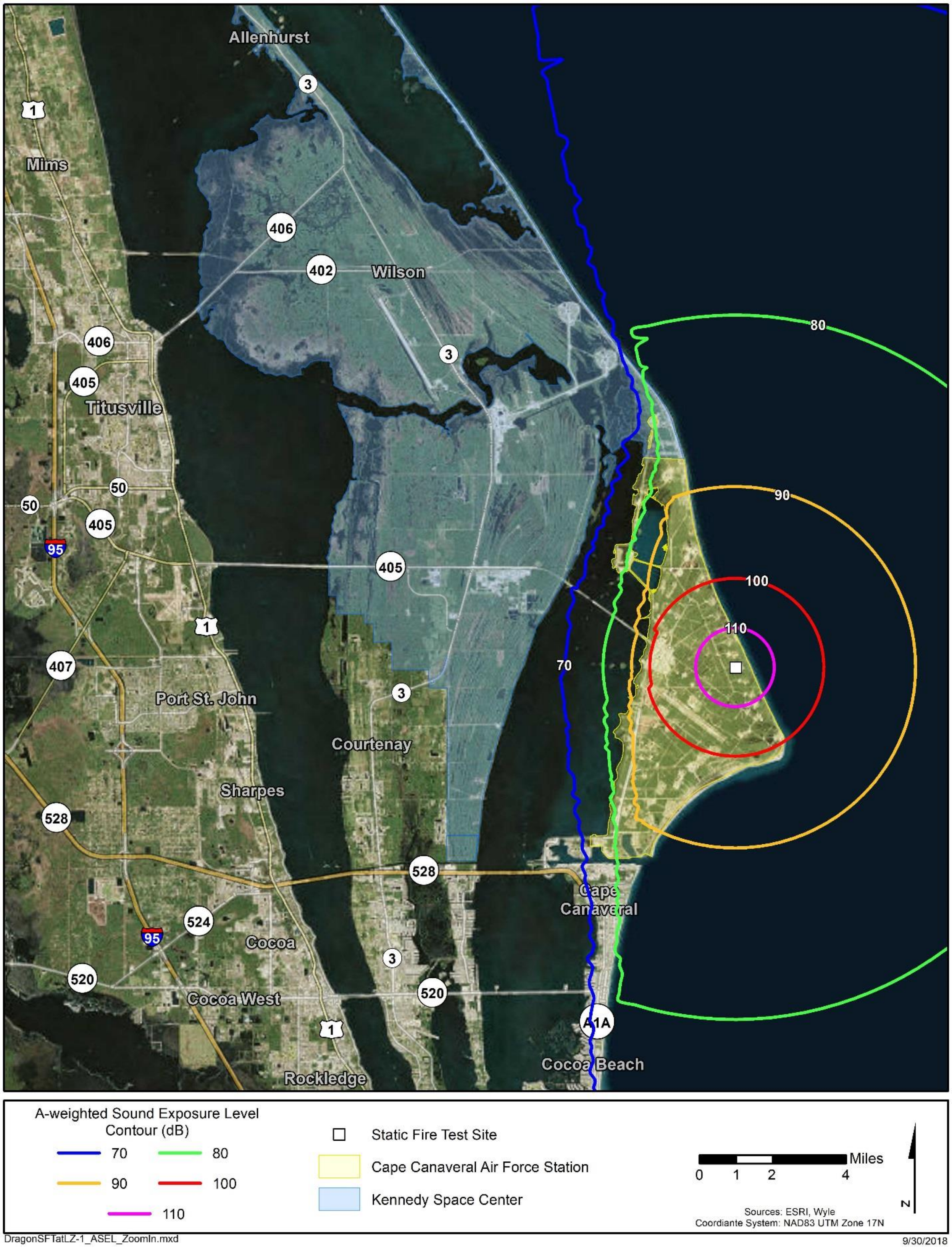

Figure 29. Sound Exposure Levels for Dragon Static Fire Test at LZ-1 (Zoomed In)

6 Cumulative Noise Levels for Rocket Operations at CCAFS and KSC

6.1 Day-Night Average Sound Levels for Rocket Operations at CCAFS and KSC

As noted in section 2, FAA Order 1050.1E specifies Day-Night Average Sound Level (DNL) as the standard metric for community noise impact analysis. DNL is appropriate for continuous noise sources, such as airport noise and road traffic noise. It is not appropriate for irregularly occurring noise events such as rocket launches or static tests, however these noise events may be evaluated using DNL for policy decisions.

This section presents an estimate of the DNL for 2017 launch operations and other typical noise events occurring at CCAFS and KSC and describes how projected future launches, booster landings, and static fire tests of the Falcon 9, Falcon Heavy, and Dragon rockets are expected to influence the DNL.

To accurately describe the DNL at CCAFS and KSC, a detailed study would be required involving either the modeling of all major noise sources or conducting noise monitoring throughout these areas for a period of time that adequately represents the different types of launch vehicles and frequency of launches conducted. The modeling estimates of DNL presented here are basic and serve to identify whether SpaceX launch operations at CCAFS and KSC are expected to have a significant noise impact per the guidelines in FAA Order 1050.1E. FAA Order 1050.1E specifies that a significant noise impact would occur if analysis shows that the proposed action will cause noise sensitive areas to experience an increase in noise of DNL 1.5 dB or more at or above DNL 65 dB noise exposure when compared to the no action alternative for the same timeframe.

Before estimating DNL for the CCAFS and KSC properties and surrounding cities it is important to note that these areas have a variety of land uses. CCAFS and KSC have areas that should be considered rural or remote, except where NASA or other launch facilities are located. KSC has a wildlife refuge. Populated areas of Merritt Island could be considered rural or quiet suburban residential areas whereas Titusville and the city of Cape Canaveral are more urban areas with mixed residential and industrial uses. It is therefore important to consider the land use category and associated background noise levels when determining if launch operations will have a significant noise impact.

The DNL estimates presented here are for the baseline year (2017) and for future year 2024 in which SpaceX proposes an increase in their Falcon 9 and Falcon Heavy launches and static fire tests. To estimate DNL for 2017, background noise levels were estimated and so was the DNL from all 2017 launch operations at CCAFS and KSC. Background DNL was estimated using ANSI/ASA S12.9-2013/Part3[9] which provides estimated background noise levels for different land use categories and population density. Table 1 shows the DNL estimated for rural or remote areas and several different categories of suburban and urban residential land use which can be used to represent DNL for the various land uses within CCAFS, KSC, and surrounding areas. According to these estimates, many of the remote areas within the CCAFS and KSC properties would be expected to have a DNL less than 49 dBA while parts of Titusville and the city of Cape Canaveral would be expected to have a DNL as high as 59 dBA. The DNL values in Table 1 provide an estimate of the background levels expected in typical noise environments and do not include noise from launch operations.

Table 1. Estimated Background Noise Levels

Example Land Use Category	Average Residential Intensity (people per acre)	DNL (dBA)		
			Daytime	Nighttime
Rural or remote areas	<2	<49	<48	<42
Quiet suburban residential	2	49	48	42
	4	52	53	47
	4.5	52	53	47
Quiet urban residential	9	55	56	50
Quiet commercial, industrial, and normal urban residential	16	58	58	52
	20	59	60	54

ANSI/ASA S12.9-2013/Part3

To estimate the 2017 DNL for CCAFS, KSC, and the surrounding areas, the noise from all 2017 launches at CCAFS and KSC should be added to the background noise estimated for these areas. Table 2 shows all of the 2017 launches at CCAFS and KSC. There were nineteen total launches including thirteen Falcon 9 Full Thrust launches, twelve of these occurred at KSC LC-39A and one occurred at CCAFS LC-40. The remaining six launches by the Atlas V (401 or 421), Delta IV M+(5,4), and Minotaur/Orion occurred at the three other CCAFS launch sites listed in Table 2. Of the nineteen launches in 2017, three (about 16%) were nighttime launches. The total first stage sea level (SL) thrust is provided for each vehicle in the table.

Table 2. Launches at CCAFS and KSC in 2017

	Launch Site	Thrust (1st stage) lbf (SL)	2017 Launches		
			Day		Total
Falcon 9 Full Thrust	KSC LC-39A	1,710,000	11	1	12
Falcon 9 Full Thrust	CCAFS LC-40	1,710,000	1	0	1
Atlas V 401 (3) or 421 (1)	CCAFS LC-41	860,000	3	1	4
Delta IV M+(5,4)	CCAFS LC-37B	705,000	1	0	1
Minotaur/Orion	CCAFS LC-46	210,000	0	1	1

The DNL for all launches in Table 2 were estimated conservatively by making a few simplifying assumptions to the actual launch data. First, all of the launches were located at LC-39A (where the majority of launches occurred by the highest thrust vehicle, Falcon 9 Full Thrust). This is a conservative approximation which serves to concentrate the noise, rather than disperse it at the other launch sites. Second, noise received in the vicinity of the launch site is mostly due to the noise emissions of the first stage and can be scaled according to the total thrust of the first stage. Although there are several different types of vehicles in Table 2, with different first stage thrust levels, for the purposes of this estimate the equivalent number of Falcon 9 Full Thrust launches were determined. The scaling of operations is done using first stage thrust levels and accounting for nighttime launches which, because of the nighttime penalty inherent in DNL, are each equivalent to ten daytime launches. In this analysis, all nighttime launches were converted to daytime launches for simplicity. Additionally, note that the first stage thrust of the Falcon 9 Full Thrust is the same as that of the Falcon 9 Block 5. And because Figures 10 and 11 show the SEL contours for the Falcon 9 Block 5 launch at LC-39A, these SEL contours were used as a basis for explaining the 2017 DNL results as described following.

By using the above simplifying assumptions and scaling methods, all of the 2017 launches listed in Table 2 are equivalent to approximately 30 annual Falcon 9 Full Thrust (or Falcon 9 Block 5) daytime launches at LC-39A, which equates to 0.082 daytime launches per average day. Given this low number of launches, it is not expected that the DNL estimated for the 2017 launches will be much higher than the DNL estimated for the background noise environments described in Table 1. Using the following relationship, the equivalent DNL can be determined from the SEL for any launch event and the scaling assumptions made for the number of daytime (N_d) and nighttime (N_n) launches.

$$DNL = SEL + 10*Log_{10}(N_d + 10*N_n) - 49.4 \tag{1}$$

This calculation was performed for all 2017 launches at CCAFS and KSC which is estimated to be equivalent to 30 annual daytime launches of the Falcon 9 Full Thrust or Falcon 9 Block 5 at LC-39A. Using Equation 1 with SEL = 100 dBA, N_d = 30/365, and N_n= 0, the equivalent DNL is 40 dBA. This means the SEL 100 dBA contour shown in Figures 10 and 11 can be used to represent the DNL for all 2017 launch operations and is equivalent to a DNL of 40 dBA and the SEL 110 dBA contour is equivalent to a DNL of 50 dBA.

In summary, all launches in 2017 (Table 2) are estimated to generate Day-Night Average Sound Levels such that the 40 DNL contour is co-located with the SEL 100 dBA contour shown in Figures 10 and 11. The estimated DNL exposure, from all 2017 launches at CCAFS and KSC, is in most areas less than any of the estimated background DNL values in Table 1. The 2017 launches at CCAFS and KSC are therefore not expected to cause significant noise impact according to the guidelines for assessing DNL in FAA Order 1050.1E. For this study, the 2017 launch operations can be considered to represent the baseline launch noise environment at CCAFS and KSC, however the projected SpaceX launches in Table 3, from 2018 through 2024, are expected to generate significantly higher cumulative noise levels due to the increase in the total number of launches and the addition of the Falcon Heavy vehicle.

Table 3. Falcon 9 Block 5 and Falcon Heavy Block 5 Launch Frequency

	Launch Complex 39A KSC		Launch Complex 40 CCAFS	Total Launches
	Falcon Heavy	Falcon 9	Falcon 9	
2018	3	4	17	24
2019	3	5	16	24
2020	10	10	44	64
2021	10	10	44	64
2022	10	10	50	70
2023	10	10	50	70
2024	10	10	50	70

The Falcon 9 Block 5 and Falcon Heavy Block 5 launches are expected to replace launches by the Falcon 9 Full Thrust vehicle starting in 2018. To estimate the cumulative noise environment due to all SpaceX rocket operations RNOISE[1,2] was used to estimate the worst case (2024) DNL for launches (Table 3), static fire test operations (Table 4) and booster landings.

Table 4. Falcon 9 Block 5, Falcon Heavy Block 5, and Dragon Static Fire Test Frequency

	Launch Complex 39A KSC		Launch Complex 40 CCAFS	
	Falcon Heavy	Falcon 9	Falcon 9	
2018	3	4	17	4
2019	5	10	25	4
2020	10	10	44	4
2021	10	10	44	4
2022	10	10	50	4
2023	10	10	50	4
2024	10	10	50	4

The series of noise maps in Figures 30 through 35 show the DNL estimated for 2024 for the following SpaceX rocket operations:

- Falcon Heavy and Falcon 9 launches at LC-39A (Figure 30)
- Falcon 9 launches at LC-40 (Figure 31)
- All Falcon 9 and Falcon Heavy launches at LC-39A and LC-40 (Figure 32)
- Simultaneous booster landings at LZ-1 and LZ-2 (Figure 33)
- Static Fire Tests of Falcon Heavy (LC-39A) and Falcon 9 (LC-39A and LC-40) (Figure 34)
- All rocket operations: Falcon Heavy and Falcon 9 Launches, Static Fire Tests, and Booster Landings (Figure 35)

Day-Night Average Sound Levels in 2024 will increase compared to the estimated 2017 baseline DNL due to the significant increase in the number of annual rocket operations and due to the addition of the Falcon Heavy. However, Figures 30 through 35 show that cumulative noise impact for 2024 rocket operations, in terms of DNL, is well contained within the CCAFS and KSC properties. The residential areas closest to where rocket operations occur, including Merritt Island, Cape Canaveral, and Titusville, would not be exposed to Day-Night Average Sound Levels above 65 dB. Figure 35 indicates that the 65 DNL contour for all rocket operations in 2024 is located well within the CCAFS and KSC properties. In summary, the planned SpaceX launches, static fire tests, and booster landings of the Falcon 9 Block 5 and Falcon Heavy Block 5, projected to occur from 2018 through 2024, are not expected to cause significant noise impact according to the guidelines for assessing DNL in FAA Order 1050.1E. Personnel working at CCAFS and KSC during rocket operations are expected to follow a hearing conservation program and be well protected from the noise generated by these operations.

The DNL estimates that used Equation 1 are based on a number of simplifying assumptions to make this analysis practical. Equation 1 is best applied to a continuous noise environment, such as a busy airport. Note that ANSI S12.9-2005/Part4[10] describes adjustments to sounds that have special characteristics so that the long-term community response to such sounds can be predicted by a method. But, this standard does not provide a method to predict the response of a community to short-term, infrequent, non-repetitive sources of sound, such as rocket launches. The method using Equation 1 may be improved if proper adjustments to SEL can be determined. Or, as mentioned previously, improved estimates of DNL in the CCAFS, KSC, and surrounding areas would require a detailed study involving either the modeling of all major noise sources or conducting noise monitoring throughout these areas for a period of time that adequately represents the different types of launch vehicles and frequency of launches conducted.

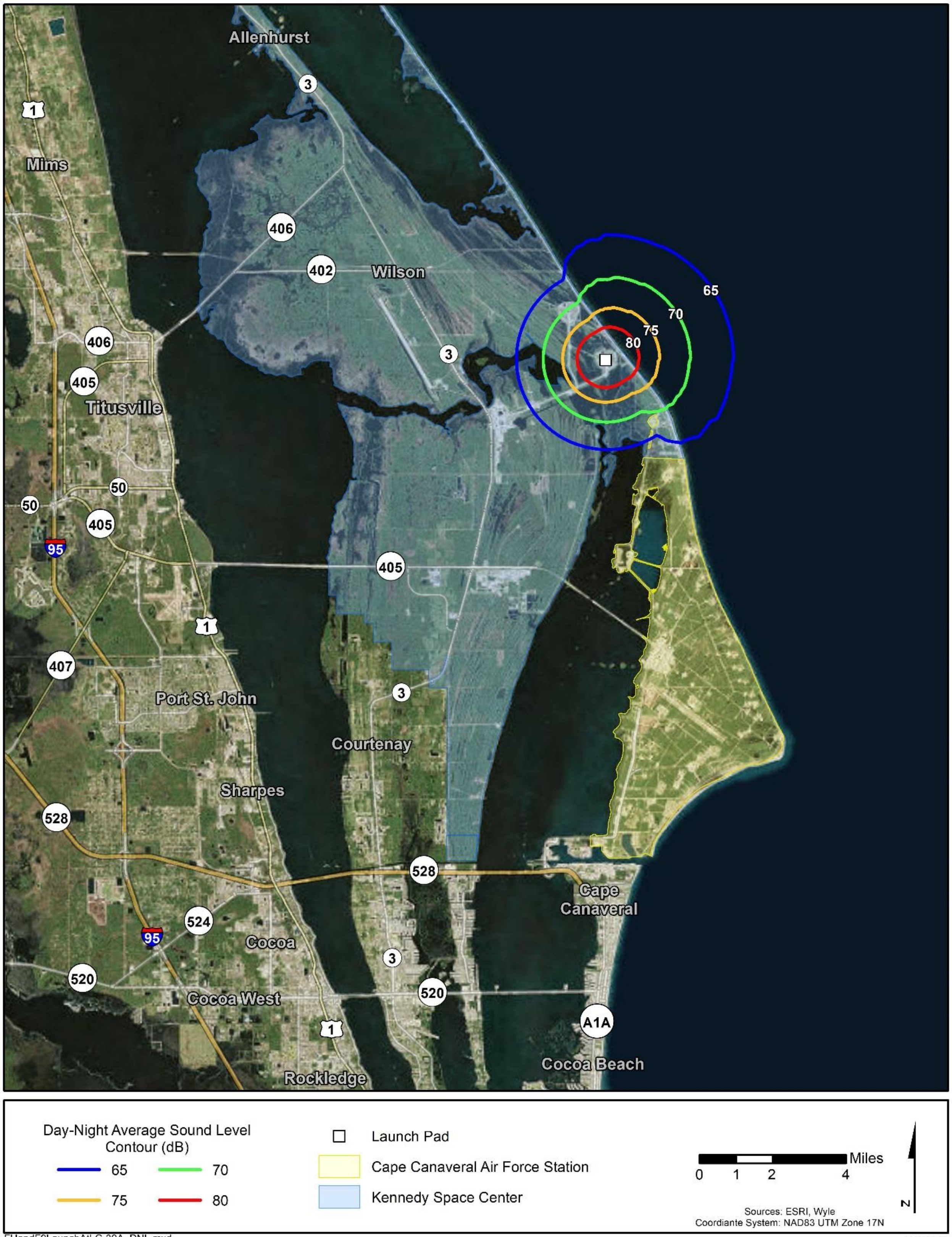

Figure 30. Day-Night Average Sound Levels (DNL) for Falcon Heavy and Falcon 9 Launches at LC-39A in 2024

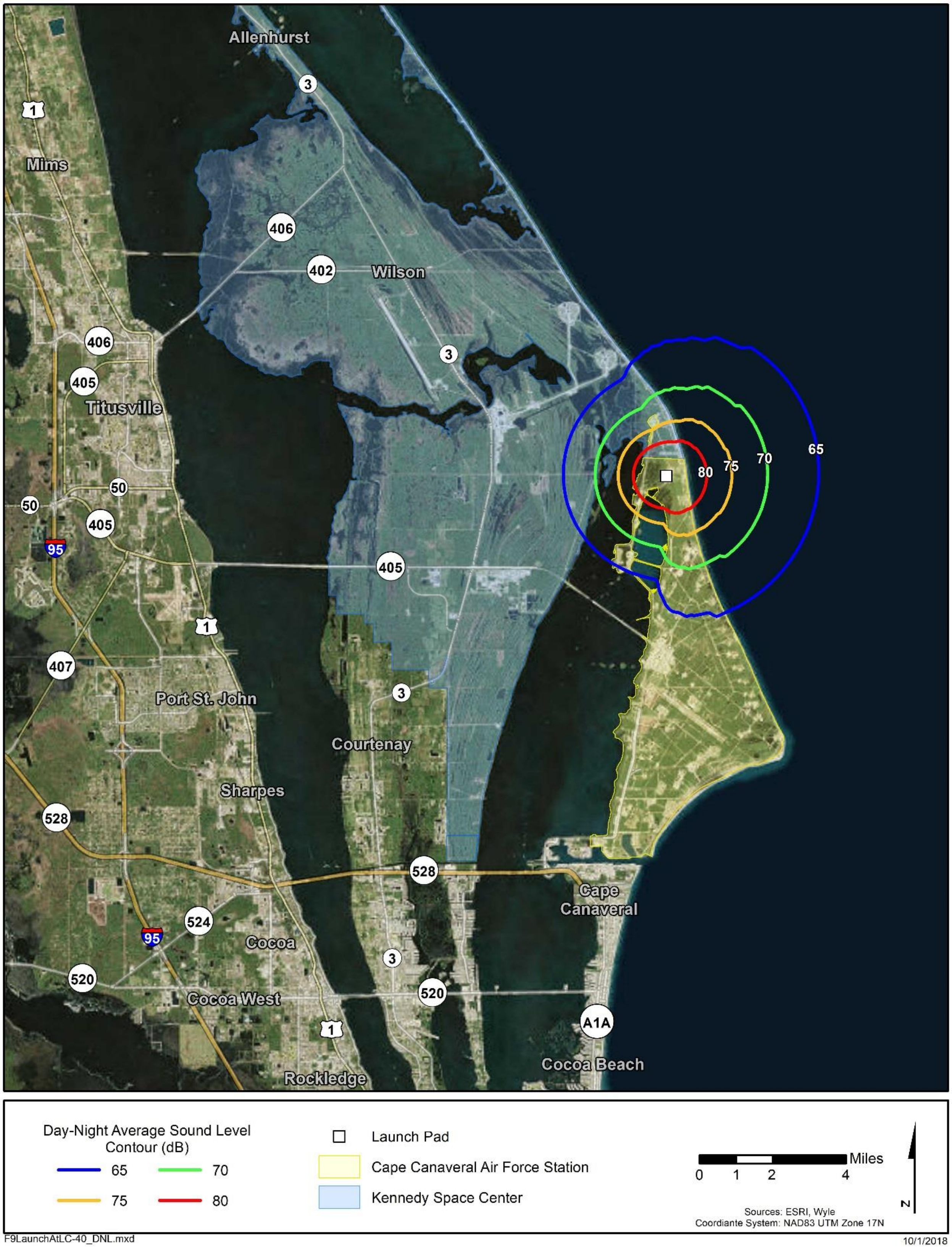

Figure 31. DNL for Falcon 9 Launches at LC-40 in 2024

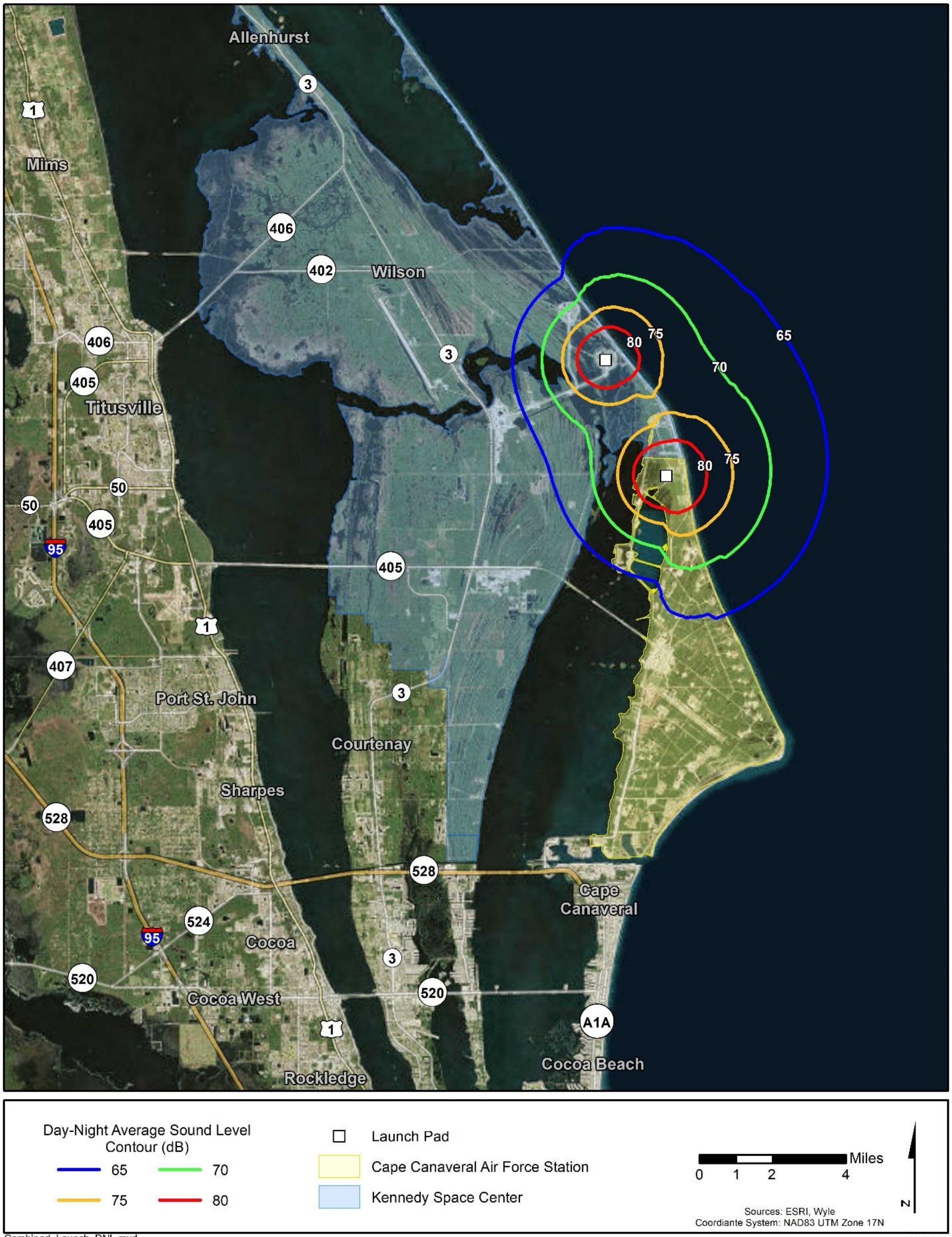

Figure 32. DNL for all Launches of Falcon Heavy (LC-39A) and Falcon 9 (LC-39A and LC-40) in 2024

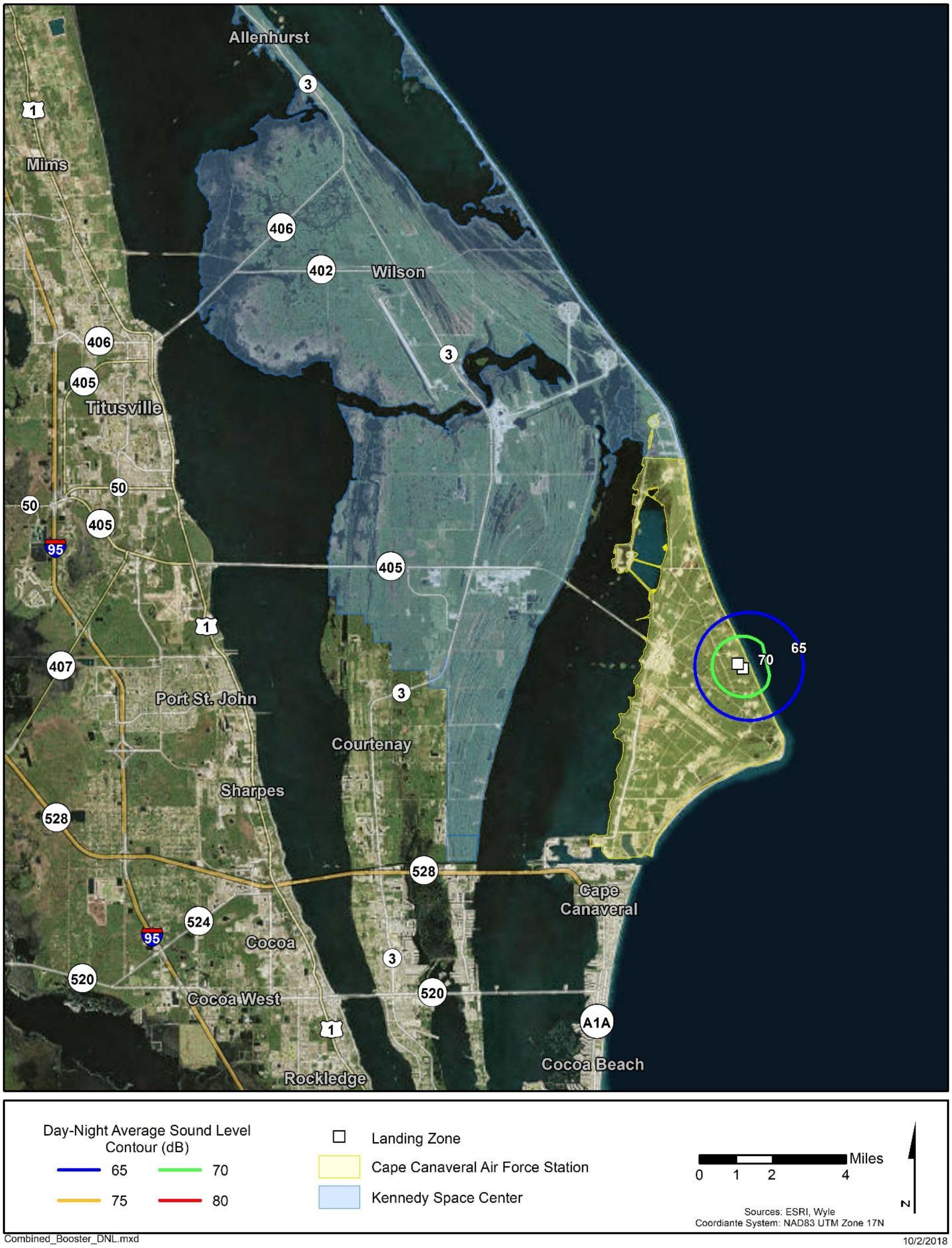

Figure 33. DNL for Simultaneous Booster Landings at LZ-1 and LZ-2 in 2024

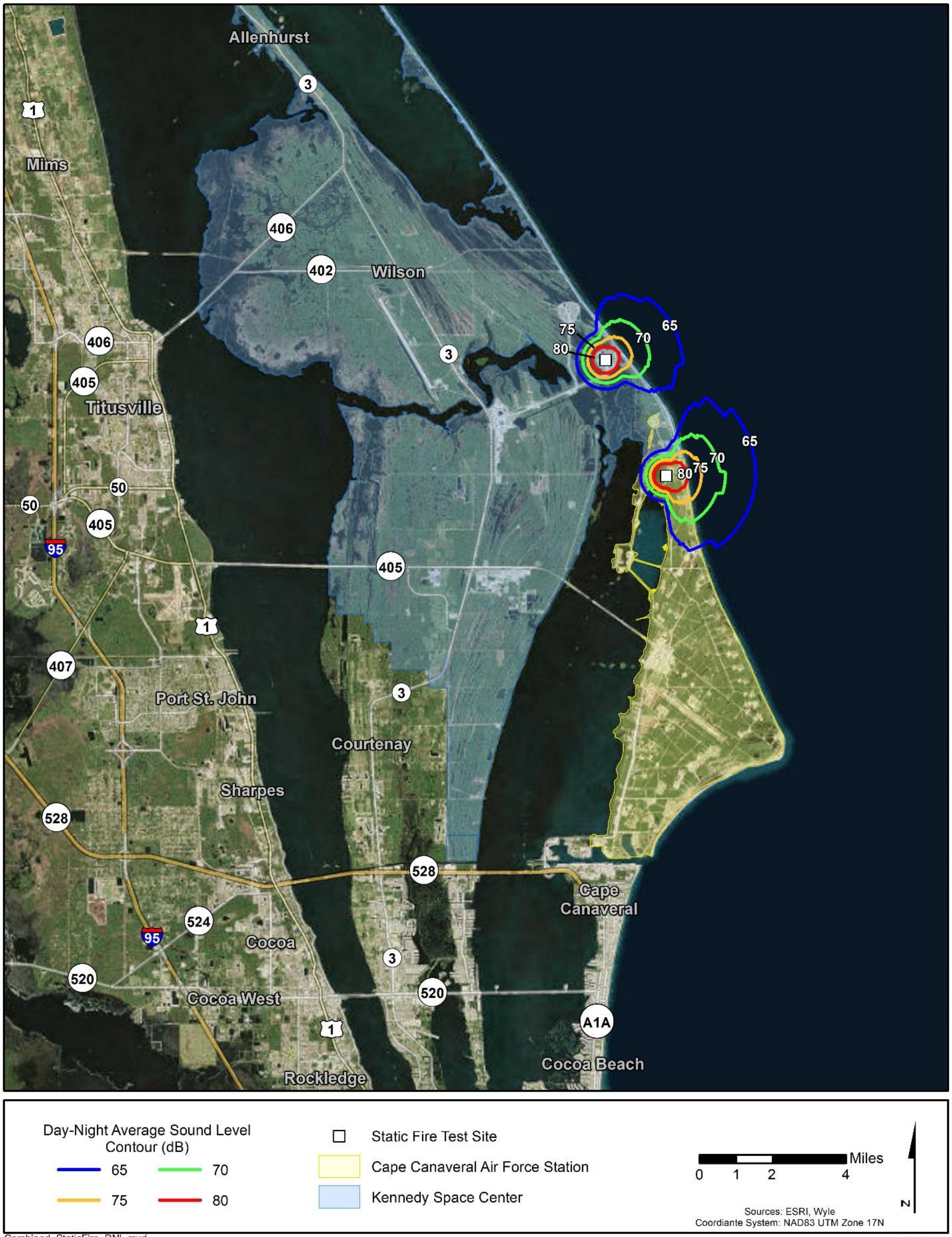

Figure 34. DNL for Static Fire Tests of Falcon Heavy (LC-39A) and Falcon 9 (LC-39A and LC-40) in 2024

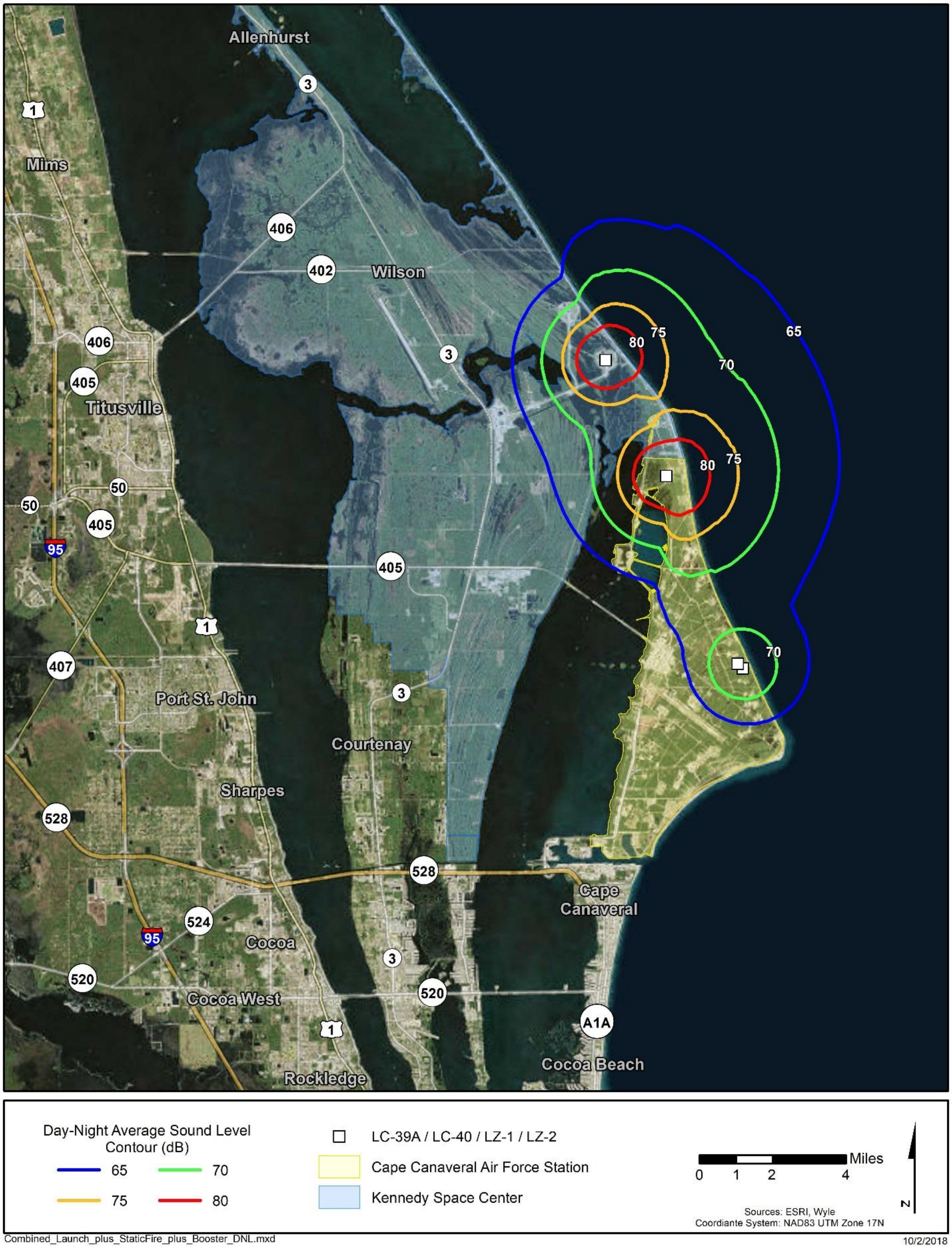

Figure 35. DNL for Falcon Heavy and Falcon 9 Launches, Static Fire Tests, and Booster Landings in 2024

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SONIC BOOM ASSESSMENT OF FALCON 9 POLAR TRAJECTORY DESCENT/LANDING AT CAPE CANAVERAL AIR FORCE STATION

TN 20-01

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1.0 Introduction

The sonic boom footprint has been estimated for the Falcon 9 Block 5 launch vehicle for the polar trajectory descent and landing of the reusable first stage at Cape Canaveral Air Force Station (CCAFS), Florida (landing pad location: latitude 28.485709 degrees and longitude -80.577127 degrees.)

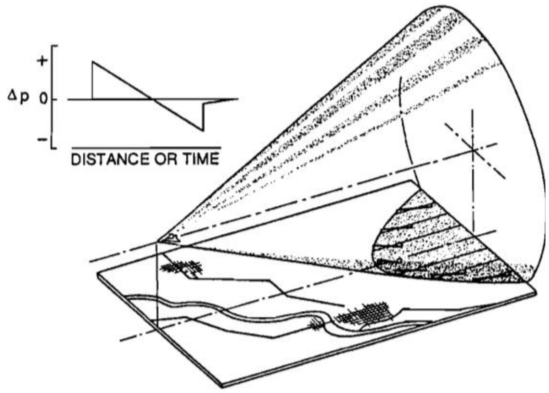
Sonic boom is generated while the Falcon 9 is supersonic during descent, above an altitude of about 12,000 feet. Sonic boom analysis was performed with Wyle's PCBoom software.[1,2] Section 2 presents a background discussion of sonic boom. Section 3 presents the results for the Falcon 9 nominal descent and landing at CCAFS.

2.0 Sonic Boom Background

A sonic boom is the wave field about a supersonic vehicle. As the vehicle moves, it pushes the air aside. Because flight speed is faster than the speed of sound, the pressure waves can't move away from the vehicle, as they would for subsonic flight, but stay together in a coherent wave pattern. The waves travel with the vehicle. Figure 1 is a classic sketch of sonic boom from an aircraft in level flight. It shows a conical wave moving with the aircraft, much like the bow wave of a boat. While Figure 1 shows the wave as a simple cone, whose ground intercept extends indefinitely, temperature gradients in the atmosphere generally distort the wave from a perfect cone to one that refracts upward, so the ground intercept goes out to a finite distance on either side. Boom is not a onetime event as the aircraft "breaks the sound barrier" but is often described as being swept out along a "carpet" across the width of the ground intercepts and the length of the flight track. Booms from steady or near-steady flight are referred to as carpet booms.

The waveform at the ground is generally an "N-wave" pressure signature, as sketched in the figure, where compression in the forward part of the vehicle and expansion and recompression at the rear coalesce into a bow shock and a tail shock, respectively, with a linear expansion between.

Figure 1 is drawn from the perspective of aircraft coordinates. The wave cone exists as shown at a particular time, but is generated over a time period. Booms can also be viewed from the perspective of rays propagating relative to ground-fixed coordinates. Figure 2 shows both perspectives. The cone represents rays that are generated at a given time, and which reach the ground at later times. The intercept of a given ray cone with the ground is called an "isopemp." When computing sonic booms the ray perspective is appropriate, since one starts the analysis from the aircraft trajectory points and each isopemp is identified with flight conditions at a given time. As sketched in Figure 2, the isopemps are forward facing crescents.



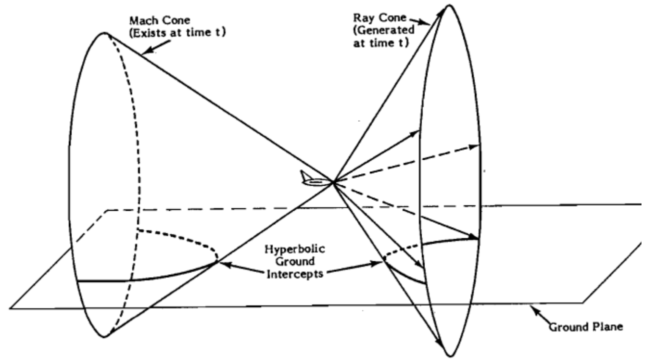


Figure 1. Sonic Boom Wave Field ***Figure 2. Wave versus Ray Viewpoints***

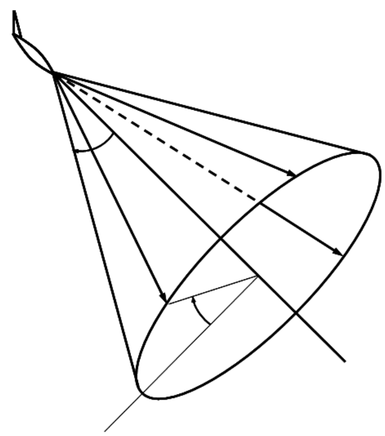


Figure 3. Ray Cone in Diving Flight

Figures 1 and 2 are drawn for steady level flight. If the aircraft climbs or dives, the ray cone tilts along with it. Figure 3 shows a ray cone in diving flight. At the angle in the figure the isopemp would still be a forward facing crescent, but would wrap around further than shown in Figure 2. In a steeper dive the isopemp could go full circle. If the vehicle is climbing at an angle steeper than the ray cone angle, there will be no boom at the ground. During very steep descent (near vertical) and at high Mach numbers the rays can be emitted at a shallow enough angle that they would refract upward and not reach the ground. For a descending vehicle that eventually decelerates to subsonic speed, some part of the trajectory will generate boom that reaches the ground.

Supersonic vehicles can turn and accelerate or decelerate. That affects the boom loudness, and under some conditions cause focused superbooms. Figure 4 is a sketch of rays from an accelerating aircraft. As the Mach number increases the ray angles steepen. The rays cross and overlap, with the focus along the "caustic" line indicated in the figure. The boom on a focusing ray is a normal N-wave before it gets close to the caustic, is amplified by a factor of two to five as it reaches the caustic, then is substantially attenuated as a "post-focus" boom after it passes the caustic.

Figure 5 shows the isopemps for this type of acceleration focus. The focal zone is the concentrated region at the left end of the footprint. The maximum focus area – where the boom is more than twice the unfocused normal boom – is very narrow, generally a hundred yards or less.

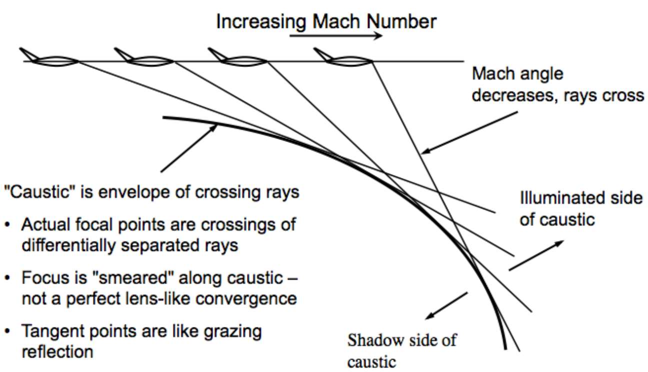


Figure 4. Ray Crossing and Overlap in an Acceleration Focus

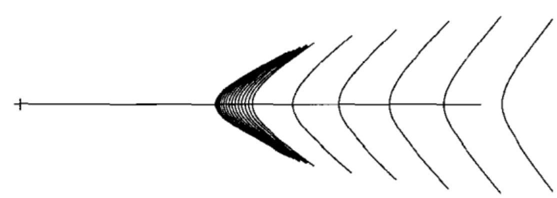


Figure 5. Isopemp Overlap in an Acceleration Focus

3.0 Falcon 9 Block 5 Descent Sonic Boom

This sonic boom analysis is based on a Falcon 9 nominal liftoff to landing trajectory provided by SpaceX. The Stage 1 descent and landing at CCAFS is supersonic from shortly after the apogee until it passes through an altitude just below 12,000 feet. Most of the Stage 1 descent is unpowered.

The boom footprint was computed using PCBoom.[1,2] The vehicle is a cylinder generally aligned with the velocity vector, descending engines first. It was modeled via PCBoom's drag-dominated blunt body mode,[3] which has been validated for entry vehicles.[4] Drag is determined by vehicle weight and the kinematics of the trajectory. Kinematics include the effect of the retro burn. Figure 6 shows the sonic boom footprint, in the form of overpressure contours, pounds per square foot (psf). The ground track of the entire trajectory is also shown in Figure 6. There is a broad forward-facing crescent region

generated as the vehicle descends below 200,000 feet at a heading of approximately 333 degrees. After the burn finishes there is an oval boom footprint region that ends when speed becomes subsonic. There are two narrow focus lines (magenta color), with contour levels in the 1.0 psf to 4.6 psf range, located on the northern edge of the crescent, generated as the vehicle accelerates at the end of the retro burn. At lower altitudes drag slows the descent, so boom following the focus is conventional carpet boom.

- The boom levels in the vicinity of the landing pad, located at latitude 28.485709 degrees and longitude -80.542901 degrees, range from about 2.0-2.7 psf.
- Boom levels in the areas adjacent to CCAFS and Kennedy Space Center (KSC) will be between 0.5-1.0 psf; boom levels on CCAFS property will range from 1.0-2.7 psf.
- The highest boom levels occurring off-shore are up to 4.6 psf in the narrow focus region just inside the north facing crescent shown in Figure 6. This zone is narrow – about 100 yards wide. The location will vary with weather conditions, so it is very unlikely that any given location will experience the focus more than once over multiple events. Variations in weather conditions could alter the sonic boom footprint, in general.
- The broad crescent, with boom levels of 0.1 psf is located over a large land area south of Orlando, FL and stretching south of Port St. Lucie, FL.

In general, booms in the 0.2 to 0.3 psf range could be heard by someone who is expecting it and listening for it, but usually would not be noticed. Booms of 0.5 psf are more likely to be noticed, and booms of 1.0 psf are certain to be noticed. Therefore, people in the communities surrounding CCAFS and KSC are likely to notice booms from Falcon 9 landings as are people located on these two properties. People located on the east coast in the vicinity of the focus region could experience boom levels up to 4.6 psf depending on weather conditions; boom levels greater than 1.0 psf could startle and possibly annoy people. Announcements of upcoming Falcon 9 launches and landings serve to warn people about these noise events and are likely to help reduce adverse reactions to these noise events. The boom levels over land are not likely to cause property damage.

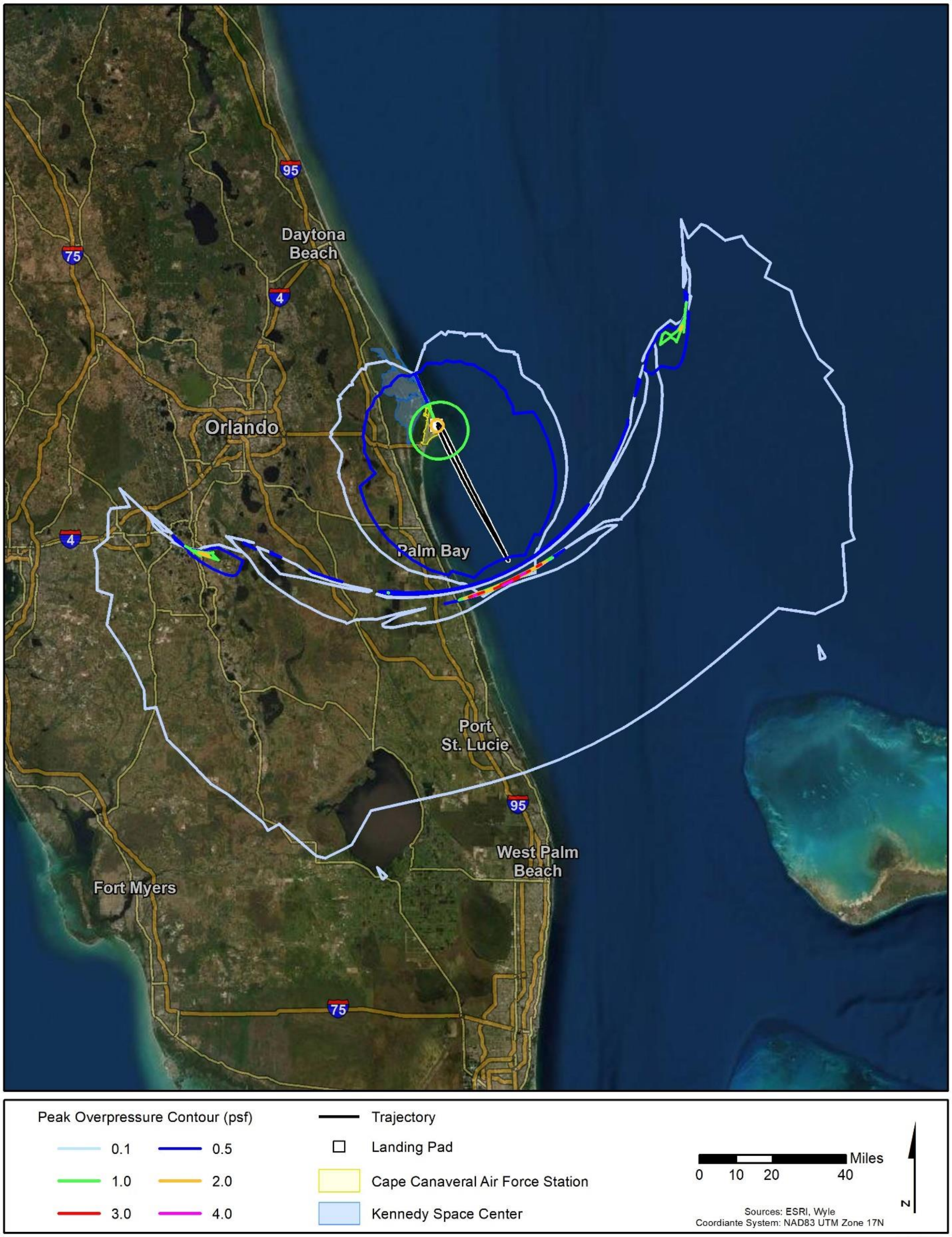


Figure 6. Sonic Boom Contours for Falcon 9 Polar Trajectory Landing at Cape Canaveral Air Force Station

References

1. Plotkin, K.J., and Grandi, F., "Computer Models for Sonic Boom Analysis: PCBoom4, CABoom, BooMap, CORBoom," Wyle Research Report WR 02-11, June 2002.
2. Page, J.A., Plotkin, K.J., and Wilmer, C., "PCBoom Version 6.6 Technical Reference and User Manual," Wyle Report WR 10-10, December 2010.
3. Tiegerman, B., *Sonic Booms of Drag-Dominated Hypersonic Vehicles*, PhD Thesis, Cornell University, August 1975.
4. Plotkin, K.J., Franz, R.J., and Haering, E.A. Jr., "Prediction and measurement of a weak sonic boom from an entry vehicle," *J. Acoust. Soc., Am.*, Vol 120, p 3077, 2006.

DEPARTMENT OF THE AIR FORCE
UNITED STATES SPACE FORCE
45TH SPACE WING

MEMORANDUM FOR 45 CES/CEIE

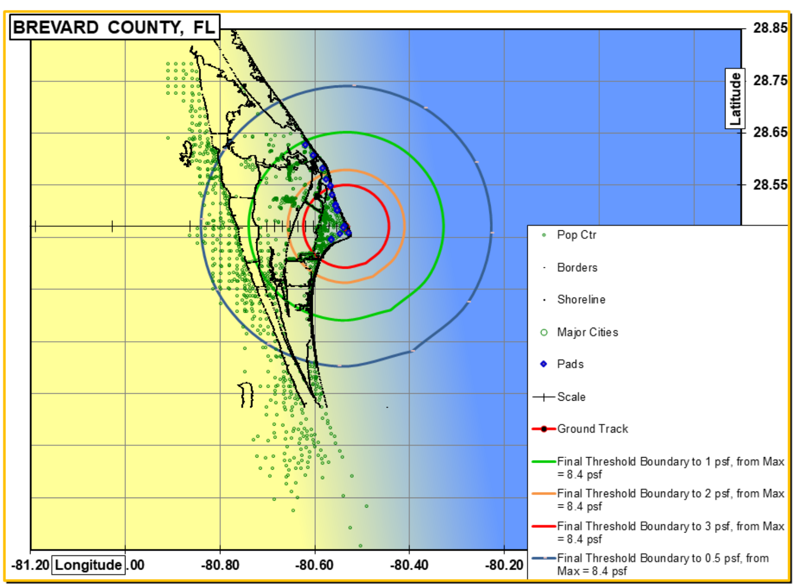
FROM: 45 SW/SELR
1201 Edward H. White II Street
Patrick AFB FL 32925-3238

SUBJECT: 45 SW/SELR Review of Falcon Program EA, February 2020

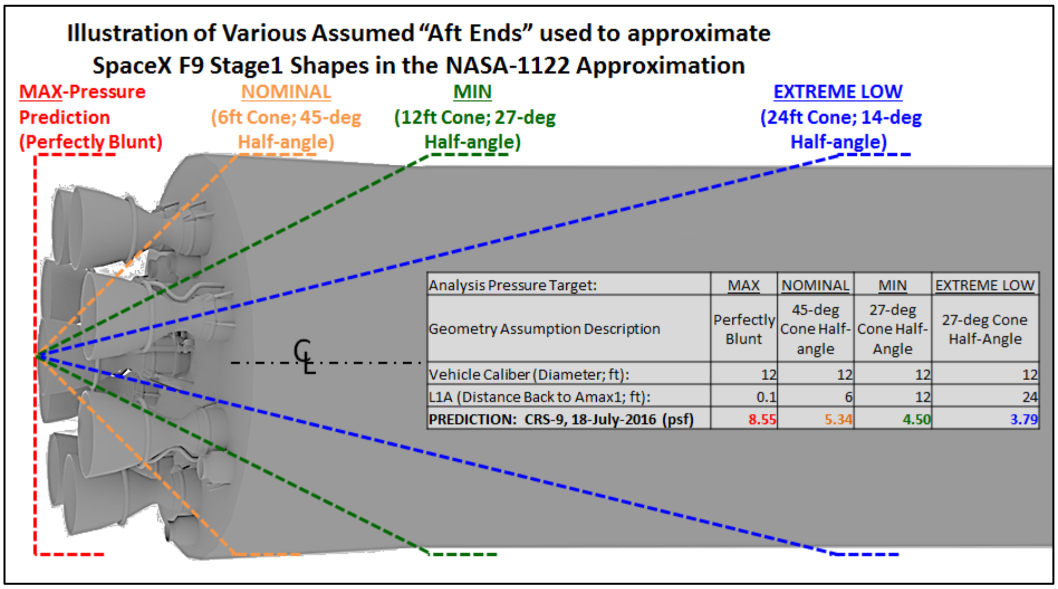
References: (a) 12 February 2020, *Draft Environmental Assessment for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station, Brevard County, Florida*.
(b) 31 December 2019, *Falcon 9 SAOCOM-1B Final Flight Data Package*

1. In support of the cooperating agency review requested by the Federal Aviation Administration, 45 SW/SELR personnel reviewed the sonic boom analysis provided in support of reference (a). This review focused on new capabilities associated with southerly mission trajectories.

2. Using information provided as part of reference (b), a maximum over pressure of 8.4 psf is expected in the near field (i.e. on federal property) with a far-field refraction attenuation to 0.5 psf roughly 28 miles away (i.e. off base). In comparison, CRS-9 flyback maximum over pressure was predicted to be 5.4 psf with far-field atmospheric refraction attenuation to ~0.5psf at 38 miles. The difference in maximum over pressure between these two flight profile could be attributed to a higher altitude transonic transition between CRS-9 and SAOCOM-1b. In general, higher altitude transonic transition causes weaker ground-zero overpressures but farther range.



3. 45 SW/SELR analysis is bounding as it assumes ideal sonic boom flight and weather conditions. According to previous studies and 45 SW/SELR feedback on earlier EAs the actual sonic boom could be expected to be somewhat less than this prediction (depending on weather; some disruptive conditions may reduce overpressure by as much as 50%). Additionally, the more blunt an object, generally the more severe the sonic boom generation. Due to the complexity of the aft end of the Falcon-9 (with multiple canted nozzle cones, folded legs, etc) an exact bluntness value is not certain. However, the body is clearly not a "supersonic shape"– nor is the nozzlebody a homogenously-blunt flat face. For this reason, a mid-range assumption was made; a "nominal; 6ft cone, 45-deg half-angle" in the tool for the prediction which is consistent with previous SpaceX flybacks sonic boom predictions



Analysis Pressure Target:	MAX	NOMINAL	MIN	EXTREME LOW
Geometry Assumption Description	Perfectly Blunt	45-deg Cone Half-angle	27-deg Cone Half-Angle	27-deg Cone Half-Angle
Vehicle Caliber (Diameter; ft):	12	12	12	12
L1A (Distance Back to Amax1; ft):	0.1	6	12	24
PREDICTION: CRS-9, 18-July-2016 (psf)	8.55	5.34	4.50	3.79

4. A significant and startling sonic boom is expected during flyback of the SpaceX Falcon9 booster following southerly missions. Analysis shows predicated damage to public areas remains very low and does not pose a safety concern. Education of the affected public is recommended, as detailed in reference (a).

5. The wing point of contact for this matter is Mr. Luis Estrada, 45 SW/SELR, (321) 494-3035, or e-mail Luis.Estrada.2@us.af.mil.

AMBER R. CHANG ARMSTRONG
Chief, Risk Analysis

Appendix B

Consultation with the National Marine Fisheries Service, U.S. Fish and Wildlife Servcie, and State Historic Preservation Officer

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Regional Office
263 13th Avenue South
St. Petersburg, Florida 33701-5505
http://sero.nmfs.noaa.gov

Nov, 21, 2018 F/SER31:DMB
SER-2018-19649

Daniel Czelusniak
Environmental Specialist
Federal Aviation Administration
800 Independence Avenue Southwest
Suite 325
Washington, DC 20591

Dear Mr. Czelusniak:

This letter responds to your request for re-initiation of consultation with us, the National Marine Fisheries Service (NMFS), pursuant to Section 7 of the Endangered Species Act (ESA) for the following action.

Applicant(s)	SER Number	Project Type(s)
Federal Aviation Administration (FAA), National Aeronautics and space Administration (NASA), and the U.S. Air Force (USAF)	SER-2018-19649	Waterborne landings of spacecraft

Consultation History

We completed consultation on the proposed action on August 8, 2016 (Public Consultation Tracking System [PCTS] identifier number SER-2016-17894). In that consultation, we determined the proposed action was not likely to adversely affect (NLAA) green sea turtle (North Atlantic and South Atlantic distinct population segments [DPSs]), Kemp's ridley sea turtle, leatherback sea turtle, loggerhead sea turtle (Northwest Atlantic DPS), loggerhead sea turtle designated critical habitat (Units LOGG-N-1 through LOGG-N-19, LOGG-S-1, and LOGG-S-2), hawksbill sea turtle, smalltooth sawfish (U.S. DPS), Gulf sturgeon, shortnose sturgeon, Atlantic sturgeon (Carolina and South Atlantic DPSs), North Atlantic right whale, North Atlantic right whale designated critical habitat (Unit 2), blue whale, fin whale, humpback whale, sei whale, and sperm whale.

On October 19, 2018, we received your letter requesting re-initiation of consultation due to our recent listing of the giant manta ray and the oceanic whitetip shark as threatened under the ESA (83 FR 2916 and 83 FR 4153, respectively). We re-initiated consultation on October 19, 2018.

Project Location

Address	Latitude/Longitude*	Water body
Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) , Brevard County, Florida	28.608402ºN, 80.604201ºW (North American Datum 1983) Coordinates provided are for launch pad 39A. Other launch pads at the KSC and CCAFS may be used.	Atlantic Ocean
Texas SpaceX Launch Site, 2 miles east of Boca Chica Village, Cameron County, Texas	25.99684°N, 97.15523°W (World Geodetic System 1984)	Gulf of Mexico

All launch areas are located in upland areas and landing areas are located in open-water within the Atlantic Ocean or Gulf of Mexico, as shown in Figures 1 and 2 below. The open-water areas for planned landings start a minimum of 5 nautical miles offshore and exclude North Atlantic right whale critical habitat in the Atlantic Ocean.

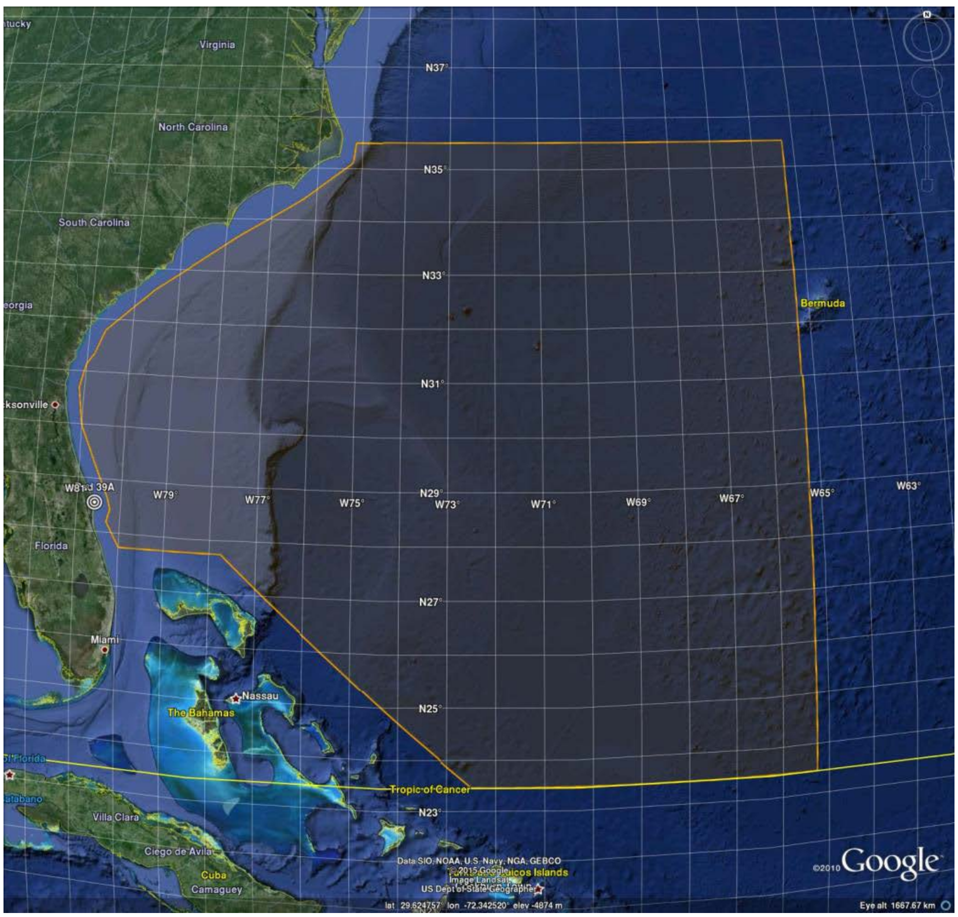


Figure 1. Representative image of action area in the Atlantic Ocean (Image provided by NASA)

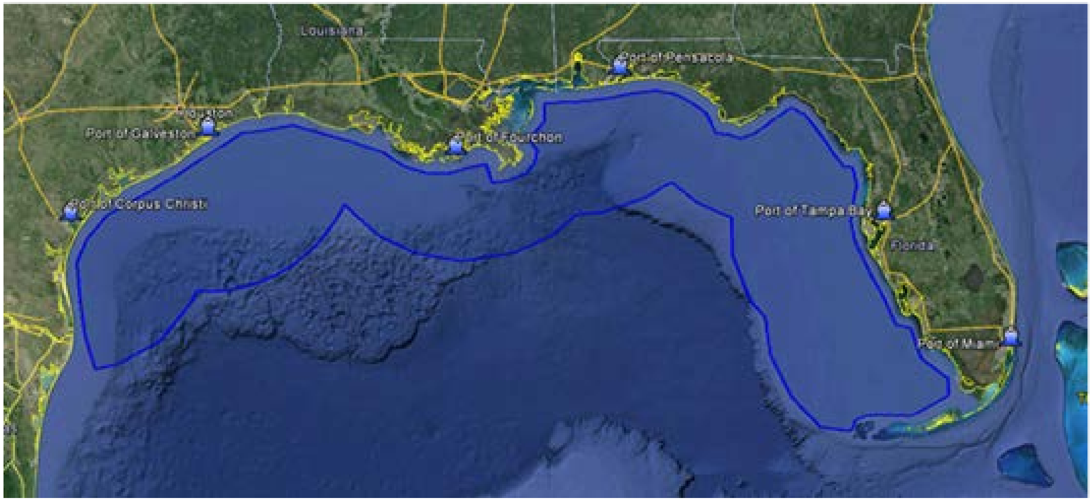


Figure 2. Representative image of action area in the Gulf of Mexico (Image provided by NASA)

Existing Site Conditions
Please refer to PCTS identifier number SER-2016-17894 for existing site conditions. The applicants have not identified any changes to the existing site conditions.

Project Description
Please refer to PCTS identifier number SER-2016-17894 for the existing project description. The applicants are not proposing any changes to the existing project description.

Construction Conditions
Please refer to PCTS identifier number SER-2016-17894 for construction conditions, including Education and Observation, Reporting, Vessel Traffic and Construction Equipment, and Hazardous Materials Emergency Response. The applicants are not proposing any changes to the existing construction conditions.

Effects Determination(s) for Species the Action Agency or NMFS Believes May Be Affected by the Proposed Action

Species	ESA Listing Status	Action Agency Effect Determination	NMFS Effect Determination
Fish			
Scalloped hammerhead shark (Central Atlantic [CA] and Southwest Atlantic [SWA] DPS)	T	--	NLAA
Giant manta ray	T	NLAA	NLAA
Oceanic whitetip shark	T	NLAA	NLAA
Marine Mammals			
Bryde’s whale	E (Proposed)	--	NLAA
E = endangered; T = threatened; NLAA = may affect, not likely to adversely affect			

Please refer to PCTS identifier number SER-2016-17894 for the previous effect determinations for species occurring within the action areas. There are no changes to these determinations.

Critical Habitat

The action area is located in North Atlantic right whale critical habitat (Unit 2) and loggerhead sea turtle critical habitat (Units Logg-N-1 through Logg-N-19, Logg-S-1, and Logg-S-2). Please refer to the PCTS identifier number SER-2016-17894 for the previous effect determinations for these critical habitat units.

Because the action area in the Gulf of Mexico starts a minimum of 5 nautical miles offshore, the project is also located within the boundary of Gulf sturgeon critical habitat (Unit 14 – Suwannee Sound). The following primary constituent elements (PCEs) are present in Unit 14:

(1) Abundant prey items within estuarine and marine habitats and substrates for juvenile, subadult, and adult life stages;
(2) Water quality, including temperature, salinity, pH, hardness, turbidity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages;
(3) Sediment quality, including texture and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages; and
(4) Safe and unobstructed migratory pathways necessary for passage within and between riverine, estuarine, and marine habitats (e.g., a river unobstructed by any permanent structure, or a dammed river that still allows for passage).

We believe only the water quality PCE of Gulf sturgeon critical habitat (Unit 14 – Suwannee Sound) may be affected by the proposed action.

Analysis of Potential Routes of Effects to Species

Scalloped hammerhead shark, giant manta ray, oceanic whitetip shark, and Bryde's whale may be affected by open-water landings if they were to be struck by falling materials, spacecraft, or controlled burn water landings. We believe that it is highly unlikely that these species will be struck and that the effects are discountable given the relatively small size of capsules (less than 200 ft^2) compared to the open ocean. These launches have been occurring for decades with no known interactions with these species. Further, launches will occur intermittently (approximately every few months) and the goal is to ultimately reduce and eliminate the need for open-water landings.

Scalloped hammerhead shark, giant manta ray, oceanic whitetip shark, and Bryde's whale may become entangled in the parachutes that will transport the capsule to the water surface. However, we believe the risk of entanglement is discountable. Due to their high mobility, these species will likely avoid the area immediately following a landing. Additionally, all materials will be retrieved quickly (approximately 1 hour). As stated previously, the ultimate goal is to reduce the need for open-water landings, thus reducing the need for parachutes.

Scalloped hammerhead shark, giant manta ray, oceanic whitetip shark, and Bryde's whale may be affected by any hazardous materials spilled into the Atlantic Ocean or Gulf of Mexico during the proposed action. For planned marine landings, all fuel valves will shut automatically prior to landing to retain any residual fuels. We believe any effect to these species from a hazardous materials spill is discountable. While a small fuel spill is possible, hazardous material spills are highly unlikely due to the NASA's 98-99% success rate. Further, failed missions do not necessarily occur over marine waters, and most, if not all, fuel would be consumed (e.g., during an explosion) or contained (according to the applicant's Hazardous Material Emergency Response Plan) during a failed mission.

Analysis of Potential Routes of Effect to Critical Habitat

Water quality, including temperature, salinity, pH, hardness, turbidity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages (PCE 2) of Gulf sturgeon critical habitat (Unit 14 – Suwannee Sound) may be affected by any hazardous materials spilled into Gulf of Mexico during the proposed action. We believe the effect to PCE 2 from a hazardous materials spill is discountable. While a small fuel spill is possible, hazardous material spills are highly unlikely due to the NASA's 98-99% success rate. Further, failed missions do not necessarily occur over marine waters, and most, if not all, fuel would be consumed (e.g., during an explosion) or contained (according to the applicant's Hazardous Material Emergency Response Plan) during a failed mission.

Conclusion

Because all potential project effects to listed species and critical habitat were found to be discountable, insignificant, or beneficial, we conclude that the proposed action is not likely to adversely affect listed species and critical habitat under NMFS's purview. This concludes your consultation responsibilities under the ESA for species under NMFS's purview. Consultation must be reinitiated if a take occurs or new information reveals effects of the action not previously considered, or if the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat in a manner or to an extent not previously considered, or if a new species is listed or critical habitat designated that may be affected by the identified action. NMFS's findings on the project's potential effects are based on the project description in this response. Any changes to the proposed action may negate the findings of this consultation and may require reinitiation of consultation with NMFS.

We look forward to further cooperation with you on other projects to ensure the conservation of our threatened and endangered marine species and designated critical habitat. If you have any questions on this consultation, please contact Dana Bethea, Consultation Biologist, at (727) 209-5974, or by email at Dana.Bethea@noaa.gov.

Sincerely,

David Bernhart
Assistant Regional Administrator
for Protected Resources

File: 1514-22.v

U.S. Department of Transportation
Federal Aviation Administration

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

UCI 1 5 2018

Roy E. Crabtree, Ph.D
Regional Administrator
National Marine Fisheries Service
Southeast Regional Office
St. Petersburg, FL 33701

RE: SER-2016-17894

Dear Mr. Crabtree,

On August 8, 2016, the National Aeronautics and Space Administration (NASA), Federal Aviation Administration (FAA), and U.S. Air Force (USAF) completed informal Endangered Species Act (ESA) consultation with your office regarding proposed rocket launch operations at NASA Kennedy Space Center, Cape Canaveral Air Force Station, and SpaceX's launch site in southeastern Texas (under construction) (SER-2016-17894). Since completing that consultation, the National Marine Fisheries Service listed the giant manta ray (*Manta birostris*) and oceanic whitetip shark (*Carcharinus lonigmanus*) as threatened species under the ESA (83 FR 2916; 83 FR 4153). Because these species could be located in the action area defined in our 2016 consultation, and because these species may be affected by the activities described in that consultation, we are reinitiating consultation with your office. We have determined the action described in the 2016 consultation **may affect, but is not likely to adversely affect**, the giant manta ray and oceanic whitetip shark for the same reasons provided for the other marine species.

The FAA, NASA, and USAF are requesting NMFS's written concurrence with our effect determination for the giant manta ray and oceanic whitetip shark. Please contact Daniel Czelusniak, FAA Environmental Specialist, at Daniel.Czelusniak@faa.gov or (202) 267-5924 to discuss any questions or concerns.

Sincerely,

Howard Searight

Howard Searight
Deputy Manager, Space Transportation Development Division

cc: Don Dankert, NASA
Eva Long, USAF

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Regional Office
263 13th Avenue South
St. Petersburg, Florida 33701-5505
http://sero.nmfs.noaa.gov

F/SER31: NMB

AUG 08 2016

Donald Dankert
Environmental Management Branch
National Aeronautics and Space Administration
John F. Kennedy Space Center
Mail Code: SI-E3
Kennedy Space Center, Florida 32899

Daniel Czelusniak
Environmental Specialist
Federal Aviation Administration
800 Independence Avenue Southwest
Suite 325
Washington, DC 20591

Dear Mr. Dankert and Mr. Czelusniak:

This letter responds to your request for consultation with us, the National Marine Fisheries Service (NMFS), pursuant to Section 7 of the Endangered Species Act (ESA) for the following action.

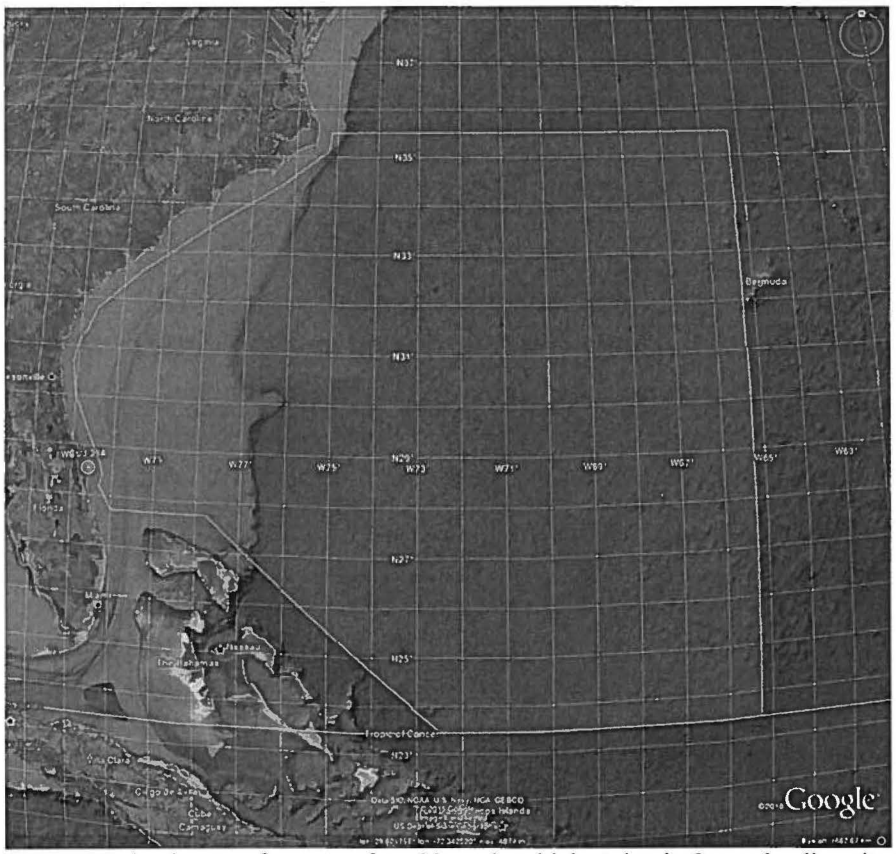
Applicant(s)	SER Number	Project Type(s)
National Aeronautics and Space Administration (NASA) and Federal Aviation Administration	SER-2016-17894	Waterborne landings of spacecraft

Consultation History

We received your letter requesting consultation on April 11, 2016. We discussed the project with the applicant on May 3, 2016, and requested additional information. During this call, we determined that the project would be expanded from the request to analyze 2 launches with NASA as the lead federal agency to now analyzing all launches occurring from the Kennedy Space Center (KSC), Cape Canaveral Air Force Station (CCAFS), and SpaceX Texas Launch Complex, with the lead federal agency being assigned as NASA, Federal Aviation Administration, or the U.S. Air Force. After exchanging 3 drafts of the project description, we received a final response on July 14, 2016, and initiated consultation that day.

Project Location

Address	Latitude/Longitude	Water body
Kennedy Space Center and Canaveral Air Force Station, Brevard County, Florida	28.608402°N, 80.604201°W (North American Datum 1983) Coordinates provided are for launch pad 39A. Other launch pads at the KSC and CCAFS may be used.	Atlantic Ocean off of Cape Canaveral and Gulf of Mexico
Texas SpaceX Launch Site, 2 miles east of Boca Chica Village, Cameron County, Texas	25.99684°N, 97.15523°W (World Geodetic System 1984)	Gulf of Mexico



Representative image of spacecraft and launch vehicle Atlantic Ocean landing site (Image provided by NASA)

Representative image of spacecraft and launch vehicle Gulf of Mexico landing site (Image provided by NASA)

Existing Site Conditions

The KSC and CCAFS are located on Merritt Island on the northeast coast of Florida. The Texas SpaceX launch site is located on a private site along the east coast of Texas away from the nearby beach. All launch areas are located in upland areas and landing areas are located in open-water within the Atlantic Ocean or Gulf of Mexico, as shown in the images above. The open-water areas for planned landings start a minimum of 5 nautical miles offshore and exclude North Atlantic right whale critical habitat in the Atlantic Ocean.

Project Description

For the purposes of this consultation, the term "spacecraft" will be used to describe modules sent into orbit on the launch vehicle carrying payloads, supplies, or crew. The term "launch vehicle" will be used to describe the rocket and all of its components.

The launch complexes on KSC and CCAFS provide the capability for a variety of vertical and horizontal launch vehicles including, but not limited to, Atlas V, Delta IV, Delta IV Heavy, Liberty, Falcon 9 and 9 v1.1, Falcon Heavy, Antares, RSLV-S, Athena IIc, Xaero, and the Space Launch System to be processed and launched. These launch vehicles and their commercial or government operators are responsible for transporting various spacecraft and payloads into orbit, including reusable manned and unmanned spacecraft such as Orion, Dream Chaser, Boeing CST-100, Liberty Composite Crew Module, and the SpaceX Crew and Cargo Dragon.

The SpaceX Texas launch site provides the capability for operating the Falcon 9 and Falcon Heavy launch vehicles. All Falcon 9 and Falcon Heavy launches would be expected to have payloads including satellites or experimental payloads. Additionally, the Falcon 9 and Falcon Heavy may also carry the SpaceX Dragon spacecraft. Most payloads would be commercial; however, some could be government sponsored launches.

Commercial and government spacecraft launched from KSC, CCAFS and the SpaceX Texas launch complex may result in portions of the spacecraft and/or launch vehicle returning to earth and landing in the Atlantic Ocean or Gulf of Mexico. The launch trajectories are specific to each particular launch vehicle's mission. However, all launches are conducted to the east over the

Atlantic Ocean, similar to past and current launches from KSC and CCAFS. All launch trajectories from the SpaceX Texas launch facility would be to the east over the Gulf of Mexico.

The following is a representative example of a nominal launch, waterborne landing and recovery based on the SpaceX Falcon 9 launch vehicle and the Crew Dragon spacecraft launched from KSC. This scenario is also generally applicable to other launch vehicles and spacecraft launch and recovery operations. It should be noted that currently not all of the above mentioned launch vehicles have a recoverable first or second stage. For example, launch vehicles in the Atlas and Delta family are classified as evolved expendable launch vehicles. These types of launch vehicles destruct upon reentry into the atmosphere and are not recovered. In the unlikely event of a launch failure, pad abort, or assent abort, efforts would be made to attempt to recover any remaining portions of the launch vehicle or spacecraft. Any debris that could not be recovered from the surface would sink to the ocean bottom.

There are several scenarios that could occur due to a launch failure:

- The entire launch vehicle and spacecraft, with onboard propellants, fails on the launch pad and an explosion occurs. The spacecraft may be jettisoned into the nearshore waters.
- The entire launch vehicle and spacecraft, with onboard propellants, is consumed in a destruction action during assent. The launch vehicle is largely consumed in the destruction action and the spacecraft is jettisoned, but residual propellant escapes and vaporizes into an airborne cloud.
- The launch vehicle and spacecraft survive to strike the water intact or partially intact potentially releasing propellants into the surface waters.

The probability of any of these launch failure scenarios is unknown and highly unlikely but could potentially have a short term localized adverse effect on marine life and habitat. To date, NASA has had a 98-99% success rate with launches.

Following the nominal launch of the launch vehicle and following first stage separation the launch vehicle would make a powered decent returning to either a designated landing pad located onshore or a drone ship located approximately 500 miles down range on the Atlantic Ocean east of Cape Canaveral or in the Gulf of Mexico. The manned or unmanned spacecraft, after completion of its mission, would descend into the Atlantic Ocean or Gulf of Mexico either under parachute canopy or propulsive landing. These capsules are relatively small in size, averaging less than 200 square feet (ft^2) in size. The main parachutes may be up to 150 feet (ft) in diameter.

A propulsive landing scenario and parachute landing scenario generally follow the same landing sequence with the main difference being that under a propulsive landing scenario the spacecraft would fire its engines to slow its decent. The spacecraft performs a deorbit burn in orbit and re-enters the atmosphere on a lifting guided trajectory. At high altitudes, the vehicle may perform an "engine burp" in order to test engine health before the propulsive landing. For a propulsive landing, the drogue chutes may be used but the main parachutes will not be deployed. Instead, at an altitude of between approximately 500 and 1,000 meters, the vehicle will light its engines and start to decelerate until ultimately it makes a waterborne landing. In a non-propulsive waterborne landing scenario the main parachutes are deployed at a predesignated altitude and slow the spacecraft to a safe speed prior to entering the water.

Following a successful landing, a contracted vessel will retrieve the parachutes and spacecraft from the water surface. Since the contracted vessel will be in the water to observe the test, recovery of the capsule and parachutes is expected to begin within an hour of the landing. The vessel will either use an overhead crane to load the capsule onto the vessel or tow the capsule back to shore at Port Canaveral or other nearby commercial wharf where it will be offloaded and transported to an inland facility.

A spacecraft reentering the atmosphere for either a propulsive or non-propulsive waterborne landing may contain residual amounts of propellant used to support on-orbit operations, the deorbit burn, entry and attitude control and propulsive landings. Spacecraft are designed to contain residual propellant and it is not expected that there would be a release of any propellants into the water. Once the spacecraft is safely transported back to land the remaining propellants would be offloaded.

In the unlikely event that any propellants are released into the water during a failed launch or a water landing, they would be quickly dispersed and diluted and would not be expected to create any long term effects on habitat or species within proximity to the landing area. According to NASA, spacecraft may carry hypergolic propellants, which are toxic to marine organisms. Specifically, the spacecraft may carry nominal values of monomethylhydrazine fuel and nitrogen tetroxide oxidizer. Propellant storage is designed to retain residual propellant, so any propellant remaining in is not expected to be released into the ocean. Nitrogen tetroxide almost immediately forms nitric and nitrous acid on contact with water, and would be very quickly diluted and buffered by seawater; hence, it would offer negligible potential for harm to marine life. With regard to hydrazine fuels, these highly reactive species quickly oxidize forming amines and amino acids. Prior to oxidation, there is some potential for exposure of marine life to toxic levels, but for a very limited area and time. A half-life of 14 days for hydrazine in water is suggested based on the unacclimated aqueous biodegradation half-life.

Within the overall missions that could potentially have waterborne landings there may be a limited number of pad abort and assent abort testing operations that would involve launching spacecraft on a low altitude non-orbit trajectory resulting in a waterborne landing within 1-20 miles east of the launch site in the coastal waters of the Atlantic Ocean. This type of testing operation would typically involve a non-propulsive landing using both drogue and main parachutes. Recovery operations would be consistent with the description above.

As the space program advances, there is currently a general progression in the development of technology and mission operations to enable both launch vehicles and spacecraft to land on barges at sea and ultimately on land. To that end, the need for open-water landings of routine missions may be phased out in the future. However, it is likely that waterborne landings in the Atlantic Ocean or Gulf of Mexico will be utilized as back-up landing locations to land based landing sites. NASA estimates that approximately 60 open-water landings could occur in the next 10 years including test launches associated with pad abort and ascent abort operations. Open-water landings may occur day or night at any time of year. This consultation address all open-water landings occurring from KSC, CCAFS and the SpaceX Texas Launch Complex result in portions that follow the protective measures defined below.

Construction Conditions

NASA will follow the protective measures listed below:

1) **Education and Observation:** All personnel associated with the project shall be instructed about the presence of species protected under the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA).
   a) A dedicated observer shall be responsible for monitoring for ESA-species during all in-water activities including transiting marine waters to retrieve space launch equipment. Observers shall survey the area where space equipment landed in the water to determine if any ESA-listed species were injured or killed.
   b) All personnel shall be advised that there are civil and criminal penalties for harming, harassing, or killing ESA listed species or marine mammals.
   c) More information about ESA-listed species is available on our website at: http://sero.nmfs.noaa.gov/protected_resources/section_7/threatened_endangered/index.html

2) **Reporting** of interactions with protected species:
   a) Any collision(s) with and/or injury to any sea turtle, sawfish, or whale, shall be reported immediately to NMFS's Protected Resources Division (PRD) at (1-727-824-5312) or by email to takereport.nmfsser@noaa.gov.
   b) Smalltooth sawfish: Report sightings to 1-941-255-7403 or email Sawfish@MyFWC.com
   c) Sea turtles and marine mammals: Report stranded, injured, or dead animals to 1-877-WHALE HELP (1-877-942-5343).
   d) North Atlantic right whale: Report injured, dead, or entangled right whales to the U.S. Coast Guard via VHF Channel 16.

3) **Vessel Traffic and Construction Equipment**: All vessel operators must watch for and avoid collision with ESA-protected species. Vessel Operators must maintain a safe distance by following these protective measures:
   a) Sea turtles: Maintain a minimum distance of 150 ft.
   b) North Atlantic right whale: Maintain a minimum 1,500 ft (500 yard) distance.
   c) Vessels 65-ft long or more must comply with the Right Whale Ship Strike Reduction Rule (50 CFR 224.105) including reducing speeds to 10 knots or less in Seasonal Management Areas (http://www.fisheries.noaa.gov/pr/shipstrike/).
   d) Mariners shall check various communication media for general information regarding avoiding ship strikes and specific information regarding right whale sightings in the area. These include NOAA weather radio, U.S. Coast Guard NAVTEX broadcasts, and Notices to Mariners.
   e) Marine mammals (i.e., dolphins, whales, and porpoises): Maintain a minimum distance of 300 ft.
   f) When these animals are sighted while the vessel is underway (e.g., bow-riding), attempt to remain parallel to the animal's course. Avoid excessive speed or abrupt changes in direction until they have left the area.

g) Reduce speed to 10 knots or less when mother/calf pairs or groups of marine mammals are observed, when safety permits.

4) **Hazardous Materials Emergency Response**: In the unlikely event of a failed launch or landing, SpaceX would follow the emergency response and cleanup procedures outlined in their Hazardous Material Emergency Response Plan. These procedures may include containing the spill using disposable containment materials and cleaning the area with absorbents or other materials to reduce the magnitude and duration of any impacts. In most launch failure scenarios at least a portion of the fuels will be consumed by the launch, and any remaining fuels will be diluted by seawater and biodegrade over time (timeframes are variable based on environmental conditions).

Effects Determination(s) for Species the Action Agency or NMFS Believes May Be Affected by the Proposed Action

Species	ESA Listing Status	Action Agency Effect Determination	NMFS Effect Determination
Sea Turtles			
Green (North Atlantic and South Atlantic distinct population segment [DPS])	T	NLAA	NLAA
Kemp's ridley	E	NLAA	NLAA
Leatherback	E	NLAA	NLAA
Loggerhead (Northwest Atlantic Ocean DPS)	T	NLAA	NLAA
Hawksbill	E	NLAA	NLAA
Fish			
Smalltooth sawfish (U.S. DPS)	E	NLAA	NLAA
Gulf sturgeon (Atlantic sturgeon, Gulf subspecies)	T	NLAA	NLAA
Shortnose sturgeon	E	NLAA	NLAA
Atlantic sturgeon (Carolina DPS)	E	NLAA	NLAA
Atlantic sturgeon (South Atlantic DPS)	E	NLAA	NLAA
Marine Mammals			
North Atlantic right whale	E	NLAA	NLAA
Blue whale	E	ND	NLAA
Fin whale	E	ND	NLAA
Humpback whale	E	ND	NLAA
Sei whale	E	ND	NLAA
Sperm whale	E	ND	NLAA
E = endangered; T = threatened; NLAA = may affect, not likely to adversely affect; ND = no determination			

Critical Habitat

North Atlantic right whale critical habitat

NASA planned landings are proposed to occur outside of North Atlantic right whale critical habitat. In the unlikely event that a launch failure occurred in nearshore waters near Cape Canaveral, it could occur in North Atlantic right whale critical habitat. The following essential features are present in Unit 2:

- Sea surface conditions associated with Force 4 or less on the Beaufort Scale
- Sea surface temperatures of 7°C to 17°C
- Water depths of 6 to 28 m, where these features simultaneously co-occur over contiguous areas of at least 231 square nautical miles of ocean waters during the months of November through April. When these features are available, they are selected by right whale cows and calves in dynamic combinations that are suitable for calving, nursing, and rearing, and which vary, within the ranges specified, depending on factors such as weather and age of the calves.

We do not believe any of the essential features may be affected by the proposed action.

Loggerhead sea turtle critical habitat

The in-water landing sites are located within the boundary of loggerhead sea turtle critical habitat. The following primary constituent elements (PCEs) are present in the Atlantic Ocean and Gulf of Mexico landing areas that include Units Logg-N-1 to Logg-N-19 plus Logg-S-1 and Logg-S-2. Since the open-water landing areas begin 5 nautical miles offshore, nearshore reproductive habitat is not considered within the planned landing areas. In the unlikely event that a launch failure occurred in nearshore waters near Cape Canaveral, it could occur in loggerhead nearshore reproductive critical habitat.

- Nearshore reproductive habitat: The physical or biological features of nearshore reproductive habitat as a portion of the nearshore waters adjacent to nesting beaches that are used by hatchlings to egress to the open-water environment as well as by nesting females to transit between beach and open water during the nesting season. The following primary constituent elements support this habitat: (i) Nearshore waters directly off the highest density nesting beaches and their adjacent beaches, as identified in 50 CFR 17.95(c), to 1.6 kilometers offshore; (ii) Waters sufficiently free of obstructions or artificial lighting to allow transit through the surf zone and outward toward open water; and (iii) Waters with minimal manmade structures that could promote predators (i.e., nearshore predator concentration caused by submerged and emergent offshore structures), disrupt wave patterns necessary for orientation, and/or create excessive longshore currents.
- Breeding areas: the physical or biological features of concentrated breeding habitat as those sites with high densities of both male and female adult individuals during the breeding season. Primary constituent elements that support this habitat are the following: (i) High densities of reproductive male and female loggerheads; (ii) Proximity to primary Florida migratory corridor; and (iii) Proximity to Florida nesting grounds.
- Constricted migratory habitat: the physical or biological features of constricted migratory habitat as high use migratory corridors that are constricted (limited in width) by land on one side and the edge of the continental shelf and Gulf Stream on the other side. Primary

constituent elements that support this habitat are the following: (i) Constricted continental shelf area relative to nearby continental shelf waters that concentrate migratory pathways; and (ii) Passage conditions to allow for migration to and from nesting, breeding, and/or foraging areas.

- Sargassum habitat: the physical or biological features of loggerhead *Sargassum* habitat as developmental and foraging habitat for young loggerheads where surface waters form accumulations of floating material, especially *Sargassum.* Primary constituent elements that support this habitat are the following: (i) Convergence zones, surface-water downwelling areas, the margins of major boundary currents (Gulf Stream), and other locations where there are concentrated components of the *Sargassum* community in water temperatures suitable for the optimal growth of *Sargassum* and inhabitance of loggerheads; (ii) *Sargassum* in concentrations that support adequate prey abundance and cover; (iii) Available prey and other material associated with *Sargassum* habitat including, but not limited to, plants and cyanobacteria and animals native to the *Sargassum* community such as hydroids and copepods; and (iv) Sufficient water depth and proximity to available currents to ensure offshore transport (out of the surf zone), and foraging and cover requirements by *Sargassum* for post-hatchling loggerheads, i.e., >10 m depth.
- Winter habitat: the physical or biological features of loggerhead winter habitat are warm water habitat south of Cape Hatteras near the western edge of the Gulf Stream used by a high concentration of juveniles and adults during the winter months. Primary constituent elements that support this habitat are the following: (i) Water temperatures above 10° C from November through April; (ii) Continental shelf waters in proximity to the western boundary of the Gulf Stream; and (iii) Water depths between 20 and 100 m.

We do not believe any of the PCEs may be affected by the proposed action.

Analysis of Potential Routes of Effects to Species

Sea turtles, smalltooth sawfish, sturgeon, whales may be affected by open-water landings if they were to be struck by falling materials, spacecraft, or controlled burn water landings. Due to the relative small size of capsules (less than 200 ft^2), NMFS believes that is highly unlikely that protected species will be struck and that the effects are discountable. Smalltooth sawfish and sturgeon are bottom dwelling and unlikely to interact with these items at the surface. Sea turtles and whales spend time at the surface to breath and are thus are at a higher risk of interacting with spacecraft. However, turtles and whales spend the majority of their time submerged as opposed to on the surface, thus lowering the risk of interactions. These launches have been occurring for decades with no known interactions with sea turtles or whales. Also, launches occur intermittently (occurring approximately every few months) and the goal is to ultimately reduce and eliminate the need for open-water landings.

Sea turtles and whales could also become entangled in the parachutes that will transport the capsule to the water surface. However, we believe that these species will avoid the area immediately following a landing and that all materials will be retrieved quickly (approximately 1 hour). Therefore, we believe the risk of entanglement is discountable.

Sea turtles, smalltooth sawfish, sturgeon, and whales could be affected by any hazardous materials spilled into the Atlantic Ocean or Gulf of Mexico during the proposed action.

However, such an effect is highly unlikely (98-99% success rate), failed missions do not necessarily occur over marine waters, and most if not all fuel would be consumed or contained. For planned marine landings, all fuel valves will shut automatically prior to landing to retain any residual fuels. Therefore, although a small fuel spill is possible, it is highly unlikely and any risk to protected species is discountable.

Conclusion

Because all potential project effects to listed species and critical habitat were found to be discountable, insignificant, or beneficial, we conclude that the proposed action is not likely to adversely affect listed species and critical habitat under NMFS's purview. This concludes your consultation responsibilities under the ESA for species under NMFS's purview. Consultation must be reinitiated if a take occurs or new information reveals effects of the action not previously considered, or if the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat in a manner or to an extent not previously considered, or if a new species is listed or critical habitat designated that may be affected by the identified action. NMFS's findings on the project's potential effects are based on the project description in this response. Any changes to the proposed action may negate the findings of this consultation and may require reinitiation of consultation with NMFS.

We have enclosed additional relevant information for your review. We look forward to further cooperation with you on other projects to ensure the conservation of our threatened and endangered marine species and designated critical habitat. If you have any questions on this consultation, please contact Nicole Bonine, Consultation Biologist, at (727) 824-5336, or by email at Nicole.Bonine@noaa.gov.

Sincerely,

for

Roy E. Crabtree, Ph.D.
Regional Administrator

Enc.: 1. *Sea Turtle and Smalltooth Sawfish Construction Conditions* (Revised March 23, 2006)
2. *PCTS Access and Additional Considerations for ESA Section 7 Consultations* (Revised March 10, 2015)

File: 1514-22.V

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

NOV 30 2018

Refer to NMFS No: FPR-2018-9287

Mr. Howard Searight
Deputy Manager
U.S. Department of Transportation
Federal Aviation Administration
800 Independence Avenue SW
Washington, DC 20591

RE: Request to reinitiate Endangered Species Act informal consultation for potential effects on giant manta ray (*Manta birostris*) from activities associated with the commercial space launch operations conducted by SpaceX.

Dear Mr. Searight:

On October 19, 2018, NOAA's National Marine Fisheries Service (NMFS) Endangered Species Act Interagency Cooperation Division received the Federal Aviation Administration's (FAA) request to reinitiate informal consultation for actions to be conducted to by the Space Exploration Technologies Corporation (SpaceX), to launch and recover spacecraft in the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean. The FAA is requesting written concurrence that the proposed actions are not likely to adversely affect the ESA-listed as threatened species, giant manta ray (*Manta birostris*). NMFS requested additional information, which was received on October 24, 2018.

On August 25, 2017, NMFS received the FAA's request for written concurrence of their conclusion of not likely to adversely affect species listed as threatened or endangered, or critical habitats designated under the Endangered Species Act (ESA) for their proposed issuance of licenses to the SpaceX to launch and recover spacecraft in the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean. On October 2, 2017, NMFS provided a Letter of Concurrence (FPR-2017-9231) to the FAA for the proposed action. Since the issuance of the Letter of Concurrence, on February 21, 2018, NMFS listed the giant manta ray as a threatened species under the ESA (83 FR 2916). The FAA's request for reinitiation of consultation for effects on giant manta ray included information supporting their conclusion of a may affect, not likely adversely affect giant manta ray from activities the permitted actions conducted by SpaceX.

NMFS reviewed the reinitiation of informal consultation request document and related materials submitted by your agency. Based on our knowledge, expertise, and the materials submitted in your request to include the giant manta ray as a species potentially affected by the SpaceX program, we concur with the FAA's conclusion that the proposed action is not likely to adversely affect ESA-listed giant manta ray.

This letter supplements the Letter of Concurrence (FPR-2017-9231), to include the newly ESA-listed as threatened giant manta ray in the list of species analyzed in the consultation and concluded on October 2, 2017. All previous effects analyses and determinations for listed species and their designated critical habitats from the proposed program remain unchanged. This concludes reinitiation of consultation under the ESA for threatened giant manta ray for the FAA's permitting of the Space Exploration Technologies Corporation proposed actions. This response was prepared by the NMFS ESA Interagency Cooperation Division pursuant to section 7(a)(2) of the ESA, implementing regulations at (50 C.F.R. §402), and agency guidance for preparation of letters of concurrence.

Reinitiation of consultation is required, and shall be requested, by FAA or NMFS where discretionary Federal involvement or control over the action has been retained or is authorized by law and: (a) ESA take occurs; (b) new information reveals effects of the action that may affect ESA-listed species or designated critical habitat in a manner or to an extent not previously considered in this consultation; (c) the action is subsequently modified in a manner that causes an effect to the ESA-listed species or designated critical habitat not previously considered in this consultation; or (d) if a new species is listed or critical habitat designated that may be affected by the action (50 C.F.R. §402.16).

We look forward to further cooperation with you on other projects to ensure the conservation of our threatened and endangered species and designated critical habitat. If you have any questions on this consultation, please contact me at (301) 427-8495 or, cathy.tortorici@noaa.gov.

Sincerely,

Cathryn E. Tortorici
Chief, ESA Interagency Cooperation Division
Office of Protected Resources

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

OCT 15 2018

Jacqueline Pearson Meyer
ESA Interagency Cooperation Division
Office of Protected Resources
National Marine Fisheries Service
1315 East-West Highway
Silver Spring, MD 20910

RE: NMFS No: FPR-2017-9231

Dear Ms. Meyer,

On October 2, 2017, the Federal Aviation Administration (FAA) completed informal Endangered Species Act (ESA) consultation with your office regarding proposed commercial space launch operations conducted by SpaceX (FPR-2017-9231). Since completing that consultation, the National Marine Fisheries Service listed the giant manta ray (*Manta birostris*) as a threatened species under the ESA (83 FR 2916). Because this species could be located in the action area defined in our 2017 consultation, and because this species may be affected by the activities described in that consultation, we are reinitiating consultation with your office. We have determined the action described in the 2017 consultation **may affect, but is not likely to adversely affect**, the giant manta ray for the same reasons provided for the other marine species.

The FAA is requesting NMFS's written concurrence with our effect determination for the giant manta ray. Please contact Daniel Czelusniak, FAA Environmental Specialist, at Daniel.Czelusniak@faa.gov or (202) 267-5924 to discuss any questions or concerns.

Sincerely,

Howard Searight

Howard Searight
Deputy Manager, Space Transportation Development Division

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

INCIDENTAL HARASSMENT AUTHORIZATION

Space Exploration Technology Corporation (SpaceX) is hereby authorized under section 101(a)(5)(D) of the Marine Mammal Protection Act (MMPA; 16 U.S.C. 1371(a)(5)(D)) to harass marine mammals incidental to recovery of Falcon 9 rockets at Vandenberg Air Force Base in California, and at contingency landing locations in the Pacific Ocean, when adhering to the following terms and conditions.

1. This Incidental Harassment Authorization (IHA) is valid from December 1, 2017 through November 30, 2018.

2. This IHA is valid only for Falcon 9 First Stage recovery activities at Vandenberg Air Force Base (VAFB), California, and at auxiliary landing sites offshore.

3. General Conditions

   (a) A copy of this IHA must be in the possession of SpaceX, its designees, and work crew personnel operating under the authority of this IHA.

   (b) The species authorized for taking are listed in Table 1. The taking, by Level B harassment only, is limited to the species and numbers listed in Table 1. Any taking exceeding the authorized amounts listed in Table 1 is prohibited and may result in the modification, suspension, or revocation of this IHA.

   (c) The taking by injury (Level A harassment), serious injury, or death of any of the species listed in Table 1, or any taking of any species of marine mammal other than those listed in Table 1, is prohibited and may result in the modification, suspension, or revocation of this IHA.

4. Mitigation Requirements

   The holder of this Authorization must implement the following mitigation measures:

   (a) Unless constrained by other factors including human safety or national security concerns, launches must be scheduled to avoid boost-backs and landings during the harbor seal pupping season of March through June when practicable.

5. Monitoring

   The holder of this Authorization must conduct marine mammal and acoustic monitoring as described below.

   (a) To conduct monitoring of Falcon 9 First Stage recovery activities, SpaceX must designate qualified, on-site individuals approved in advance by NMFS;

(b) If sonic boom model results indicate that a peak overpressure of 1.0 pounds per square foot (psf) or greater is likely to impact VAFB, then acoustic and biological monitoring at VAFB must be implemented;

(c) If sonic boom model results indicate that a peak overpressure of 1.0 psf or greater is predicted to impact the Channel Islands between March 1 and June 30, greater than 1.5 psf between July 1 and September 30, and greater than 2.0 psf between October 1 and February 28, monitoring of pinniped haulout sites on the Channel Islands must be implemented;

(d) Monitoring must be conducted at the haulout site closest to the area predicted to experience the greatest sonic boom intensity, when practicable;

(e) If Falcon 9 First Stage recovery activities are scheduled during daylight, time-lapse photography or video recording must be used to document the behavior of marine mammals during Falcon 9 First Stage recovery activities;

(f) If Falcon 9 First Stage recovery activities are scheduled during nighttime, night vision devices must be used by monitors to observe pinniped behavior;

(g) Monitors must conduct hourly pinniped counts for 6 hours per day on the day of the Falcon 9 launch. Hourly pinniped counts shall be centered around the launch time when events occur during daylight hours. For nighttime events, hourly pinniped counts shall be conducted from daybreak to 6 hours after daybreak;

(h) Monitors must remain at the monitoring location until pinniped behavior is observed to return to normal, when practicable;

(i) Monitoring must be conducted for at least 72 hours prior to any planned Falcon 9 First Stage recovery and continue until at least 48 hours after the event;

(j) Monitoring must include multiple surveys each day that record the species, number of animals, general behavior, presence of pups, age class, gender and reaction to noise associated with Falcon 9 First Stage recovery, sonic booms or other natural or human caused disturbances, in addition to recording environmental conditions such as tide, wind speed, air temperature, and swell;

(k) Monitors must document marine mammal responses to noise associated with Falcon 9 First Stage recovery activities using the categories shown in Table 2.

(l) For Falcon 9 First Stage recovery activities that occur from March through June, follow-up surveys of harbor seal haulouts on VAFB will be conducted within two weeks of the Falcon 9 First Stage recovery;

(m) If sonic boom model results indicate a peak overpressure of 1.0 psf or greater is likely to impact VAFB during January or February, then acoustic and biological monitoring must be implemented at northern elephant seal rookeries at VAFB, when practicable;

(n) Acoustic measurements of the sonic boom created during boost-back at the monitoring location must be recorded to determine the overpressure level.

6. Reporting

The holder of this Authorization is required to:

(a) Submit a report to the Office of Protected Resources, NMFS, and the West Coast Regional Administrator, NMFS, within 60 days after each Falcon 9 First Stage recovery action. This report must contain the following information:

(1) Date(s) and time(s) of the Falcon 9 First Stage recovery action;

(2) Design of the monitoring program; and

(3) Results of the monitoring program, including, but not necessarily limited to:

(i) Numbers of pinnipeds present on the haulout prior to the Falcon 9 First Stage recovery;

(ii) Numbers of pinnipeds that may have been harassed as a result of Falcon 9 First Stage recovery activities;

(iii) For pinnipeds estimated to have been harassed as a result of Falcon 9 First Stage recovery noise, the length of time pinnipeds remained off the haulout or rookery;

(iv) Any other observed behavioral modifications by pinnipeds that were likely the result of Falcon 9 First Stage recovery activities, including sonic boom; and

(v) Results of acoustic monitoring including comparisons of modeled sonic booms with actual acoustic recordings of sonic booms.

(b) Submit an annual report on all monitoring conducted under the IHA. A draft of the annual report must be submitted within 90 calendar days of the expiration of this IHA, or, within 45 calendar days of the requested renewal of the IHA (if applicable). A final annual report must be prepared and submitted within 30 days following resolution of comments on the draft report from NMFS. The annual report will summarize the information from the 60-day post-activity reports, including but not necessarily limited to:

(1) Date(s) and time(s) of the Falcon 9 First Stage recovery action;

(2) Design of the monitoring program; and

(3) Results of the monitoring program, including, but not necessarily limited to:

(i) Numbers of pinnipeds present on the haulout prior to the Falcon 9 First Stage recovery;

(ii) Numbers of pinnipeds estimated to have been harassed as a result of Falcon 9 First Stage recovery activities at the monitoring location;

(iii) For pinnipeds estimated to have been harassed as a result of Falcon 9 First Stage recovery noise, the length of time pinnipeds remained off the haulout or rookery;

(iv) Any other observed behavioral modifications by pinnipeds that were likely the result of Falcon 9 First Stage recovery activities, including sonic boom;

(v) Any cumulative impacts on marine mammals as a result of the activities, such as long term reductions in the number of pinnipeds at haulouts as a result of the activities; and

(vi) Results of acoustic monitoring including comparisons of modeled sonic booms with actual acoustic recordings of sonic booms.

(c) Reporting injured or dead marine mammals:

(1) In the unanticipated event that the specified activity clearly causes the take of a marine mammal in a manner prohibited by this IHA (as determined by the lead marine mammal observer), such as an injury (Level A harassment), serious injury, or mortality, SpaceX will immediately cease the specified activities and report the incident to the NMFS Office of Protected Resources ((301) 427-8401) and the NMFS West Coast Region Stranding Coordinator ((562) 980-3230). The report must include the following information:

(i) Time and date of the incident;

(ii) Description of the incident;

(iii) Status of all Falcon 9 First Stage recovery activities in the 48 hours preceding the incident;

(iv) Description of all marine mammal observations in the 48 hours preceding the incident;

(v) Environmental conditions (*e.g.*, wind speed and direction, Beaufort sea state, cloud cover, and visibility);

(vi) Species identification or description of the animal(s) involved;

(vii) Fate of the animal(s); and

(viii) Photographs or video footage of the animal(s).

Activities will not resume until NMFS is able to review the circumstances of the prohibited take. NMFS will work with SpaceX to determine what measures are necessary to minimize the likelihood of further prohibited take and ensure MMPA compliance. SpaceX may not resume their activities until notified by NMFS via letter, email, or telephone.

(2) In the event that SpaceX discovers an injured or dead marine mammal, and the lead observer determines that the cause of the injury or death is unknown and the death is relatively recent (*e.g.*, in less than a moderate state of decomposition), SpaceX will immediately report the incident to the NMFS Office of Protected Resources ((301) 427-8401) and the NMFS West Coast Region Stranding Coordinator ((562) 980-3230). The report must include the same information identified in 6(c)(1) of this IHA. Activities may continue while NMFS reviews the circumstances of the incident and makes a final determination on the cause of the reported injury or death. NMFS will work with SpaceX to determine whether additional mitigation measures or modifications to the activities are appropriate.

(3) In the event that SpaceX discovers an injured or dead marine mammal, and the lead observer determines that the injury or death is not associated with or related to the activities authorized in the IHA (*e.g.*, previously wounded animal, carcass with moderate to advanced decomposition, scavenger damage), SpaceX will report the incident to the NMFS Office of Protected Resources ((301) 427-8401) and the NMFS West Coast Region Stranding Coordinator ((562) 980-3230), within 24 hours of the discovery. SpaceX will provide photographs or video

footage or other documentation of the stranded animal sighting to NMFS. The cause of injury or death may be subject to review and a final determination by NMFS.

7. Modification and suspension

(a) This IHA may be modified, suspended or withdrawn if the holder fails to abide by the conditions prescribed herein, or if NMFS determines that the authorized taking is having more than a negligible impact on the species or stock of affected marine mammals.

Donna S. Wieting

Donna S. Wieting,
Director,
Office of Protected Resources,
National Marine Fisheries Service.

NOV 30 2017

Date

Table 1. Numbers of Incidental Take of Marine Mammals Authorized

Species	Number of Takes by Level B Harassment Authorized
Pacific Harbor Seal	16,608
California Sea Lion	45,000
Northern Elephant Seal	2,724
Steller Sea Lion	240
Northern Fur Seal	3,000
Guadalupe Fur Seal	12

Table 2. Classifications of Levels of Pinniped Behavioral Disturbance on Land

Level	Type of response	Definition	Classified as behavioral harassment by NMFS
1	Alert	Head orientation or brief movement in response to disturbance, which may include turning head towards the disturbance, craning head and neck while holding the body rigid in a u-shaped position, changing from a lying to a sitting position, or brief movement of less than twice the animal's body length.	No
2	Movement	Movements in response to the source of disturbance, ranging from short withdrawals at least twice the animal's body length to longer retreats over the beach, or if already moving a change of direction of greater than 90 degrees.	Yes
3	Flush	All retreats (flushes) to the water.	Yes

U.S. Department of Transportation
Federal Aviation Administration

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

January 27, 2020

Jacqueline Pearson Meyer
National ESA Section 7 Coordinator
ESA Interagency Cooperation Division
Office of Protected Resources
National Marine Fisheries Service
Silver Spring, MD 20910
Submitted via email: jacqueline.pearson-meyer@noaa.gov

RE: NMFS No: FPR-2018-9287

Dear Ms. Meyer,

The Federal Aviation Administration (FAA) is reinitiating Endangered Species Act (ESA) consultation with the National Marine Fisheries Service (NMFS) due to a change to the federal action previously analyzed in consultation FPR-2018-9287. As before, the FAA is proposing to modify existing launch licenses or issue new launch licenses to SpaceX to conduct launch and reentry operations originating from Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC). As further discussed below, SpaceX has expanded their proposed Falcon 9 launch trajectories to include a southern trajectory for payloads requiring polar orbits, which expands the action area previously analyzed. This letter provides a brief consultation history and an update to the project description, action area, and effects analysis, and seeks NMFS's concurrence with the FAA's determination that the proposed action would not adversely affect ESA-listed species under NMFS's jurisdiction.

Consultation History

- On April 11, 2016, the National Aeronautics and Space Administration (NASA), FAA, and U.S. Air Force (USAF) submitted a request for ESA section 7 informal consultation to NMFS's Southeast Regional Office (SERO) for SpaceX launch operations occurring from CCAFS, KSC, and the SpaceX Texas Launch Site, and recovery operations occurring in open waters in the Atlantic Ocean and Gulf of Mexico. On August 8, 2016, NMFS issued a Letter of Concurrence for those proposed activities (SER-2016-17894).
- Subsequent to concluding the 2016 consultation, SpaceX informed the FAA that parafoils and parachutes associated with the payload fairings that descend through the Earth's atmosphere and land in the Atlantic Ocean after a launch might not be fully recovered by SpaceX. The FAA also learned the parachutes associated with other spacecraft (e.g., Dragon) reentry were not always recovered. These aspects of the project were not considered in the 2016 consultation since it was assumed all parachutes and parafoils would be fully recovered. Also subsequent to the 2016 consultation, SpaceX proposed to conduct Falcon and Dragon recovery operations in the Pacific Ocean, which were not addressed in the 2016 consultation. Actions in the Pacific Ocean include recovery of parafoils and parachutes associated with payload fairings and Dragon.

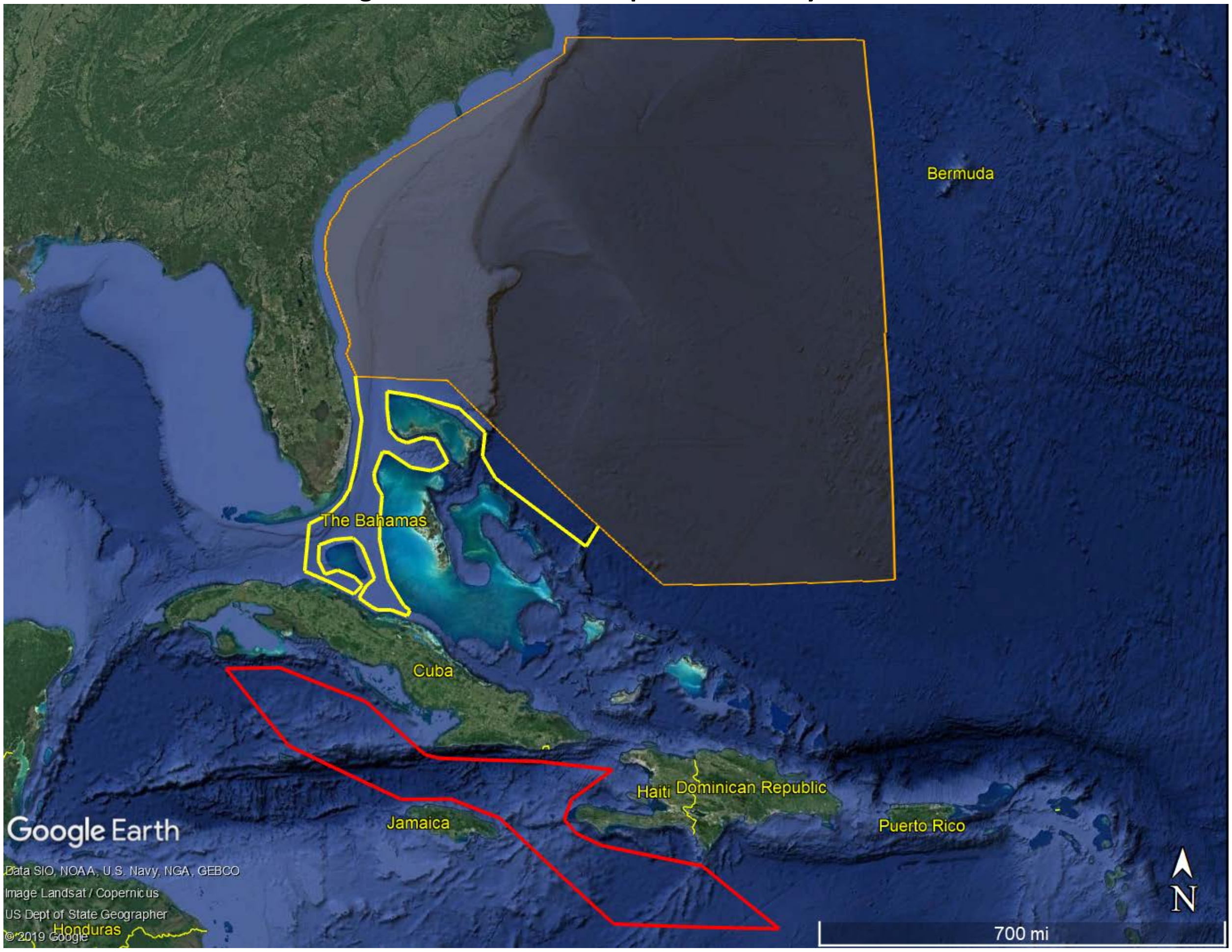
- On June 7, 2017, via conference call, staff from the FAA, NASA, USAF, and NMFS Office of Protected Resources (Headquarters and SERO) discussed ongoing operations and ESA coverage needs for future operations. The parties mutually agreed that NMFS ESA Interagency Cooperation Division at NMFS Headquarters would complete the ESA section 7 consultation for the expanded operations.
- On October 2, 2017, NMFS issued a Letter of Concurrence for SpaceX's proposed launch and recovery operations in the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean (NMFS No: FPR-2017-9231).
- On October 15, 2018, the FAA reinitiated ESA consultation with NMFS (Headquarters and SERO) to add the giant manta ray (*Manta birostris*) and/or the oceanic whitetip shark (*Carcharinus lonigmanus*) to the consultations, since these species were federally listed subsequent to the 2016 and 2017 consultations. On November 21, 2018, NMFS SERO issued a Letter of Concurrence, and on November 30, 2018, NMFS Headquarters issued a Letter of Concurrence.

Proposed Action and Action Area

The FAA's proposed action is the same as previously analyzed—to modify existing launch licenses or issue new launch licenses to SpaceX for launch and recovery operations in the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean. In addition to their typical Falcon 9 launch trajectories from Florida, SpaceX is proposing to increase the launch azimuth window to include a greater range of launch trajectories, including a southern trajectory for payloads requiring polar orbits. The southern trajectory for Falcon 9 polar missions would expand the recovery area in the Atlantic Ocean, as shown in Figure 1. Figures 2 and 3 show sonic boom footprints associated with Falcon 9 first stage booster return and droneship landing during a polar mission. Figures 1–3 define the action area for Falcon 9 first stage booster return and recovery operations in the Atlantic Ocean for polar missions. The action area consists of deep ocean waters. SpaceX cannot conduct recovery operations in shallow waters. Therefore, the action area avoids sensitive nearshore marine habitats, including coral reefs.

It is SpaceX's goal to recover and reuse as many of the Falcon 9 boosters and fairings in order to reduce the cost of launches. SpaceX booster landings are becoming routine, and are rarely left to splash down in the ocean, break up, and sink. However, due to specific requirements of certain payloads, booster landings and recovery may be infeasible. During these scenarios, the booster would splashdown in the action area in Figure 1 and sink. All Falcon 9 launch and recovery operations would be the same as discussed in the 2016 and 2017 consultations. The only change is the new location where recovery operations and sonic booms would occur. All operations would continue to occur at least five nautical miles from the coast. The FAA and SpaceX would follow the environmental protection measures and reporting described in the 2016 and 2017 consultations.

Figure 1. Action Area – SpaceX Recovery Areas



Orange = previously analyzed and approved recovery area for first stage booster and fairing recovery
Yellow = new proposed area for first stage booster and fairing recovery for polar missions
Red = new proposed area for fairing recovery only for polar missions

Figure 2. Sonic Boom Footprint for Falcon 9 Booster Droneship Landing (Polar Mission) – Option 1

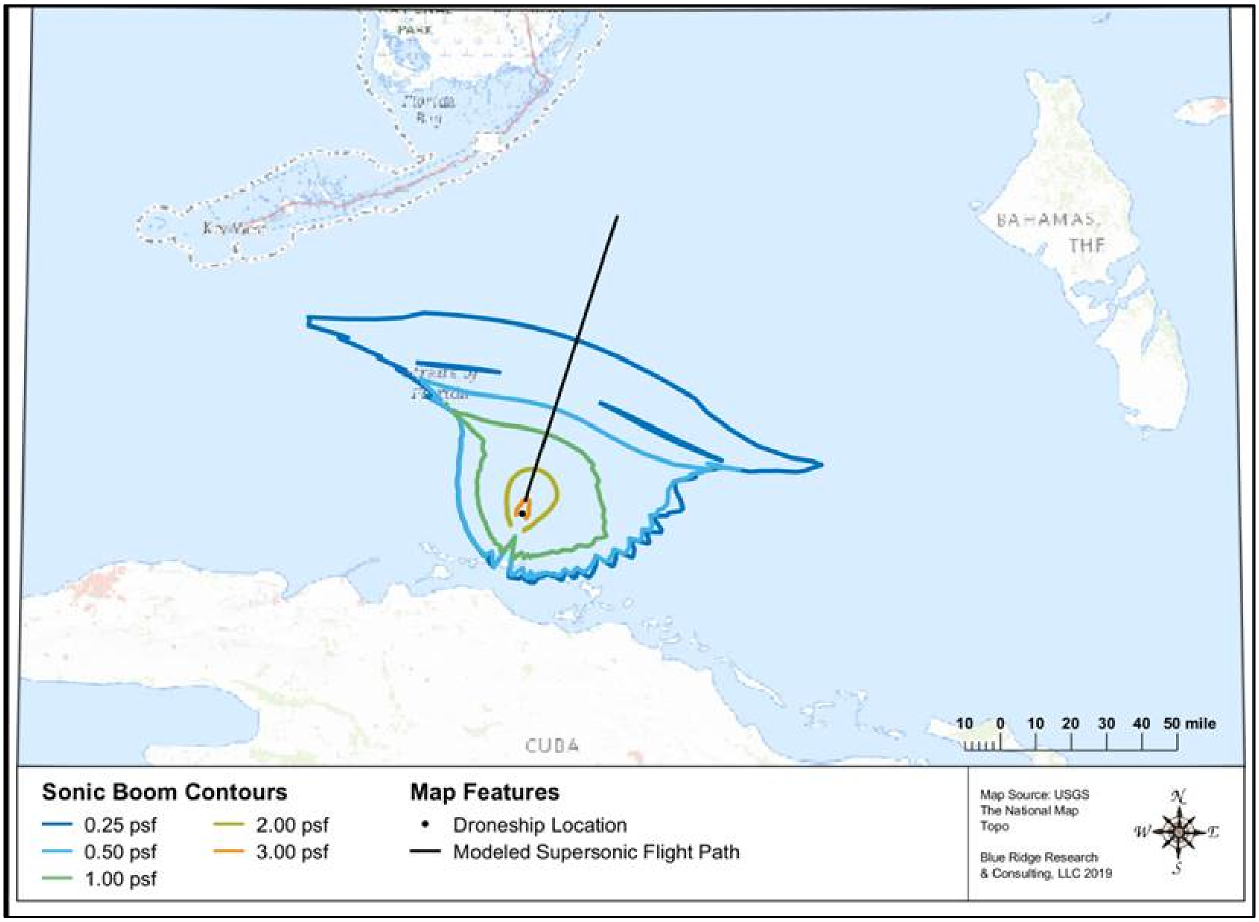
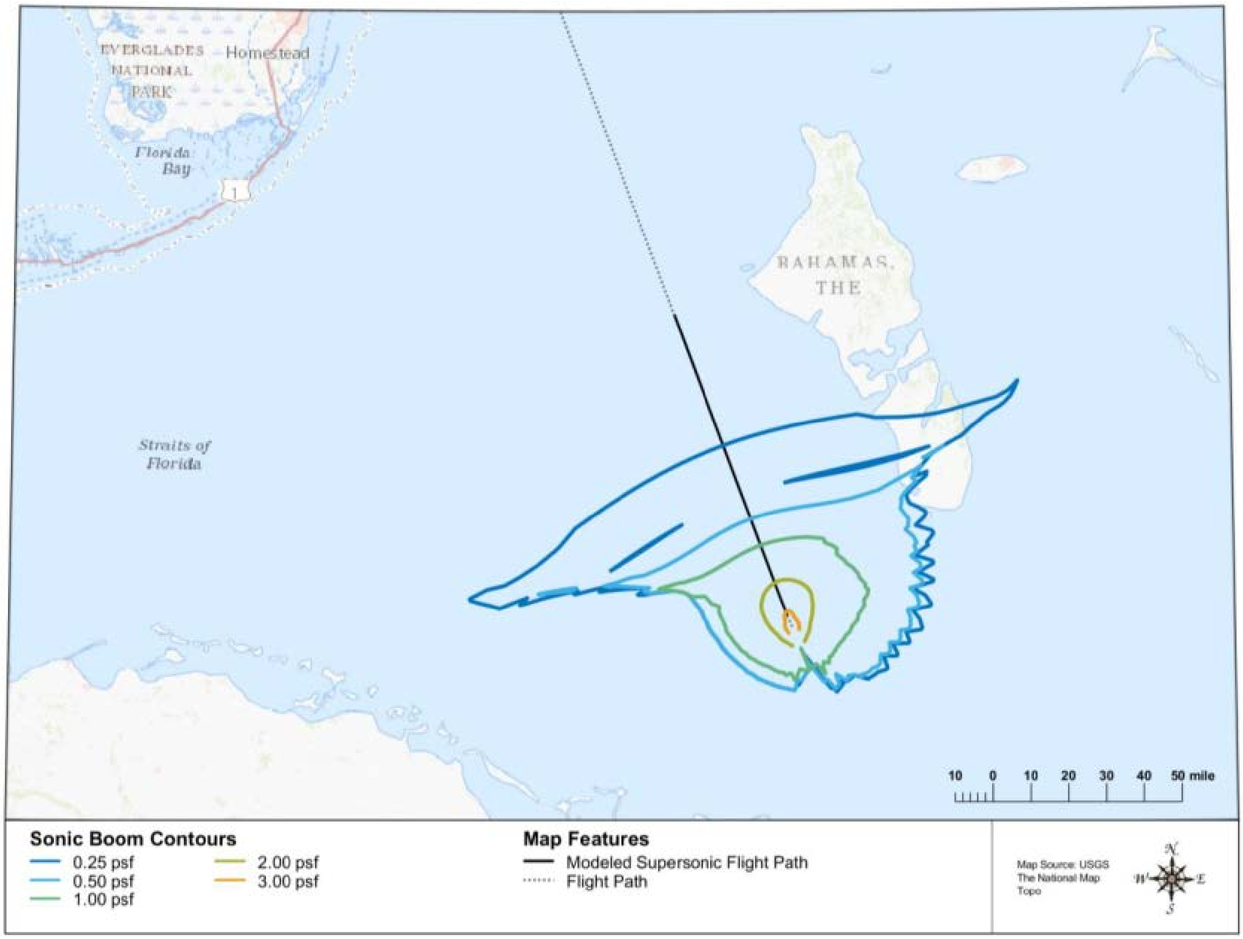


Figure 3. Sonic Boom Footprint for Falcon 9 Booster Droneship Landing (Polar Mission) – Option 2



ESA-Listed Species and Critical Habitat in the Action Area

Table 1 lists the ESA-listed species under NMFS jurisdiction in the action area. The action area is close to or overlaps critical habitat for the loggerhead sea turtle (*Caretta caretta*)—namely the loggerhead's critical habitat for migration, breeding, and foraging and developing (Sargassum). The action area does not include coral reef areas; thus, the proposed action would have no effect on ESA-listed corals.

Table 1. ESA-listed Species Potentially Present in the Action Area

Common Name	Scientific Name	ESA Status
Marine Mammals		
North Atlantic right whale	*Eubalaena glacialis*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Fin whale	*Balaenoptera physalus*	Endangered
Sei whale	*Balaenoptera borealis*	Endangered
Sperm whale	*Physeter macrocephalus*	Endangered
Bryde's whale	*Balaenoptera edeni*	Endangered
Sea Turtles		
Green sea turtle – North and South DPSs	*Chelonia mydas*	Threatened
Hawksbill sea turtle	*Eretmochelys imbricata*	Endangered
Loggerhead sea turtle – Northwest Atlantic Ocean DPS	*Caretta caretta*	Endangered
Olive ridley sea turtle	*Lepidochelys olivacea*	Threatened

Common Name	Scientific Name	ESA Status
Kemp's ridley sea turtle	*Lepidochelys kempii*	Endangered
Leatherback sea turtle	*Dermochelys coriaacea*	Endangered
Fishes		
Atlantic sturgeon – South Atlantic DPS	*Acipenser oxyrinchus*	Endangered
Green sturgeon – Southern DPS	*Acipenser medirostris*	Threatened
Shortnose sturgeon	*Acipenser brevirostrum*	Endangered
Nassau grouper	*Epinephelus striatus*	Threatened
Scalloped hammerhead shark – Central and Southwest Atlantic DPSs	*Sphyrna lewini*	Threatened
Oceanic whitetip shark	*Carcharhinus longimanus*	Threatened
Smalltooth sawfish – U.S. population	*Pristis pectinata*	Endangered
Giant manta ray	*Manta birostris*	Threatened

Notes:
DPS = distinct population segment

Effects on ESA-Listed Species in Action Area

The effects analysis is similar to the analysis presented in the 2016 and 2017 consultations. NMFS previously concluded that the potential stressors would be unlikely to adversely affect ESA-listed species. A summary of the analysis is provided here.

Potential effects from SpaceX launch and recovery operations in the action area relate to Falcon 9 first stage booster landings on a droneship, re-entry sonic booms, and open ocean splashdowns of fairings and parachute components. Effects could include direct strikes to an animal, ingestion of material, entanglement with parachute or parafoil lines and material, and exposure to a sonic boom.

Direct Strike

The ESA-listed fish species that might be present in the action area do not spend a large majority of time at the shallower surface depths where direct strikes could occur. They are expected to be distributed throughout deeper depths in the water column (e.g., salmonids, sharks), or located along the shelf or substrate waters less than 110 meters deep (e.g., smalltooth sawfish, groupers, and sturgeon species). Additionally, a physical strike affecting a fish depends on the relative size of the object potentially striking the fish and the location of the fish in the water column. Since fish are able to detect an object descending in the water column (e.g., sensing the pressure wave or displacement of water), they would have the ability to swim away from an oncoming object.

Marine mammals and sea turtles spend time at the surface to bask and breathe and thus may be at a higher risk of interacting with the fairing and other parts compared to fish species. Since turtles and whales spend the majority of their time submerged as opposed to on the surface, the risk of being directly hit by any falling parts is extremely low.

Expended materials from rocket launches have been occurring for decades with no known interactions with any of these species. Because it would be extremely unlikely for an ESA-listed species to be directly struck by any rocket component, the potential effects of a direct strike for any ESA-listed species is considered discountable.

Payload Fairing Recovery

In most cases, SpaceX expects to recover both the halves of the fairing and main portions of the recovery system of parafoils. Recovery of the drogue parachute assembly is attempted if the recovery team can get a visual fix on the splashdown location. However, because the drogue parachute assembly is deployed at a high altitude, it is difficult to locate. In addition, based on the size of the assembly and the density of the material, the drogue parachute assembly becomes saturated within approximately one minute of splashing down and begins to sink. The drogue parachute's primary material (nylon) is in the family of high molecular weight polymers, which are not easily degraded by abiotic (physical or chemical) or biotic processes. Photooxidative degradation—the process of decomposition of the material by light (most effectively by near-ultraviolet [UV] and UV wavelengths)—would be the most effective source of damage exerted on the nylon parachute. However, upon entering the water column, the drogue parachute would rapidly sink below the depths to which UV radiation in the ocean penetrates, eventually resting on the ocean floor where exposure to UV light would not occur, making photo-oxidation improbable. Once on the ocean floor, the relatively constant temperatures and lower oxygen concentration (as compared to the atmosphere) would slow any resultant degradation. Small fragments may also temporarily re-suspend in the water column, but the potential for this would be based entirely on local ocean floor conditions and the fragments would not be expected to resuspend higher in the water column where they would likely be encountered by ESA-listed species.

The two primary pathways of potential adverse effects to ESA-listed marine species from fairing recovery operations would be via ingestion of parachute material or entanglement in parachute lines. Given the rapid descent of the parachute in the water column, ESA-listed species are not expected to be exposed to either the opportunity for ingestion or entanglement for more than one hour, generally.

Ingestion

Foraging individuals at or near the sea surface could ingest portions of the parachutes or parafoils. Ingestion of debris may cause a physical blockage in the digestive system to the point of starvation or that results in ulceration or rupture, cause the animal to feel satiated and reduce its foraging effort and overall fitness, or to introduce toxic chemicals into the tissues of animals, causing adverse health or reproductive consequences. However, the rapid sink times for unrecovered parts would limit the opportunity for individuals foraging at the surface or higher in the water column to a very short duration, in most cases no longer than one to two hours. In addition, because of the ultimate settlement depths and time it would take for the parachute material to degrade into smaller plastic components, re-suspension and availability for ingestion by marine mammals in the water column is unlikely. For these reasons, the likelihood of any marine mammal ingesting portions of the parachutes or parafoils is so low as to be discountable.

Entanglement

Entanglement of an ESA-listed marine species could occur if an individual was struck by or encountered the parachute or parafoil after it lands in the water. Entanglement in lines or the material can wrap an animal's flippers, flukes, fins, or head, and make movement or breathing and other natural behaviors difficult or impossible. Unlike other materials in which fish may become entangled (such as gill nets and nylon fishing line which are hard to see), parachutes and parafoils are relatively large and visible, reducing the chance that visually oriented fish would accidentally become entangled in it. Additionally, due to their size, mobility, and likely inhabited areas of the water column and ocean substrates, ESA-listed fish species are not expected to become entangled in parachutes or parafoils (and associated lines and fragments) floating or sinking in the water column.

Entanglement by parachutes and lines poses a greater risk for marine mammals. However, given the relative size difference between the (comparatively small) parachutes and parafoils (and the associated lines), and a (much larger) individual whale, the probability of entanglement is unlikely. Furthermore, since the unrecovered fairing drogue parachute or parafoil would sink fairly rapidly following water impact, the material would not be available for entanglement except for a short period of time during its descent to the ocean floor. Upon reaching the sea floor, marine mammals are not likely to interact with the material as these species would not likely be engaged in foraging behaviors at that depth, and, consequently, would be located higher in the water column.

Sea turtles could encounter an unrecovered parachute or parafoil and subsequently become entangled. However, similar to marine mammals, multiple factors render this potential stressor highly unlikely. First, payload fairing recovery attempts would be infrequent. Second, the expected sink rate of the fairing drogue parachutes and parafoils would remove the material from the water column stratum most commonly frequented by migrating and foraging sea turtles in a short time frame. Though it is possible the ultimate location of the material on the seafloor could be within the range of depths observed for diving sea turtles, particularly leatherbacks, it has recently been determined from satellite telemetry that very deep dives are rare. Lastly, the low density of sea turtles in the action area makes the likelihood of an individual becoming entangled in the descending or seafloor-resting material highly unlikely.

Given that it is extremely unlikely for ESA-listed species to be struck by the fairings and drogue parachute assembly, it is also expected that animals investigating and becoming entangled in the accompanying parafoils or the drogue parachute assembly during the hour or so they are at or near the surface of the water to be similarly unlikely, and therefore discountable.

Sonic Boom

Overpressures from sonic booms are not expected to travel through the water column and affect marine species. Acoustic energy from in-air noise does not effectively cross the air/water interface; therefore, most of the noise is reflected off the water surface. In addition, underwater sound pressure levels from in-air noise are not expected to reach or exceed threshold levels for injury to any marine species. Previous research conducted by the USAF supports this conclusion with respect to sonic booms, indicating there is no risk of harassment for protected marine species in water. Therefore, sonic booms would have no effect on ESA-listed marine species located underwater.

Species Summary

In summary, based on the discussion above, the stressors associated with SpaceX's Falcon 9 launch and recovery operations in the action area present a very low risk to species present in the action area, such that any potential effects would be insignificant or discountable. Because of this, the FAA determined the proposed action "may affect, but would not likely adversely affect" ESA-listed species.

Effects on Critical Habitat in Action Area

Designated critical habitat for the loggerhead turtle is located within or near the action area. These areas of habitat include areas of constricted migratory habitat, breeding habitat, and Sargassum habitat. None of the proposed activities occurring within critical habitat are expected to affect essential features. Therefore, the FAA has determined the proposed action would have no effect on loggerhead turtle critical habitat.

Conclusion
We seek your concurrence on our "may affect" determination for the above-listed species and welcome any additional comments. Thank you for your assistance in this matter. Please provide your response to Daniel Czelusniak via e-mail at Daniel.Czelusniak@faa.gov.

Sincerely,

Daniel Murray
Manager, Space Transportation Development Division

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

February 20, 2020

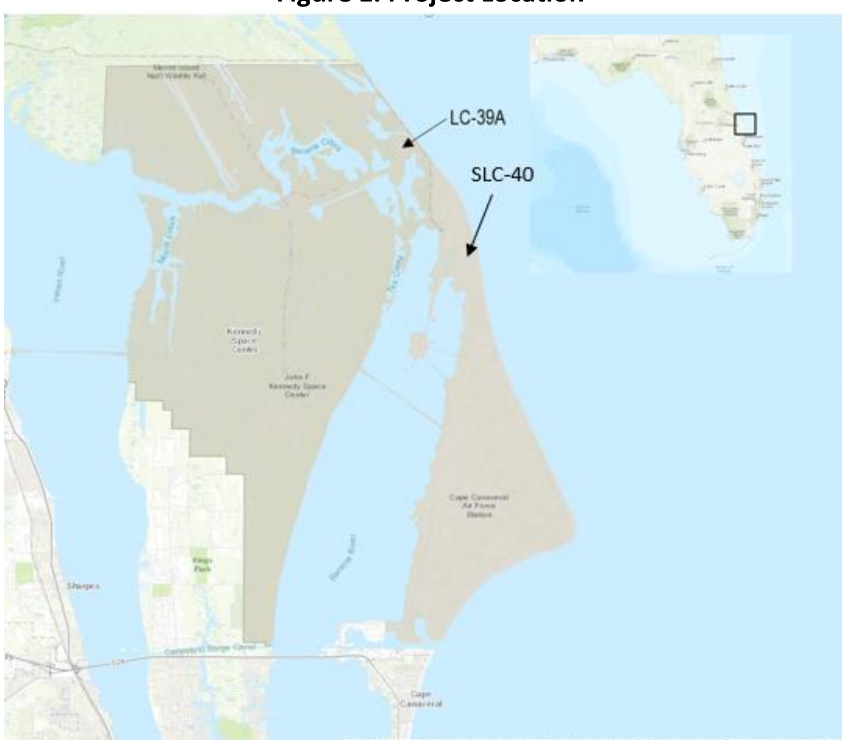
Annie Dziergowski
Chief, Project Review and Consultation
U.S. Fish and Wildlife Service
North Florida Ecological Services Office
7915 Baymeadows Way, Suite 200
Jacksonville, FL 32256-7517
Submitted to: jaxregs@fws.gov

SUBJECT: Endangered Species Act Consultation for SpaceX's Falcon Launch Vehicles, Kennedy Space Center and Cape Canaveral Air Force Station, Brevard County, Florida

Dear Ms. Dziergowski,

The Federal Aviation Administration (FAA) is evaluating SpaceX's proposal to increase the number of annual launches of their Falcon family of launch vehicles at the National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) and U.S. Air Force (USAF) Cape Canaveral Air Force Station (CCAFS) in Brevard County, Florida (see Figure 1 for project location). As authorized by Chapter 509 of Title 51 of the U.S. Code, the FAA licenses and regulates U.S. commercial space launch and reentry activity, which includes SpaceX's commercial launch operations at KSC and CCAFS.

Figure 1. Project Location



Pursuant to section 7 of the Endangered Species Act (ESA), we are requesting U.S. Fish and Wildlife Service (USFWS) concurrence with our assessment and determination of potential effects of our proposed action on ESA-listed species. The following sections of this letter provide a description of the project, define the action area, provide ESA-listed species and critical habitat in the action area, discuss potential effects to the listed species and critical habitat, and provide FAA's effect determination for each species and critical habitat.

Project Description

Operations

The FAA's proposed action is to modify existing SpaceX launch licenses or issue new launch licenses to SpaceX to conduct Falcon 9 and Falcon Heavy launch operations at KSC (LC-39A) and CCAFS (LC-40). SpaceX is proposing to increase their annual launch cadence for the next six years, such that by 2025, SpaceX estimates to conduct 60 Falcon 9 and 10 Falcon Heavy launches per year from Florida (see Table 1).

Table 1. Estimated Number of Annual Falcon 9 and Falcon Heavy Launches at KSC and CCAFS, 2020–2025

Year	KSC Launch Complex 39A		CCAFS Launch Complex 40	Total Launches
	Falcon Heavy	Falcon 9	Falcon 9	
2020	3	5	30	38
2021	10	10	44	64
2022	10	10	44	64
2023	10	10	50	70
2024	10	10	50	70
2025	10	10	50	70

The Falcon 9 launch vehicle consists of a first stage booster, a second stage, and a payload (Figure 2). Falcon 9 is powered by Merlin 1D (M1D) engines, which are propelled by rocket propellant (RP-1) and liquid oxygen (LOX), and are capable of providing 190,000 pounds (pound-force) of thrust at sea level. Falcon 9's first stage includes nine M1D engines for a total of approximately 1.71 million pounds of thrust at liftoff. The first stage has four deployable landing legs to enable booster return (boost-back) and landing shortly after takeoff.

The Falcon Heavy launch vehicle is comprised of three first stage boosters, a second stage, and a payload (Figure 3). Falcon Heavy uses the same M1D engines as Falcon 9. Falcon Heavy's first stage includes 27 M1D engines, which produces approximately 5.13 million pounds of thrust at liftoff. Each first stage has four deployable landing legs to enable boost-back and landing shortly after takeoff.

Each Falcon 9 and Falcon Heavy launch would be preceded by a static fire test of the first stage engines, which lasts a few seconds. In addition to their typical launch trajectories from Florida, SpaceX is proposing to increase the launch azimuth window to include a greater range of launch trajectories, including a Falcon 9 southern trajectory for payloads requiring polar orbits. SpaceX estimates approximately 10 percent of their planned annual Falcon 9 launches would be polar missions requiring a southern launch azimuth.

Figure 2. Falcon 9 Configuration

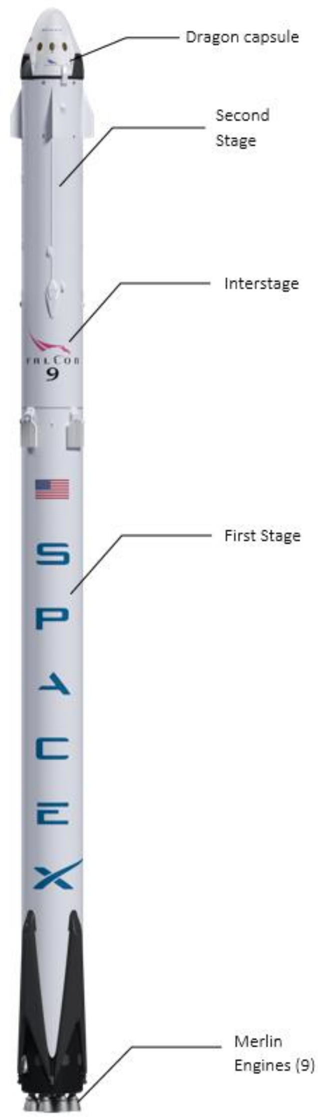


Figure 3. Falcon 9 and Falcon Heavy Configurations

Following a nominal launch from LC-40 or LC-39A, the first stage booster(s) would boost-back and land at Landing Zone 1 (LZ-1) and/or LZ-2 at CCAFS or on SpaceX's drone ship in the Atlantic Ocean. As the first stage booster is approaching the landing pad or drone ship, the landing legs deploy in preparation for a final single-engine burn that slows the booster to a velocity of zero before landing on the pad or drone ship. During first stage boost-back, a sonic boom(s) is generated by each booster (the number of booms depends on the number of returning boosters). Although propellants would be burned to depletion during flight, there is a potential for residual LOX and RP-1 to remain in the booster(s) upon landing. Any hazardous materials would be handled in accordance with federal, state, and local laws and regulations. SpaceX has an established emergency response team and any unexpected spills would be contained and cleaned up per the procedures identified in the SpaceX Emergency Action Plan and Spill Control and Countermeasures Plan.

While it is SpaceX's goal to boost-back and land all first stage boosters for reuse, because some payloads require additional fuel to reach desired orbits or destinations (due to increased weight or extended trajectory), not all the launches listed in Table 1 would include boost-back and landing. SpaceX estimates that more than 75 percent of missions would include a boost-back and landing. For Falcon Heavy boost-back and landing (which involves three first stage boosters), each of the three boosters would be controlled separately so their approach and landing would be managed independently. Not all boosters would land at CCAFS (LZ-1 and/or LZ-2). Some boosters would land on SpaceX's drone ship in the Atlantic Ocean. The action assumes 54 boosters per year would land at LZ-1 and/or LZ-2 and 27 boosters per year would land on the drone ship.

Table 3. Returning First Stage Boosters

Year	From Falcon Heavy Launches	From Falcon 9 Launches	Total Boosters
2020	9	35	44
2021	14	44	58
2022	14	44	58
2023	27	54	81
2024	27	54	81
2025	27	54	81

[a] Not all boosters would land at CCAFS (LZ-1 and/or LZ-2). Some boosters would land on SpaceX's drone ship in the Atlantic Ocean. The proposed action assumes 54 boosters per year would land at CCAFS and 27 boosters per year would land on the drone ship.

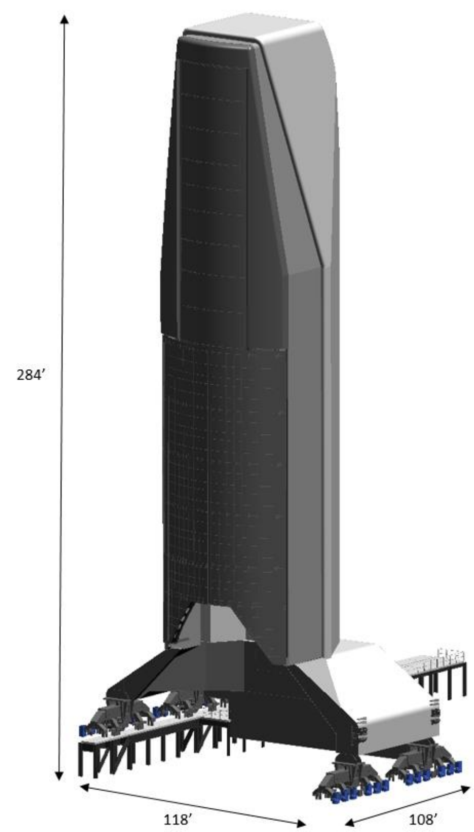
During operations (including launches and landings), there is a possibility of temporary restricted access on portions of KSC property managed by USFWS (Merritt Island National Wildlife Refuge [MINWR]), as have occurred for past SpaceX launch operations from LC-39A and LC-40. Closures due to safety hazards are dependent upon the risk assessment performed by the USAF Range Safety office and the FAA (for commercially licensed launches) using the specific launch trajectory and fuel loads on the rocket prior to launch. MINWR closures might also occur due to the volume of visitor traffic, because launch activity on KSC has historically attracted people to the area including MINWR and Canaveral National Seashore (CNS), enhancing the visitor experience and public enjoyment. Such closures are coordinated between KSC security, USFWS, and the National Park Service by monitoring to ensure parking lot thresholds are not exceeded, and roadways allow for emergency egress for any form of emergency associated with large crowds. All closures, whether dictated by public safety concerns (i.e., the Range or FAA require the closure) or due to visitor volumes exceeding capacity, would be temporary, lasting approximately three to six hours each time.

The conservation lands surrounding LC-39A (and areas on CCAFS) are subject to controlled burning operations, one of MINWR's primary habitat management tools. NASA KSC, working with MINWR, would continue to include SpaceX in their prescribed fire planning and coordination activities to ensure that controlled burning of adjacent land and related issues are well-communicated with the goal of limited, if any, impact to operations at the launch complexes. The burn planning and operations of these areas adhere to a Prescribed Burn Memorandum of Understanding (MOU) (KCA-4205 Rev B; KSC 2019). The MOU includes conditions and constraints for conducting prescribed burns, both on KSC and CCAFS. When KSC or CCAFS receives USFWS notification of a planned prescribed burn adjacent to LC-39A or LC-40, KSC or CCAFS shall notify SpaceX within three days to allow coordination of prescribed burns. KSC management and CCAFS would assist the USFWS in resolving any operational or other barriers in order to accomplish prescribed burns. The proposed action would not change the fire management program activities in the area surrounding LC-39A and LC-40.

Construction

In addition to Falcon 9 and Falcon Heavy launch operations, SpaceX is also proposing to construct a mobile service tower (MST) on the existing LC-39A launch pad to support vertical integration capabilities. The MST would consist of a steel-trussed tower, a base, and a rail bridge (Figure 4). Four transport bogies located at the corners of the tower would be constructed and used to move the tower 130 feet from integration to launch position. The tower would be approximately 284 feet tall. This activity would include a small amount of earthwork at LC-39A. NASA is responsible for approving the construction of the MST at LC-39A. The FAA has no federal action related to the construction of the MST. However, the FAA is including this aspect of SpaceX's proposal to facilitate NASA's ESA compliance.

Figure 4. MST Design



Action Area

The action area is defined as all areas directly or indirectly affected by the federal action. The action area encompasses those areas that would be affected by construction, static fire engine tests, Falcon 9 or Falcon Heavy takeoff, and first stage booster landing at CCAFS.

On behalf of SpaceX, KBR conducted a noise assessment for the project (see Attachment 1 for the noise report). The noise report contains figures showing maximum A-weighted sound levels (L_{Amax}) for a Falcon 9 and Falcon Heavy launch. As a Falcon Heavy launch produces higher noise levels than a Falcon 9 launch (and higher noise levels than a first stage boost-back and landing), the action area is defined by the noise generated during a Falcon Heavy launch (Figure 5). This area also includes any effects that might occur from MST construction and static fire engine tests. As shown in Figure 5, the 70 A-weighted decibel (dBA) contour includes all of Brevard County and portions of Volusia, Seminole, Orange, and Osceola counties. The higher L_{Amax} contours (90, 100, and 110 dBA) are located entirely within the CCAFS and KSC properties (Brevard County).

Sonic booms during rocket takeoff and ascent are generated downrange. For SpaceX's current operations, which include easterly or southeasterly trajectories, the sonic boom generated during rocket ascent impacts the broad open ocean. However, for southern launch azimuths (polar missions), the sonic boom generated during ascent could impact parts of Florida. Blue Ridge Research and Consulting (BRRC) conducted sonic boom modeling for rocket ascent for a Falcon 9 polar mission. The sonic boom is modeled to impact parts of Florida (Figure 6; see also Attachment 2 for the sonic boom report). Therefore, the action area also includes the sonic boom footprint shown in Figure 6. This area includes portions of the following counties: St. Lucie, Indian River, Okeechobee, Highlands, Glades, and Martin.

BRRC modeled sonic booms generated during Falcon first stage booster return to CCAFS (LZ-1 and LZ-2) for two SpaceX missions (non-polar) (see Attachment 3). As shown in Attachment 3, weather conditions (e.g., wind and wind direction) can affect the location of the boom footprint. However, in general, the footprint is mostly contained within Brevard County.

For Falcon 9 polar missions, which have never been previously analyzed, a sonic boom is also generated during first stage boost-back and landing at LZ-1 or LZ-2. KBR conducted sonic boom modeling for Falcon 9 first stage landing at LZ-1 or LZ-2 during a polar mission (Figure 7; see also Attachment 4 for the sonic boom report). The modeled sonic boom footprint expands the action area to include portions of the following additional counties: Desoto, Hardee, Hillsborough, and Polk. Sonic booms generated during first stage landing on a drone ship in the Atlantic Ocean during a polar mission would not affect areas within U.S. boundaries and thus are not considered in this consultation.

Figure 5. Maximum A-weighted Sound Levels for Falcon Heavy Launch from LC-39A

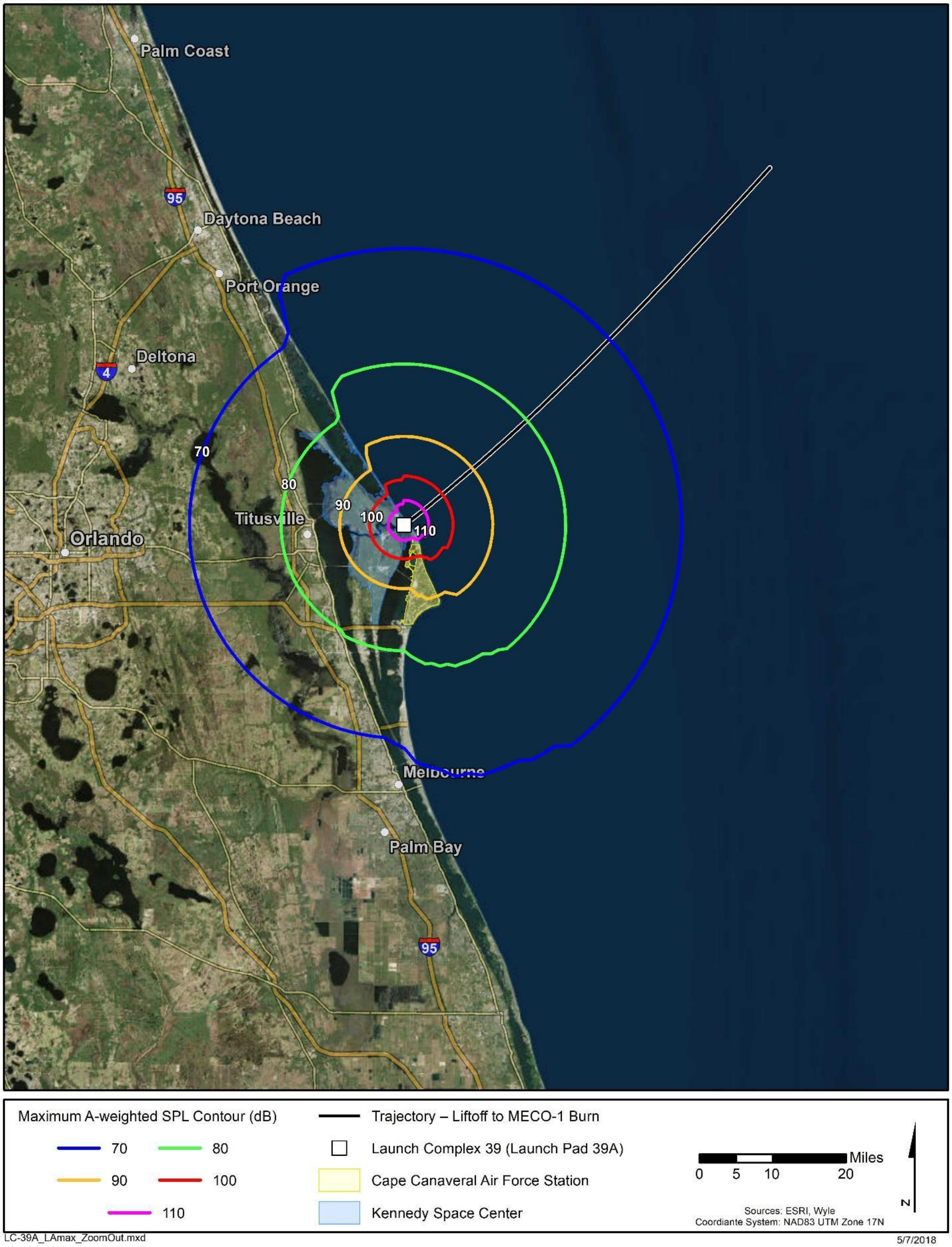


Figure 6. Predicted Sonic Boom Overpressure Contours for a Falcon 9 Southern Trajectory (Ascent)

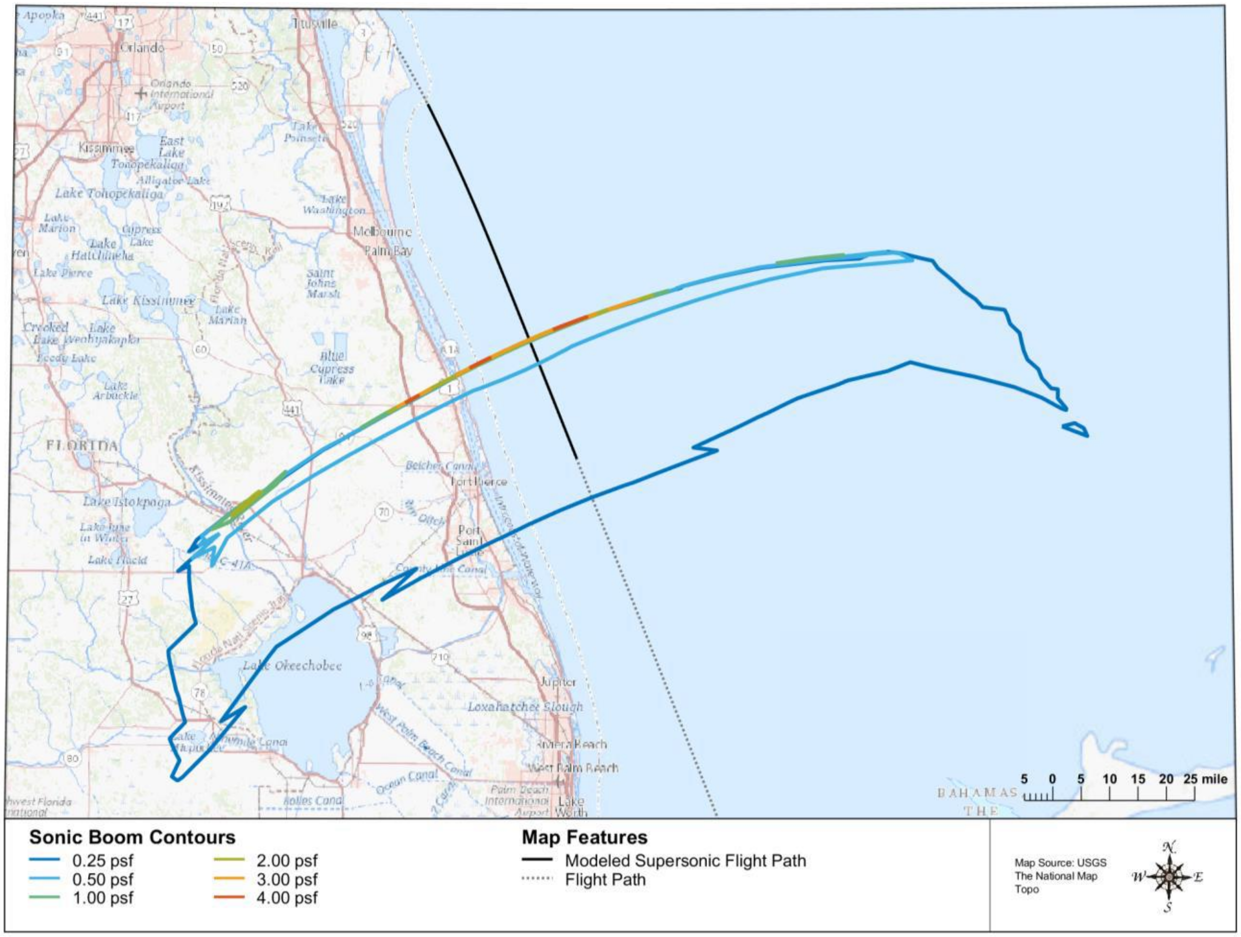
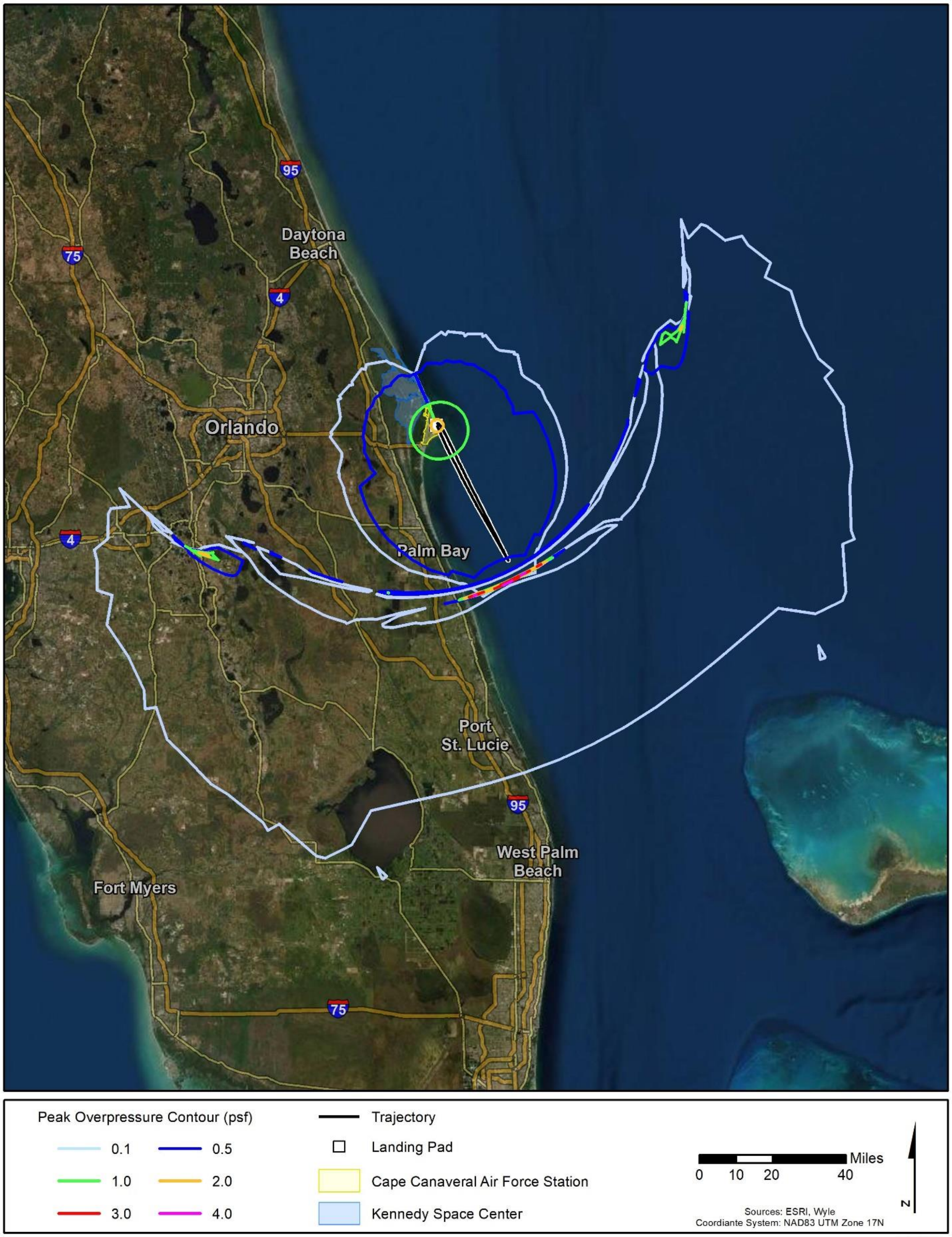


Figure 7. Predicted Sonic Boom Overpressure Contours for a Falcon 9 Southern Trajectory (Landing)



ESA-Listed Species and Critical Habitat

We used the USFWS's Information for Planning and Consultation (IPaC) online system to generate a species list and identify critical habitat for the project. Table 4 includes ESA-listed species and critical habitat within the action area. Designated critical habitat for the West Indian manatee (*Trichechus manatus latirostris*), loggerhead sea turtle (*Caretta caretta*), and Everglade snail kite (*Rostrhamus sociabilis plumbeus*) is present within the action area.

In 1977, the USFWS designated multiple waterways and parts of coastal Florida, from Jacksonville south to Miami and west around the peninsula to Tampa Bay, as critical habitat for manatees (42 FR 47840). The waters around KSC and CCAFS are critical habitat for the manatee. The Upper Banana River is an area of particular emphasis for cautious boat operations and is managed by NASA and MINWR. The estuarine waters surrounding KSC provide year-round safe harbor and foraging areas for West Indian manatees.

The USFWS designated specific areas in the terrestrial environment of the U.S. Atlantic and Gulf of Mexico coasts as critical habitat for the Northwest Atlantic Ocean distinct population segment of the loggerhead sea turtle in July 2014 (79 FR 39756). Nesting beaches along Florida's coast are critical habitat for the loggerhead.

The USFWS designated critical habitat for the Everglade snail kite in 1977 (42 FR 47840). Within the action area, critical habitat includes western portions of Lake Okeechobee in Glades and Okeechobee counties.

Table 4. ESA-Listed Species and Critical Habitat in the Action Area

Category	Species Common Name (Scientific Name)	County	Status	Critical Habitat
Mammals	Florida bonneted bat (Eumops)	De, Ha, Ok, Po	E	No
	Florida panther (*Puma* [=*Felis*] *concolor coryi*)	De, Gl, Ha, Hig, In, Ma, Ok, Os, Po, St	E	No
	Puma (=mountain lion) (*Puma* [=*Felis*] *concolor* [all subspecies except *coryi*)	De, Gl, Ha, Hig, In, Ma, Ok, Os, Po, St	SAT	No
	Southeastern beach mouse (*Peromyscus polionotus nineiventris*)	Br, In, Ma, Ok, Os, St, Vo	T	No
	West Indian manatee (*Trichechus manatus latirostris*)	Br, Gl, Hig, Hil, In, Ma, Ok, Se, St, Vo	T	Yes
Birds	Audubon's crested caracara (*Polyborus plancus audubinii*)	Br, De, Gl, Ha, Hig, Hil, In, Ma, Ok, Or, Os, Po, St	T	No
	Eastern black rail (*Laterallus jamaicensis* spp. *jamaicensis*)	Br, Hil, Or, Os, Se, Vo	PT	No
	Everglade snail kite (*Rostrhamus sociabilis plumbeus*)	Br, Gl, Ha, Hig, Hil, In, Ma, Ok, Or, Po, St, Vo	E	Yes
	Florida grasshopper sparrow (*Ammodramus savannarum*)	De, Gl, Ha, Hig, Hil, In, Ok, Os, Po	E	No
	Florida scrub-jay (*Aphelocoma coeruluscens*)	Br, De, Gl, Ha, Hig, Hil, Or, Ma, Ok, Os, Po, Se, St, Vo	T	No
	Ivory-billed woodpecker (*Campephilus principalis*)	De, Gl, Ha, Hig, In, Ma, Ok, Os, Po, St	E	No
	Piping plover (*Charadrius melodus*)	Br, Hil, In, Ma, St, Vo	T	No

Category	Species Common Name (Scientific Name)	County	Status	Critical Habitat
	Red knot (*Calidris canutus rufa*)	Br, In, Ma, St, Vo	T	No
	Red-cockaded woodpecker (*Picoides borealis*)	Br, De, Gl, Hig, In, Ma, Ok, Or, Os, Po, Se, St, Vo	E	No
	Whooping crane (*Grus americana*)	De, Gl, Ha, Hig, In, Ma, Ok, Os, Po, St	EXPN	No
	Wood stork (*Mycteria americana*)	Br, De, Gl, Ha, Hig, Hil, In, Ma, Ok, Or, Os, Po, Se, St, Vo	T	No
Reptiles	American alligator (*Alligator mississippiensis*)	De, Gl, Ha, Hig, In, Ma, Ok, Os, Po, St	SAT	No
	Atlantic salt marsh snake (*Nerodia clarkii taeniata*)	Br, In, Vo	T	No
	Bluetail mole skink (*Eumeces egregius lividus*)	Gl, Hig, Hil, Os, Po	T	No
	Eastern indigo snake (Drymarchon corais couperi)	Br, De, Gl, Ha, Hig, Hil, In, Ma, Ok, Or, Os, Po, Se, St, Vo	T	No
	Gopher Tortoise (*Gopherus polyphemus*)	Br, Hil, Or, Se, Vo	C	No
	Green sea turtle (*Chelonia mydas*)	Br, Vo	T	No
	Hawksbill sea turtle (*Eremochelys imbricata*)	Br, Hil, Ma, St, Vo	E	No
	Kemp's ridley sea turtle (*Lepidochelys kempii*)[1]	See table note		
	Leatherback sea turtle (*Dermochelys coriacea*)	Br, Hil, In, Ma, St, Vo	E	No
	Loggerhead sea turtle (*Caretta caretta*)	Br, Hil, In, Ma, St, Vo	T	Yes
	Sand skink (*Neoseps reynoldsi*)	Gl, Hig, Hil, Or, Os, Po, Se	T	No
Insects	Miami blue butterly (*Cyclargus* (=*Hemiargus*) *thomasi bethunebakeri*)	In, Ma, St	E	No
	Florida leafwing butterfly (*Anaea troglodyta*)	Ma	E	No
Plants[2]	Carter's mustard (*Warea carteri*)	Br	E	No
	Lewton's polygala (*Polygala lewtonii*)	Br	E	No

Source: USFWS 2019a

Notes:

Br = Brevard County; C = candidate; De = Desoto County; E = endangered; EXPN = experimental population, non-essential; Gl = Glades County; Ha = Hardee County; Hig = Highlands County; Hil = Hillsborough County; In = Indian River County; Ma = Martin County; Ok = Okeechobee County; Or = Orange County; Os = Osceola County; Po = Polk County; PT = proposed threatened; SAT = similarity in appearance; Se = Seminole County; St = St Lucie County; T = threatened; Vo = Volusia County

[1] IPaC does not list Kemp's ridley sea turtle for the counties comprising the action area. However, previous ESA consultations with USFWS for the same area have included this species.

[2] The table only includes listed plants for Brevard County because the action would only have the potential to affect listed plants in Brevard County.

Potential Effects to ESA-listed Species and Critical Habitat

Effects from Construction and Launch-Related Operations

Potential effects to ESA-listed species potentially occurring in Brevard County from MST construction and launch-related operations (e.g., facility operations, personnel working, nighttime lighting, etc.) are included here. MST construction and launch-related operations would have no effect on ESA-listed species occurring outside Brevard County. Potential effects from launches (rocket takeoff and landing) are discussed separately below.

Mammals

Southeastern beach mouse

The southeastern beach mouse occurs within sea oat habitat in coastal primary dunes and in adjacent sandy habitat in coastal strand communities (USFWS 2019b). Construction activities at LC-39A would not occur within or near the mouse's habitat. LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the southeastern beach mouse. The Florida Natural Areas Inventory (FNAI) Biodiversity Matrix online server (FNAI 2019) does not include documented occurrences for this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the southeastern beach mouse.

West Indian manatee

Construction activities would have no effect on the West Indian manatee because the species is aquatic and does not occur near LC-39A. Barges transporting first stage boosters from the Atlantic Ocean recovery areas to Port Canaveral might encounter manatees near the port. Manatee numbers in this area have dropped considerably in recent years due to a decline in seagrasses (potentially from algal blooms). Barge and boating activity has been ongoing in the port since the 1950s and manatee protection measures are in place. The port's manatee protection program includes the following: an acoustic sensor system in the Canaveral Lock to prevent manatees from getting caught in the closing gates, fenders at piers and bulkheads that give manatees room to maneuver while vessels are being docked, slow speed zone sign posting, and stormwater outfall grates that prevent manatees from getting trapped in discharge pipes (Port Canaveral 2019). These measures minimize the potential for adversely affecting manatees. Any effects to manatees during barge operation are expected to be discountable or insignificant. Therefore, the Proposed Action **may affect, but is not likely to adversely affect**, the West Indian manatee.

West Indian manatee critical habitat

The Upper Banana River continues to provide critical habitat for manatees regardless of the loss of seagrasses in the area. Recent algal blooms have impacted seagrass populations in this area, as well as in many areas of the Indian River Lagoon. However, this area still offers waters with limited boating of any kind. The highly controlled barge and boat activity (with slow speeds and manatee observers for certain operations) within this critical habitat has been well managed for decades. Construction and launch-related operations would have **no effect** on West Indian manatee critical habitat because required construction Best Management Practices would prevent impacts to surface waters and barge operations would not affect the manatee's habitat, including seagrass populations.

Birds

Audubon's crested caracara

The Audubon's crested caracara prefers to nest in cabbage palms (*Sabal palmetto*) surrounded by open habitats with low ground cover and low density of tall or shrubby vegetation (USFWS 1999). LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the caracara. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the Audubon's crested caracara.

Eastern black rail

Although eastern black rails currently are not provided legal protection under the ESA, we have included an assessment here in case the species becomes listed in the future. Eastern black rails are found in a variety of salt, brackish, and freshwater marsh habitats that can be tidally or non-tidally influenced. Within these habitats, the birds occupy relatively high elevations along heavily vegetated wetland gradients, with soils that are moist or flooded to a shallow depth (83 FR 50613). LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the eastern black rail. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the eastern black rail.

Everglade snail kite

The range of the Florida population of snail kites is restricted to watersheds in the central and southern part of the state. The Everglade snail kite forages on apple snails on emergent aquatic vegetation in wetlands and along pond and lake margins. LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the snail kite. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the Everglade snail kite.

Florida scrub-jay

The Florida scrub-jay lives only in the scrub and scrubby flatwoods habitats of Florida. This type of habitat grows only on nearly pure, excessively well-drained sandy soils, and occurs along Florida coastlines and other inland areas (USFWS 2019d). KSC supports one of the largest remaining populations of Florida scrub-jays. Scrub-jay habitat is intensively managed on KSC and CCAFS property, primarily by controlled burning and mechanical treatment.

Construction at LC-39A would not affect Florida scrub-jay habitat. LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the scrub-jay. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, MST construction would have **no effect** on the Florida scrub-jay.

Launch-related operations have the potential to result in indirect effects to the Florida scrub-jay by interfering with prescribed burns at KSC and CCAFS. LC-39A and LC-40 are close to Fire Management Units at KSC and CCAFS (see Figure 7). Some payloads that would be launched on a Falcon rocket are sensitive to smoke. Therefore, close coordination between SpaceX and NASA and/or CCAFS is required to prevent conflicts with the prescribed burn schedule. NASA and CCAFS, working with MINWR, would continue to include SpaceX in their prescribed fire planning and coordination activities to ensure that controlled burning of adjacent land and related issues are well-communicated with the goal of limited, if any, impact to operations at KSC and CCAFS. As stated above, the burn planning and operations of these areas adhere to a Prescribed Burn MOU, which includes conditions and constraints for conducting prescribed burns, both on KSC and CCAFS. When KSC or CCAFS receives USFWS notification of a planned prescribed burn adjacent to LC-39A or LC-40, KSC or CCAFS shall notify SpaceX within three days to allow coordination of prescribed burns. KSC management and CCAFS would assist the USFWS in resolving any operational or other barriers in order to accomplish prescribed burns. The proposed action would not change the fire management program activities in the area surrounding LC-39A and LC-40. Therefore, any effects to the Florida scrub-jay's habitat management program at KSC and CCAFS are expected to be discountable. Accordingly, launch-related operations **may affect, but would not likely adversely affect**, the Florida scrub-Jay.

Figure 7. Fire Management Units at KSC and CCAFS

Piping plover

The piping plover is a wintering migrant in Florida that uses sandy beaches, particularly those near ends of barrier islands, on peninsulas, and near inlets. LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the piping plover. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the piping plover.

Red knot

Red knots are known to overwinter at Merritt Island/Cape Canaveral and to stopover in Atlantic coastal areas during migration. They use tidal flats in the Indian River Lagoon and intertidal zones of beaches. LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the red knot. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the red knot.

Red-cockaded woodpecker

The red-cockaded woodpecker typically uses mature pine forest with a low growing understory for nesting habitat. In these habitats, the woodpecker excavates nest cavities within the trunks of large pine trees. The understory of the habitat is reduced due to frequent naturally occurring fire events. Longleaf pine is the preferred canopy species, although red-cockaded woodpeckers will use pine forest where other species such as slash pine are more prevalent (USFWS 2008). LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the red-cockaded woodpecker. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the red-cockaded woodpecker.

Wood stork

Wood storks are birds of freshwater and estuarine wetlands, primarily nesting in cypress or mangrove swamps. They feed in freshwater marshes, narrow tidal creeks, or flooded tidal pools. Particularly attractive feeding sites are depressions in marshes or swamps where fish become concentrated during periods of falling water levels (USFWS 2013a). LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the wood stork. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. The construction area is not located within 15 miles of a wood stork core foraging area (USFWS 2019c). Therefore, construction and launch-related operations would have **no effect** on the wood stork.

<u>Reptiles</u>

Atlantic salt marsh snake

The Atlantic salt marsh snake inhabits brackish tidal marshes (USFWS 1999). LC-39A, LC-40, and LZ-1/LZ-2 do not provide suitable habitat for the snake. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at these three launch complexes. Therefore, construction and launch-related operations would have **no effect** on the Atlantic salt marsh snake.

Eastern indigo snake

The eastern indigo snake is thought to be common on KSC, although actual population numbers have been difficult to obtain. Eastern indigo snakes have very large home ranges and use a variety of habitat types that include uplands, wetlands, hammocks, and disturbed areas (FWC 2019). It's possible that MST construction could affect the snake. Indigo snakes are closely associated (commensal) with gopher tortoises; they occupy gopher tortoise burrows. All gopher tortoise burrows inside or within 25 feet of the construction footprint, whether appearing to be active or inactive, would be excavated prior to commencing construction activities in the vicinity of the burrows. Per the USFWS' programmatic effect determination key for the eastern indigo snake and update addendum (USFWS 2013b), in the event an indigo snake is encountered, the construction contractor would be required to allow the snake to vacate the area prior to commencing work in the area. Holes, cavities, and other snake shelter, other than gopher tortoise burrows, would be inspected each morning before planned site manipulation of an area. If any such features are occupied by an indigo snake, no work would commence until the snake has vacated the work area. In addition, the construction contractor would be required to perform all work in accordance the USFWS's "Standard Protection Measures for the Eastern Indigo Snake" (USFWS 2013c). Given the potential presence of indigo snakes in the project area, and given protection measures that SpaceX and the construction contractor would be required to implement, construction and launch-related operations **may affect, but are not likely to adversely affect**, the eastern indigo snake.

Gopher tortoise

Although gopher tortoises currently are not provided legal protection under the ESA, we have included a brief assessment here. Gopher tortoises are present inside the fence at LC-39A and could be affected by MST construction activities. Each tortoise burrow within the construction footprint would be surveyed with a burrow camera to determine if the burrow is occupied. Any tortoises observed within the construction footprint would be relocated in coordination with the Florida Fish and Wildlife Conservation Commission.

Green, hawksbill, Kemp's ridley, leatherback, and loggerhead sea turtles

MST construction at LC-39A is expected to take place during the day and at nighttime. Construction activities (e.g., operation of construction equipment) would not affect sea turtles given the distance (approximately 0.5 mile) to nesting beaches. However, nighttime lighting associated with construction has a potential to affect (disorient) nesting and hatching sea turtles between March and October. The same is true for launch-related nighttime lighting operations at LC-39A, LC-40, and LZ-1/LZ-2. As described below, the existing exterior lighting management programs at KSC and CCAFS assist in avoiding or minimizing potential lighting effects on sea turtles. All launch facilities would continue to operate under KSC and CCAFS exterior lighting requirements.

KSC's exterior lighting requirements (KNPR 8500.1, Rev. E) state that all site lighting must be operated in accordance with the LC-39A Light Operations Manual (NASA 2018). In addition, KSC actions must comply with a USFWS Biological Opinion (BO; Attachment 5). NASA monitors the beach during the nesting season to assess if launch operations are affecting sea turtles. The data are communicated to environmental managers at KSC to ensure compliance with the USFWS's incidental take authorization. The BO's terms and conditions include measures to avoid or minimize effects to sea turtles. The proposed action would not change existing operational lighting. The Light Operations Manual for LC-39A is pending approval by NASA and USFWS. A construction Light Operations Manual would be developed and approved by USFWS prior to any installation of construction lighting to support the MST.

Launch operations at LC-40 and landing operations at LZ-1/LZ-2 would comply with the 45th Space Wing Instruction for Exterior Lighting Management (45SWI 32-7001; April 23, 2018). All CCAFS tenants must comply with the instruction and provide a Light Management Plan for all facilities. Prior to SpaceX conducting Falcon booster landings at LZ-1/LZ-2 for the first time, the USAF conducted ESA consultation with the USFWS. As a result of this consultation, the USFWS issued an updated BO (Attachment 6) to include landing operations at LZ-1. The terms and conditions identified in the BO are similar to those included in KSC's BO to help avoid or minimize potential effects to sea turtles. The proposed action would not change existing lighting. The Light Management Plan for LC-40 is pending approval by CCAFS and USFWS.

As documented in the BOs for KSC and CCAFS, launch-related lighting may adversely affect sea turtles and hatchlings on the beach. The proposed action falls within the scope of actions included in the BOs. All SpaceX launch operations must comply with the terms and conditions stated in the BOs and associated lighting plans. No incidental take beyond that authorized in the BOs is expected.

Loggerhead sea turtle critical habitat

The USFWS identified the following primary constituent elements (PCEs) in the final rule for designating loggerhead sea turtle critical habitat:

1. Suitable nesting beach habitat that has (a) relatively unimpeded near shore access from the ocean to the beach for nesting females and from the beach to the ocean for both post-nesting females and hatchlings; and, (b) is located above mean high water to avoid being inundated frequently by high tides.
2. Sand that (a) allows for suitable nest construction, (b) is suitable for facilitating gas diffusion conducive to embryo development, and (c) is able to develop and maintain temperatures and moisture content conducive to embryo development.
3. Suitable nesting beach habitat with sufficient darkness to ensure nesting turtles are not deterred from emerging onto the beach, post-nesting females re-orient back to the sea and emerging hatchlings orient correctly towards the sea.

4. Natural coastal processes or artificially created or maintained habitat mimicking natural conditions. This includes artificial habitat types that mimic the natural conditions described in the PCEs above for beach access, nest site selection, nest construction, egg deposition and incubation, and hatchling emergence and movement to the sea.

Given the distance between the construction site at LC-39A and the loggerhead's critical habitat (beaches), construction and launch-related operations would not affect PCEs #1, 2, and 4 above. As noted above, nighttime construction and launch-related operations (lighting) have the potential to add to the overall sky glow at the beach. SpaceX (and NASA and CCAFS) would be required to implement measures to minimize potential effects of nighttime lighting on the beach, per the USFWS BOs mentioned above. Because nighttime construction and launch-related operations could occur at night during the nesting season, but given the lighting measures in place, nighttime construction and launch-related operations during the nesting season **may affect, but are not likely to adversely affect**, loggerhead sea turtle critical habitat (PCE #3).

<u>Plants</u>

Carter's mustard

Carter's mustard is primarily known from the Lake Wales Ridge of inland central Florida, but has been documented from coastal scrub habitat in Brevard County (USFWS 1999). The only documentation of an occurrence in Brevard County is in an area of coastal scrub, several miles away from LC-39A (University of Florida). The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at LC-39A. Therefore, construction and launch-related operations would have **no effect** on Carter's mustard.

Lewton's polygala

Lewton's polygala occurs in oak scrub, sandhill, and transition zones between high pine and turkey oak barrens (FNAI 200). It is endemic to central Florida ridges. No suitable habitat for this species occurs at LC-39A. The FNAI Biodiversity Matrix online server does not include documented occurrences of this species at LC-39A. Therefore, construction and launch-related operations would have **no effect** on Lewton's polygala.

<u>Effects from Launches</u>

Launches have the potential to affect ESA-listed species in the action area, mainly from noise, including engine noise and sonic booms. Animal species differ greatly in their responses to noise. Noise effects on domestic animals and wildlife are classified as primary, secondary, and tertiary. Primary effects are direct, physiological changes to the auditory system, and most likely include the masking of auditory signals. Masking is defined as the inability of an individual to hear important environmental signals that may arise from mates, predators, or prey. There is some potential that noise could disrupt a species' ability to communicate or could interfere with behavioral patterns (Manci et al. 1988). Although the effects are likely temporal, launch noise may cause masking of auditory signals within exposed faunal communities. Animals rely on hearing to avoid predators, obtain food, and communicate with, and attract, other members of their species. Launch noise may mask or interfere with these functions.

Secondary effects may include non-auditory effects such as stress and hypertension; behavioral modifications; interference with mating or reproduction; and impaired ability to obtain adequate food, cover, or water. Tertiary effects are the direct result of primary and secondary effects, and include population decline and habitat loss. Most of the effects of noise are mild enough that they may never be detectable as variables of change in population size or population growth against the background of normal variation (Bowles 1995). Other environmental variables (e.g., predators, weather, changing prey base, ground-based disturbance) also influence secondary and tertiary effects, and confound the ability to identify the ultimate factor in limiting productivity of a certain nest, area, or region. Overall, the literature suggests that species differ in their response to various types, durations, and sources of noise (Manci et al. 1988; Bowles 1995).

Many scientific studies have investigated the effects of aircraft noise and sonic booms on wildlife, and some have focused on wildlife "flight" due to noise. Natural factors which affect reaction include season, group size, age and sex composition, on-going activity, motivational state, reproductive condition, terrain, weather, and temperament (Bowles 1995). Individual animal response to a given noise event or series of events also can vary widely due to a variety of factors, including time of day, physical condition of the animal, physical environment, the experience of the individual animal with noises, and whether or not other physical stressors (e.g., drought) are present (Manci et al. 1988). Consequently, it is difficult to generalize animal responses to noise disturbances across species.

One result of the Manci et al. (1988) literature review was the conclusion that, while behavioral observation studies were relatively limited, a general behavioral reaction in animals from exposure to aircraft noise is the "startle response." The intensity and duration of the startle response appears to be dependent on which species is exposed, whether there is a group or an individual, and whether there have been some previous exposures. Responses range from flight, trampling, stampeding, jumping, or running, to movement of the head in the apparent direction of the noise source. Manci et al. (1988) reported that the literature indicated that avian species may be more sensitive to aircraft noise than mammals.

The following discussion presents a summary of some of the more relevant studies addressing the potential impacts to wildlife from sonic booms.

Teer and Truett (1973) tested quail eggs subjected to sonic booms at 2, 4, and 5.5 pounds per square foot (psf) and found no adverse effects. Heinemann and LeBrocq (1965) exposed chicken eggs to sonic booms at 3–18 psf and found no adverse effects. In a mathematical analysis of the response of avian eggs to sonic boom overpressures, Ting et al. (2002) determined that it would take a sonic boom of 250 psf to crack an egg. Bowles (1995) states that it is physically impossible for a sonic boom to crack an egg because one cannot generate sufficient sound pressure in air to crack eggs.

Teer and Truett (1973) examined reproductive success in mourning doves, mockingbirds, northern cardinals, and lark sparrows when exposed to sonic booms of 1 psf or greater and found no adverse effects. Awbrey and Bowles (1990) in a review of the literature on the effects of aircraft noise and sonic booms on raptors found that the available evidence shows very marginal effects on reproductive success. Ellis et al. (1991) examined the effects of sonic booms (actual and simulated) on nesting peregrine falcons, prairie falcons, and six other raptor species. While some individuals did respond by leaving the nest, the response was temporary and overall there were no adverse effects on nesting. Lynch and Speake (1978) studied the effects of both real and simulated sonic booms on the nesting and brooding of eastern wild turkey in Alabama. Hens at four nest sites were subjected to between 8 and 11 combined real and simulated sonic booms. All tests elicited similar responses, including quick lifting of the head and apparent alertness for between 10 and 20 seconds. No apparent nest failure occurred as a result of the sonic booms.

The literature suggests that common animal responses to noise include the startle response and, ultimately, habituation. It has been reported that the intensities and durations of the startle response decrease with the numbers and frequencies of exposures, suggesting no long-term adverse effects. The majority of the literature suggests that domestic animal species (cows, horses, chickens) and wildlife species exhibit adaptation, acclimation, and habituation after repeated exposure to jet aircraft noise and sonic booms.

No behavior anomalies were observed in Florida scrub-jays or southeastern beach mice after Delta, Atlas, and Titan launches at CCAFS, implying no noise-related effects (Schmalzer 1998). Similarly, studies of the southeastern beach mouse during the space shuttle program reported no observable, measurable impacts to the mouse. The FAA is not aware of any take of an ESA-listed species occurring at KSC or CCAFS from noise during a rocket launch.

During a Falcon 9 polar mission, sonic booms would be generated during the rocket's ascent and first stage landing at CCAFS. Based on SpaceX's estimate, up to six launches per year could fly a southern trajectory. Thus, sonic booms could impact Florida up to 12 times per year as part of polar missions – once during ascent and once during landing (see Figures 6 and 7 for the sonic boom footprints). Sonic booms are low-frequency impulsive noise events with durations lasting a fraction of a second. The majority of land within the sonic boom footprints is predicted to experience overpressures of less than 1 psf. An overpressure of 1 psf is similar to a clap of thunder. A narrow region north of Vero Beach with land area less than 3 square miles is predicted to receive overpressures greater than 2 psf during ascent. An area less than 0.01 square miles could experience a maximum overpressure of 4.6 psf during ascent.

Sonic booms would also occur during first stage boost-back and landing at CCAFS for non-polar Falcon 9 and Falcon Heavy missions. Per Attachment 3, most of the area exposed to this sonic boom would experiences overpressures of 1 psf or less. A small area located at and near the landing pads could experience an overpressure up to 5 or 6 psf. Previous ESA consultation between the USAF and USFWS concluded that sonic booms generated during Falcon 9 and Falcon Heavy first stage booster landings would not adversely affect ESA-listed species (Attachment 6).

Based on the lack of observed adverse effects to wildlife in the studies mentioned above and the lack of known adverse effects to ESA-listed over decades of launch operations at KSC and CCAFS, the FAA expects launch noise associated with the proposed action **may affect, but would not likely to adversely affect**, ESA-listed wildlife species in the action area (Table 4).

Conclusion

In summary, the FAA anticipates MST construction (nighttime lighting) and launch-related operations **may affect, but would not likely to adversely affect**, the West Indian manatee, Florida scrub jay, eastern indigo snake, and loggerhead sea turtle critical habitat. The FAA anticipates launches (engine noise and sonic booms) **may affect, but would not likely to adversely affect**, all of the ESA-listed wildlife species in Table 4. NASA, USAF, and SpaceX will continue to implement the terms and conditions stated in the existing BOs for launch operations at their facilities. The FAA will further impose the applicable terms and conditions on SpaceX via any launch license issued to SpaceX.

We seek your concurrence on our effect determinations and welcome any additional comments. Thank you for your assistance in this matter. Please provide your response to Daniel Czelusniak via e-mail at Daniel.Czelusniak@faa.gov.

Sincerely,

Daniel Murray
Manager, Space Transportation Development Division

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Attachment 1. Engine Noise Assessment for the Falcon Launch Vehicles at KSC and CCAFS

ROCKET NOISE STUDY FOR SPACEX FLIGHT AND STATIC TEST OPERATIONS AT CAPE CANAVERAL AIR FORCE STATION AND KENNEDY SPACE CENTER

TN 18 03

October 2018

Prepared for:

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We Deliver

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1 Introduction

Noise levels have been estimated for SpaceX Falcon 9 Block 5 and Falcon Heavy Block 5 launches, booster landings, and static fire tests at Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC). The Falcon 9 Block 5 succeeds the Falcon 9 Block 4 with changes that include 7-8% more thrust by uprating the engines, improvements on landing legs, and modifications to increase the efficiency of recovery and reusability of first-stage boosters. The Falcon 9 Block 5 has uprated Merlin 1D (M1D) engines that each provide sea-level thrust of 190 Klbf. Falcon 9 Block 5 launches and static fire tests occur at Kennedy Space Center Launch Complex 39 (LC-39A) and Cape Canaveral Air Force Station Space Launch Complex 40 (LC-40). Falcon Heavy Block 5 launches and static fire tests occur at LC-39A. Dragon static fire tests occur at LZ-1. Booster landings occur at LZ-1 and LZ-2. This assessment was conducted to estimate the single event and cumulative noise levels in the vicinity of CCAFS and KSC due to all of these rocket operations.

SpaceX provided the following data for noise modeling:

- Vehicle launch trajectories for the Falcon 9 and Falcon Heavy from liftoff to main engine cutoff (MECO).
- Falcon 9 Block 5 engine operating data and nominal ascent thrust profile per engine (Figure 1).
- Side booster landing trajectories from separation to landing with descent thrust profiles.
- Static fire test parameters for the Falcon 9, Falcon Heavy, and Dragon.
- Projected launch and static fire test operations at CCAFS and KSC from 2018 through 2024.

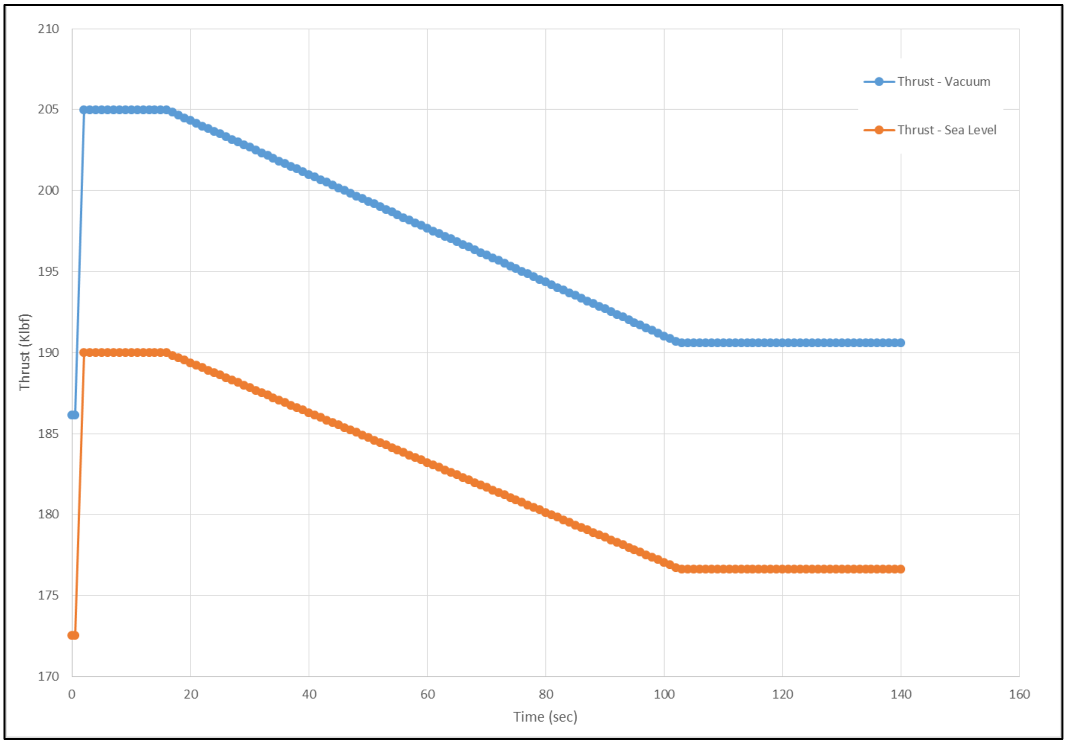


Figure 1. Falcon 9 Block 5 Nominal Ascent Thrust Profile (Per Engine)

To estimate the noise levels around LC-39A, LC-40, and LZ-1 and LZ-2, rocket noise from the Falcon 9 Block 5 and Falcon Heavy Block 5 was computed by Wyle's RNOISE model. RNOISE[1,2] is a far-field (distances beyond several hundred feet) community noise model for launch noise assessment. A description of rocket noise fundamentals and noise metrics are provided in Section 2. Estimates of Falcon 9 and Falcon Heavy launch noise levels around LC-39A and LC-40 are provided in Section 3. Estimates of booster landing noise levels around LZ-1 and LZ-2 are provided in Section 4. Static fire test noise levels for Falcon 9, Falcon Heavy, and Dragon are presented in Section 5. Cumulative noise levels for existing launches and projected future year 2024 launches, static firings, and booster landings are presented in Section 6.

2 Rocket Noise

2.1 Background

Rockets generate significant noise from the combustion process and turbulent mixing of the exhaust flow with the surrounding air. Figure 2 is a sketch of rocket noise. There is a supersonic potential core of exhaust flow, surrounded by mixing region. Noise is generated in this flow. It is directional, with the highest noise levels at an angle of 40 to 50 degrees from the direction of the exhaust flow. The fundamentals of predicting rocket noise were established by Wilhold et al.[3] for moving rockets and by Eldred et al.[4] for static firing. Sutherland[5] has refined modeling of rocket source noise, improving its consistency relative to jet noise theory. Based on those fundamentals, Wyle has developed the PAD model for near field rocket noise[6] and the RNOISE model for far field noise in the community. RNOISE was used for the current analysis.

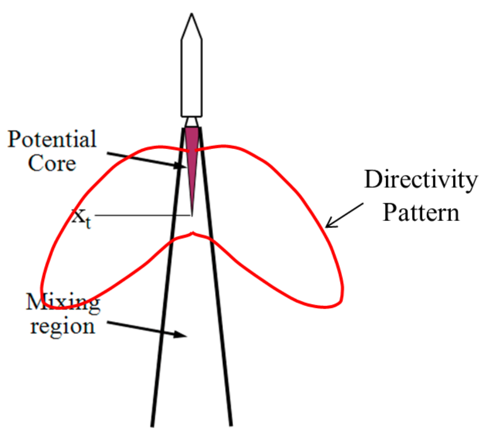


Figure 2. Rocket Noise Source

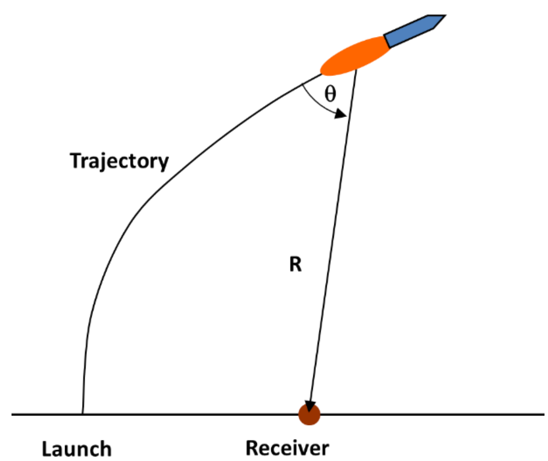


Figure 3. Modeling Rocket Noise at the Ground

Figure 3 is a sketch of far field rocket noise as treated by RNOISE. The vehicle position and attitude is known from the trajectory. Rocket noise source characteristics are known from the engine properties, with thrust and exhaust velocity being the most important parameters. The emission angle and distance to the receiver are known from the flight path and receiver position. Noise at the ground is computed accounting for distance, ground impedance,[7] and atmospheric absorption of sound.[8] RNOISE propagates the full spectrum to the ground, accounting for Doppler shift from vehicle motion. It is a time simulation model, computing the noise at individual points or on a regular grid for every time point in the trajectory. Propagation time from the vehicle to the receiver is accounted for, yielding a spectral time history at the ground. A variety of noise metrics can be computed from the full calculated noise field and the metrics commonly used to assess rocket noise are described in the following section.

2.2 Noise Metrics

FAA Order 1050.1E specifies Day-Night Average Sound Level (DNL) as the standard metric for community noise impact analysis, but also specifies that other supplemental metrics may be used as appropriate for the circumstances. DNL is appropriate for continuous noise sources, such as airport noise and road traffic noise. It is not appropriate for irregularly occurring noise events such as rocket launches or static tests.

The noise metrics used for rocket noise analysis are:

- DNL, as defined by FAA Order 1050.1E;
- SEL, the Sound Exposure Level, for individual events;
- L_{Amax}, the maximum A-weighted level, for individual events;
- OASPL, the maximum overall sound pressure level, for individual events; and
- One third octave spectra at particular sensitive receptors.

As mentioned, DNL is necessary for policy. The next two metrics (L_{Amax} and SEL) are A-weighted and provide a measure of the impact of individual events. Loud individual events can pose a hearing damage hazard to people, and can also cause adverse reactions by animals. Adverse animal reactions can include flight, nest abandonment, and interference with reproductive activities. The last two metrics, OASPL and spectra, may be needed to assess potential damage to structures and adverse reaction of species whose hearing response is not similar to that of humans. The estimated noise results presented in section 3 will be L_{Amax} and SEL contours for single event noise assessment over the study area.

L_{Amax} is appropriate for community noise assessment of a single event, such as a rocket launch or static fire test. This metric represents the highest A-weighted integrated sound level for the event in which the sound level changes value with time. The L_{Amax} metric indicates the maximum sound level occurring for a fraction of a second. Slowly varying or steady sounds are generally integrated over a period of one second. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleep, or other common activities. Although it provides some measure of the intrusiveness of the event, it does not completely describe the total event, because it does not include the period of time that the sound is heard.

SEL is a composite metric that represents both the intensity of a sound and its duration. Individual time-varying noise events (e.g., aircraft overflights) have two main characteristics: a sound level that changes throughout the event and a period of time during which the event is heard. SEL provides a measure of the net impact of the entire acoustic event, but it does not directly represent the sound level heard at any given time. For example, during an aircraft flyover, SEL would include both the maximum noise level and the lower noise levels produced during onset and recess periods of the overflight. SEL is a logarithmic measure of the total acoustic energy transmitted to the listener during the event. Mathematically, it represents the sound level of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For a rocket launch, the SEL is expected to be greater than the L_{Amax} because the launch noise event is up to several minutes in duration whereas the maximum sound level (L_{Amax}) occurs instantaneously.

Sections 3 through 5 present the single event noise levels, including L_{Amax} and SEL contours, for rocket launches, booster reentry/landings, and static fire tests, respectively. In Section 6, cumulative noise levels are presented for these operations, individually and combined, in terms of DNL.

3 Rocket Launch Noise Levels

3.1 Falcon 9 Launches at LC-39A and LC-40

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon 9 Block 5 Launches at LC-39A and LC-40 using trajectory data, from liftoff to MECO, provided by SpaceX in file 'Falcon_9_Full_Thrust_Block5_Representative_Cape_Trajectory.asc'. The L_{Amax} contours indicate the maximum sound level at each location over the duration of the launch, from liftoff to MECO, where engine thrust varies according to the ascent thrust profile (Figure 1). Both launch events were modeled with a duration of 161 seconds, SEL values are higher than L_{Amax} values.

RNOISE computations were done using a radial grid consisting of 128 azimuths and 100 intervals out to 300,000 feet from the launch point. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. As will be shown in the resulting noise contour maps (Figures 4 through 11), the shape of the innermost contours is approximately circular. The shape of the outermost contours is due to rocket noise directivity and the difference between acoustically hard water and acoustically soft ground. The launch pad locations at LC-39A and LC-40 are indicated in the map legends as are the CCAFS and KSC properties. SLC-40 is located about four miles southeast, along the coast, from LC-39A.

The L_{Amax} 70 dB through 110 dB contours shown in Figures 4 and 5 represent the maximum levels estimated for the Falcon 9 Block 5 launch at LC-39A; Figure 5 shows these contours using a zoomed in map scale to better show the extent of the noise exposure relative to cities located around LC-39A. The higher L_{Amax} contours (90, 100, and 110 dB) are located entirely within both the CCAFS and KSC properties. If a Falcon 9 Block 5 launch occurs during the day, when background levels are in the 50 dB to 60 dB range, residents of Titusville, Merritt Island, and Cape Canaveral may notice launch noise levels above 70 dB. If the same launch occurs during the night, when background levels are lower than during the day (e.g., below 40 dB to 50 dB range), these residents may notice launch noise levels that exceed 60 dB. A prevailing on-shore or off-shore breeze may also strongly influence noise levels in these communities.

SEL contour levels of 80, 90, 100, and 110 dB are shown in Figures 6 for the Falcon 9 Block 5 launch at LC-39A with Figure 7 showing a zoomed in map scale. As mentioned previously, SEL is an integrated metric and is expected to be greater than the L_{Amax} because the launch event is up to several minutes in duration whereas the maximum sound level (L_{Amax}) occurs instantaneously. Figure 7 indicates that the 100 and 110 dB SEL contours are expected to remain almost entirely within the CCAFS and KSC properties.

The L_{Amax}, and SEL contours estimated for Falcon 9 Block 5 Launches at LC-40 are shown in Figures 8 through 11 in the same sequence as the figures presented for LC-39A. In general, the estimated noise exposure from Falcon 9 Block 5 launches at LC-40 is similar to the estimated noise exposure for launches at LC-39A, except the noise contours are shifted southeast, along the coast, by about four miles.

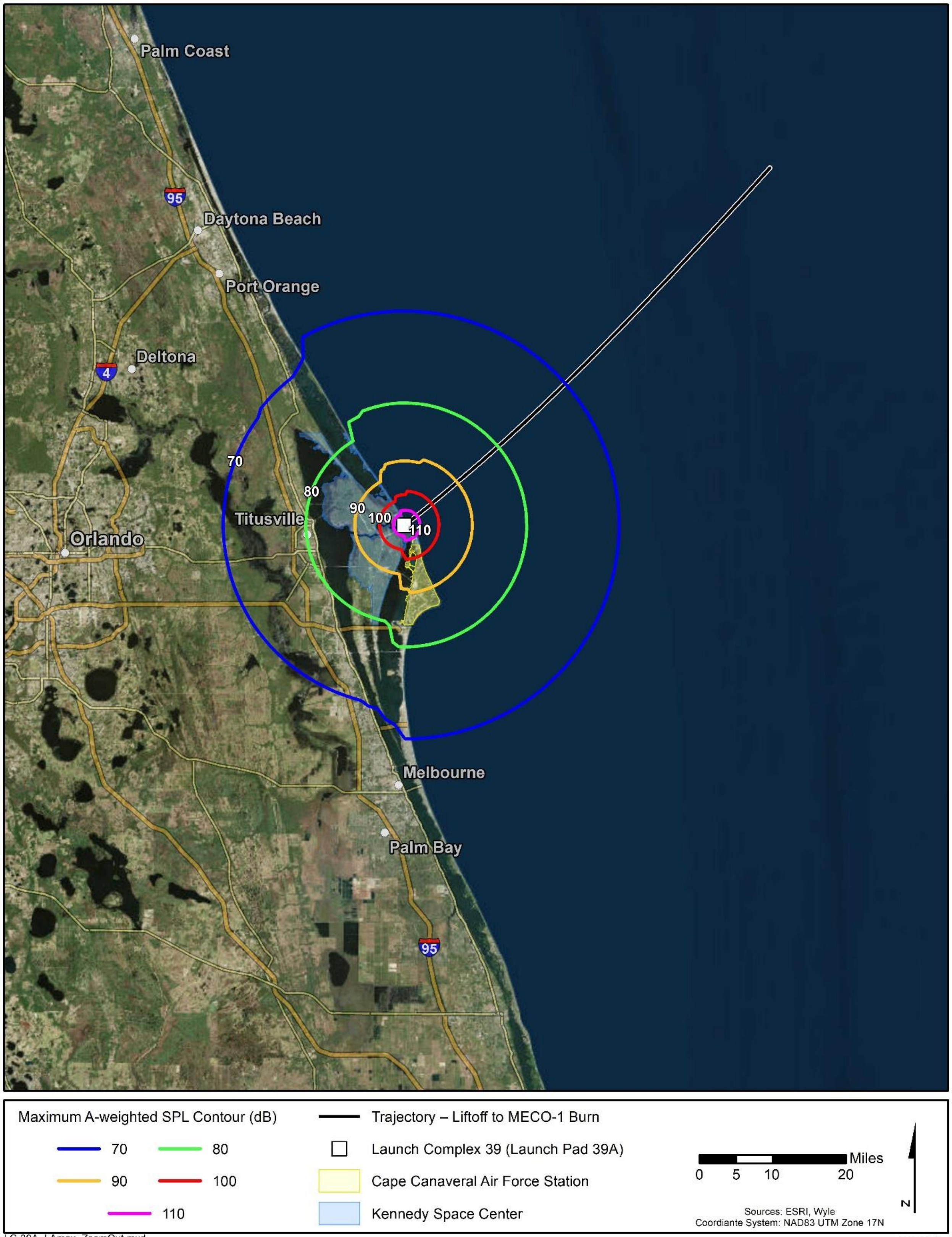


Figure 4. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-39A

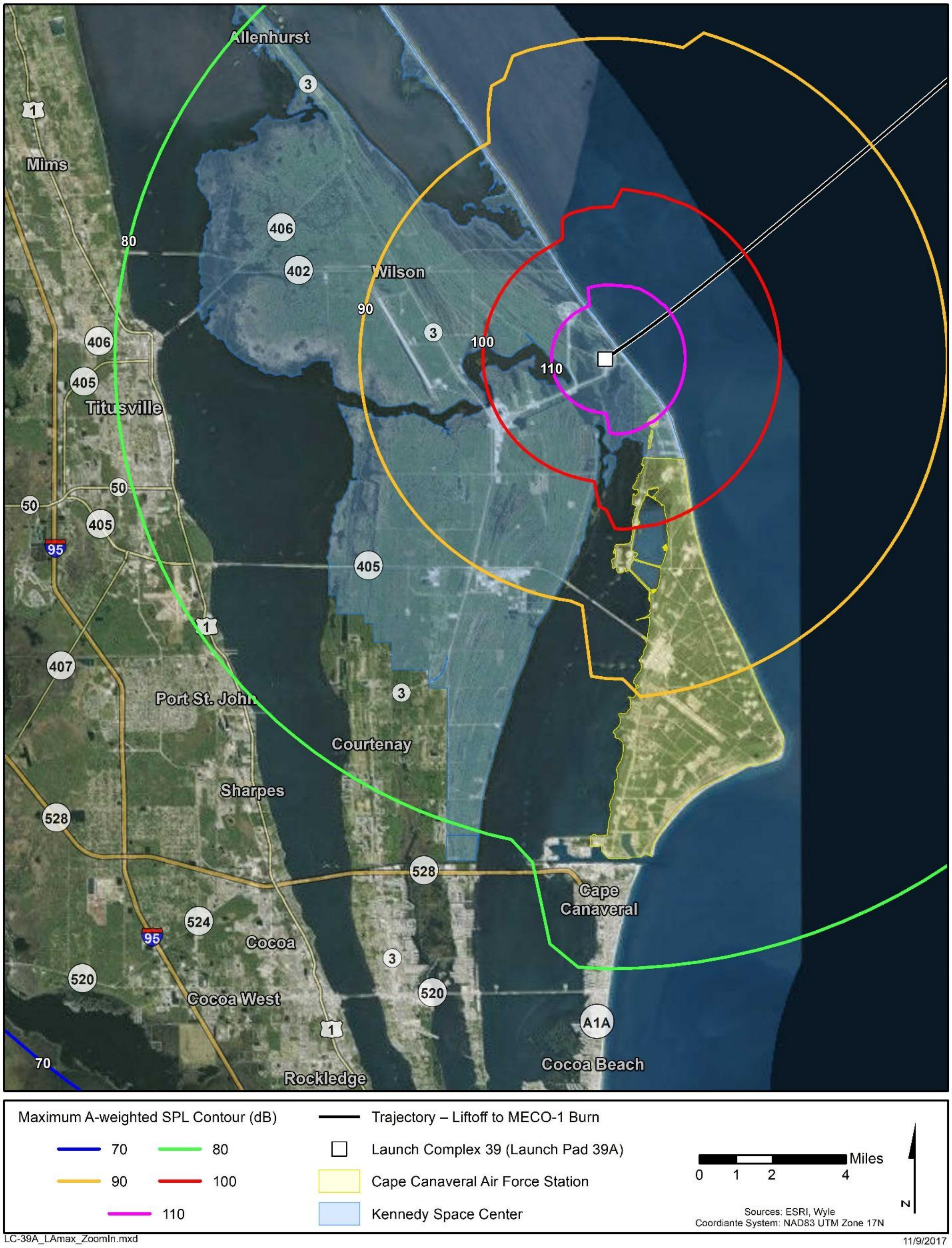


Figure 5. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-39A (Zoomed in)

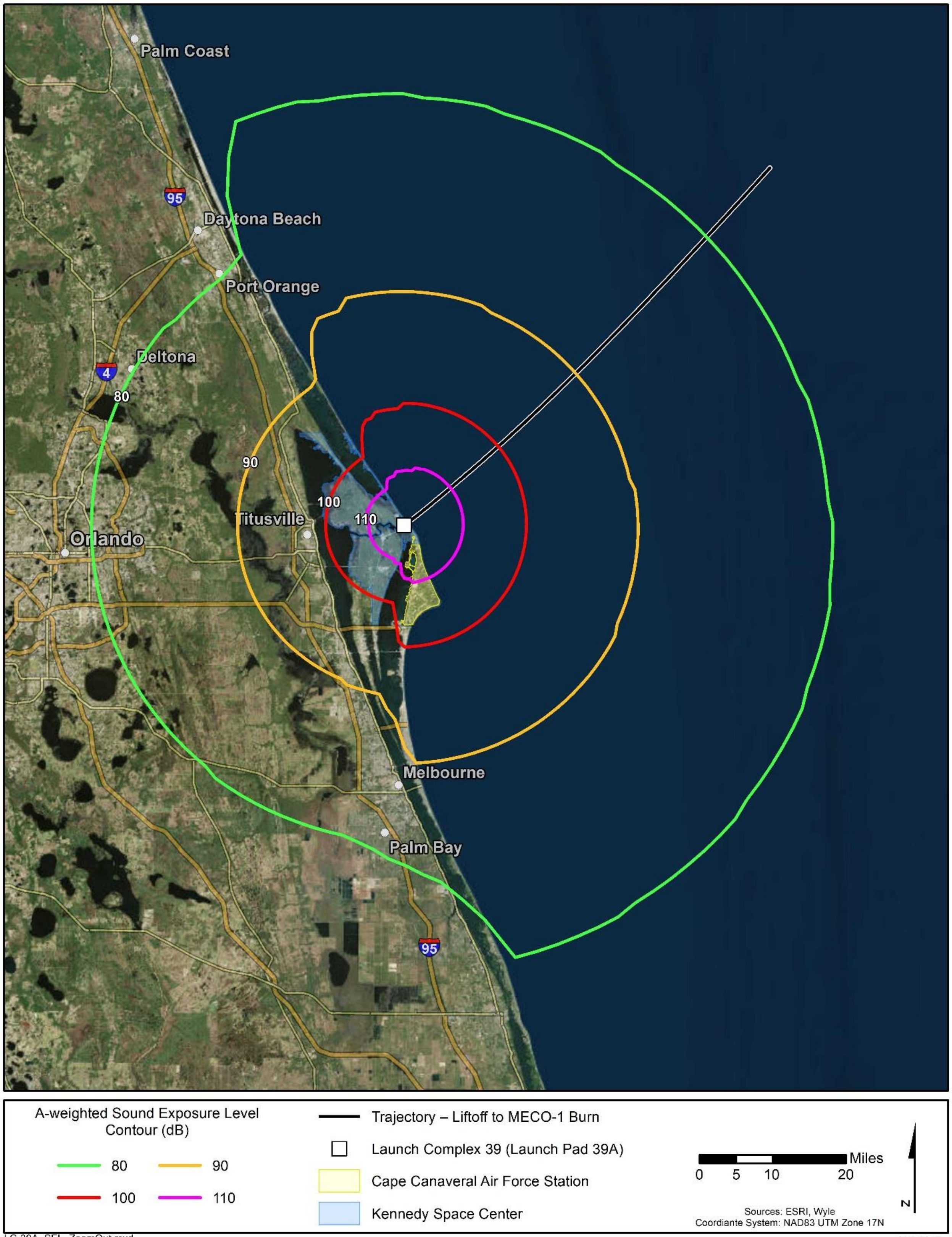


Figure 6. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-39A

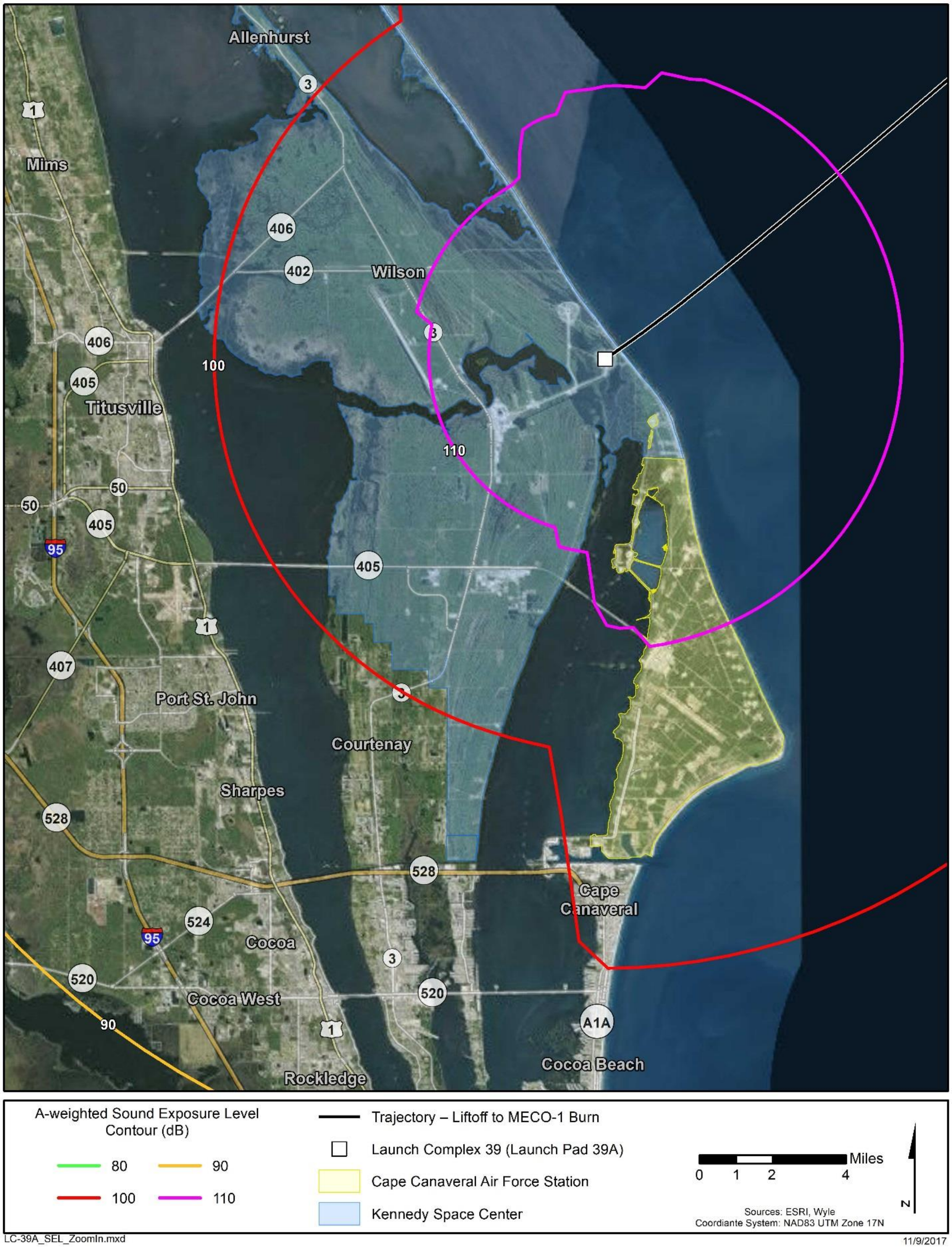


Figure 7. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-39A (Zoomed In)

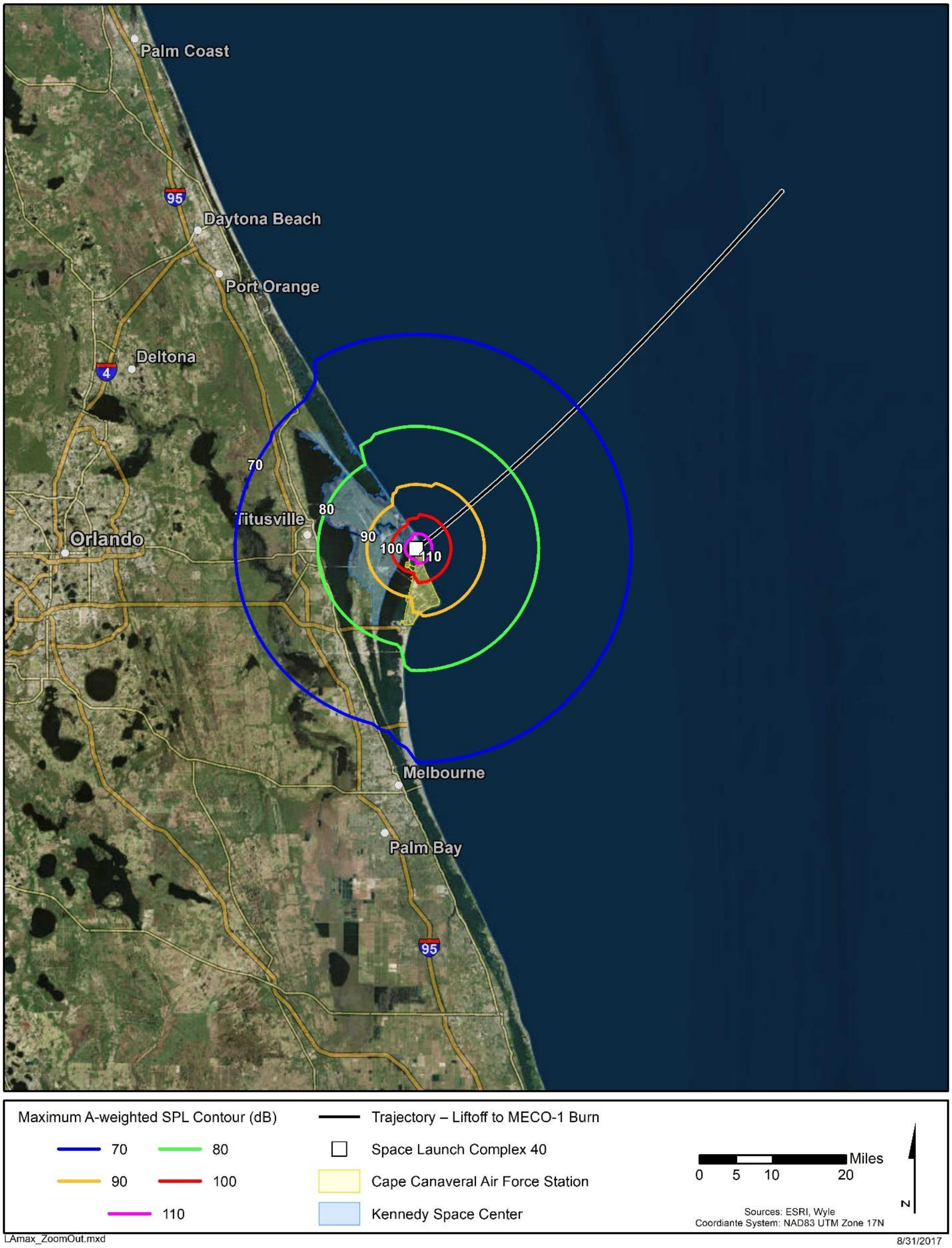


Figure 8. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-40

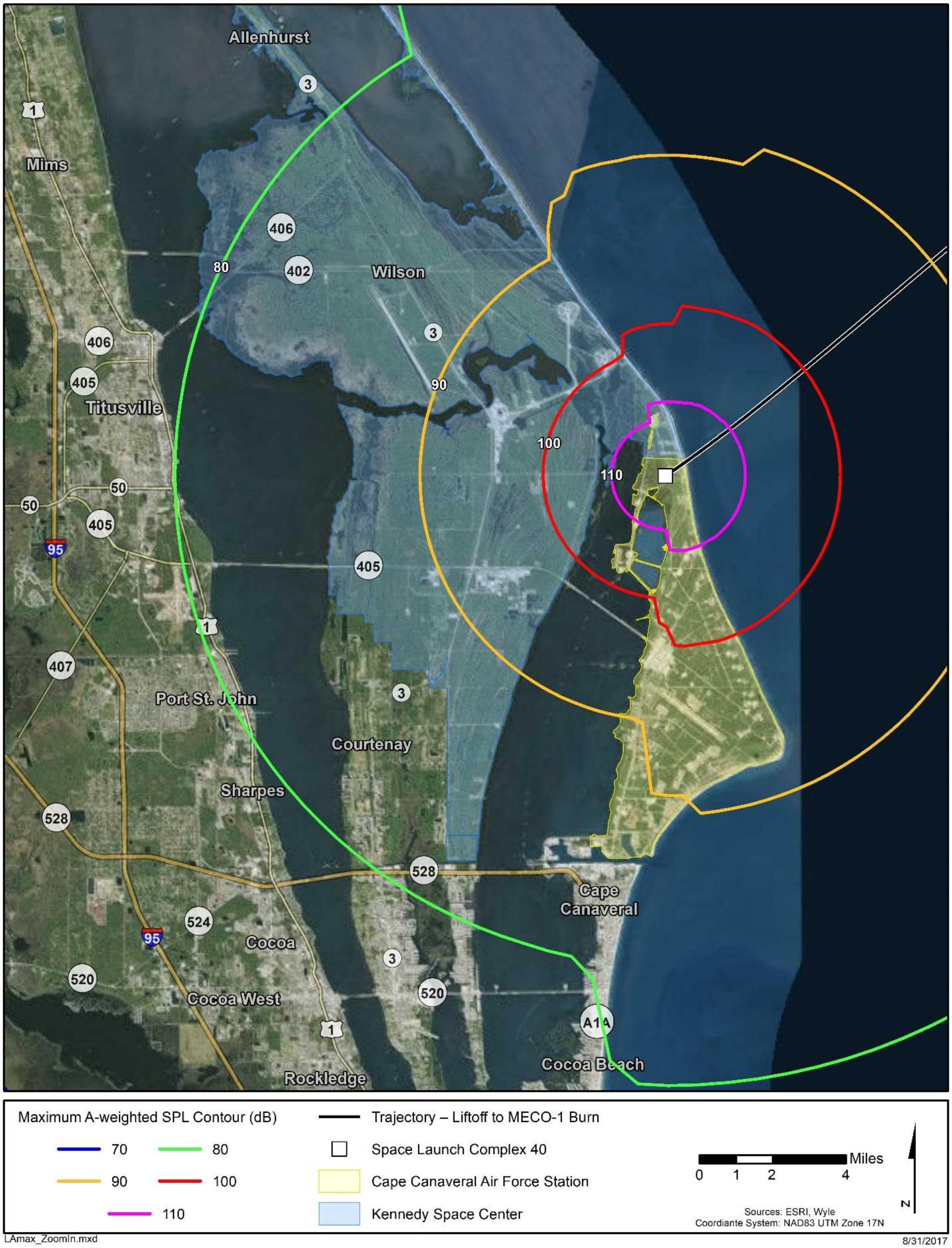


Figure 9. Maximum A-Weighted Sound Levels for Falcon 9 Block 5 Launch from LC-40 (Zoomed in)

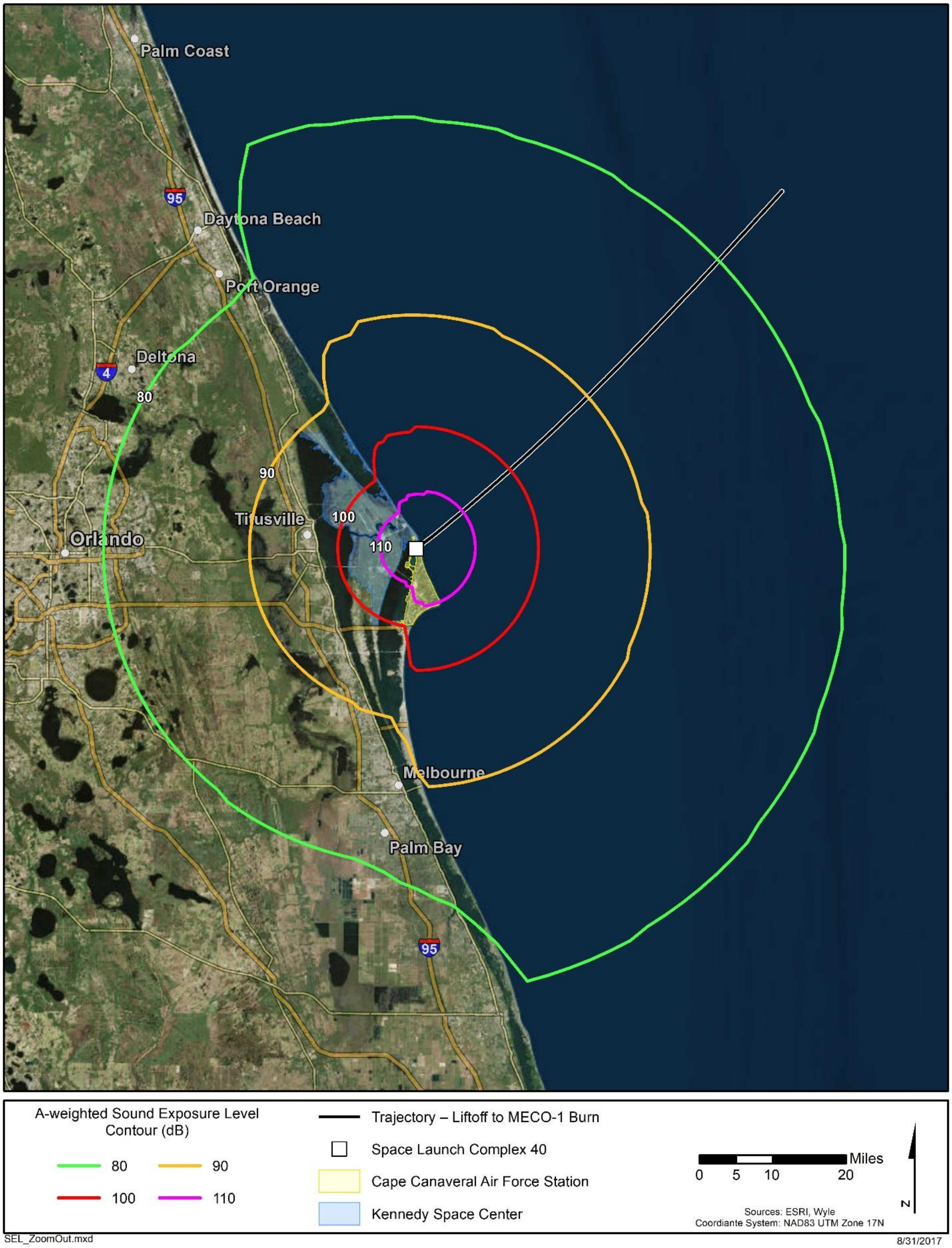


Figure 10. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-40

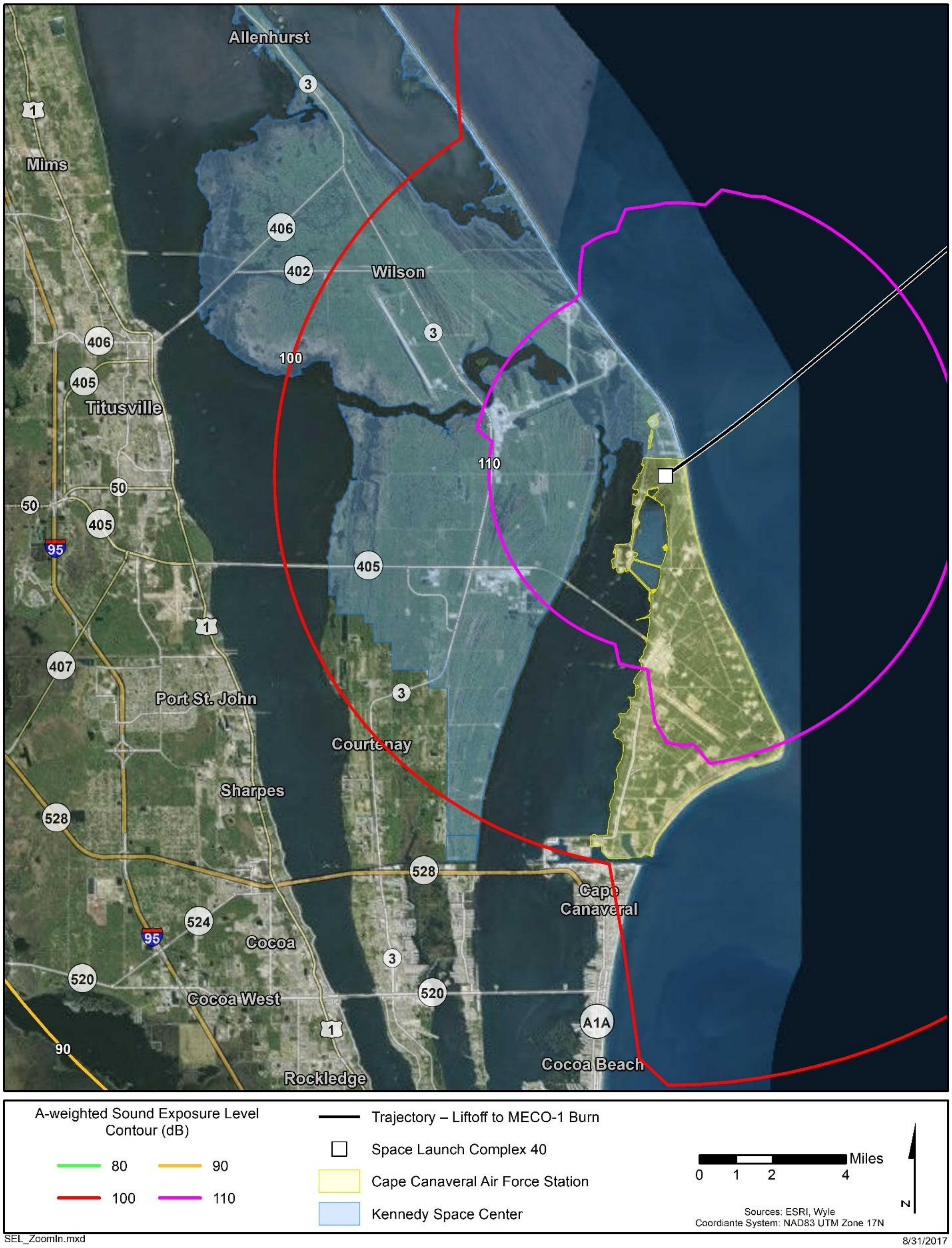


Figure 11. Sound Exposure Levels for Falcon 9 Block 5 Launch from LC-40 (Zoomed In)

3.2 Falcon Heavy Launches at LC-39A

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon Heavy Block 5 Launches at LC-39A using trajectory data, from liftoff to MECO, provided by SpaceX in file 'FH_REPRESENTATIVE_ASCENT_80_12.asc'. The L_{Amax} contours indicate the maximum sound level at each location over the duration of the launch, from liftoff to MECO, where engine thrust varies according to the ascent thrust profile provided with the trajectory data.

RNOISE computations were done using a radial grid consisting of 128 azimuths and 100 intervals out to 300,000 feet from the launch point. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. As will be shown in the resulting noise contour maps (Figures 12 through 15), the shape of the innermost contours is approximately circular. The shape of the outermost contours is due to rocket noise directivity and the difference between acoustically hard water and acoustically soft ground. The launch pad location at LC-39A is indicated in the map legends as are the CCAFS and KSC properties.

The L_{Amax} 70 dB through 110 dB contours shown in Figures 12 and 13 represent the maximum levels estimated for the Falcon Heavy Block 5 launch at LC-39A; Figure 13 shows these contours using a zoomed in map scale to better show the extent of the noise exposure relative to cities located around LC-39A. The higher L_{Amax} contours (90, 100, and 110 dB) are located entirely within both the CCAFS and KSC properties. If a Falcon Heavy Block 5 launch occurs during the day, when background levels are in the 50 dB to 60 dB range, residents of Titusville, Merritt Island, and Cape Canaveral may notice launch noise levels above 70 dB. If the same launch occurs during the night, when background levels are lower than during the day (e.g., below 40 dB to 50 dB range), these residents may notice launch noise levels that exceed 60 dB. A prevailing on-shore or off-shore breeze may also strongly influence noise levels in these communities.

SEL contour levels of 90, 100, and 110 dB are shown in Figures 14 and 15 for the Falcon Heavy Block 5 launch at LC-39A with Figure 15 showing a zoomed in map scale. SEL is an integrated metric and is expected to be greater than the L_{Amax} for rocket launches. Figure 14 indicates that the 110 dB SEL contour is expected to remain within the CCAFS and KSC properties whereas Merritt Island and parts of Titusville are expected to be exposed to SELs higher than 100 dB.

The L_{Amax}, and SEL contours estimated for Falcon Heavy Block 5 Launches at LC-39A are shown in Figures 12 through 15 in the same sequence as Figures 4 through 7 presented for Falcon 9 Block 5 launches at LC-39A. In general, the estimated noise exposure from Falcon Heavy Block 5 launches at LC-39A is 4 to 5 dB higher than the estimated noise exposure for Falcon 9 Block 5 launches at LC-39A. This difference reflects the higher power of the Falcon Heavy Block 5 which has three times the number of Merlin 1D engines as the Falcon 9 Block 5. Two different trajectory data sets provided by SpaceX account for the differences in the Falcon Heavy Block 5 and Falcon 9 Block 5 noise contours which do not have the exact same delta (i.e. change in noise level) at all locations. The noise contours at LC-39A for the Falcon Heavy Block 5 and Falcon 9 Block 5 can be compared to see how the levels change at specific locations.

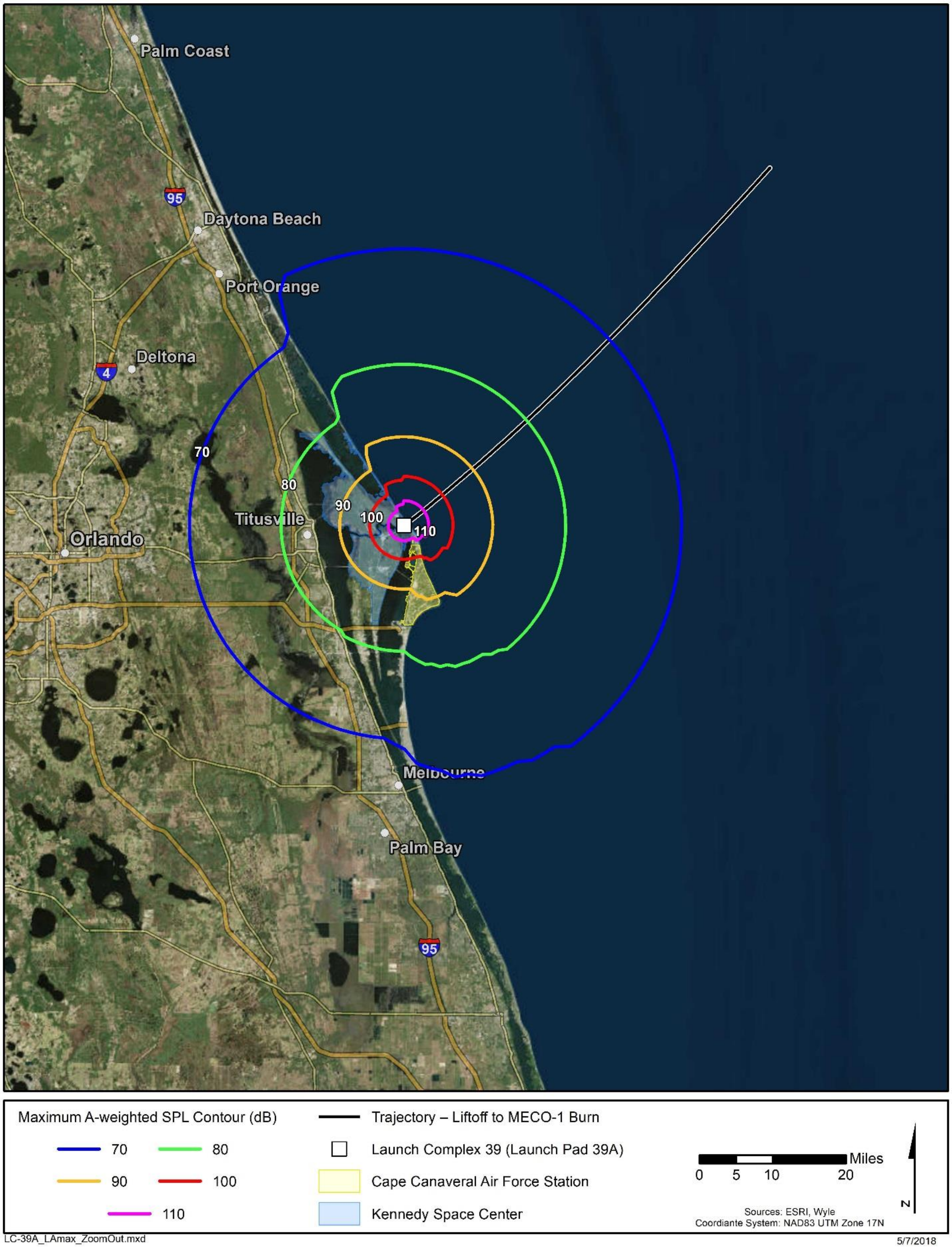


Figure 12. Maximum A-Weighted Sound Levels for Falcon Heavy Block 5 Launch from LC-39A

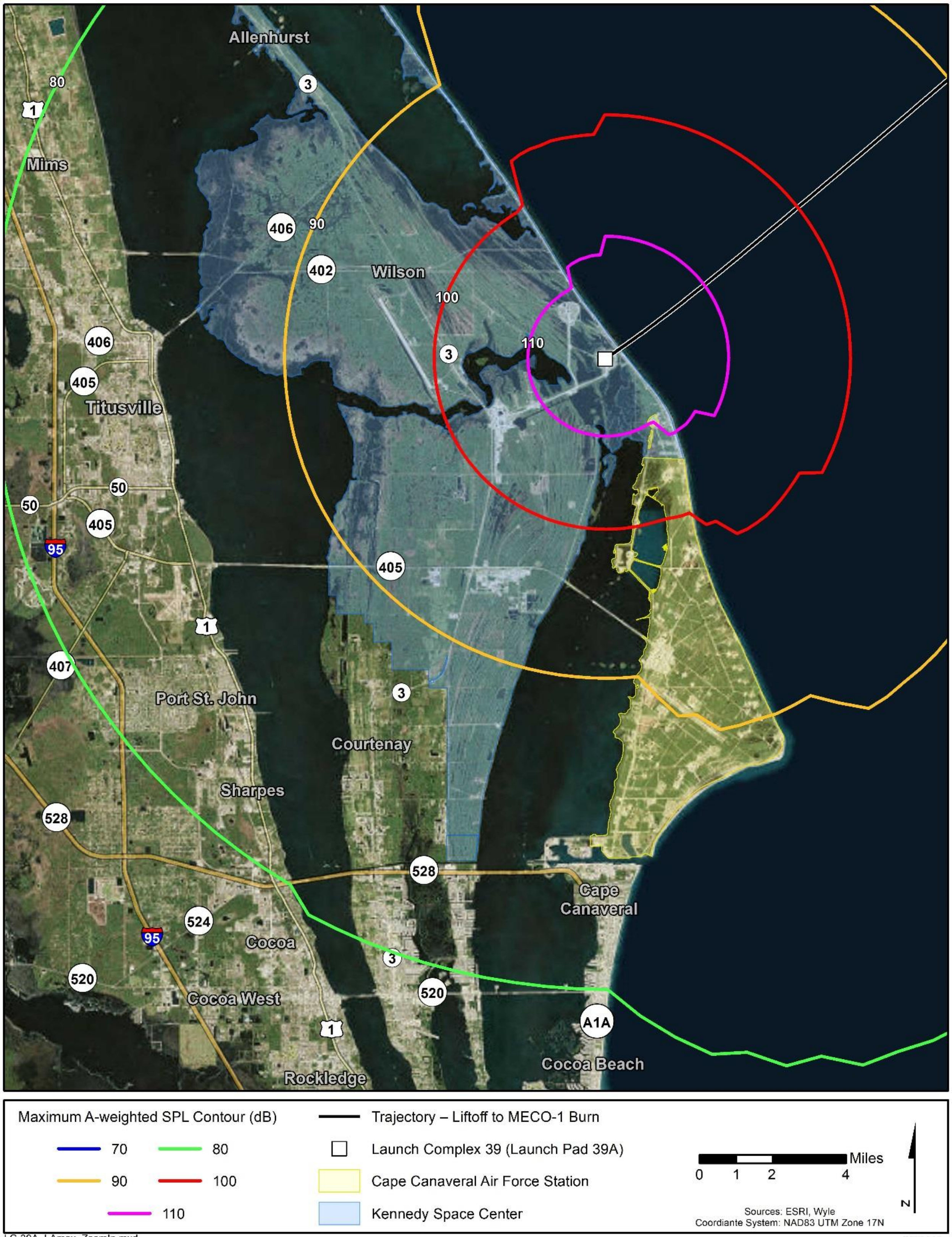


Figure 13. Maximum A-Weighted Sound Levels for Falcon Heavy Block 5 Launch from LC-39A (Zoomed in)

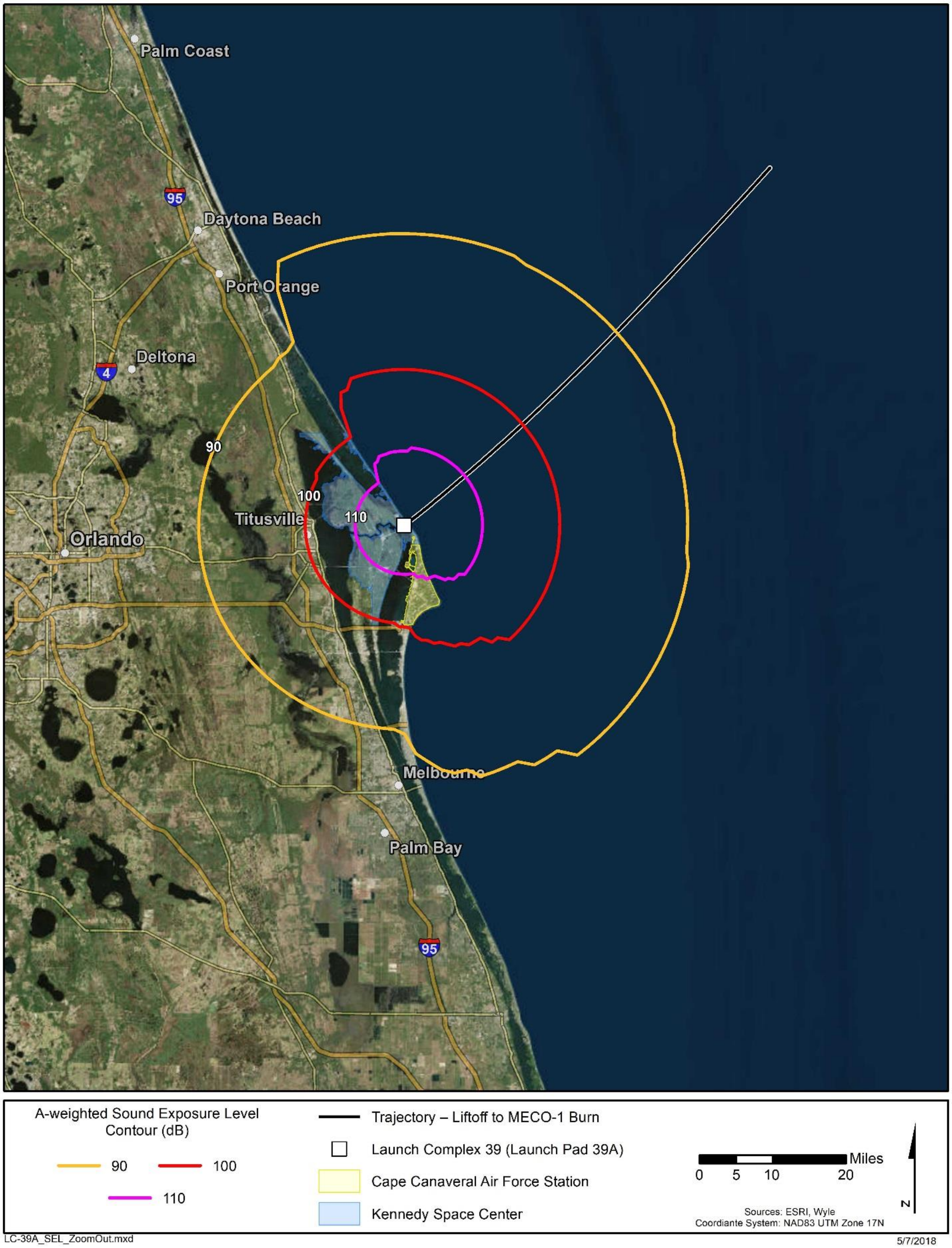


Figure 14. Sound Exposure Levels for Falcon Heavy Block 5 Launch from LC-39A

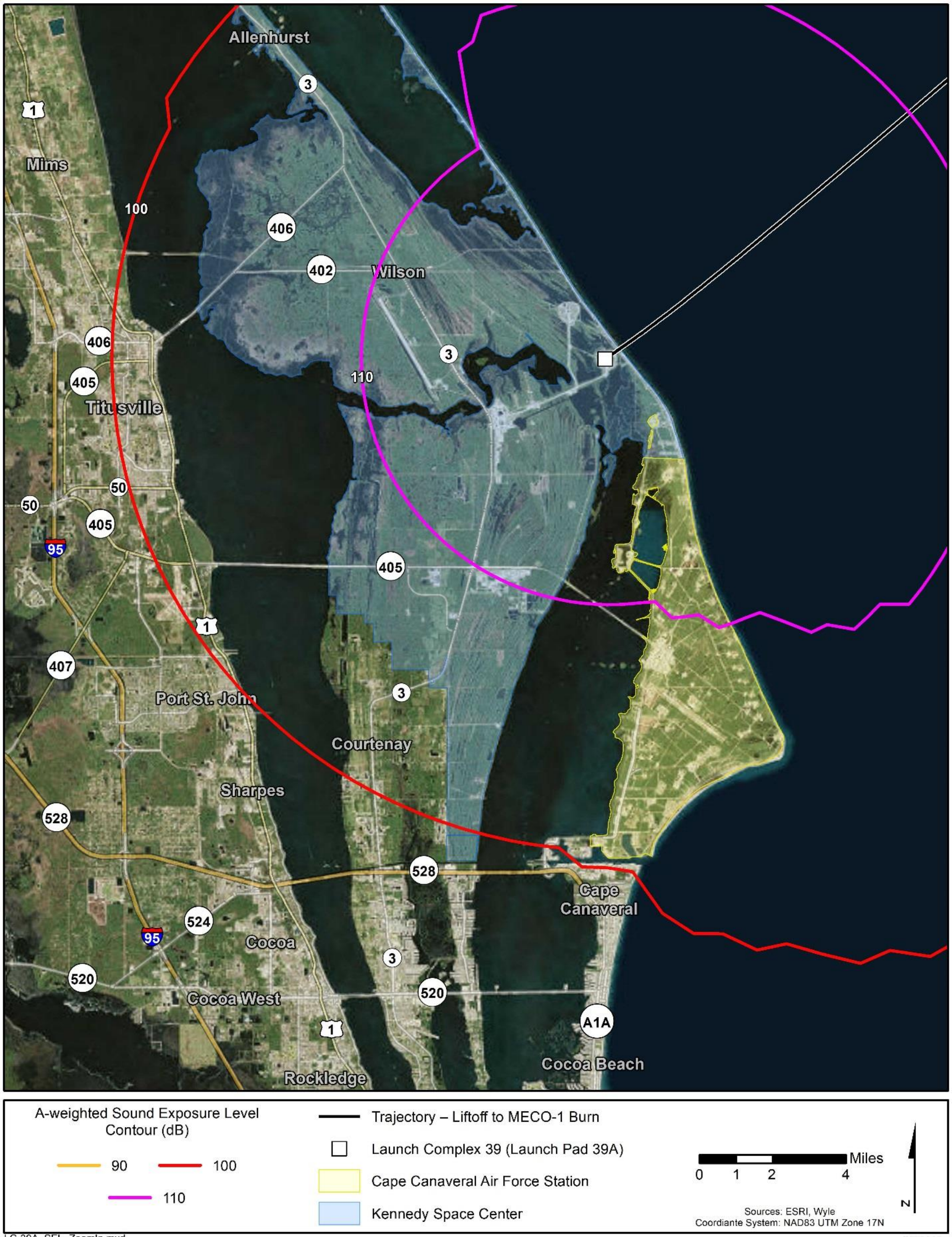


Figure 15. Sound Exposure Levels for Falcon Heavy Block 5 Launch from LC-39A (Zoomed In)

4 Booster Reentry/Landing Noise Levels

4.1 Booster Landings at LZ-1 and LZ-2

RNOISE was used to estimate the L_{Amax}, and SEL contours for Falcon Heavy side booster (recovery) landings at LZ-1 and LZ-2. Booster fly back trajectories, from booster separation to landing, were provided by SpaceX in files 'FH-1_FH_DEMO_+Y_BOOSTER_NOM_BOOSTER_SEP_TO_LANDING_80_12.ASC' and 'FH-1_FH_DEMO_-Y_BOOSTER_NOM_BOOSTER_SEP_TO_LANDING_80_12.ASC'. These trajectory files represent two Falcon Heavy side boosters landing simultaneously with the +Y Booster landing at LZ-1 and the –Y Booster landing at LZ-2. L_{Amax} contours indicate the maximum sound level at each location over the duration of the landings where engine thrust varies according to the reentry/descent thrust profiles provided with the trajectory data.

RNOISE computations were performed as noted in Section 3.1. Ground areas were considered to be acoustically soft, and water acoustically hard. Ground effect was based on a weighted average over the propagation path. Figures 16 and 17 show the L_{Amax} and SEL contours for the booster landings at LZ-1 and Figures 18 and 19 show the L_{Amax} and SEL contours for the booster landings at LZ-2, respectively. The landing pad locations at LZ-1 and LZ-2 and landing trajectories are indicated in the map legends as are the CCAFS and KSC properties. Only the zoomed out map scale is used in this series of figures. In all four figures the 70 dB contour (L_{Amax} or SEL) extends to the west partly into the city of Titusville. Residents of Titusville may therefore notice the noise from booster landings at LZ-1 and LZ-2. Higher noise levels (90 to 110 dB L_{Amax} or SEL) are mostly within the CCAFS and KSC properties. Merritt Island and parts of the city of Cape Canaveral may be exposed to SELs higher than 100 dB.

Compared with the launch noise levels presented in Section 3, booster landing noise levels are considerably lower reflecting the much lower total engine thrust required for landing operations. Also of note in this series of figures is that the SEL contours for booster landings at LZ-1 (Figure 17) are noticeably larger (about 10 dB higher) than the SEL contours for booster landings at LZ-2 (Figure 19); whereas the L_{Amax} contours are about the same at both locations. This is due to the two booster landing trajectories having somewhat different thrust schedules during the landings, affecting SEL but not L_{Amax}. Both thrust schedules are similar in general, but have individual differences since these are actual flight trajectories.

While single booster landings can occur, the two booster fly back trajectories provided by SpaceX represent simultaneous booster landings at LZ-1 and LZ-2. Overall single event noise levels from these simultaneous landings are shown in Figure 20 (L_{Amax}) and Figure 21 (SEL). The Maximum A-Weighted Sound Levels are several dB higher for the combined, simultaneous landings than for either individual landing alone. The Sound Exposure Levels for the combined, simultaneous booster landings are only about 1 dB higher than the Sound Exposure Levels for the booster landing at LZ-1; since the levels at LZ-1 are about 10 dB higher than the levels at LZ-2; i.e., the Sound Exposure Levels from simultaneous landings at LZ-1 and LZ-2 is not much higher than the Sound Exposure Levels from the landing at LZ-1 alone.

The next section presents single event noise levels for four different SpaceX rocket static fire tests including the Falcon 9 at LC-39A and LC-40, Falcon Heavy at LC-39A, and Dragon at LZ-1.

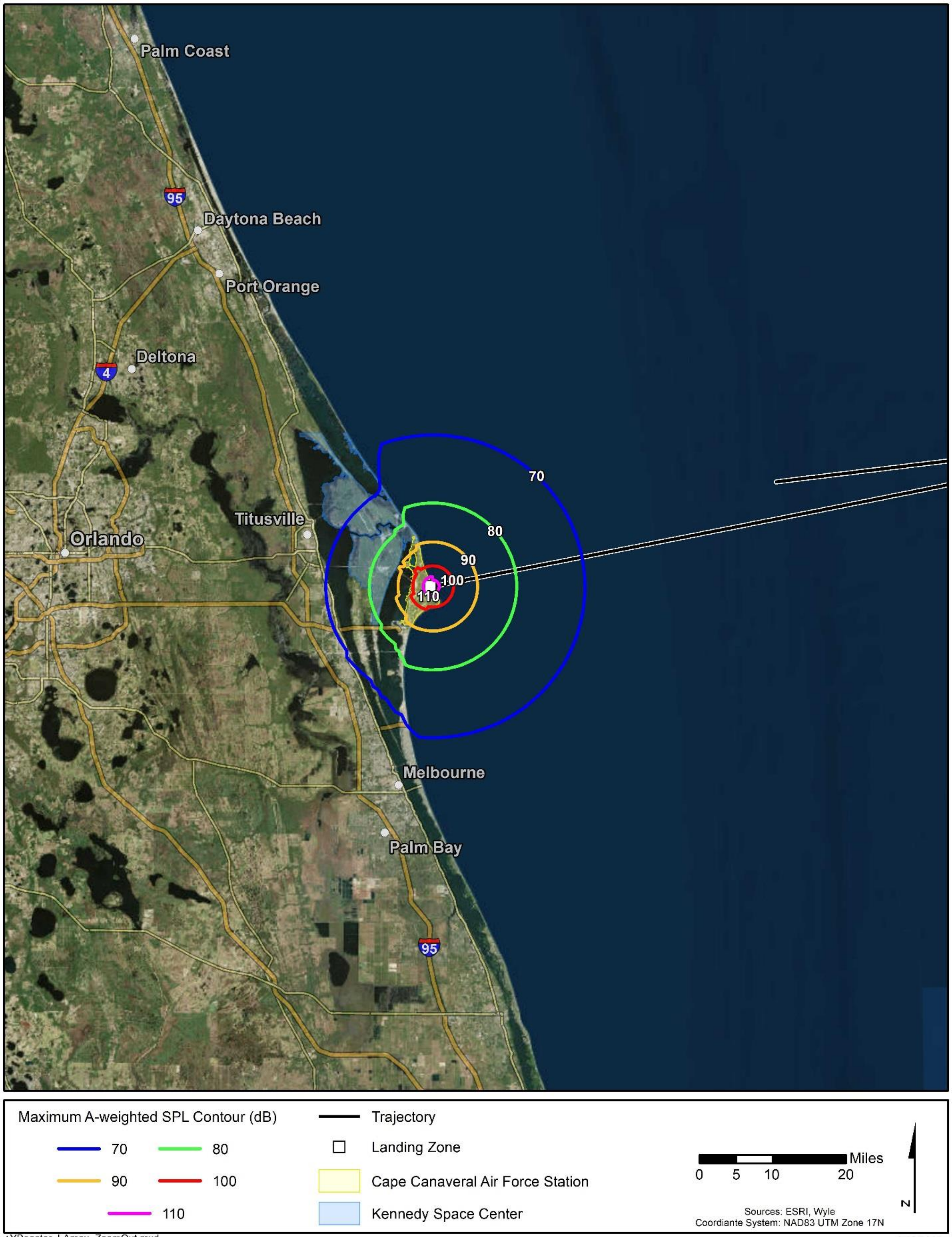


Figure 16. Maximum A-Weighted Sound Levels for Booster Landing at LZ-1

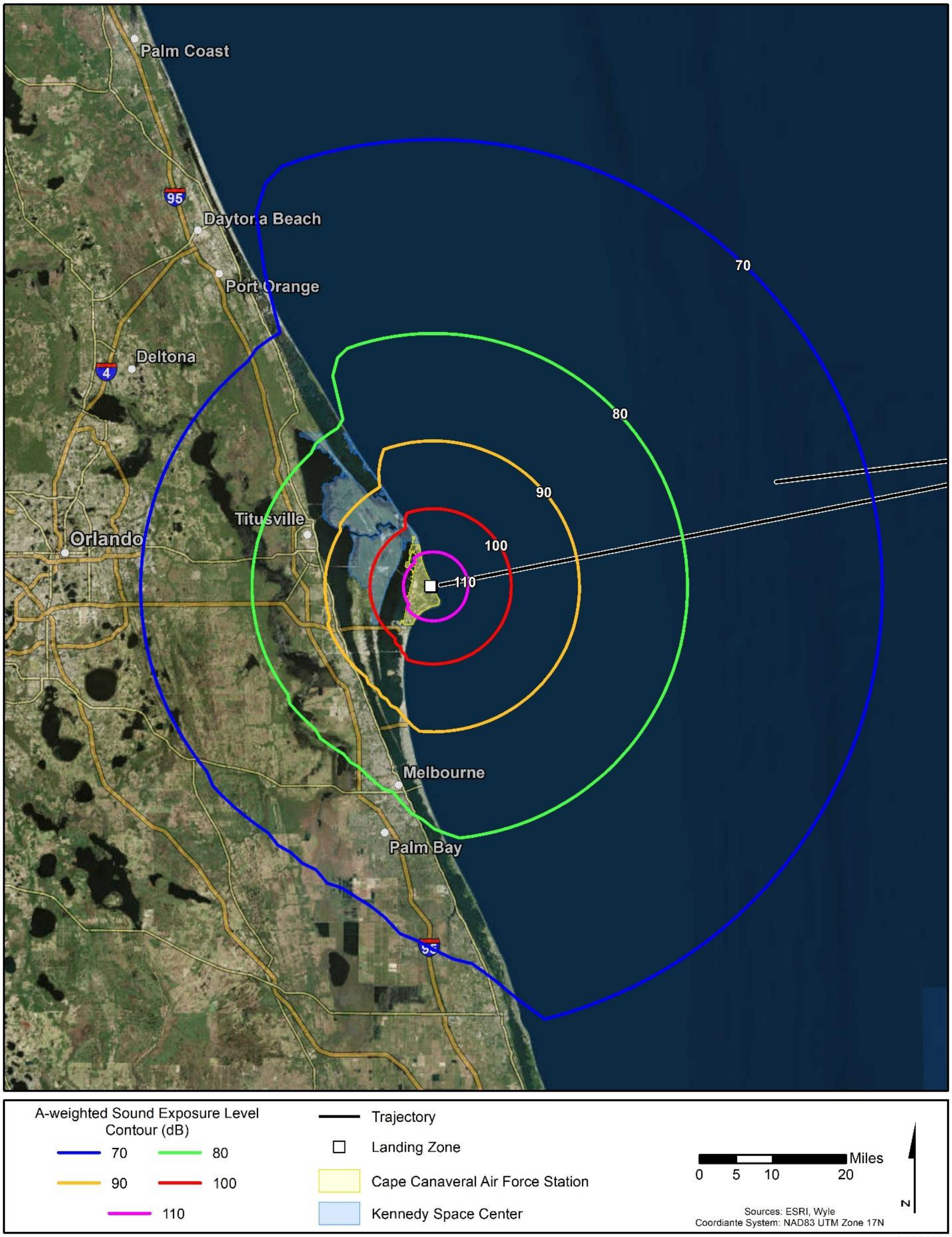


Figure 17. Sound Exposure Levels for Booster Landing at LZ-1

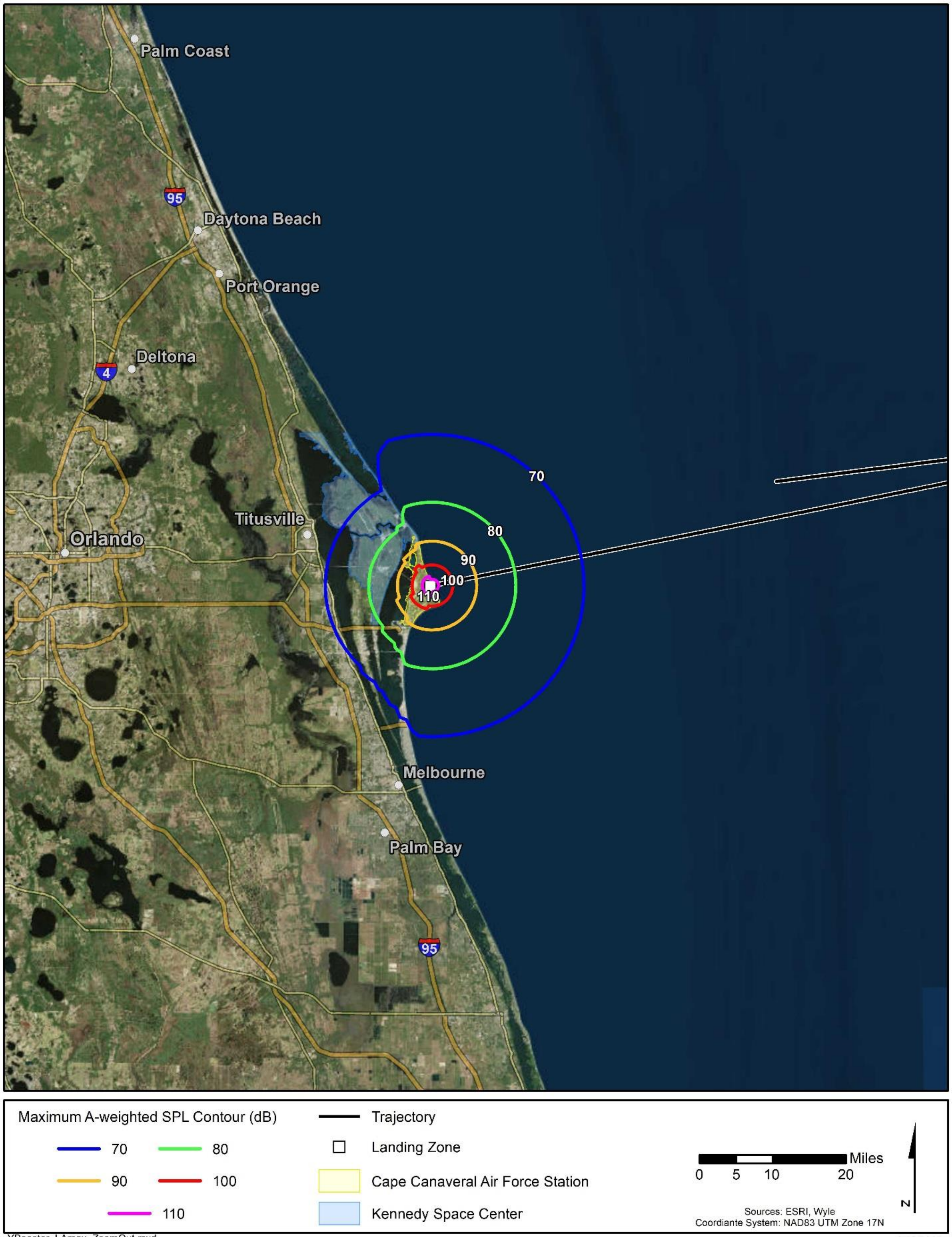


Figure 18. Maximum A-Weighted Sound Levels for Booster Landing at LZ-2

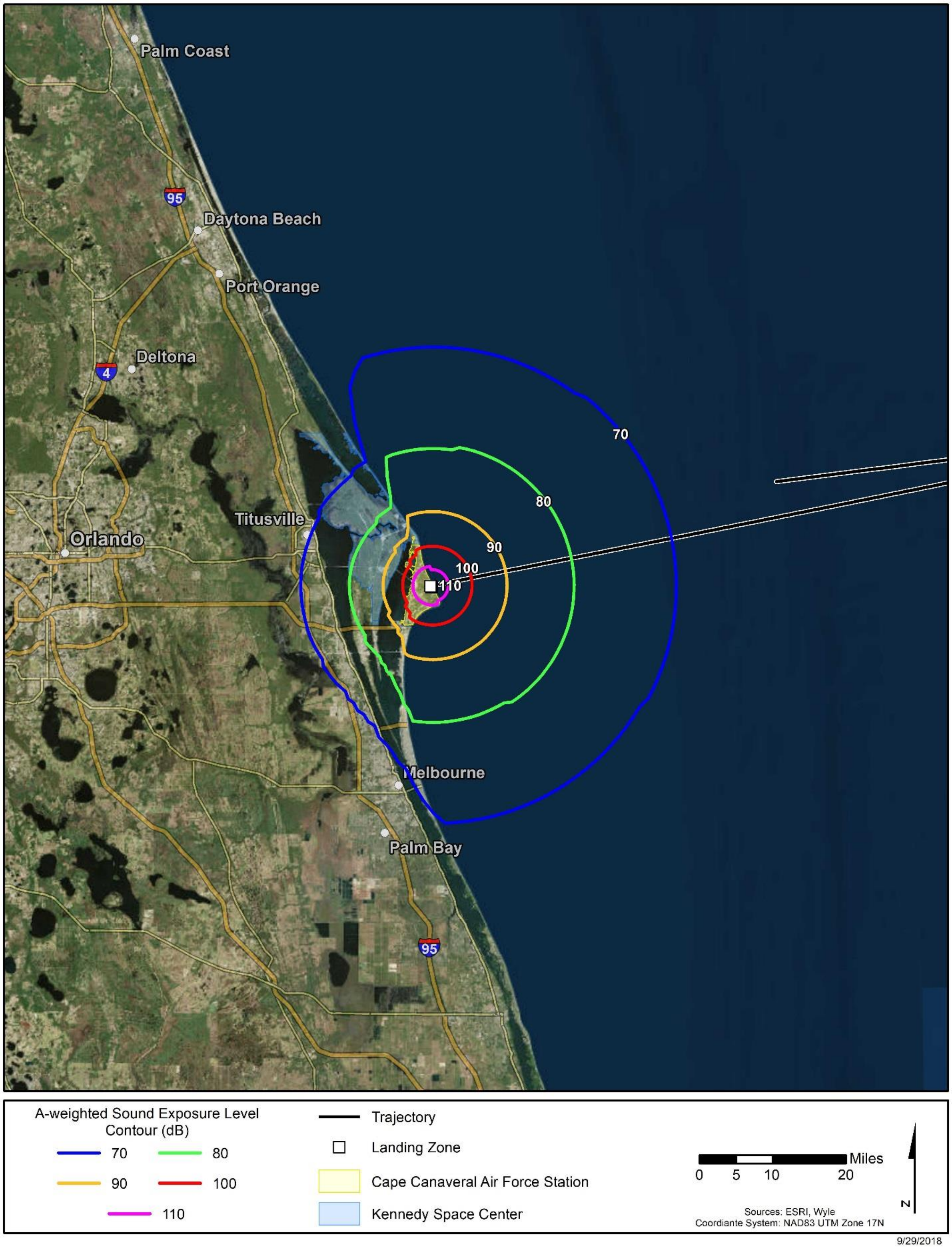


Figure 19. Sound Exposure Levels for Booster Landing at LZ-2

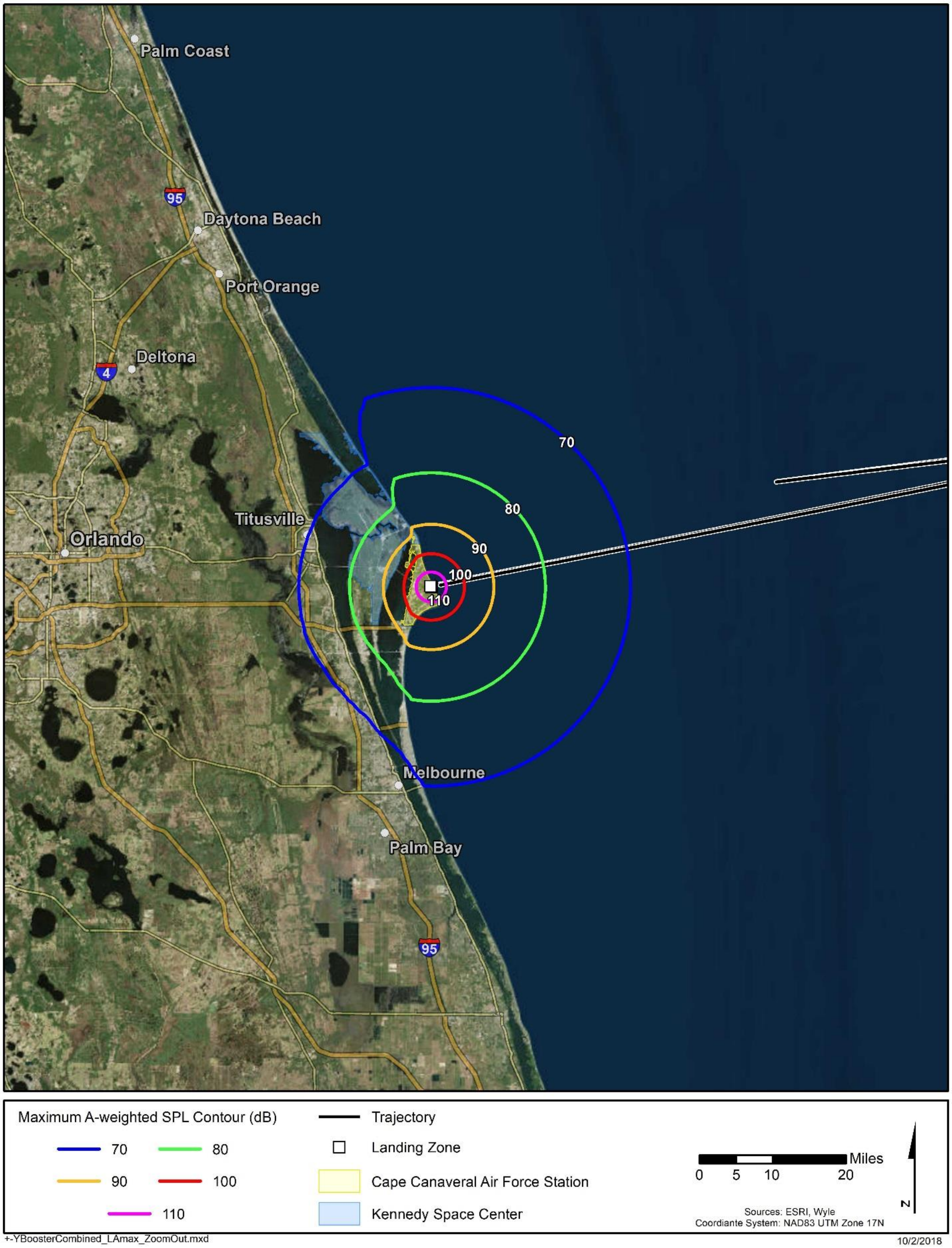


Figure 20. Maximum A-Weighted Sound Levels for Simultaneous Booster Landings at LZ-1 and LZ-2

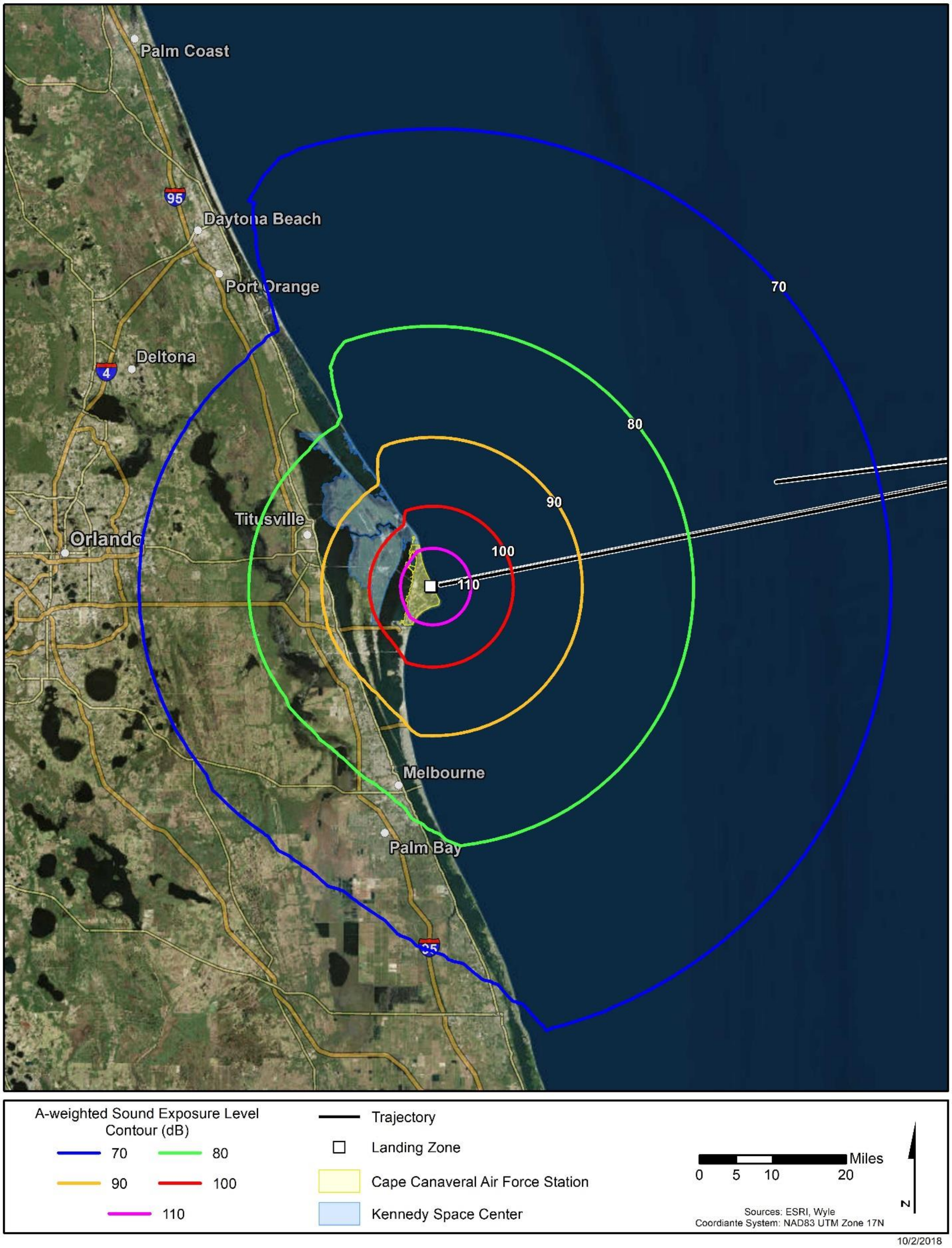


Figure 21. Sound Exposure Levels for Simultaneous Booster Landings at LZ-1 and LZ-2

5 Static Fire Test Noise Levels

5.1 Falcon 9 Static Tests at LC-39A and LC-40

Falcon 9 static fire tests occur at LC-39A and LC-40 where all engines (on vehicle, on mount) are fired for up to 12 seconds. Figures 22 and 23 show the estimated L_{Amax} and SEL contours, respectively, for a Falcon 9 static fire test at LC-39A. Figures 24 and 25 show similar L_{Amax} and SEL contours, respectively, for a Falcon 9 static fire test at LC-40. Falcon 9 static fire tests at both locations generate Sound Exposure Levels that are above 70 dB at the most eastern parts of Titusville. Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS and KSC properties.

5.2 Falcon Heavy Static Tests at LC-39A

Falcon Heavy static fire tests occur at LC-39A. Figures 26 and 27 show the estimated L_{Amax} and SEL contours, respectively, for a Falcon Heavy static fire test at LC-39A. All engines are fired for up to 12 seconds during these tests. Figure27, which shows a zoomed in map scale, indicates that Sound Exposure Levels will exceed 70 dB in nearby cities (Titusville, Cape Canaveral, Port St. John, and northern parts of Cocoa). Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS and KSC properties.

5.3 Dragon Static Tests at LZ-1

Dragon static fire tests occur at LZ-1 where all engines are fired for up to 12 seconds. Figures 28 and 29 show zoomed in maps of the L_{Amax} and SEL contours, respectively, for a Dragon static fire test at LZ-1. LZ-1 is located about six miles south, along the coastline, from LC-39A. In Figure 29, the 70 SEL contour extends south along the coast; residents of Cape Canaveral and Cocoa Beach may notice these tests, especially at night when background levels are lower. Higher Sound Exposure Levels (above 80 dB) are mostly contained within the CCAFS property.

This concludes the analysis of single event levels for SpaceX rocket operations. L_{Amax} and SEL contours were shown for shown for single rocket launches (Section 3), booster landings (Section 4), and static fire tests (Section 5). In Section 6, cumulative noise levels are estimated, in terms of DNL, for these same rocket operations accounting for their projected annual operations from 2018 through 2024.

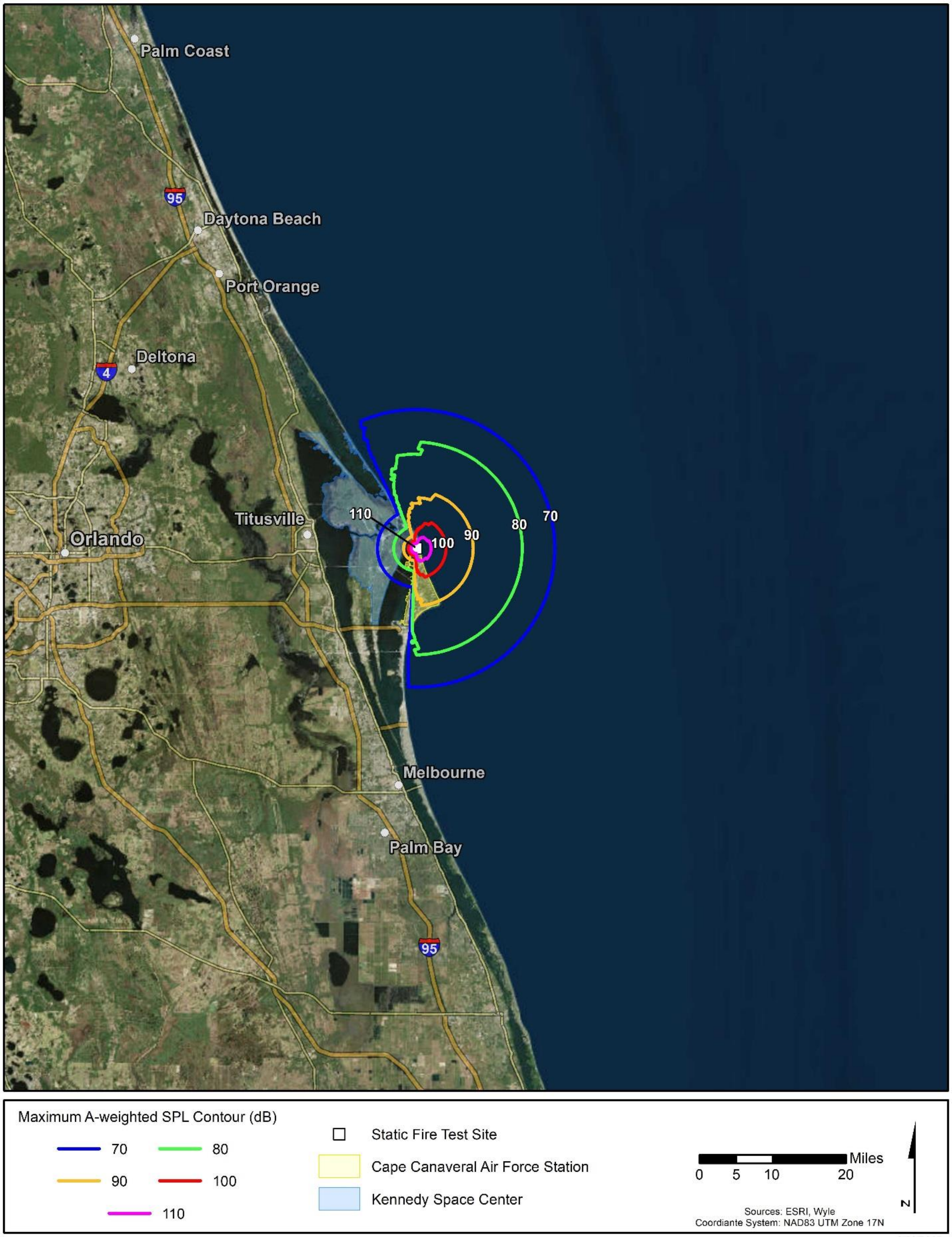


Figure 22. Maximum A-Weighted Sound Levels for Falcon 9 Static Fire Test at LC-39A

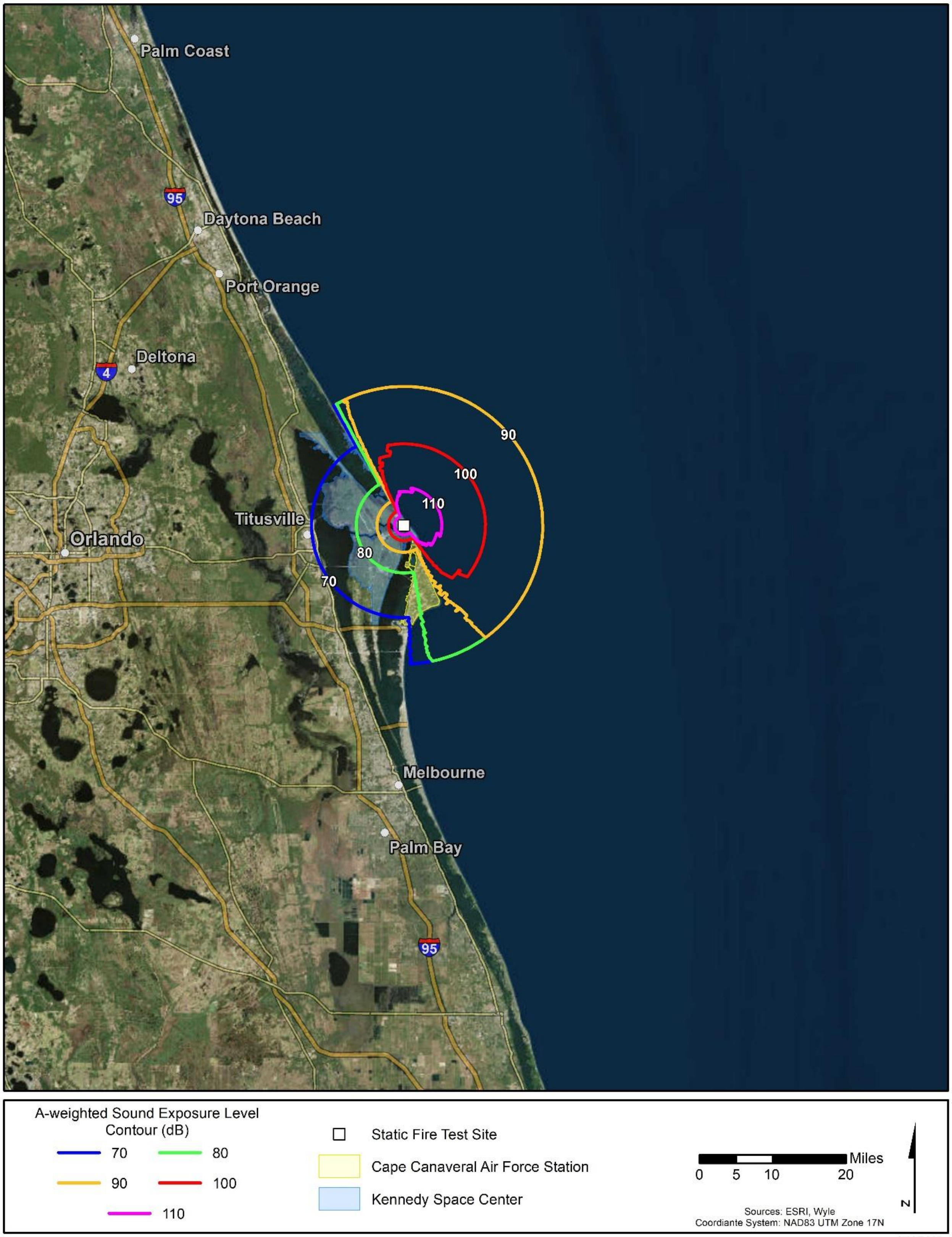


Figure 23. Sound Exposure Levels for Falcon 9 Static Fire Test at LC-39A

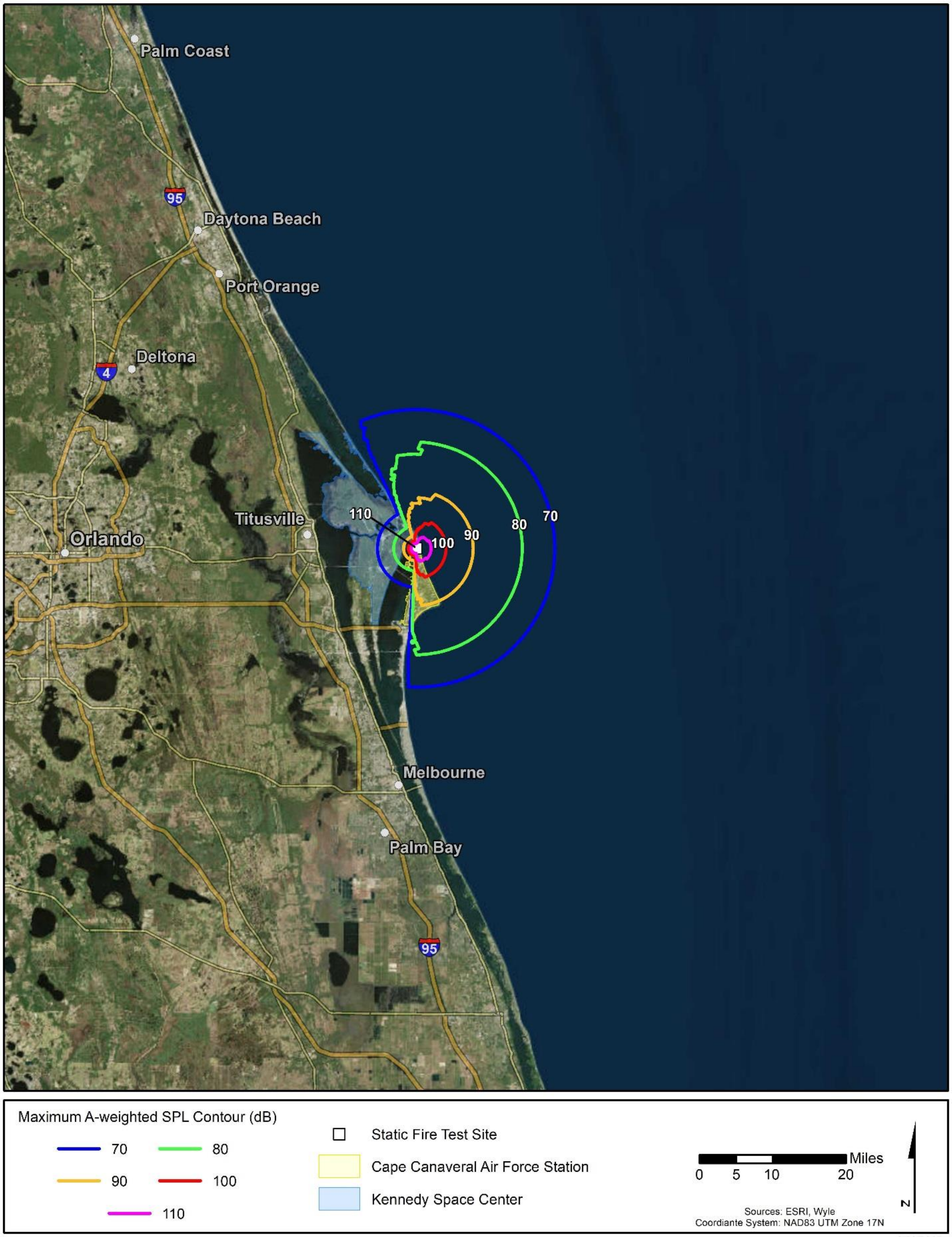


Figure 24. Maximum A-Weighted Sound Levels for Falcon 9 Static Fire Test at LC-40

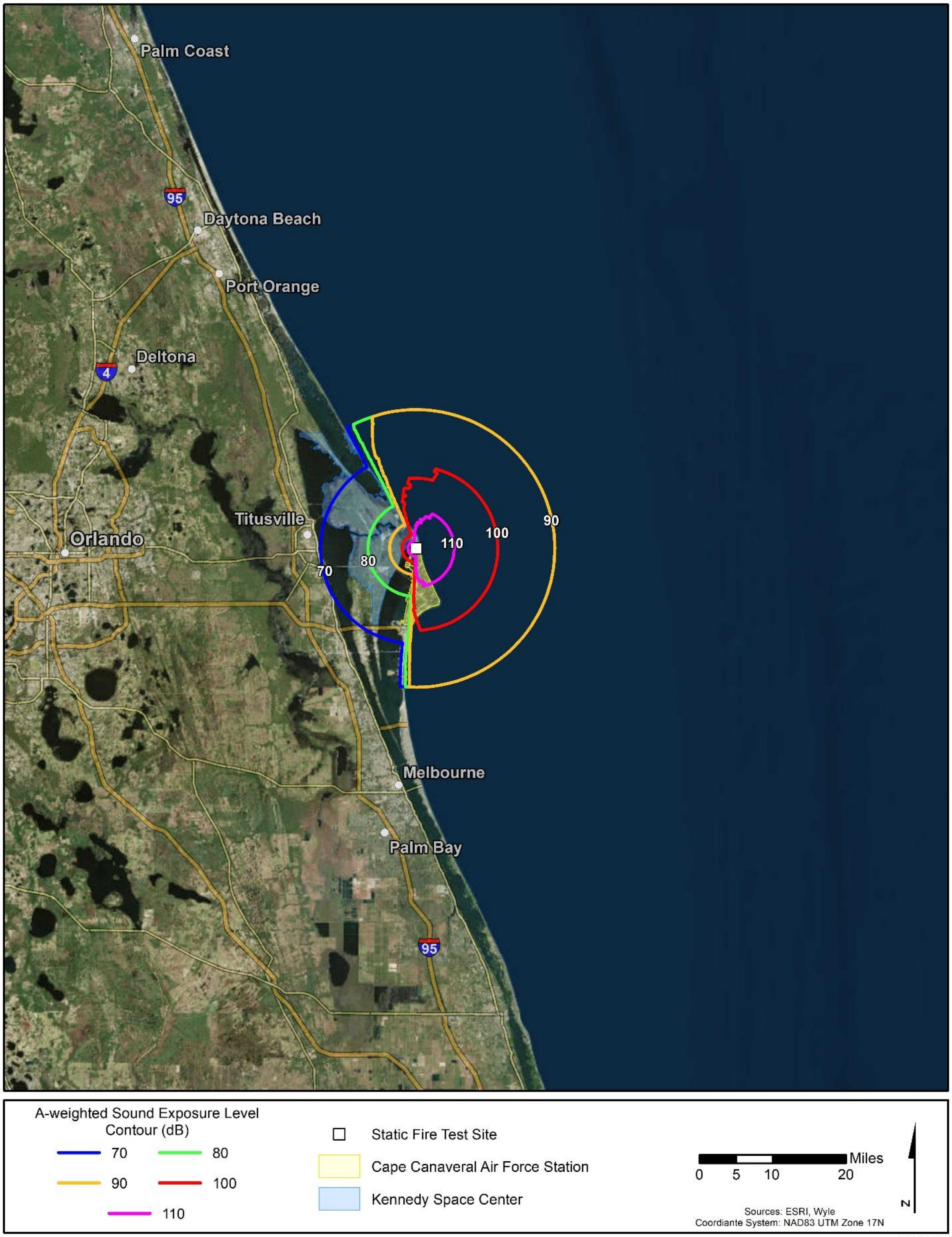


Figure 25. Sound Exposure Levels for Falcon 9 Static Fire Test at LC-40

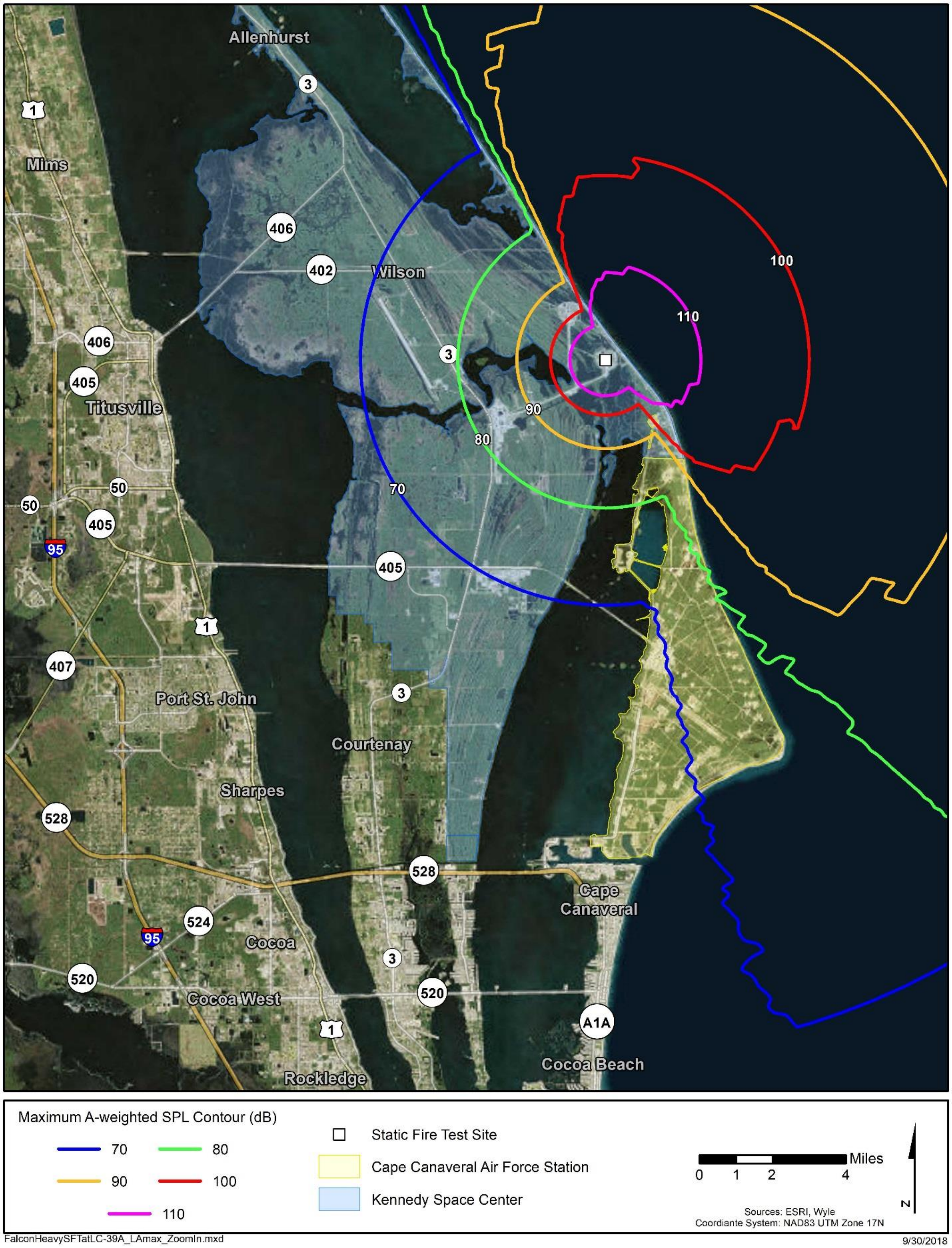


Figure 26. Maximum A-Weighted Sound Levels for Falcon Heavy Static Fire Test at LC-39A (Zoomed In)

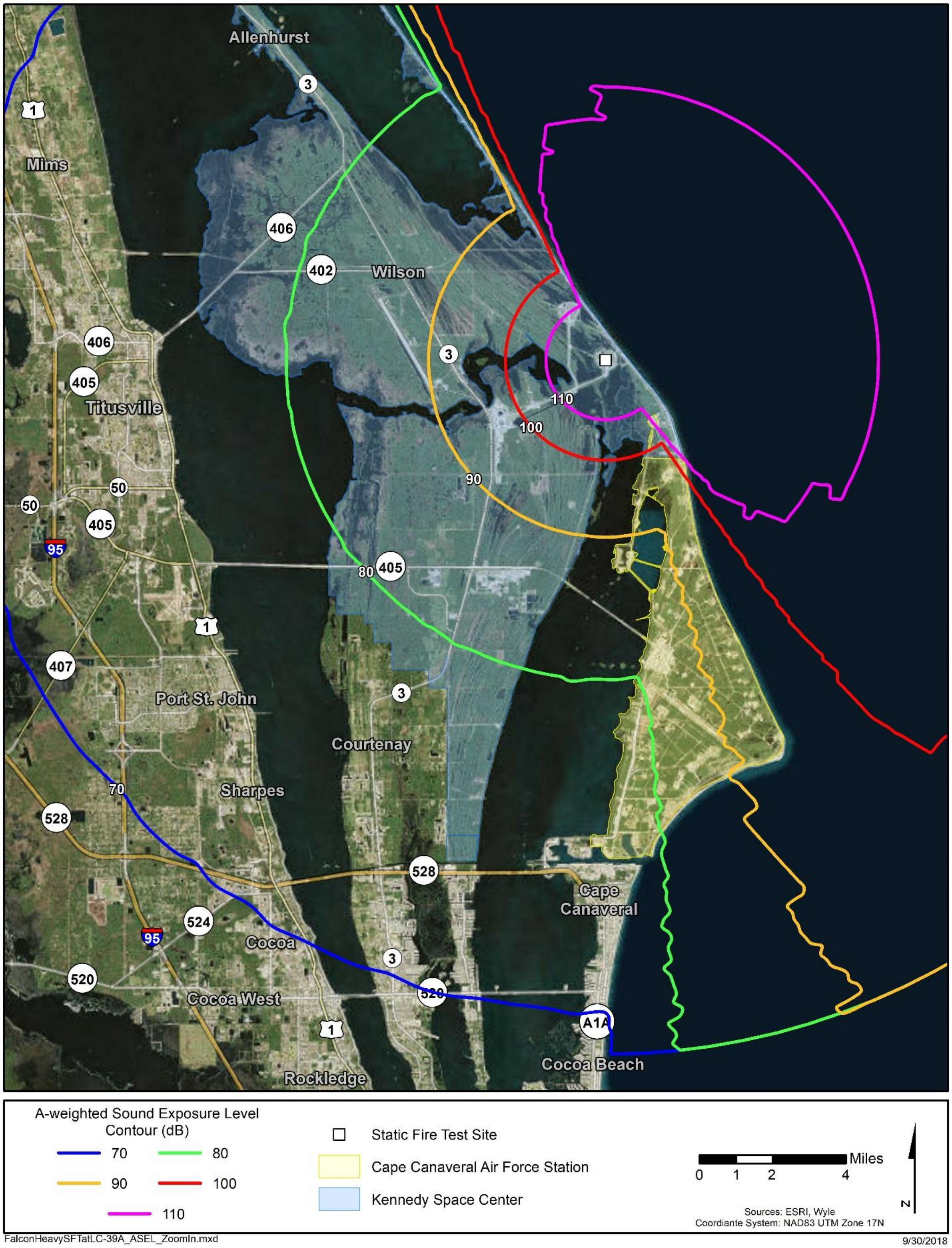


Figure 27. Sound Exposure Levels for Falcon Heavy Static Fire Test at LC-39A (Zoomed In)

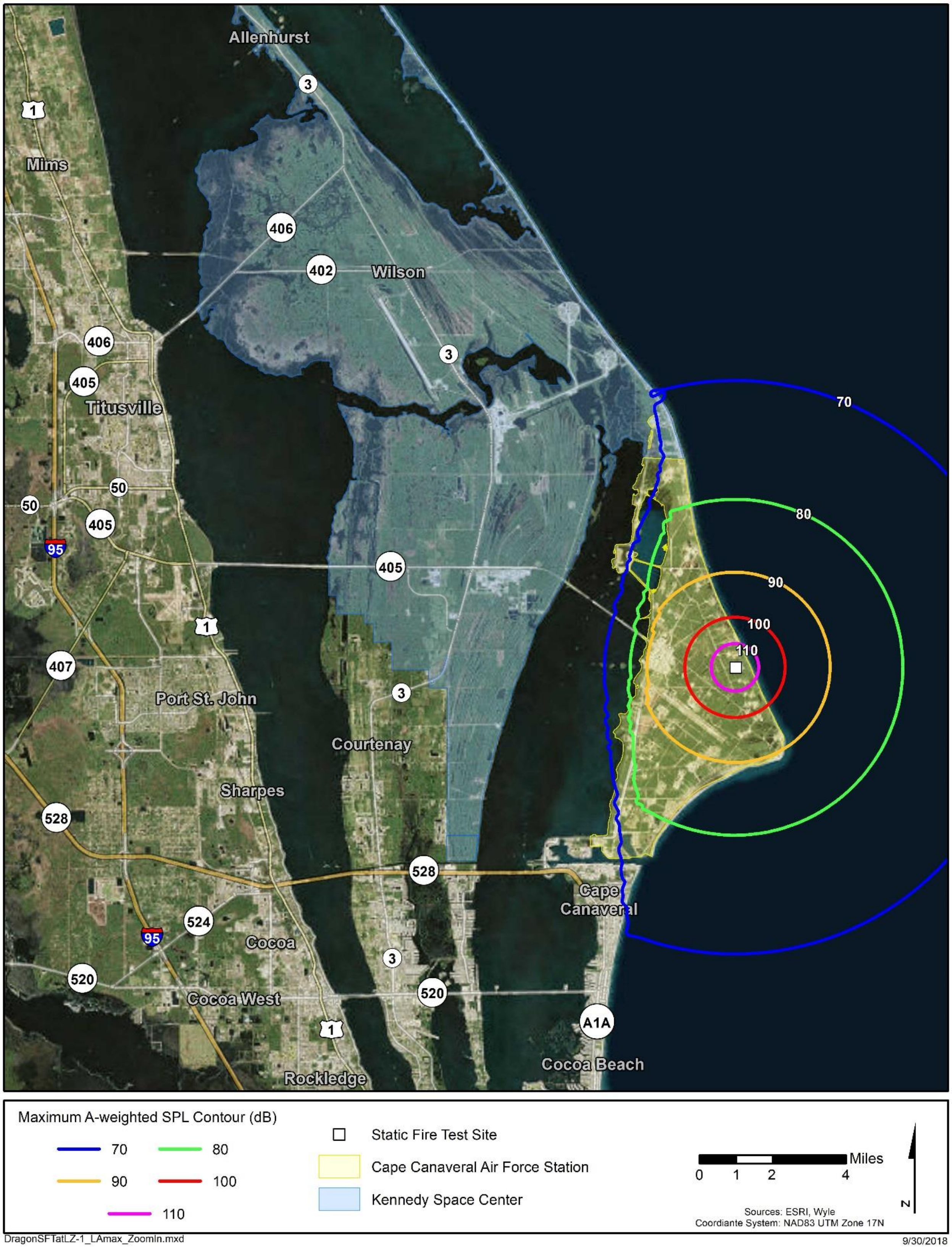


Figure 28. Maximum A-Weighted Sound Levels for Dragon Static Fire Test at LZ-1 (Zoomed In)

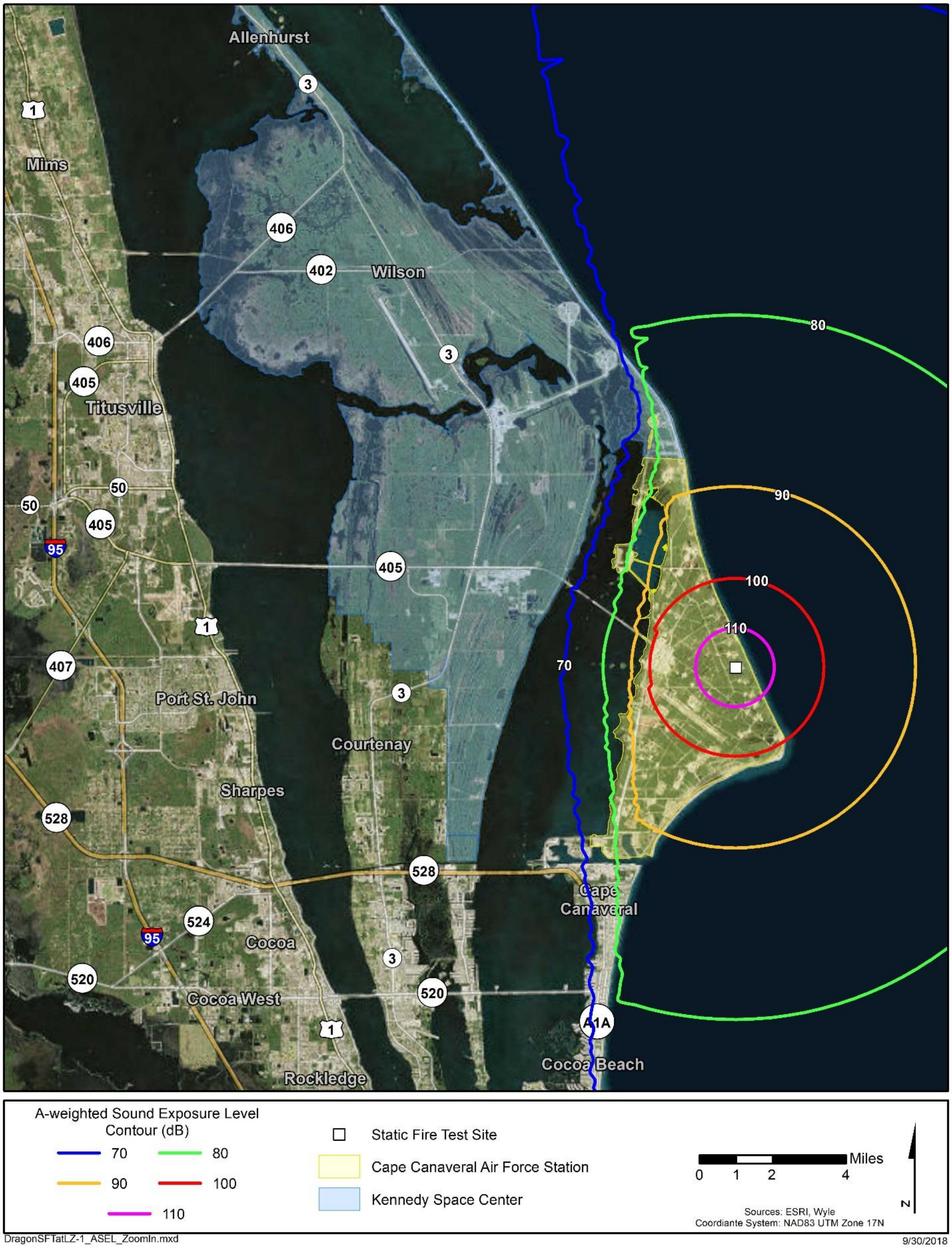


Figure 29. Sound Exposure Levels for Dragon Static Fire Test at LZ-1 (Zoomed In)

6 Cumulative Noise Levels for Rocket Operations at CCAFS and KSC

6.1 Day-Night Average Sound Levels for Rocket Operations at CCAFS and KSC

As noted in section 2, FAA Order 1050.1E specifies Day-Night Average Sound Level (DNL) as the standard metric for community noise impact analysis. DNL is appropriate for continuous noise sources, such as airport noise and road traffic noise. It is not appropriate for irregularly occurring noise events such as rocket launches or static tests, however these noise events may be evaluated using DNL for policy decisions.

This section presents an estimate of the DNL for 2017 launch operations and other typical noise events occurring at CCAFS and KSC and describes how projected future launches, booster landings, and static fire tests of the Falcon 9, Falcon Heavy, and Dragon rockets are expected to influence the DNL.

To accurately describe the DNL at CCAFS and KSC, a detailed study would be required involving either the modeling of all major noise sources or conducting noise monitoring throughout these areas for a period of time that adequately represents the different types of launch vehicles and frequency of launches conducted. The modeling estimates of DNL presented here are basic and serve to identify whether SpaceX launch operations at CCAFS and KSC are expected to have a significant noise impact per the guidelines in FAA Order 1050.1E. FAA Order 1050.1E specifies that a significant noise impact would occur if analysis shows that the proposed action will cause noise sensitive areas to experience an increase in noise of DNL 1.5 dB or more at or above DNL 65 dB noise exposure when compared to the no action alternative for the same timeframe.

Before estimating DNL for the CCAFS and KSC properties and surrounding cities it is important to note that these areas have a variety of land uses. CCAFS and KSC have areas that should be considered rural or remote, except where NASA or other launch facilities are located. KSC has a wildlife refuge. Populated areas of Merritt Island could be considered rural or quiet suburban residential areas whereas Titusville and the city of Cape Canaveral are more urban areas with mixed residential and industrial uses. It is therefore important to consider the land use category and associated background noise levels when determining if launch operations will have a significant noise impact.

The DNL estimates presented here are for the baseline year (2017) and for future year 2024 in which SpaceX proposes an increase in their Falcon 9 and Falcon Heavy launches and static fire tests. To estimate DNL for 2017, background noise levels were estimated and so was the DNL from all 2017 launch operations at CCAFS and KSC. Background DNL was estimated using ANSI/ASA S12.9-2013/Part3[9] which provides estimated background noise levels for different land use categories and population density. Table 1 shows the DNL estimated for rural or remote areas and several different categories of suburban and urban residential land use which can be used to represent DNL for the various land uses within CCAFS, KSC, and surrounding areas. According to these estimates, many of the remote areas within the CCAFS and KSC properties would be expected to have a DNL less than 49 dBA while parts of Titusville and the city of Cape Canaveral would be expected to have a DNL as high as 59 dBA. The DNL values in Table 1 provide an estimate of the background levels expected in typical noise environments and do not include noise from launch operations.

Table 1. Estimated Background Noise Levels

Example Land Use Category	Average Residential Intensity (people per acre)	DNL (dBA)	Leq (dBA)	
			Daytime	Nighttime
Rural or remote areas	<2	<49	<48	<42
Quiet suburban residential	2	49	48	42
	4	52	53	47
	4.5	52	53	47
Quiet urban residential	9	55	56	50
Quiet commercial, industrial, and normal urban residential	16	58	58	52
	20	59	60	54

ANSI/ASA S12.9-2013/Part3

To estimate the 2017 DNL for CCAFS, KSC, and the surrounding areas, the noise from all 2017 launches at CCAFS and KSC should be added to the background noise estimated for these areas. Table 2 shows all of the 2017 launches at CCAFS and KSC. There were nineteen total launches including thirteen Falcon 9 Full Thrust launches, twelve of these occurred at KSC LC-39A and one occurred at CCAFS LC-40. The remaining six launches by the Atlas V (401 or 421), Delta IV M+(5,4), and Minotaur/Orion occurred at the three other CCAFS launch sites listed in Table 2. Of the nineteen launches in 2017, three (about 16%) were nighttime launches. The total first stage sea level (SL) thrust is provided for each vehicle in the table.

Table 2. Launches at CCAFS and KSC in 2017

Launch Vehicle	Launch Site	Thrust (1st stage) lbf (SL)	2017 Launches		
			Day	Night	Total
Falcon 9 Full Thrust	KSC LC-39A	1,710,000	11	1	12
Falcon 9 Full Thrust	CCAFS LC-40	1,710,000	1	0	1
Atlas V 401 (3) or 421 (1)	CCAFS LC-41	860,000	3	1	4
Delta IV M+(5,4)	CCAFS LC-37B	705,000	1	0	1
Minotaur/Orion	CCAFS LC-46	210,000	0	1	1

The DNL for all launches in Table 2 were estimated conservatively by making a few simplifying assumptions to the actual launch data. First, all of the launches were located at LC-39A (where the majority of launches occurred by the highest thrust vehicle, Falcon 9 Full Thrust). This is a conservative approximation which serves to concentrate the noise, rather than disperse it at the other launch sites. Second, noise received in the vicinity of the launch site is mostly due to the noise emissions of the first stage and can be scaled according to the total thrust of the first stage. Although there are several different types of vehicles in Table 2, with different first stage thrust levels, for the purposes of this estimate the equivalent number of Falcon 9 Full Thrust launches were determined. The scaling of operations is done using first stage thrust levels and accounting for nighttime launches which, because of the nighttime penalty inherent in DNL, are each equivalent to ten daytime launches. In this analysis, all nighttime launches were converted to daytime launches for simplicity. Additionally, note that the first stage thrust of the Falcon 9 Full Thrust is the same as that of the Falcon 9 Block 5. And because Figures 10 and 11 show the SEL contours for the Falcon 9 Block 5 launch at LC-39A, these SEL contours were used as a basis for explaining the 2017 DNL results as described following.

By using the above simplifying assumptions and scaling methods, all of the 2017 launches listed in Table 2 are equivalent to approximately 30 annual Falcon 9 Full Thrust (or Falcon 9 Block 5) daytime launches at LC-39A, which equates to 0.082 daytime launches per average day. Given this low number of launches, it is not expected that the DNL estimated for the 2017 launches will be much higher than the DNL estimated for the background noise environments described in Table 1. Using the following relationship, the equivalent DNL can be determined from the SEL for any launch event and the scaling assumptions made for the number of daytime (N_d) and nighttime (N_n) launches.

$$DNL = SEL + 10*Log_{10}(N_d + 10*N_n) - 49.4 \quad (1)$$

This calculation was performed for all 2017 launches at CCAFS and KSC which is estimated to be equivalent to 30 annual daytime launches of the Falcon 9 Full Thrust or Falcon 9 Block 5 at LC-39A. Using Equation 1 with SEL = 100 dBA, N_d = 30/365, and N_n= 0, the equivalent DNL is 40 dBA. This means the SEL 100 dBA contour shown in Figures 10 and 11 can be used to represent the DNL for all 2017 launch operations and is equivalent to a DNL of 40 dBA and the SEL 110 dBA contour is equivalent to a DNL of 50 dBA.

In summary, all launches in 2017 (Table 2) are estimated to generate Day-Night Average Sound Levels such that the 40 DNL contour is co-located with the SEL 100 dBA contour shown in Figures 10 and 11. The estimated DNL exposure, from all 2017 launches at CCAFS and KSC, is in most areas less than any of the estimated background DNL values in Table 1. The 2017 launches at CCAFS and KSC are therefore not expected to cause significant noise impact according to the guidelines for assessing DNL in FAA Order 1050.1E. For this study, the 2017 launch operations can be considered to represent the baseline launch noise environment at CCAFS and KSC, however the projected SpaceX launches in Table 3, from 2018 through 2024, are expected to generate significantly higher cumulative noise levels due to the increase in the total number of launches and the addition of the Falcon Heavy vehicle.

Table 3. Falcon 9 Block 5 and Falcon Heavy Block 5 Launch Frequency

Year	Launch Complex 39A KSC		Launch Complex 40 CCAFS	Total Launches
	Falcon Heavy	Falcon 9	Falcon 9	
2018	3	4	17	24
2019	3	5	16	24
2020	10	10	44	64
2021	10	10	44	64
2022	10	10	50	70
2023	10	10	50	70
2024	10	10	50	70

The Falcon 9 Block 5 and Falcon Heavy Block 5 launches are expected to replace launches by the Falcon 9 Full Thrust vehicle starting in 2018. To estimate the cumulative noise environment due to all SpaceX rocket operations RNOISE[1,2] was used to estimate the worst case (2024) DNL for launches (Table 3), static fire test operations (Table 4) and booster landings.

Table 4. Falcon 9 Block 5, Falcon Heavy Block 5, and Dragon Static Fire Test Frequency

Year	Launch Complex 39A KSC		Launch Complex 40 CCAFS	LZ-1
	Falcon Heavy	Falcon 9	Falcon 9	Dragon
2018	3	4	17	4
2019	5	10	25	4
2020	10	10	44	4
2021	10	10	44	4
2022	10	10	50	4
2023	10	10	50	4
2024	10	10	50	4

The series of noise maps in Figures 30 through 35 show the DNL estimated for 2024 for the following SpaceX rocket operations:

- Falcon Heavy and Falcon 9 launches at LC-39A (Figure 30)
- Falcon 9 launches at LC-40 (Figure 31)
- All Falcon 9 and Falcon Heavy launches at LC-39A and LC-40 (Figure 32)
- Simultaneous booster landings at LZ-1 and LZ-2 (Figure 33)
-
- All rocket operations: Falcon Heavy and Falcon 9 Launches, Static Fire Tests, and Booster Landings (Figure 35)

Day-Night Average Sound Levels in 2024 will increase compared to the estimated 2017 baseline DNL due to the significant increase in the number of annual rocket operations and due to the addition of the Falcon Heavy. However, Figures 30 through 35 show that cumulative noise impact for 2024 rocket operations, in terms of DNL, is well contained within the CCAFS and KSC properties. The residential areas closest to where rocket operations occur, including Merritt Island, Cape Canaveral, and Titusville, would not be exposed to Day-Night Average Sound Levels above 65 dB. Figure 35 indicates that the 65 DNL contour for all rocket operations in 2024 is located well within the CCAFS and KSC properties. In summary, the planned SpaceX launches, static fire tests, and booster landings of the Falcon 9 Block 5 and Falcon Heavy Block 5, projected to occur from 2018 through 2024, are not expected to cause significant noise impact according to the guidelines for assessing DNL in FAA Order 1050.1E. Personnel working at CCAFS and KSC during rocket operations are expected to follow a hearing conservation program and be well protected from the noise generated by these operations.

The DNL estimates that used Equation 1 are based on a number of simplifying assumptions to make this analysis practical. Equation 1 is best applied to a continuous noise environment, such as a busy airport. Note that ANSI S12.9-2005/Part4[10] describes adjustments to sounds that have special characteristics so that the long-term community response to such sounds can be predicted by a method. But, this standard does not provide a method to predict the response of a community to short-term, infrequent, non-repetitive sources of sound, such as rocket launches. The method using Equation 1 may be improved if proper adjustments to SEL can be determined. Or, as mentioned previously, improved estimates of DNL in the CCAFS, KSC, and surrounding areas would require a detailed study involving either the modeling of all major noise sources or conducting noise monitoring throughout these areas for a period of time that adequately represents the different types of launch vehicles and frequency of launches conducted.

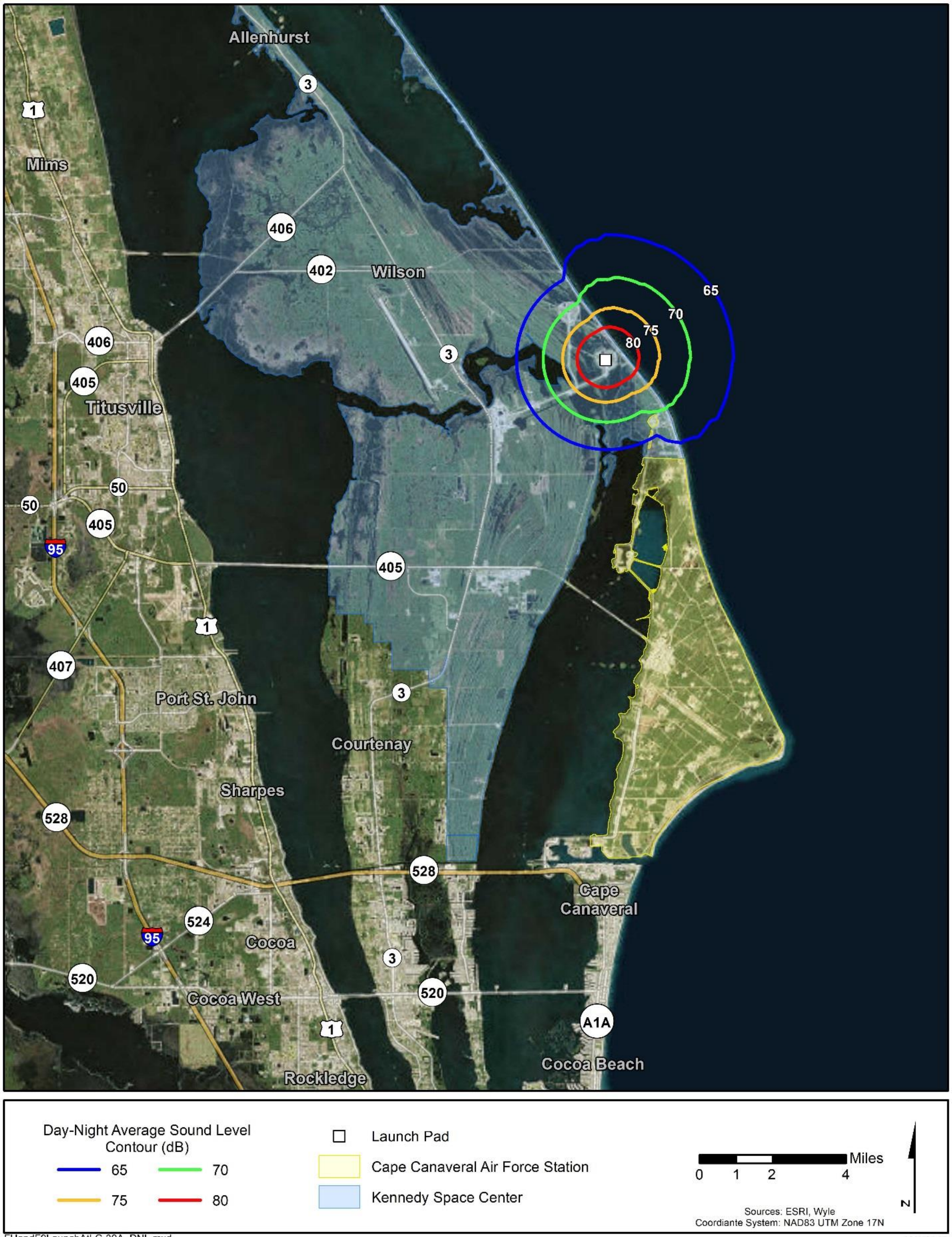
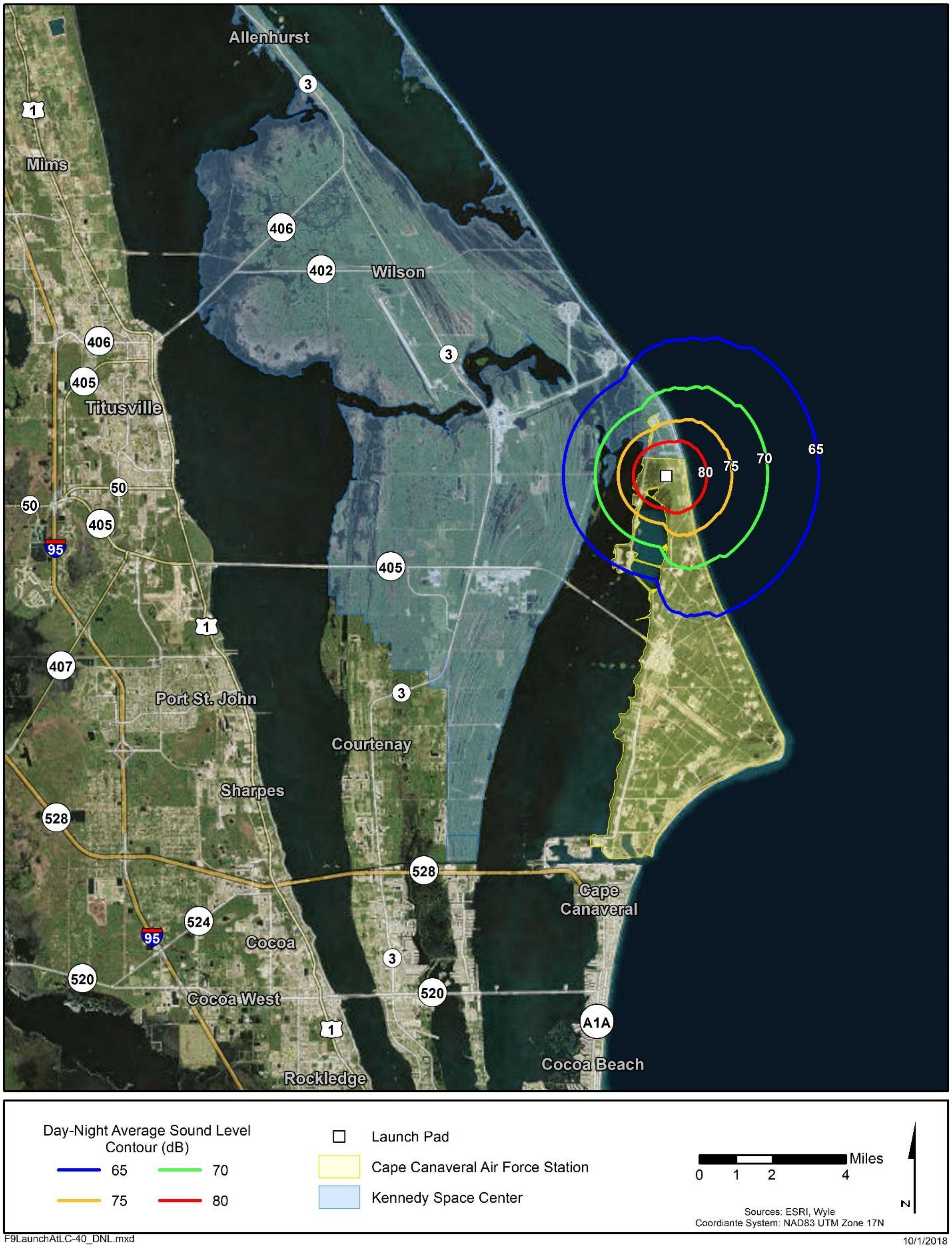


Figure 30. Day-Night Average Sound Levels (DNL) for Falcon Heavy and Falcon 9 Launches at LC-39A in 2024



F9LaunchAtLC-40_DNL.mxd

10/1/2018

Figure 31. DNL for Falcon 9 Launches at LC-40 in 2024

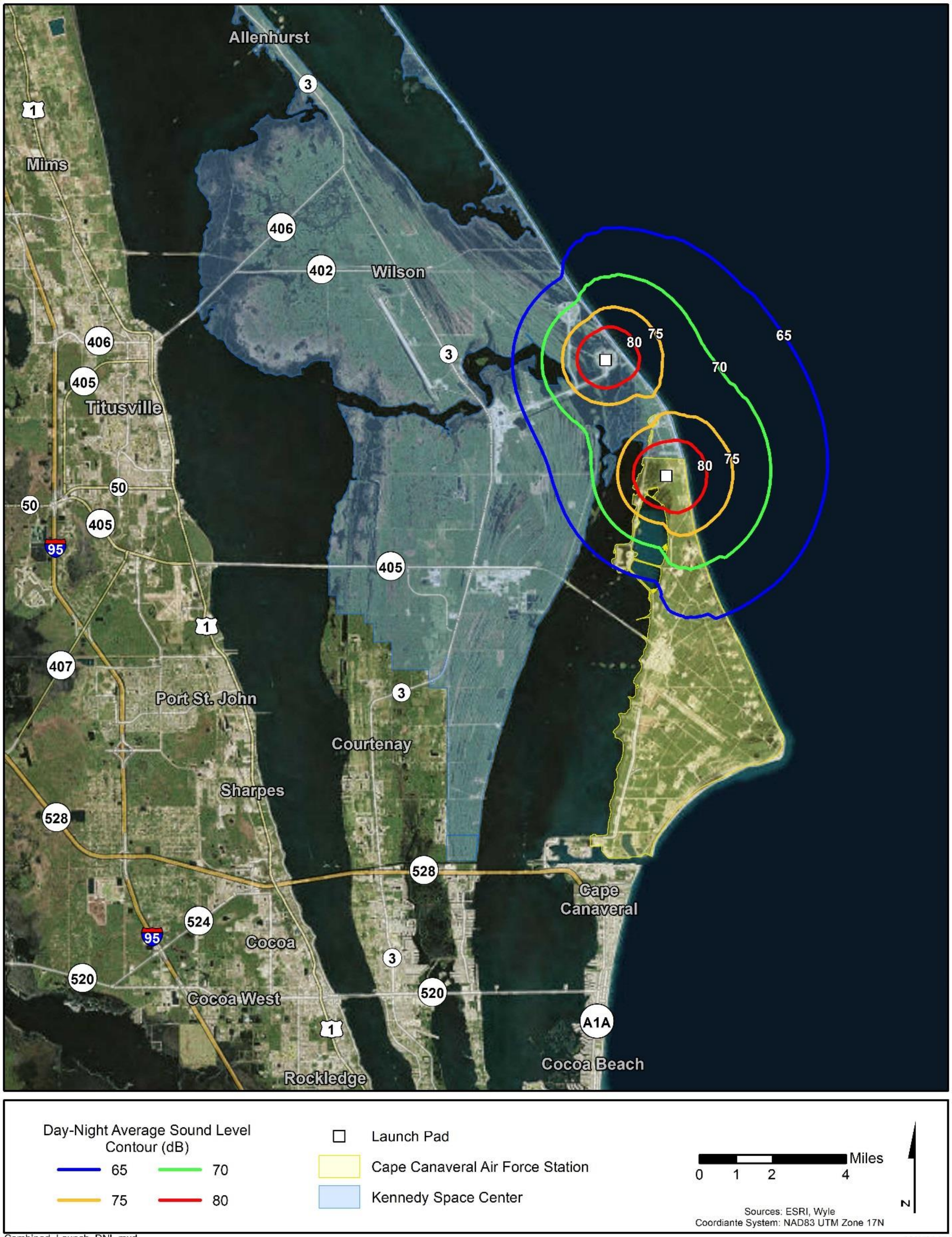


Figure 32. DNL for all Launches of Falcon Heavy (LC-39A) and Falcon 9 (LC-39A and LC-40) in 2024

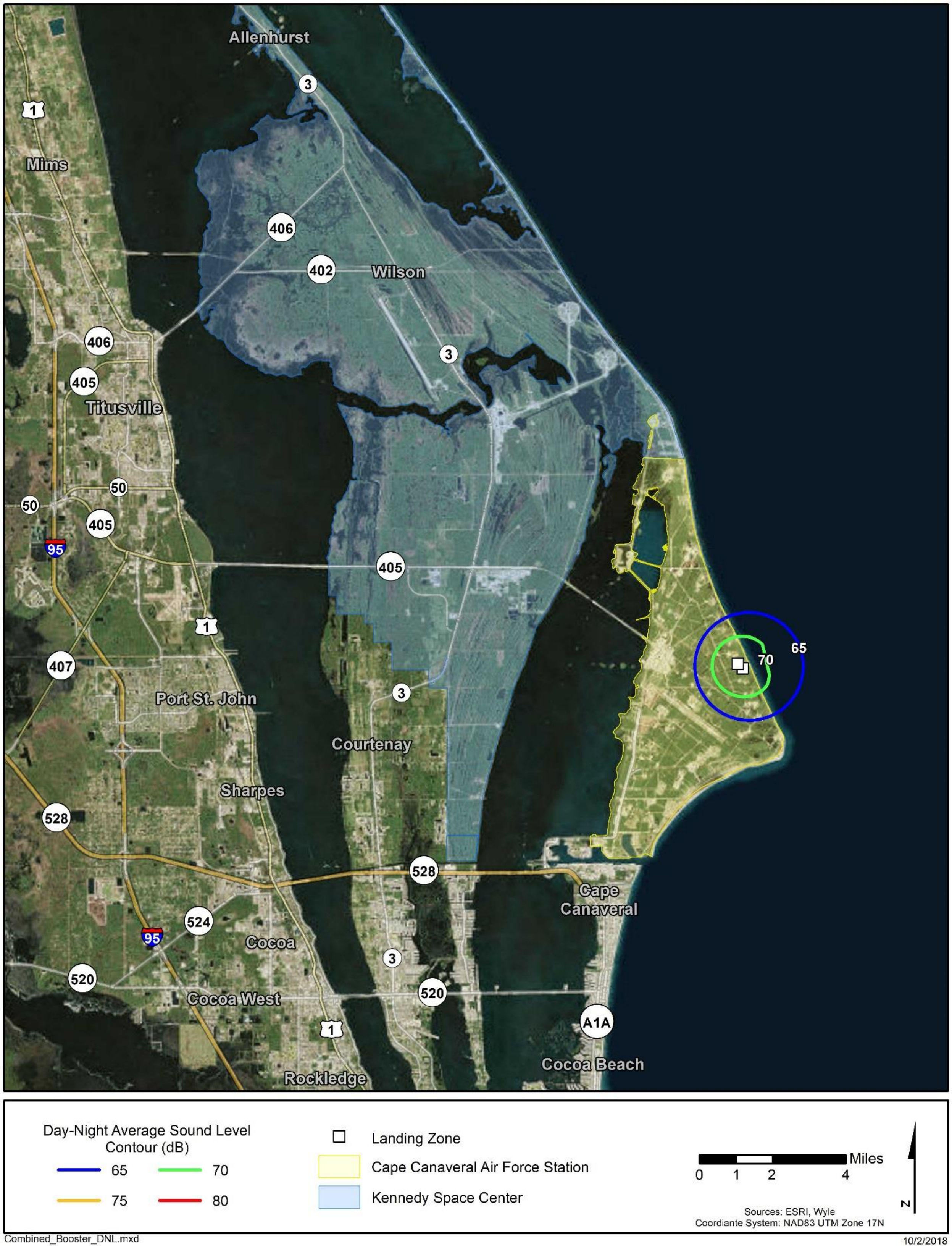


Figure 33. DNL for Simultaneous Booster Landings at LZ-1 and LZ-2 in 2024

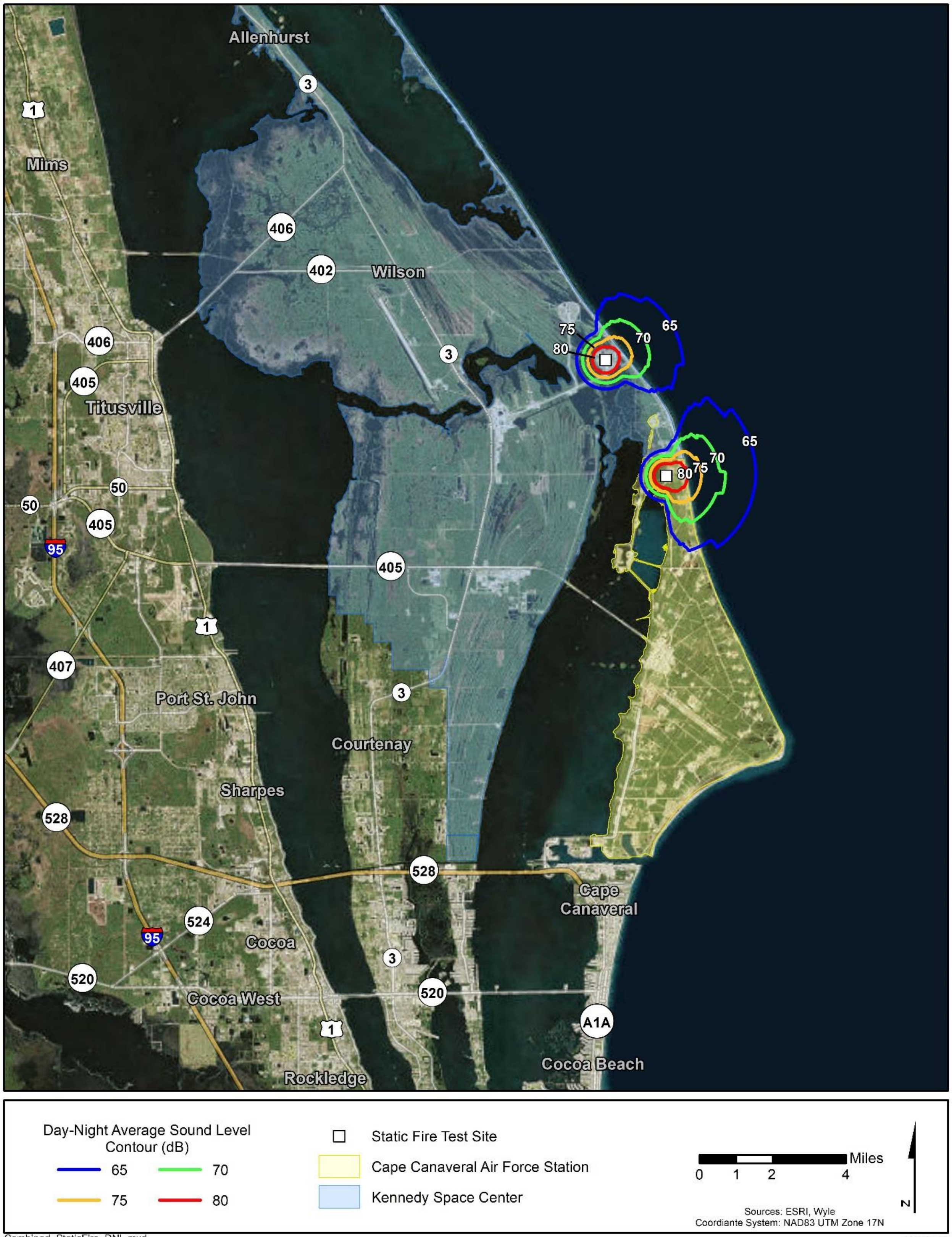


Figure 34. DNL for Static Fire Tests of Falcon Heavy (LC-39A) and Falcon 9 (LC-39A and LC-40) in 2024

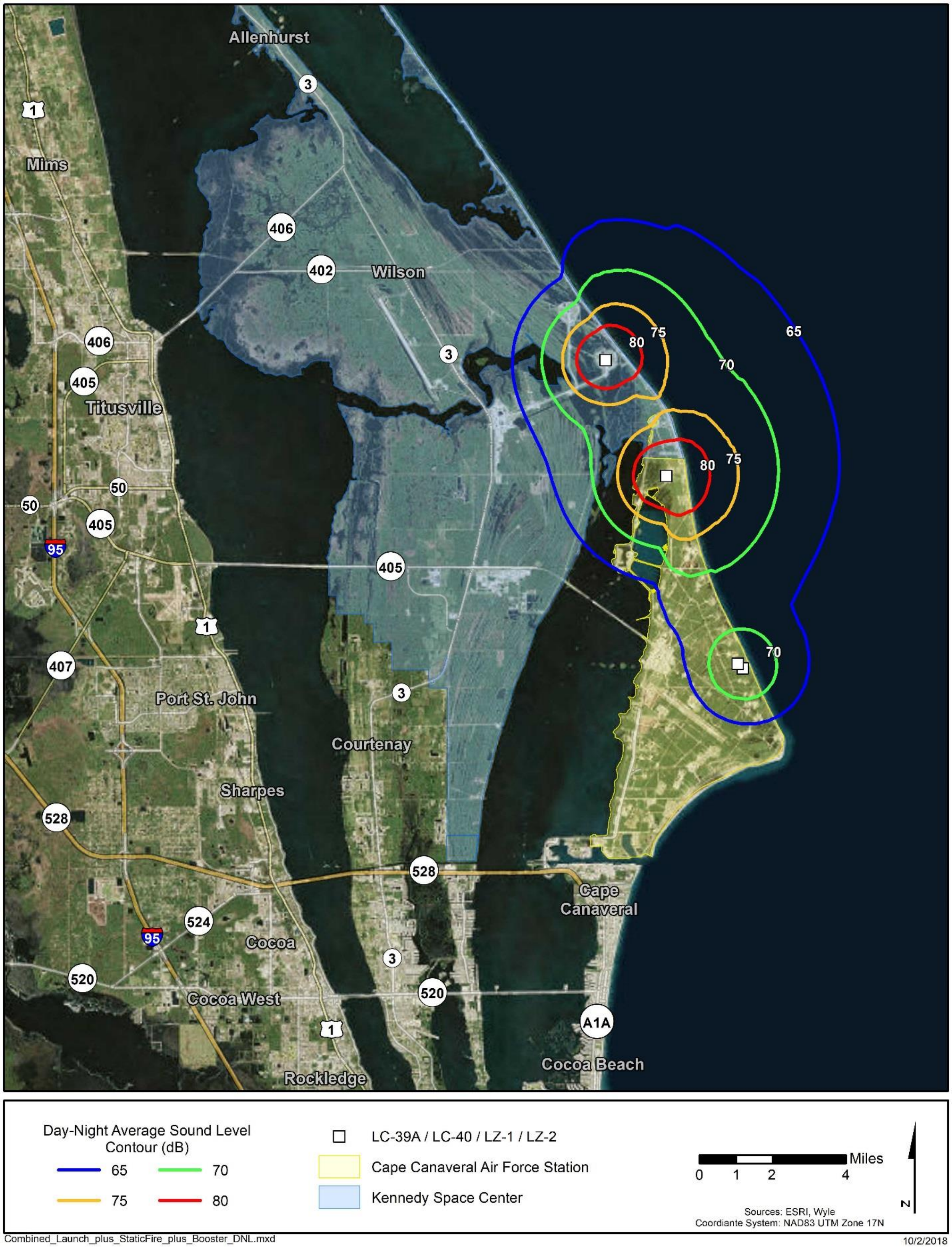


Figure 35. DNL for Falcon Heavy and Falcon 9 Launches, Static Fire Tests, and Booster Landings in 2024

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Attachment 2. Sonic Boom Assessment for a Falcon Launch Vehicle Polar Mission

Blue Ridge Research and Consulting, LLC

Technical Report

Sonic Boom Analysis for SpaceX's Falcon 9 Polar Launch and Lading Operations from CCAFS

March 1, 2019

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Acronyms and Abbreviations

The following acronyms and abbreviations are used in the report:

BRRC	Blue Ridge Research and Consulting, LLC
CCAFS	Cape Canaveral Air Force Station
dB	Decibel
dBA	A-weighted Decibel Level
DNL	Day-Night Average Sound Level
DOD	Department of Defense
FAA	Federal Aviation Administration
ft	Foot/Feet
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
P_k	Peak Pressure
psf	Pounds per Square Foot
SEL	Sound Exposure Level in decibels
SLC	Space Launch Complex
SpaceX	Space Exploration Technologies Corp.

1 Introduction

This report documents the sonic boom analysis performed as part of Space Exploration Technologies Corp.'s (SpaceX's) environmental analysis for the proposed Falcon 9 polar launch and landing operations from Cape Canaveral Air Force Station (CCAFS). SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS Space Launch Complex 40 (SLC-40). The largest configuration, Falcon 9 with composite fairing as shown in Figure 1, will be modeled to determine the potential for sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts will be evaluated for a nominal trajectory for up to five annual launches per year. Potential sonic boom impacts are evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

This noise study describes the sonic booms associated with the proposed Falcon 9 polar operations. Section 2 describes the proposed Falcon 9 polar operations; Section 3 summarizes the basics of sound and describes the noise metrics and impact criteria discussed throughout this report; Section 4 describes the general methodology of the sonic boom modeling; and Section 5 presents the sonic boom modeling results. A summary is provided in Section 6 to document the notable findings of this sonic boom analysis.

Figure 1. SpaceX's Falcon 9 with composite fairing (left), launch of Falcon 9 (middle), and droneship landing of the Falcon 9's first stage (right) (image credit: SpaceX)

2 Falcon 9 Polar Operations

SpaceX's Falcon 9 is a two-stage rocket that delivers payloads to space inside a composite fairing or aboard the Dragon spacecraft. The Falcon 9 with composite fairing will be modeled to determine the potential extent of sonic boom impacts from Falcon 9 launches. The vehicle parameters are presented in Table 1.

Table 1. Vehicle modeling parameters

Modeling Parameters	Values
Manufacturer	SpaceX
Name	Falcon 9
Length	272 ft (launch w/fairing) 154 ft (1st stage landing)
Diameter	12 ft
Gross Vehicle Weight	1,200,000 lbs (launch w/fairing) 97,000 lbs (1st stage landing)

Falcon 9 polar trajectories flown from CCAFS SLC-40 will be unique to the vehicle configuration, mission, and environmental conditions. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. For the purposes of this study, the sonic boom modelling utilizes a nominal launch trajectory provided by SpaceX [1] and shown in Figure 2 to model the sonic booms generated from Falcon 9 polar operations. The nominal launch trajectory follows an azimuth of approximately 160° for most of the trajectory.

The proposed action includes a total of five annual launch operations, four of which are planned to occur during acoustic daytime hours (0700 - 2200), and one during acoustic nighttime hours (2200 – 0700).

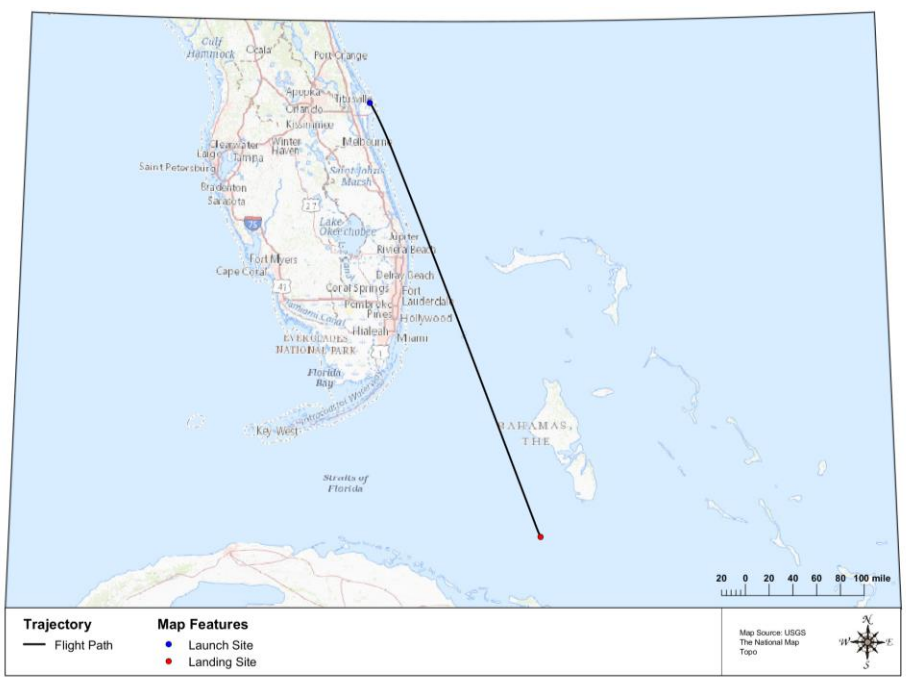

Figure 2. Falcon 9 polar trajectory

3 Acoustics Overview

An overview of sound-related terms, metrics, and effects, which are pertinent to this study, is provided to assist the reader in understanding the terminology used in this noise study.

3.1 Fundamentals of Sound

Any unwanted sound that interferes with normal activities or the natural environment is defined as noise. Three principal physical characteristics are involved in the measurement and human perception of sound: intensity, frequency, and duration [2].

- **Intensity** is a measure of a sound's acoustic energy and is related to sound pressure. The greater the sound pressure, the more energy is carried by the sound and the louder the perception of that sound.
- **Frequency** determines how the pitch of the sound is perceived. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.
- **Duration** is the length of time the sound can be detected.

The loudest sounds that can be comfortably detected by the human ear have intensities a trillion times higher than those of sounds barely audible. Because of this vast range, using a linear scale to represent the intensity of sound can become cumbersome. As a result, a logarithmic unit known as the decibel (abbreviated dB) is often used to represent sound levels. A sound level of 0 dB approximates the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level around 60 dB. Sound levels above 120 dB begin to be felt inside the human ear as discomfort. Sound levels between 130 and 140 dB are experienced as pain [3].

The intensity of sonic booms is quantified with physical pressure units rather than levels. Intensities of sonic booms are traditionally described by the amplitude of the front shock wave, referred to as the peak overpressure. The peak overpressure is normally described in units of pounds per square foot (psf). The amplitude is particularly relevant when assessing structural effects as opposed to loudness or cumulative community response. In this study, sonic booms are quantified by either psf or dB, as appropriate for the particular impact being assessed [4]. A chart of typical impulsive events along with their corresponding peak overpressures in terms of psf and peak dB values are shown in Figure 3. For example, thunder overpressure resulting from lightning strikes at a distance of one kilometer (0.6 miles) is estimated to be near two psf, which is equivalent to 134 dB [5].

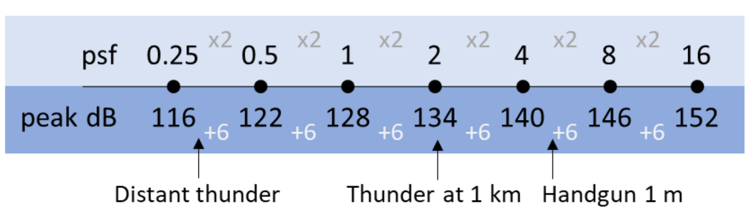

Figure 3. Typical impulsive event levels [5]

Sound frequency is measured in terms of cycles per second or hertz (Hz). Human hearing ranges in frequency from 20 Hz to 20,000 Hz, although perception of these frequencies is not equivalent across this range. Human hearing is most sensitive to frequencies in the 1,000 to 4,000 Hz range. Most sounds are not simple pure tones, but contain a mix, or spectrum, of many frequencies. Sounds with different spectra are perceived differently even if the sound levels are the same. Weighting curves have been developed to correspond to the sensitivity and perception of different types of sound. A-weighting and C-weighting are the two most common weightings. These two curves, shown in Figure 4, are adequate to quantify most environmental noises. A-weighting puts emphasis on the 1,000 to 4,000 Hz range to match the reduced sensitivity of human hearing for moderate sound levels. For this reason, the A-weighted decibel level (dBA) is commonly used to assess community sound.

Very loud or impulsive sounds, such as explosions or sonic booms, can sometimes be felt, and they can cause secondary effects, such as shaking of a structure or rattling of windows. These types of sounds can add to annoyance and are best measured by C-weighted sound levels, denoted dBC. C-weighting is nearly flat throughout the audible frequency range and includes low frequencies that may not be heard but cause shaking or rattling. C-weighting approximates the human ear's sensitivity to higher intensity sounds.

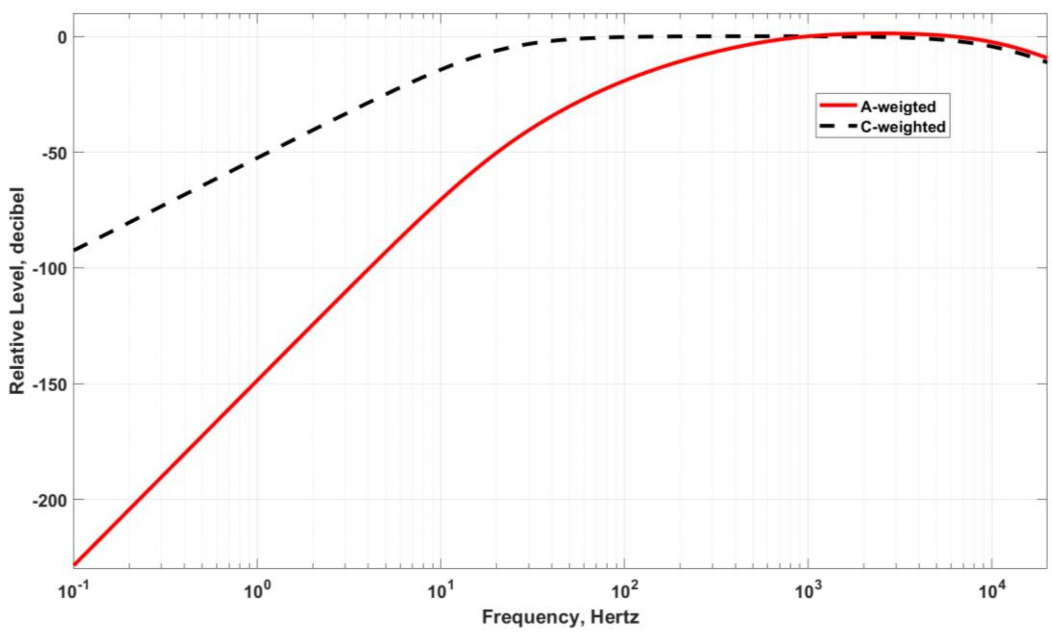

Figure 4. Frequency adjustments for A-weighting and C-weighting [6]

Sound sources can contain a wide range of frequency (pitch) content as well as variations in extent from short-durations to continuous, such as back-up alarms and ventilation systems, respectively. Sonic booms are considered low-frequency impulsive noise events with durations lasting a fraction of a second.

3.2 Noise Metrics

A variety of acoustical metrics have been developed to describe sound events and to identify any potential impacts to receptors within the environment. These metrics are based on the nature of the event and who or what is affected by the sound. A brief description of the noise metrics used in this noise study are provided below.

Peak Sound Level (L_{pk})

For impulsive sounds, the true instantaneous peak sound pressure level, which lasts for only a fraction of a second, is important in determining impacts. The peak pressure of the front shock wave is used to describe sonic booms, and it is usually presented in psf. Peak sound levels are not frequency weighted.

Day-Night Average Sound Level (DNL)

Day-Night Average Sound Level is a cumulative metric that accounts for all noise events in a 24-hour period. To account for our increased sensitivity to noise at night, DNL applies an additional 10 dB adjustment to events during the acoustical nighttime period, defined as 10:00 PM to 7:00 AM. The notations DNL and L_{dn} are both used for Day-Night Average Sound Level and are equivalent. DNL represents the average sound level exposure for annual average daily events. DNL does not represent a level heard at any given time but represents long term exposure to noise.

3.3 Noise Effects

Noise criteria have been developed to protect the public health and welfare of the surrounding communities. The impacts of launch vehicle sonic booms are evaluated on a cumulative basis in terms of human annoyance. In addition, the launch vehicle sonic boom impacts are evaluated on a single-event basis in relation to hearing conservation and potential structural damage. Although FAA Order 1050.1F does not have guidance on hearing conservation or structural damage criteria, it recognizes the use of supplemental noise analysis to describe the noise impact and assist the public's understanding of the potential noise impact.

3.3.1 Human Annoyance

A significant noise impact would occur if the "action would increase noise by DNL 1.5 dB[A] or more for a noise sensitive area that is exposed to noise at or above the DNL 65 dB[A] noise exposure level, or that will be exposed at or above this level due to the increase, when compared to the No Action Alternative for the same timeframe" [7]. A-weighted DNL is based on long-term cumulative noise exposure and has been found to correlate well with long-term community annoyance for regularly occurring events including aircraft, rail, and road noise [8, 9]. For impulsive noise sources with significant low-frequency content such as sonic booms, C-weighted DNL (CDNL) is preferred over A-weighted DNL [10]. In terms of percent highly annoyed, DNL 65 dBA is equivalent to CDNL 60 dBC [11]. Additionally, it has been noted that the DNL "threshold does not adequately address the effects of noise on visitors to areas within a national park or national wildlife refuge where other noise is very low and a quiet setting is a generally recognized purpose and attribute" [7]. DNL contours are provided as the most widely accepted metric to estimate the changes in long-term community annoyance.

3.3.2 Hearing Conservation

Multiple federal government agencies have provided guidelines on permissible noise exposure limits on impulsive noise such as a sonic boom. These documented guidelines are in place to protect one's hearing from exposures to high noise levels and aid in the prevention of noise-induced hearing loss (NIHL). In terms of upper limits on impulsive noise levels; National Institute for Occupational Safety and Health (NIOSH) [12], Occupational Safety and Health Administration (OSHA) [13], and the Department of Defense (DOD) [14] have stated that levels should not exceed 140 dB peak sound pressure level, which equates to a sonic boom level of approximately 4 psf.

3.3.3 Structural Damage

Sonic booms are also commonly associated with structural damage. Most damage claims are for brittle objects, such as glass and plaster. Table 2 summarizes the threshold of damage that may be expected at various overpressures [15]. A large degree of variability exists in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. The probability of a window breaking at 1 psf ranges from one in a billion [16] to one in a million [17]. These damage rates are associated with a combination of boom load and window pane condition. At 10 psf, the probability of breakage is between one in 100 and one in 1,000. Laboratory tests involving glass [18] have shown that properly installed window glass will not break at overpressures below 10 psf even when subjected to repeated booms. However, in the real world, installed window glass is not always in pristine condition.

Damage to plaster occurs at similar ranges to glass damage. Plaster has a compounding issue in that it will often crack due to shrinkage while curing or from stresses as a structure settles, even in the absence of outside loads. Sonic boom damage to plaster often occurs when internal stresses are high as a result of these factors. In general, for well-maintained structures, the threshold for potential damage from sonic booms is 2 psf [15]; below 2 psf, damage is unlikely.

Table 2. Possible damage to structures from sonic booms [15]

***Nominal* Level *and* *Comparative* Events**	**Damage Type**	**Item Affected**
0.5 – 2 psf *Compares to piledriver at construction site*	Plaster	Fine cracks; extension of existing cracks; more in ceilings; over doorframes; between some plasterboards.
	Glass	Rarely shattered; either partial or extension of existing.
	Roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Those carefully balanced or on edges can fall; fine glass, such as large goblets, can fall and break.
	Other	Dust falls in chimneys.
2 – 4 psf *Compares to cap gun or firecracker near ear*	Glass, plaster, roofs, ceilings	Failures show that would have been difficult to forecast in terms of their existing localized condition. Nominally in good condition.
4 – 10 psf *Compares to handgun at shooter's ear*	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, in fairly good condition can collapse.
	Walls (in)	Inside ("party") walls known to move at 10 psf.
> 10 psf *Compares to fireworks display from viewing stand*	Glass	Some good glass will fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plasterboards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gale-end and will-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Internal party walls can move even if carrying fittings such as hand basins or taps; secondary damage due to water leakage.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

4 Sonic Boom Modeling

A vehicle creates sonic booms during supersonic flight. The potential for the boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. The sonic boom is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom. The noise is perceived as a deep boom, with most of its energy concentrated in the low frequency range. Although sonic booms generally last less than one second, their potential for impact may be considerable.

When a vehicle moves through the air, it pushes the air out of its way. At subsonic speeds, the displaced air forms a pressure wave that disperses rapidly. At supersonic speeds, the vehicle is moving too quickly for the wave to disperse, so it remains as a coherent wave. This wave is a sonic boom. When heard at ground level, a sonic boom consists of two shock waves (one associated with the forward part of the vehicle, the other with the rear part) of approximately equal strength and (for fighter aircraft) separated by 100 to 200 milliseconds. When plotted, this pair of shock waves and the expanding flow between them has the appearance of a capital letter "N," so a sonic boom pressure wave is usually called an "N-wave." An N-wave has a characteristic "bang-bang" sound that can be startling. Figure 5 shows the generation and evolution of a sonic boom N-wave under the vehicle.

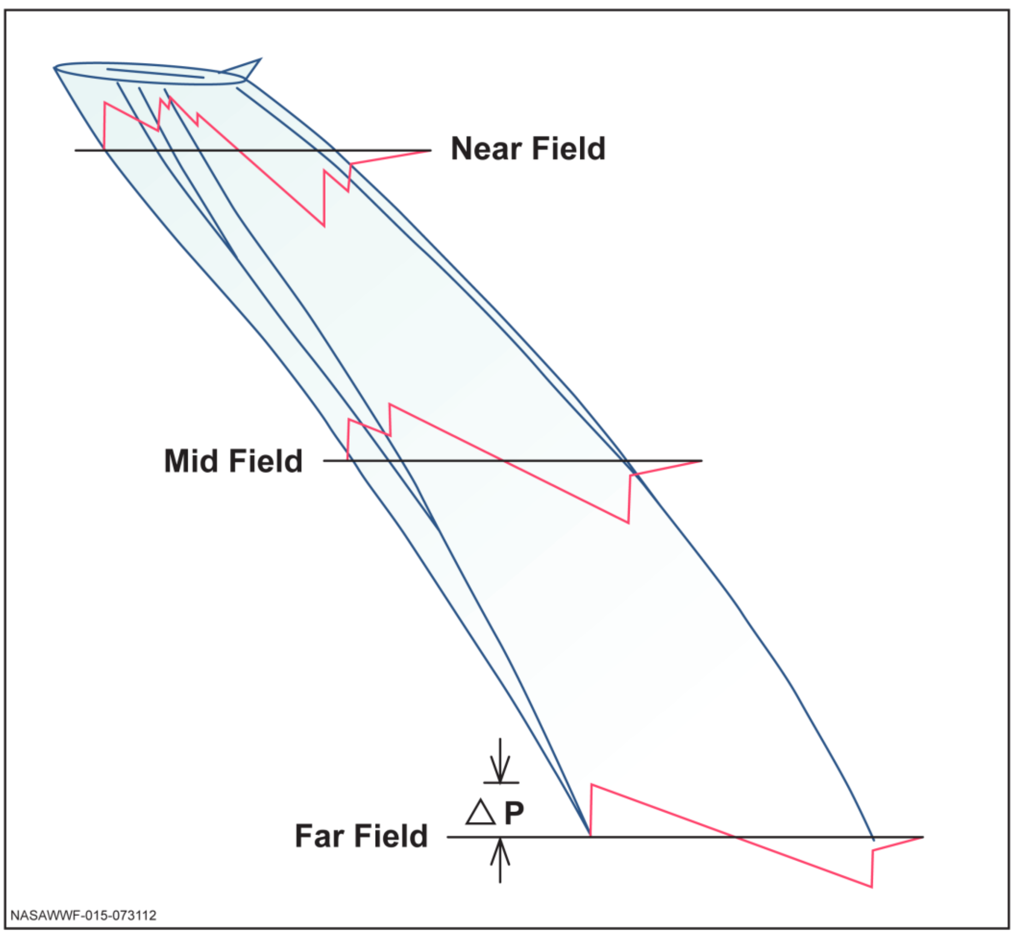

Figure 5. Sonic boom generation and evolution to N-wave [19]

Figure 6 shows the sonic boom pattern for a vehicle in steady, level supersonic flight. The boom forms a cone that is said to sweep out a "carpet" under the flight track. The boom levels vary along the lateral extent of the "carpet" with the highest levels directly underneath the flight track and decreasing levels as the lateral distance increases to the cut-off edge of the "carpet." When the vehicle is maneuvering, the sonic boom energy can be focused in highly localized areas on the ground.

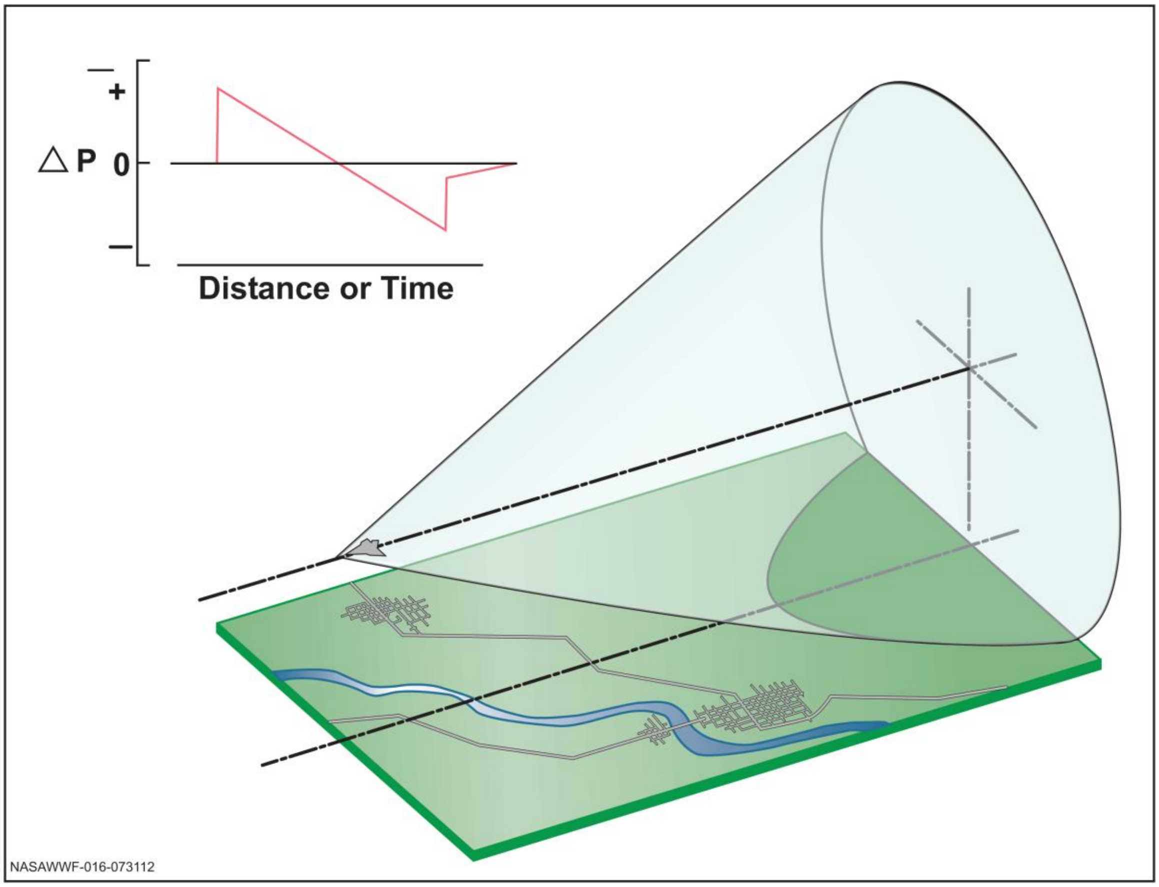

Figure 6. Sonic boom carpet for a vehicle in steady flight [20]

The complete ground pattern of a sonic boom depends on the size, weight, shape, speed, and trajectory of the vehicle. Since aircraft fly supersonically with relatively low horizontal angles, the boom is directed toward the ground. However, for rocket trajectories, the boom is directed upward and laterally until the rocket rotates significantly away from vertical, as shown in Figure 7. This difference causes a sonic boom from a rocket to propagate much further downrange compared to aircraft sonic booms. This extended propagation usually results in relatively lower sonic boom levels from rocket launches. For aircraft, the front and rear shock are generally the same magnitude. However, for rockets, in addition to the two shock waves generated from the vehicle body, the plume itself acts as a large supersonic body, and it generates two additional shock waves (one associated with the forward part of the plume, the other with the rear part) and extends the waveform duration to as large as one second. The sonic boom generated by the plume is stronger since the plume volume is significantly larger than the rocket.

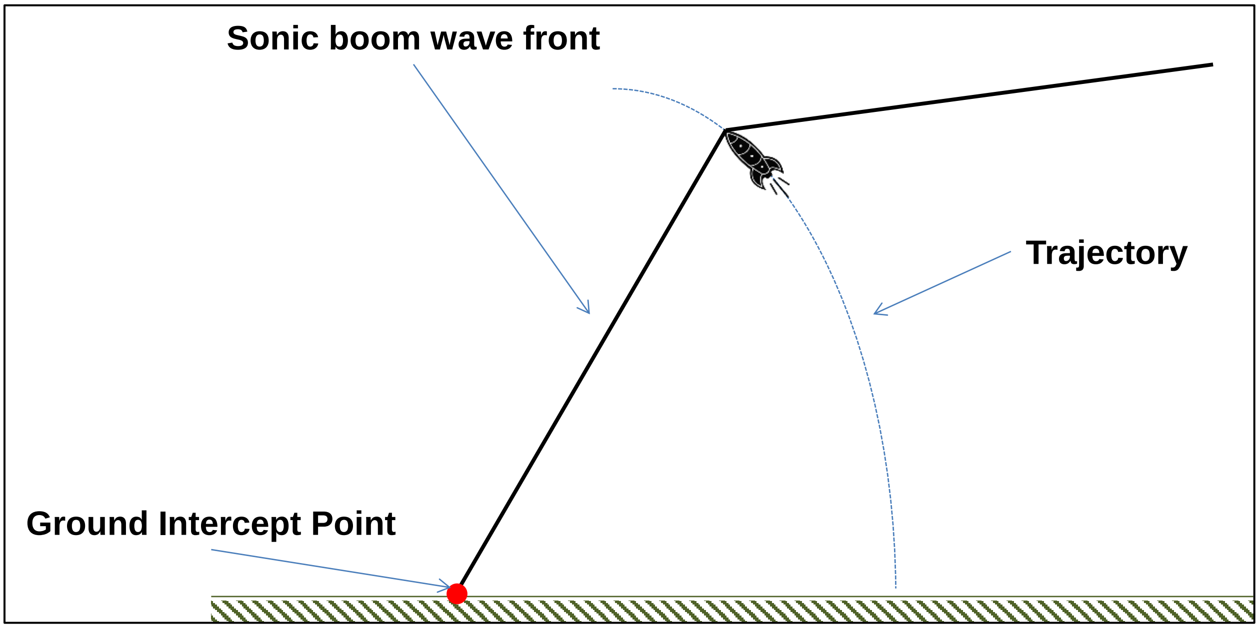

Figure 7. Sonic boom propagation for rocket launch

The single-event prediction model, PCBoom [21, 22, 23] is used to predict the sonic boom footprint from a supersonic vehicle trajectory. PCBoom is a full ray trace sonic boom program that calculates the magnitude, waveform, and location of sonic boom overpressures on the ground from supersonic flight operations. The model computes detailed ground signature shapes from a variety of near-field signature definitions. Additionally, PCBoom accounts for the effect of underexpanded rocket exhaust plumes on the boom [24]. Several inputs are required to calculate the sonic boom impact, including the aircraft 3-dimensional model, the trajectory path, the atmospheric conditions and the ground surface height. Predicted sonic boom footprints are presented in the form of equal pressure contours.

5 Results

The following section presents the results of the environmental sonic boom impacts associated with the proposed Falcon 9 polar operations. Site-specific atmospheric profiles including temperature and wind were used to model the sonic boom impacts. The modeled sonic boom contours associated with the polar launch and droneship landing of the Falcon 9 are presented in Figure 8 and Figure 9, respectively. In addition to the contours, the black ground path represents the portion of supersonic flight that is below the edge of space and generates sonic boom footprints that intercept the ground.

Falcon 9 Polar Launch

The sonic boom wavefront for a vertical rocket launch is directed upward and laterally during the initial portion of the launch, and thus it does not intercept the ground. As the vehicle rotates away from the vertical and its velocity increases, the sonic boom wavefront starts to be directed toward the ground. At this point the sonic boom will begin to intercept the ground. The Falcon 9 polar launch generates a sonic boom over a long, narrow, forward-facing crescent shaped focus boom region as shown in Figure 8. As the vehicle continues to ascend, the sonic boom levels generated decrease and the crescent shape becomes slightly longer and wider. A summary of the modeled results is detailed below:

- The sonic boom is modeled to intercept the southern Florida Atlantic coastal region including the communities of Vero Beach, Fort Pierce, and Port St Lucie along the coast; as well as inland communities near Okeechobee. The contours extend approximately 30 miles along the coast and reach up to approximately 75 miles west of the coast. The vast-majority of this region will experience peak overpressures of less than 1 psf. Areas south of Port St. Lucie and Okeechobee may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.
- A narrow focus boom region north of Vero Beach, with land area less than 3 square miles, is modeled to receive levels greater than 2 psf. In this region, the modeled peak overpressure may reach 4.6 psf, but these levels occur over significantly smaller areas (less than 0.01 square miles). Note, the location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions at the time of flight. Therefore, it is unlikely that any given location will experience the focus more than once over multiple events.

The maximum modeled overpressure levels are predicted to be less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region that experience sonic booms from Falcon 9 polar launches. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels between 2 to 4 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf (less than 0.01 square miles). The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

A modeled maximum peak overpressure of 4.6 psf translates to an equivalent CDNL of 51 dBC for the maximum projected reentry operation tempo. Therefore, the proposed Falcon 9 polar launch operation does not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA).

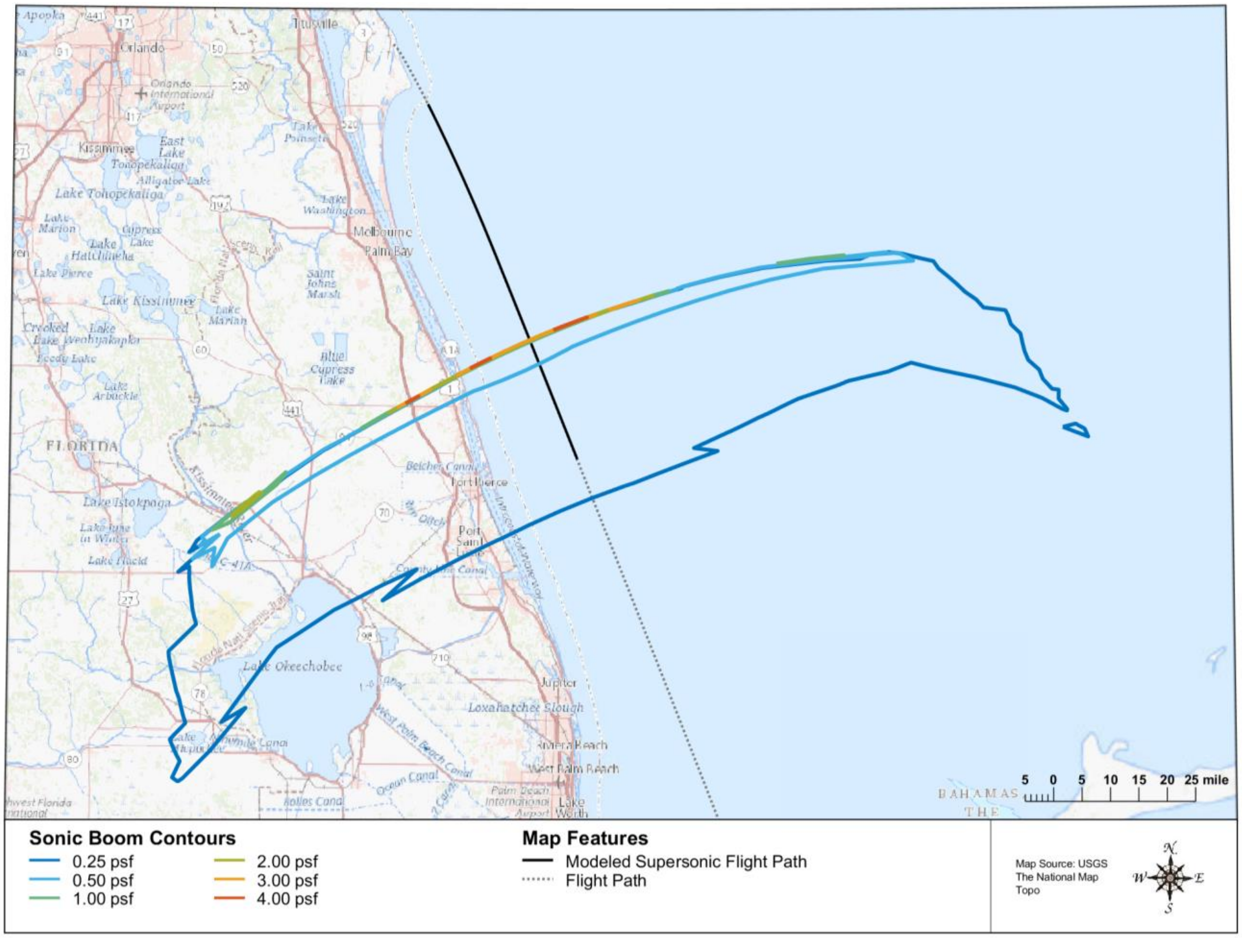

Figure 8. Sonic boom peak overpressure contours for the Falcon 9 polar launch

Note, sonic booms have previously impacted mainland Florida during shuttle orbiter reentries, with measured levels ranging from about 0.6 psf from the vehicle at higher altitudes to a maximum of 2.3 psf just prior to landing [25].

Falcon 9 Polar Droneship Landing

The Falcon 9 polar droneship landing modeled sonic boom contours are presented in Figure 9. After the first stage separates and the vehicle descends, the sonic boom will intercept the ground. As the vehicle descends further, the sonic boom contours become smaller and end when the vehicle's speed becomes subsonic. A summary of the modeled results is detailed below:

- The crescent shaped portion of the contours includes land area on the southern part of Andros Island within the Bahamas, the majority of which is part of West Side National Park but also includes small settlements along the eastern coast near Kemp's Bay. The predicted overpressure levels for a vast majority of this area is less than 0.5 psf. North Andros Island and as far north as New Providence Island may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.

- An area of approximately 18 square miles of ocean surrounding the droneship landing site may experience levels of 3 psf and above. In this region, the predicted levels are up to 4 psf, but they occur over significantly smaller areas.

Although the maximum peak overpressure level is predicted to be 4 psf (located adjacent to the droneship landing site), it should be noted that the maximum level measured adjacent to the CCAFS landing site during the July 18, 2016 landing event was 5.48 psf [26].

The potential for structural damage is unlikely as the modeled sonic boom overpressure levels over land are less than 2 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are substantially lower than the ~4 psf impulsive hearing conservation noise criteria. For the maximum projected reentry operation tempo, peak overpressures of approximately 0.5 psf translate to an equivalent CDNL that is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA). Therefore, the proposed Falcon 9 polar landing operation does not pose a significant impact with regards to human annoyance.

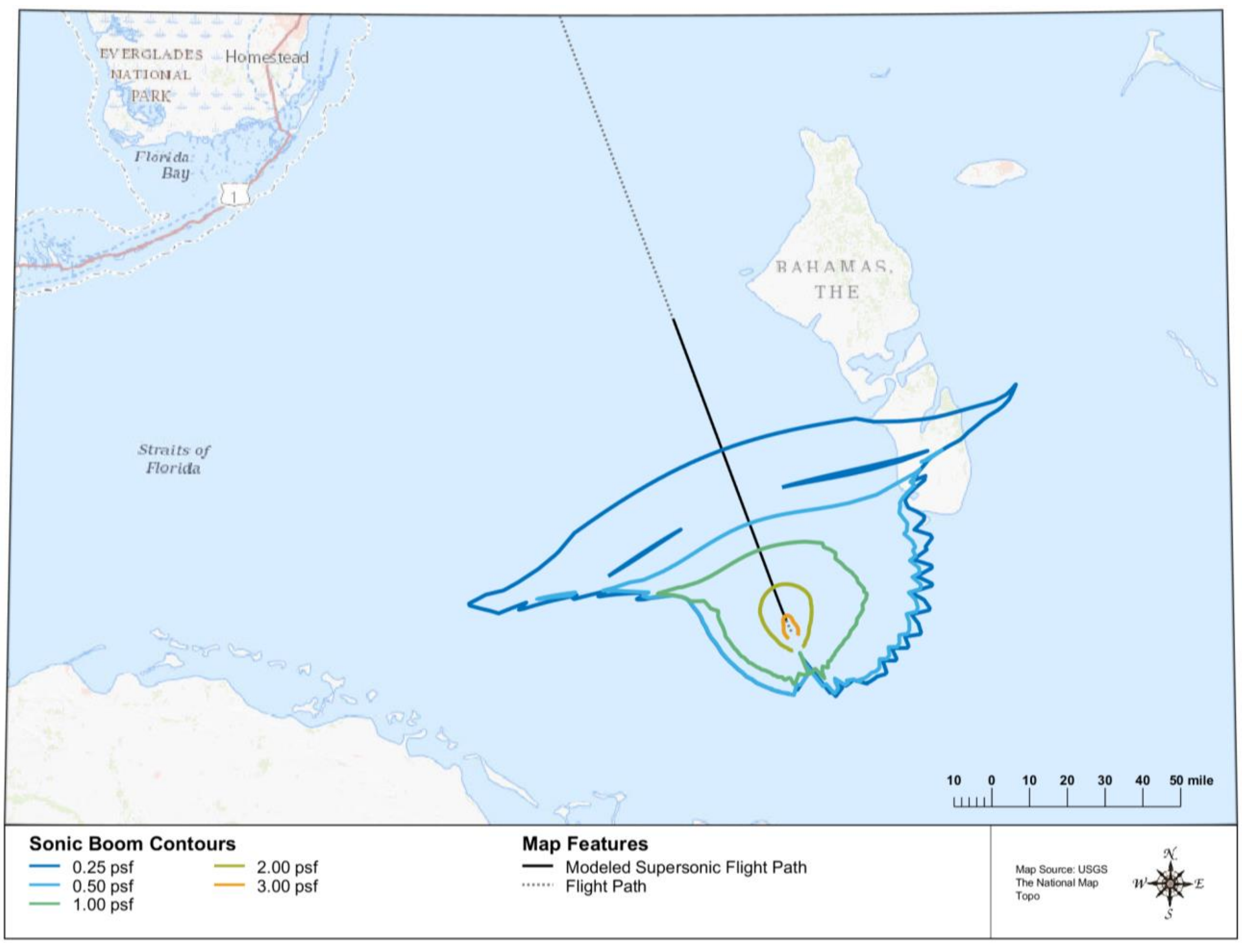

Figure 9. Sonic boom peak overpressure contours for the Falcon 9 polar droneship landing

Although the proposed polar operations do not pose significant impacts in relation to human annoyance, hearing conservation, or structural damage; the unexpected, loud impulsive noise of sonic booms tend to cause a startle effect in people. However, when humans are exposed to impulse noises with similar characteristics on a regular basis, they tend to become conditioned to the stimulus and the resulting startle reaction is generally not displayed. The physiological effects of single sonic booms on humans [27] for the levels produced by the proposed operations can be grouped as presented in Table 3.

Table 3. Physiological effects of single sonic booms on humans [27]

Sonic boom overpressure	Behavioral effects
< 0.3 psf	Orienting, but no startle response; eyeblink response in 10% of subjects; no arm/hand movement.
0.6 – 2.3 psf	Mixed pattern of orienting and startle responses; eyeblink in about half of subjects; arm/hand movements in about a fourth of subjects, but not gross bodily movements.
2.7 – 6.5 psf	Predominant pattern of startle responses; eyeblink response in 90 percent of subjects; arm/hand movements in more than 50 percent of subjects with gross body flexion in about a fourth of subjects.

6 Summary

This report documents the sonic boom analysis performed as part of SpaceX's efforts on the environmental analysis for the proposed Falcon 9 polar launch and landing operations from CCAFS. SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS SLC-40. The largest configuration, Falcon 9 with composite fairing, was modeled to determine potential sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts were evaluated for a nominal launch trajectory for up to five annual launches per year. The potential sonic boom impacts were evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

The representative Falcon 9 polar launch generated sonic boom peak overpressures of less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region the sonic boom is modeled to intercept. A narrow focus boom region north of Vero Beach with land area less than 3 square miles is modeled to receive levels greater than 2 psf, with a maximum peak overpressure of approximately 4.6 psf. Note, focus regions are highly localized and dependent on the mission specific trajectory and atmospheric conditions during the launch event.

The proposed launch operations do not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels above 2 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

The representative Falcon 9 droneship landing generates peak overpressures over land of less than approximately 0.5 psf. Therefore, the proposed landing operations do not pose a significant impact with regards to human annoyance, structural damage, or hearing damage (with regards to humans).

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Attachment 3. Sonic Boom Assessment for a Falcon Launch Vehicle Booster Return to CCAFS

Blue Ridge Research and Consulting, LLC

Technical Memo

Sonic Boom Study for SpaceX Falcon 9 Flybacks to CCAFS and VAFB

March 2017

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BRRC 17-05

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1 Introduction

Sonic boom analysis has been completed for the SpaceX Falcon 9 reusable first stage flybacks to Cape Canaveral Air Force Station (CCAFS), Florida and Vandenberg Air Force Base (VAFB), CA. Recent sonic boom measurements collected by SpaceX personnel during the CRS-9 and CRS-10 missions from CCAFS present the opportunity to identify a PCBoom modeling methodology appropriate for modeling Falcon 9 flybacks. A comparison of measured and modeled results for the two CCAFS missions are presented along with modeled peak overpressure contours. Using the same PCBoom modeling methodology implemented for the CCAFS flybacks, the resulting sonic booms peak overpressure contours are also presented for Falcon 9 flybacks to VAFB.

2 Sonic Boom Modeling

A vehicle creates a sonic boom continuously during supersonic flight. The potential for a boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. A sonic boom waveform is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom heard on the ground. Sonic boom modeling and analysis utilized PCBoom4 software (1; 2), which includes the above factors. PCBoom4 calculates the magnitude and location of sonic boom overpressures on the ground from a vehicle in supersonic flight.

3 Cape Canaveral Air Force Station

The sonic boom peak overpressure measurements for two Falcon 9 flybacks to CCAFS, associated with the CRS-9 and CRS-10 missions, were compared to predicted levels generated using a number of PCBoom modeling methodologies to determine an appropriate modeling methodology based on optimal agreement between the measured and modeled levels. The modeling methodology identified uses PCBoom's mode 3, the Carlson F-function mode, and an axisymmetric shape factor of 0.084.

The trajectory and atmospheric profile data used to model the Falcon 9 flybacks to CCAFS were provided by SpaceX and summarized in Table 1. The CRS-9 and CRS-10 trajectory files include the supersonic portion of the Falcon 9's reusable first stage return to CCAFS. The CRS-9 and CRS-10 atmospheric data files include the winds, temperature, and pressure as a function of altitude as recorded by a weather balloon released prior to the launch and from a ground station approximately 1 mile from the landing site. The weather balloon data were provided for altitudes up to 11 miles. To extend the altitude range within the trajectory data, the temperature profile was extended using data obtained from the National Climatic Data Center (NCDC) Station 74794 at Cape Canaveral for altitudes up to 19 miles and the NASA Technical Memo 4511 and the "Handbook of Astronautical Engineering" (McGraw-Hill 1961) for altitudes up to 56 miles.

Table 1. Data provided by SpaceX

Mission	Trajectory Filename	Atmospheric Profile Filename	Date Received
CRS-9	CRS9_AsFlown.xlsx	F9_27_Boom_Atmospheric.xls	30 Jan 17
CRS-10	CRS10.txt	CRS_10_Boom_Atmospheric.xls	22 Mar 17

The CRS-9 and CRS-10 Falcon 9 flyback sonic boom peak overpressure levels are presented in Figure 1 along with the modeled levels. The peak overpressures are provided in pounds per square foot (psf) with the measured levels (green circles) compared to the modeled levels without wind (filled grey circles) and modeled with wind (outlined grey circles). Table 2 shows the measured levels compared to the predicted levels modeled without wind and with wind. The modeled levels for LZ-1 and Bldg 20185 locations are represented by a range of levels because the locations are within the highest modeled contour and are generated as the vehicles decelerate through Mach 1.0. The selected sonic boom modeling methodology results in predicted levels that compare favorably to measured levels, with a majority of the predictions within 0.5 psf of measured levels as shown in Table 2.

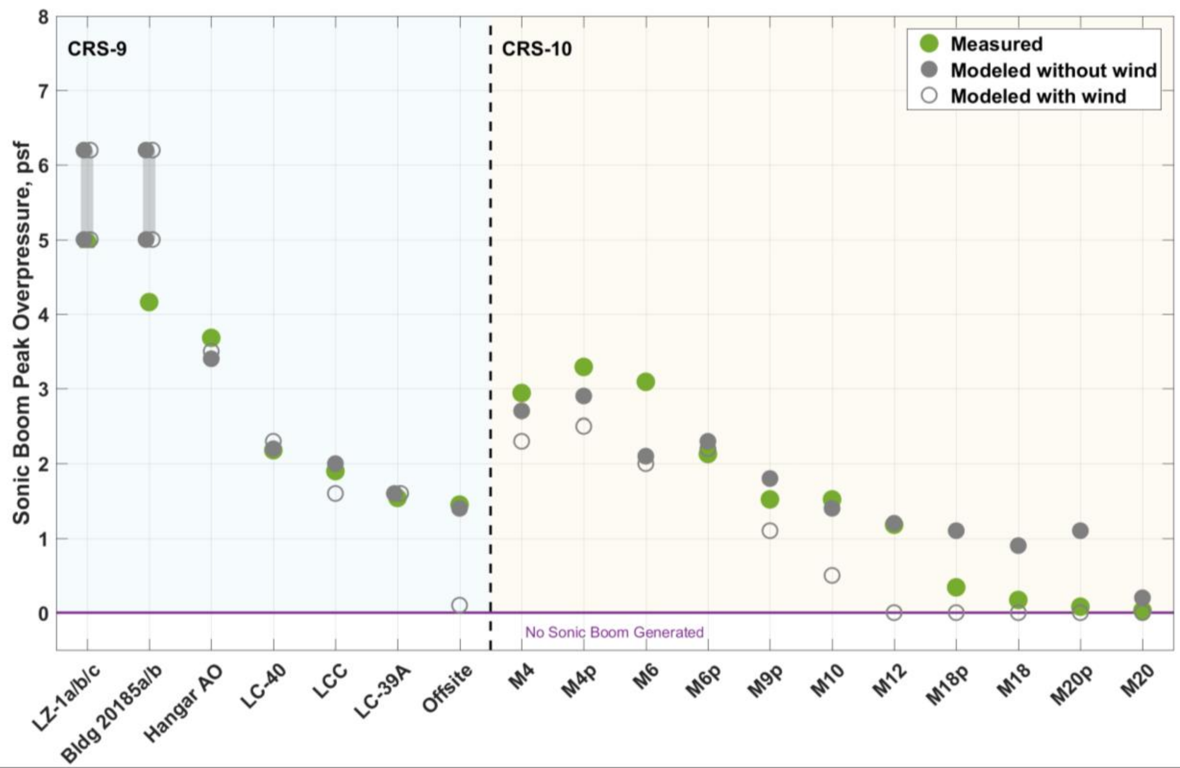

Figure 1. CRS-9 and CRS-10 measured vs. modeled peak overpressure levels comparison

The sonic boom peak overpressure contours are presented for CRS-9 in Figure 2 (without wind) and Figure 3 (with wind), and for CRS-10 in Figure 4 (without wind) and Figure 5 (with wind), along with the mission specific measurement locations (filled red circles). These figures demonstrate the effect wind has on the sonic boom footprint. For the cases with wind included, the sonic boom footprints are shifted and more complex because of the interaction of sonic boom propagation and wind speed profile. As the atmospheric profile was collected prior to the flyback operation, it is important to note that the actual sonic boom generated propagated through a similar but different wind speed profile. These figures provide a demonstration of the variation inherent in sonic boom propagating through a real atmosphere.

Overall, the comparison demonstrates great agreement between the measured and modeled data. Modeling results over-estimated levels for 12 of the 18 measurement locations (67%) when the wind data were not included and 9 measurement locations (50%) with wind included. Modeling without wind provided better estimates overall with levels within 0.1 psf for 14 of the 18 of the measurement locations (78%). The four sites in which modeling with wind results in a significantly smaller difference between measured and modeled are the four farthest CRS-10 measurement locations (M18p, M18, M20p, and M20). The estimated levels at these four sites is 0 psf (no sonic boom generated) because the CRS-10 winds effectively shifted the ground intercept of the sonic so that these last four sites were outside of the boom's footprint.

Table 2. Measured and modeled peak overpressure levels for CRS-9 and CRS-10 flybacks

				Atmosphere (without wind)		Atmosphere (with wind)	
	Location	Distance from LZ 1, miles	Measured psf	Predicted psf	Diff psf	Predicted psf	Diff psf
CRS 9	LZ-1a/b/c	0.2 - 0.3	5.0 - 5.5	5.0 - 6.2	0.0 - 1.2	5.0 - 6.2	0.0 - 1.2
	Bldg20185a/b	1.1 - 1.2	4.2 - 4.3	5.0 - 6.2	0.7 - 2.0	5.0 - 6.2	0.7 - 2.0
	Hanger AO	2.3	3.7	3.4	-0.3	3.5	-0.2
	LC-40	5.5	2.2	2.2	0.0	2.3	0.1
	LCC	6.0	1.9	2.0	0.1	1.6	-0.3
	LC-39A	9.3	1.5	1.6	0.1	1.6	0.1
	Offsite	10.1	1.5	1.4	-0.1	0.1	-1.4
CRS 10	M4	4.0	2.9	2.7	-0.2	2.3	-0.6
	M4p	4.1	3.3	2.9	-0.4	2.5	-0.8
	M6	6.0	3.1[a]	2.1	-1.0	2.0	-1.1
	M6p	6.0	2.1[a]	2.3	0.2	2.2	0.1
	M9p	9.5	1.5[b]	1.8	0.3	1.1	-0.4
	M10	9.9	1.5[a]	1.4	-0.1	0.5	-1.0
	M12	12.0	1.2[a]	1.2	0.0	0.0	1.2
	M18p	17.8	0.3	1.1	0.8	0.0	0.3
	M18	18.1	0.2	0.9	0.7	0.0	0.2
	M20p	20.1	0.1	1.1	1.0	0.0	0.1
	M20	20.8	0.03	0.2	0.17	0.0	0.03

[a] Value is estimated by SpaceX from Clipped Data.

[b] Data is from SpaceX Pad measurement and microphone has a 20 Hz – 20 kHz response.

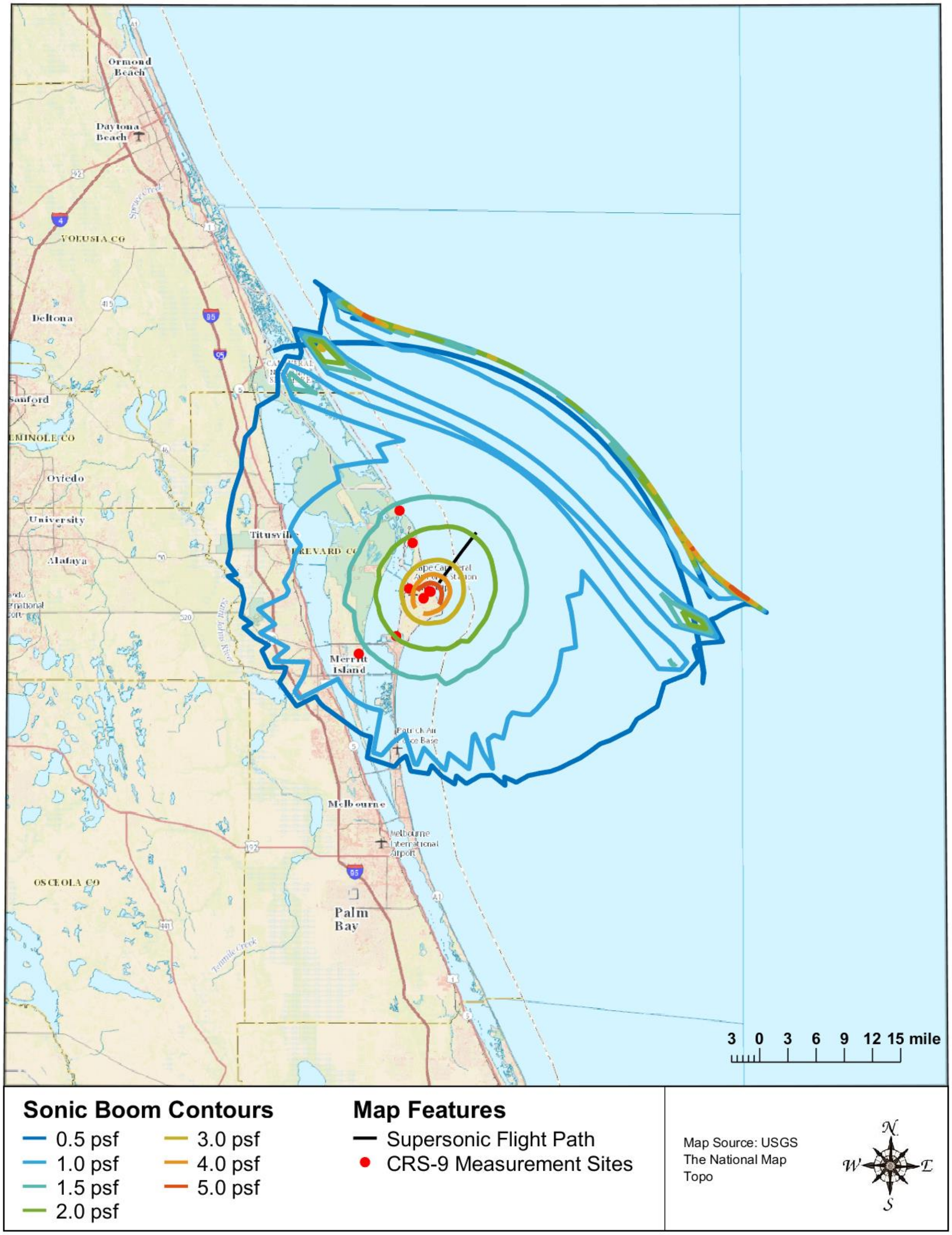

Figure 2. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled without wind

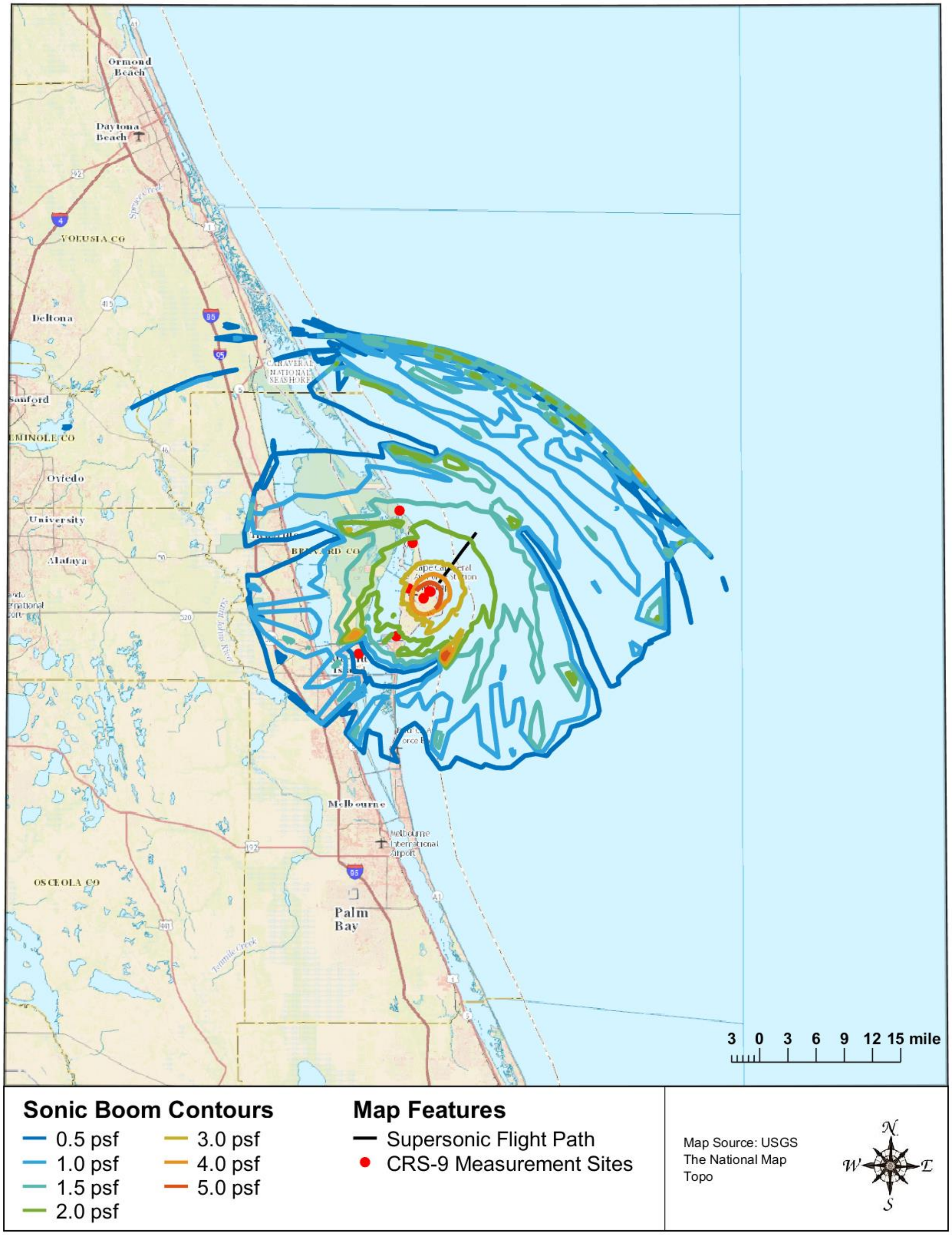

Figure 3. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled with wind

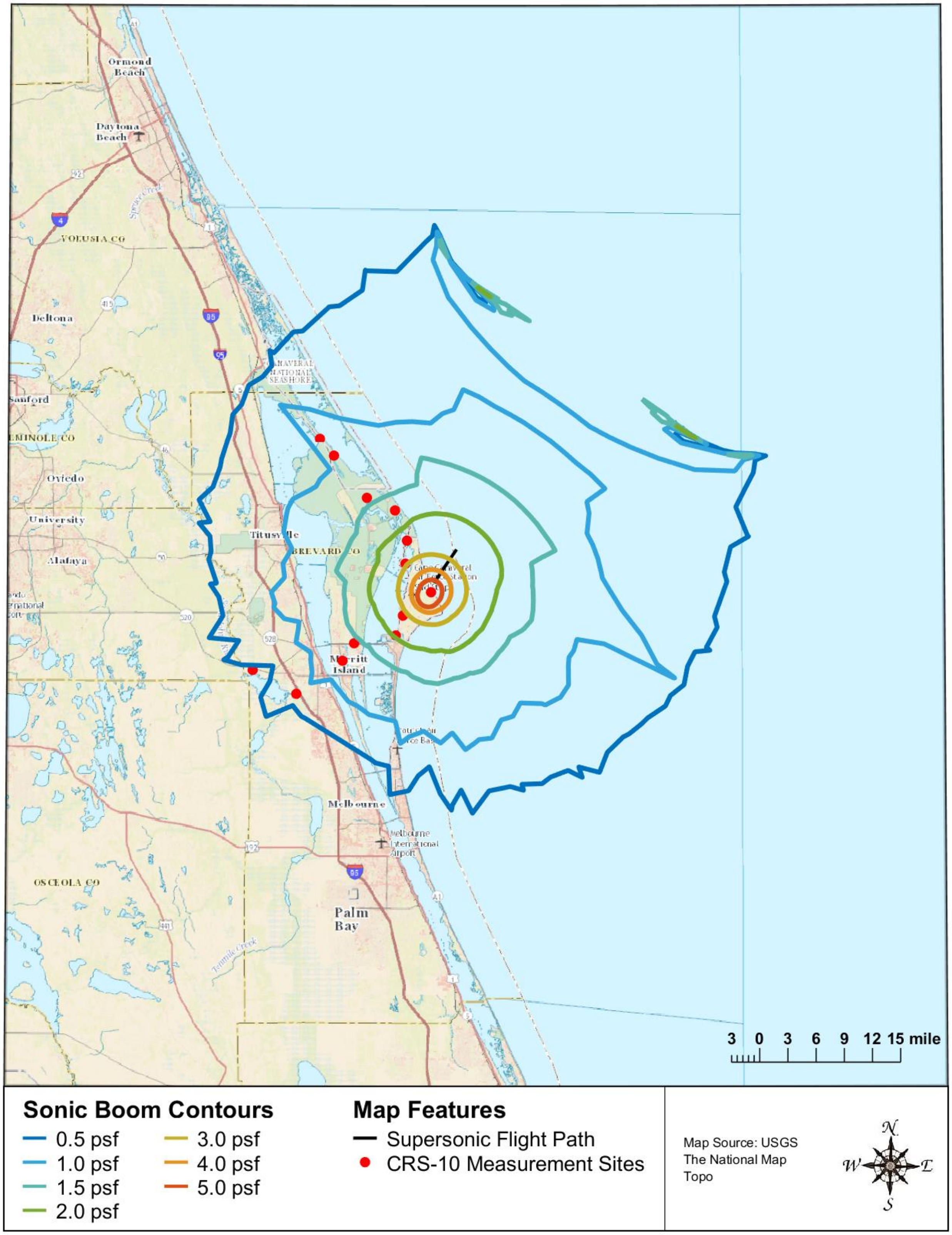

Figure 4. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled without wind

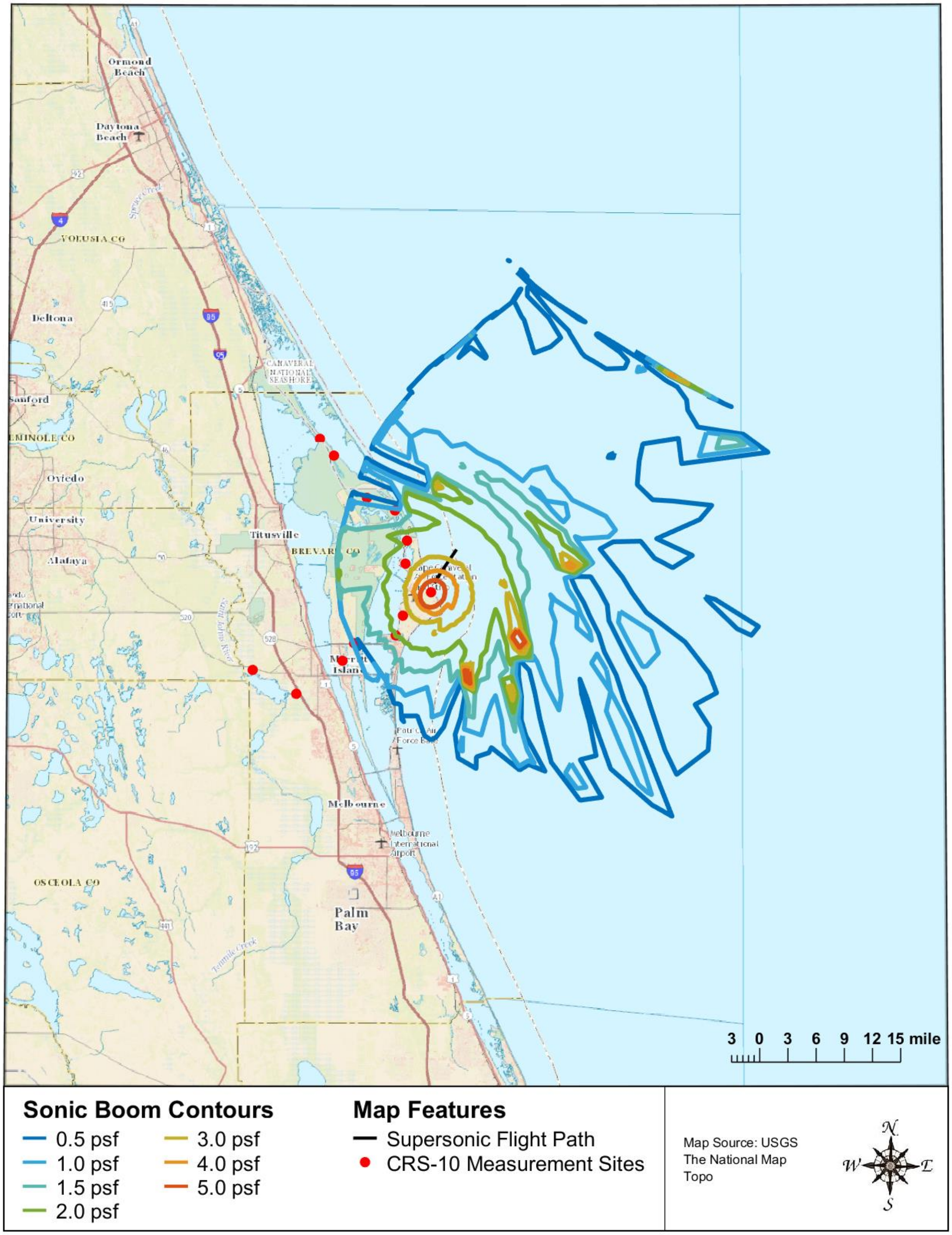

Figure 5. Sonic boom contours generated by the CRS-9 Falcon 9 flyback modeled with wind

4 Vandenberg Air Force Base

The peak overpressure contours, in psf, resulting from the Falcon 9 first stage flyback at VAFB are shown in Figure 6, along with the ground track of the boom-producing portion of the trajectory. Sonic boom modeling of the VAFB flyback used a nominal trajectory provided by SpaceX ('Iridium_Prediction.xlsx') and a U.S. standard atmospheric profile.

As the vehicle descends below 32 miles, the sonic boom generates a forward-facing crescent shaped contour. As the vehicle descends further, the sonic boom generates oval shaped contours, which end when the vehicle's speed becomes subsonic. A summary of the modeled results are detailed below:

- An area of approximately 7.6 square miles surrounding the landing site may experience levels of 5 psf and above. In this region, the predicted levels are up to 7.8 psf, but they occur over significantly smaller areas. The sonic boom levels fall to 2 psf approximately 7.8 miles east of the landing site near the western edge of the city of Lompoc. The 0.5 psf contour is bounded by Hwy 101 to the east and Orcutt to the north.
- The broad and narrow crescent shaped contour includes land area on Santa Rosa Island and the tip of Santa Cruz Island. The predicted overpressure levels in these areas are less than 2 psf. Note that the location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions at the time of flight. Therefore, it is unlikely that any given location will experience the focus more than once over multiple events.

Note, although the maximum peak overpressure level is predicted to be 7.8 psf (located adjacent to the landing site), it should be noted that levels measured adjacent to the CCAFS landing site during the CRS-9 mission did not exceed 5.5 psf (3).

The maximum modeled overpressure levels for the vast majority of the community surrounding VAFB are predicted to be less than 2 psf. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures (4). Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair (4). The land area between 2 psf and 3 psf surrounding VAFB is largely uninhabited (based on GoogleEarth satellite imagery), with the exception of farm land to the northeast of the landing site between VAFB and Lompoc. The 3 psf contour area over land falls entirely within the VAFB property boundary, with the expectation of approximately 2.5 uninhabited acres.

A large degree of variability exists in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. The probability of a window breaking at 1 psf ranges from one in a billion (5) to one in a million (6). These damage rates are associated with a combination of boom load and glass condition. At 10 psf, the probability of breakage is between one in 100 and one in 1,000. Laboratory tests involving glass (7) have shown that properly installed window glass will not break at overpressures below 10 psf, even when subjected to repeated booms. However, in the real world, glass is not always in pristine condition.

At peak overpressure levels between 2 to 4 psf, there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels between 4 to 10 psf (4). The potential for hearing damage (with regards to humans) is negligible outside of the area adjacent to the landing site, as the modeled sonic boom overpressure levels in the community are substantially lower than the ~4 psf impulsive hearing conservation noise criteria.

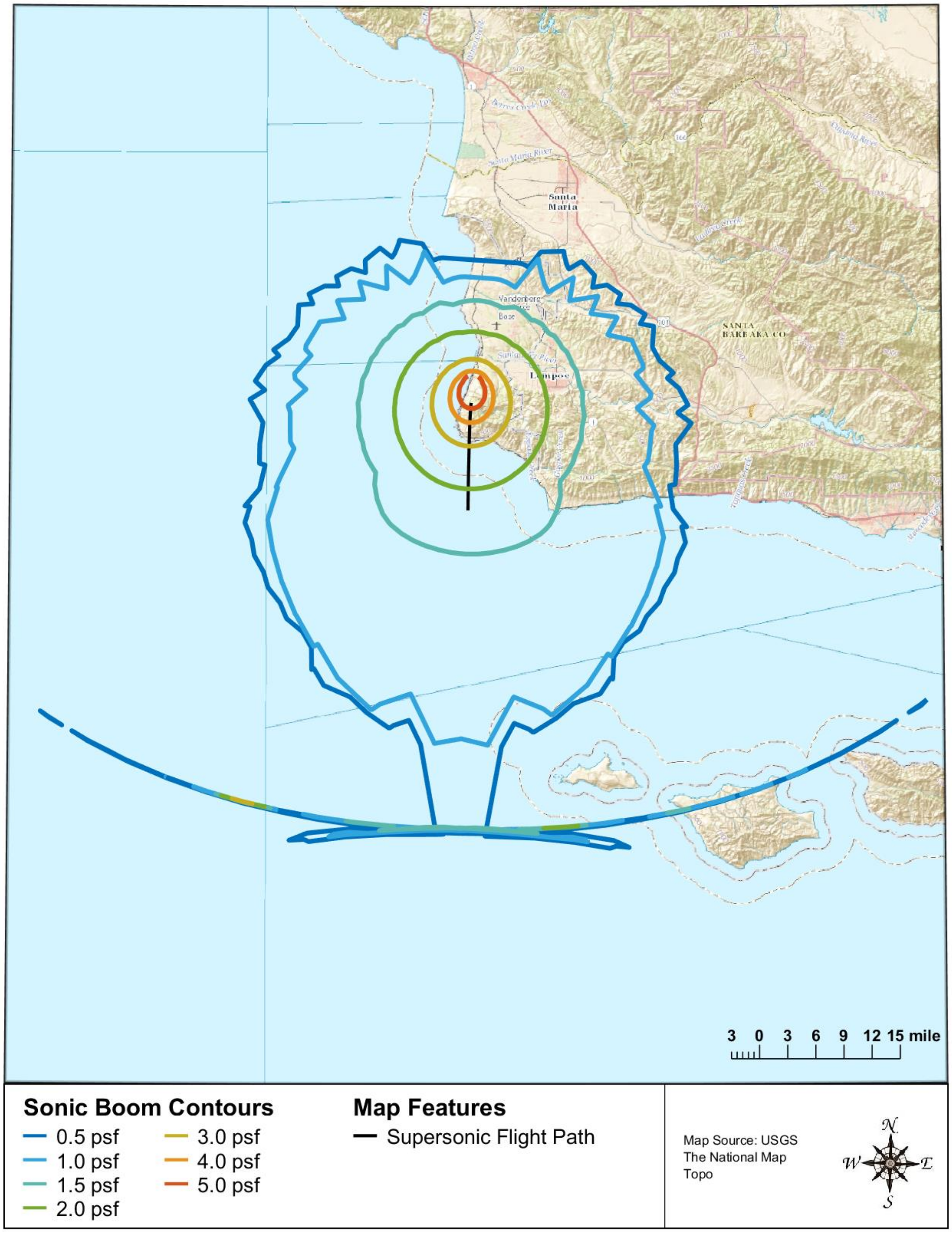

Figure 6. Sonic boom contours generated by the VAFB Falcon 9 Landing

5 Summary

Sonic boom analysis has been completed for the SpaceX Falcon 9 reusable first stage flybacks to CCAFS and VAFB. Recent sonic boom measurements collected by SpaceX personnel during the CRS-9 and CRS-10 missions from CCAFS were used to identify an appropriate PCBoom modeling methodology for Falcon 9 flybacks. The sonic boom peak overpressure measurements for the two Falcon 9 flybacks to CCAFS were compared to predicted levels generated using the selected modeling methodology and resulted in favorable agreement between the measured and modeled levels. The CCAFS modeling methodology was then used to model the sonic boom peak overpressures generated by flybacks to VAFB. A discussion of the VAFB sonic boom contours describes the potential impacts to the surrounding community.

6 References

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Attachment 4. Sonic Boom Assessment for a Falcon 9 First Stage Booster Return to CCAFS (Polar Mission)

SONIC BOOM ASSESSMENT OF FALCON 9 POLAR TRAJECTORY DESCENT/LANDING AT CAPE CANAVERAL AIR FORCE STATION

TN 20-01

February 2020

Prepared for:

Space Exploration Technologies Corporation

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1.0 Introduction

The sonic boom footprint has been estimated for the Falcon 9 Block 5 launch vehicle for the polar trajectory descent and landing of the reusable first stage at Cape Canaveral Air Force Station (CCAFS), Florida (landing pad location: latitude 28.485709 degrees and longitude -80.577127 degrees.)

Sonic boom is generated while the Falcon 9 is supersonic during descent, above an altitude of about 12,000 feet. Sonic boom analysis was performed with Wyle's PCBoom software.[1,2] Section 2 presents a background discussion of sonic boom. Section 3 presents the results for the Falcon 9 nominal descent and landing at CCAFS.

2.0 Sonic Boom Background

A sonic boom is the wave field about a supersonic vehicle. As the vehicle moves, it pushes the air aside. Because flight speed is faster than the speed of sound, the pressure waves can't move away from the vehicle, as they would for subsonic flight, but stay together in a coherent wave pattern. The waves travel with the vehicle. Figure 1 is a classic sketch of sonic boom from an aircraft in level flight. It shows a conical wave moving with the aircraft, much like the bow wave of a boat. While Figure 1 shows the wave as a simple cone, whose ground intercept extends indefinitely, temperature gradients in the atmosphere generally distort the wave from a perfect cone to one that refracts upward, so the ground intercept goes out to a finite distance on either side. Boom is not a onetime event as the aircraft "breaks the sound barrier" but is often described as being swept out along a "carpet" across the width of the ground intercepts and the length of the flight track. Booms from steady or near-steady flight are referred to as carpet booms.

The waveform at the ground is generally an "N-wave" pressure signature, as sketched in the figure, where compression in the forward part of the vehicle and expansion and recompression at the rear coalesce into a bow shock and a tail shock, respectively, with a linear expansion between.

Figure 1 is drawn from the perspective of aircraft coordinates. The wave cone exists as shown at a particular time, but is generated over a time period. Booms can also be viewed from the perspective of rays propagating relative to ground-fixed coordinates. Figure 2 shows both perspectives. The cone represents rays that are generated at a given time, and which reach the ground at later times. The intercept of a given ray cone with the ground is called an "isopemp." When computing sonic booms the ray perspective is appropriate, since one starts the analysis from the aircraft trajectory points and each isopemp is identified with flight conditions at a given time. As sketched in Figure 2, the isopemps are forward facing crescents.

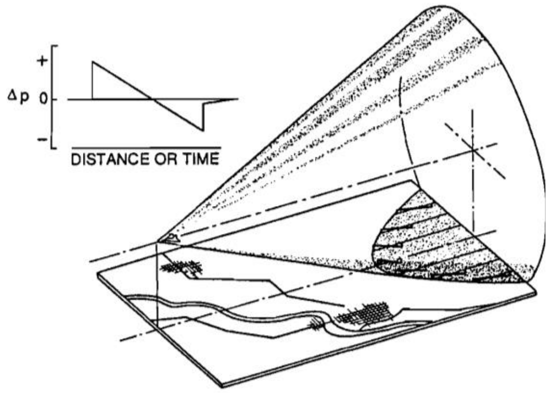

Figure 1. Sonic Boom Wave Field

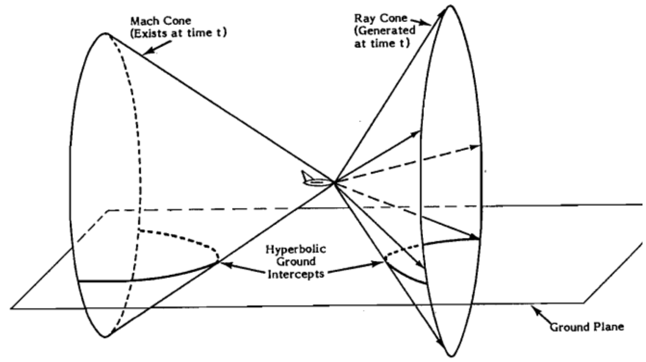

Figure 2. Wave versus Ray Viewpoints

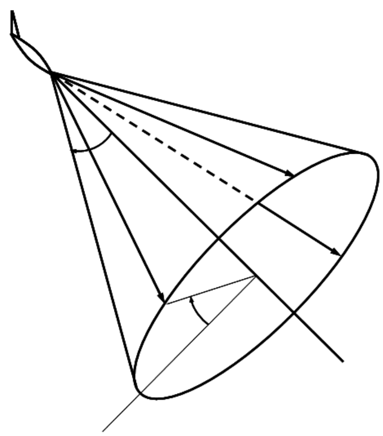

Figure 3. Ray Cone in Diving Flight

Figures 1 and 2 are drawn for steady level flight. If the aircraft climbs or dives, the ray cone tilts along with it. Figure 3 shows a ray cone in diving flight. At the angle in the figure the isopemp would still be a forward facing crescent, but would wrap around further than shown in Figure 2. In a steeper dive the isopemp could go full circle. If the vehicle is climbing at an angle steeper than the ray cone angle, there will be no boom at the ground. During very steep descent (near vertical) and at high Mach numbers the rays can be emitted at a shallow enough angle that they would refract upward and not reach the ground. For a descending vehicle that eventually decelerates to subsonic speed, some part of the trajectory will generate boom that reaches the ground.

Supersonic vehicles can turn and accelerate or decelerate. That affects the boom loudness, and under some conditions cause focused superbooms. Figure 4 is a sketch of rays from an accelerating aircraft. As the Mach number increases the ray angles steepen. The rays cross and overlap, with the focus along the "caustic" line indicated in the figure. The boom on a focusing ray is a normal N-wave before it gets close to the caustic, is amplified by a factor of two to five as it reaches the caustic, then is substantially attenuated as a "post-focus" boom after it passes the caustic.

Figure 5 shows the isopemps for this type of acceleration focus. The focal zone is the concentrated region at the left end of the footprint. The maximum focus area – where the boom is more than twice the unfocused normal boom – is very narrow, generally a hundred yards or less.

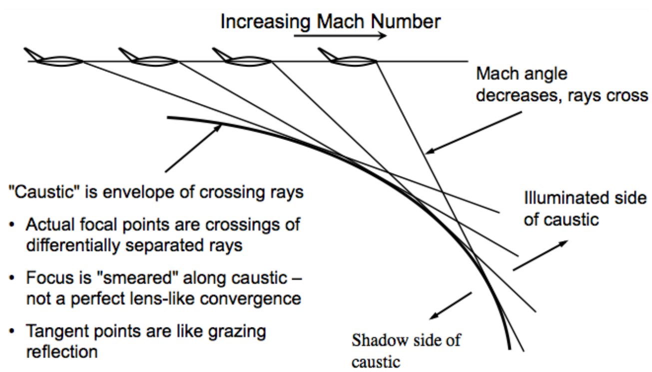

Figure 4. Ray Crossing and Overlap in an Acceleration Focus

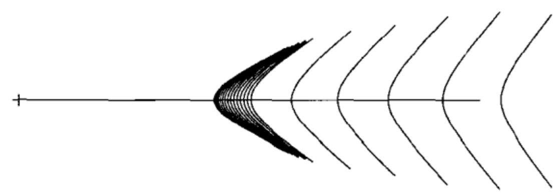

Figure 5. Isopemp Overlap in an Acceleration Focus

3.0 Falcon 9 Block 5 Descent Sonic Boom

This sonic boom analysis is based on a Falcon 9 nominal liftoff to landing trajectory provided by SpaceX. The Stage 1 descent and landing at CCAFS is supersonic from shortly after the apogee until it passes through an altitude just below 12,000 feet. Most of the Stage 1 descent is unpowered.

The boom footprint was computed using PCBoom.[1,2] The vehicle is a cylinder generally aligned with the velocity vector, descending engines first. It was modeled via PCBoom's drag-dominated blunt body mode,[3] which has been validated for entry vehicles.[4] Drag is determined by vehicle weight and the kinematics of the trajectory. Kinematics include the effect of the retro burn. Figure 6 shows the sonic boom footprint, in the form of overpressure contours, pounds per square foot (psf). The ground track of the entire trajectory is also shown in Figure 6. There is a broad forward-facing crescent region

generated as the vehicle descends below 200,000 feet at a heading of approximately 333 degrees. After the burn finishes there is an oval boom footprint region that ends when speed becomes subsonic. There are two narrow focus lines (magenta color), with contour levels in the 1.0 psf to 4.6 psf range, located on the northern edge of the crescent, generated as the vehicle accelerates at the end of the retro burn. At lower altitudes drag slows the descent, so boom following the focus is conventional carpet boom.

- The boom levels in the vicinity of the landing pad, located at latitude 28.485709 degrees and longitude -80.542901 degrees, range from about 2.0-2.7 psf.
- Boom levels in the areas adjacent to CCAFS and Kennedy Space Center (KSC) will be between 0.5-1.0 psf; boom levels on CCAFS property will range from 1.0-2.7 psf.
- The highest boom levels occurring off-shore are up to 4.6 psf in the narrow focus region just inside the north facing crescent shown in Figure 6. This zone is narrow – about 100 yards wide. The location will vary with weather conditions, so it is very unlikely that any given location will experience the focus more than once over multiple events. Variations in weather conditions could alter the sonic boom footprint, in general.
- The broad crescent, with boom levels of 0.1 psf is located over a large land area south of Orlando, FL and stretching south of Port St. Lucie, FL.

In general, booms in the 0.2 to 0.3 psf range could be heard by someone who is expecting it and listening for it, but usually would not be noticed. Booms of 0.5 psf are more likely to be noticed, and booms of 1.0 psf are certain to be noticed. Therefore, people in the communities surrounding CCAFS and KSC are likely to notice booms from Falcon 9 landings as are people located on these two properties. People located on the east coast in the vicinity of the focus region could experience boom levels up to 4.6 psf depending on weather conditions; boom levels greater than 1.0 psf could startle and possibly annoy people. Announcements of upcoming Falcon 9 launches and landings serve to warn people about these noise events and are likely to help reduce adverse reactions to these noise events. The boom levels over land are not likely to cause property damage.

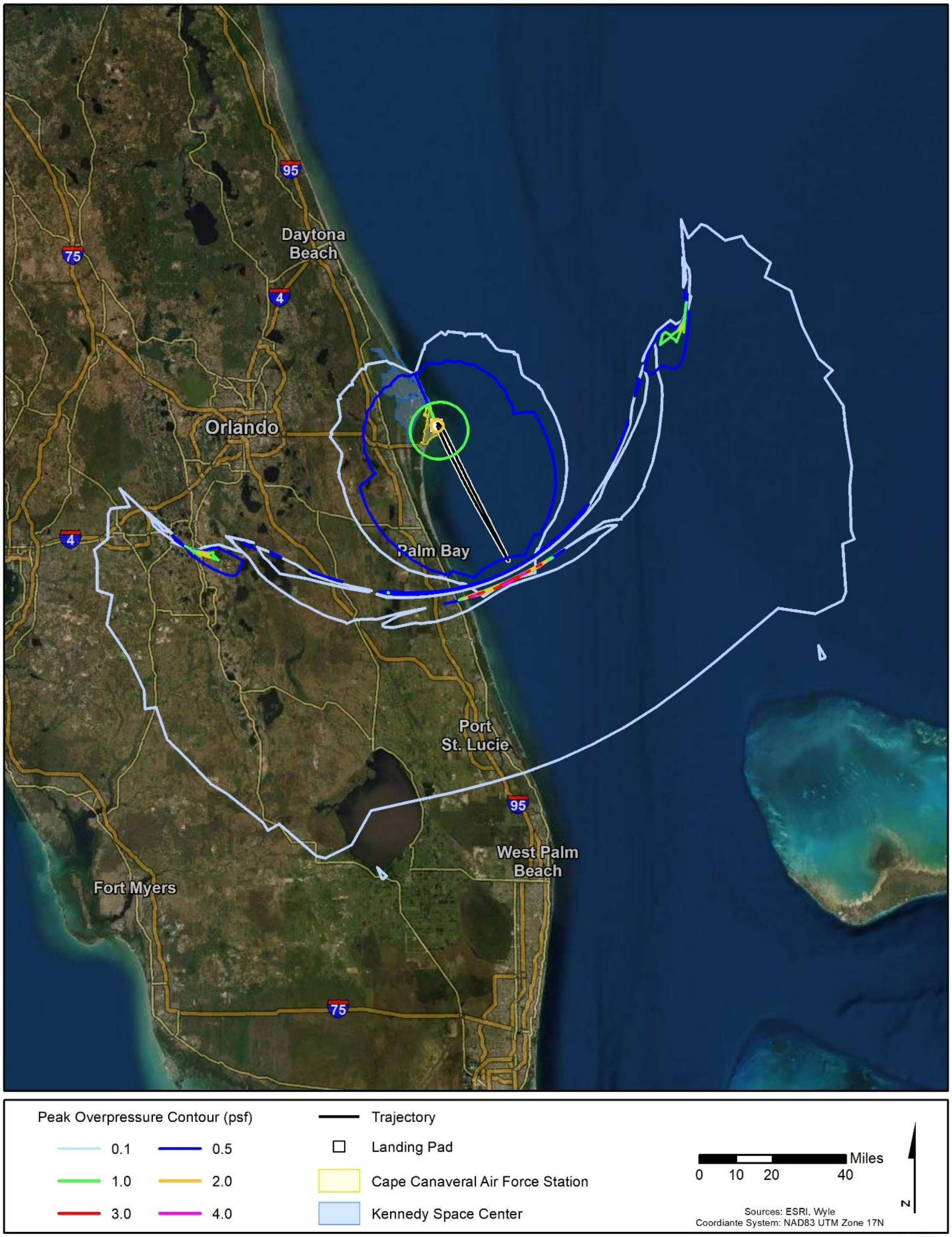

Figure 6. Sonic Boom Contours for Falcon 9 Polar Trajectory Landing at Cape Canaveral Air Force Station

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Attachment 5. USFWS Biological Opinion for Kennedy Space Center Master Development

United States Department of the Interior

U. S. FISH AND WILDLIFE SERVICE

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IN REPLY REFER TO:
FWS Log No. 04EF1000-2016-F-0083

April 4, 2017

Mr. Glenn Semmel
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(Attn: John Schaffer)

Dear Mr. Semmel:

This document is the Fish and Wildlife Service's (Service) Biological Opinion (BO) based on our review of the Biological Assessment (BA) for the proposed update of the Kennedy Center Master Plan development. The Kennedy Center Master Plan describes a 20-year transformation of the facility from a single, government-user launch complex to a multi-user spaceport. Kennedy Space Center (KSC) has prepared a Biological Assessment in support of re-initiation of consultation for artificial lighting impacts on nesting loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*), leatherback sea turtle (*Dermochelys coriacea*), hawksbill sea turtle (*Eretmochelys imbricata*), and Kemp's ridley sea turtle (*Lepidochelys kempii*), per Section 7 of the Endangered Species Act (Act) of 1973, as amended (16 U.S.C. 1531 et seq.). Your request for formal consultation was received on December 30, 2015, and the final BA was provided on April 4, 2016.

KSC has determined that the proposed revision of the plan may affect, and is likely to adversely affect, the loggerhead, green, leatherback, hawksbill, and Kemp's ridley sea turtles. The Service concurs with your determination. A complete administrative record is on file at the Ecological Service Office in Jacksonville, Florida.

CONSULTATION HISTORY

January 6, 2017 - KSC Environmental Branch submitted comments for review and consideration on the draft Conservation Measures, Reasonable and Prudent Measures and Terms and Conditions.

October 25, 2016 - The Service submitted via email to the KSC Environmental Branch the draft Conservation Measures, Reasonable and Prudent Measures and Terms and Conditions for the Opinion for review and comment.

April 29, 2016 - The Service and KSC Environmental Branch coordinated on the 2016 Nesting Season Protocol and agreed to continue implementing the Terms and Conditions of the 2009 Biological Opinion.

February 2016 - The Service and KSC Environmental Branch discussed the Biological Assessment (BA). The Service submitted comments on the BA and the Environmental Branch updated the BA and provided additional Conservation Measures in the project description.

December 31, 2015 - KSC Environmental Branch submitted a request to update the Interim Biological Opinion (BO), issued in 2009 and revised Biological Assessment for the proposed Kennedy Space Center Master Plan.

DESCRIPTION OF THE PROPOSED ACTION

To address the potential impacts to listed species during space launch operations at KSC, the Service has engaged in formal consultations since 1993. The most recent consultation addressing sea turtles and lighting impacts, the Interim Biological Opinion (BO), was issued in 2009. The Interim BO describes the history of the continuing lighting impacts and initiation of light management plans for particular areas, such as, launch complexes on KSC. The Interim BO was to support KSC through 2010, when the Constellation Program was expected to be in full swing, with clear plans for Launch Complex (LC) 39A and B. The NASA Authorization Act of 2010 cancelled the Constellation Program and in September 2011, President Obama announced its replacement by the Space Launch System, under the U.S. National Space Policy.

The recently completed Kennedy Space Center (KSC) Master Plan builds upon earlier planning efforts as an update to describe how KSC will transform over the next 20 years to become a multi-user spaceport supporting government, commercial and other space launch users and providers. The Master Plan describes KSC's future state, along with the supporting business focused implementation and operating framework necessary to enable this transformation. (KSC Master Plan)

Under the KSC multi-user space port both NASA and commercial launch activities will occur in the same operational areas used during the Shuttle Program. Operational areas with light sources near the KSC beaches, dune restoration site and nesting beach kilometer locations are detailed in the sections below.

Launch Complex 39A

Launch Complex 39A (LC-39A) was the primary launch site for the Shuttle Program and the site of the final launch on July 8, 2011. This complex came under lease to SpaceX in 2014. SpaceX is one of several commercial companies that deliver payloads to the International Space Station on behalf of NASA and is also one of several companies striving to develop a vehicle to support future NASA missions.

Some minor modifications to LC-39A pad have been made but the service structure and many associated lighting features remain in place. SpaceX has constructed a Horizontal Integration Facility (HIF) on the crawlerway, just outside the perimeter gate and conducting other related infrastructure updates in preparation for launch in 2016. For the construction period, KSC required SpaceX to submit a light management plan for the 2015 nesting season. Construction projects within the HIF were observed by MINWR and KSC support staff to have no light trespass during night time activities through the beginning of nesting season. From late July through the end of season exterior lighting was needed for pad upgrades. Lighting was directed where needed and in compliance with the plan. Work is expected to be complete in 2017 and SpaceX will then move into their launch operational phase in the same year.

Launch Complex 39B

The original LC-39B fixed launch structure was identical to LC-39A. The structure was retrofitted as a clean pad to support the recently constructed mobile launcher (ML). Currently, the ML is located north of the Vehicle Assembly Building (VAB), approximately 5.6 km (3.5 miles) west of the beach. The process will be for the ML to be picked up by the crawler, moved to the VAB for rocket assembly, and then moved to the pad in preparation for launch. Immediately after launch, the ML will be returned to the VAB site. The ML lighting was designed and implemented in accordance with the KSC Exterior Lighting Guidance. The combination of the turtle friendly lighting on the ML and the clean pad design resulted in a substantial reduction at this launch pad.

Launch Complex 39C

LC-39C is a new Small Class Vehicle Launch Pad (Figure 1) located inside the southeast area of the LC-39B perimeter. The new concrete pad measures about 50 feet wide by about 100 feet long and will serve as a multi-purpose site for companies to test vehicles and capabilities in the smaller class of rockets. Launch activities from this pad will be conducted during daylight hours only.

Future Potential Launch Complexes

The KSC Master Plan identifies several notional launch site areas that could be developed for additional vertical launch operations. These areas are located north of LC-39B and south of LC-39A based on a Site Evaluation Study performed in 2007 addressing small/medium launch vehicles and described in the Draft Programmatic Environmental Impact Statement for Center-Wide Operations at KSC (Draft KSC PEIS for Center-Wide Operations 2016).

Beach House

The Beach House, a historic property utilized by astronauts prior to launch and as a meeting facility for KSC personnel, is located near the southern end of the KSC property. There is permanently posted signage on the interior and exterior of the facility as well as information sheets explaining lighting responsibilities for persons occupying this building.

Corrosion Test Facility

The Corrosion Test Facility (CTF) is located on the primary dune 1 km (0.6 mi) north of the False Cape. The purpose of the CTF is to provide a site to measure the effects of atmospheric exposure along the Atlantic coast. A number of different kinds of structures and materials are tested by government and commercial entities at this facility. No exterior lighting is required or used at this site. This facility is used during daylight hours only. A sign is posted next to the exits reminding Staff to turn off all lights and close blinds when leaving the support building.

Eagle Four Security Post

Eagle Four is a security tower located west of the primary dune at the border between CNS and KSC. This is also the delineation between the secure area and public use area of KSC. Stairway egress lighting was retrofitted with Low Pressure Sodium (LPS) fixtures and is typically "off". No other exterior lighting is present. A sign is posted next to the exits reminding Staff to turn off all lights and close blinds when leaving the support building.

Road Block Guard Shack

This facility provides observational visibility necessary for boundary security. Lighting that enables full color rendition is required for the safety and security of Security Officers that supervise access within the gates of KSC. Guard Shacks on Beach Road have the status to occupy as required, which to support launch operation roadblocks for LC-39A, LC-39B on KSC and LC-41 on CCAFS. There are not launches scheduled on KSC before 2018 but will likely become more active once space vehicle launches resume at LC- 39A and LC-39B. Current lighting plan is for lights out unless in use, and when in use lights out when not manned.

Other KSC Artificial Light Sources

The KSC Light Management Assessment Report (Mercadante and Provancha, 2013) documented an extensive survey of KSC lighting and addressed artificial light sources that potentially contribute to light pollution across the Center. Light sources throughout KSC have also been identified each year during lighting surveys conducted in compliance with the 2009 Interim BO (Service 2009a) and results from those surveys are found in Appendix A of the KSC Biological Assessment.

Off-Site Launch Complexes

The Cape Canaveral Air Force Station is located immediately south of KSC and the LC-40 and LC-41 are the closest to KSC property and managed by CCAFS. LC-41 is 0.5 km (0.3 miles) landward of the KSC nesting beach and LC-40 is ~0.75 km (0.5 miles) SW of the southern boundary of the KSC beach. These areas are included in the nighttime lighting surveys.

Other Off-Site Source

The KSC Light Management Assessment Report (Mercadante and Provancha, 2013) documented an extensive survey of KSC lighting, and also addressed distant light sources. They noted lights or glow clearly visible from the cities of Titusville and New Smyrna/Daytona from the KSC secured beach.

Conservation Measures

To ensure continued reduction of artificial lighting impacts on nesting sea turtles, KSC will continue to implement the following measures that were outlined as terms and conditions in the

2009 Interim Biological Opinion and has committed to the additional conservation measures. All conservation measures listed below will be considered as a part of the project description and used in the following analysis for the effects of the actions. Conservation measures are binding commitments from the agency to implement as described below.

<u>CM 1: Exterior Lighting Plan Requirements and NEPA Lighting Review</u>

Environmental Management Branch (EMB) developed the KSC Exterior Lighting Requirement guidance (ELG) for exterior lighting installation and use at KSC in 1995. This guidance document was last revised in 2009. The document is provided to all KSC Facility Managers, lighting project engineers and managers, and is posted on both an internal and external webpage. This document serves to inform project proponents, regardless of whether the proponent is NASA, private industry or other governmental agency, of the lighting requirements set forth in the 2009 Interim Biological Opinion and how to ensure that their project is compliant with these requirements. The Service has reviewed the updated version and provided comments for the 2016 update.

EMB staff conduct NEPA reviews on all new lighting actions including new projects, existing facility refurbishments, and maintenance actions through the KSC Checklist NEPA Process.

The updated ELG will require all new facilities, newly leased facilities and major facility modifications to develop and implement a site specific Lighting Operations Manual (LOM) to be reviewed and approved by the NASA EMB and Service prior to the construction.

Project Proponent shall submit a lighting plan to EMB, direct coordination via email or formal meetings occur depending on the complexity and level of compliance of the project.

- New large scale construction projects and launch pad plans will be reviewed by the Service. The updated ELG will require all new facilities, newly leased facilities and major facility modifications to develop and implement a site specific Lighting Operations Manual (LOM) approved by the NASA EMB and Service.

- Small scale projects that meet the ELG will be reviewed by KSC Environmental Planning staff. Variances will be reviewed by both KSC and FWS.

For existing facilities or projects that are found to be non-compliant, EMB initiates a compliance action. Actions range from a telephone call or email to immediately rectify the issue, to meetings with senior level managers for more complex issues. Prime contacts for compliance assurance are Facility Managers for existing facilities and Project Managers for proposed facilities.

<u>CM 2: Facility Coordination and Education during the Sea Turtle Nesting Season</u>

EMB shall provide routine coordination and nesting season updates to the facility and the non-government agencies. EMB shall attend quarterly meetings to the Facility Management (FM). The FMs shall post weekly bulletins to building tenants and include sea turtle notes provided to them by EMB throughout the season.

EMB requires training of pertinent personnel including but limited to FMs and PMs on nesting sea turtles. The trainings are held on site by invited guests and staff or at the CCAFS every two years.

EMB shall disseminate pamphlets and posters to all lobbies and most break rooms at the beginning of the season and periodically updates supplies through the season.

EMB posts video clips on the KSC Communicator, an online Center-wide web portal and written notifications in the KSC daily news throughout the season.

CM 3: Lighting Surveys

KSC will perform 5 nighttime surveys during the nesting season. EMB support contractor has performed annual routine night time lighting surveys throughout the sea turtle nesting season since 2010. In addition, the USFWS MINWR staff will also provide updates on observations of artificial lighting visible from the nesting beach while conducting predator control/monitoring. EMB and support contractor coordinated with Service in the 2015 nesting season to modify lighting surveys to reduce manual surveys and add sky glow meter data.

Sky glow meter data will provide supplemental information to the nighttime survey reports. In 2015/2016, twelve Unihedron light loggers were installed along the beach at KSC kilometers 24, 26, 30, 33, and CNS Grid 93, 42. Loggers on the KSC beach are checked for physical damage/debris and data are downloaded routinely.

Going forward, EMB will develop a long term monitoring program of sky quality as it pertains to artificial light photo pollution visible from the KSC nesting beach using permanent light meter sampling stations. The MINWR staff or EMB support contractor will monitor adult and hatchling disorientation incidents within the affected area. EMB contractor will analyze sky quality and sea turtle nesting/hatching behavior to enhance KSC planning and management of the nesting beach. This monitoring will provide a baseline from which to assess trends in photo pollution as lighting improvements at KSC are implemented over time.

CM 4: Reporting and Compliance

Monthly nesting and disorientation reports shall be provided and reviewed by EMB.

KSC ensures specific facilities, including but not limited to those listed above in the project description, found to be commonly non-compliant are contacted by phone at the beginning of each season. At the FM meeting in April, EMB provides information to send out in the weekly Facility update regarding nesting season protocol.

EMB directed the support Contractor to provide a report on existing conditions on KSC. The report was generated to identify both positive and negative actions and locate artificial light sources that can be seen from the action area (9.8 km section of beach) and is attached in Appendix D.

EMB will prepare an annual activity report for submittal to Service at the end of each calendar year to include all actions taken to retrofit or eliminate existing light sources, to identify newly constructed/leased or modified facility LOM approved for the previous year, and provide other information pertinent to BO compliance.

CM 5: KSC Amber LED Lighting Fixtures and Retrofitting

KSC has recently approved the Facilities Services Contractor to stock a true amber LED lamp to replace street, parking lot and general safety area lighting lamps as they become non-functional. Approving this fixture for Center-wide application and maintaining a bench stock will facilitate rapid change-out of older, disruptive area lighting that contributes indirect lighting visible from the nesting beach.

EMB will use the data from the Activity Report listed in the CM #3 (including historic and future nighttime surveys) to generate and maintain a prioritized list of retrofit lighting projects and will specifically identify those proposed for retrofitting each calendar year.

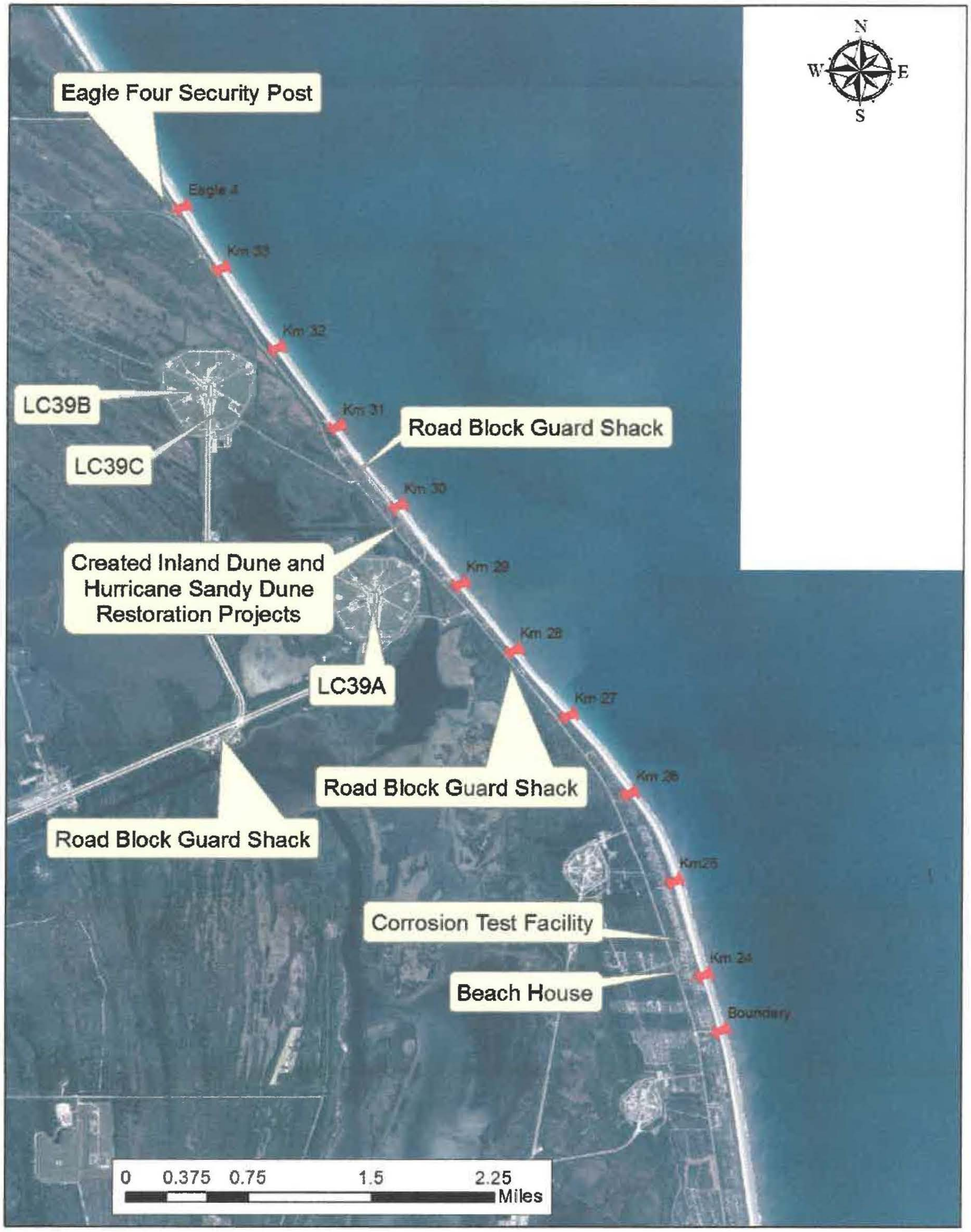

Figure 1. Facilities with light sources near the KSC beaches, dune restoration site and nesting beach kilometer locations

STATUS OF THE SPECIES/CRITICAL HABITAT

This section provides pertinent biological and ecological information for loggerhead sea turtle, green sea turtle, leatherback sea turtle, hawksbill sea turtle, and Kemp's ridley sea turtle, as well as information about their status and trends throughout their entire range. We use this information to assess whether a federal action is likely to jeopardize the continued existence of the above-mentioned species.

SEA TURTLES

Status of the Species/Critical Habitat

Loggerhead Sea Turtle

The loggerhead sea turtle was federally listed as a threatened species on July 28, 1978 (43 Federal Register [FR] 32800). The Service and the National Marine Fisheries Service (NMFS) listed the Northwest Atlantic Ocean (NWAO) distinct population segment (DPS) of the loggerhead sea turtle as threatened on September 22, 2011 (76 FR 58868). The loggerhead occurs throughout the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans.

The loggerhead sea turtle grows to an average weight of about 200 pounds and is characterized by a large head with blunt jaws. Adults and subadults have a reddish-brown carapace. Scales on the top of the head and top of the flippers are also reddish-brown with yellow on the borders. Hatchlings are a dull brown color (NMFS 2009a). The loggerhead feeds on mollusks, crustaceans, fish, and other marine animals. The loggerhead may be found hundreds of miles out to sea, as well as in inshore areas such as bays, lagoons, salt marshes, creeks, ship channels, and the mouths of large rivers. Coral reefs, rocky places, and ship wrecks are often used as feeding areas.

Within the Northwest Atlantic, the majority of nesting activity occurs from April through September, with a peak in June and July (Williams-Walls *et al.* 1983, Dodd 1988, Weishampel *et al.* 2006). Nesting occurs within the Northwest Atlantic along the coasts of North America, Central America, northern South America, the Antilles, Bahamas, and Bermuda, but is concentrated in the southeastern U.S. and on the Yucatán Peninsula in Mexico on open beaches or along narrow bays having suitable sand (Sternberg 1981, Ehrhart 1989, Ehrhart *et al.* 2003, NMFS and Service 2008).

Critical habitat has been designated for the NWAO DPS of the loggerhead sea turtle (U.S. Fish and Wildlife Service 2014)

Green Sea Turtle

The green sea turtle was federally listed on July 28, 1978 (43 FR 32800). Breeding populations of the green turtle in Florida and along the Pacific Coast of Mexico are listed as endangered; all other populations are listed as threatened. The green sea turtle has a worldwide distribution in tropical and subtropical waters. The green sea turtle grows to a maximum size of about four feet and a weight of 440 pounds. It has a heart-shaped shell, small head, and single-clawed flippers. The carapace is smooth and colored gray, green, brown and black. Hatchlings are black on top and white on the bottom (NMFS 2009b). Hatchling green turtles eat a variety of plants and animals, but adults feed almost exclusively on seagrasses and marine algae.

Major green turtle nesting colonies in the Atlantic occur on Ascension Island, Aves Island, Costa Rica, and Surinam. Within the U.S., green turtles nest in small numbers in the U.S. Virgin Islands and Puerto Rico, and in larger numbers along the east coast of Florida, particularly in Brevard, Indian River, St. Lucie, Martin, Palm Beach, and Broward Counties (NMFS and Service 1991). Nesting also has been documented along the Gulf coast of Florida from Escambia County through Santa Rosa County in northwest Florida and from Pinellas County through Collier County in southwest Florida (FWC 2009a).

Most green turtles spend the majority of their lives in coastal foraging grounds. These areas include fairly shallow waters both open coastline and protected bays and lagoons. While in these 22 areas, green turtles rely on marine algae and seagrass as their primary diet constituents, although some populations also forage heavily on invertebrates. These marine habitats are often highly dynamic and in areas with annual fluctuations in seawater and air temperatures, which can cause the distribution and abundance of potential green turtle food items to vary substantially between seasons and years (Carballo *et al.*, 2002). Many prey species that are abundant during winter and spring periods become patchy during warm summer periods. Some species may altogether vanish during extreme temperatures, such as those that occur during El Niño Southern Oscillation events (Carballo *et al.*, 2002).

Open beaches with a sloping platform and minimal disturbance are required for nesting.

Critical habitat for the green sea turtle has been designated for the waters surrounding Culebra Island, Puerto Rico, and its outlying keys.

Leatherback Sea Turtle

The leatherback sea turtle was federally listed as an endangered species on June 2, 1970 (35 FR 8491). Leatherbacks have the widest distribution of the sea turtles; nonbreeding animals have been recorded as far north as the British Isles and the Maritime Provinces of Canada and as far south as Argentina and the Cape of Good Hope (Pritchard 1992). Foraging leatherback excursions have been documented into higher-latitude subpolar waters. They have evolved physiological and anatomical adaptations (Frair *et al.* 1972, Greer *et al.* 1973) that allow them to exploit waters far colder than any other sea turtle species would be capable of surviving.

The adult leatherback can reach four to eight feet in length and weigh 500 to 2,000 pounds. The carapace is distinguished by a rubber-like texture, about 1.6 inches thick, made primarily of tough, oil-saturated connective tissue. Hatchlings are dorsally mostly black and are covered with tiny scales; the flippers are edged in white, and rows of white scales appear as stripes along the length of the back (NMFS 2009c). Jellyfish are the main staple of its diet, but it is also known to feed on sea urchins, squid, crustaceans, tunicates, fish, blue-green algae, and floating seaweed. This is the largest, deepest diving of all sea turtle species.

Leatherback turtle nesting grounds are distributed worldwide in the Atlantic, Pacific and Indian Oceans on beaches in the tropics and sub-tropics. The Pacific Coast of Mexico historically supported the world's largest known concentration of nesting leatherbacks.

The leatherback turtle regularly nests in the U.S. Caribbean in Puerto Rico and the U.S. Virgin Islands. Along the U.S. Atlantic coast, most nesting occurs in Florida (NMFS and Service 1992). Leatherback nesting has also been reported on the northwest coast of Florida (LeBuff 1990, FWC 2009a); and in southwest Florida a false crawl (non-nesting emergence) has been observed on Sanibel Island (LeBuff 1990). Nesting has also been reported in Georgia, South Carolina, and North Carolina (Rabon *et al.* 2003) and in Texas (Shaver 2008).

Adult females require sandy nesting beaches backed with vegetation and sloped sufficiently so the distance to dry sand is limited. Their preferred beaches have proximity to deep water and generally rough seas.

Marine and terrestrial critical habitat for the leatherback sea turtle has been designated at Sandy Point on the western end of the island of St. Croix, U.S. Virgin Islands (50 Code of Federal Regulations (CFR) 17.95).

Hawksbill Sea Turtle

The hawksbill sea turtle was federally listed as an endangered species on June 2, 1970 (35 FR 8491). The hawksbill is found in tropical and subtropical seas of the Atlantic, Pacific, and Indian Oceans. The species is widely distributed in the Caribbean Sea and western Atlantic Ocean.

Data collected in the Wider Caribbean reported that hawksbills typically weigh around 176 pounds or less; hatchlings average about 1.6 inches straight length and range in weight from 0.5 to 0.7 ounces. The carapace is heart shaped in young turtles, and becomes more elongated or egg-shaped with maturity. The top scutes are often richly patterned with irregularly radiating streaks of brown or black on an amber background. The head is elongated and tapers sharply to a point. The lower jaw is V-shaped (NMFS 2009d).

Within the continental U.S., hawksbill sea turtle nesting is rare and is restricted to the southeastern coast of Florida (Volusia through Miami-Dade Counties) and the Florida Keys (Monroe County) (Meylan 1992, Meylan *et al.* 1995). However, hawksbill tracks are difficult to differentiate from those of loggerheads and may not be recognized by surveyors. Therefore, surveys in Florida likely underestimate actual hawksbill nesting numbers (Meylan *et al.* 1995). In the U.S. Caribbean, hawksbill nesting occurs on beaches throughout Puerto Rico and the U.S. Virgin Islands (NMFS and Service 1993).

Critical habitat for the hawksbill sea turtle has been designated for selected beaches and/or waters of Mona, Monito, Culebrita, and Culebra Islands, Puerto Rico.

Kemp's Ridley Sea Turtle

The Kemp's ridley sea turtle was federally listed as endangered on December 2, 1970 (35 FR 18320). The Kemp's ridley, along with the flatback sea turtle (*Natator depressus*), has the most geographically restricted distribution of any sea turtle species. The range of the Kemp's ridley includes the Gulf coasts of Mexico and the U.S., and the Atlantic coast of North America as far north as Nova Scotia and Newfoundland.

Adult Kemp's ridleys, considered the smallest sea turtle in the world, weigh an average of 100 pounds with a carapace measuring between 24-28 inches in length. The almost circular carapace has a grayish green color while the plastron is pale yellowish to cream in color. The carapace is often as wide as it is long. Their diet consists mainly of swimming crabs, but may also include fish, jellyfish, and an array of mollusks.

The majority of nesting for the entire species occurs on the primary nesting beach at Rancho Nuevo, Mexico (Marquez-Millan 1994). Outside of nesting, adult Kemp's ridleys are believed to spend most of their time in the Gulf of Mexico, while juveniles and subadults also regularly occur along the eastern seaboard of the U.S. (Service and NMFS 1992). There have been rare instances when immature ridleys have been documented making transatlantic movements (NMFS and Service 1992). It was originally speculated that ridleys that make it out of the Gulf of Mexico might be lost to the breeding population (Hendrickson 1980), but data indicate that many of these 25 turtles are capable of moving back into the Gulf of Mexico (Henwood and Ogren 1987). In fact, there are documented cases of ridleys captured in the Atlantic that migrated back to the nesting beach at Rancho Nuevo (Schmid and Witzell 1997, Schmid 1998, Witzell 1998).

Hatchlings, after leaving the nesting beach, are believed to become entrained in eddies within the Gulf of Mexico, where they are dispersed within the Gulf and Atlantic by oceanic surface currents until they reach about 7.9 inches in length, at which size they enter coastal shallow water habitats (Ogren 1989).

No critical habitat has been designated for the Kemp's ridley sea turtle.

Life History

Loggerhead Sea Turtle

Loggerheads are long-lived, slow-growing animals that use multiple habitats across entire ocean basins throughout their life history. This complex life history encompasses terrestrial, nearshore, and open ocean habitats. The three basic ecosystems in which loggerheads live are the:

1. Terrestrial zone (supralittoral) - the nesting beach where both oviposition (egg laying) and embryonic development and hatching occur.
2. Neritic zone - the inshore marine environment (from the surface to the sea floor) where water depths do not exceed 656 feet (200 meters). The neritic zone generally includes the

continental shelf, but in areas where the continental shelf is very narrow or nonexistent, the neritic zone conventionally extends to areas where water depths are less than 656 feet.

3. Oceanic zone - the vast open ocean environment (from the surface to the sea floor) where water depths are greater than 656 feet.

Maximum intrinsic growth rates of sea turtles are limited by the extremely long duration of the juvenile stage and fecundity. Loggerheads require high survival rates in the juvenile and adult stages, common constraints critical to maintaining long-lived, slow-growing species, to achieve positive or stable long-term population growth (Congdon *et al.* 1993, Heppell 1998, Crouse 1999, Heppell *et al.* 1999, 2003, Musick 1999).

Numbers of nests and nesting females are often highly variable from year to year due to a number of factors including environmental stochasticity, periodicity in ocean conditions, anthropogenic effects, and density-dependent and density-independent factors affecting survival, somatic growth, and reproduction (Meylan 1982, Hays 2000, Chaloupka 2001, Solow *et al.* 2002). Despite these sources of variation, and because female turtles exhibit strong nest site fidelity, a nesting beach survey can provide a valuable assessment of changes in the adult female population, provided that the study is sufficiently long and effort and methods are standardized (Meylan 1982, Gerrodette and Brandon 2000, Reina *et al.* 2002).

Loggerheads nest on ocean beaches and occasionally on estuarine shorelines with suitable sand. Nests are typically laid between the high tide line and the dune front (Routa 1968, Witherington 1986, Hailman and Elowson 1992). Wood and Bjorndal (2000) evaluated four environmental factors (slope, temperature, moisture, and salinity) and found that slope had the greatest influence on loggerhead nest-site selection on a beach in Florida. Loggerheads appear to prefer relatively narrow, steeply sloped, coarse-grained beaches, although nearshore contours may also play a role in nesting beach site selection (Mortimer 1982; Provancha and Ehrhart 1987).

The warmer the sand surrounding the egg chamber, the faster the embryos develop (Mrosovsky and Yntema 1980). Sand temperatures prevailing during the middle third of the incubation period also determine the sex of hatchling sea turtles (Mrosovsky and Yntema 1980). Incubation temperatures near the upper end of the tolerable range produce only female hatchlings while incubation temperatures near the lower end of the tolerable range produce only male hatchlings.

Loggerhead hatchlings pip and escape from their eggs over a one to three day interval and move upward and out of the nest over a two to four day interval (Christens 1990). The time from pipping to emergence ranges from four to seven days with an average of 4.1 days (Godfrey and Mrosovsky 1997). Hatchlings emerge from their nests en masse almost exclusively at night, and presumably using decreasing sand temperature as a cue (Hendrickson 1958, Mrosovsky 1968, Witherington *et al.* 1990). Moran *et al.* (1999) concluded that a lowering of sand temperatures below a critical threshold, which most typically occurs after nightfall, is the most probable trigger for hatchling emergence from a nest. After an initial emergence, there may be secondary emergences on subsequent nights (Carr and Ogren 1960, Witherington 1986, Ernest and Martin 1993, Houghton and Hays 2001).

Hatchlings use a progression of orientation cues to guide their movement from the nest to the marine environments where they spend their early years (Lohmann and Lohmann 2003). Hatchlings first use light cues to find the ocean. On naturally lighted beaches without artificial lighting, ambient light from the open sky creates a relatively bright horizon compared to the dark silhouette of the dune and vegetation landward of the nest. This contrast guides the hatchlings to the ocean (Daniel and Smith 1947, Limpus 1971, Salmon *et al.* 1992, Witherington and Martin 1996, Witherington 1997, Stewart and Wyneken 2004).

Loggerheads in the Northwest Atlantic display complex population structure based on life history stages. Based on mitochondrial deoxyribonucleic acid (mtDNA), oceanic juveniles show no structure, neritic juveniles show moderate structure and nesting colonies show strong structure (Bowen *et al.* 2005). In contrast, a survey using microsatellite (nuclear) markers showed no significant population structure among nesting populations (Bowen *et al.* 2005), indicating that while females exhibit strong philopatry, males may provide an avenue of gene flow between nesting colonies in this region.

Green Sea Turtle

Green sea turtles deposit from one to nine clutches within a nesting season, but the overall average is about 3.3 nests. The interval between nesting events within a season varies around a mean of about 13 days (Hirth 1997). Mean clutch size varies widely among populations. Average clutch size reported for Florida was 136 eggs in 130 clutches (Witherington and Ehrhart 1989). Only occasionally do females produce clutches in successive years. Usually two or more years intervene between breeding seasons (NMFS and Service 1991). Age at sexual maturity is believed to be 20 to 50 years (Hirth 1997).

Leatherback Sea Turtle

Leatherbacks nest an average of five to seven times within a nesting season, with an observed maximum of 11 nests (NMFS and Service 1992). The interval between nesting events within a season is about nine to 10 days. Clutch size averages 80 to 85 yolked eggs, with the addition of usually a few dozen smaller, yolkless eggs, mostly laid toward the end of the clutch (Pritchard 1992). Nesting migration intervals of two to three years were observed in leatherbacks nesting on the Sandy Point National Wildlife Refuge, St. Croix, U.S. Virgin Islands (McDonald and Dutton 1996). Leatherbacks are believed to reach sexual maturity in six to 10 years (Zug and Parham 1996).

Hawksbill Sea Turtle

Hawksbills nest on average about 4.5 times per season at intervals of approximately 14 days (Corliss *et al.* 1989). In Florida and the U.S. Caribbean, clutch size is approximately 140 eggs, although several records exist of over 200 eggs per nest (NMFS and Service 1993). On the basis of limited information, nesting migration intervals of two to three years appear to predominate. Hawksbills are recruited into the reef environment at about 14 inches in length and are believed to begin breeding about 30 years later. However, the time required to reach 14 inches in length is unknown and growth rates vary geographically. As a result, actual age at sexual maturity is unknown.

Kemp's Ridley Sea Turtle

Nesting occurs from April into July during which time the turtles appear off the Tamaulipas and Veracruz coasts of Mexico. Precipitated by strong winds, the females swarm to mass nesting emergences, known as "arribadas or arribazones," to nest during daylight hours. The period between Kemp's ridley arribadas averages approximately 25 days (Rostal *et al.* 1997), but the precise timing of the arribadas is highly variable and unpredictable (Bernardo and Plotkin 2007). Clutch size averages 100 eggs and eggs typically take 45 to 58 days to hatch depending on temperatures (Marquez-Millan 1994, Rostal 2007).

Some females breed annually and nest an average of one to four times in a season at intervals of 10 to 28 days. Analysis by Rostal (2007) suggested that ridley females lay approximately 3.1 nests per nesting season. Interannual remigration rate for female ridleys is estimated to be approximately 1.8 (Rostal 2007) to 2.0 years (Marquez-Millan *et al.* 1989). Age at sexual maturity is believed to be between 10 to 17 years (Snover *et al.* 2007).

Population Dynamics

Loggerhead Sea Turtle

The loggerhead occurs throughout the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans. However, the majority of loggerhead nesting is at the western rims of the Atlantic and Indian Oceans. The most recent reviews show that only two loggerhead nesting beaches have greater than 10,000 females nesting per year (Baldwin *et al.* 2003, Ehrhart *et al.* 2003, Kamezaki *et al.* 2003, Limpus and Limpus 2003, Margaritoulis *et al.* 2003): South Florida (U.S.) and Masirah (Oman). Those beaches with 1,000 to 9,999 females nesting each year are Georgia through North Carolina (U.S.), Quintana Roo and Yucatán (Mexico), Cape Verde Islands (Cape Verde, eastern Atlantic off Africa), and Western Australia (Australia). Smaller nesting aggregations with 100 to 999 nesting females annually occur in the Northern Gulf of Mexico (U.S.), Dry Tortugas (U.S.), Cay Sal Bank (Bahamas), Sergipe and Northern Bahia (Brazil), Southern Bahia to Rio de Janerio (Brazil), Tongaland (South Africa), Mozambique, Arabian Sea Coast (Oman), Halaniyat Islands (Oman), Cyprus, Peloponnesus (Greece), Island of Zakynthos (Greece), Turkey, Queensland (Australia), and Japan.

The loggerhead is commonly found throughout the North Atlantic including the Gulf of Mexico, the northern Caribbean, the Bahamas archipelago, and eastward to West Africa, the western Mediterranean, and the west coast of Europe.

The major nesting concentrations in the U.S. are found in South Florida. However, loggerheads nest from Texas to Virginia. Total estimated nesting in Florida, where 90 percent of nesting occurs, has fluctuated between 52,374 and 98,602 nests per year from 2009-2013 (FWC 2014, http://myfwc.com/media/2786250/loggerheadnestingdata09-13.pdf). About 80 percent of loggerhead nesting in the southeast U.S. occurs in six Florida counties (Brevard, Indian River, St. Lucie, Martin, Palm Beach, and Broward Counties). Adult loggerheads are known to make considerable migrations between foraging areas and nesting beaches (Schroeder *et al.* 2003, Foley *et al.* 2008). During non-nesting years, adult females from U.S. beaches are distributed in waters off the eastern U.S. and throughout the Gulf of Mexico, Bahamas, Greater Antilles, and Yucatán.

From a global perspective, the U.S. nesting aggregation is of paramount importance to the survival of the species as is the population that nests on islands in the Arabian Sea off Oman (Ross 1982, Ehrhart 1989). The status of the Oman loggerhead nesting population, reported to be the largest in the world (Ross 1979), is uncertain because of the lack of long-term standardized nesting or foraging ground surveys and its vulnerability to increasing development pressures near major nesting beaches and threats from fisheries interaction on foraging grounds and migration routes (Possardt 2005). The loggerhead nesting aggregations in Oman and the U.S. account for the majority of nesting worldwide.

Green Sea Turtle

The majority of nesting occurs along the Atlantic coast of eastern central Florida, with an average of 10,377 each year from 2008 to 2012 (B. Witherington, Florida Fish and Wildlife Conservation Commission, pers. comm., 2013). In the U.S. Pacific, over 90 percent of nesting throughout the Hawaiian archipelago occurs at the French Frigate Shoals, where about 200 to 700 females nest each year (NMFS and Service 1998b). Elsewhere in the U.S. Pacific, nesting takes place at scattered locations in the Commonwealth of the Northern Marianas, Guam, and American Samoa. In the western Pacific, the largest green turtle nesting aggregation in the world occurs on Raine Island, Australia, where thousands of females nest nightly in an average nesting season (Limpus *et al.* 1993). In the Indian Ocean, major nesting beaches occur in Oman where 30,000 females are reported to nest annually (Ross and Barwani 1995).

Leatherback Sea Turtle

A dramatic drop in nesting numbers has been recorded on major nesting beaches in the Pacific. Spotila *et al.* (2000) have highlighted the dramatic decline and possible extirpation of leatherbacks in the Pacific.

The East Pacific and Malaysia leatherback populations have collapsed. Spotila *et al.* (1996) estimated that only 34,500 females nested annually worldwide in 1995, which is a dramatic decline from the 115,000 estimated in 1980 (Pritchard 1992). In the eastern Pacific, the major nesting beaches occur in Costa Rica and Mexico. At Playa Grande, Costa Rica, considered the most important nesting beach in the eastern Pacific, numbers have dropped from 1,367 leatherbacks in 1988-1989 to an average of 188 females nesting between 2000-2001 and 2003-2004. In Pacific

Mexico, 1982 aerial surveys of adult female leatherbacks indicated this area had become the most important leatherback nesting beach in the world. Tens of thousands of nests were laid on the beaches in 1980s, but during the 2003-2004 seasons a total of 120 nests were recorded. In the western Pacific, the major nesting beaches lie in Papua New Guinea, Papua, Indonesia, and the Solomon Islands. These are some of the last remaining significant nesting assemblages in the Pacific. Compiled nesting data estimated approximately 5,000 to 9,200 nests annually with 75 percent of the nests being laid in Papua, Indonesia.

However, the most recent population size estimate for the North Atlantic alone is a range of 34,000 to 94,000 adult leatherbacks (TEWG 2007). In Florida, the number of nests has been increasing since 1979 (Stewart *et al.* 2011). The average annual number of nests in the 1980s was 63 nests, which rose to 263 nests in the 1990s and to 754 nests in the 2000s (Stewart *et al.* 2011). In 2012, 1,712 nests were recorded statewide (http://myfwc.com/research/wildlife/sea-turtles/nesting/).

Nesting in the Southern Caribbean occurs in the Guianas (Guyana, Suriname, and French Guiana), Trinidad, Dominica, and Venezuela. The largest nesting populations at present occur in the western Atlantic in French Guiana with nesting varying between a low of 5,029 nests in 1967 to a high of 63,294 nests in 2005, which represents a 92 percent increase since 1967 (TEWG 2007). Trinidad supports an estimated 6,000 leatherbacks nesting annually, which represents more than 80 percent of the nesting in the insular Caribbean Sea. Leatherback nesting along the Caribbean Central American coast takes place between Honduras and Colombia. In Atlantic Costa Rica, at Tortuguero, the number of nests laid annually between 1995 and 2006 was estimated to range from 199 to 1,623.

In Puerto Rico, the main nesting areas are at Fajardo on the main island of Puerto Rico and on the island of Culebra. Between 1978 and 2005, annual population growth rate was estimated to be 1.10 percent (TEWG 2007). Recorded leatherback nesting on the Sandy Point National Wildlife Refuge on the island of St. Croix, U.S. Virgin Islands between 1990 and 2005, ranged from a low of 143 in 1990 to a high of 1,008 in 2001 (Garner et al. 2005). In the British Virgin Islands, annual nest numbers have increased in Tortola from zero to six nests per year in the late 1980s to 35 to 65 nests per year in the 2000s (TEWG 2007).

The most important nesting beach for leatherbacks in the eastern Atlantic lies in Gabon, Africa. It was estimated there were 30,000 nests along 60 miles of Mayumba Beach in southern Gabon during the 1999-2000 nesting season (Billes et al. 2000). Some nesting has been reported in Mauritania, Senegal, the Bijagos Archipelago of Guinea-Bissau, Turtle Islands and Sherbro Island of Sierra Leone, Liberia, Togo, Benin, Nigeria, Cameroon, Sao Tome and Principe, continental Equatorial Guinea, Islands of Corisco in the Gulf of Guinea and the Democratic Republic of the Congo, and Angola. In addition, a large nesting population is found on the island of Bioko (Equatorial Guinea) (Fretey et al. 2007).

Hawksbill Sea Turtle

About 15,000 females are estimated to nest each year throughout the world with the Caribbean accounting for 20 to 30 percent of the world's hawksbill population. Only five regional populations remain with more than 1,000 females nesting annually (Seychelles, Mexico, Indonesia, and two in Australia) (Meylan and Donnelly 1999). Mexico is now the most important region for hawksbills in the Caribbean with about 3,000 nests per year (Meylan 1999). In the U.S. Pacific, hawksbills nest only on main island beaches in Hawaii, primarily along the east coast of the island of Hawaii. Hawksbill nesting has also been documented in American Samoa and Guam (NMFS and Service 1998c).

Kemp's Ridley Sea Turtle

Most Kemp's ridleys nest on the coastal beaches of the Mexican states of Tamaulipas and Veracruz, although a small number of Kemp's ridleys nest consistently along the Texas coast (TEWG 1998). In addition, rare nesting events have been reported in Alabama, Florida, Georgia, South Carolina, and North Carolina. Historical information indicates that tens of thousands of ridleys nested near Rancho Nuevo, Mexico, during the late 1940s (Hildebrand 1963). The Kemp's ridley population experienced a devastating decline between the late 1940s and the mid-1980s. The total number of nests per nesting season at Rancho Nuevo remained below 1,000 throughout the 1980s, but gradually began to increase in the 1990s. In 2009, 16,273 nests were documented along the 18.6 miles of coastline patrolled at Rancho Nuevo, and the total number of nests documented for all the monitored beaches in Mexico was 21,144 (Service 2009b). In 2010, a total of 13,302 nests were documented in Mexico (Service 2010). In addition, 207 and 153 nests were recorded during 2009 and 2010, respectively, in the U.S., primarily in Texas.

Status and Distribution

Loggerhead Sea turtle

Five recovery units have been identified in the Northwest Atlantic based on genetic differences and a combination of geographic distribution of nesting densities, geographic separation, and geopolitical boundaries (NMFS and Service 2008). Recovery units are subunits of a listed species that are geographically or otherwise identifiable and essential to the recovery of the species. Recovery units are individually necessary to conserve genetic robustness, demographic robustness, important life history stages, or some other feature necessary for long-term sustainability of the species. The five recovery units identified in the Northwest Atlantic are:

1. Northern Recovery Unit (NRU) - defined as loggerheads originating from nesting beaches from the Florida-Georgia border through southern Virginia (the northern extent of the nesting range);
2. Peninsula Florida Recovery Unit (PFRU) - defined as loggerheads originating from nesting beaches from the Florida-Georgia border through Pinellas County on the west coast of Florida, excluding the islands west of Key West, Florida;
3. Dry Tortugas Recovery Unit (DTRU) - defined as loggerheads originating from nesting beaches throughout the islands located west of Key West, Florida;

4. Northern Gulf of Mexico Recovery Unit (NGMRU) - defined as loggerheads originating from nesting beaches from Franklin County on the northwest Gulf coast of Florida through Texas; and
5. Greater Caribbean Recovery Unit (GCRU) - composed of loggerheads originating from all other nesting assemblages within the Greater Caribbean (Mexico through French Guiana, The Bahamas, Lesser Antilles, and Greater Antilles).

The mtDNA analyses show that there is limited exchange of females among these recovery units (Ehrhart 1989, Foote et al. 2000, NMFS 2001, Hawkes et al. 2005). Based on the number of haplotypes, the highest level of loggerhead mtDNA genetic diversity in the Northwest Atlantic has been observed in females of the GCRU that nest at Quintana Roo, Mexico (Encalada et al. 1999, Nielsen et al. 2012).

Nuclear DNA analyses show that there are no substantial subdivisions across the loggerhead nesting colonies in the southeastern U.S. Male-mediated gene flow appears to be keeping the subpopulations genetically similar on a nuclear DNA level (Francisco-Pearce 2001).

Historically, the literature has suggested that the northern U.S. nesting beaches (NRU and NGMRU) produce a relatively high percentage of males and the more southern nesting beaches (PFRU, DTRU, and GCRU) a relatively high percentage of females (e.g., Hanson *et al.* 1998, NMFS 2001, Mrosovsky and Provancha 1989). The NRU and NGMRU were believed to play an important role in providing males to mate with females from the more female-dominated subpopulations to the south. However, in 2002 and 2003, researchers studied loggerhead sex ratios for two of the U.S. nesting subpopulations, the northern and southern subpopulations (NGU and PFRU, respectively) (Blair 2005, Wyneken *et al.* 2005). The study produced interesting results. In 2002, the northern beaches produced more females and the southern beaches produced more males than previously believed. However, the opposite was true in 2003 with the northern beaches producing more males and the southern beaches producing more females in keeping with prior literature. Wyneken *et al.* (2005) speculated that the 2002 result may have been anomalous; however, the study did point out the potential for males to be produced on the southern beaches. Although this study revealed that more males may be produced on southern recovery unit beaches than previously believed, the Service maintains that the NRU and NGMRU play an important role in the production of males to mate with females from the more southern recovery units.

The NRU is the second largest loggerhead nesting aggregation in the Northwest Atlantic. Annual nest totals from northern beaches averaged 5,215 nests from 1989-2008, a period of near-complete surveys of NRU nesting beaches (NMFS and Service 2008), representing approximately 1,272 nesting females per year (4.1 nests per female, Murphy and Hopkins 1984). The loggerhead nesting trend from daily beach surveys showed a significant decline of 1.3 percent annually. Nest totals from aerial surveys conducted by the South Carolina Department of Natural Resources showed a 1.9 percent annual decline in nesting in South Carolina since 1980. Overall, there is strong statistical data to suggest the NRU has experienced a long-term decline (NMFS and Service 2008).

The PFRU is the largest loggerhead nesting assemblage in the Northwest Atlantic. A near complete nest census of the PFRU undertaken from 1989 to 2007 reveals a mean of 64,513 loggerhead nests per year representing approximately 15,735 females nesting per year (4.1 nests per female, Murphy and Hopkins 1984) (FWC 2008d). This near-complete census provides the best statewide estimate of total abundance, but because of variable survey effort, these numbers cannot be used to assess trends. Loggerhead nesting trends are best assessed using standardized nest counts made at INBS sites surveyed with constant effort over time. In 1979, the Statewide Nesting Beach Survey (SNBS) program was initiated to document the total distribution, seasonality, and abundance of sea turtle nesting in Florida. In 1989, the INBS program was initiated in Florida to measure seasonal productivity, allowing comparisons between beaches and between years (FWC 2009b). Of the 190 SNBS surveyed areas, 33 participate in the INBS program (representing 30 percent of the SNBS beach length).

INBS nest counts from 1989–2010 show a shallow decline. However, recent trends (1998–2010) in nest counts have shown a 25 percent decline, with increases only observed in the most recent 6-year period, 2008–2013 although there was no trend observed (FWC/FWRI 2014). The analysis that reveals this decline uses nest-count data from 345 representative Atlantic-coast index zones (total length = 187 miles) and 23 representative zones on Florida's southern Gulf coast (total length = 14.3 miles). The spatial and temporal coverage (annually, 109 days and 368 zones) accounted for an average of 70 percent of statewide loggerhead nesting activity between 1989 and 2010.

The NGMRU is the third largest nesting assemblage among the four U.S. recovery units. Nesting surveys conducted on approximately 186 miles of beach within the NGMRU (Alabama and Florida only) were undertaken between 1995 and 2007 (statewide surveys in Alabama began in 2002). The mean nest count during this 13-year period was 906 nests per year, which equates to about 221 females nesting per year (4.1 nests per female, Murphy and Hopkins 1984; FWC 2008d). Evaluation of long-term nesting trends for the NGMRU is difficult because of changed and expanded beach coverage. Loggerhead nesting trends are best assessed using standardized nest counts made at INBS sites surveyed with constant effort over time. There are 12 years (1997- 2008) of Florida INBS data for the NGMRU (FWC 2008d). A log-linear regression showed a significant declining trend of 4.7 percent annually (NMFS and Service 2008).

The DTRU, located west of the Florida Keys, is the smallest of the identified recovery units. A near-complete nest census of the DTRU undertaken from 1995 to 2004, excluding 2002, (nine years surveyed) reveals a mean of 246 nests per year, which equates to about 60 females nesting per year (4.1 nests per female, Murphy and Hopkins 1984) (FWC 2008d). Surveys after 2004 did not include principal nesting beaches within the recovery unit (i.e., Dry Tortugas National Park). The nesting trend data for the DTRU are from beaches that are not part of the INBS program, but are part of the SNBS program. There are nine years of data for this recovery unit. A simple linear regression accounting for temporal autocorrelation revealed no trend in nesting numbers. Because of the annual variability in nest totals, a longer time series is needed to detect a trend (NMFS and Service 2008).

The GCRU is composed of all other nesting assemblages of loggerheads within the Greater Caribbean. Statistically valid analyses of long-term nesting trends for the entire GCRU are not available because there are few long-term standardized nesting surveys representative of the region. Additionally, changing survey effort at monitored beaches and scattered and low-level nesting by loggerheads at many locations currently precludes comprehensive analyses. The most complete data are from Quintana Roo and Yucatán, Mexico, where an increasing trend was reported over a 15-year period from 1987-2001 (Zurita *et al.* 2003). However, since 2001, nesting has declined and the previously reported increasing trend appears not to have been sustained (NMFS and Service 2008). Other smaller nesting populations have experienced declines over the past few decades (e.g., Amorocho 2003).

Recovery Criteria (only the Demographic Recovery Criteria are presented below; for the Listing Factor Recovery Criteria, please see NMFS and Service 2008)

1. Number of Nests and Number of Nesting Females

    a. Northern Recovery Unit

        i. There is statistical confidence (95 percent) that the annual rate of increase over a generation time of 50 years is 2 percent or greater resulting in a total annual number of nests of 14,000 or greater for this recovery unit (approximate distribution of nests is North Carolina =14 percent [2,000 nests], South Carolina =66 percent [9,200 nests], and Georgia =20 percent [2,800 nests]); and 37

        ii. This increase in number of nests must be a result of corresponding increases in number of nesting females (estimated from nests, clutch frequency, and remigration interval).

    b. Peninsular Florida Recovery Unit

        i. There is statistical confidence (95 percent) that the annual rate of increase over a generation time of 50 years is statistically detectable (one percent) resulting in a total annual number of nests of 106,100 or greater for this recovery unit; and

        ii. This increase in number of nests must be a result of corresponding increases in number of nesting females (estimated from nests, clutch frequency, and remigration interval).

    c. Dry Tortugas Recovery Unit

        i. There is statistical confidence (95 percent) that the annual rate of increase over a generation time of 50 years is three percent or greater resulting in a total annual number of nests of 1,100 or greater for this recovery unit; and

ii. This increase in number of nests must be a result of corresponding increases in number of nesting females (estimated from nests, clutch frequency, and remigration interval).

d. Northern Gulf of Mexico Recovery Unit

i. There is statistical confidence (95 percent) that the annual rate of increase over a generation time of 50 years is three percent or greater resulting in a total annual number of nests of 4,000 or greater for this recovery unit (approximate distribution of nests (2002-2007) is Florida= 92 percent [3,700 nests] and Alabama =8 percent [300 nests]); and

ii. This increase in number of nests must be a result of corresponding increases in number of nesting females (estimated from nests, clutch frequency, and remigration interval).

e. Greater Caribbean Recovery Unit

i. The total annual number of nests at a minimum of three nesting assemblages, averaging greater than 100 nests annually (e.g., Yucatán, Mexico; Cay Sal Bank, Bahamas) has increased over a generation time of 50 years; and

ii. This increase in number of nests must be a result of corresponding increases in number of nesting females (estimated from nests, clutch frequency, and remigration interval).

2. Trends in Abundance on Foraging Grounds A network of in-water sites, both oceanic and neritic, across the foraging range is established and monitoring is implemented to measure abundance. There is statistical confidence (95 percent) that a composite estimate of relative abundance from these sites is increasing for at least one generation.

3. Trends in Neritic Strandings Relative to In-water Abundance Stranding trends are not increasing at a rate greater than the trends in in-water relative abundance for similar age classes for at least one generation.

The Recovery Plan for the Northwest Atlantic Population of the Loggerhead Sea Turtle was signed in 2008 (NMFS and Service 2008), and the Recovery Plan for U.S. Pacific Populations of the Loggerhead Turtle was signed in 1998 (NMFS and Service 1998e).

Green Sea Turtle

Annual nest totals documented as part of the Florida SNBS program from 1989-2008 have ranged from 435 nests laid in 1993 to 12,752 in 2007. The nest count for 2013 was more than twice the count from 2007 with a total of 36,195 nests recorded (http://myfwc.com/research/wildlife/seaturtles/nesting/statewide/). Nesting occurs in 26 counties with a peak along the east coast, from Volusia through Broward Counties. Although the SNBS program provides information on distribution and total abundance statewide, it cannot be used to assess trends because of variable survey effort. Therefore, green turtle nesting trends are best assessed using standardized nest counts made at INBS sites surveyed with constant effort over time (1989-2009). Green sea turtle nesting in Florida is increasing based on 19 years (1989-2009) of INBS data from throughout the state (FWC 2009a). The increase in nesting in Florida is likely a result of several factors, including: (1) a Florida statute enacted in the early 1970s that prohibited the killing of green turtles in Florida; (2) the species listing under the Act afforded complete protection to eggs, juveniles, and adults in all U.S. waters; (3) the passage of Florida's constitutional net ban amendment in 1994 and its subsequent enactment, making it illegal to use any gillnets or other entangling nets in State waters; (4) the likelihood that the majority of Florida green turtles reside within Florida waters where they are fully protected; (5) the protections afforded Florida green turtles while they inhabit the waters of other nations that have enacted strong sea turtle conservation measures (e.g., Bermuda); and (6) the listing of the species on Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which stopped international trade and reduced incentives for illegal trade from the U.S.

Recovery Criteria

The U.S. Atlantic population of green sea turtles can be considered for delisting if, over a period of 25 years, the following conditions are met:

1. The level of nesting in Florida has increased to an average of 5,000 nests per year for at least six years. Nesting data must be based on standardized surveys;

2. At least 25 percent (65 miles) of all available nesting beaches (260 miles) is in public ownership and encompasses at least 50 percent of the nesting activity;

3. A reduction in stage class mortality is reflected in higher counts of individuals on foraging grounds;

4. All priority one tasks identified in the recovery plan have been successfully implemented.

The Recovery Plan for U.S. Population of Atlantic Green Turtle was signed in 1991 (NMFS and Service 1991), the Recovery Plan for U.S. Pacific Populations of the Green Turtle was signed in 1998 (NMFS and Service 1998b), and the Recovery Plan for U.S. Pacific Populations of the East Pacific Green Turtle was signed in 1998 (NMFS and Service 1998a).

Leatherback Sea Turtle

Declines in leatherback nesting have occurred over the last two decades along the Pacific coasts of Mexico and Costa Rica. The Mexican leatherback nesting population, once considered to be the world's largest leatherback nesting population (historically estimated to be 65 percent of the worldwide population), is now less than one percent of its estimated size in 1980. (Spotila *et al.* 1996) estimated the number of leatherback sea turtles nesting on 28 beaches throughout the world from the literature and from communications with investigators studying those beaches. The estimated worldwide population of leatherbacks in 1995 was about 34,500 females on these beaches with a lower limit of about 26,200, and an upper limit of about 42,900. This is less than one-third the 1980 estimate of 115,000. Leatherbacks are rare in the Indian Ocean and in very low numbers in the western Pacific Ocean. The largest population is in the western Atlantic. Using an age-based demographic model, (Spotila *et al.* 1996) determined that leatherback populations in the Indian Ocean and western Pacific Ocean cannot withstand even moderate levels of adult mortality and that the Atlantic populations are being exploited at a rate that cannot be sustained. They concluded that leatherbacks are on the road to extinction and further population declines can be expected unless action is taken to reduce adult mortality and increase survival of eggs and hatchlings.

In the U.S., nesting populations occur in Florida, Puerto Rico, and the U.S. Virgin Islands. In Florida, the SNBS program documented an increase in leatherback nesting numbers from 98 nests in 1988 to between 800 and 900 nests per season in the early 2000s (FWC 2009a, Stewart and Johnson 2006). Although the SNBS program provides information on distribution and total abundance statewide, it cannot be used to assess trends because of variable survey effort. Therefore, leatherback nesting trends are best assessed using standardized nest counts made at INBS sites surveyed with constant effort over time (1989-2009). An analysis of the INBS data has shown a substantial increase in leatherback nesting in Florida since 1989 (FWC 2009b, TEWG Group 2007).

Recovery Criteria

The U.S. Atlantic population of leatherbacks can be considered for delisting if the following conditions are met:

1. The adult female population increases over the next 25 years, as evidenced by a statistically significant trend in the number of nests at Culebra, Puerto Rico, St. Croix, U.S. Virgin Islands, and along the east coast of Florida;
2. Nesting habitat encompassing at least 75 percent of nesting activity in U.S. Virgin Islands, Puerto Rico, and Florida is in public ownership; and
3. All priority one tasks identified in the recovery plan have been successfully implemented. The Recovery Plan for Leatherback Turtles in the U.S. Caribbean, Atlantic, and Gulf of Mexico was signed in 1992 (NMFS and Service 1992), and the Recovery Plan for U.S. Pacific Populations of the Leatherback Turtle was signed in 1998 (NMFS and Service 1998d).

<u>Hawksbill Sea Turtle</u>

The hawksbill sea turtle has experienced global population declines of 80 percent or more during the past century and continued declines are projected (Meylan and Donnelly 1999). Most populations are declining, depleted, or remnants of larger aggregations. Hawksbills were previously abundant, as evidenced by high-density nesting at a few remaining sites and by trade statistics.

Recovery Criteria

The U.S. Atlantic population of hawksbills can be considered for delisting if, over a period of 25 years, the following conditions are met:

1. The adult female population is increasing, as evidenced by a statistically significant trend in the annual number of nests on at least five index beaches, including Mona Island and Buck Island Reef National Monument;
2. Habitat for at least 50 percent of the nesting activity that occurs in the U.S. Virgin Islands and Puerto Rico is protected in perpetuity;
3. Numbers of adults, subadults, and juveniles are increasing, as evidenced by a statistically significant trend on at least five key foraging areas within Puerto Rico, U.S. Virgin Islands, and Florida; and
4. All priority one tasks identified in the recovery plan have been successfully implemented.

The Recovery Plan for the Hawksbill Turtle in the U.S. Caribbean, Atlantic, and Gulf of Mexico was signed in 1993 (NMFS and Service 1993), and the Recovery Plan for U.S. Pacific Populations of the Hawksbill Turtle was signed in 1998 (NMFS and Service 1998c).

Kemp's Ridley Sea Turtle

Today, under strict protection, the population appears to be in the early stages of recovery. The recent nesting increase can be attributed to full protection of nesting females and their nests in Mexico resulting from a binational effort between Mexico and the U.S. to prevent the extinction of the Kemp's ridley, and the requirement to use Turtle Excluder Devices (TEDs) in shrimp trawls both in the U.S. and Mexico.

The Mexico government also prohibits harvesting and is working to increase the population through more intensive law enforcement, by fencing nest areas to diminish natural predation, and by relocating most nests into corrals to prevent poaching and predation. While relocation of nests into corrals is currently a necessary management measure, this relocation and concentration of eggs into a "safe" area is of concern since it can reduce egg viability.

Recovery Criteria

The goal of the recovery plan is for the species to be reduced from endangered to threatened status. The Recovery Team members feel that the criteria for a complete removal of this species from the endangered species list need not be considered now, but rather left for future revisions of the plan. Complete removal from the federal list would certainly necessitate that some other instrument of protection, similar to the MMPA, be in place and be international in scope. Kemp's ridley can be considered for reclassification to threatened status when the following four criteria are met:

1. Continuation of complete and active protection of the known nesting habitat and the waters adjacent to the nesting beach (concentrating on the Rancho Nuevo area) and continuation of the bi-national protection project;
2. Elimination of mortality from incidental catch in commercial shrimping in the U.S. and Mexico through the use of TEDs and achievement of full compliance with the regulations requiring TED use;
3. Attainment of a population of at least 10,000 females nesting in a season; and
4. Successful implementation of all priority one recovery tasks in the recovery plan.

The Recovery Plan for the Kemp's Ridley Sea Turtle was signed in 1992 (Service and NMFS 1992). Significant new information on the biology and population status of Kemp's ridley has become available since 1992. Consequently, a full revision of the recovery plan has been completed by the Service and NMFS. The Bi-National Recovery Plan for the Kemp's Ridley Sea 42 turtle (2011) provides updated species biology and population status information, objective and measurable recovery criteria, and updated and prioritized recovery actions.

<u>Common threats to sea turtles in Florida</u>

Anthropogenic factors that impact hatchlings and adult female turtles on land, or the success of nesting and hatching include: beach erosion; armoring and nourishment; artificial lighting; beach cleaning; increased human presence; recreational beach equipment; beach driving; coastal construction and fishing piers; exotic dune and beach vegetation; and poaching. An increased human presence at some nesting beaches or close to nesting beaches has led to secondary threats such as the introduction of exotic fire ants (*Solenopsis* spp.), feral hogs (*Sus scrofa*), dogs (*Canis familiaris*), and an increased presence of native species (e.g., raccoons (*Procyon lotor*), armadillos (*Dasypus novemcinctus*), and opossums (*Didelphis virginiana*), which raid nests and feed on turtle eggs. Although sea turtle nesting beaches are protected along large expanses of the western North Atlantic coast, other areas along these coasts have limited or no protection.

Anthropogenic threats in the marine environment include oil and gas exploration and transportation; marine pollution; underwater explosions; hopper dredging; offshore artificial lighting; power plant entrainment or impingement; entanglement in debris; ingestion of marine debris; marina and dock construction and operation; boat collisions; and poaching and fishery interactions. On April 20, 2010, an explosion and fire on the Mobile Offshore Drilling Unit Deepwater Horizon MC252 occurred approximately 50 miles southeast of the Mississippi Delta. A broken well head at the sea floor resulted in a sustained release of oil, estimated at 35,000 and 60,000 barrels per day. On July 15, the valves on the cap were closed, which effectively shut in the well and all sub-sea containment systems. Damage assessment from the sustained release of oil is ongoing and the Service does not have a basis at the present time to predict the complete scope of effects to sea turtles range-wide.

Fibropapillomatosis, a disease of sea turtles characterized by the development of multiple tumors on the skin and internal organs, is also a mortality factor, particularly for green turtles. This disease has seriously impacted green turtle populations in Florida, Hawaii, and other parts of the world. The tumors interfere with swimming, eating, breathing, vision, and reproduction, and turtles with heavy tumor burdens may die.

Artificial lighting

Experimental field work by Witherington (1992a) directly implicated artificial lighting in deterring sea turtles from nesting. In these experiments, both green and loggerhead turtles showed a significant tendency to avoid stretches of beach with artificial lights that have predominantly blue and green wavelengths. Because adult females rely on visual brightness cues to find their way back to the ocean after nesting, those turtles that nest on lighted beaches may be disoriented by artificial lights and have difficulty finding their way back to the ocean. In the lighted-beach experiments described by Witherington (1992a), few nesting turtles returning to the sea were misdirected by lighting; however, those that were, spent a large portion of the night wandering in search of the ocean. In some cases, nesting females have ended up on coastal highways and been struck by vehicles. However, turtles returning to the sea after nesting are not misdirected nearly as often as hatchlings emerging on the same beaches (Witherington and Martin 1996).

Under natural conditions, hatchling sea turtles, which typically emerge from nests at night, move toward the brightest, most open horizon, which is over the ocean. However, when bright light sources are visible on the beach, they become the brightest spot on the horizon and attract hatchlings in the wrong direction, making them more vulnerable to predators, desiccation, entrapment in debris or vegetation, and exhaustion, and often luring them onto roadways and parking lots where they are run over. Artificial lights can also disorient hatchlings once they reach the water. Hatchlings have been observed to exit the surf onto land where lighting is nearby (Daniel and Smith 1947, Carr and Ogren 1960, Witherington 1986). Artificial beachfront lighting from buildings and streetlights is a well-documented cause of hatchling disorientation (loss of bearings) and misorientation (incorrect orientation) on nesting beaches (McFarlane 1963, Philibosian 1976, Mann 1978, Florida Fish and Wildlife Conservation Commission unpubl. data).

Extensive research has demonstrated that visual cues are the primary sea finding mechanism for hatchlings (Carr and Ogren 1960, Ehrenfeld and Carr 1967, Mrosovsky and Carr 1967, Mrosovsky and Shettleworth 1968, Dickerson and Nelson 1989, Witherington and Bjorndal 1991). Loggerhead, green and hawksbill hatchlings demonstrate a strong preference for short-wavelength light (Witherington and Bjorndal 1991, Witherington 1992b). Green and hawksbill turtles were most strongly attracted to light in the near-ultraviolet to yellow region of the spectrum and were weakly attracted or indifferent to orange and red light. Loggerheads were most strongly attracted to light in the near-ultraviolet to green region and showed differing responses to light in the yellow region of the spectrum depending on light intensities. At intensities of yellow light comparable to a full moon or a dawn sky, loggerhead hatchlings showed an aversion response to yellow light sources, but at low, nighttime intensities, loggerheads were weakly attracted to yellow light.

ENVIRONMENTAL BASELINE

The "Environmental Baseline" section summarizes information on status and trends of nesting sea turtle specifically within the action area. These summaries provide the foundation for our assessment of the effects of the proposed action, as presented in the "Effects of the Action" section.

Status of the Species in the Action Area and vicinity

KSC is located at the northern end of the highest concentration of loggerhead sea turtle nesting in the Western Hemisphere. The following paragraphs discuss the nesting season and status from the four species of federally protected sea turtles have been documented as nesting on the beaches of KSC and MINWR or in the vicinity: the loggerhead, green, leatherback, and hawksbill sea turtle.

Loggerhead Sea Turtle

Nesting season for loggerhead sea turtle for southern Florida Atlantic beaches begins in extends from March 15 through November 30. Incubation ranges from about 45 to 95 days. Between 655 and 1,586 loggerhead nests were deposited annually on KSC/MINWR from 2000 through 2016.

Green Sea Turtle

The green sea turtle nesting and hatching season for southern Florida Atlantic beaches extends from May 1 through November 30. Incubation ranges from about 45 to 75 days. Between 2 and 103 green turtle nests were deposited annually on KSC/MINWR from 2000 through 2016.

Leatherback Sea Turtle

The leatherback sea turtle nesting and hatching season for Southern Florida Atlantic beaches extends from February 15 through November 15. Incubation ranges from about 55 to 85 days. Between 0 and 1 leatherback turtle nests were deposited annually on KSC/MINWR from 2000 through 2016.

Hawksbill Sea Turtle

The hawksbill sea turtle nesting and hatching season for Southern Florida Atlantic beaches extends from June 1 through December 31. Incubation lasts approximately 60 days.
Hawksbill sea turtle nesting is rare and restricted to the southeastern coast of Florida (Volusia through Dade Counties) and the Florida Keys (Monroe County) (Meylan 1992, Meylan *et al.* 1995). However, hawksbill tracks are difficult to differentiate from those of loggerheads and may not be recognized by surveyors. Therefore, surveys in Florida likely underestimate actual hawksbill nesting numbers (Meylan *et al.* 1995). Although no hawksbill nests have ever been recorded in

Brevard County, one was reported at the Canaveral National Seashore in Volusia County in 1982 (Meylan *et al.* 1995). Therefore, the potential exists for such an occurrence at KSC/MINWR.

History of Disorientation/Misorientation in the Action Area and vicinity

The first observations of hatchling disorientations were recorded on KSC/MINWR beach in 1989. In 1990, sea turtle disorientation events began to be routinely observed and 36 disorientation events were recorded that year. Seven out of the 36 appeared to be caused by LC 39A and 39B. In 1991, 12 of the 42 nests most likely disoriented because of LC 39A and 39B facility lighting. In 1992, seven of the 46 disorientation events appeared to be caused by LC 39A and 39B. Since then, hatchling disorientation and misorientation incidents are routinely documented on the KSC/MINWR beach. Disorientation and misorientation reports may be underreported because the tracks of hatchlings are easily obscured by rain or windblown sand. The number of hatchling disorientation/misorientation incidents may be higher than what was actually observed and reported. To assess the success of light management activities, KCS has used a standard monitoring and reporting protocol for disorientations/misorientations to estimate the percentage of all nests laid that produce hatchlings compared to those that are misdirected on an annual basis.

Most disorientations recorded are attributed to lighting from the Space Shuttle LCs. In 1999, three hurricanes caused erosion of approximately 600 meters of dune front. Following the damage from these hurricanes, the dune profile was lower and absent of vegetation, and the effect of the lighting from the Space Shuttle LCs in 2000 substantially increased the number of hatchling disorientation events. NASA in collaboration with MINWR continues to restore and re-vegetate the dune.

During the summer of 2010, an inland dune (locally referred to as the Pilot Dune) was constructed at a highly degraded site behind the primary dune between LC-39A and LC-39B, east of Phillips Parkway. The new dune is 221 m (725 ft) long, 24 m (80 ft) wide, and 4.6 m (15 ft) tall. The purpose of that dune was to minimize light trespass from the LC-39 complex and thus improving conditions for sea turtle nesting. The stretch of primary dune adjacent to this area was severely compromised by activities associated with railroad operations, and during the last several years by wash overs and inundation from storm surges. Vegetation planting on the constructed dune occurred in April 2011 to improve sea turtle habitat. Post construction sampling showed successful vegetative establishment and colonization by beach mice and tortoises (Bolt et al. 2012). The dune does provide visual screening of some KSC infrastructure for at least this small stretch of beach, a section that continues to experience serious erosion of the beach face which has moved westerly over 30 m in the last decade.

NASA completed an Environmental Assessment for a KSC shoreline protection program (NASA 2015) in 2013 to ensure protection of high value launch infrastructure threatened by persistent and worsening beach erosion between launch complexes 39A and 39B (Figure 1). The preferred alternative selected involved the construction of a large secondary dune behind the existing primary dune in areas most vulnerable to erosion and flooding. These areas are located along the northern

5.8 km (3.6 mi) of the KSC shoreline roughly between beach kilometer stations 27 and 33 (Figure 1). Hurricane Sandy recovery funds enabled the restoration of the most severely damaged section of KSC beach along approximately 1.75 km of degraded primary and secondary dune between kilometer stations 29 and 31 (Figure 1). Native, salt-tolerant dune vegetation was planted along the dune crest and side slopes to stabilize the constructed dune and facilitate habitat restoration and provide a barrier from light trespass from the LC-39 Area.

In 2009, the Service issued an Interim BO for the lighting operations for the proposed Light Constellation Plan. To further minimize incidental take associated with lighting from the proposed operations, the Service listed a number of Terms and Conditions within the Interim BO. The Service acknowledged that some adverse impacts would occur to some number of sea turtles and would continue due to KSC light sources that are necessary for conducting nighttime launch operations, human safety and national security and issued an incidental take statement to KSC, which was not to exceed 3% for hatchlings and 3% for nesting females on the KSC beach.

Since the BO has been in effect, the level of incidental take at KSC has ranged from 2% to 5%. In 2013, a study conducted by contractors reviewed the status of the Terms and Conditions KSC BO and provided an assessment of the issues related to lighting use at KSC. In addition, the report updated the KSC Lighting Guidance, and provided a template for the specific Light Operations Manual (LOM).

KSC reinitated the 2009 BO based on new planning efforts and developed a suite of conservation measures to address the future facilities and the recent increase in disorientation rates. According to the 2016 Sea Turtle Hatchling Disorientation Report that we received on January 25, 2017, the hatchling disorientation rate at KSC was recorded at 0%. Of the five disorientations, all occurred from a light source at Cape Canaveral Air Force Station's Pad 41 Area.

Factors Affecting Species' Environment within the Action Area

This analysis describes factors affecting the environment for in the action area. There are no State, tribal, local or private actions affecting the species or that will occur contemporaneously with this consultation. Federal actions have taken place within the action areas that have impacted sea turtles. These projects sometimes resulted in incidental take anticipated through section 7 of the Act. The impacts associated with some of these projects resulted in the loss of occupied habitat or habitat suitable for occupation within the action area.

EFFECTS OF THE ACTION

Effects of the action refer to the direct and indirect effects of an action on the species or proposed critical habitat that would be added to the environmental baseline, along with the effects of other activities that are interrelated or interdependent with that action. Interrelated actions are those that are part of a larger action and depend on the larger action for their justification. Interdependent actions are those that have no independent utility apart from the action under consideration. Indirect effects are those that are caused by the proposed action and are later in time, but are still reasonably certain to occur. Indirect effects can be both spatial and temporal in nature. In contrast to direct effects, indirect effects can often be more subtle, and may affect species and habitat quality over an extended period, long after project activities have been completed. Indirect effects are of particular concern for long-lived species such as sea turtles, because project-related effects may not become evident in individuals or populations until years later.

In the "Environmental Baseline" section above, we discussed the numbers of turtles that are likely to nest within the action area based on previous nesting data collected at KSC and the adjacent MINWR. We also discussed the percentage of hatchling and adults disorientation reports that have been recorded from 1992. Because these sources constitute the best available information, we have used the estimates to derive the percentage of likely misorientation and disorientation reports for the following analyses. We acknowledge, however, that not all individuals disorient or that misorientation during future spaceport construction activities or during operations and maintenance will be detected by surveys and reported. The inability to detect all killed or injured individuals is largely due to sea turtles spending much of their lives in the ocean, with females coming ashore each year to nest. Another confounding factor is that scavengers may locate carcasses before monitors and either remove them from the site or dismember them to the extent that the cause of death cannot be determined.

As discussed in the status of the species section under common threats, research has shown that females will avoid highly illuminated beaches and postpone nesting. Artificial lights have also resulted in hatchling mortality as disoriented hatchlings move toward these light sources rather than the ocean. Exterior lighting by the proposed action has the potential to directly and indirectly affect nesting sea turtles and hatchlings. Extensive research has demonstrated that the principal component of the sea-finding behavior of emergent hatchlings is a visual cue (Carr and Ogren 1960, Dickerson and Nelson 1989, Witherington and Bjorndal 1991). Artificial lighting can be detrimental to sea turtles in several ways; either through misorientation, when hatchings emerge from a nest they are directed to an artificial light source away from the sea, or disorientation, a loss of bearings of hatchling or adult sea turtles (Witherington and Martin 1996). Field observations have also shown a correlation between lighted beaches and reduced loggerhead and green sea turtle nesting (Mortimer 1982, Raymond 1984, Mattison *et al.* 1993).

Since 1995, KSC has taken an aggressive approach to minimize the impacts on sea turtles caused by exterior lighting by implementing guidance for lighting installation. In 2001, managers at KSC initiated a "Turtle mode" lighting plan that consisted of turning off the majority of lights at each Pad unless there were specific operational requirements. However, security lighting was increased around the Shuttle launch pads. The increased lighting accounted for a hatchling disorientation increase from 3-6% to 10%. Light sources that were major causes of disorientations and/or misorientations were identified.

The Space Shuttle LC 39A and 39B, and CCAFS's LC 37, 40, and 41 continue to be the main cause of disorientations and/or misorientations at KSC. Implementation of the "Turtle mode" lighting plan minimized the number of sea turtle disorientations and decreased the rate to 3%. In 2016, KSC revised the ELR guidelines to reflect the most recent FWC lighting guidelines. In addition to address the potential of direct and indirect lighting effects at future facilities, LOMs shall be required for new, large construction projects within the KSC. LOMs will be coordinated with the Service in order to ensure that lighting issues for that particular site are addressed from design to post construction (CM1).

For the Master Plan, KSC has offered a suite of measures to address future and existing light pollution at the facilities to minimize direct and indirect take of the species. The EMB has developed a NEPA checklist process for all new small scale lighting projects to ensure compliance (CM1). KSC is transitioning to amber LED lamps which are energy efficient and more turtle friendly when feasible and to streamline retrofitting, KSC is stocking true amber LED lamps to replace street, parking, and general safety area lighting as they become non-functional (CM 5).

Research shows that various types of lights affect sea turtles to varying degrees and there is uncertainty over how to measure the acceptable amount of light pollution for nesting sea turtles. Therefore, it is most productive to minimize light pollution and use the best available technology. To reduce the impacts to nesting and emerging sea turtles, light sources near the beach that are necessary for human safety for operations of the facility should be retrofitted (Witherington *et al.* 2014). KSC has performed annual routine night time lighting surveys throughout the sea turtle nesting season since 2010 (CM 3) and a priority list of lighting issues shall be outlined in the annual Activity report to guide retrofitting activities (CM 4,5).

CUMULATIVE EFFECTS

Cumulative effects include the effects of future State, tribal, local or private actions that are reasonably certain to occur in the action area considered in this BO. Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the Act. The Service is not aware of any cumulative effects in the project area.

CONCLUSION

After reviewing the current status of the loggerhead, green, leatherback, hawksbill and Kemp's ridley sea turtles, the environmental baseline for the action area, the effects of the proposed plan, and the cumulative effects, it is the Service's biological opinion that the project, as proposed, is not likely to jeopardize the continued existence of these species and is not likely to destroy or adversely modify designated critical habitat.

It is our opinion that considering NASA has implemented since the issuance of the 2009 Biological Opinion and will be implementing to minimize direct lighting of the nesting beaches and background lighting glow at KSC, the proposed update for the Master Plan is not likely to jeopardize the continued existence of listed sea turtles. We do, however, believe that adverse impacts to sea turtles will continue from lighting sources essential for human safety and national security at KSC. We believe the reasonable and prudent measures provided with the incidental take statement below will effectively reduce the take of sea turtles.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act and Federal regulation pursuant to section 4(d) of the Act prohibit the take of endangered or threatened species, respectively, without special exemption. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harm is further defined by the Service to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. Harass is defined by the Service as intentional or negligent actions that create the likelihood of injury to listed species to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering. Incidental take is defined as take that is incidental to, and not the purpose of, carrying out an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited under the Act provided that such taking is in compliance with the terms and conditions of this incidental take statement.

The measures described below are non-discretionary, and must be implemented by NASA so that they become binding conditions of any grant or permit issued to the applicant, as appropriate, for the exemption in section 7(o)(2) to apply. NASA has a continuing duty to regulate the activity covered by this incidental take statement. If NASA (1) fails to implement the conservation measures or fails to require the applicants to adhere to KSC's conservation measures in the project description (2) fails to assume and implement reasonable and prudent measures and associated terms and conditions or (3) fails to require the applicant to adhere to the reasonable and prudent measures and associated terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, the protective coverage of section 7(o)(2) may lapse. In order to monitor the impact of incidental take, NASA must report the progress of the action and its impacts on the species to the Service as specified in the incidental take statement. [50 CFR §402.14(i) (3)].

AMOUNT OR EXTENT OF TAKE

The Service has determined that incidental take of hatchlings will be calculated as the number of surveyed nests where hatchlings that disoriented/misoriented divided by the number of observed emergences. Surveys will be conducted 3 times a week during the hatchling emergence period to determine the incidental take.

The Service anticipates that up to a total of 3 % of all hatchlings disoriented/misoriented events from a representative sample of surveyed nests may occur. The incidental take is expected to be in the form of hatchling and nesting female disorientations and misorientations. The hatchling disorientation rate will be based on the total number of nests where disoriented hatchlings were observed, divided by the total number of nests with observed emergences. A nest is considered "disoriented" when more than four hatchlings exhibit disorientation or misorientation behavior.

The disorientation rate for adult female turtles is anticipated to be up to a total of 3%. Adult disorientations will be calculated separately and based on the number of adult females that disorient/misorient and the total number of nests laid. While the tracks of all marine turtle species that have historically nested on the KSC/MINWR beach loggerhead, green, or leather back sea turtles will be identified, disorientation rate will be based on their combined numbers. NASA will be held responsible for disorientation or misorientation incidents caused by KSC lighting only. It will not be held responsible for disorientation and misorientation incidents that might occur as a result of CCAFS lighting (i.e., lighting at the CCAFS LC 40 and 41 located on KSC property or any of the LC on CCAFS property).

EFFECT OF THE TAKE

In the accompanying BO, the Service has determined that this level of anticipated take (3% hatchlings and 3 % adult nesting females) is not likely to result in jeopardy to the species or destruction or adverse modification of critical habitat.

REASONABLE AND PRUDENT MEASURES

The Service considered all conservation measures when analyzing the effects of the action. The conservation measures on page 5-9 are binding measures for the protective coverage of section 7(o)(2). The shelter that section 7(o)2 provides from section 9 liabilities applies to both the applicants and the action agency provided all conservation measures and the following reasonable and prudent measures and associated terms and conditions. The Service believes the following reasonable and prudent measures are necessary and appropriate to further minimize take of sea turtles.

1. Facility compliance monitoring shall be conducted randomly during the sea turtle nesting and hatching season to ensure the operational constraints of approved LOM and facilities using the ELR are met.

2. Lighting policies shall apply for all existing and future facilities and KSC will be responsible for compliance.

3. During the sea turtle nesting and hatching season, the use of short-arc xenon lights at LC 39A and 39B will occur 24 hours prior to a launch and 24 hours post launch.

4. Lighting surveys will be conducted annually per CM #3 and reporting shall be submitted to the Service.

5. Nighttime surveys shall be conducted to record sea turtle nesting activities and hatchling disorientation and misorientation events. Surveys will continue annually to monitor the potential of lighting to harm or harass sea turtles.

6. Operational constraints will preclude use of exterior lights between 9 p.m. and dawn from May 1 through October 31 except where essential to support launch-related activities at active launch complexes for the safety/security of night operations.

7. Exterior lighting to be replaced at KSC will follow the approved ELM or the site specific LOMs that has been reviewed and approved by the Service.

8. The site specific LOMs for new large scale construction projects and launch pad plans developed per CM# 1 shall be reviewed and approved by the NASA EMB and the Service.

9. To monitor take, calculations of disorientation/misorientation events must be reported to the Service.

TERMS AND CONDITIONS

In order to be exempt from the prohibitions of section 9 of the Act, NASA must comply with the following terms and conditions, which implement reasonable and prudent measures described above and outline required reporting/monitoring requirements. These terms and conditions are non-discretionary.

1. The EMB will inspect and record noncompliance of approved site specific LOM, EML compliant facilities, and LOMs for all existing facilities during the sea turtle nesting and hatching season. In addition to contacting non-compliant facilities and

initiating compliance actions per CM #4, KSC will provide a summary of the compliance inspections, corrective actions, and success of the action in the annual activity report provided per CM #4. The annual activity report shall also include annual retrofitting actions or corrective actions taken to eliminate existing light sources. The annual activity report shall also include data from compliance inspections that shall inform adaptive light management.

2. To ensure compliance and that CM #2 lighting outreach and education is effective, KSC shall include engineers, facility managers, and any other representatives that design and/or enforce lighting at KSC to attend the lighting workshop that is conducted at CCAFS every two years. Facility managers of non-compliant facilities are required to attend.

3. During the sea turtle nesting and hatching season, use of short-arc xenon lights will occur 24 hours before launch and 24 hours post launch. Any light source which is not directly related to the launch operation and needed for safety and security must be shut off.

4. Five lighting surveys will be completed and submitted to the Service for each nesting season. Additional lighting surveys will be conducted, as needed, to ensure observed lighting violations are brought into compliance and to confirm light sources of hatchling disorientations that cannot be identified during hatchling disorientation surveys. The nighttime lighting survey data shall also be included in the annual activity report (CM#4). The annual activity report include information on the evaluation of the effectiveness of artificial light management at existing facilities, compliance with the ELR, approved site specific LOMs, and the new operational policies, prioritize retrofitting actions, and identify any needs for modifications for site specific LOM and ELRs.

5. Nighttime surveys to record sea turtle nesting activities and hatchling disorientation and misorientation events will continue annually on the following schedule: prior to nesting season by March 1st, during early nesting season May 1st, peak nesting season July 1st and late nesting season and early hatching season September 1st, peak and late hatching season by November 1st. These reports must be sent to the Service via email to JaxRegs@fws.gov to on March 15th, May 15th, July 15th, September 15th, and November 15th. After the first five years of reporting with satisfactory implementation of surveys and reporting, reporting shall be annually thereafter.

6. Operational constraints for all facilities at KSC include use of amber LED or exterior lights off between 9 p.m. and dawn from May 1 through October 31, except

where essential to support launch-related activities at active launch complexes for the safety/security of night operations. If incubating nests are still present on the beach after October 31 that could be impacted by particular noncompliant light sources, the lighting must be corrected to prevent potential disorientation/misorientation events in those particular cases.

7. KSC will generate a priority list of lighting projects and identify retrofitting or fixture replacement actions for each calendar year (CM # 5). KSC shall implement up to two retrofitting or fixture replacement projects per year, selecting the highest priority projects as determined by the lighting surveys. If this can't be achieved due then KSC should contact the Service to reinitiate consultation. The recommendations in the Florida Marine Research Institute Technical Report titled "Understanding, Assessing, and Resolving Light- Pollution Problems on Sea Turtle Nesting Beaches, updated in 2014" should be used as a guide when replacing fixtures. This report can be downloaded on the following website: http://myfwc.com/research/wildlife/sea-turtles/threats/artificial-lighting/

8. Coordination and review for new large scale site specific LOMs shall be submitted during the design phase and approved prior to construction of the project.

9a. Per CM #4, the EMB shall review monthly disorientation reports and shall provide monthly reports as outlined below and an annual summary of disorientation/misorientation. If an event is not included in the annual summary per EMB review, the event must be reported to the Service and shall include a rational of why the EMB did not qualify the event as a lighting disorientation/misorientation event.

All disorientation/misorientation will be provided in the annual activity report using the following methods:

i. $\dfrac{\text{Number of marked nests where more than 5 hatchlings disoriented}}{\text{Total number of all marked nests with signs of emergence tracks}}$

ii. $\dfrac{\text{Number of disoriented or misoriented adult nesting female turtles}}{\text{Total number of nests}}$

9b. In the event disoriented or misoriented hatchlings are discovered, the following procedures shall be followed:

1. Live hatchlings shall be maintained in covered, rigid walled containers on moist

sand in a building protected from extremes of heat or cold. Hatchlings shall be released after dark on the first night subsequent to the disorientation/misorientation event if their health permits.

2. A Florida Fish and Wildlife Conservation Commission "Marine Turtle Hatchling Disorientation Incident Report Form" shall be completed for each disorientation/misorientation incident. These forms shall be submitted to the Service's Jacksonville Field Office on a monthly basis on May 15th, June 15th, July 15th, August 15th, September 15th, October 15th, and November 15th. Reports shall be sent to Jaxregs@fws.gov. If there are no disorientations to reports, please send a brief email documenting that there were no disorientations. After the first five years of reporting, reporting shall be on an annual basis.

The Service has determined that up to a total of 3% of all disoriented/misoriented surveyed nests and 3% of all females nesting at KSC for each nesting season will be incidentally taken as a result of the proposed action. The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize the impact of incidental take that might otherwise result from the proposed action. If, during the course of the action, this level of incidental take is exceeded, such incidental take represents new information requiring reinitiation of consultation and review of the reasonable and prudent measures provided. The Federal agency must immediately provide an explanation of the causes of the taking and review with the Service the need for possible modification of the reasonable and prudent measures.

CONSERVATION RECOMMENDATIONS

Section 7(a) (1) of the Act directs Federal agencies to utilize their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information.

1. Educational information should be provided to personnel where appropriate at beach access points explaining the importance of the area to sea turtles and/or the life history of sea turtle species that nest in the area.

In order for the Service to be kept informed of actions minimizing or avoiding adverse effects or benefiting listed species or their habitats, the Service requests notification of the implementation of any conservation recommendations.

REINITIATION NOTICE

This concludes formal consultation on the action outlined in the request for reinitiation. As provided in 50 CFR §402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of incidental take is exceeded; (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion; (3) the agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not considered in this opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action. In instances where the amount or extent of incidental take is exceeded, any operations causing such take must cease pending reinitiation. The Service appreciates the cooperation of the NASA during this consultation. We would like to continue working with you and your staff regarding the lighting at KSC. For further coordination please contact Tera Baird at (904) 791-3196.

Sincerely,

Jay B. Herrington
Field Supervisor

cc: Jean Higgins, Florida Fish and Wildlife Conservation Commission, Tequesta, FL
Mike LeGare, Merritt Island National Wildlife Refuge, Titusville, FL
John Shaffer, Kennedy Space Center

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Attachment 6. USFWS Biological Opinion for SpaceX Operations at LZ-1/LZ-2

United States Department of the Interior

U. S. FISH AND WILDLIFE SERVICE

7915 BAYMEADOWS WAY, SUITE 200
JACKSONVILLE, FLORIDA 32256-7517

IN REPLY REFER TO:
FWS Log. No. 04EF1000-2014-F-0259

February 12, 2016

Mr. Michael Blaylock, Chief, Environmental Conservation
Department of the Air Force, 45th Space Wing
45 CES/CEIE
1224 Jupiter Street
Patrick AFB, Florida 32925-3343
(Attention: Angy Chambers)

RE: Additional Requests for Re-initiation of Section 7 Consultation: SpaceX Vertical Landing at Launch Complex 13 (Landing Complex 1), Cape Canaveral Air Force Station, Florida

Dear Mr. Blaylock:

Our office has reviewed the 45th Space Wing's (45 SW) correspondence dated July 23, 2015. The 45 SW again has requested re-initiation of section 7 consultation as a result of significant modifications by SpaceX to the original proposed site plan. These modifications involve the removal of four contingency landing pads due to improved radar landing accuracy, and the construction of two additional large landing pads for the purpose of supporting the landing of the Falcon Heavy three first stage vehicles. The changes will result in an increase in temporary site lighting during vehicle reentry and recovery due to the first stage rockets, water cannons, and portable pad lighting. In addition, construction of the two new pads will result in the clearing of an additional 23 acres of potential Florida scrub-jay habitat. Impacts to scrub-jay habitat from the original site design were addressed in our Biological Opinion (BO) dated September 17, 2014, and to nesting and hatchling sea turtles in an amended BO dated November 4, 2015. The latter included a reasonable and prudent measure to revise the site light management plan, which has been completed (Revision 7).

As a result of the further modifications, we are providing this second amendment to the September 17, 2014 BO and its November 4, 2015 amendment. This amendment addresses the impacts of the additional site lighting and the minimization measures needed for nesting and hatchling loggerhead (*Caretta caretta*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), Kemp's ridley (*Lepidochelys kempii*) and hawksbill (*Eretmochelys imbricata*) sea turtles, and land clearing impacts and minimization measures for the Florida scrub-jay. We submit the following in accordance with section 7 of the Endangered Species Act of 1973 (Act), as amended (16 U.S.C. 1531 *et seq.*).

The U.S. Fish and Wildlife Service (Service) provided the 45 SW a Biological Opinion in November 2008 (2008 BO) that covered the effects of lighting on nesting and hatchling sea turtles for the previously-mentioned species at both Cape Canaveral Air Force Station (CCAFS) and

Patrick Air Force Base (PAFB). The information in the 2008 BO relative to Status of the Species, Environmental Baseline, Effects of the Action, Cumulative Effects, and Conclusion (no jeopardy) remains generally current with two exceptions. The Service on September 22, 2011 designated nine distinct population segments (DPS) of the loggerhead sea turtle (76 FR 58868) and updated their status. Loggerhead sea turtles nesting at CCAFS and PAFB are part of the Northwest Atlantic DPS. The listing status of that DPS remained as threatened, so the DPS designation and status update for these turtles will not change the conclusion, RPMs and T&Cs of the 2008 BO. In addition, the Service published a final rule on July 10, 2014 (79 FR 39756) designating critical habitat for the Northwest loggerhead DPS. Due to the habitat protection and conservation measures in place at both CCAFS and PAFB that are reflected in the 45 SW's Integrated Natural Resource Management Plan and various individual active BOs, the 45 SW was exempt from this critical habitat designation. The exemption means that the absence of a critical habitat assessment in the 2008 BO remains valid.

Incidental Take Statement

<u>Amount or extent of take anticipated</u>

Sea turtles

The Service anticipates that nesting and hatchling sea turtles present within an action area that includes the beach approximately 2.5 miles northwest and southeast of Launch Complex-13/Landing Complex-1 during first stage rocket booster landing and the post-landing processing operations, may be taken from the additional lighting associated with those actions. The incidental take is expected in the form of direct and indirect harm to nesting and hatchling sea turtles resulting from misorientation or disorientation by the operational lighting that results in post nesting and hatching turtle movement in directions other than immediately towards open marine waters. Direct harm includes mortality from predation, desiccation, adverse physical impacts with pedestrians, vehicles, and equipment on or contiguous to the beach, and entrapment within vegetation and other natural landscape features, and within man-made structures, holes, ruts, etc. Indirect harm includes a reduced survivorship probability in post hatchling turtles due to yolk depletion resulting from lighting misorientation or disorientation that increases hatchling time spent on a beach before reaching open marine waters.

The 2008 BO established an annual level of take of sea turtles for all lighting present on CCAFS and PAFB at that time of 3% of all hatchlings at each installation, as well as a 3% take of adult females nesting at each installation due to disorientation/misorientation caused by lighting. Since that BO has been in effect, the levels of take at CCAFS has ranged from 0.26% to 2.53%. The high range represented the 2015 take figure that included six nests on the adjacent Kennedy Space Center Beach, and attributed to Launch Complex 41, its Vehicle Integration Facility, and Launch Complex 37. This situation is under investigation, and any lighting/monitoring issues identified are expected to be corrected prior to the beginning of the 2016 major sea turtle nesting season. Based on this and the preponderance of past annual disorientation being well under the 3% threshold, we anticipate that the additional take from the proposed project will not appreciably add to those figures, and will not exceed the 3% threshold established for nesting and hatchling sea turtles at each installation under the 2008 BO. We therefore are applying that take threshold to the project.

Scrub-jays

The Service anticipates the loss of approximately 23 acres of potential scrub-jay habitat.

Effects of the take

In this amended BO, the Service determined that this level of anticipated take is not likely to result in jeopardy to the five species of sea turtles and the Florida scrub-jay, or the destruction or adverse modification of any designated critical sea turtle nesting habitat.

Reasonable and prudent measures

The incidental take statement provides nondiscretionary measures that are necessary and appropriate to minimize the impact of incidental take. The Service's view is that the following reasonable and prudent measures (RPM) are necessary and appropriate to minimize impacts of incidental take of the five species of nesting and hatchling sea turtles and Florida scrub-jay, from some of the additional operational lighting and land clearing, respectively, associated with the proposed modified action. These measures have been developed in coordination with the 45 SW.

- Adherence to the reasonable and prudent measures included in the November 2008 BO on light management activities at CCAFS and PAFB, except as noted in the below
- Additional revision of the approved a site-specific LMP (Revision 7) in accordance with the USFWS's 2008 Programmatic BO, the September 2014 site-specific BO, the 45 SW Lighting Instruction, and to the maximum practical extent the Florida Fish and Wildlife Conservation Commissions' Sea Turtle Light Management Guidelines. This revision shall reflect the site modification and lighting changes
- LMP compliance inspection, monitoring, and enforcement by the site operator, SpaceX, and personnel from the 45 SW Civil Engineering Squadron/Civil Engineering Installation Environmental (CES/CEIE)
- Restoration of approximately 46 acres of potential scrub-jay habitat within Land Management Unit 33

Replacements of reasonable and prudent measures

- Replace RPM #1 with the following : "Assess the habitat scheduled for clearing for scrub-jay presence, including nests, prior to any clearing activities"
- Replace RPM #2 with the following: "Compensate for the amount of occupied and potential, unoccupied scrub-jay habitat permanently lost as a result of land clearing activities, with the enhancement/restoration and perpetual management of scrub-jay habitat within Land Management Unit (LMU) 33
- Replace RPM #4 with the following: "Monitor scrub-jay status within the enhancement/restoration area"

Terms and conditions

In order to be exempt from the prohibitions of section 9 of the Act, the 45 SW must comply with the following terms and conditions (T&C) that implement the reasonable and prudent measures described above, and outline required reporting/monitoring requirements. These terms and conditions are non-discretionary.

- Application of the terms and conditions included in the November 2008 BO on light management activities at CCAFS and PAFB.
- Full implementation of the additionally revised, site-specific LMP.
- The site operator shall provide the 45 SW CES/CEIE Office within 72-hours of completion of site construction a written, signed, and dated statement verifying that the constructed lighting is/is not in compliance with the LMP. Any lighting not in compliance shall be noted on the statement, and a date given for making such lighting compliant. The date will afford CES/CEIE personnel time to inspect the site and confirm lighting compliance. The site may not become operational until all constructed lighting complies with the LMP.
- The site operator and 45 SW CES/CEIE personnel shall conduct a joint site inspection not later than 48 hours prior to a scheduled launch and landing to confirm that the proposed portable lighting is of the correct type, and in the physical positions, direction, and angle stipulated in the LMP. Lighting not compliant with the LMP must be made compliant prior to commencement of the launch/landing/processing operation.
- Personnel from the 45 SW CES/CEIE will make at least one unannounced nighttime. inspection of the site per year to confirm continued lighting compliance with the LMP.
- Scrub-jay habitat restoration shall be in accordance with the 45 SW Scrub-Jay Habitat Management Plan.

Replacements of terms and conditions

- Replace T&C #1 with the following: "Use established guidelines and protocols to survey for nesting scrub-jays, and avoid construction during the nesting season that extends from March 1 through June 30, if applicable"
- Replace T&C #3 with the following: "Use the most current version of the 'State of Florida Scrub Management Guidelines for Peninsular Florida' http:/myfwc.com/media/130823/IssuesScrubMgmtGuidelines for PeninsularFlorida.pdf as the primary source to enhance/restore/perpetually manage suitable scrub-jay habitat at a ratio of two acres enhanced/restored/managed to one acre cleared (2:1). The initial enhancement/restoration work shall be completed within one year following completion of the LC-13/LC-1 land-clearing activity. The site manager shall develop a habitat enhancement/restoration assessment plan, and submit it to the U.S. Fish and Wildlife Service for approval prior to any habitat enhancement/restoration. The plan shall include photographs, and be based on scientifically accepted, standard habitat assessment methodology".
- Replace T&C #4 with the following: Use established guidelines and protocols to annually monitor and assess the status of scrub-jays within the enhanced/restored habitat, and to adaptively manage the habitat. The resulting information shall be included within the annual Interagency Integrated Natural Resource Management Plan review".

The Service has determined that the proposed action will not result in a level of incidental take of potential scrub-jay habitat exceeding 23 acres, or of nesting and hatchling sea turtles from disorientation and misorientation by site lighting that will result in the 45 SW's exceeding its 3 percent annual allowable threshold for take from lighting at both installations. The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize the impact of incidental take that might otherwise result from the proposed action. If during the course of the action this level of incidental take is exceeded, such incidental take represents new information requiring reinitiation of formal consultation and a review of the reasonable and prudent measures provided (see **Reinitiation Notice** below).

Reinitiation Notice

This concludes our amendment to the formal consultation on the action outlined in the reinitiation request. As provided in 50 CFR 402.16, reinitiation of formal consultation is required where the discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of incidental take is exceeded; (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in the opinion; and/or (4) a new species is listed or critical habitat designated that may be affected by the action. In the instance where the amount or extent of incidental take is exceeded, and to avoid or minimize the potential for additional unauthorized take, we strongly recommend the 45 SW contact our office within 24 hours to again reinitiate formal consultation. As part of that contact, the 45 SW must provide us the amount or extent of unauthorized take, and known or possible cause(s) of the taking. If as a result it is determined that further taking is imminent prior to completion of the additional consultation , the 45 SW should strongly consider ceasing the action in order to limit any liability it may have under Section 9 of the Act.

If you have any questions regarding this response, please contact Mr. John Milio of my staff at the address on the letterhead, by email, john_milio@fws.gov, or by calling (904)-731-3098.

Sincerely,

Jay B. Herrington
Field Supervisor

cc:
FWC, Tallahassee, Florida (Ron Mezich)

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

February 20, 2020

Mr. Timothy Parsons, Ph.D.
State Historic Preservation Officer
Florida Division of Historical Resources
R.A. Gray Building
500 South Bronough Street
Tallahassee, Florida 32399-0250
timothy.parsons@dos.myflorida.com

SUBJECT: **Section 106 Consultation for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station**

Dear Mr. Parsons,

As authorized by Chapter 509 of Title 51 of the U.S. Code, the Federal Aviation Administration (FAA) licenses and regulates U.S. commercial space launch and reentry activity. The FAA is currently evaluating SpaceX's proposal to conduct Falcon 9 launches (including landings) on a new southern launch trajectory from the National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) and U.S. Air Force (USAF) Cape Canaveral Air Force Station (CCAFS) in Brevard County, Florida. This would be an additional launch trajectory from those previously licensed to allow delivery of payloads to polar orbits from Florida. Issuing licenses for commercial space launch operations is a federal action subject to compliance with the National Environmental Policy Act and is considered an undertaking subject to compliance with the National Historic Preservation Act (NHPA). The FAA is currently preparing a draft environmental assessment (EA), which includes the new southern launch trajectory. The draft EA will be sent to you for review during the FAA's public comment period. This letter is intended to initiate Section 106 consultation and solicit your feedback.

Background

SpaceX has been operating its Falcon family of launch vehicles, which includes the Falcon 9 and Falcon Heavy, from Launch Complex 39A (LC-39A) at KSC, LC-40 at CCAFS, and Landing Zones 1 and 2 (LZ-1 and LZ-2) at CCAFS. SpaceX has launched over 40 times from KSC and CCAFS (and Vandenberg Air Force Base). All of SpaceX's past Falcon launch operations at these launch sites were analyzed by the USAF and NASA (FAA was a cooperating agency) in accordance with NEPA, including the following:

- 2013 NASA EA for Multi-Use of Launch Complexes 39A and 39B, KSC, Florida (2013 NASA EA)
- 2007 USAF EA for Operation and Launch of Falcon 1 and Falcon 9 Space Vehicles at CCAFS, Florida (2007 USAF EA)
- 2013 USAF Supplemental EA for Operation and Launch of the Falcon 1 and Falcon 9 Space Vehicles at CCAFS, Florida (2013 USAF SEA)
- 2014 USAF EA for SpaceX Vertical Landing of the Falcon Vehicle and Construction at LC-13 [renamed LZ-1 and LZ-2] at CCAFS, Florida (2014 USAF EA)
- 2017 USAF Supplemental EA for SpaceX Vertical Landing of the Falcon Vehicle and Construction at LC-13 [renamed LZ-1 and LZ-2] at CCAFS, Florida (2017 USAF SEA)

As part of these NEPA reviews, NASA and USAF analyzed potential impacts to historic properties and conducted Section 106 consultation with the Florida State Historic Preservation Officer (SHPO) as needed. During preparation of the 2013 NASA EA, which included Falcon 9 and Falcon Heavy launches from LC-39A, NASA determined the action analyzed in the EA would constitute an adverse effect on LC-39A (a historic property) in accordance with the 2009 *Programmatic Agreement Among the National Aeronautics and Space Administration, John F. Kennedy Space Center, Advisory Council on Historic Preservation, and the Florida State Historic Preservation Officer Regarding Management of Historic Properties at the Kennedy Space Center,* Florida (2009 PA) and consulted the SHPO. The SHPO concurred with NASA's finding and noted that KSC has previously completed and will be following the appropriate mitigation stipulations identified in the 2009 PA (**DHR Project File Number: 2013-1817**).

The 2013 USAF SEA analyzed potential effects to historic properties from Falcon 9 operations at LC-40. USAF's analysis concluded that Falcon launch operations at LC-40 would not affect historic properties because there are no historic properties located at or near LC-40.

The 2017 USAF SEA analyzed the potential effects to historic properties for Falcon Heavy first stage boost-back and landing at LZ-1 and LZ-2. Three previously unrecorded archaeological sites were identified during an archaeological survey conducted by the USAF between June and August 2014. The USAF determined the sites were ineligible for listing on the National Register of Historic Places (NRHP) and the SHPO concurred with that determination. USAF's analysis concluded that Falcon booster landings at LZ-1 and LZ-2 would not affect historic properties (**DHR Project File Number: 2014-4037**).

The only aspect of SpaceX's current proposal that has not been previously evaluated as part of Section 106 consultation with the SHPO is SpaceX's proposed southern launch trajectory (polar missions). Therefore, the FAA is focusing this consultation on that aspect of SpaceX's Falcon 9 launch program.

Description of Undertaking

The FAA's undertaking under this consultation is to modify existing SpaceX launch licenses or issue new launch licenses to SpaceX to conduct Falcon 9 launches at KSC (LC-39A) and CCAFS (LC-40) for payloads requiring a polar orbit (southern launch trajectory). SpaceX is proposing to fly up to six polar missions per year through 2025.

Area of Potential Effects

The Area of Potential Effects (APE) is the geographic area or areas within which an undertaking may directly or indirectly cause alterations in the character or use of historic properties, if any such properties exist. In addition to engine noise generated during rocket takeoff from LC-39A or LC-40 (which was considered in the previous consultations identified above in the Background section), a sonic boom is expected to impact parts of Florida as the rocket ascends and again as the first stage booster returns and lands at LZ-1 or LZ-2. Therefore, the FAA has defined the APE based on the sonic boom footprints generated during flight (ascent and landing).

Blue Ridge Research and Consulting (BRRC) conducted sonic boom modeling for the ascent part of the launch and KBR conducted sonic boom modeling for the landing part of the launch. Figure 1 shows the modeled sonic boom footprint for ascent and Figure 2 shows the modeled sonic boom footprint for landing (see Attachment 1 for the sonic boom reports). These two figures represent the APE. The APE for the Falcon 9 ascent includes portions of the following counties: St. Lucie, Indian River, Okeechobee, Highlands, Glades, and Martin. The APE for the first stage booster landing includes portions of the following counties: Brevard, Orange, Osceola, Polk, Hillsborough, Hardee, Desoto, Glades, Martin, St. Lucie, Indian River, Okeechobee, and Highlands. Note that Brevard, Velousia, and Orange counties were included in previous NASA and USAF consultations with your office as counties that could be exposed to a sonic boom during Falcon first stage landings at LZ-1 and/or LZ-2.

Figure 1. Predicted Sonic Boom Overpressure Contours for a Falcon 9 Southern Trajectory (Ascent)

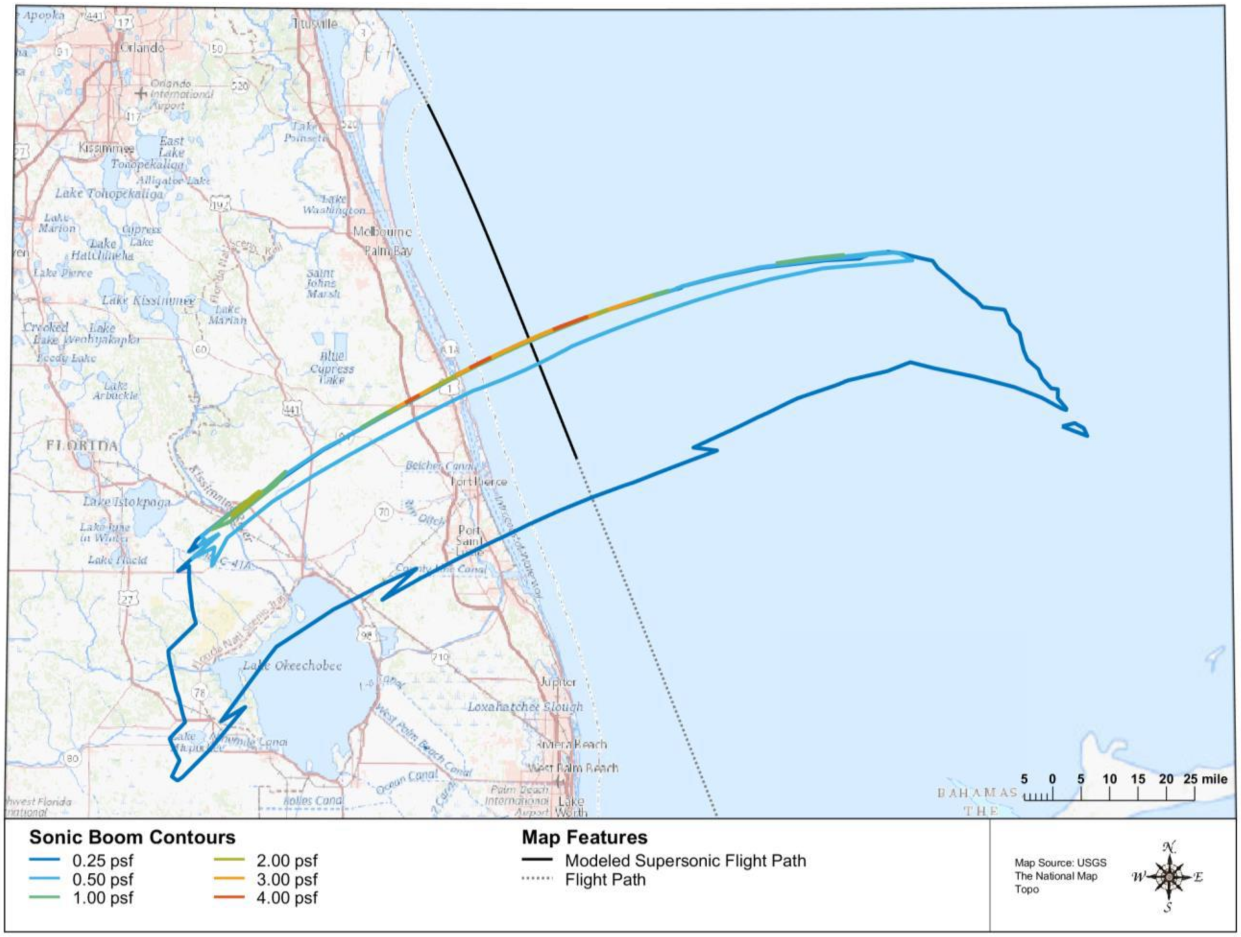
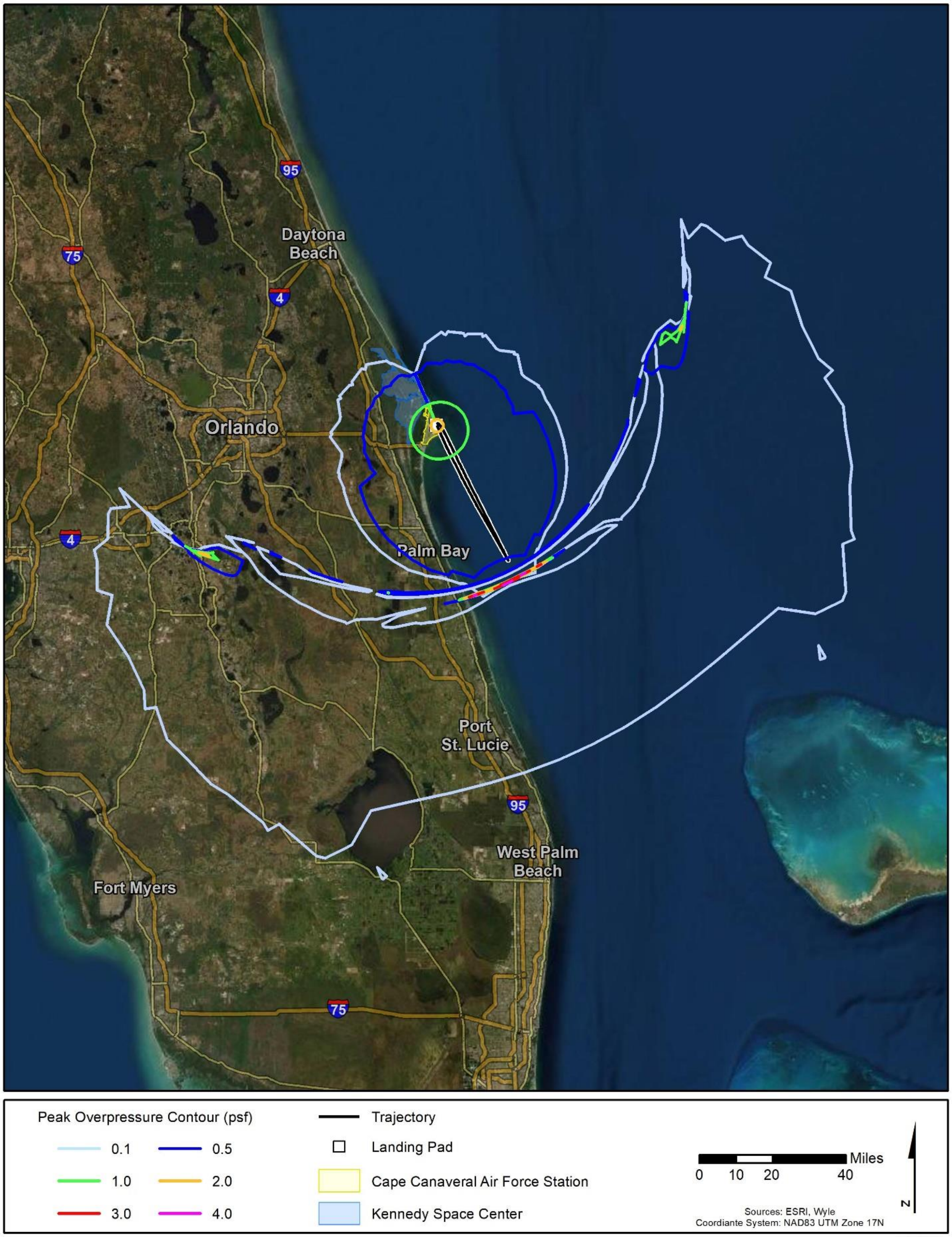


Figure 2. Predicted Sonic Boom Overpressure Contours for a Falcon 9 Southern Trajectory (Landing)



Historic Properties in the APE and Finding of Effect

The FAA conducted a search of properties listed on the NRHP using the National Park Service's geospatial database. The identified properties are listed in Table 3. The majority of the historic properties identified in the APE are buildings.

Table 3. NRHP-Listed Properties in the Sonic Boom APE

Property Name	Reference Number	Resource Type	City
Driftwood Inn and Restaurant	94000751	Building	Vero Beach
Vero Railroad Station	86003560	Building	Vero Beach
Gregory, Judge Henry F., House	94000540	Building	Vero Beach
Vero Beach Community Building, Old	92001746	Building	Vero Beach
Vero Beach Woman's Club	95000051	Building	Vero Beach
Indian River County Courthouse	99000768	Building	Vero Beach
Pueblo Arcade	97000211	Building	Vero Beach
Royal Park Arcade	98000925	Building	Vero Beach
Vero Theatre	92000421	Building	Vero Beach
Maher Building	94001274	Building	Vero Beach
Vero Beach Diesel Power Plant	99000252	Building	Vero Beach
Old Palmetto Hotel	91001650	Building	Vero Beach
Osceola Park Historic Residential District	12001196	District	Vero Beach
Hausmann, Theodore, Estate	97000230	Building	Vero Beach
McKee Jungle Gardens	97001636	Site	Vero Beach
Hallstrom House	02000605	Building	Vero Beach
Immokolee	93001450	Building	Fort Pierce
Casa Caprona	84000955	Building	Fort Pierce
St. Lucie Village Historic District	89002062	District	St. Lucie Village
Hurston, Zora Neale, House	91002047	Building	Fort Pierce
Moores Creek Bridge	01000890	Structure	Fort Pierce
St. Anastasia Catholic School, Old	00000941	Building	Fort Pierce
Fort Pierce City Hall, Old	01001338	Building	Fort Pierce
Fort Pierce Old Post Office	01000567	Building	Fort Pierce
Arcade Building	01001085	Building	Fort Pierce
Sunrise Theatre	01001339	Building	Fort Pierce
Cresthaven	85000770	Building	Fort Pierce
St. Lucie High School	84000956	Building	Fort Pierce
Fort Pierce Site	74002181	Site	Fort Pierce
Frere, Jules, House	95000467	Building	Fort Pierce
Hammond, Captain, House	90000310	Building	White City
First Methodist Episcopal Church, South	15000509	Building	Okeechobee
Freedman-Raulerson House	85000764	Building	Okeechobee
Okeechobee Battlefield	66000269	Site	Okeechobee
Red Barn	08001243	Building	Okeechobee
Moore Haven Downtown Historic District	95001166	District	Moore Haven
Moore Haven Residential Historic District	98000714	District	Moore Haven
Florida Power and Light Company Ice Plant	82001033	Building	Melbourne
Gleason, William H., House	96001608	Building	Melbourne
Rossetter, James Wadsworth, House	05000734	Building	Melbourne
Green Gables	16000269	Building	Melbourne
Community Chapel of Melbourne Beach	92000505	Building	Melbourne Beach

Melbourne Beach Pier	84000829	Structure	Melbourne Beach
St. Joseph's Catholic Church	87000816	Building	Palm Bay
Fell, Marian, Library	96001059	Building	Fellsmere
Fellsmere Public School	96001368	Building	Fellsmere
First Methodist Episcopal Church	96001521	Building	Fellsmere
Heiser, Frank and Stella, House	100001862	Building	Fellsmere
Jungle Trail	03000700	Site	Orchid
Lawson, Bamma Vickers, House	90001116	Building	Sebastian
Old Town Sebastian Historic District East	03000728	District	Sebastian
Old Town Sebastian Historic District, West	03001364	District	Sebastian
Pelican Island National Wildlife Refuge	66000265	Site	Sebastian
Sebastian Grammar and Junior High School	01000889	Building	Sebastian
Smith, Archie, Wholesale Fish Company	94001275	Building	Sebastian
Spanish Fleet Survivors and Salvors Camp Site	70000186	Site	Sebastian
Desert Inn	93001158	Building	Yeehaw Junction
Auburndale Citrus Growers Association Packing House	90001277	Building	Auburndale
Auburndale City Hall	72000350	Building	Auburndale
Baynard, Ephriam M., House	90001272	Building	Auburndale
Jenks, Holland, House	75000567	Building	Auburndale
Babson Park Woman's Club	90001085	Building	Babson Park
Dundee ACL Railroad Depot, Old	90001271	Building	Dundee
Atlantic Coast Line Railroad Depot	90001273	Building	Lake Wales
Bok Mountain Lake Sanctuary and Singing Tower	85003331	Building	Lake Wales
Bullard, B. K., House	90001275	Building	Lake Wales
Casa De Josefina	89001481	Building	Lake Wales
Chalet Suzanne	00000265	Building	Lake Wales
Church of the Holy Spirit	90001274	Building	Lake Wales
Dixie Walesbilt Hotel	90000732	Building	Lake Wales
El Retiro	97000858	Building	Lake Wales
First Baptist Church	91000113	Building	Lake Wales
Johnson, C. L., House	93000871	Building	Lake Wales
Lake of the Hills Community Club	01001086	Building	Lake Wales
Lake Wales City Hall	01000306	Building	Lake Wales
Lake Wales Commercial Historic District	90001276	District	Lake Wales
Lake Wales Historic Residental District	14000152	District	Lake Wales
Mountain Lake Colony House	01001414	Building	Lake Wales
Mountain Lake Estates Historic District	02000266	District	Lake Wales
North Avenue Historic District	01001337	District	Lake Wales
Roosevelt School	00000660	Building	Lake Wales
Tillman, G. V., House	98000927	Building	Lake Wales
Cypress Gardens	90001277	Site	Winter Haven
Downtown Winter Haven Historic District	72000350	District	Winter Haven
Interlaken Historic Residential District	90001272	District	Winter Haven
Pope Avenue Historic District	75000567	District	Winter Haven
Winter Haven Heights Historic Residential District	90001085	District	Winter Haven
Woman's Club of Winter Haven	90001271	Building	Winter Haven

Based on SpaceX's estimate, up to six launches per year could fly a southern trajectory. Thus, sonic booms could impact Florida up to 12 times per year – once during ascent and once during landing (see Figures 1 and 2 for the sonic boom footprints). Sonic booms are low-frequency impulsive noise events with durations lasting a fraction of a second. The majority of land within the APE is predicted to experience overpressures of less than 1 pound per square foot (psf). An overpressure of 1 psf is similar to a clap of thunder. A narrow region north of Vero Beach with land area less than 3 square miles is predicted to receive overpressures greater than 2 psf during ascent. An area less than 0.01 square miles could experience a maximum overpressure of 4.6 psf during ascent. Based on the sonic boom modeling, no historic properties are expected to experience overpressures greater than 2 psf, with most of the properties experiencing a maximum overpressure of 0.25 psf.

Attachment 1 discusses the potential for structural damage from sonic booms. In general, for well-maintained structures, the threshold for potential damage from sonic booms is 2 psf; below 2 psf, damage is unlikely. Therefore, the FAA does not expect any adverse effects to the historic structures within the APE. Also, because sonic booms would occur a maximum of 12 times per year and would be similar to or less than the noise experienced during a clap of thunder in the majority of the APE, the FAA does not expect any adverse effects related to the setting of historic sites within the sonic boom APE.

Conclusion

NASA and USAF have previously conducted Section 106 consultation for SpaceX launches, including landings, at LC-39A, LC-40, LZ-1, and LZ-2. Therefore, the FAA has focused this consultation on aspects of SpaceX's Falcon 9 program that are new and have not undergone Section 106 consultation (i.e., sonic booms impacting Florida during a polar launch). The FAA is making of finding of *No Adverse Effect*. We seek your concurrence with our findings. Thank you for your assistance in this matter. Please provide your response to Daniel Czelusniak via e-mail at Daniel.Czelusniak@faa.gov or 703-624-7115.

Sincerely,

Daniel Murray
Manager, Space Transportation Development Division

Attachment 1. Sonic Boom Assessments for a Falcon 9 Polar Mission

Blue Ridge Research and Consulting, LLC

Technical Report

Sonic Boom Analysis for SpaceX's Falcon 9 Polar Launch and Lading Operations from CCAFS

March 1, 2019

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Acronyms and Abbreviations

The following acronyms and abbreviations are used in the report:

BRRC	Blue Ridge Research and Consulting, LLC
CCAFS	Cape Canaveral Air Force Station
dB	Decibel
dBA	A-weighted Decibel Level
DNL	Day-Night Average Sound Level
DOD	Department of Defense
FAA	Federal Aviation Administration
ft	Foot/Feet
NIHL	Noise-Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
P_k	Peak Pressure
psf	Pounds per Square Foot
SEL	Sound Exposure Level in decibels
SLC	Space Launch Complex
SpaceX	Space Exploration Technologies Corp.

1 Introduction

This report documents the sonic boom analysis performed as part of Space Exploration Technologies Corp.'s (SpaceX's) environmental analysis for the proposed Falcon 9 polar launch and landing operations from Cape Canaveral Air Force Station (CCAFS). SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS Space Launch Complex 40 (SLC-40). The largest configuration, Falcon 9 with composite fairing as shown in Figure 1, will be modeled to determine the potential for sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts will be evaluated for a nominal trajectory for up to five annual launches per year. Potential sonic boom impacts are evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

This noise study describes the sonic booms associated with the proposed Falcon 9 polar operations. Section 2 describes the proposed Falcon 9 polar operations; Section 3 summarizes the basics of sound and describes the noise metrics and impact criteria discussed throughout this report; Section 4 describes the general methodology of the sonic boom modeling; and Section 5 presents the sonic boom modeling results. A summary is provided in Section 6 to document the notable findings of this sonic boom analysis.

Figure 1. SpaceX's Falcon 9 with composite fairing (left), launch of Falcon 9 (middle), and droneship landing of the Falcon 9's first stage (right) (image credit: SpaceX)

2 Falcon 9 Polar Operations

SpaceX's Falcon 9 is a two-stage rocket that delivers payloads to space inside a composite fairing or aboard the Dragon spacecraft. The Falcon 9 with composite fairing will be modeled to determine the potential extent of sonic boom impacts from Falcon 9 launches. The vehicle parameters are presented in Table 1.

Table 1. Vehicle modeling parameters

Modeling Parameters	Values
Manufacturer	SpaceX
Name	Falcon 9
Length	272 ft (launch w/fairing) 154 ft (1st stage landing)
Diameter	12 ft
Gross Vehicle Weight	1,200,000 lbs (launch w/fairing) 97,000 lbs (1st stage landing)

Falcon 9 polar trajectories flown from CCAFS SLC-40 will be unique to the vehicle configuration, mission, and environmental conditions. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. For the purposes of this study, the sonic boom modelling utilizes a nominal launch trajectory provided by SpaceX [1] and shown in Figure 2 to model the sonic booms generated from Falcon 9 polar operations. The nominal launch trajectory follows an azimuth of approximately 160° for most of the trajectory.

The proposed action includes a total of five annual launch operations, four of which are planned to occur during acoustic daytime hours (0700 - 2200), and one during acoustic nighttime hours (2200 – 0700).

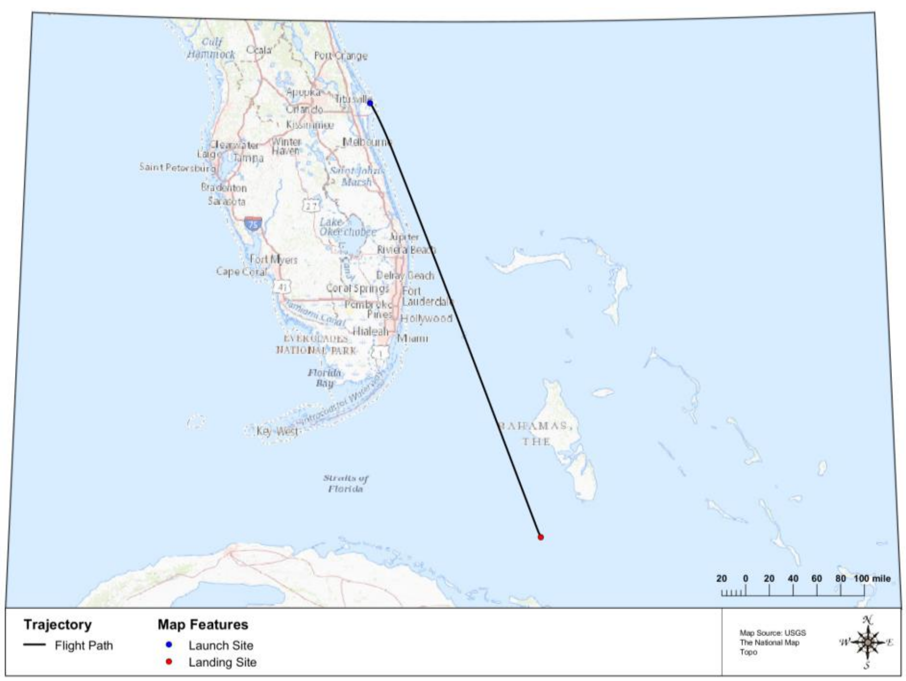

Figure 2. Falcon 9 polar trajectory

3 Acoustics Overview

An overview of sound-related terms, metrics, and effects, which are pertinent to this study, is provided to assist the reader in understanding the terminology used in this noise study.

3.1 Fundamentals of Sound

Any unwanted sound that interferes with normal activities or the natural environment is defined as noise. Three principal physical characteristics are involved in the measurement and human perception of sound: intensity, frequency, and duration [2].

- **Intensity** is a measure of a sound's acoustic energy and is related to sound pressure. The greater the sound pressure, the more energy is carried by the sound and the louder the perception of that sound.
- **Frequency** determines how the pitch of the sound is perceived. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.
- **Duration** is the length of time the sound can be detected.

The loudest sounds that can be comfortably detected by the human ear have intensities a trillion times higher than those of sounds barely audible. Because of this vast range, using a linear scale to represent the intensity of sound can become cumbersome. As a result, a logarithmic unit known as the decibel (abbreviated dB) is often used to represent sound levels. A sound level of 0 dB approximates the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level around 60 dB. Sound levels above 120 dB begin to be felt inside the human ear as discomfort. Sound levels between 130 and 140 dB are experienced as pain [3].

The intensity of sonic booms is quantified with physical pressure units rather than levels. Intensities of sonic booms are traditionally described by the amplitude of the front shock wave, referred to as the peak overpressure. The peak overpressure is normally described in units of pounds per square foot (psf). The amplitude is particularly relevant when assessing structural effects as opposed to loudness or cumulative community response. In this study, sonic booms are quantified by either psf or dB, as appropriate for the particular impact being assessed [4]. A chart of typical impulsive events along with their corresponding peak overpressures in terms of psf and peak dB values are shown in Figure 3. For example, thunder overpressure resulting from lightning strikes at a distance of one kilometer (0.6 miles) is estimated to be near two psf, which is equivalent to 134 dB [5].

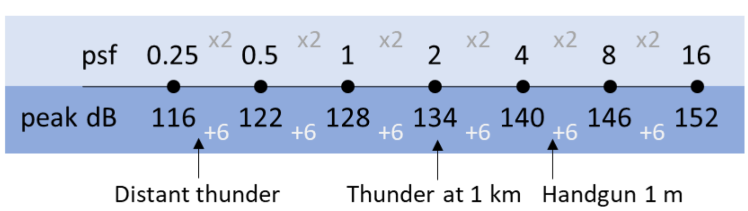

Figure 3. Typical impulsive event levels [5]

Sound frequency is measured in terms of cycles per second or hertz (Hz). Human hearing ranges in frequency from 20 Hz to 20,000 Hz, although perception of these frequencies is not equivalent across this range. Human hearing is most sensitive to frequencies in the 1,000 to 4,000 Hz range. Most sounds are not simple pure tones, but contain a mix, or spectrum, of many frequencies. Sounds with different spectra are perceived differently even if the sound levels are the same. Weighting curves have been developed to correspond to the sensitivity and perception of different types of sound. A-weighting and C-weighting are the two most common weightings. These two curves, shown in Figure 4, are adequate to quantify most environmental noises. A-weighting puts emphasis on the 1,000 to 4,000 Hz range to match the reduced sensitivity of human hearing for moderate sound levels. For this reason, the A-weighted decibel level (dBA) is commonly used to assess community sound.

Very loud or impulsive sounds, such as explosions or sonic booms, can sometimes be felt, and they can cause secondary effects, such as shaking of a structure or rattling of windows. These types of sounds can add to annoyance and are best measured by C-weighted sound levels, denoted dBC. C-weighting is nearly flat throughout the audible frequency range and includes low frequencies that may not be heard but cause shaking or rattling. C-weighting approximates the human ear's sensitivity to higher intensity sounds.

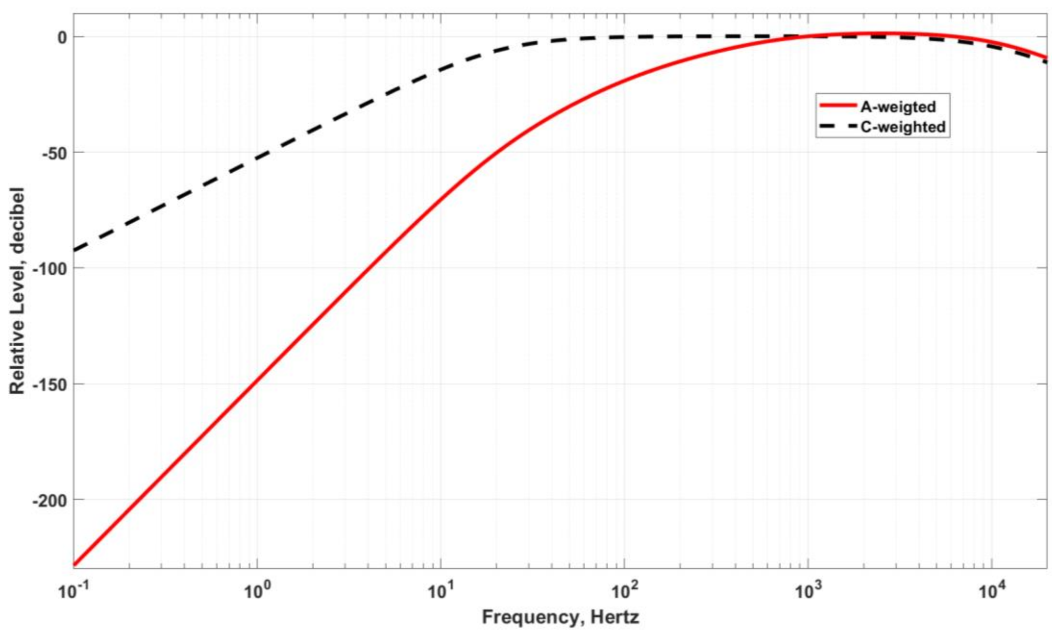

Figure 4. Frequency adjustments for A-weighting and C-weighting [6]

Sound sources can contain a wide range of frequency (pitch) content as well as variations in extent from short-durations to continuous, such as back-up alarms and ventilation systems, respectively. Sonic booms are considered low-frequency impulsive noise events with durations lasting a fraction of a second.

3.2 Noise Metrics

A variety of acoustical metrics have been developed to describe sound events and to identify any potential impacts to receptors within the environment. These metrics are based on the nature of the event and who or what is affected by the sound. A brief description of the noise metrics used in this noise study are provided below.

Peak Sound Level (L_{pk})

For impulsive sounds, the true instantaneous peak sound pressure level, which lasts for only a fraction of a second, is important in determining impacts. The peak pressure of the front shock wave is used to describe sonic booms, and it is usually presented in psf. Peak sound levels are not frequency weighted.

Day-Night Average Sound Level (DNL)

Day-Night Average Sound Level is a cumulative metric that accounts for all noise events in a 24-hour period. To account for our increased sensitivity to noise at night, DNL applies an additional 10 dB adjustment to events during the acoustical nighttime period, defined as 10:00 PM to 7:00 AM. The notations DNL and L_{dn} are both used for Day-Night Average Sound Level and are equivalent. DNL represents the average sound level exposure for annual average daily events. DNL does not represent a level heard at any given time but represents long term exposure to noise.

3.3 Noise Effects

Noise criteria have been developed to protect the public health and welfare of the surrounding communities. The impacts of launch vehicle sonic booms are evaluated on a cumulative basis in terms of human annoyance. In addition, the launch vehicle sonic boom impacts are evaluated on a single-event basis in relation to hearing conservation and potential structural damage. Although FAA Order 1050.1F does not have guidance on hearing conservation or structural damage criteria, it recognizes the use of supplemental noise analysis to describe the noise impact and assist the public's understanding of the potential noise impact.

3.3.1 Human Annoyance

A significant noise impact would occur if the "action would increase noise by DNL 1.5 dB[A] or more for a noise sensitive area that is exposed to noise at or above the DNL 65 dB[A] noise exposure level, or that will be exposed at or above this level due to the increase, when compared to the No Action Alternative for the same timeframe" [7]. A-weighted DNL is based on long-term cumulative noise exposure and has been found to correlate well with long-term community annoyance for regularly occurring events including aircraft, rail, and road noise [8, 9]. For impulsive noise sources with significant low-frequency content such as sonic booms, C-weighted DNL (CDNL) is preferred over A-weighted DNL [10]. In terms of percent highly annoyed, DNL 65 dBA is equivalent to CDNL 60 dBC [11]. Additionally, it has been noted that the DNL "threshold does not adequately address the effects of noise on visitors to areas within a national park or national wildlife refuge where other noise is very low and a quiet setting is a generally recognized purpose and attribute" [7]. DNL contours are provided as the most widely accepted metric to estimate the changes in long-term community annoyance.

3.3.2 Hearing Conservation

Multiple federal government agencies have provided guidelines on permissible noise exposure limits on impulsive noise such as a sonic boom. These documented guidelines are in place to protect one's hearing from exposures to high noise levels and aid in the prevention of noise-induced hearing loss (NIHL). In terms of upper limits on impulsive noise levels; National Institute for Occupational Safety and Health (NIOSH) [12], Occupational Safety and Health Administration (OSHA) [13], and the Department of Defense (DOD) [14] have stated that levels should not exceed 140 dB peak sound pressure level, which equates to a sonic boom level of approximately 4 psf.

3.3.3 Structural Damage

Sonic booms are also commonly associated with structural damage. Most damage claims are for brittle objects, such as glass and plaster. Table 2 summarizes the threshold of damage that may be expected at various overpressures [15]. A large degree of variability exists in damage experience, and much of the damage depends on the pre-existing condition of a structure. Breakage data for glass, for example, spans a range of two to three orders of magnitude at a given overpressure. The probability of a window breaking at 1 psf ranges from one in a billion [16] to one in a million [17]. These damage rates are associated with a combination of boom load and window pane condition. At 10 psf, the probability of breakage is between one in 100 and one in 1,000. Laboratory tests involving glass [18] have shown that properly installed window glass will not break at overpressures below 10 psf even when subjected to repeated booms. However, in the real world, installed window glass is not always in pristine condition.

Damage to plaster occurs at similar ranges to glass damage. Plaster has a compounding issue in that it will often crack due to shrinkage while curing or from stresses as a structure settles, even in the absence of outside loads. Sonic boom damage to plaster often occurs when internal stresses are high as a result of these factors. In general, for well-maintained structures, the threshold for potential damage from sonic booms is 2 psf [15]; below 2 psf, damage is unlikely.

Table 2. Possible damage to structures from sonic booms [15]

***Nominal* Level *and Comparative* Events**	**Damage Type**	**Item Affected**
0.5 – 2 psf *Compares to piledriver at construction site*	Plaster	Fine cracks; extension of existing cracks; more in ceilings; over doorframes; between some plasterboards.
	Glass	Rarely shattered; either partial or extension of existing.
	Roof	Slippage of existing loose tiles/slates; sometimes new cracking of old slates at nail hole.
	Damage to outside walls	Existing cracks in stucco extended.
	Bric-a-brac	Those carefully balanced or on edges can fall; fine glass, such as large goblets, can fall and break.
	Other	Dust falls in chimneys.
2 – 4 psf *Compares to cap gun or firecracker near ear*	Glass, plaster, roofs, ceilings	Failures show that would have been difficult to forecast in terms of their existing localized condition. Nominally in good condition.
4 – 10 psf *Compares to handgun at shooter's ear*	Glass	Regular failures within a population of well-installed glass; industrial as well as domestic greenhouses.
	Plaster	Partial ceiling collapse of good plaster; complete collapse of very new, incompletely cured, or very old plaster.
	Roofs	High probability rate of failure in nominally good state, slurry-wash; some chance of failures in tiles on modern roofs; light roofs (bungalow) or large area can move bodily.
	Walls (out)	Old, free standing, in fairly good condition can collapse.
	Walls (in)	Inside ("party") walls known to move at 10 psf.
> 10 psf *Compares to fireworks display from viewing stand*	Glass	Some good glass will fail regularly to sonic booms from the same direction. Glass with existing faults could shatter and fly. Large window frames move.
	Plaster	Most plaster affected.
	Ceilings	Plasterboards displaced by nail popping.
	Roofs	Most slate/slurry roofs affected, some badly; large roofs having good tile can be affected; some roofs bodily displaced causing gale-end and will-plate cracks; domestic chimneys dislodged if not in good condition.
	Walls	Internal party walls can move even if carrying fittings such as hand basins or taps; secondary damage due to water leakage.
	Bric-a-brac	Some nominally secure items can fall; e.g., large pictures, especially if fixed to party walls.

4 Sonic Boom Modeling

A vehicle creates sonic booms during supersonic flight. The potential for the boom to intercept the ground depends on the trajectory and speed of the vehicle as well as the atmospheric profile. The sonic boom is shaped by the physical characteristics of the vehicle and the atmospheric conditions through which it propagates. These factors affect the perception of a sonic boom. The noise is perceived as a deep boom, with most of its energy concentrated in the low frequency range. Although sonic booms generally last less than one second, their potential for impact may be considerable.

When a vehicle moves through the air, it pushes the air out of its way. At subsonic speeds, the displaced air forms a pressure wave that disperses rapidly. At supersonic speeds, the vehicle is moving too quickly for the wave to disperse, so it remains as a coherent wave. This wave is a sonic boom. When heard at ground level, a sonic boom consists of two shock waves (one associated with the forward part of the vehicle, the other with the rear part) of approximately equal strength and (for fighter aircraft) separated by 100 to 200 milliseconds. When plotted, this pair of shock waves and the expanding flow between them has the appearance of a capital letter "N," so a sonic boom pressure wave is usually called an "N-wave." An N-wave has a characteristic "bang-bang" sound that can be startling. Figure 5 shows the generation and evolution of a sonic boom N-wave under the vehicle.

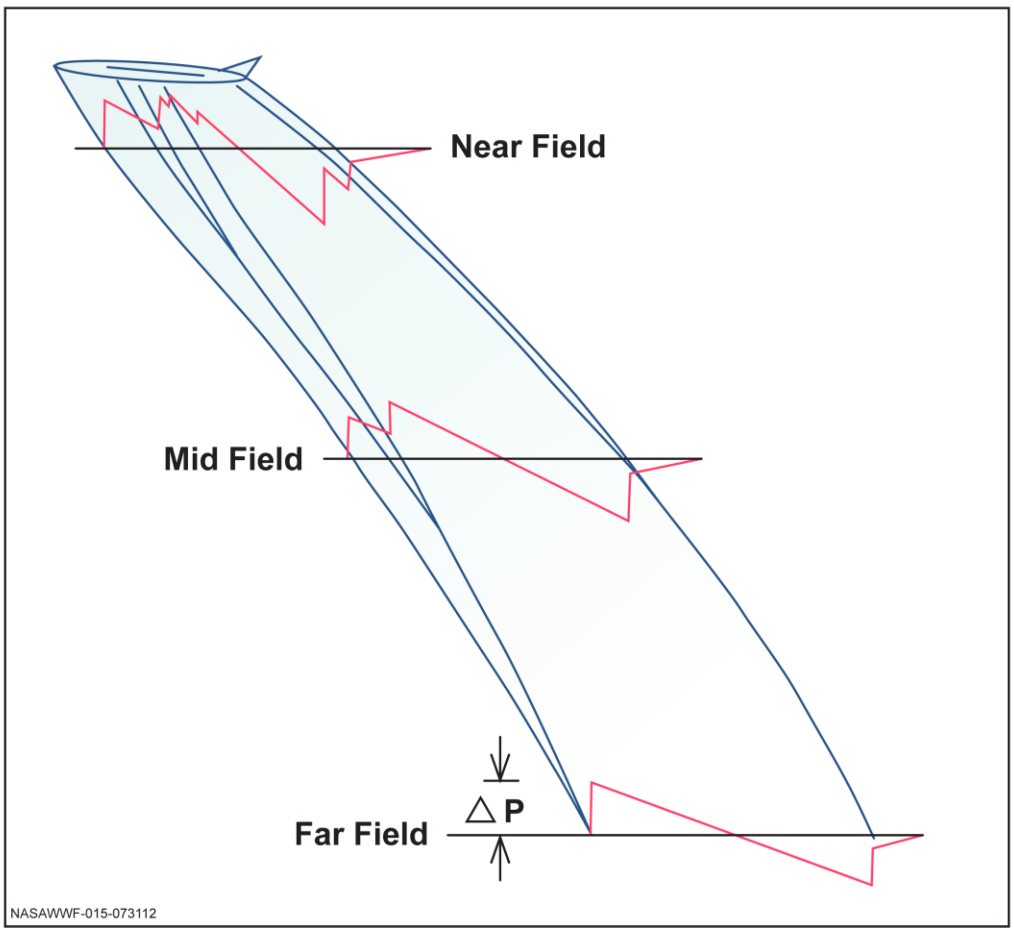

Figure 5. Sonic boom generation and evolution to N-wave [19]

Figure 6 shows the sonic boom pattern for a vehicle in steady, level supersonic flight. The boom forms a cone that is said to sweep out a "carpet" under the flight track. The boom levels vary along the lateral extent of the "carpet" with the highest levels directly underneath the flight track and decreasing levels as the lateral distance increases to the cut-off edge of the "carpet." When the vehicle is maneuvering, the sonic boom energy can be focused in highly localized areas on the ground.

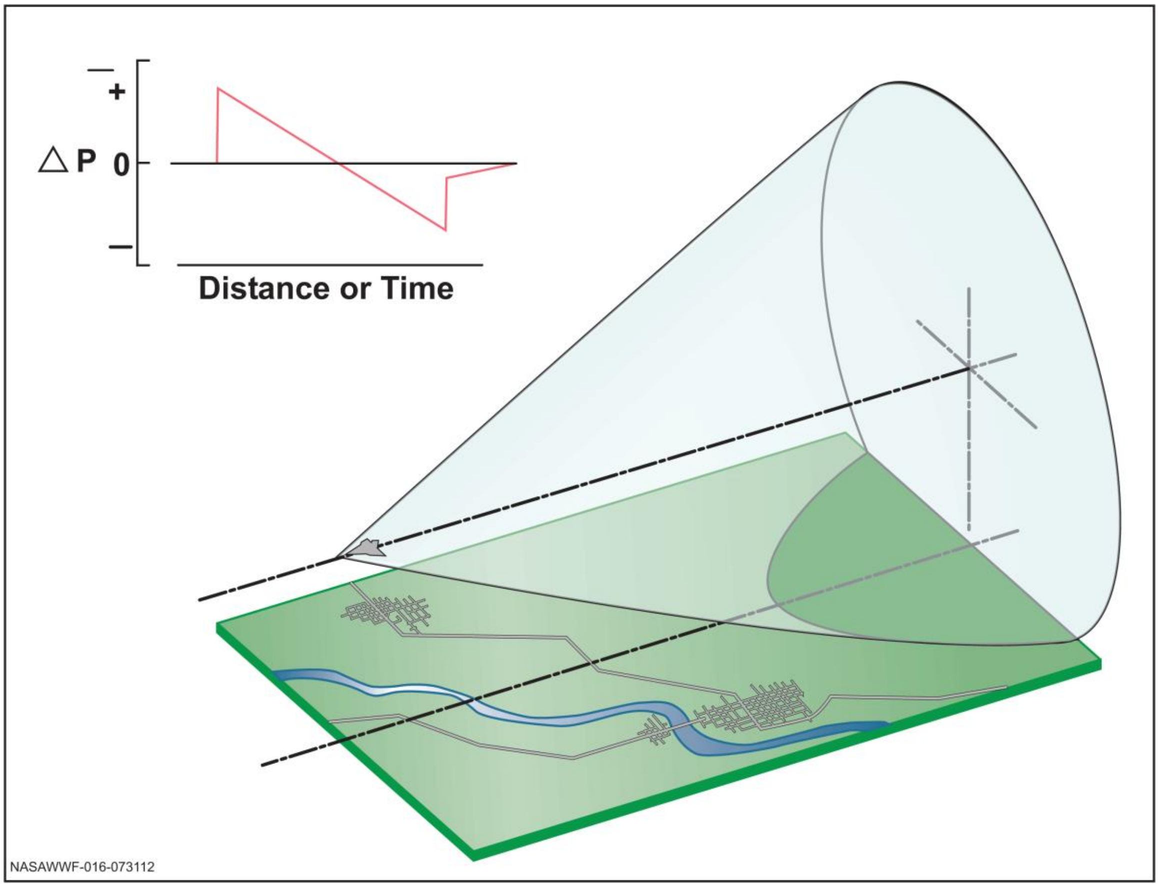

Figure 6. Sonic boom carpet for a vehicle in steady flight [20]

The complete ground pattern of a sonic boom depends on the size, weight, shape, speed, and trajectory of the vehicle. Since aircraft fly supersonically with relatively low horizontal angles, the boom is directed toward the ground. However, for rocket trajectories, the boom is directed upward and laterally until the rocket rotates significantly away from vertical, as shown in Figure 7. This difference causes a sonic boom from a rocket to propagate much further downrange compared to aircraft sonic booms. This extended propagation usually results in relatively lower sonic boom levels from rocket launches. For aircraft, the front and rear shock are generally the same magnitude. However, for rockets, in addition to the two shock waves generated from the vehicle body, the plume itself acts as a large supersonic body, and it generates two additional shock waves (one associated with the forward part of the plume, the other with the rear part) and extends the waveform duration to as large as one second. The sonic boom generated by the plume is stronger since the plume volume is significantly larger than the rocket.

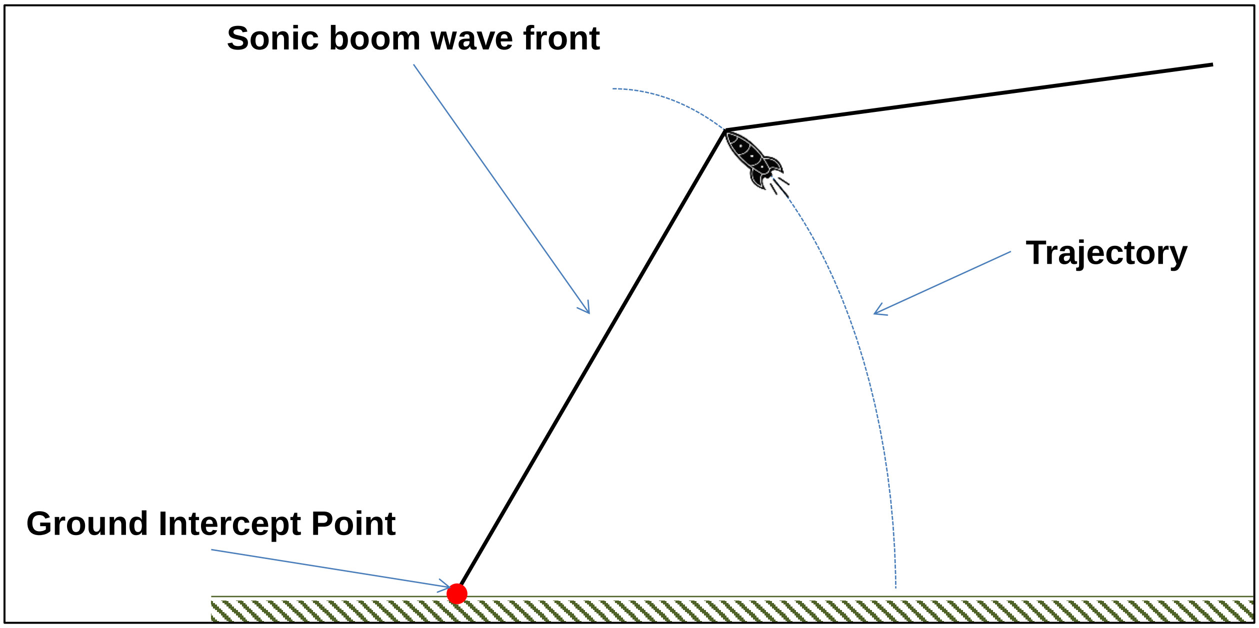

Figure 7. Sonic boom propagation for rocket launch

The single-event prediction model, PCBoom [21, 22, 23] is used to predict the sonic boom footprint from a supersonic vehicle trajectory. PCBoom is a full ray trace sonic boom program that calculates the magnitude, waveform, and location of sonic boom overpressures on the ground from supersonic flight operations. The model computes detailed ground signature shapes from a variety of near-field signature definitions. Additionally, PCBoom accounts for the effect of underexpanded rocket exhaust plumes on the boom [24]. Several inputs are required to calculate the sonic boom impact, including the aircraft 3-dimensional model, the trajectory path, the atmospheric conditions and the ground surface height. Predicted sonic boom footprints are presented in the form of equal pressure contours.

5 Results

The following section presents the results of the environmental sonic boom impacts associated with the proposed Falcon 9 polar operations. Site-specific atmospheric profiles including temperature and wind were used to model the sonic boom impacts. The modeled sonic boom contours associated with the polar launch and droneship landing of the Falcon 9 are presented in Figure 8 and Figure 9, respectively. In addition to the contours, the black ground path represents the portion of supersonic flight that is below the edge of space and generates sonic boom footprints that intercept the ground.

Falcon 9 Polar Launch

The sonic boom wavefront for a vertical rocket launch is directed upward and laterally during the initial portion of the launch, and thus it does not intercept the ground. As the vehicle rotates away from the vertical and its velocity increases, the sonic boom wavefront starts to be directed toward the ground. At this point the sonic boom will begin to intercept the ground. The Falcon 9 polar launch generates a sonic boom over a long, narrow, forward-facing crescent shaped focus boom region as shown in Figure 8. As the vehicle continues to ascend, the sonic boom levels generated decrease and the crescent shape becomes slightly longer and wider. A summary of the modeled results is detailed below:

- The sonic boom is modeled to intercept the southern Florida Atlantic coastal region including the communities of Vero Beach, Fort Pierce, and Port St Lucie along the coast; as well as inland communities near Okeechobee. The contours extend approximately 30 miles along the coast and reach up to approximately 75 miles west of the coast. The vast-majority of this region will experience peak overpressures of less than 1 psf. Areas south of Port St. Lucie and Okeechobee may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.
- A narrow focus boom region north of Vero Beach, with land area less than 3 square miles, is modeled to receive levels greater than 2 psf. In this region, the modeled peak overpressure may reach 4.6 psf, but these levels occur over significantly smaller areas (less than 0.01 square miles). Note, the location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions at the time of flight. Therefore, it is unlikely that any given location will experience the focus more than once over multiple events.

The maximum modeled overpressure levels are predicted to be less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region that experience sonic booms from Falcon 9 polar launches. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels between 2 to 4 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf (less than 0.01 square miles). The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

A modeled maximum peak overpressure of 4.6 psf translates to an equivalent CDNL of 51 dBC for the maximum projected reentry operation tempo. Therefore, the proposed Falcon 9 polar launch operation does not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA).

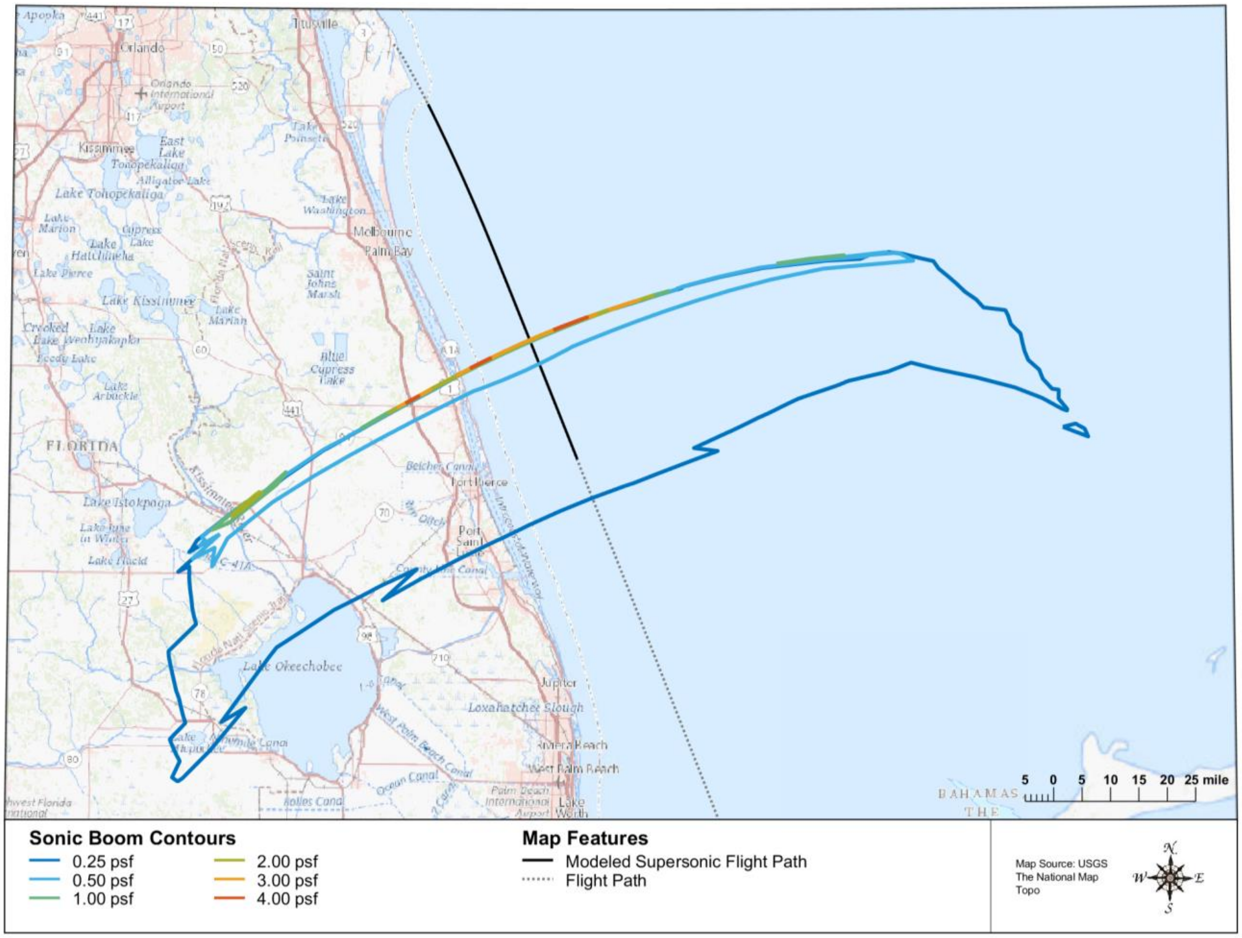

Figure 8. Sonic boom peak overpressure contours for the Falcon 9 polar launch

Note, sonic booms have previously impacted mainland Florida during shuttle orbiter reentries, with measured levels ranging from about 0.6 psf from the vehicle at higher altitudes to a maximum of 2.3 psf just prior to landing [25].

Falcon 9 Polar Droneship Landing

The Falcon 9 polar droneship landing modeled sonic boom contours are presented in Figure 9. After the first stage separates and the vehicle descends, the sonic boom will intercept the ground. As the vehicle descends further, the sonic boom contours become smaller and end when the vehicle's speed becomes subsonic. A summary of the modeled results is detailed below:

- The crescent shaped portion of the contours includes land area on the southern part of Andros Island within the Bahamas, the majority of which is part of West Side National Park but also includes small settlements along the eastern coast near Kemp's Bay. The predicted overpressure levels for a vast majority of this area is less than 0.5 psf. North Andros Island and as far north as New Providence Island may experience low level sonic booms (less than 0.25 psf) comparable to distant thunder.

- An area of approximately 18 square miles of ocean surrounding the droneship landing site may experience levels of 3 psf and above. In this region, the predicted levels are up to 4 psf, but they occur over significantly smaller areas.

Although the maximum peak overpressure level is predicted to be 4 psf (located adjacent to the droneship landing site), it should be noted that the maximum level measured adjacent to the CCAFS landing site during the July 18, 2016 landing event was 5.48 psf [26].

The potential for structural damage is unlikely as the modeled sonic boom overpressure levels over land are less than 2 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are substantially lower than the ~4 psf impulsive hearing conservation noise criteria. For the maximum projected reentry operation tempo, peak overpressures of approximately 0.5 psf translate to an equivalent CDNL that is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA). Therefore, the proposed Falcon 9 polar landing operation does not pose a significant impact with regards to human annoyance.

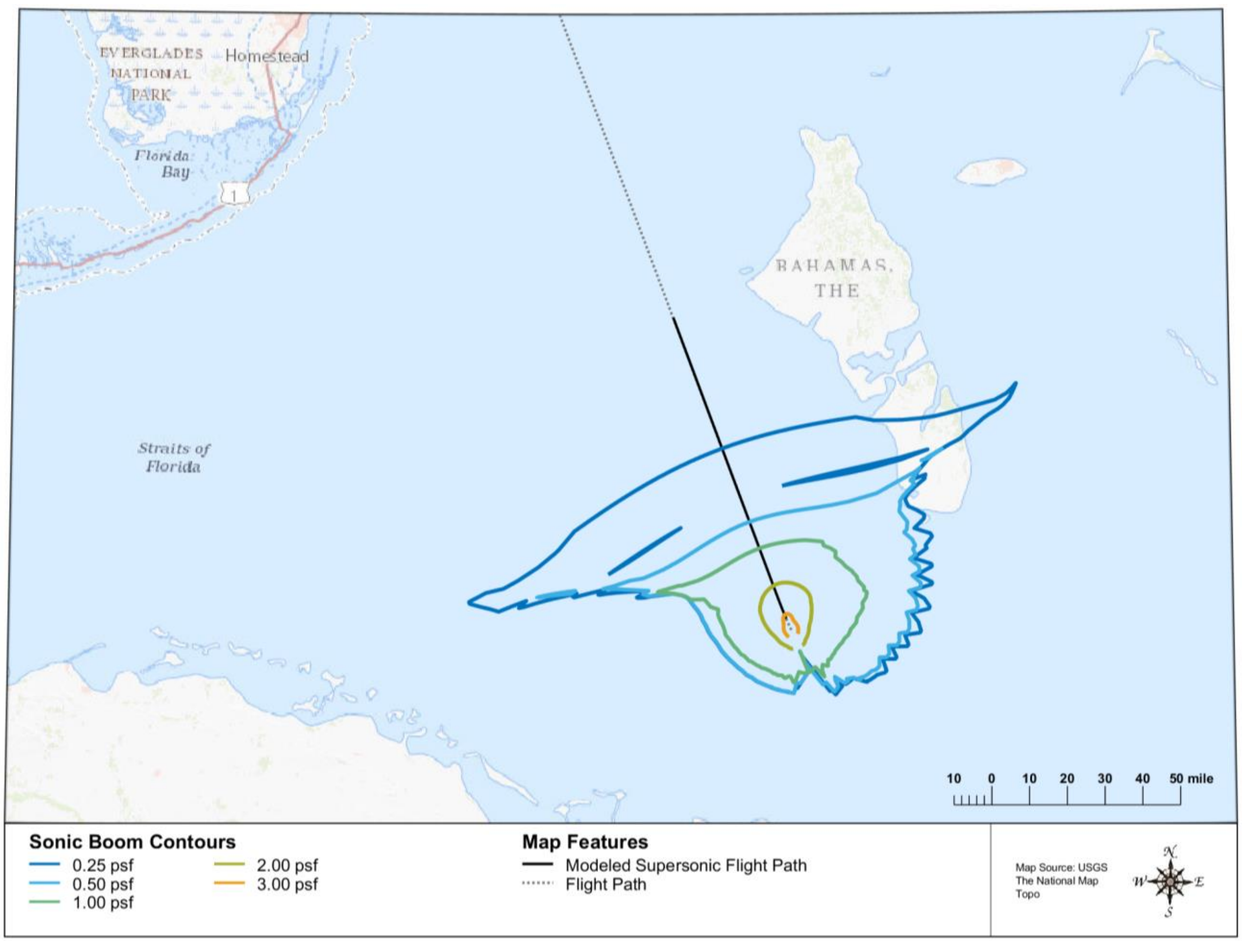

Figure 9. Sonic boom peak overpressure contours for the Falcon 9 polar droneship landing

Although the proposed polar operations do not pose significant impacts in relation to human annoyance, hearing conservation, or structural damage; the unexpected, loud impulsive noise of sonic booms tend to cause a startle effect in people. However, when humans are exposed to impulse noises with similar characteristics on a regular basis, they tend to become conditioned to the stimulus and the resulting startle reaction is generally not displayed. The physiological effects of single sonic booms on humans [27] for the levels produced by the proposed operations can be grouped as presented in Table 3.

Table 3. Physiological effects of single sonic booms on humans [27]

Sonic boom overpressure	Behavioral effects
< 0.3 psf	Orienting, but no startle response; eyeblink response in 10% of subjects; no arm/hand movement.
0.6 – 2.3 psf	Mixed pattern of orienting and startle responses; eyeblink in about half of subjects; arm/hand movements in about a fourth of subjects, but not gross bodily movements.
2.7 – 6.5 psf	Predominant pattern of startle responses; eyeblink response in 90 percent of subjects; arm/hand movements in more than 50 percent of subjects with gross body flexion in about a fourth of subjects.

6 Summary

This report documents the sonic boom analysis performed as part of SpaceX's efforts on the environmental analysis for the proposed Falcon 9 polar launch and landing operations from CCAFS. SpaceX plans to conduct polar launch operations of multiple Falcon 9 configurations from CCAFS SLC-40. The largest configuration, Falcon 9 with composite fairing, was modeled to determine potential sonic boom impacts. Following stage separation, the first stage of the Falcon 9 will land on a droneship stationed in the Atlantic Ocean, north of Cuba and west of the Bahamas. Sonic boom impacts were evaluated for a nominal launch trajectory for up to five annual launches per year. The potential sonic boom impacts were evaluated on a single-event and cumulative basis in relation to human annoyance, hearing conservation, and structural damage.

The representative Falcon 9 polar launch generated sonic boom peak overpressures of less than 1 psf for the vast-majority of the southern Florida Atlantic coastal region the sonic boom is modeled to intercept. A narrow focus boom region north of Vero Beach with land area less than 3 square miles is modeled to receive levels greater than 2 psf, with a maximum peak overpressure of approximately 4.6 psf. Note, focus regions are highly localized and dependent on the mission specific trajectory and atmospheric conditions during the launch event.

The proposed launch operations do not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold. The potential for structural damage for levels less than 2 psf is unlikely for well-maintained structures. Damage would be generally limited to bric-a-brac or structural elements that are in ill-repair. At peak overpressure levels above 2 psf (modeled to be less than three square miles), there is a low probability of structure damage (to glass, plaster, roofs, and ceilings) for well-maintained structures and increases for levels greater than 4 psf. The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels over land are lower than the ~4 psf impulsive hearing conservation noise criteria, except for an area less than 0.01 square miles.

The representative Falcon 9 droneship landing generates peak overpressures over land of less than approximately 0.5 psf. Therefore, the proposed landing operations do not pose a significant impact with regards to human annoyance, structural damage, or hearing damage (with regards to humans).

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SONIC BOOM ASSESSMENT OF FALCON 9 POLAR TRAJECTORY DESCENT/LANDING AT CAPE CANAVERAL AIR FORCE STATION

TN 20-01

February 2020

Prepared for:

Space Exploration Technologies Corporation

Acknowledgements

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KBR Technical Note TN 20-01

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1.0 Introduction

The sonic boom footprint has been estimated for the Falcon 9 Block 5 launch vehicle for the polar trajectory descent and landing of the reusable first stage at Cape Canaveral Air Force Station (CCAFS), Florida (landing pad location: latitude 28.485709 degrees and longitude -80.577127 degrees.)

Sonic boom is generated while the Falcon 9 is supersonic during descent, above an altitude of about 12,000 feet. Sonic boom analysis was performed with Wyle's PCBoom software.[1,2] Section 2 presents a background discussion of sonic boom. Section 3 presents the results for the Falcon 9 nominal descent and landing at CCAFS.

2.0 Sonic Boom Background

A sonic boom is the wave field about a supersonic vehicle. As the vehicle moves, it pushes the air aside. Because flight speed is faster than the speed of sound, the pressure waves can't move away from the vehicle, as they would for subsonic flight, but stay together in a coherent wave pattern. The waves travel with the vehicle. Figure 1 is a classic sketch of sonic boom from an aircraft in level flight. It shows a conical wave moving with the aircraft, much like the bow wave of a boat. While Figure 1 shows the wave as a simple cone, whose ground intercept extends indefinitely, temperature gradients in the atmosphere generally distort the wave from a perfect cone to one that refracts upward, so the ground intercept goes out to a finite distance on either side. Boom is not a onetime event as the aircraft "breaks the sound barrier" but is often described as being swept out along a "carpet" across the width of the ground intercepts and the length of the flight track. Booms from steady or near-steady flight are referred to as carpet booms.

The waveform at the ground is generally an "N-wave" pressure signature, as sketched in the figure, where compression in the forward part of the vehicle and expansion and recompression at the rear coalesce into a bow shock and a tail shock, respectively, with a linear expansion between.

Figure 1 is drawn from the perspective of aircraft coordinates. The wave cone exists as shown at a particular time, but is generated over a time period. Booms can also be viewed from the perspective of rays propagating relative to ground-fixed coordinates. Figure 2 shows both perspectives. The cone represents rays that are generated at a given time, and which reach the ground at later times. The intercept of a given ray cone with the ground is called an "isopemp." When computing sonic booms the ray perspective is appropriate, since one starts the analysis from the aircraft trajectory points and each isopemp is identified with flight conditions at a given time. As sketched in Figure 2, the isopemps are forward facing crescents.

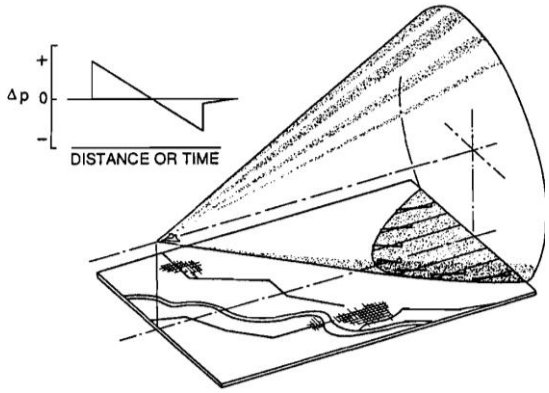

Figure 1. Sonic Boom Wave Field

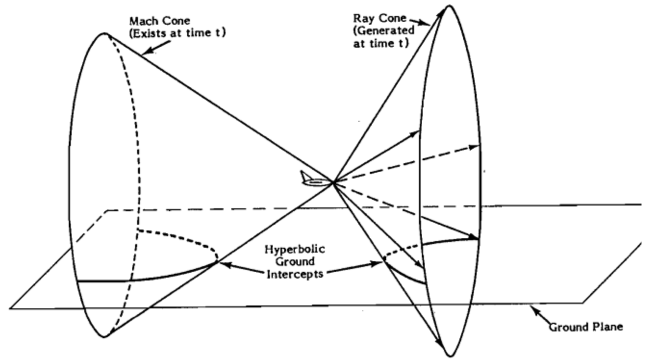

Figure 2. Wave versus Ray Viewpoints

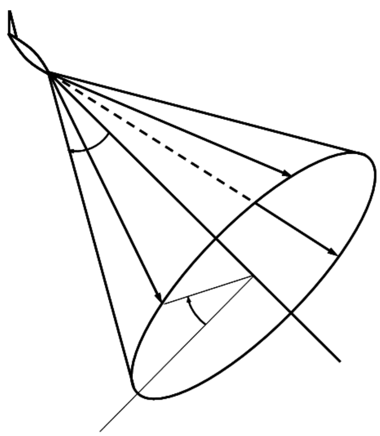

Figure 3. Ray Cone in Diving Flight

Figures 1 and 2 are drawn for steady level flight. If the aircraft climbs or dives, the ray cone tilts along with it. Figure 3 shows a ray cone in diving flight. At the angle in the figure the isopemp would still be a forward facing crescent, but would wrap around further than shown in Figure 2. In a steeper dive the isopemp could go full circle. If the vehicle is climbing at an angle steeper than the ray cone angle, there will be no boom at the ground. During very steep descent (near vertical) and at high Mach numbers the rays can be emitted at a shallow enough angle that they would refract upward and not reach the ground. For a descending vehicle that eventually decelerates to subsonic speed, some part of the trajectory will generate boom that reaches the ground.

Supersonic vehicles can turn and accelerate or decelerate. That affects the boom loudness, and under some conditions cause focused superbooms. Figure 4 is a sketch of rays from an accelerating aircraft. As the Mach number increases the ray angles steepen. The rays cross and overlap, with the focus along the "caustic" line indicated in the figure. The boom on a focusing ray is a normal N-wave before it gets close to the caustic, is amplified by a factor of two to five as it reaches the caustic, then is substantially attenuated as a "post-focus" boom after it passes the caustic.

Figure 5 shows the isopemps for this type of acceleration focus. The focal zone is the concentrated region at the left end of the footprint. The maximum focus area – where the boom is more than twice the unfocused normal boom – is very narrow, generally a hundred yards or less.

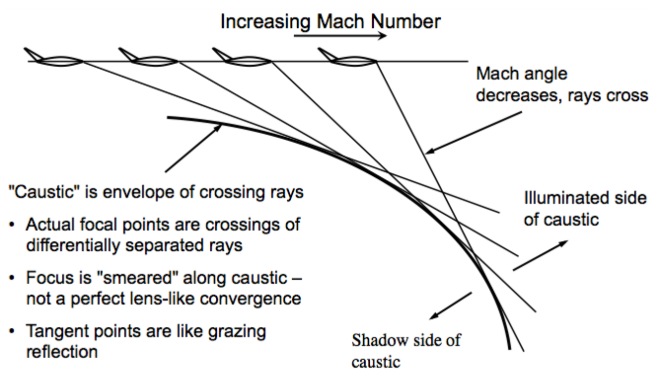

Figure 4. Ray Crossing and Overlap in an Acceleration Focus

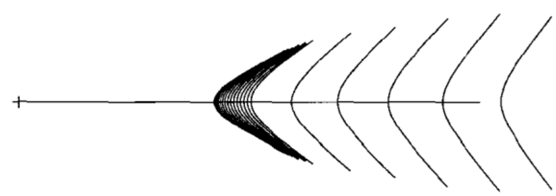

Figure 5. Isopemp Overlap in an Acceleration Focus

3.0 Falcon 9 Block 5 Descent Sonic Boom

This sonic boom analysis is based on a Falcon 9 nominal liftoff to landing trajectory provided by SpaceX. The Stage 1 descent and landing at CCAFS is supersonic from shortly after the apogee until it passes through an altitude just below 12,000 feet. Most of the Stage 1 descent is unpowered.

The boom footprint was computed using PCBoom.[1,2] The vehicle is a cylinder generally aligned with the velocity vector, descending engines first. It was modeled via PCBoom's drag-dominated blunt body mode,[3] which has been validated for entry vehicles.[4] Drag is determined by vehicle weight and the kinematics of the trajectory. Kinematics include the effect of the retro burn. Figure 6 shows the sonic boom footprint, in the form of overpressure contours, pounds per square foot (psf). The ground track of the entire trajectory is also shown in Figure 6. There is a broad forward-facing crescent region

generated as the vehicle descends below 200,000 feet at a heading of approximately 333 degrees. After the burn finishes there is an oval boom footprint region that ends when speed becomes subsonic. There are two narrow focus lines (magenta color), with contour levels in the 1.0 psf to 4.6 psf range, located on the northern edge of the crescent, generated as the vehicle accelerates at the end of the retro burn. At lower altitudes drag slows the descent, so boom following the focus is conventional carpet boom.

- The boom levels in the vicinity of the landing pad, located at latitude 28.485709 degrees and longitude -80.542901 degrees, range from about 2.0-2.7 psf.
- Boom levels in the areas adjacent to CCAFS and Kennedy Space Center (KSC) will be between 0.5-1.0 psf; boom levels on CCAFS property will range from 1.0-2.7 psf.
- The highest boom levels occurring off-shore are up to 4.6 psf in the narrow focus region just inside the north facing crescent shown in Figure 6. This zone is narrow – about 100 yards wide. The location will vary with weather conditions, so it is very unlikely that any given location will experience the focus more than once over multiple events. Variations in weather conditions could alter the sonic boom footprint, in general.
- The broad crescent, with boom levels of 0.1 psf is located over a large land area south of Orlando, FL and stretching south of Port St. Lucie, FL.

In general, booms in the 0.2 to 0.3 psf range could be heard by someone who is expecting it and listening for it, but usually would not be noticed. Booms of 0.5 psf are more likely to be noticed, and booms of 1.0 psf are certain to be noticed. Therefore, people in the communities surrounding CCAFS and KSC are likely to notice booms from Falcon 9 landings as are people located on these two properties. People located on the east coast in the vicinity of the focus region could experience boom levels up to 4.6 psf depending on weather conditions; boom levels greater than 1.0 psf could startle and possibly annoy people. Announcements of upcoming Falcon 9 launches and landings serve to warn people about these noise events and are likely to help reduce adverse reactions to these noise events. The boom levels over land are not likely to cause property damage.

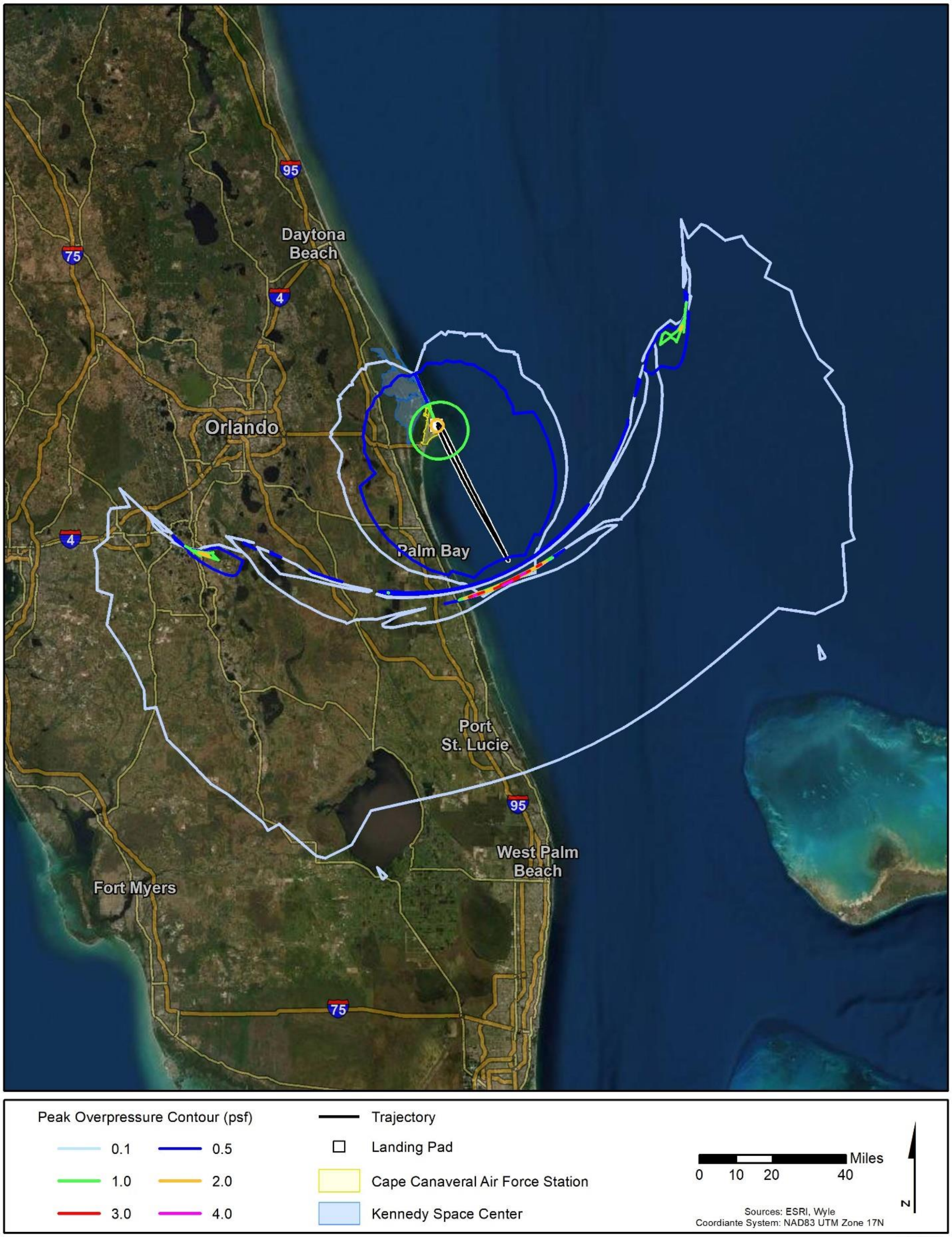

Figure 6. Sonic Boom Contours for Falcon 9 Polar Trajectory Landing at Cape Canaveral Air Force Station

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Daniel Murray
Manager, Space Transportation Development Division
Office of Commercial Space Transportation
800 Independence Ave., SW
Washington, D.C. 20591

March 10, 2020

RE: DHR Project File No.: 2020-0402, Additional Information Received by DHR: February 20, 2020
Section 106 Consultation for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station

Dear Mr. Murray:

The Florida State Historic Preservation Officer reviewed the referenced project for possible effects on historic properties listed, or eligible for listing, in the *National Register of Historic Places (NRHP).* The review was conducted in accordance with Section 106 of the *National Historic Preservation Act of 1966*, as amended, and its implementing regulations in *36 CFR Part 800: Protection of Historic Properties.*

The proposed undertaking includes allowing SpaceX's proposal to conduct Falcon 9 launches and landings on a new southern launch trajectory from Kennedy Space Center and Cape Canaveral Air Force Station in Brevard County, Florida. The FAA established an area of potential effect (APE) for the project including the area of launch and landing, as well as the area affected by the sonic boom that will be generated by launch and landing. The FAA included a study of sonic boom effects as part of the effects determination noting that historic properties would experience relatively minor effects, similar to a clap of thunder, from the sonic boom. The FAA finds that the proposed undertaking will have no adverse effect to historic properties listed, or eligible for listing, in the NRHP.

Based on the information provided and our review of similar Section 106 consultation for SpaceX launches, our office concurs with the FAA's finding that the proposed undertaking will have no adverse effect to historic properties listed, or eligible for listing, in the NRHP.

If you have any questions, please contact me by email at *Jason.Aldridge@dos.myflorida.com* or by telephone at 850-245-6344.

Sincerely,

Jason Aldridge

Jason Aldridge
Deputy State Historic Preservation Officer
for Compliance and Review

United States Department of the Interior
FISH AND WILDLIFE SERVICE
North Florida Ecological Services
7915 BAYMEADOWS WAY, SUITE 200
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FWS Log No. 04EF1000-2020-I-0549

April 22, 2020

Mr. Daniel Murray
Manager, Space Transportation Development Division
U.S. Department of Transportation
Federal Aviation Administration
800 Independence Avenue SW
Washington, DC 20591

Subject: SpaceX Falcon Launch Vehicles at Kennedy Space Center and Cape Canaveral Air Force Station

Dear Mr. Murray:

This letter acknowledges the U.S. Fish and Wildlife Service (Service) has reviewed the consultation request and the supporting Biological Assessment (BA) for SpaceX's Falcon Launch Vehicles at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Brevard County, FL. The Federal Aviation Administration (FAA) has prepared a BA pursuant to section 7 of the Endangered Species Act of 1973 (Act) (16 U.S.C. 1531 *et seq*.) and is requesting our concurrence.

FAA has determined that Falcon launch operations at KSC (Launch Complex -39A, LC-39A) and CCAFS (Launch Complex-40, LC-40), including construction of a mobile service tower (MST) at LC-39A, may affect, but is not likely to adversely affect the West Indian manatee (*Trichechus manatus latirostris*), Florida Scrub-Jay *(Aphelocoma coerulescens*), and Eastern indigo snake (*Drymarchon corais couperi*). The Service provides comments for the may affect, but is not likely to adversely affect (MANLAA) species' determinations in the following sections.

West Indian Manatee

SpaceX will use barges to transport the first stage booster from the Atlantic Ocean (recovery areas) to Port Canaveral. Port Canaveral has a manatee protection program to ensure that manatees are not injured or trapped. SpaceX will ensure that barges that use the Port follow the speeds and any needs for marine observers, as outlined in the Port Canaveral manatee protection program. The Service concurs with the FAA's determination.

Eastern Indigo Snake

SpaceX has agreed to implement the *Standard Protection Measures for Eastern Indigo Snakes* (SPM) to minimize any potential effects on the species. The eastern indigo snake has been observed at KSC but has not been documented in the MST project area. Scoping of burrows before collapsing will ensure that the species is not entombed during the collapse of refugia habitat. Although eastern indigo snakes in the area are vulnerable to mortality during construction activities, the SPM will educate construction personnel. If any indigo snakes are encountered during clearing activities, they will be allowed to safely move out of the project area. The Service concurs with the FAA's determination.

Florida Scrub-Jay

FAA has acknowledged that launch-related operations have the potential to result in indirect effects to the Florida Scrub-Jay by interfering with prescribed burns at KSC and CCAFS. The FAA consultation involves the proposed issuance of one license that will increase launches at two different installations. The installations have developed varying conservation measures to meet the MANLAA determination, to be clear on what is proposed for each facility, this section has subheadings for each installation.

Merritt Island National Wildlife Refuge

SpaceX has agreed to coordinate with KSC to prevent conflicts with the prescribed burn schedule at Merritt Island National Wildlife Refuge (MINWR) near LC-39A. The burn planning and operations of these areas shall adhere to a Prescribed Burn Memorandum of Understanding (MOU KCA-4205 Rev B; KSC 2019), which includes conditions and constraints for conducting prescribed burns.

The Prescribed Burn MOU between the MINWR, KSC, and the CCAFS is the best tool for coordinating and conducting operations around launch operations and facilitates. All parties intend to adhere to the Prescribed Burn MOU, but there will be significant increases to launch operations and subsequent increase in smoke sensitive hardware processed or housed at KSC. These actions could conflict with habitat management operations and have the potential to effect Florida Scrub-Jays and other protected species negatively. Some issues with smoke-sensitive hardware and payloads being manufactured or processed at KSC can be mitigated with better filtration systems in facilities. These mitigation techniques are not addressed by the current Prescribed Burn MOU and will need to be addressed by KSC and their customers through their own agreements.

With that said, not all areas will be affected the same or have the same impacts. The most important area for Florida Scrub-Jays on the MINWR is the Tel-4 core area. This is also currently the most challenging area to coordinate prescribed fire activities. The Happy Creek and Schwartz Road core areas are both within the Security area of KSC and managed through the Prescribed Burn MOU. An increase in operations would also impact this area;however, given the defenses in operations and facilities, they would have different impacts at different times. Happy Creek has more flexibility than Schwartz Road because there are still minimal operational facilities to the north.

A MANLAA determination would mean that the effects of the action (i.e., the issuance of license and increase in the number of annual launches) are discountable or insignificant to the Florida Scrub-Jay. The proposed increase to launch operations and subsequent smoke-sensitive hardware that will be processed, manufactured, or housed at KSC, could at times present conflicts with MINWR prescribed fire operations. The Service and KSC have agreed to strictly adhere to the Prescribed Burn MOU and KSC will coordinate with its customers that have sensitive payloads and smoke sensitive operations so that these operations coupled with the proposed launches do not interfere with scheduled prescribed burns.

The Service and KSC propose to consult programmatically on an upland BO that will address operations and the fire management at KSC. KSC is projecting a BA in the near future; however to address the issues for this consultation specifically, the MINWR and KSC have agreed to develop a prescribed burn tracking tool that will enable KSC and MINWR staff to track the success of proposed or scheduled prescribed burns on KSC. The tracking tool will record the monthly scheduled burns by Burn Unit and all pertinent data related to the burn including successful implementation. If a burn is not successfully implemented as proposed or scheduled, we will also track the rationale for postponing the burn. Moving forward, the tracking tool measure will allow KSC and MINWR staff to have a more global picture of the MINWR burn program and lend detail to the forthcoming KSC Upland Species Programmatic BO. Based on the Prescribed Burn MOU and prescribed fire tracking tool as an additional measure, the Service concurs with FAA's determination for the Florida Scrub-Jay at MINWR, LC-39A.

Cape Canaveral Air Force Station

As mentioned above, the Prescribed Burn MOU between the MINWR, KSC, and the CCAFS is used to coordinate habitat management and launch operations. All parties intend to adhere to the Prescribed Burn MOU, but there will be significant increases to launch operations and subsequent increase in smoke sensitive hardware processed or housed at CCAFS, as well.

To resolve potential habitat management conflicts not addressed by the MOU, the 45th Space Wing (SW) has had multiple discussions with SpaceX via conference calls. SpaceX, in close coordination with the 45th SW, is developing a SpaceX-specific Burn Management Plan to address effects at CCAFS near LC-40 and other SpaceX facilities. The plan will contain specific actions and responsibilities so that SpaceX's operations do not prevent the 45 SW from meeting the burn requirements and goals documented in the BOs, the 45 SW Integrated Natural Resources Management Plan, and the Service /45 SW NRO Burn Plan. Based on the Prescribed Burn MOU and the development and implementation of the SpaceX Burn Management Plan, the Service concurs with FAA's determination for Florida Scrub-Jay at CCAFS, LC-40 and supporting SpaceX facilities.

The FAA also reviewed potential effects to nesting sea turtles. The FAA anticipates that nighttime lighting and any launch-related operations at LC-39A and LC-40 may affect, and is likely to adversely affect the following nesting marine turtles: leatherback (*Dermocheuls coriacea*), green (*Chelona mydas*), loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*), and hawksbill (*Eretmochelys imbricata*). The Service has analyzed programmatically the effects of facility lighting adjacent to nesting marine turtle habitat and has exempted incidental take under the CCAFS BO, FWS Log. 2009-F-0087 and KSC BO, FWS Log. 2016-F-0083. The applicant, SpaceX, has agreed to implement the measures outlined in the BOs, and as part of complying with the BO, SpaceX will keep Light Management Plans up-to-date. The Service has determined that such actions that perform all the terms and conditions of the BOs will not jeopardize the continued existence of nesting marine turtles.

Under the revised regulations 50 CFR §402.16, reinitiating criteria is clarified to include informal consultations (see italics below). Reinitiating of consultation is required and shall be requested by the Federal agency or by the Service, where discretionary Federal involvement or control over the action has been retained or is authorized by law and:

a. If the amount or extent of incidental take is exceeded;
b. If new information reveals that the Action may affect listed species or designated critical habitat in a manner or to an extent not considered;
c. If the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in the biological opinion or *written concurrence*; or
d. If a new species is listed or critical habitat designated that the Action that may be affected by the identified actions.

FAA anticipates that launch vehicle engine noise and sonic booms may affect, but would not likely to adversely affect all the listed species at KSC and CCAFS. The Service concurs with the determination. If you have any questions about our concurrence letter or the reinitiation triggers, please contact Ms. Tera Baird by phone at 904-731-3196 or by email at tera_baird@fws.gov.

Sincerely,

Jay B. Herrington
Field Supervisor

cc: Daniel Czelusniak, Daniel.Czelusniak@faa.gov
Michael Blaylock, Michael.blaylock.4@us.af.mil
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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

FEB 2 6 2020

Refer to NMFS No: OPR-2020-00268

Mr. Howard Searight
Deputy Manager
U.S. Department of Transportation
Federal Aviation Administration
800 Independence Avenue SW
Washington, DC 20591

RE: Request to reinitiate Endangered Species Act informal consultation for potential effects on ESA-listed species from an expanded action area and activities associated with the commercial space launch operations conducted by SpaceX.

Dear Mr. Searight:

On January 27, 2020 NOAA's National Marine Fisheries Service (NMFS) Endangered Species Act Interagency Cooperation Division received the Federal Aviation Administration's (FAA) request to reinitiate informal consultation for actions to be conducted to by the Space Exploration Technologies Corporation (SpaceX), to launch and recover spacecraft in the Atlantic Ocean, Gulf of Mexico, and Pacific Ocean. The FAA is requesting written concurrence that the proposed actions are not likely to adversely affect the ESA-listed species located within an expanded action area from what was considered in the original project activities analyzed in NMFS consultations FPR-2017-9231, and FPR-2018-4287. Multiple phone calls and meetings occurred between October 2019 and February 2020, resulting with the FAA modifying the project area to avoid any activities occurring in nearshore, sensitive marine areas including coral reefs.

Since the issuance of the concurrence letters in 2017 and 2018, the FAA determined that the existing launch permits for the SpaceX program need to be modified in order to include an expanded action area (Figure 1) for their proposed Falcon 9 program activities which will include a southern trajectory for payloads requiring polar orbits. This alters the extent of the action area previously analyzed for the program. No other changes are proposed for the program.

The FAA's request for reinitiation of consultation for the expanded area effects on ESA-listed species and critical habitats included information supporting their conclusion of a may affect, not likely adversely affect ESA-listed species and critical habitats within the expanded action area from activities and the permitted actions conducted by SpaceX.

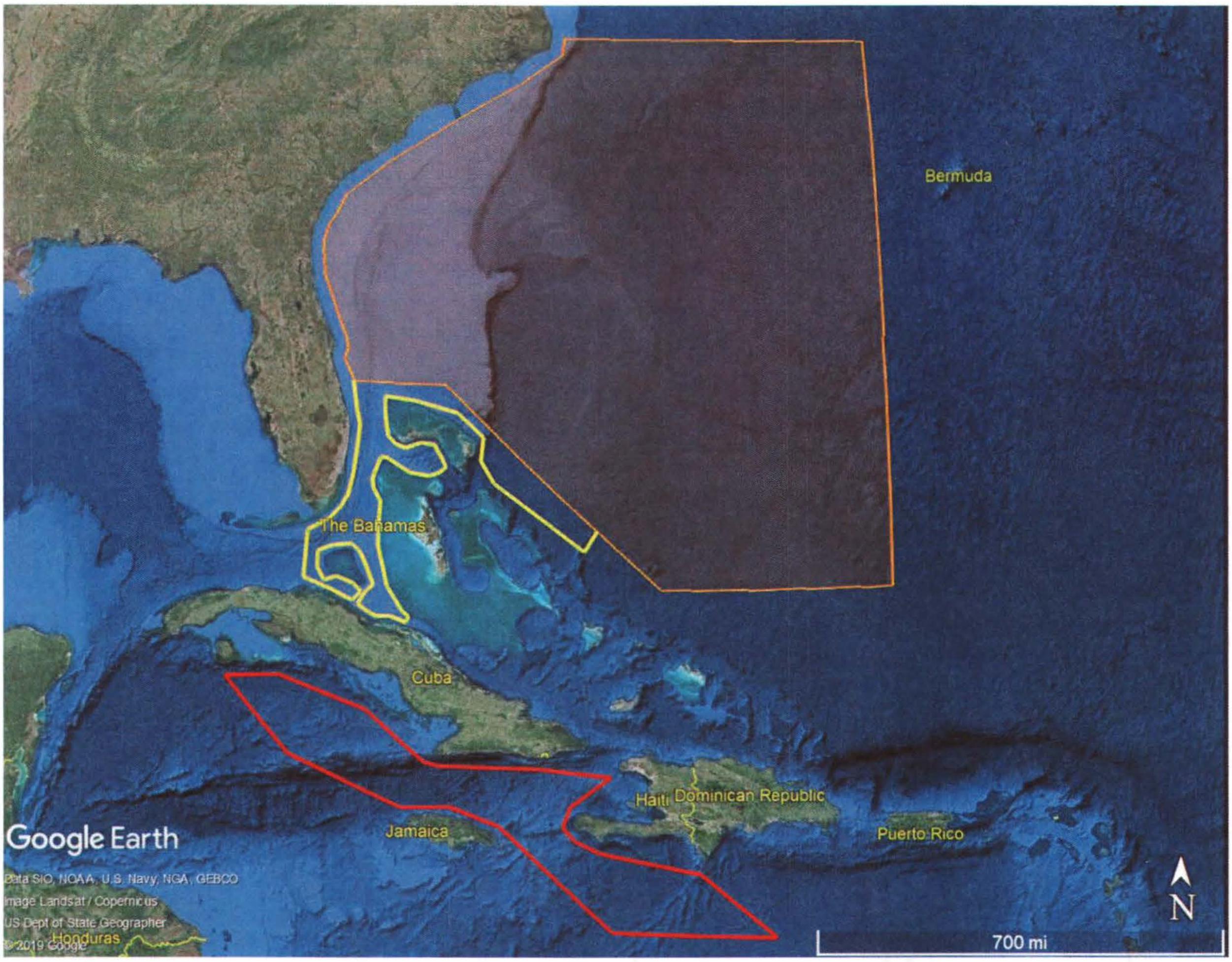


Figure 1. Action Area – SpaceX Recovery Areas (FAA 2020).

Orange = previously analyzed and approved recovery area for first stage booster and fairing recovery

Yellow = new proposed area for first stage booster and fairing recovery for polar missions

Red = new proposed area for fairing recovery only for polar missions

NMFS reviewed the reinitiation of informal consultation request document and related materials submitted by your agency. Based on our knowledge, expertise, and the materials submitted in your request to include all ESA-listed species and critical habitats previously considered in the 2017 and 2018 consultations that may be affected by the SpaceX program, we concur with the FAA's conclusion that the proposed action is not likely to adversely affect ESA-listed species and critical habitats.

This letter supplements the Letters of Concurrence (FPR-2017-9231 and FPR-2018-4287), to include the SpaceX program activities occurring in a larger action area. All previous effects analyses and determinations for listed species and their designated critical habitats from the proposed program remain unchanged. This concludes reinitiation of consultation under the ESA for the FAA's permitting of the Space Exploration Technologies Corporation proposed actions. This response was prepared by the NMFS ESA Interagency Cooperation Division pursuant to section 7(a)(2) of the ESA, implementing regulations at (50 C.F.R. §402), and agency guidance for preparation of letters of concurrence.

Reinitiation of consultation is required, and shall be requested, by FAA or NMFS where discretionary Federal involvement or control over the action has been retained or is authorized by law and: (a) ESA take occurs; (b) new information reveals effects of the action that may affect ESA-listed species or designated critical habitat in a manner or to an extent not previously considered in this consultation; (c) the action is subsequently modified in a manner that causes an effect to the ESA-listed species or designated critical habitat not previously considered in this consultation; or (d) if a new species is listed or critical habitat designated that may be affected by the action (50 C.F.R. §402.16).

We look forward to further cooperation with you on other projects to ensure the conservation of our threatened and endangered species and designated critical habitat. If you have any questions on this consultation, please contact me at (301) 427-8495 or, cathy.tortorici@noaa.gov.

Sincerely,

Cathryn E. Tortorici
Chief, ESA Interagency Cooperation Division
Office of Protected Resources

Appendix C

Emissions Modeling

Sierra Engineering & Software, Inc.

ANALYSIS REPORT	**NUMBER: 2019-002** **DATE: 14 June 2019**
SUBJECT: Exhaust Plume Calculations for SpaceX Merlin5 Booster Engine	**PAGE 1 OF 11** **NO. OF APPEN. 0**
PREPARED FOR: Matthew Thompson, SpaceX	**(W.O. 6012)**
DISTRIBUTION: Katy Smith, SpaceX	

1.0 SUMMARY

Calculations were performed to estimate the far-field exhaust constituents of the SpaceX Merlin 5 LOX-kerosene booster rocket engine firing under sea-level conditions. Although the exit-plane exhaust is fuel-rich and contains high concentrations of carbon monoxide (CO), subsequent entrainment of ambient air results in complete conversion of the CO into carbon dioxide (CO_2) and oxidation of the soot from the gas generator exhaust. A small amount of thermal nitrous oxides (NOx) is formed, all as NO. The NO emission is predicted to be 1.047 lb_m/s under nominal power (100%) operation.

2.0 ENGINE DESCRIPTION

The subject engine is the baseline booster engine for the SpaceX Falcon 9 launch vehicle family. This analysis address the latest version of the engine, the Merlin 5. The propellants are liquid oxygen (LOX) and the RP-1 grade of kerosene. The subject engine consists of a 16.27:1 regeneratively-cooled thrust chamber nozzle exhaust plus a fuel-rich gas exhaust from the turbopump drive system. As a simplification needed to address the problem with the existing axisymmetric analysis tools, the computational nozzle exit plane includes an outer annulus of low mixture ratio turbine exhaust gas generator surrounding the physical thrust chamber exhaust plume. Characteristic dimensions of the thrust chamber nozzle are included in Table 1.

The nominal operating condition for the Merlin 5 engine is an injector face stagnation pressure (Pc) of 1859 psia and an engine O/F mixture ratio (MR) of 2.356. The associated thrust chamber MR is 2.576 and the gas generator (GG) MR is 0.423. The GG mass fraction is about 4.28% of the total engine flow. The current analysis was performed for the 100% nominal engine operating pressure (Pc=1859 psia) and an engine MR of 2.58.

Table 1: Merlin 5 Nozzle Characteristics

Throat Radius (in)	4.429
Downstream radius of curvature (in)	1.250
Tangency angle (deg)	35.33
Nozzle lip exit angle (deg)	8.973
Nozzle exit diameter (in) [excluding GG exhaust duct]	35.733
Nozzle throat to exit length (in)	39.617

3.0 ANALYSIS APPROACH

A series of simulations were required to estimate the emissions from the Merlin 5 engine. The PERCORP analysis model[1] was used to estimate the O/F mixture ratio variations that exist within the Merlin 5 thrust chamber. The fuel-rich combustion model in PERCORP was also used to estimate the gas generate exhaust constituents. The VIPER parabolized Navier-Stokes model[2] was used to kinetically expand the thrust chamber exhaust to the nozzle exit plane. The VIPER results were used to assess the validity of the PERCORP solution, correlating engine thrust, mass flow rate and specific impulse (ISP) to test results. PERCORP input parameters were adjusted until there was good agreement between the VIPER performance predictions and the test results. The SPF code[3] was used to predict the flow structure of the free exhaust plume and the entrainment of ambient air. VIPER solution was used as the starting condition for the SPF. Though the SPF code can handle detailed chemical kinetics within the plume evolving flow field, the strong barrel shock downstream of the nozzle exit produces numerical convergence problems with the version of SPF used. The present SPF simulations were performed without chemical kinetics. The results were air entrainment and gas temperature profiles. The SPF and VIPER results were used as inputs for one-dimensional kinetic modelling of the plume flow field. The kinetic model in the TDK code[4] was used to model chemical reactions within the evolving plume flow field.

TDK modelling of the plume flow field included chemical mechanism that address a) the oxidation of CO to CO_2, b) the complex oxidation of hydrocarbons to H_2O and CO_2, c) the oxidation of soot to CO_2, and d) the thermal generation of NOx in a mixture of air and combustion products. Table 2 includes the chemical reactions and rates used in the TDK simulation.

Table 2: Kinetic Reactions Included in One Dimensional Chemistry Simulations*

	A	N	B
H + H + m = H2 + m†	6.4E17	1.0	0.0
H + OH + m = H2O + m	8.4E21	2.0	0.0
O + O + m = O2 + m	1.9E13	0.0	-1.79
CO + O + m = CO2 + m	1.0E14	0.0	0.0
O + H + m = OH + m	3.62E18	1.0	0.0
CH4 + m = CH3 + H + m	1.259E17	0	88.4
HCO + m = CO + H + m	5.012E14	0	19.0
C2H3 + m = C2H2 + H + m	7.943E14	0	31.5
N+NO = N2+O	2.700E13	0	0.355
N+O2 = NO+O	9.000E9	-1.0	6.5
N+OH = NO+H	3.360E13	0	0.385
HO2+NO = NO2+OH	2.110E12	0	-0.480
NO2+O = NO+O2	3.900E12	0	-0.240
NO2+H = NO+OH	1.320E14	0	0.360
O2 + H = O + OH	2.2E14	0.0	16.8
H2 + O = H + OH	1.8E10	-1.	8.9
H2 + OH = H2O + H	2.2E13	0.0	5.15
OH + OH = H2O + O	6.3E12	0.0	1.09
CO + OH = CO2 + H	1.5E7	-1.3	-.765
CO + O = CO2	2.5E6	0.0	3.18
CO2 + O = CO + O2	1.7E13	0.0	52.7
CH4+ OH = CH3 + H2O	3.162E13	0	6.0
H + CH4 = CH3 + H2	6.310E14	0	15.1
O + CH4 = CH3 + OH	3.981E14	0	14.0
CH3 + O = CH2O + H	1.259E14	0	2.0
CH3 + OH = CH2O + H2	3.981E12	0	0
C2H2 + OH = C2H + H2O	6.310E12	0	7.0
H + CH2O = HCO + H2	3.162E14	0	10.5
O + CH2O = HCO + OH	1.995E13	0	3.1

* TDK reaction format is k=AT**(-N)*EXP(-1000B/RT) [cc-Kcal-K-mole-s]

† m is any molecule for a third body reaction

Table 2: Kinetic Reactions Included in One Dimensional Chemistry Simulations (ctd)

	A	N	B
OH + CH2O = HCO + H2O	7.943E12	0	0.2
H + HCO = CO + H2	1.995E14	0	0
OH + HCO = CO + H2O	1.000E14	0	0
H + C2H2 = C2H + H2	1.995E14	0	19.0
O + C2H2 = CH2 + CO	5.012E13	0	3.7
C2H + O2 = HCO + CO	1.000E13	0	7.0
CH2 + O2 = HCO + OH	1.000E14	0	3.7
H + C2H4 = C2H3 + H2	1.000E14	0	8.5
C2H2 + H = C2H3	5.500E12	0	2.39
H + C3H6 = C2H4 + CH3	3.981E12	0	0
C(GR)[‡] + OH = CO + H	6.02E8	-0.5	0

4.0 ANALYSIS RESULTS

The PERCORP modelling of the Merlin 5 thrust chamber included 11.1% fuel film cooling injected at two locations down the chamber wall. The SpaceX supplied chamber wall temperature profile agreed well with the PERCORP results. The PERCORP solution for the nominal 319.36 lbf-s/lb_m thrust chamber specific impulse includes a 2.0% core mixing loss, yielding a characteristic velocity (C*) efficiency of 96.4%. The C* efficiency agrees well with SpaceX test data. The fuel-rich combustion model was used to predict the GG exhaust species mass fractions (Table 3). The PERCORP results included initial boundary conditions for the VIPER nozzle flow field simulation. The predicted thrust chamber nozzle exit species mass fractions from VIPER are listed in Table 4.

The GG exhaust species from PERCORP and the nozzle exhaust species, temperature and velocity fields from VIPER were used as initial conditions for the SPF exhaust plume flow field modelling. Three heavy hydrocarbon species ($C_{12}H_{23}$, C_7H_{14} and C_3H_6) predicted to exist in the GG exhaust were thermally cracked into smaller constituents (C_2H_2, C_2H_4, CH_4, H_2) using relationships suggested by Reference 5.

The SPF modelling stepped to 100 nozzle exit radii (Rexit = 18.3214 inches, 1.527 ft). Predicted plume contours for temperature and mass fractions of N_2, CO and soot are presented in Figure 1 through Figure 4. Since there plume entrainment and mixing field is simulated for chemically frozen flow, the N_2 contours are representative of the air entrainment, while the CO and soot contours indicate key products of incomplete combustion.

‡ C(GR) is the carbon representative of soot

Table 3: Gas Generator Exhaust Species Mass Fraction from PERCORP

Species	Mass Fraction
CO	0.3035
CO2	0.0625
H2	0.0030
H2O	0.0918
CH4	0.0476
C2H2	0.0114
C2H4	0.2098
C(GR)	0.0030
C2H6	0.0471
C3H6	0.0662
C7H14	0.0397
C12H23	0.1144

Table 4: Thrust Chamber Nozzle Exit Species Mass Fraction from VIPER Simulation

Species	Mass Fraction
CO2	0.4230
H2O	0.2538
CO	0.2536
O2	0.0367
H2	0.0086
C(GR)	0.0066
OH	0.0064
C2H2	0.0062
CH4	0.0027
O	0.0013
C2H4	7.79E-04
H	1.31E-04
HCO	1.49E-05

Figure 1: Plume Temperature Contours (degrees K)
R is radius normalized by Rexit, X is axial distance from nozzle exit normailzied by Rexit

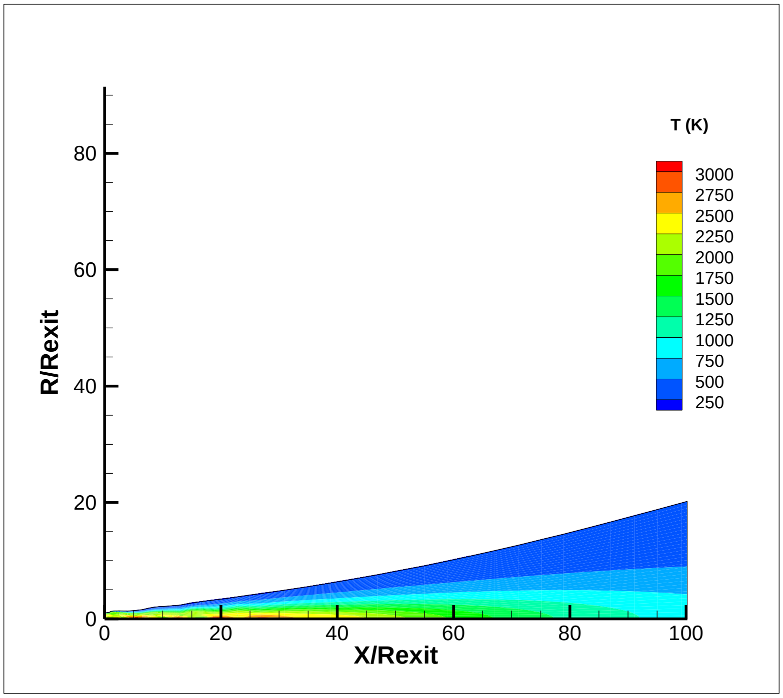


Figure 2: Plume N_2 Mass Fraction Contours (degrees K)
R is radius normalized by Rexit, X is axial distance from nozzle exit normailzied by Rexit

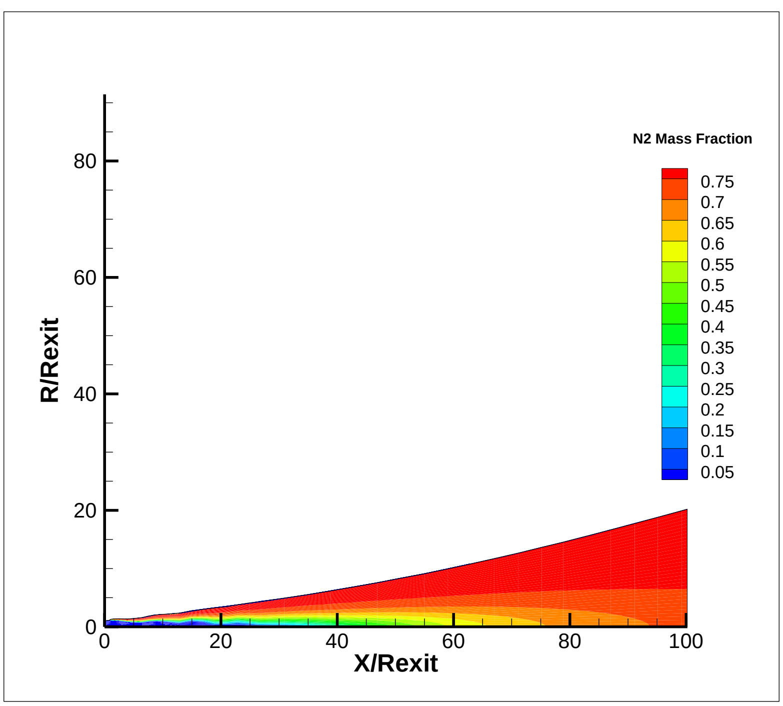


Figure 3: Plume CO Mass Fraction
R is radius normalized by Rexit, X is axial distance from nozzle exit normailzied by Rexit

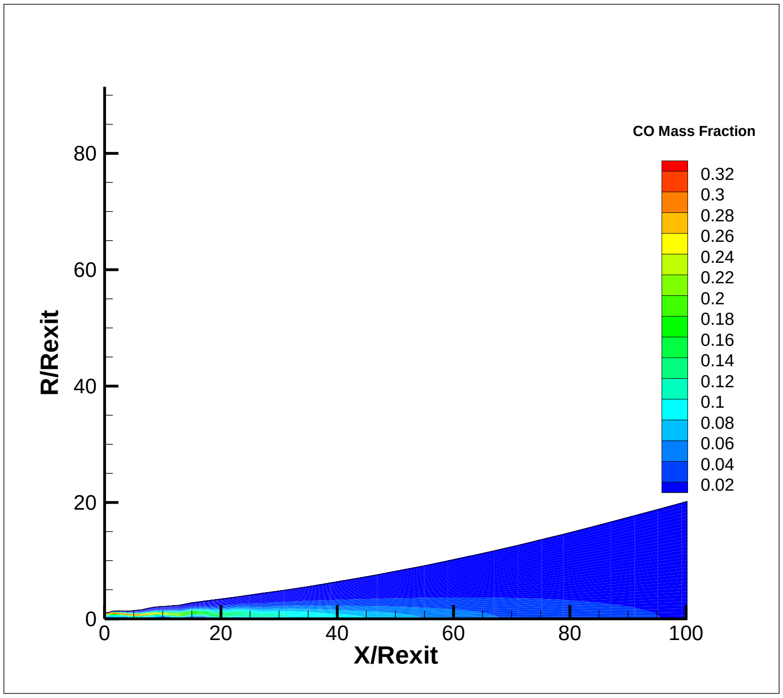
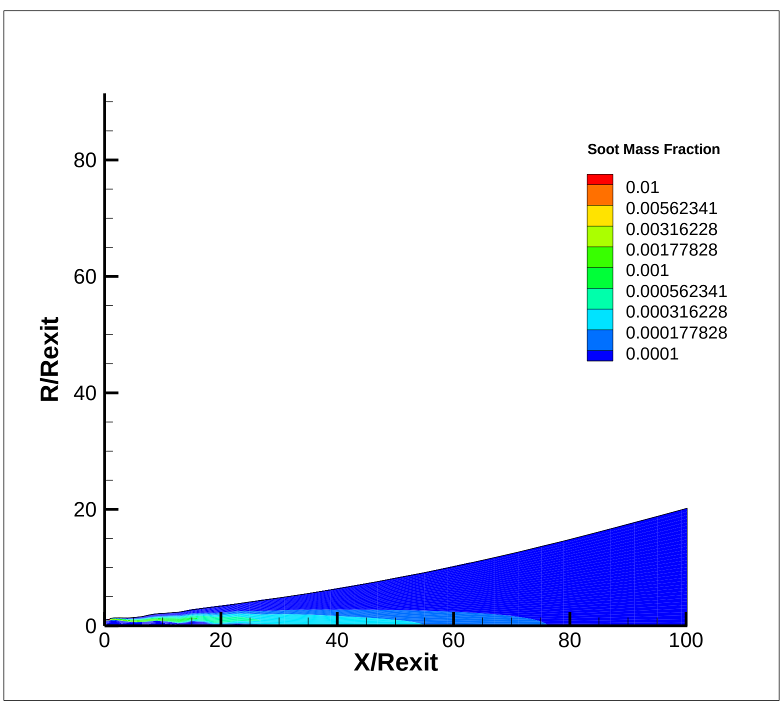


Figure 4: Plume Soot Mass Fraction Contours
R is radius normalized by Rexit, X is axial distance from nozzle exit normailzied by Rexit



The reactive plume was defined to include all flow that had a CO concentration greater than 1,000 ppm. Integration of the SPF data indicates that 18,390 lb/s air is entrained by the end of the simulation (Figure 5). It is estimated that the 153 meter entrainment end point is reached 294 msec after the plume flow exits the nozzle.

Figure 5: Axial Air Entrainment Estimates from SPF.

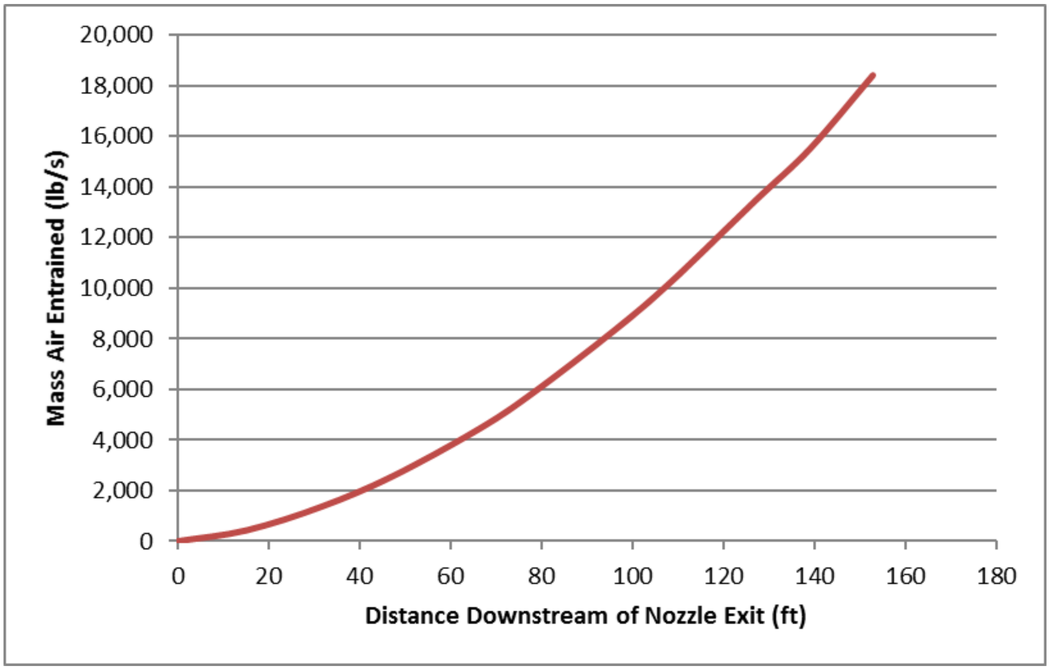
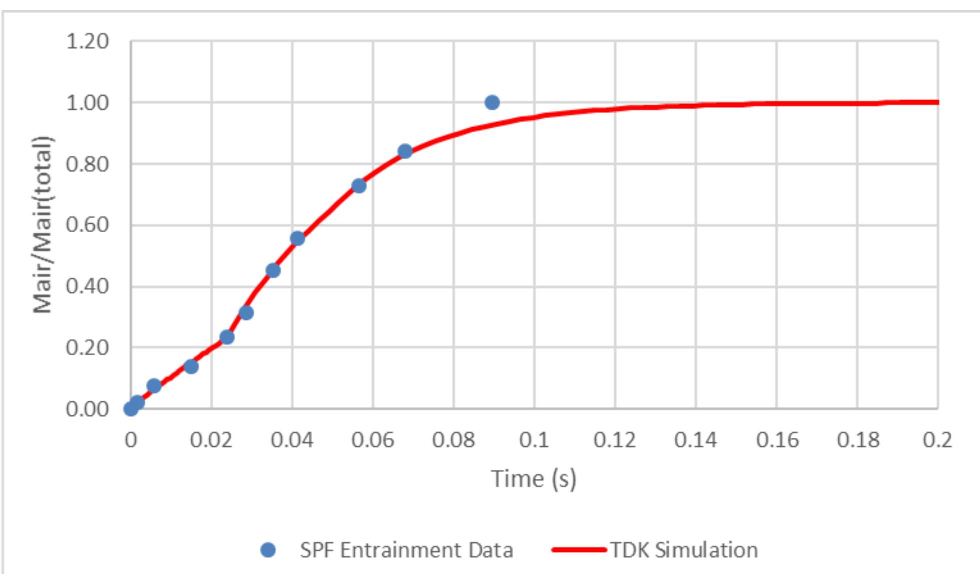


Figure 6: Approximate Air Entrainment Profile used in TDK Simulations



The subsequent TDK simulation of the plume chemistry required an approximate fit of the air entrainment rate. The SPF air entrainment profile was fit to an “availability profile” for the TDK simulations, whereby ambient air is mixed into the plume flow. Figure 6 shows that the approximate TDK air addition agrees well with the entrainment rate predicted by SPF.

The one-dimensional kinetics modeling of the after-burning characteristics of the exhaust plume was performed assuming a piecemeal constant pressure (13.6-14.7 psia) and entrainment of ambient temperature air. The model predicted that all the soot quickly (<5 msec) burns out (i.e. converts to CO). Complete CO oxidation occurs within 35 msec, with concentrations reduced to 2 ppm. The small concentration of unburnt hydrocarbons (CH_4, C_2H_2, C_2H_4, CH_3) are rapidly oxidized, surviving less than 1 msec. The limited thermal NO formation occurs during the early part of the entrainment process, with NO mass fraction constant after about 10 msec. The NO mass fraction at the end of the 157 ft long plume entrainment is 0.000055. Given the total mixed plume mass flow rate of 19041 lb/s, this corresponds to a NO mass flow of 1.047 lb/s. Figure 7 and Figure 8 show the predicted temperature and pollutant species mass fraction profiles. The pollutant flow rates were calculated in terms of lb_m generated per second of steady engine operation.

Figure 7: Predicted Profile of Bulk Plume Temperature and Species Concentration

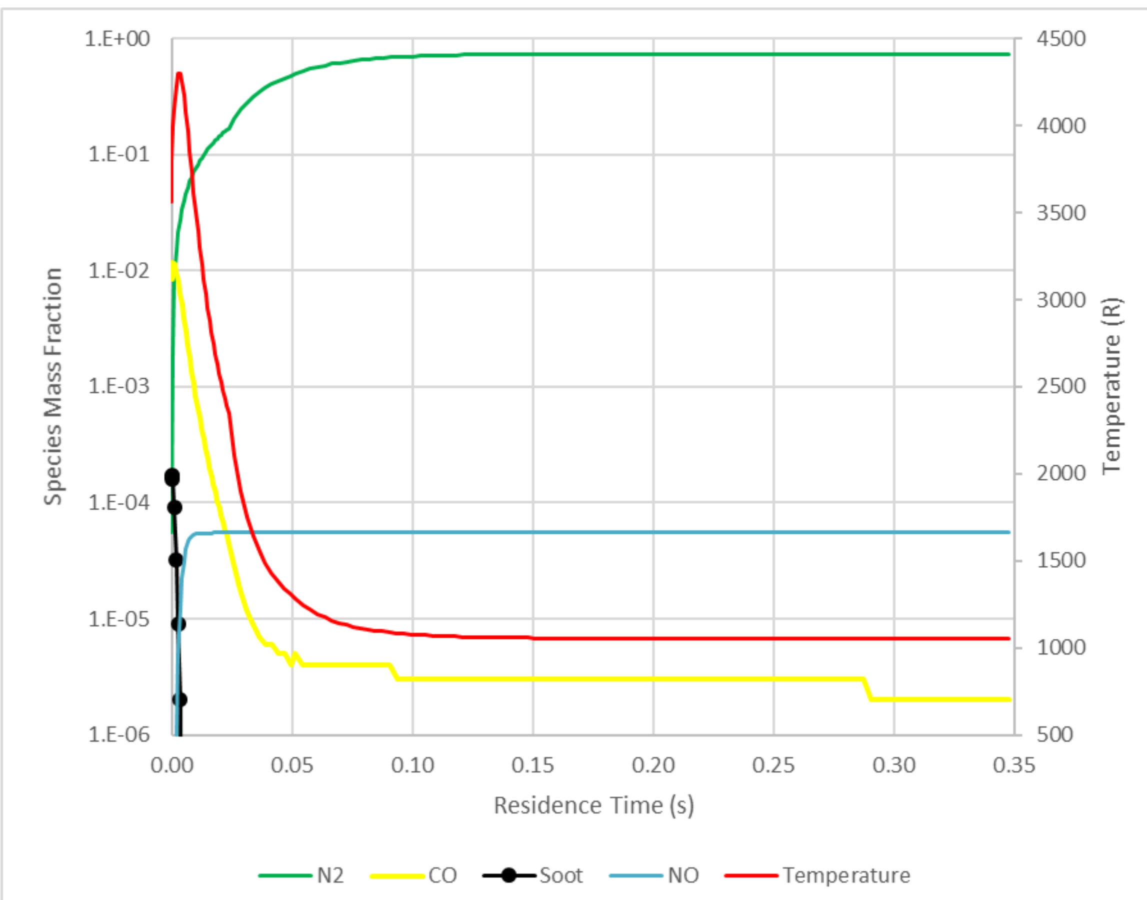
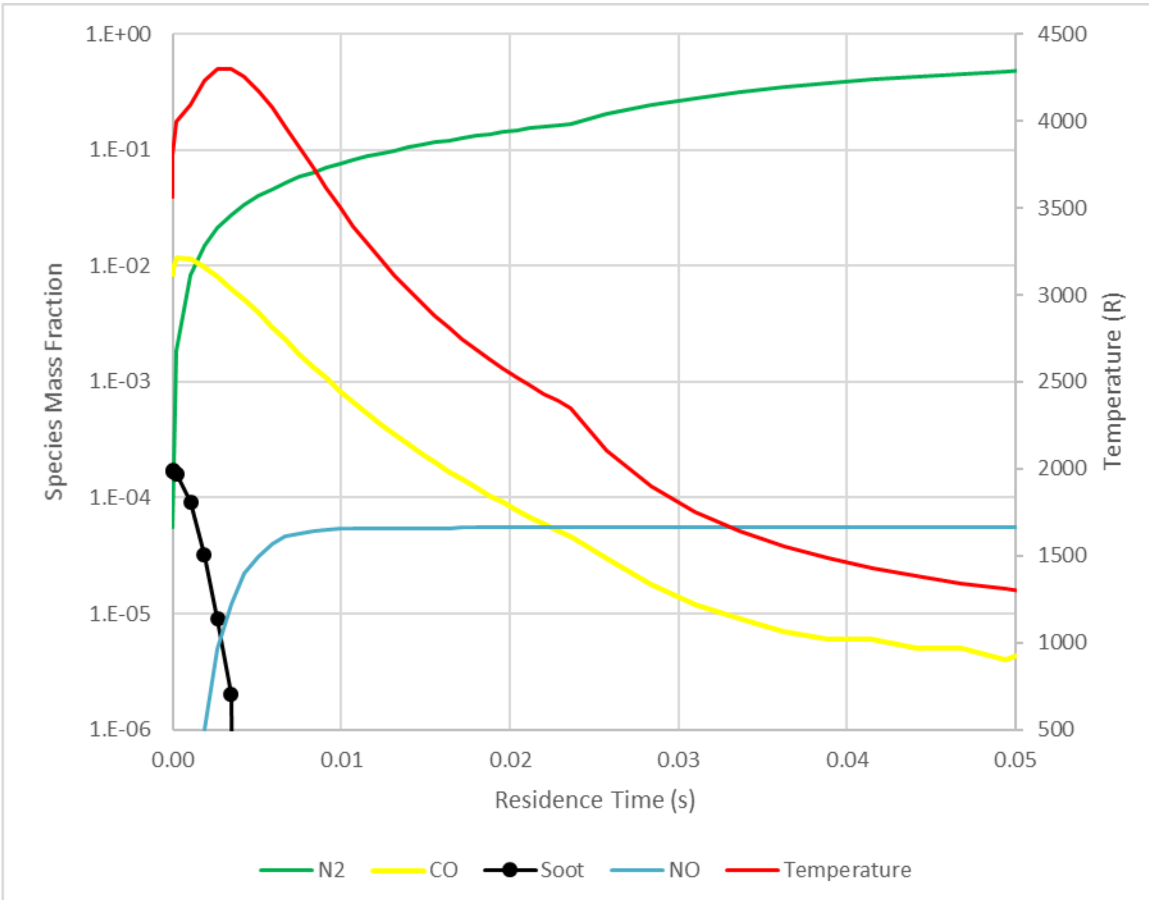


Figure 8: Predicted Profile of Bulk Plume Temperature and Species Concentration for Initial Residence Times



5.0 REFERENCES

[1] *Performance Correlation Program (PERCORP 2006) Reference and User's Manual, Version 2.0*, Sierra Engineering Inc., Carson City, NV, June 2009

[2] *Viscous Interaction Performance Evaluation Routine For Two-Phase Nozzle Flows With Finite Rate Chemistry, VIPER 4.5*, Software and Engineering Associates, Carson City, NV, 2018

[3] Taylor, M.W. and Pergament, H.S.; *Standardized Plume Flowfield Model SPF-III, Version 4.2 Program User's Manual*, PST TR-51, Propulsion Science and Technology, Inc. East Windsor, NJ, June 2000

[4] Nickerson, G. R., Dunn, S.S., Coats, D.E. and Berker, D.R.; *Two-Dimensional Kinetics (TDK) Nozzle Performance Computer Program User's Manual*, Software and Engineering Associates, Carson City, NV, Jan 1999

[5] Nickerson, G.R. and Johnson, C.W.; "A Sooting Model for Fuel Rich LOX/Hydrocarbon Combustion", 28th JANNAF Combustion Meetings, San Antonio, TX, 28 Oct-1 Nov, 1991

Appendix D

Public Comments and FAA Responses

AIR LINE PILOTS ASSOCIATION, INTERNATIONAL
7950 Jones Branch Drive, Suite 400S | McLean, VA 22102 | 703-689-2270 | 888-FLY-ALPA
THE WORLD'S LARGEST PILOTS UNION | WWW.ALPA.ORG

March 19, 2020

Mr. Daniel Czelusniak
Federal Aviation Administration
800 Independence Avenue SW
Suite 325, Washington D.C. 20591

ATTN: Docket No. FAA-2020-04039

Subject: Request for Comment on the Draft Environmental Assessment for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station

Dear Mr. Czelusniak

The Air Line Pilots Association, International (ALPA), represents the safety interests of more than 63,000 professional airline pilots, flying for 35 airlines in the United States and Canada. ALPA's long-held position is that all operations in the national airspace system (NAS) must be conducted to a level of safety that does not threaten to reduce safety levels of other NAS operations, including airline operations. ALPA's goal is to continue to support the Federal Aviation Administration (FAA), aviation industry, and other stakeholders in maintaining a safe NAS by fostering the safe integration of commercial space operations into the NAS.

Although the Environmental Assessment (EA) document focuses on environmental impacts, ALPA identified safety concerns during the review of the EA document. Currently there is no process established for NAS stakeholders to address or review operational launch plans to identify potential safety risks outside the environmental coordination process. There needs to be a collaborative process established where NAS stakeholders have an opportunity to review launch plans to assist the FAA and commercial space operators identify potential risks. ALPA respectfully submits the following comments and requests clarification of certain portions of the draft EA.

Section 2.1.2. Falcon Launch Operations at LC-39A, LC-40, LZ-1, and LZ-2

As part of the licensing process for Falcon 9 polar missions, SpaceX would negotiate and enter into Letters of Agreement (LOA) with relevant Air Traffic Control (ATC) facilities and issuance of Notices to Airman (NOTAM).

Any negotiated LOA will have significant impact on commercial aviation stakeholders' access to airspace during a southern polar launch. ALPA requests the FAA include industry partners in the negotiation process and safety analysis of impacted airspace.

Section 2.1.2 Falcon Launch Operations at LC-39A, LC-40, LZ-1, and LZ-2

Published NOTAMs for previous commercial space launches were unclear and did not notify stakeholders of the increased risk commercial space operations introduce into the NAS or potential falling debris. ALPA requests the FAA clarify what is considered extraordinary circumstances and describe basic procedures that have been developed for extraordinary circumstances such as a catastrophic breakup or falling debris.

Section 2.1.2.2. Payload Fairing Recovery Operations

The Falcon fairing cover and parachute system recovery areas are developed using modeling tools. Although modeling is a good tool for predicting impact points, under real environmental conditions the actual impacts points may vary significantly. Given the high altitude of the drogue parachute deployment (50,000ft) and size of the recovery areas, there needs to be a requirement for real time tracking of the drogue parachute and assembly.

ALPA recommends the FAA publish a NOTAM for the fairing recovery operations to alert flight crews of falling debris hazards 50,000 ft to surface.

Section 2.1.2.3 Boost Back and Landing

When reviewing the SpaceX plan for missions involving boost-back and landing, SpaceX measures wind speed in the landing area using weather balloons at various intervals before launch and landing events.

ALPA requests the FAA provide a mitigation strategy for how SpaceX weather balloons and “radiosonde, which is the size of a shoe box and is powered by a 9-volt battery” are tracked and accounted for during the free fall back to earth?

Section 4.5.1.2. Sonic Booms

An analysis of sonic boom peak overpressures were modeled for southern polar trajectories impact on populated land with peak pressures experienced on the ground of 4.6 psf. Potential damage to structures on the ground at 2 psf and above were identified. There was no analysis included in the EA for the effects sonic boom footprints have on aircraft at cruise altitudes.

The “NASA Armstrong Fact Sheet: Sonic Booms” (August 15, 2017) noted the distance shock waves travel before reaching the ground determines the intensity of the sonic boom based on the size and speed of the vehicle and atmospheric conditions. Typical overpressures were based on aircraft type, speed, and altitude. According to the Fact Sheet the typical overpressure from altitude to ground for the Space Shuttle was rated at 1.25 psf, speed of Mach 1.5, 60,000 feet, on landing approach.

ALPA requests the FAA clarify impacts sonic booms may have on aircraft in flight and under sonic boom footprints.

ALPA appreciates the opportunity to submit comments to the SpaceX EA. If you would like to contact us, please call Darrell Pennington at (703) 689-4333 or email at Darrell.Pennington@alpa.org.

Sincerely,

Donald L. Dobias, Jr.

Capt. Donald Dobias
Air Traffic Services Chair
Airline Pilots Association, International

AOPA
your freedom to fly

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March 16, 2020

Mr. Daniel Czelusniak
Environmental Protection Specialist
Federal Aviation Administration
800 Independence Avenue SW
Suite 325
Washington, DC 20591

Re: ***Request for Comment on the Draft Environmental Assessment for SpaceX Launch Licenses at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Florida.***

Dear Mr. Czelusniak,

The Aircraft Owners and Pilots Association (AOPA), the world's largest aviation membership association, submits the following comment in response to the request for comments on the Draft Environmental Assessment (EA) for the SpaceX launch licenses at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Florida. While AOPA supports the advancement of the commercial space industry, full consideration must be given to the impact commercial space operations will have on general aviation operations within the National Airspace System (NAS). It is important the FAA integrate commercial space operations into the NAS and take care to not give one commercial operator priority access to the airspace over all other NAS users.

AOPA contends that the establishment of commercial space ports and subsequent commercial space launches should not lead to additional temporary or permanent airspace restrictions. We are concerned about the potential airspace impacts of SpaceX's proposed launch and reentry rates, and the new southern launch trajectory. The Draft EA's assessment of the airspace impacts of these two proposed actions is totally insufficient. The FAA fails to clarify what the public can expect as far as airspace restrictions and what, if any, mitigations the FAA has planned. The FAA must clarify the foreseeable airspace impacts so that the public can be fully informed and offer substantive comments.

Commercial space launches in the National Airspace System

Safety is paramount and must be the primary consideration regarding integration of commercial space operations into the NAS. AOPA recognizes the FAA has a congressional mandate to ensure that commercial space launches provide a sufficient level of safety for all users of the NAS. However, the FAA must ensure that Temporary Flight Restrictions (TFR) are justified and minimized to what is necessary for the safety of the NAS. AOPA has regularly gone on record since the early 2000s noting our serious concerns with any long-term strategy that would rely on TFRs for air traffic separation to accommodate commercial space operations given the negative impact they have on routine operations.

AOPA encourages the FAA to leverage the industry recommendations submitted by the Airspace Access Priorities Aviation Rulemaking Committee (ARC) and Spaceport Categorization ARC to ensure commercial space transportation occurs seamlessly within the NAS. There are many opportunities for existing practices to be optimized to limit airspace closures. Depending on the risk contour of the launch, manned aircraft may be able to safety transit a TFR by maintaining a minimum speed or by flying a set route, which would minimize any exposure to the hazard while mitigating the adverse effects of the TFR. It is important the FAA leverage the consensus recommendations made in the ARCs to find effective solutions for all airspace users.

Letter of Agreements are opaque and not publicly available

The Draft EA states the proponent would enter into a Letter of Agreement (LOA) with the FAA in advance of launch operations:

> "SpaceX would negotiate and enter into Letters of Agreement (LOA) with relevant Air Traffic Control facilities…to accommodate the flight parameters of the integrated launch system. These LOAs would call for and define procedures for Air Traffic Control to issue a NOTAM defining the affected airspace…prior to launch. A NOTAM provides notice of unanticipated or temporary changes to components of, or hazards in, the National Airspace System (FAA Order JO 7930.2M, Air Traffic Policy)."

It is not clear why this LOA cannot be included or discussed within the Draft EA when its contents would directly pertain to the environmental (airspace) impact of these operations on the public. The LOA process itself is opaque to other airspace users in that this document is negotiated directly between the FAA and the proponent with no external review or comment. The LOA is also not publicly available for review after it is signed except through a Freedom of Information Act (FOIA) request.

The contents of the LOA affect other airspace users and would provide valuable information on the launch process, airspace restrictions, and mitigations put in place. The FAA's decision to not include this information in the Draft EA for public review is part of a troubling trend of blindfolding the public during opportunities to weigh in on foreseeable airspace restrictions that will affect the environment and have economic impact on the public. We contend environmental studies conducted under NEPA for establishing large recurring airspace restrictions must include a discussion regarding the full impact to general aviation. The FAA must provide this information to the public in a transparent fashion.

The FAA further states in the Draft EA:

> "…temporary closures of existing airspace…would be necessary to ensure public safety during launch operations. Advance notice via NOTAMs…would assist general aviation pilots…in scheduling around any temporary disruption of flight…activities in the area of operation. Launches would be of short duration and scheduled in advance to minimize interruption to airspace and waterways. For these reasons, significant environmental impacts of the temporary closures of airspace and waterways, and the issuance of NOTAMS…under the Proposed Action, are not anticipated. Moreover, in accordance with FAA Order 1050.1F, Paragraph 5-6.1 (Categorical Exclusions for Administrative/General Actions), issuance of NOTAMs are categorically excluded from NEPA review, absent extraordinary circumstances."

We disagree that these temporary airspace closures "of short duration" should be administratively dismissed via a categorical exclusion and not discussed in the Draft EA. The proposal discusses a significant ramp up of launch and reentry operations such that airspace closures will be more frequent. The FAA's text fails to mention how large vertically and laterally the airspace restrictions are for space launches and how a significant number of civil flights can be affected by any one launch. Airspace closures of limited duration on the Florida coast, which is one of the busiest general and commercial aviation corridors in the country, have a significant impact. These airspace closures are usually from the surface to unlimited and can be tens of nautical miles in radius.

AOPA is concerned that the Draft EA does not adequately assess the airport and airspace impacts that commercial space launches will have on general aviation flight operations. With airspace and airport closures likely for some launch operations, this Draft EA is woefully inadequate at articulating what general aviation operators and local communities can expect. The publication of a NOTAM is mentioned but there are no details on what the NOTAM might consist of, or how far in advance these notices will be published. The FAA must address these gaps in information to ensure other airspace users are fully informed as to what the launch operations mean in terms of airport and airspace access and efficiency.

There would be an excessive economic hardship for those who need to detour, delay, or divert due to airspace or airport restrictions that could be as frequent as what is proposed in the Draft EA. Implementing TFRs that restrict general aviation operations has significant environmental consequences on the communities, businesses, and airports that this airspace overlies and on the aircraft operators themselves. Adverse impacts include economic disruption, increasing costs, shifting of aircraft routes, and limitations on the public's freedom to fly. These impacts must be identified and calculated in the draft EA. The communication of airport and airspace restrictions may also not be transmitted clearly to pilots, which would exacerbate the impact, as there is minimal information in the Draft EA that discusses this aspect. Bottom line, we do not believe integration of commercial space operations should happen at the expense of other airspace users.

Southern launch route concerning

The FAA's Draft EA outlines a proposed southern launch trajectory that would bring the rocket parallel to the east coast of Florida in order to support polar orbits. The FAA documentation is silent on what this route means as far as airspace impacts and simply states:

> "…until SpaceX completes the LOA with Air Traffic Control for a southern launch trajectory that identifies any temporary airspace closures prior to launch, the FAA will not have the information necessary to determine the existence of any extraordinary circumstances deriving from such an LOA. The FAA would analyze any extraordinary circumstances and associated impacts before finalizing the operator LOA to the extent necessary under NEPA."

This limited information is totally insufficient for the public to understand the significant airspace closures that may be required to accommodate such an operation from KSC and CCAFS. For example, AOPA anticipates this trajectory may require certain airports to be unavailable, all traffic between the Caribbean and Florida to cease, and all domestic north- and southbound traffic to be moved inland, which would cause flight delays and increased costs for civil aviation. Each event will be highly public and result in considerable workload for air traffic control. As the Draft EA does not contain enough information to understand the extent and magnitude of the airspace closures, we must go off what existing airspace closures look like, which makes this trajectory highly concerning.

We are concerned about the possibility of routine launches along this southern trajectory taking place from KSC and CCAFS. The Florida coast is the home of many large flight training operations and general aviation airports. The impact of shutting down these operations, even if for just several days a year, would be an economic impact that the FAA must assess as part of the NEPA process.

Conclusion

AOPA recognizes the importance of commercial space operations and is supporting their integration by participating in the FAA ARCs and other FAA sponsored working groups. We believe the various ARC recommendations could help inform a seamless integration and further support the case not to implement airspace and airport restrictions.

As provided, this Draft EA is too ambiguous for us to fully detail the potential impact any airport or airspace restrictions will have on general aviation in this area of the country. Due to the lack of details, the FAA must fully examine the potential impacts of the proposed increase in launch operations and establishment of a southern route on general aviation operations before entering into a final agreement, and, should there be an adverse effect expected, allow the public an opportunity to comment.

Thank you for reviewing our comment on this important issue. Please feel free to contact me at 202-509-9515 if you have any questions.

Sincerely,

Rune Duke
Senior Director, Airspace, Air Traffic, and Aviation Security

The Aircraft Owners and Pilots Association (AOPA) is a not-for-profit individual membership organization of General Aviation Pilots and Aircraft Owners. AOPA's mission is to effectively serve the interests of its members and establish, maintain and articulate positions of leadership to promote the economy, safety, utility, and popularity of flight in General Aviation aircraft. Representing two-thirds of all pilots in the United States, AOPA is the largest civil aviation organization in the world.

Airlines for America®

We Connect the World

March 20, 2020

Mr. Daniel Czelusniak
Environmental Protection Specialist
Federal Aviation Administration
800 Independence Avenue, SW, Suite 325
Washington, DC 20591

Submitted Electronically via FAAFalconProgramEA@icf.com

Re: Comments on Draft Environmental Assessment for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station

Dear Mr. Czelusniak:

Airlines for America (A4A),[1] the principal trade and service organization of the U.S. airline industry, appreciates the opportunity to provide comments on FAA's Draft Environmental Assessment (EA) for SpaceX Falcon Launches at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). While appreciating the work FAA put into the Draft EA, A4A nonetheless find the Draft EA to be deficient because FAA has not completed necessary assessments of the environmental impacts from holding and re-routing commercial air traffic away from closed airspace during the proposed commercial space launch and reentry activities. This appears to stem from FAA's failure to address key questions regarding integration of the proposed launches in the existing National Airspace System, which should be a condition precedent to proceeding with and necessary to properly conducting the EA.

Currently, SpaceX has licenses to (1) launch Falcon 9 from CCAFS through January 18, 2023; (2) launch Falcon 9 and Falcon Heavy from KSC through February 14, 2024; and (3) allow for reentry of Dragon from Earth orbit through October 1, 2020. The previous environmental reviews associated with these launch licenses accounted for up to 12 annual launches and landings at CCAFS, up to 10 annual launches and landings at KSC, and up to 6 annual Dragon landings through 2020.[2] SpaceX's newly Proposed Action that FAA's Draft EA aims to assess includes (1) increasing Falcon 9/Heavy and Dragon launch and reentry rates for the years 2020–25, (2) creating a new Falcon 9 southern launch trajectory, and (3) constructing and using a new mobile service tower at KSC's launch site.[3]

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[1] A4A's members are: Alaska Airlines, Inc.; American Airlines Group; Atlas Air, Inc.; Delta Air Lines, Inc.; Federal Express Corporation; Hawaiian Airlines; JetBlue Airways Corp.; Southwest Airlines Co.; United Continental Holdings, Inc.; and United Parcel Service Co. Air Canada is an associate member.

[2] Draft EA at 26. While the environmental review for Dragon landings also analyzed for up to 12 Dragon landings in 2021–2024, the Dragon landing license only allows for reentry through October 1, 2020. As a result, those statistics are not included here.

[3] *Id.* at 1. As A4A's main concern is relative to the launch and reentry of SpaceX's proposed operations, we do not address the proposed action to construct and use a mobile service tower at KSC. At any rate, the Draft EA does not assess the environmental consequences of this action.

As an initial matter, the Draft EA does not accurately describe the scope of the Proposed Action. Given SpaceX's current licenses to launch its vehicles, the Proposed Action is not simply to increase launch and reentry rates for the years 2020–25 but add additional routes and new types of operations. SpaceX's current licenses have staggered expiration dates that would limit launches in 2024 and provide for *no* launches in 2025. In addition, the Proposed Action includes creating a *new* southern launch trajectory. As a result, the Proposed Action for the Draft EA is really to *extend* and expand the launch and reentry rates for the years 2020–25.

As it pertains to increasing the number of total annual launches from KSC and CCAFS for Falcon 9/Heavy and Dragon missions, the Draft EA assesses a dramatic increase in launches from an annual average of 11 launches from 2015 through 2019 to 38 launches in 2020, 64 annual launches in 2021 and 2022, and 70 annual launches for 2023–25.[4] Moreover, 75 percent of these launches will include boost-back and landing.[5]

While the Draft EA purports to account for the noise and emissions impacts of the Proposed Action, it does not assess the attendant environmental impacts or consequences from the need to hold and re-route aircraft around the restricted airspace during these launches. The Draft EA notes that Notices to Airmen would necessarily be issued to accommodate the launches in the National Airspace System (NAS), yet FAA has not included an assessment of the clear environmental impacts that would come from having to hold and re-route aircraft during the time of the launch restrictions. Holding aircraft will result in aircraft circling nearby airports, and grounded aircraft enduring tarmac delays, each of which would increase noise and emissions. Moreover, re-routing aircraft will result in longer flight paths that will increase emissions and potentially noise impacts should aircraft be routed over more populated areas that commercial space operations much avoid. These impacts could very well have significant environmental consequences particularly considering the increased number of annual launches SpaceX has proposed; 64–70 launches per year for 2021 through 2025 equates to 5–6 launches per month or *at least* one launch per week each year, yet FAA did not assess the potential environmental impacts from the Proposed Action's very real effect on NAS operations.

Furthermore, the Proposed Action expects 75 percent of these launches to include boost-back and landing, which would lengthen the amount of time airspace is restricted. By way of example, A4A members and the traveling and shipping public experienced dramatic negative impacts during the February 6, 2018 launch of the SpaceX Falcon 9 Heavy rocket. That launch required a six-hour closure of a massive volume of airspace off the east coast of Florida during the active afternoon and early evening period. More than 600 aircraft were delayed and issued alternative routes, resulting in additional distance flown of approximately 35,000 miles. The residual traffic flow management impacts were exponential. During this launch, both side boosters performed their boost-back simultaneously,[6] so it appears that the observed impact on commercial aviation on February 6th could occur 3–4 times (or 75% of the total launches) every month from 2021 through 2025.

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[4] *Id.* at 16.

[5] *Id*. at 21.

[6] Chris Gebhardt, NASA Spaceflight.com, "SpaceX successfully debuts Falcon Heavy in demonstration launch from KSC" (Feb. 5, 2018), https://www.nasaspaceflight.com/2018/02/spacex-debut-falcon-heavy-demonstration-launch/.

Similarly, the Draft EA notes that the new southern launch trajectory, which could be used in up to 10 percent of launches, will increase the potential fairing splashdown area.[7] Increasing the area in which the payload fairing may land means that the airspace closed for the launch operations will be that much larger further exacerbating the potential environmental effects from additional holding and re-routing of aircraft.

Likewise, the totals provided in Table 2-2 of the Draft EA[8] reflect the number of *launches* while Dragon missions included in those totals would also need restricted airspace to allow for Dragon reentry. The number of Dragon reentries are estimated to be 6 reentries in 2020, 7 in 2021, and 10 annually for 2022–25.[9] These reentry operations will require the closure at least 92 square nautical miles.[10] While the restricted airspace requirements of the reentry may vary in time and space from the launch requirements, they nonetheless will be similarly disruptive to the NAS, increasing noise and emissions from commercial aviation operations an additional 6–10 times per year through 2025.

FAA's failure to include in the Draft EA an analysis of the environmental effects of holding and rerouting aircraft due to the launches at issue renders the Draft EA fatally flawed. FAA cannot properly separate these environmental effects from the launches subject to FAA approval nor can FAA defer any such analysis until the agency develops the expected Notices to Airmen or otherwise, because the launches and the airspace effects are connected and/or cumulative actions with cumulative impacts that the NEPA regulations require be considered together.[11] Because the Draft EA does not assess the attendant noise and emissions impacts of the Proposed Action from its effects on NAS operations, FAA cannot proceed until it takes appropriate actions to correct this error.

Beyond FAA's lack of environmental review of the Proposed Action's impact on the NAS, A4A is even more concerned that FAA has proceeded with this environmental analysis and approval process for the Proposed Action without answering critical questions about the Proposed Action's integration with existing NAS operations. The assessment of the Proposed Action in the Draft EA appears to be devoid of any consideration of airspace efficiency, which is critical to minimize adverse operational and financial impacts resulting from prolonged closures of airspace necessary for commercial space launches. In addition to adverse environmental impacts, commercial space operations impose substantial costs on airlines, their passengers, cargo shippers, the public, and the U.S. economy, including:

- Additional operating costs for increased flight distances and times resulting from re-routing aircraft, including additional airline resources to plan/manage events, flight crew, and maintenance.
- Denied boarding compensation for passengers that are denied boarding as a result of aircraft weight restrictions when additional fuel is required for longer routes.

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[7] Draft EA at 16–17.
[8] *Id.* at 16.

[9] *Id.* at 25–26.

[10] *Id*. at 23.

[11] *See* 40 CFR § 1508.25(a); see also FAA Order 1050.1F, Policies and Procedures for Considering Environmental Impacts, at § 2-3.2(b).

- Passenger and airline costs resulting from impacts to flights and passengers that are not re-routed around the commercial space operation, but are otherwise impacted by the resulting NAS congestion—e.g., flight delays, flow controls, gate and slot availability, and reduced on-time performance.
- Increased employment costs resulting from crew scheduling changes, including from limitations on flight and duty times.
- Increased passenger costs as a result of impacted passenger travel, including time lost from delayed flights, flight cancellations, and missed connections
- Lost revenue from decreased demand due to passengers avoiding air travel as a result of longer flights, lack of predictability, delays, cancellations, and missed connections.
- Costs from delayed cargo and package delivery for the public and businesses.
- Lost productivity for business travelers and increased costs of doing business for other sectors.

The FAA should address these identified issues, omissions, and concerns before finalizing its NEPA documentation. A4A further suggests that it would be more beneficial for FAA to undertake a number of actions before proceeding with any licensing decision on the Proposed Action. FAA should first formalize time-based launch procedures under development by the Joint Space Operations Group (JSpOG) located at the Air Traffic Control System Command Center. Likewise, FAA should mature the Space Data Integrator (SDI) and the Hazard Risk Assessment Management (HRAM) system or other technologies that improve existing procedures, the development of new procedures, ATC surveillance and tracking capabilities including Space-based ADS-B in FAA oceanic airspace, and automated depictions of hazardous areas to improve the FAA's ability to more efficiently manage traffic in response to increases in commercial space activity as suggested by the Proposed Action.

A4A also recommends FAA move forward with programs to ensure safe commercial space integration with the NAS including the improvement of existing procedures; the development of new procedures to improve launch planning; the creation of air traffic control surveillance and tracking capabilities to include automated depictions of hazard areas and launch vehicles; improved and uniform hazard mitigation policies; and two-way communications. These tools will help the FAA achieve the sought-after integration of commercial space with the NAS while minimizing environmental impacts.

* * *

Thank you in advance for your consideration of these comments on FAA's Draft EA. We would be pleased to provide any additional information or answer any questions FAA may have as it proceeds on this matter.

Sincerely,

Nancy N Young

Nancy Young
Vice President, Environmental Affairs

From: Tony Rome
To: FAAFalconProgramEA
Subject: Draft Environmental Assessment for SpaceX Launch Licenses
Date: Monday, March 2, 2020 1:34:25 PM
Attachments: ~~DraftEAR.txt~~

The Draft EA is now available for public review and comment.

Comments should be mailed to Mr. Daniel Czelusniak, Environmental Protection Specialist, Federal Aviation Administration, 800 Independence Avenue, SW, Suite 325, Washington, DC 20591. Comments may also be submitted by email to FAAFalconProgramEA@icf.com.

Environmental Documents in Progress

In Progress: Draft Environmental Assessment for SpaceX Launch Licenses at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Florida

Please find the attached file;DraftEAR.txt
I could not find;
FONSI (FAA 2016)
issued FONSIs (FAA 2009, 2013)
FONSI (FAA 2015)

Anthony Intravaia
234 Houghton Street
Mountain View, Ca
94041.
6505752534.

The Draft EA is now available for public review and comment.
Comments should be mailed to Mr. Daniel Czelusniak, Environmental Protection Specialist, Federal Aviation Administration, 800 Independence Avenue, SW, Suite 325, Washington, DC 20591. Comments may also be submitted by email to FAAFalconProgramEA@icf.com.

From: Anthony Intravaia
234 Houghton Street
Mountain View, California
94062
6505752534.

Sections;
****
Comments
****

1.3.2. Cooperating Agencies
As defined in 40 CFR §1508.5, a cooperating agency may be any federal agency other than the lead agency that has jurisdiction by law or special expertise with respect to the environmental impacts expected to result from a proposal. An agency has "jurisdiction by law" if it has the authority to approve, veto, or finance all or part of the proposal (40 CFR §1508.15). An agency has "special expertise" if it has statutory responsibility, agency mission, or related program experience with regards to a proposal (40 CFR §1508.26). A lead agency must request the participation of cooperating agencies as early as possible in the NEPA process, use the environmental analyses and proposals prepared by cooperating agencies as much as possible, and meet with cooperating agencies at their request (40 CFR §1501.6[a]).

The FAA requested the participation of NASA and the USAF (45th Space Wing) as cooperating agencies in the preparation of this EA due to their jurisdiction by law and special expertise. LC-39A is located on KSC property and the KSC Director has ultimate responsibility for all operations and improvements that occur on KSC property. Additionally, NASA provides special expertise with respect to environmental issues concerning space launch vehicles, especially crewed capsules like the Dragon-2. LC-40 is located at CCAFS, which is controlled by the 45th Space Wing. The 45th Space Wing has a special interest and specific expertise with regards to all activities located at CCAFS. The 45th Space Wing also has interest in managing their local environmental related activities performed by the growing number of tenants at CCAFS who may be affected by any proposed actions.

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The comments on the above paragraph, The Lead agency is FAA? The cooperating agency is the NASA/DOD?
The facilities are US Government that are leased via the NASA Space act agreements; The agreements should be referenced in the Draft Environmental Assessment (EA)
https://www.nasa.gov/sites/default/files/atoms/files/house_approps_action_domestic_nonfed_saas_active_as_of_12-31-2019.pdf

638 30261 SPACE EXPLORATION TECHNOLOGIES CORP Annex No. 17 to Fully Reimbursable Space Act Umbrella Agreement between NASA and Space Exploration Technologies Corporation for Use of Kennedy Space Center Capabilities 5/21/2019 9/30/2020 Reimbursable ----- KSC KCA-4513-17 Rev Basic

624 30997 SPACE EXPLORATION TECHNOLOGIES CORP Annex No. 18 to Fully Reimbursable Space Act Umbrella Agreement between NASA and Space Exploration Technologies Corporation for Use of Kennedy Space Center Capabilities 9/16/2019 9/30/2022 Reimbursable ----- KSC KCA-4513-18 Rev Basic

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3. AFFECTED ENVIRONMENT
This chapter provides a description of the environmental impact categories that have the potential to be affected by the Proposed Action, as required by FAA Order 1050.1F. The environmental impact categories assessed in detail in this EA include air quality; biological resources; climate; coastal resources; Department of Transportation Act Section 4(f); hazardous materials, solid waste, and pollution prevention; land use; natural resources and energy supply; noise and noise-compatible land use; socioeconomics; visual effects (including light emissions); and water resources (surface waters and groundwater). In

accordance with 40 CFR §1502.15 and Paragraph 6-2.1.e of FAA Order 1050.1F, the level of detail provided in this section is commensurate with the importance of the potential impact on the environmental impact categories. The following environmental impact categories are not analyzed in detail for the reasons stated:

- LC-39A: The 2013 NASA EA for the multi-use of LC-39A and LC-39B (NASA 2013). The FAA was a cooperating agency in the preparation of this EA and issued a FONSI (FAA 2016) to support issuing launch licenses to SpaceX for Falcon 9 and Falcon Heavy launch operations at LC-39A.
- LC-40 and Dragon Recovery in Atlantic and Pacific Oceans: The 2007 USAF EA and 2013 USAF SEA for Falcon 9 and Falcon Heavy launch operations at LC-40, including Dragon recovery in the Atlantic Ocean or Pacific Ocean (USAF 2007, 2013). The FAA was a cooperating agency in the preparation of the 2007 USAF EA and 2013 USAF SEA and issued FONSIs (FAA 2009, 2013) to support issuing licenses to SpaceX for Falcon 9 and Falcon Heavy launch operations at LC-40 and Dragon reentry.
- LZ-1: The 2014 USAF EA for Falcon 9 first stage boost-back and landing at LZ-1 (formerly called LC-13) (USAF 2014). The FAA was a cooperating agency in the preparation of the 2014 USAF EA and issued a FONSI (FAA 2015) to support issuing launch licenses to SpaceX for Falcon 9 first stage boost-back and landing at LZ-1.

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The FONSIs referenced are not included or made available for the reviewer. The following environmental impact categories are not analyzed in detail for the reasons stated: I do read any reasons except for FONSI issued.

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3.3. Air Quality
This section describes air quality resources for KSC and CCAFS at altitudes below 3,000 feet, which contain the atmospheric boundary layer. The Earth's atmosphere consists of five main layers: the troposphere, stratosphere, mesosphere, ionosphere, and exosphere. For the purposes of this EA, the lower troposphere is defined as at or below 3,000 feet above ground level (AGL), which the U.S. Environmental Protection Agency (EPA) accepts as the nominal height of the atmosphere mixing layer in assessing contributions of emissions to ground-level ambient air quality under the Clean Air Act (CAA) (EPA 1992). Although Falcon 9 launch vehicles and Dragon emissions from operations at or above 3,000 feet AGL would occur, these emissions would not result in appreciable ground-level concentrations. Since the Falcon launch vehicle program occurs at both KSC and CCAFS, and the proposed Dragon reentry, splashdown, and recovery operations would primarily occur in Atlantic Ocean, Pacific Ocean, Port Canaveral, Florida, and Port of Los Angeles, California, the study area for air quality is Brevard County, Florida and Los Angeles County, California.

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Why is Los Angeles County, California part of the Draft EA?

****

Virgin Galactic's space tourism spinoff company, Virgin Orbit, has developed LauncherOne to serve the small-satellite industry. LauncherOne is a two-stage, expendable, LOX/RP-1 rocket that launches from a dedicated 747-400 carrier aircraft named Cosmic Girl. It may operate from multiple locations including KSC. LauncherOne will be capable of placing a 661-pound payload into a sun-synchronous orbit and a 992-pound payload into an equatorial orbit. LauncherOne will be able to launch polar and sun-synchronous missions from approximately 50 miles off the west coast of Los Angeles, California, and a similar distance off the east coast of Cape Canaveral, Florida, for equatorial missions (Virgin Orbit 2017).

****

why is Virgin Galactic's referenced in the draft EA? Why is west coast of Los Angeles, California referenced?

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3.11. Hazardous Materials, Solid Waste, and Pollution Prevention
Hazardous materials, solid waste, and pollution prevention as an impact category includes an evaluation of the following:

- waste streams that would be generated by a project, potential for the wastes to impact environmental resources, and the impacts on waste handling and disposal facilities that would likely receive the wastes;

- potential hazardous materials that could be used during construction and operation of a project, and applicable pollution prevention procedures;
- potential to encounter existing hazardous materials at contaminated sites during construction, operation, and decommissioning of a project; and
- potential to interfere with any ongoing remediation of existing contaminated sites at the proposed project site or in the immediate vicinity of a project site.

Solid Waste is defined by the implementing regulations of the Resource Conservation and Recovery Act (RCRA) generally as any discarded material that meets specific regulatory requirements, and can include such items as refuse and scrap metal, spent materials, chemical by-products, and sludge from industrial and municipal waste water and water treatment plants (see 40 CFR § 261.2 for the full regulatory definition).

Hazardous waste is a type of solid waste defined under the implementing regulations of RCRA. A hazardous waste (see 40 CFR § 261.3) is a solid waste that possesses at least one of the following four characteristics: ignitibility, corrosivity, reactivity, or toxicity as defined in 40 CFR part 261 subpart C, or is listed in one of four lists in 40 CFR part 261 subpart D, which contains a list of specific types of solid waste that the U.S. EPA Environmental Assessment for SpaceX Falcon Launch Vehicle at KSC and CCAFS has deemed hazardous. RCRA imposes stringent requirements on the handling, management, and disposal of hazardous waste, especially in comparison to requirements for non- hazardous wastes.

Hazardous substance is a term broadly defined under Section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (see 42 U.S.C. § 9601(14)). Hazardous substances include:

- any element, compound, mixture, solution, or substance designated as hazardous under Section
- 102 of CERCLA;
- any hazardous substance designated under Section 311(b)(2)(A) or any toxic pollutant listed under
- Section 307(a) of the Clean Water Act (CWA);
- any hazardous waste under Section 3001 of RCRA;
- any hazardous air pollutant listed under Section 112 of the CAA; and
- any imminently hazardous chemical substance or mixture for which the EPA Administrator has “taken action under” Section 7 of the Toxic Substances Control Act (TSCA).

The definition of hazardous substances under CERCLA excludes petroleum products, unless specifically listed or designated there under.

Hazardous material is any substance or material that has been determined to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce. The term hazardous materials includes both hazardous wastes and hazardous substances, as well as petroleum and natural gas substances and materials (see 49 CFR § 172.101).

Pollution prevention describes methods used to avoid, prevent, or reduce pollutant discharges or emissions through strategies such as using fewer toxic inputs, redesigning products, altering manufacturing and maintenance processes, and conserving energy.

The study area for hazardous materials, pollution prevention, and solid waste is CCAFS, KSC, the Port Canaveral, CCAFS wharf facilities, the Port of Los Angeles, and Atlantic Ocean and Pacific Ocean recovery areas which could be affected by the materials transported, stored, and used; waste generated; or spills/releases that may occur during launch operations, landings, and recovery. KSC and CCAFS each have their own pollution prevention programs. SpaceX is compliant with those programs and also strives to prevent and reduce various forms of pollution.

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https://www.militarytimes.com/2019/07/14/heres-an-updated-map-of-military-sites-where-dod-found-cancer-causing-chemicals-in-the-drinking-water/

Can you please include the FONSIs for references?

****

3.11.2.2. Pollution Prevention

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes and was adopted at the International Maritime Organization in 1973. The Convention includes regulations aimed at preventing and minimizing pollution from ships, both accidental pollution and that from routine operations, and currently includes six technical Annexes. Special Areas with strict controls on operational discharges are included in most Annexes. Annex I covers prevention of pollution by oil from operational measures as well as from accidental discharges. Annex II details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk. Annex III contains general requirements for the issuing of detailed standards on packing, marking, labeling, documentation, stowage, quantity limitations, exceptions and notifications. Annex IV contains requirements to control pollution of the sea by sewage. Annex V deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed. Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances.

Large commercial vessels routinely discharge ballast water, gray and black water, bilge water, and deck runoff consistent with applicable international and national standards. Discharges of sewage (also known as black water) and gray water, which is the effluent generated from wash basins and showers on board ships, are regulated under MARPOL Annex IV. Discharges of black water are prohibited except for specific conditions stipulated under the Annex. In addition to the international standards established under MARPOL Annex IV, the U.S. regulates vessel discharges of sewage, gray water, bilge water, and a variety of other vessel discharges through the EPA's Clean Water Act (CWA) NPDES Program.

Port Canaveral Port Authority has conducted a voluntary water quality monitoring program since 1992, regularly analyzing water samples from six stations in the Harbor and five stations in the Barge Canal. This enables the identification of short-term fluctuations and long-term trends in water quality. Water is regularly sampled from Port stormwater outfalls. Efforts to decrease contaminants include sweeping piers after cargo operations, cleaning pipes, installing stormwater treatment boxes and educating tenants on managing potential pollutants.

The Port also monitors water quality along the beaches south of the Port. In 2005, a study funded by the Port Authority and Brevard County and carried out by NOAA concluded there was no evidence of a water quality problem in the form of elevated bacteria or nutrient levels along these beaches. However, to Environmental Assessment for SpaceX Falcon Launch Vehicle at KSC and CCAFS increase available data and maintain water quality, additional monitoring stations have been added (Port Canaveral 2018).

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why is the discussion included? What does this have to do with the space act agreements for SpaceX. The FAA/NASA/DOD?

****

Baker, Nicholas

From: Baker, Nicholas
Sent: Thursday, March 19, 2020 11:03 AM
To: Baker, Nicholas
Subject: State Clearance Letter For FL202002258855C - Draft Environmental Assessment For SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station, Brevard County, Florida

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From: Stahl, Chris <Chris.Stahl@dep.state.fl.us>
Sent: Thursday, March 19, 2020 10:50 AM
To: Czelusniak, Daniel (FAA) <Daniel.Czelusniak@faa.gov>
Cc: State_Clearinghouse <State.Clearinghouse@dep.state.fl.us>; LONG, EVA M CIV USSF SPOC 45 CES/CEIE <eva.long@us.af.mil>
Subject: State Clearance Letter For FL202002258855C - Draft Environmental Assessment For SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station, Brevard County, Florida

March 19, 2020

Daniel A. Czelusniak
Federal Aviation Administration
Office of Commercial Space Transportation
800 Independence Avenue S.W., Suite 331
Washington, DC 20591

RE: Federal Aviation Administration - Environmental Assessment - Draft Environmental Assessment For SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station, Brevard County, Florida
SAI # FL202002258855C

Dear Daniel:

Florida State Clearinghouse staff has reviewed the proposal under the following authorities: Presidential Executive Order 12372; § 403.061(42), Florida Statutes; the Coastal Zone Management Act, 16 U.S.C. §§ 1451-1464, as amended; and the National Environmental Policy Act, 42 U.S.C. §§ 4321-4347, as amended.

Based on the information submitted and minimal project impacts, the state has no objections to the subject project and therefore it is consistent with the Florida Coastal Management Program (FCMP). The state's final concurrence of the project's consistency with the FCMP will be determined during any environmental permitting processes, in accordance with Section 373.428, Florida Statutes, if applicable.

Thank you for the opportunity to review the proposed plan. If you have any questions or need further assistance, please don't hesitate to contact me.

Sincerely,

Chris Stahl

Chris Stahl, Coordinator
Florida State Clearinghouse
Florida Department of Environmental Protection
2600 Blair Stone Road, M.S. 47
Tallahassee, FL 32399-2400
ph. (850) 717-9076
State.Clearinghouse@dep.state.fl.us

From:	Jack Kennedy
To:	FAAFalconProgramEA
Subject:	Draft Environmental Assessment for SpaceX Launch Licenses at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), Florida
Date:	Sunday, May 10, 2020 2:43:38 PM

Dear FAA Falcon Program Reviewer:

PLEASE take official note of my support for issuance of launch licenses to launch the Falcon 9 and Falcon Heavy from KSC Launch Complex 39A (LC-39A) and CCAFS Launch Complex 40 (LC-40). In addition thereto, my strong support for issuance to SpaceX FAA for reentry licenses for Dragon reentry operations at LZ-1 and LZ-2 as may be deemed necessary and appropriate for civil, commercial and military operations.

SpaceX is essential to the modernization of human spaceflight and expansion of commercial space activities off-Earth in this decade. The US Department of Transportation generally, and the FAA specifically, need to issue all the necessary flight launch and landing permits that may be required while reasonably mitigating risk to public safety within a 3-to-5-mile radius of launch and landing operations as if time is of the essence.

Expanding the opportunity to return to land at Cape Canaveral is of particular economic interest to those touting the Space Coast as a hub of advancing flight technology. In short, "seeing is believing" leading to more significant investment in the sector and attracting more visitors and infrastructure investment directly and indirectly associated with FAA regulatory activities. Any delay hinders economic growth of the region and human expansion in building the necessary on-Earth and off-Earth infrastructure needed to expand American national security and economic influence. The environmental degradation appears minimal, especially balanced against the overall public good and the global commons.

Therefore, after review of the associated published FAA documents, I strongly urge the FAA to issue the launch and landing license for Kennedy Space Center and Cape Canaveral Air Force Station operations requested by SpaceX to continue to expand utilization of Launch Complex 39A for Falcon 9, Falcon Heavy and Starship on Kennedy Space Center and SpaceX expanded utilization of Launch Complex 40 and Landing Zones 1 and 2 on Cape Canaveral.

Thank you for accepting my public input for issuance of the FAA licenses referenced.

AdLuna2024!

Jack Kennedy, Esq., M.S., M.A.
Wise, Virginia 24293-3444
[276] 275.4700 (cellular)

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FAA Responses to the Comments

Air Line Pilots Association, International (ALPA)

Section 2.1.2 Falcon Launch Operations at LC-39A, LC-40, LZ-1, and LZ-2

Regarding Letters of Agreements (LOAs), Eastern Range operations (which includes SpaceX's launches from Kennedy Space Center [KSC] and Cape Canaveral Air Force Station [CCAFS]) currently follow the procedures stated in a LOA (dated May 1, 2020) between the U.S. Air Force (USAF) 45th Space Wing (SW) and FAA. This agreement cancels the previous Eastern Range LOA (dated September 8, 2014). The LOA establishes responsibilities and describes procedures for the 45th SW, Eastern Range operations, within airspace common to the Miami Center, Jacksonville Center, New York Center, San Juan Center Radar Approach Control, Central Florida Terminal Radar Approach Control, National Aeronautics and Space Administration (NASA) Shuttle Landing facility, Fleet Area Control and Surveillance Facility Jacksonville, Air Traffic Control System Command Center, and Central Altitude Reservation Function areas of jurisdiction. The LOA defines responsibilities and procedures applicable to launch operations, which require the use of Restricted Areas, Warning Areas, Air Traffic Control Assigned Airspace (ATCAA), and/or Altitude Reservation within Eastern Range airspace. A separate LOA dated October 1, 2015 between SpaceX, 45th SW, FAA, and Fleet Area Control and Surveillance Facility (FACSFAC), San Diego, covers reentry operations. The FAA appreciates the request for other stakeholders to participate in the airspace planning processes specific to commercial space operations. The FAA recognizes that the Airspace Access Priorities Aviation Rulemaking Committee (ARC) concluded with similar recommendations. The FAA intends to continue to work with all stakeholders to advance the work of the ARC.

Extraordinary circumstances are factors or circumstances in which a normally categorically excluded action may have a significant environmental impact that then requires further analysis in an EA or an EIS. An extraordinary circumstance exists if a proposed action involves any of the following circumstances and has the potential for a significant impact:

1. An adverse effect on cultural resources protected under the National Historic Preservation Act of 1966, as amended, 54 U.S.C. §300101 et seq.;
2. An impact on properties protected under Section 4(f);
3. An impact on natural, ecological, or scenic resources of federal, state, tribal, or local significance (e.g., federally listed or proposed endangered, threatened, or candidate species, or designated or proposed critical habitat under the Endangered Species Act, 16 U.S.C. §§ 1531-1544);
4. An impact on the following resources: resources protected by the Fish and Wildlife Coordination Act, 16 U.S.C. §§ 661-667d; wetlands; floodplains; coastal zones; national marine sanctuaries; wilderness areas; National Resource Conservation Service-designated prime and unique farmlands; energy supply and natural resources; resources protected under the Wild and Scenic Rivers Act, 16 U.S.C. §§ 1271-1287, and rivers or river segments listed on the Nationwide Rivers Inventory; and solid waste management;
5. A division or disruption of an established community, or a disruption of orderly, planned development, or an inconsistency with plans or goals that have been adopted by the community in which the project is located;

6. An increase in congestion from surface transportation (by causing decrease in level of service below acceptable levels determined by appropriate transportation agency, such as a highway agency);
7. An impact on noise levels of noise sensitive areas;
8. An impact on air quality or violation of federal, state, tribal, or local air quality standards under the Clean Air Act, 42 U.S.C. §§ 7401-7671q;
9. An impact on water quality, sole source aquifers, a public water supply system, or state or tribal water quality standards established under the Clean Water Act, 33 U.S.C. §§ 1251-1387, and the Safe Drinking Water Act, 42 U.S.C. §§ 300f-300j-26;
10. Impacts on the quality of the human environment that are likely to be highly controversial on environmental grounds. The term "highly controversial on environmental grounds" means there is a substantial dispute involving reasonable disagreement over the degree, extent, or nature of a proposed action's environmental impacts or over the action's risks of causing environmental harm. Mere opposition is not sufficient for a proposed action or its impacts to be considered highly controversial on environmental grounds. Opposition on environmental grounds by a federal, state, or local government agency or by a tribe or a substantial number of the persons affected by the action should be considered in determining whether or not reasonable disagreement regarding the impacts of a proposed action exists;
11. Likelihood to be inconsistent with any federal, state, tribal, or local law relating to the environmental aspects of the proposed action; or
12. Likelihood to directly, indirectly, or cumulatively create a significant impact on the human environment, including, but not limited to, actions likely to cause a significant lighting impact on residential areas or commercial use of business properties, likely to cause a significant impact on the visual nature of surrounding land uses, likely to cause environmental contamination by hazardous materials, or likely to disturb an existing hazardous material contamination site such that new environmental contamination risks are created.

Please refer to FAA Order 1050.1F, Paragraph 5-2 for additional information on extraordinary circumstances.

Prior to every launch, the launch operator and the FAA conduct several hazard analyses, including 1) a launch site hazard area analysis, 2) downrange hazard area analysis, 3) an aircraft hazard area analysis, and 4) a ship hazard area analysis (see 14 CFR Part 400). These analyses include the possibility of a launch anomaly (e.g., catastrophic break-up) and are used to determine closure areas for the launch to ensure public safety.

Section 2.1.2.2 Payload Fairing Recovery Operations

SpaceX tracks when and where the drogue parachutes are released. After the drogue parachutes are released, SpaceX does not track them. SpaceX is unable to recover the drogue parachutes because of the wind profile from the point of drogue parachute release to the ocean surface, and the speed at which the drogue parachutes sink.

The NOTAMs published for SpaceX launches that include fairing recovery operations include the fairing recovery component of the launch and thus flight crews are aware of this potential hazard. The airspace remains closed until all hazards are gone.

Section 2.1.2.3 Boost Back and Landing

SpaceX tracks the radiosondes until the weather balloon pops. SpaceX only releases weather balloons for launch missions that involve a drone ship landing. The CCAFS Weather Squadron releases its own radiosondes during all other launch and landing operations. Note that weather balloons are released every day, multiple times a day, around the world by several entities, including the National Weather Service.

Section 4.5.1.2 Sonic Booms

A NOTAM is issued prior to all launches. Air Traffic Control prohibits aircraft within the identified airspace, including booster fly back and landing. This avoids the potential of an aircraft to be exposed to sonic boom levels that would result in an impact.

Aircraft Owners and Pilots Association (AOPA)

Thank you for your comments. The FAA works collaboratively to ensure a safe National Airspace System (NAS) for all airspace users. The FAA will continue to consider the recommendations made by the Airspace Access Priorities Aviation Rulemaking Committee (ARC) and Spaceport Categorization ARC. The ARCs were formed to provide stakeholder input to the FAA, which may inform future changes to the FAA regulations. However, the FAA must follow existing regulations when making a license determination.

Regarding Letters of Agreements (LOAs), the LOA itself does not contain information that directly pertains to the environmental (airspace) impact of these operations that is not already otherwise publicly available. Rather, it describes the terms and conditions that are used when making airspace closure decisions.

Eastern Range operations (which includes SpaceX's launches from KSC and CCAFS) currently follow the procedures stated in a LOA (dated May 1, 2020) between the 45th SW and FAA. This agreement cancels the previous Eastern Range LOA (dated September 8, 2014). The LOA establishes responsibilities and describes procedures for the 45th SW, Eastern Range operations, within airspace common to the Miami Center, Jacksonville Center, New York Center, San Juan Center Radar Approach Control, Central Florida Terminal Radar Approach Control, NASA Shuttle Landing facility, Fleet Area Control and Surveillance Facility Jacksonville, Air Traffic Control System Command Center, and Central Altitude Reservation Function areas of jurisdiction. The LOA defines responsibilities and procedures applicable to launch operations, which require the use of Restricted Areas, Warning Areas, Air Traffic Control Assigned Airspace (ATCAA), and/or Altitude Reservation within Eastern Range airspace. A separate LOA dated October 1, 2015 between SpaceX, 45th SW, FAA, and FACSFAC, San Diego, covers reentry operations.

For more information regarding airspace closures associated with commercial space launch operations and the potential environmental consequences from such closures, refer to Appendix E of the final EA.

Airlines for America (A4A)

Thank you for your comments. In response to your comments, an appendix was added to the final EA (see Appendix E). The appendix addresses airspace closures associated with commercial space launch operations and identifies the potential environmental consequences of such closures. Based on previous experience with commercial space launch operations at KSC and CCAFS, the FAA does not expect commercial space-related airspace closures would result in significant environmental consequences. As commercial space operations increase and new vehicles are developed, the FAA continues to explore ways to better manage airspace to increase the efficiency and capacity of the NAS for all users. The FAA's Air Traffic Organization is currently examining dynamic launch and reentry windows and time-based launch procedures to enable air traffic to move dynamically through airspace even when it is closed via a NOTAM. These procedures involve being in constant contact with the launch operator and knowing the status of a launch or reentry so the airspace can be used by aircraft as long as possible prior to the moment a rocket takes off or a reentry vehicle reenters Earth's atmosphere.

Anthony Intravaia

Section 1.3.2 Cooperating Agencies

Yes, the FAA is the lead federal agency preparing this EA. NASA and USAF (45th SW) are cooperating agencies. Section 1.2 of the EA states the location (i.e., CCAFS or KSC) of each launch complex that SpaceX uses for commercial launch operations. The U.S. Government owns the launch complexes and SpaceX has authority to operate the launch complexes under agreements with the U.S. Government.

Chapter 3 Affected Environment

Please see EA Chapter 8, *Literature Cited*, for links to the FONSIs (FAA 2009, 2013, 2015, and 2016. The FONSIs are posted on the FAA's website: https://www.faa.gov/space/environmental/nepa_docs/.

Section 3.3 Air Quality

Los Angeles County is part of the study area for the proposed action because SpaceX Dragon recovery operations occur within this county at the Port of Los Angeles.

Section 5.1 Projects Considered for Potential Cumulative Effects

The FAA must consider the potential cumulative impacts from the proposed action. The FAA identified Virgin Galactic's LauncherOne launch program as one of the reasonably foreseeable future actions that should be considered in the cumulative impacts analysis.

See response above regarding the inclusion of Los Angeles County in the study area.

Section 3.11 Hazardous Materials, Solid Waste, and Pollution Prevention

The FAA acknowledges the Military Times article provided by the commenter. Without a specific comment associated with the article, the FAA is unable to provide a response.

See response above regarding the FONSIs.

Section 3.11.2.2 Pollution Prevention

The FAA must consider the proposed action's potential environmental consequences associated with pollution prevention. Section 3.11.2.2 of the EA discusses the topic of pollution prevention in the study areas analyzed. Refer to Chapter 7 the FAA's Order 1050.1F Desk Reference for additional information regarding pollution prevention. The Desk Reference can be accessed on the FAA's website: https://www.faa.gov/about/office_org/headquarters_offices/apl/environ_policy_guidance/policy/faa_nepa_order/.

Florida State Clearinghouse

Thank you for your response.

Jack Kennedy

Thank you for your comments.

Appendix E

Airspace

E. AIRSPACE

E.1. Introduction

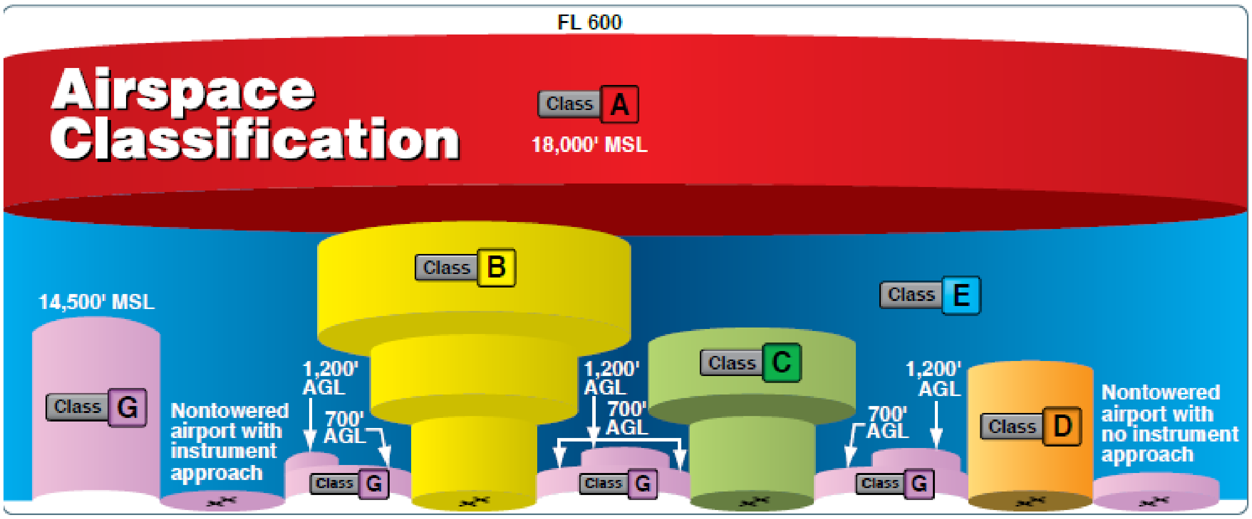
Airspace management considers how airspace is designated, used, and administered to best accommodate the individual and common needs of military, commercial, and general aviation. The FAA considers multiple and sometimes competing demands for airspace in relation to airport operations, federal airways, jet routes, military flight training activities, commercial space operations, and other special needs to determine how the National Airspace System (NAS) can be best structured to address all user requirements.

The FAA designs and manages the NAS based on the Code of Federal Regulations (CFR) (14 CFR Part 71). The FAA has designated four types of airspace above the United States: controlled airspace, Special Use Airspace (SUA), other airspace, and uncontrolled airspace.

- **Controlled airspace** is a generic term that covers the different classifications of airspace and defined dimensions within which air traffic control service is provided in accordance with the airspace classification. Controlled airspace consists of five classes: A, B, C, D, and E (Figure E-1).
    - **Class A** airspace is generally the airspace from 18,000 feet mean sea level (MSL) up to and including flight level 600, including the airspace overlying the waters within 12 nautical miles of the coast of the 48 contiguous states and Alaska. Unless otherwise authorized, all operation in Class A airspace is conducted under instrument flight rules (IFR).
    - **Class B** airspace is generally airspace from the surface to 10,000 feet MSL surrounding the nation's busiest airports in terms of airport operations or passenger enplanements.
    - **Class C** airspace is generally airspace from the surface to 4,000 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower, are serviced by a radar approach control, and have a certain number of IFR operations or passenger enplanements.
    - **Class D** airspace is generally airspace from the surface to 2,500 feet above the airport elevation (charted in MSL) surrounding those airports that have an operational control tower.
    - **Class E** airspace is the controlled airspace not classified as Class A, B, C, or D airspace. A large amount of the airspace over the United States is designated as Class E airspace.
- **SUA** is the designation for airspace in which certain activities must be confined, or where limitations may be imposed on aircraft operations that are not part of those activities. The FAA has designated SUA areas that are listed in FAA Order 7400.10B and 7400.2M. SUA usually consists of prohibited areas, restricted areas, warning areas, military operation areas, alert areas, and controlled firing areas. Most SUA areas have specific hours of operations, and users must remain clear of or obtain permission from the using agency or the controlling agency before flight through the defined areas.
- **Other airspace areas** is a general term referring to the majority of the remaining airspace. Examples include local airport advisory areas, military training routes, temporary flight restriction (TFR) areas, parachute jump aircraft operations areas, published visual flight rules routes, terminal radar service areas, and national security areas.

- **Uncontrolled airspace or Class G airspace** is the portion of the airspace that has not been designated as Class A, B, C, D, or E. Class G airspace extends from the surface to the base of the overlying Class E airspace.

Figure E-1. Airspace Profile



Source: FAA 2016

E.2. Study Area

The airspace study area includes the airspace above Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS), the airspace surrounding the launch trajectory, and the airspace associated with any hazard areas that must be protected to ensure public safety. With the exception of the polar launch missions (southern trajectory), all launch trajectories would be to the east over the Atlantic Ocean. The study area's airspace is controlled primarily by Miami Air Route Traffic Control Center (ARTCC), Jacksonville ARTCC, and New York ARTCC.

Additionally, for missions involving reentry of the launch vehicle's second stage, the study area includes a downrange airspace hazard area (e.g., south Pacific Ocean or Indian Ocean). These airspaces could be controlled by the FAA, such as Oakland ARTCC, or another air navigation service provider.

For each FAA-licensed mission, SpaceX, in collaboration with the FAA and U.S. Air Force (USAF) 45th Space Wing (SW), Eastern Range, establish hazard areas to ensure public safety. The size, location, and extent of these areas varies mission-to-mission, based on the launch vehicle and mission-specific parameters.

E.3. Existing Conditions

The study area consists of airspace made up of SUA (Warning Areas and Restricted Areas) as well as altitude reservations (ALTRVs), Air Traffic Controlled Assigned Airspace (ATCAA), and TFRs (see figures in Attachment E-1). The 45th SW is the using agency for the Warning Areas and Restricted Areas when these areas are activated by a Notice to Airmen (NOTAM). The Miami and Jacksonville ARTCCs control the airspace around the Warning Areas and Restricted Areas. These ARTCCs, as well as the New York ARTCC, also control the airspace around the ALTRVs, ATCAAs, and TFRs. The ARTCCs do not allow any air traffic they are controlling to enter these areas when active. The study area contains many published aviation routes (see Figure E-6 in Attachment E-1). The specific routes that would be impacted are identified prior to each launch and vary by mission.

Eastern Range operations (which includes SpaceX's launches from KSC and CCAFS) currently follow the procedures stated in a Letter of Agreement (LOA) (dated May 1, 2020) between the 45th SW and FAA. This agreement cancels the previous Eastern Range LOA (dated September 8, 2014). The LOA establishes responsibilities and describes procedures for the 45th SW, Eastern Range operations, within airspace common to the Miami Center, Jacksonville Center, New York Center, San Juan Center Radar Approach Control, Central Florida Terminal Radar Approach Control, NASA Shuttle Landing facility, Fleet Area Control and Surveillance Facility Jacksonville, Air Traffic Control System Command Center, and Central Altitude Reservation Function areas of jurisdiction. The LOA defines responsibilities and procedures applicable to launch operations, which require the use of Restricted Areas, Warning Areas, ATCAA, and/or ALTRVs within Eastern Range airspace. A separate LOA dated October 1, 2015 between SpaceX, 45th SW, FAA, and Fleet Area Control and Surveillance Facility (FACSFAC), San Diego, covers Dragon reentry operations.

E.4. Airspace Closures and Temporary Flight Restrictions

The FAA's proposed action is to modify existing SpaceX launch licenses or issue new launch licenses to SpaceX to continue conducting Falcon launch operations at KSC and CCAFS and to issue new reentry licenses to SpaceX for Dragon reentry operations. The Proposed Action does not include altering the dimensions (shape and altitude) of the airspace. All launch operations would continue to comply with the necessary notification requirements, including issuance of NOTAMs and Local Notices to Mariners (NOTMARs), consistent with current procedures. Launches would be of short duration and scheduled in advance to minimize interruption to airspace and waterways.

SpaceX's launch operations would require closing airspace for a period of time before a Falcon launch or Dragon reentry and during the launch or reentry. The temporarily closed airspace would be defined and published through a NOTAM prior to each launch or reentry. Airspace controlled by the FAA may be restricted through the SUA, the implementation of a TFR, or the activation of an ALTRV. The FAA generally uses TFRs to protect domestic airspace and uses ALTRVs to protect oceanic airspace. The NOTAM would establish a closure window that is intended to warn aircraft to keep out of a specific region throughout the time that a hazard may exist. The length of the window is primarily intended to account for the time needed for the operator to meet its mission objectives. The location and size of the closure area is defined to protect the public. For a launch, typically the keep-out must begin at the time of launch and must end when any potential debris, including items that are planned to be jettisoned (e.g., stages or fairings) and any debris generated by a failure, has reached the bottom of the affected airspace. For a re-entry, the keep-out begins at the first time debris could reach the top of the airspace until the last time the debris has fallen to the bottom of the affected airspace. SUA, TFRs, and ALTRVs are immediately released once the mission has successfully cleared the area and all planned jettisoned items no longer impose a risk to the public. The actual duration of airspace closure is normally much less than the original planned closure, especially if the launch window is relatively long and the launch occurs at the beginning of the window. The FAA typically begins to clear airspace and reroute aircraft in advance of a launch and directs aircraft back into the released airspace after the launch to recover to normal flow and volume.

The airspace closure duration depends on the mission type. For International Space Station resupply and commercial crew missions, the closure time is less than one hour. For other launches (polar, geostationary), the closure time can vary from less than one hour to about 2.5 hours. There are a few missions (e.g., the initial Falcon Heavy launch) that go beyond 2.5 hours; however, these are rare. These closure times represent maximum values for these types of missions. For all missions, the FAA and the operators take steps to reduce the closure durations as a successful mission unfolds. First, the launch operators plan to conduct their liftoff at the beginning of their launch window. So while they may request a window that spans hours in order to have more opportunity to work around weather or technical issues, they make every effort to launch as soon as they are ready in the launch window. While percentages are not readily available, far more launches occur at or near the launch window opening than the closing. Further, as the launch unfolds successfully, the FAA incrementally releases airspace as it is no longer affected. For example, the airspace nearest the launch site can generally be released within 3 to 5 minutes of liftoff as the rocket successfully progresses along its trajectory. In practice, the FAA attempts to divide airspace closures into subsets that can be released incrementally in time, as well as geographically based on airspace boundaries. In doing so, the actual closure times are often significantly smaller than these maximum values.

The location and size of airspace closures for commercial space operations also vary with each mission type and are influenced by multiple factors, including hardware reliability, and the number and type of items that may be jettisoned. The size of airspace closures shrink as reliability is established with results and analysis from each launch. For example, airspace closures for past Falcon 9 launches have ranged from several hundred miles in length for early launches to less than 30 miles in length for a recent launch. For the initial launch of a new launch vehicle, the hazard areas and associated airspace closures are bigger to account for the increased likelihood of a vehicle failure, relative to a mature rocket. Subsequent launches of that launch vehicle include smaller hazard areas compared to the initial launch. Thus, the airspace closure for Falcon Heavy's initial launch in 2018 was much larger than subsequent Falcon Heavy launches are expected to be.

Airspace closures due to commercial space operations can result in delayed aircraft departures and arrivals, aircraft being re-routed along established alternative routes in the airspace, and aircraft flying more miles due to the re-routing. Aircraft departures could be delayed if airspace was closed over or around the airport. Ground delays are also used under some circumstances to avoid airborne reroutes. After departure, the aircraft is re-routed as needed along established alternative routes to avoid the closed airspace. Based on the FAA's previous experience with launches at KSC and CCAFS, most of the NAS-related impact is aircraft being re-routed in the airspace and thus aircraft flying more miles. Rarely, if ever, does the FAA receive notification that a launch-related airspace closure resulted in aircraft departures or arrivals being delayed at least 15 minutes (referred to as a "reportable" delay). Re-routing associated with launch-related closures represents a small fraction of the total amount of re-routing that occurs from all other reasons in any given year. For example, weather results in the greatest amount of re-routing in any given year.

All aircraft re-routing in response to commercial space operations would occur along established alternative routes according to existing flight procedures that have already undergone environmental review. The alternative flight paths would be the same flight paths that are used for other re-route reasons, such as weather issues, runway closures, wildfires, military exercises, and presidential flights. The magnitude of aircraft re-routing depends on several conditions, including the time of day, the day of the week, and the month of the year, since air traffic volume fluctuates over time. For example, a SpaceX launch operation occurring during the day would have more airspace-related impacts than a nighttime operation when there are fewer or no aircraft that could enter the affected airspace. The duration of the closure also affects the number of necessary re-routes to ensure safety in the affected airspace. Launches with instantaneous launch windows could affect only a fraction of the air traffic of longer duration windows at the same day and time.

The FAA conducts an analysis of the effects on NAS efficiency and capacity for each licensed launch or reentry operation. These analyses are documented in Airspace Management Plans, which are completed approximately 3–5 days prior to a launch. They help the FAA determine whether the proposed launch would result in an unacceptable limitation on air traffic. If that were the case, the FAA may need to work with the operator to identify appropriate mitigation strategies, such as shortening the requested launch window or shifting the launch time, if possible. The FAA currently shares data with launch and reentry operators to avoid operations during days with high seasonal aviation traffic volume. These analyses have concluded that the majority of commercial space launch operations result in minor or minimal impacts on the NAS. This is largely due to the relatively low aircraft traffic density in the oceanic regions where SpaceX operations occur and the ability of the FAA to manage the airspace for all users. One exception was the initial Falcon Heavy launch in 2018, which had an unusually large hazard area, due to the uncertainty of the reliability of the rocket, and a long launch window duration, to afford extended opportunities to successfully complete the flight test.

As commercial space operations increase and new vehicles are developed, the FAA continues to explore ways to better manage airspace to increase the efficiency and capacity of the NAS for all users. For example, the FAA's Air Traffic Organization is currently examining dynamic launch and reentry windows and time-based launch procedures to enable air traffic to move dynamically through airspace even when it is closed via a NOTAM. These procedures involve ATC being in constant contact with the launch operator and knowing the status of a launch or reentry so the airspace can be used by aircraft as long as possible prior to the moment a rocket takes off or a reentry vehicle reenters Earth's atmosphere.

E.5. Environmental Consequences

The environmental impacts associated with airspace closures during commercial space operations include increased aircraft emissions (which could affect air quality and climate), potential increases in noise levels near an airport, and socioeconomic impacts. The following sections discuss each of these types of impacts. The FAA does not expect launch-related airspace closures associated with the proposed action to result in significant impacts to the environment. The FAA has been licensing and permitting launches, including Falcon 9 and Falcon Heavy launches, for many years and has not seen evidence of significant environmental impacts from airspace closures. Although the FAA has never licensed or permitted a launch from KSC or CCAFS that involved a southern (or polar) launch trajectory, SpaceX is proposing to conduct only six polar launches per year. The FAA would prepare an Airspace Management Plan prior to a polar mission to assess the potential impacts on the NAS. If the FAA's analysis concludes a polar launch would create an unacceptable limitation on air traffic, the FAA would work with SpaceX to identify appropriate mitigation strategies, such as shortening the requested launch window or shifting the launch time. Given that previous FAA analyses for launches occurring at KSC and CCAFS have typically concluded minor impacts on the NAS, the FAA does not expect polar launches would generate significant environmental impacts.

E.5.1. Air Quality

Airspace closures associated with commercial space operations would result in additional aircraft emissions mainly from aircraft being re-routed and expending more fuel. Minimal, if any, additional emissions would be generated from aircraft departure delays because the FAA has rarely, if ever, received reportable departure delays associated with launches at KSC and CCAFS. Based on SpaceX's proposal, airspace-related impacts could increase up to a maximum of 70 times per year. Any delays in aircraft departures from affected airports would be short-term. Thus, any increases in air emissions from grounded aircraft are expected to be minimal and would occur in attainment areas. Therefore, these emissions increases are not expected to result in an exceedance of a National Ambient Air Quality Standard for any criteria pollutant. Emissions from aircraft being re-routed would occur above 3,000 feet (the mixing layer) and thus would not affect ambient air quality. Therefore, airspace closures associated with commercial space operations are not expected to result in significant air quality impacts.

E.5.2. Climate

Airspace closures associated with commercial space operations would result in additional aircraft emissions mainly from aircraft being re-routed and expending more fuel. These emissions include carbon dioxide (CO_2), which is a greenhouse gas (GHG). Based on SpaceX's proposal, these temporary increases in aircraft emissions could increase up to a maximum of 70 times per year. The amount of time that affected aircraft spend being re-routed would be short-term. In addition, the number of aircraft that would be impacted per launch would not be expected to produce additional emissions that would have a notable impact on climate. Therefore, the increases in GHGs caused by short-term airspace closures during commercial space operations is not expected to result in significant climate-related impacts. The scientific community is continuing efforts to better understand the impact of aviation emissions on the global atmosphere. The FAA is leading and participating in a number of initiatives intended to clarify the role that commercial aviation plays in GHG emissions and climate. The FAA, with support from the U.S. Global Change Research Program and its participating federal agencies, has developed the Aviation Climate Change Research Initiative in an effort to advance scientific understanding of regional and global climate impacts of aircraft emissions.

E.5.3. Noise

Airspace closures associated with commercial space operations could result in temporarily grounded aircraft at affected airports and re-routing of en-route flights on established alternate flight paths. As noted above, the FAA has rarely, if ever, received reportable departure delays associated with launches at KSC and CCAFS. Aircraft could be temporarily grounded if airspace above or around the airport is closed. Ground delays are also used under some circumstances to avoid airborne reroutes. If aircraft were grounded, noise levels at the airport could temporarily increase as the planes sit idle. Also, depending on the altitude at which aircraft approach an airport, there could be temporary increases in noise levels in communities around the airports. However, aircraft would travel on existing en-routes and flight paths that are used on a daily basis to account for weather and other temporary restrictions. Also, not all launch and reentry missions would affect the same aircraft routes or the same airports, and re-routing associated with launch-related closures represents a small fraction of the total amount of re-routing that occurs from all other reasons in any given year. Any incremental increases in noise levels at individual airports would only last the duration of the airspace closure on a periodic basis and are not expected to meaningfully change existing day-night average sound levels at the affected airports and surrounding areas. Therefore, airspace closures due to commercial space operations are not expected to result in significant noise impacts. Advancements in airspace management as mentioned above are expected to further reduce the number of aircraft that would contribute to noise at the affected airports and surrounding areas.

E.5.4. Socioeconomics

Purely social or economic effects are not required to be analyzed under NEPA. Even if NEPA recognizes socioeconomic impacts from re-routing aircraft due to commercial space operations, such impacts would be similar to re-rerouting aircraft for other reasons (e.g., weather issues, runway closures, wildfires, military exercises, and presidential flights). Potential socioeconomic impacts include additional airline operating costs for increased flight distances and times resulting from re-routing aircraft and increased passenger costs as a result of impacted passenger travel, including time lost from delayed flights, flight cancellations, and missed connections. Alternatively, restricting or preventing a launch event would have socioeconomic impacts on SpaceX, commercial payload providers, and consumers of payload services. Operations would not result in the closure of any public airport during the operation nor so severely restrict the use of the surrounding airspace as to prevent access to an airport for an extended period of time. Given existing airspace closures for SpaceX operations are temporary as discussed above and the FAA's previous analyses related to the NAS have concluded minor or minimal impacts on the NAS from commercial space launches, the FAA does not expect airspace closures from SpaceX's proposal would result in significant socioeconomic impacts. Furthermore, local air traffic controls would coordinate with airports and aircraft operators to minimize the effect of the launch operations on airport traffic flows as well as traffic flows in en-route airspace.

E.6. References

FAA (Federal Aviation Administration). 2016. Pilots Handbook of Aeronautical Knowledge. FAA-H-8083-258. U.S. Department of Transportation. Available: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/.

Attachment E-1. Eastern Range Special Use Airspace and Published Aviation Routes

Table E-1. Restricted Areas (Reference Figure E-2)

R-2932	Surface – 4999 MSL	Active continuously
R-2933	5000 MSL – Unlimited	Active by NOTAM
R-2934	Surface – Unlimited	Active by NOTAM
R-2935	11000 MSL – Unlimited	Active by NOTAM

Figure E-2. Restricted Areas

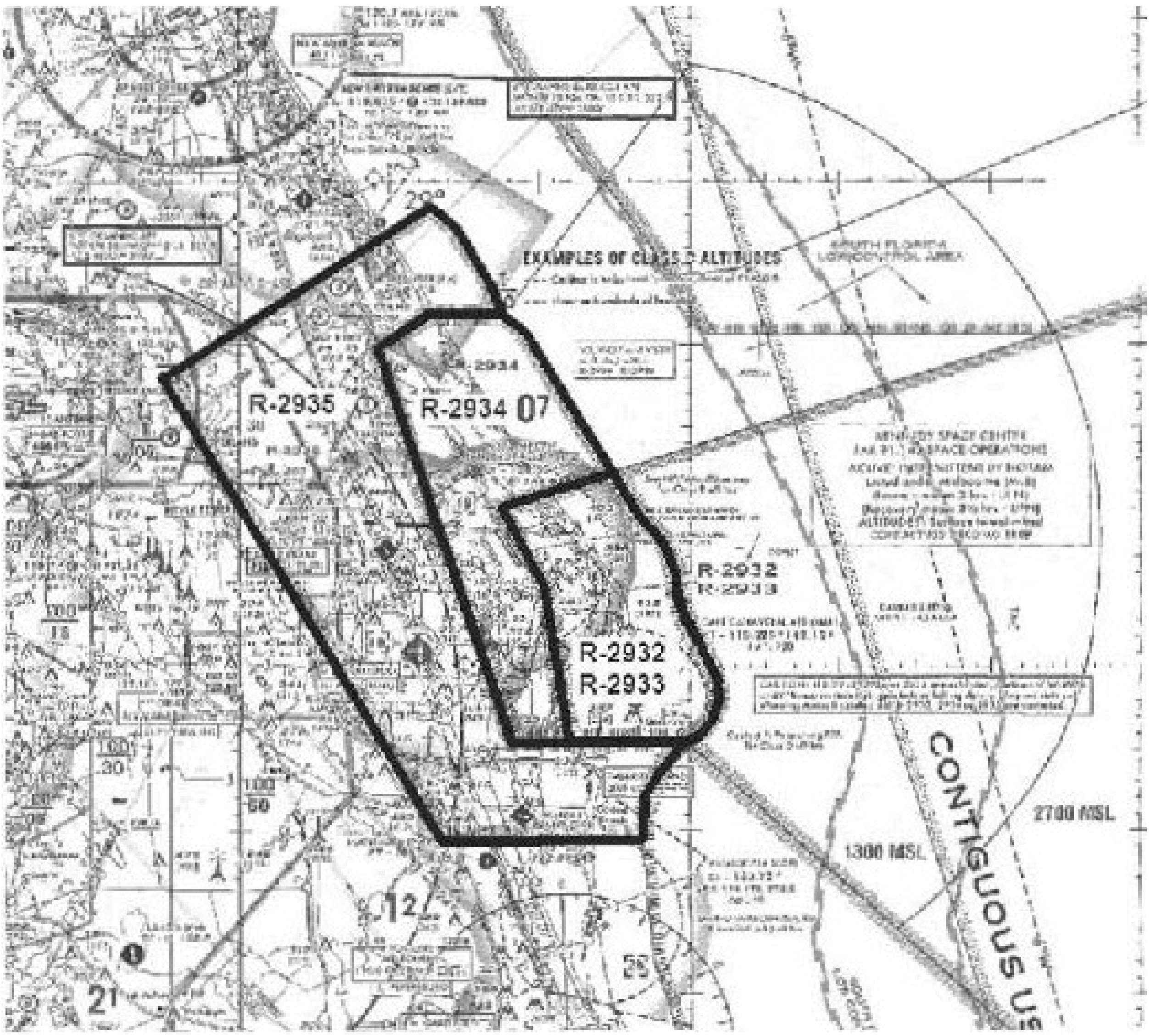


Table E-2. Warning Areas (Reference Figure E-3)

W-497A	Surface – Unlimited	Active by NOTAM
W-497B	Surface – Unlimited	Active by NOTAM

Figure E-3. Warning Areas

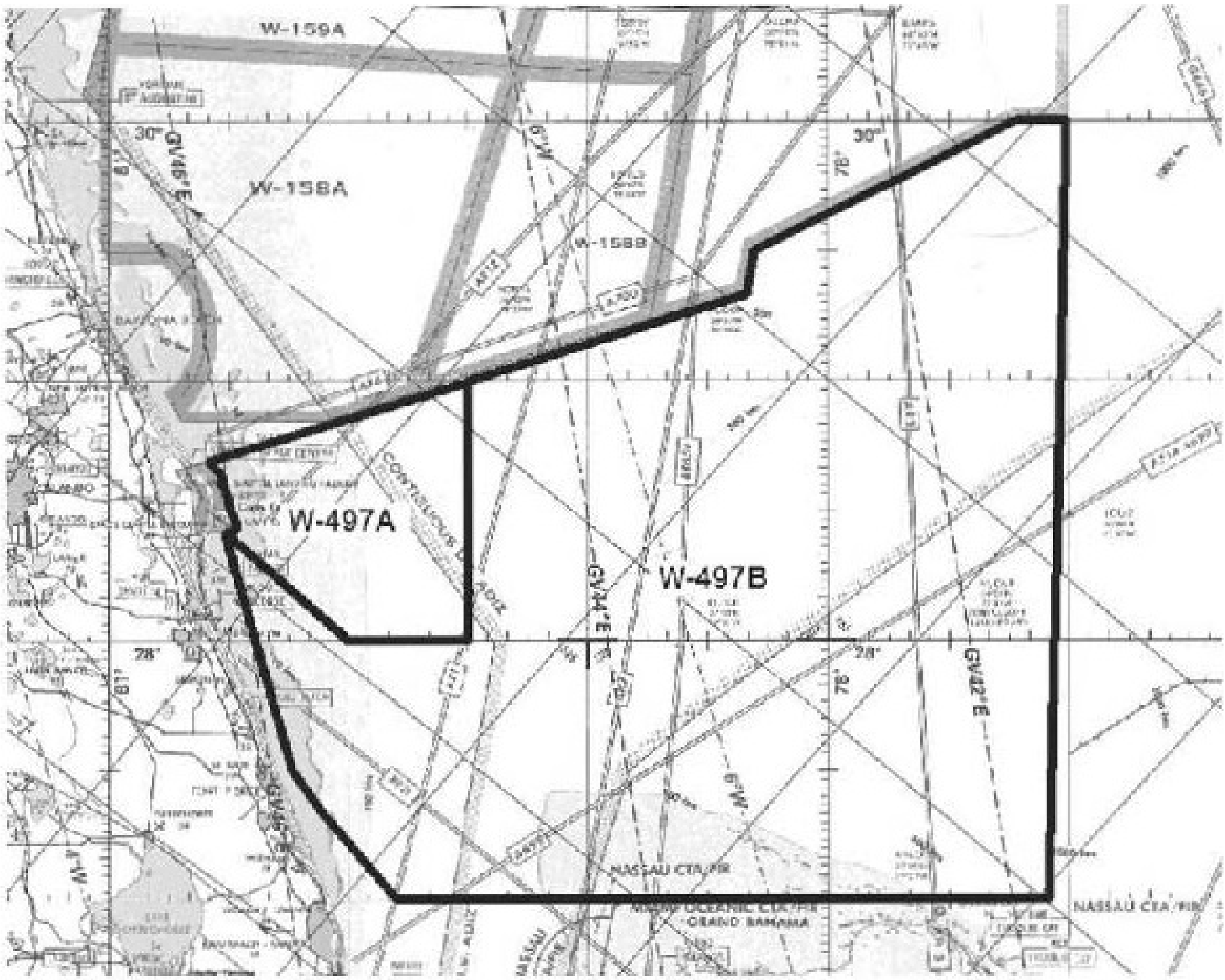


Table E-3. Air Traffic Control Assigned Airspace (Reference Figure E-4)

CAPE ATCAA	Surface – FL 180	Active by NOTAM

Figure E-4. Air Traffic Control Assigned Airspace

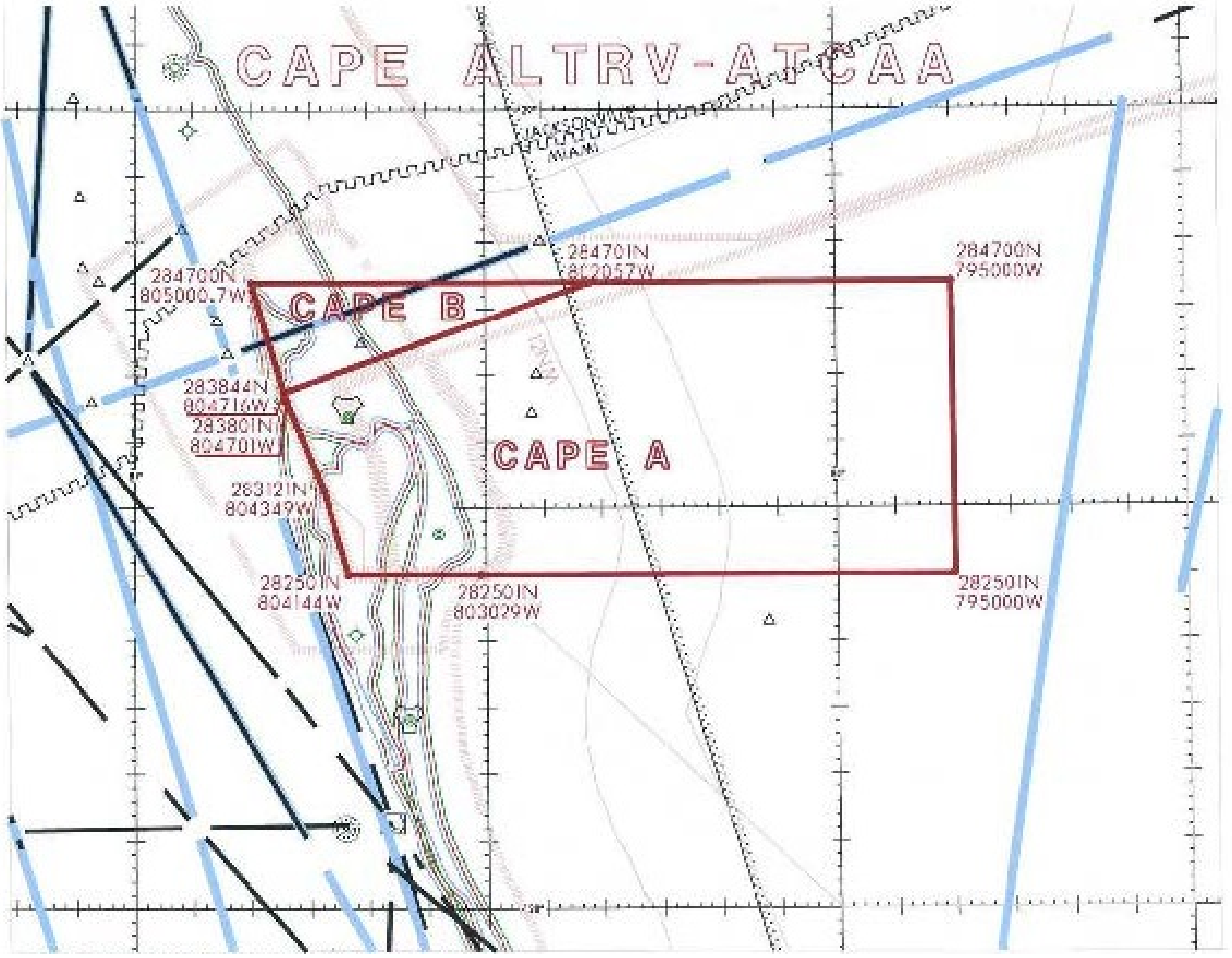


Table E-4. Space Launch Area Temporary Flight Restriction (Reference Figure E-5)

14 CFR 91.143	Surface – Unlimited	Active by NOTAM

Figure E-5. Temporary Flight Restriction

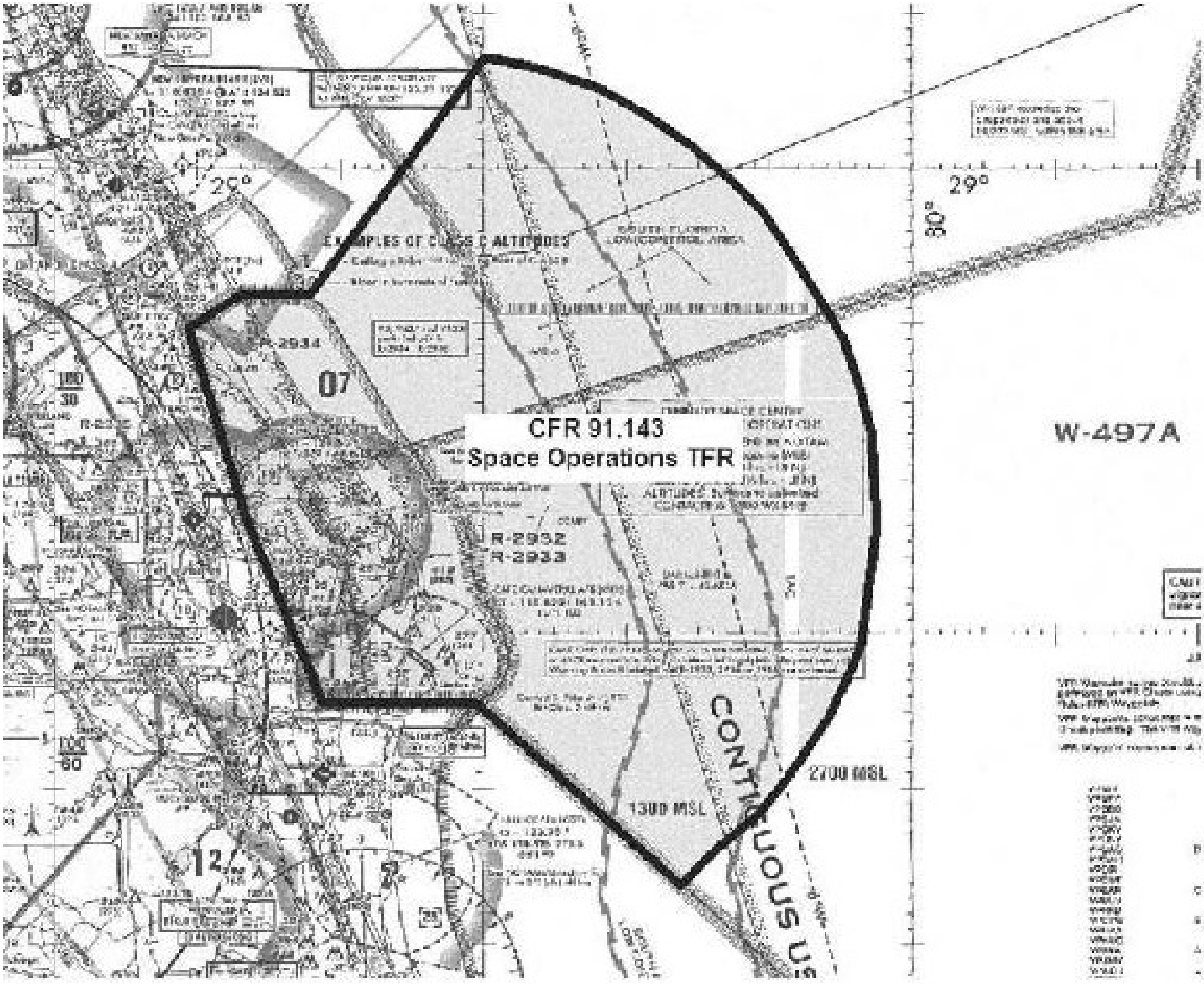
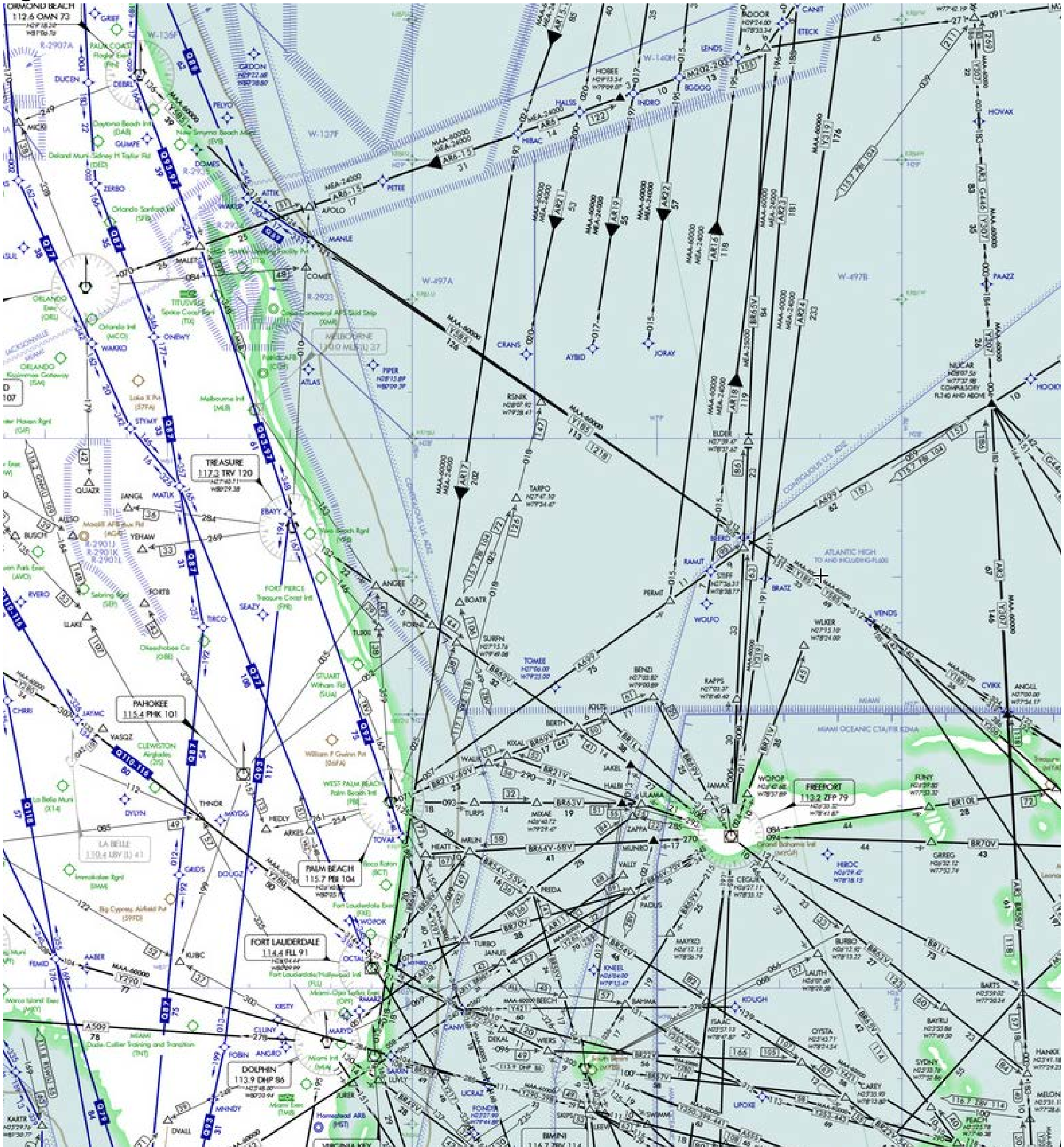


Figure E-6. Published Aviation Routes



Source: https://skyvector.com/