Written Re-evaluation of the 2022 Final Programmatic Environmental Assessment for the SpaceX Starship/Super Heavy Launch Vehicle Program at the Boca Chica Launch Site in Cameron County, Texas

Starship/Super Heavy Vehicle Ocean Landings and Launch Pad Detonation Suppression System

Introduction and Background

Introduction

This written re-evaluation (WR) evaluates whether supplemental environmental analysis is needed to support the Federal Aviation Administration (FAA) Office of Commercial Space Transportation decision to issue a vehicle operator license to Space Exploration Technologies Corporation (SpaceX) for the operation of the Starship/Super Heavy launch vehicle at its existing Boca Chica Launch Site in Cameron County, Texas. The affected environment and environmental impacts of Starship/Super Heavy operations at the Boca Chica Launch Site were analyzed in the 2022 *Final Programmatic Environmental Assessment for the SpaceX Starship/Super Heavy Launch Vehicle Program at the SpaceX Boca Chica Launch Site in Cameron County, Texas* (2022 PEA; FAA 2022). The FAA issued a Mitigated Finding of No Significant Impact (FONSI) based on the 2022 PEA on June 13, 2022. This WR provides the determination of whether the contents, analyses, and conditions of approval in the PEA remain current and substantially valid.

The issuance of a vehicle operator license is a major federal action subject to the requirements of the National Environmental Policy Act of 1969 (NEPA), 42 U.S.C. § 4321 et seq. As such, the FAA must assess the potential environmental impacts of issuing a vehicle operator license to SpaceX for Starship/Super Heavy operations at the Boca Chica Launch Site. FAA Order 1050.1F, *Environmental Impacts: Policies and Procedures* provides that the FAA may prepare a WR to determine whether the contents of previously prepared environmental documents remain substantially valid or whether significant changes to a previously analyzed proposed action require the preparation of a supplemental Environmental Assessment or Environmental Impact Statement (EIS).

In accordance with Paragraph 9-2.c of FAA Order 1050.1F, the preparation of a new or supplemental EA or EIS is not necessary when the following can be documented:

1. The proposed action conforms to plans or projects for which a prior EA and FONSI have been issued or a prior EIS has been filed and there are no substantial changes in the action that are relevant to environmental concerns;

2. Data and analyses contained in the previous EA and FONSI or EIS are still substantially valid and there are no significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts; and

3. Pertinent conditions and requirements of the prior approval have been, or will be, met in the current action.

This WR provides documentation for the above three factors including the FAA's conclusion that the contents of the 2022 PEA remain current and substantially valid and that the decision to issue a vehicle operator license for Starship/Super Heavy operations at the Boca Chica Launch Site does not require the preparation of a new or supplemental EA or EIS.

Background

The FAA prepared the 2022 PEA to analyze the potential environmental impacts of constructing launch-related infrastructure and operating the Starship/Super Heavy launch vehicle at the Boca Chica Launch Site. SpaceX's proposed operations include launches originating from this site, as well as landings at this site, in the Gulf of Mexico, or in the Pacific Ocean off the coast of Hawaii. SpaceX has applied to the FAA for a license for the Starship/Super Heavy launch vehicle. Prior to submitting a vehicle operator license application to the FAA, SpaceX provided the FAA with a launch profile of proposed launch operations, which was analyzed in the 2022 PEA.

Since publication of the 2022 PEA, SpaceX informed the FAA that it has installed a detonation suppression system on the orbital launch pad. The detonation suppression system sprays water towards the engines during ignition events (e.g. launches and other tests) to prevent the risk of a fire on the launch pad. SpaceX is proposing to use the detonation suppression system for the first launch. As described in the PEA, for any water used in conjunction with a launch or test, a majority (if not all) of the approximately 3,000 gallons of water would be vaporized by the heat of the rocket engines. Any remaining water would be collected in a system of gutters and directed to an onsite lined sump pit that is pumped out and hauled offsite. The footprint of a sump pit is smaller than the multiple retention ponds that were contemplated in the 2022 PEA and is within the PEA launch site area.

In addition to the detonation suppression system, since publication of the 2022 PEA, SpaceX provided the FAA with additional information regarding Starship and Super Heavy planned descents during the first launch. While the additional information was not contemplated in the 2022 PEA, it does not modify or add to the vehicle's performance or the overall launch profile described in the PEA and therefore does not require the FAA to produce an environmental document tiered off the 2022 PEA. Rather, the additional information provides more detail regarding Starship's planned landing and Super Heavy's planned soft water landing. This WR is intended to more clearly define the existing launch profile for Starship and Super Heavy ocean landings and cover the expansion of the potential area for Starship's ocean landing location. Super Heavy's ocean landing location is still within the area of the Gulf of Mexico that was analyzed in the 2022 PEA and is shown in Figure 2.

Starship Landing Location

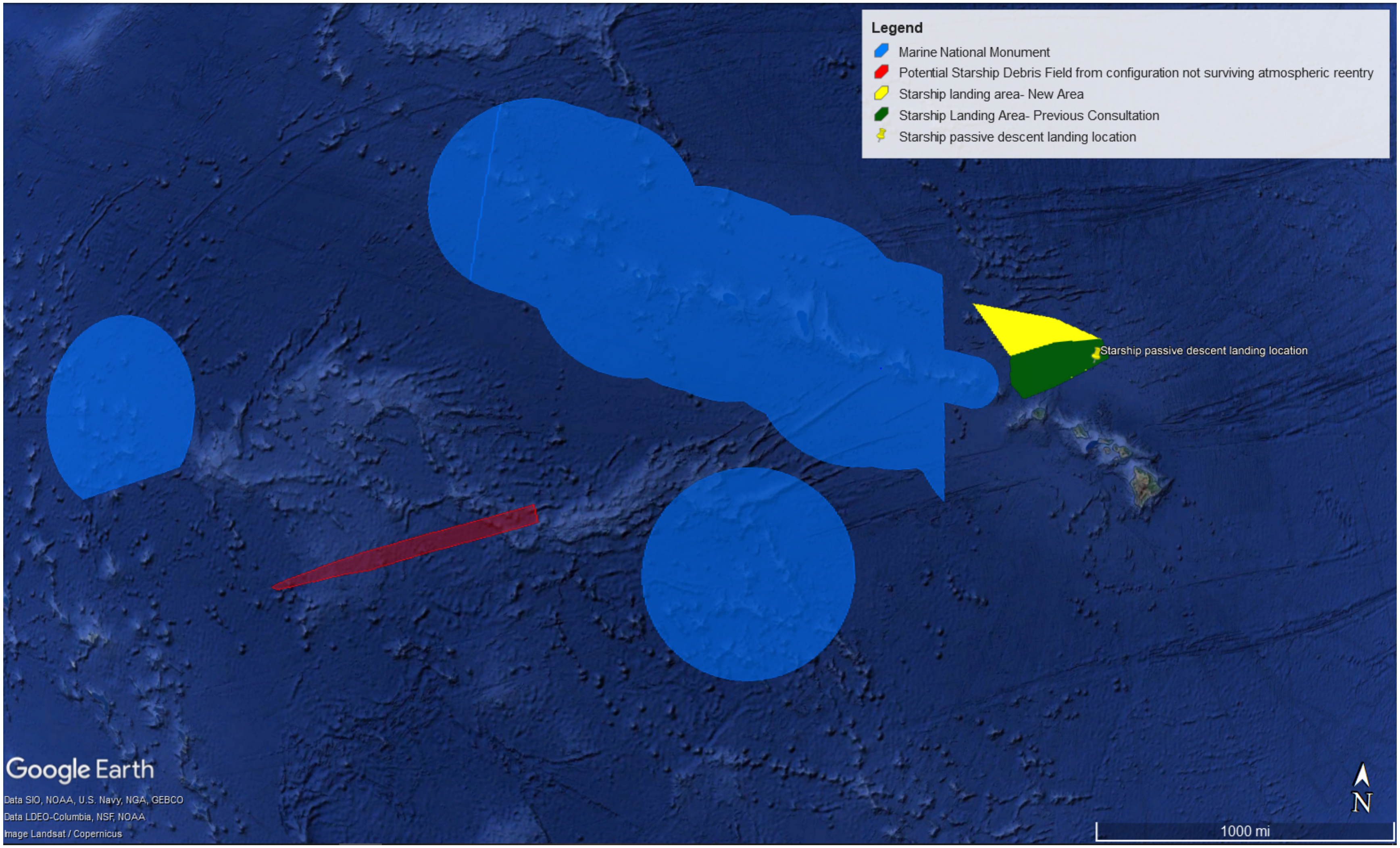
Based on Starship's hardware configuration, for the first launch, SpaceX plans to conduct a passive descent that would result in Starship's intact impact with the ocean's surface. Starship's planned landing location for the first launch is shown in Figure 1 below.

To provide SpaceX with additional launch planning flexibility for the first launch, SpaceX proposes to increase Starship's ocean landing area by expanding it approximately 155 miles to the north of the area described in the 2022 PEA. The nominal landing area remains no closer than approximately 62 nautical miles north of Kauai, Hawaii, as stated in the 2022 PEA. The proposed expanded landing area, shown in yellow in Figure 1, represents the area within which Starship could land, not the entire impact area from a single Starship landing. The nominal plan is to land in the passive descent landing location as shown in Figure 1 (240 nm east of the Papahanaumokuakea Marine National Monument). Any landing location within the green and yellow area other than the pinned location shown would not be considered nominal.

SpaceX also proposes to add an area southwest of Hawaii, uprange of the passive descent ocean landing area, to account for the potential Starship debris field for the second and third launches of Starship that are not configured to survive atmospheric reentry.[1] This area is shown in red in Figure 1.

[1] When Starship is not configured to survive atmospheric reentry, Starship would tumble as it descends through the atmosphere and break apart at greater than 50 kilometers (km) above ground level (AGL).

Figure 1. Starship Nominal Landing Areas



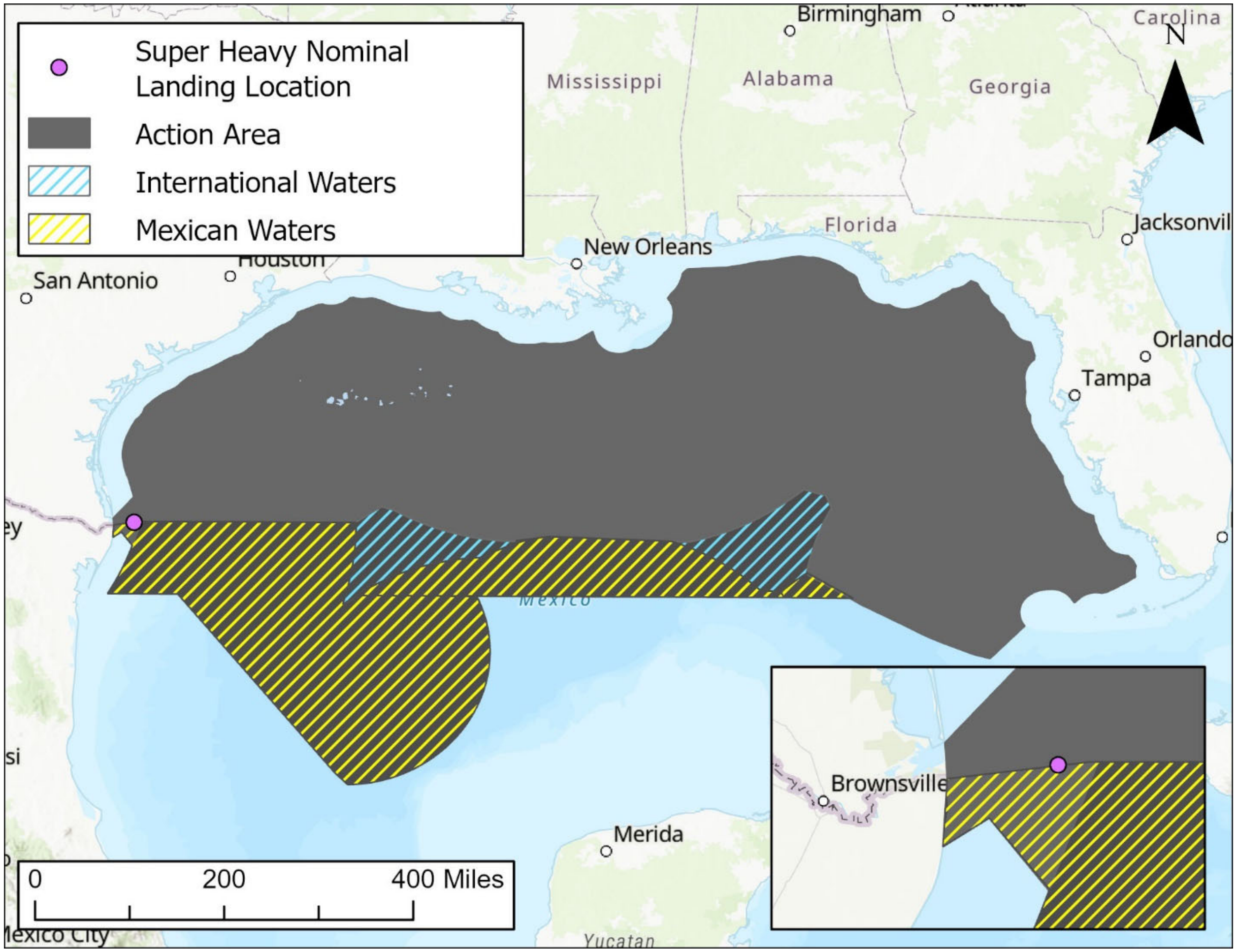


Figure 2: Super Heavy Landing Area and Nominal Landing Location

Starship/Super Heavy Ocean Landings

The following paragraphs provide additional detail that more clearly defines the launch profile for Starship's and Super Heavy's planned landings for the first launch. If Super Heavy completes the descent phases as nominally planned, SpaceX expects Super Heavy to land intact in the Gulf of Mexico and is expected to sink. If Starship completes the descent phases as nominally planned, SpaceX expects Starship would explode and break up upon impact with the Pacific Ocean's surface, where most debris would be expected to sink. As stated in the 2022 PEA, SpaceX would sink or, to the greatest possible extent, recover any large floating debris. Additional detail regarding the events that would occur during descent is provided below.

Super Heavy: After stage separation of the Super Heavy from Starship, the flight plan is for Super Heavy to conduct a boost-back burn prior to descending into the atmosphere. After descent through the atmosphere, Super Heavy would conduct a landing burn, which would cutoff at approximately the ocean's surface, and then impact the water. After the landing burn ends, the flight plan is for Super Heavy to impact the water intact vertically. Then, within several seconds, Super Heavy would tip over and impact the water horizontally. The landing would impart forces onto the liquid oxygen (LOX) tank and methane tank; however, the tanks' structural capabilities allow it to withstand these forces. Therefore, the tanks would remain intact, and there would be no resultant interaction between the LOX and methane. Nominally, Super Heavy will remain intact. Following the landing burn, Super Heavy would sink at an angle (similar to a sinking ship), during which sea water would flood the tanks through the fill drain valves near the bottom. As the tanks flood, the vehicle would become waterlogged and sink to the ocean floor. If in an off-nominal event, Super Heavy did not sink, SpaceX would attempt to scuttle Super Heavy. The primary means of scuttling the vehicle is to remotely open the tank vents allowing water to ingress into the tank and sink the vehicle. If the vents are determined to be closed, SpaceX would attempt to command the valves open, inducing the flooding. Should SpaceX receive positive confirmation that the valves are open but the vehicle is not taking on water, SpaceX would attempt to orientate the vehicle in a manner that would be expected to induce sinking by using a vessel to physically interact with the vehicle and cause it to roll on its long axis. This could be accomplished with a vessel and tow line attached to the aft end of the vehicle or grid fins. During an off-nominal event where Super Heavy did not sink, additional methods for scuttling could be considered such as puncturing the outer shell of the vehicle using a firearm or remote operating vessel. Consistent with the 2022 LOC, it is SpaceX's goal to recover and reuse the Super Heavy boosters. However, during the first three launches, SpaceX may require landing the Super Heavy in the Gulf of Mexico intact and then let it sink.

Starship: For the first launch**,** after ascent engine cutoff, Starship would vent residual main tank propellant during the in-space coast phase of the launch at or above 120 kilometers AGL. Following the in-space coast phase, Starship would begin its passive descent. Some residual LOX (approximately 10 metric tons) and methane (approximately 4 metric tons) would remain in Starship, which is the minimum amount that can remain in Starship after venting to serve as ballast in order to successfully maintain trajectory to the landing location. The 14 metric tons of remaining propellant represents approximately 1.1 percent[2] of the total fill levels for the Starship main tanks. Starship would impact the Pacific Ocean intact, horizontally, and at terminal velocity (i.e., the steady speed achieved by a freely falling object), and the impact would disperse settled remaining propellants and drive structural failure of the vehicle. The structural failure would immediately lead to failure of the transfer tube, which would allow the remaining LOX and methane to mix, resulting in an explosive event.

SpaceX would expend Starship (break up upon atmospheric entry) following the second and third launches. The Starships would be expended in the red area shown in Figure 1.

As required by 14 CFR Chapter III, SpaceX would coordinate directly with the USCG to protect public health and safety prior to any launch or reentry activity licensed by the FAA that overflies or affects Navigable Waters. SpaceX and USCG have entered into the *Letter Of Intent (LOI) For Space Exploration Technologies Corp. (SpaceX) to Provide Information Related To Launch And Reentry Operations To The United States Coast Guard (USCG) For Launch And Reentry Operations In The Coast Guard Pacific Area (PACAREA) Area Of Responsibility (AOR) To Ensure Safety Of The Maritime Domain* (U.S. Coast Guard 2022) that outlines coordination efforts (Section 5 and 6 of the LOI) to ensure that any hazards to the environment or navigation are properly managed and mitigated. These coordination efforts are described below.

Following the Starship breakup, SpaceX would have a vessel in the area of highest likelihood of debris that would identify large debris for salvage. SpaceX would use the vessel to survey the debris field for approximately of 24 to 48 hours (using visual survey in the day and onboard vessel radar at night) depending on the outcome of the breakup. The initial survey area would be determined based on last known data location point received from the telemetry on the vehicle upon splashdown. Weather and ocean current data would be used to further characterize the debris field as the operation is conducted. During the operation SpaceX would coordinate findings and action items directly with the USCG Sector 14 to ensure all of the requirements of the LOI are met. SpaceX vessels would be equipped with multiple forms of communication equipment (Starlink, VHF, Sat phone) to enable communications directly with USCG representatives while offshore. As explained in the 2022 PEA and LOC, for all landing events in the ocean, if debris is generated, SpaceX expects the majority of the Starship debris would sink because it is made of steel and will have sufficient mass to sink to the seafloor (U.S. Navy 2022). Debris is expected to sink within the nominal landing location (240 nm east of the Papahanaumokuakea Marine National Monument) and is not expected to drift into the Papahanaumokuakea Marine National Monument. Some lighter items (e.g., items not made of steel, such as composite overwrapped pressure vessels) may float but they are expected to become water logged and sink. Though not expected and unlikely, if there is floating debris found by the vessel during the debris field survey, SpaceX would sink or recover any floating debris before it could drift into the Papahanaumokuakea Marine National Monument by physically removing the item or puncturing the item to cause it to sink. Methods to physically remove debris could include using a net or a boat hook. Methods for puncturing debris to help induce sinking would be the same as described above for Super Heavy. SpaceX would report debris findings to the USCG to determine the most appropriate method of recovery or sinking as described above and would be on a case-by-case basis

[2] Early Falcon missions involved first stage ocean impacts with approximately 0.9 percent of the total fill levels for the first stage's propellant tanks.

depending on personnel safety, vessel safety, and capability. As mentioned earlier, SpaceX would act to mitigate the debris in coordination with USCG to verify the debris sinks within 10 days as noted in the January 31, 2022 National Marine Fisheries Service (NMFS) Letter of Concurrence (2022 LOC). If debris is still identified after the 24-48 hours survey and recovery efforts, SpaceX would use another method including, an aerial asset, an additional vessel or satellite imaging to confirm and characterize any debris and take appropriate action to retrieve or sink it. SpaceX would also attempt to locate the launch vehicle launch recording device (aka the "black box") which has a global positioning system (GPS) tracking signal. Should the recording device be located, scuba divers may be deployed to facilitate device retrieval.

As described in the 2022 LOC, any aircraft and surveillance vessels (watercraft) described above would comply with the Project Design Criteria (PDCs)'s environmental protection measures for vessel operations and/or aircraft procedures.

Proposed Action

The FAA's Federal Action is to issue one or more experimental permits and/or a vehicle operator license to SpaceX that would allow SpaceX to operate its Starship/Super Heavy launch vehicle at the Boca Chica Launch Site.

Affected Environment

The Boca Chica Launch Site is located on SpaceX-owned land in Cameron County, Texas, near the cities of Brownsville and South Padre Island. The larger area around the Boca Chica Launch Site includes several private and public industries, including the SpaceX production and manufacturing facility, the Port of Brownsville, the City of Port Isabel, San Roman Wind Farm, and development on South Padre Island. Boca Chica Village now includes support infrastructure, such as housing, restaurants, and offices used in connection with SpaceX's production and manufacturing facility near Boca Chica Village. For all environmental impact categories, the affected environment remains the same as discussed in the 2022 PEA. Accordingly, the 2022 PEA remains valid documentation of the affected environment for the Proposed Action.

Re-evaluation of Environmental Consequences

This WR is intended to evaluate the potential environmental consequences associated with the additional information regarding the detonation suppression system and the Starship and Super Heavy descent and landing operations. As described in the 2022 PEA, the descent of the Starship/Super Heavy launch vehicle is planned to occur in the open ocean, no closer than 19 miles offshore, and all water used in conjunction with a launch or test from the detonation suppression system will remain on the launch site until it is hauled offsite. Accordingly, the analysis in this WR is focused on the environmental impact categories with the potential to be affected, including: air quality; biological resources (terrestrial and marine wildlife); climate; hazardous materials, solid waste, and pollution prevention; noise and noise-compatible land use; and water resources (including Wetlands, Floodplains, Surface Waters, Ocean Waters, and Groundwater).

Air Quality

Air quality impacts, taking into account the new information related to the Proposed Action, would be comparable to those discussed in the 2022 PEA. As stated in the 2022 PEA, rocket engine combustion emissions are not subject to limitations on production or use because the U.S. Environmental Protection Agency (EPA) has not set emissions standards for rocket engines. The proposed descent and landing activities do not generate ozone depleting substances. Air permits are not required for emissions from descent and landing as rockets are mobile sources, the emissions are temporary in nature and are not considered to be major emissions of criteria pollutants or hazardous air pollutants.

SpaceX expects all fuel onboard Starship to be consumed during vehicle breakup, as all residual propellant would be combusted. Super Heavy would remain intact and is expected to sink to the bottom of the ocean floor. Residual methane would be expected to vent to the atmosphere through open valves.

Most emissions associated with Starship/Super Heavy descent and landing, including any in-space venting described above, would occur well above the mixing height of 3,000 feet AGL, and therefore, would not be likely to impact ground level pollutant concentrations. Further, all emissions during breakup would occur offshore, beyond state boundaries, where attainment status is unclassified and the National Ambient Air Quality Standards (NAAQS) do not apply.

The operation of the detonation suppression system for launch would not result in an increase in the amount of air pollutant emissions reported in the 2022 PEA.

No additional airspace closures beyond those described in the 2022 PEA would occur from the descent and landing operations of the Super Heavy and Starship. Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant air quality impacts.

Biological Resources (Marine Wildlife)

Impacts on biological resources, taking into account the new information related to the Proposed Action, would be comparable to those discussed in the 2022 PEA. The 2022 PEA determined the Proposed Action would not be expected to result in significant impacts on marine habitats and wildlife.

Biological resource impacts under the Proposed Action would be similar to those impacts described in the 2022 PEA. In accordance with Section 7 of the Endangered Species Act (ESA), the FAA conducted consultation with the U.S. Fish and Wildlife Service (USFWS). The FAA determined the Proposed Action may affect and is likely to adversely affect ESA-listed species and critical habitat under USFWS jurisdiction and conducted formal consultation with the USFWS. The USFWS issued a Biological Opinion (BO), which concluded the Proposed Action is not likely to jeopardize the continued existence of any federally listed species or adversely modify designated critical habitat. The BO contains Reasonable and Prudent Measures and associated Terms and Conditions to avoid, minimize, and mitigate the effects on listed species and critical habitat. SpaceX must implement the Terms and Conditions. The FAA and SpaceX are committed to implementing the conservation measures and terms and conditions outlined in the BO to minimize potential effects to ESA-listed species and critical habitat. Additional best management practices and industrial waste water controls would be implemented to avoid any discharge or additional impacts to the surrounding habitat. The Proposed Action would not introduce any additional operational or construction-related effects that are outside the scope of impacts analyzed in the 2022 PEA and the USFWS BO.

As described in the 2022 PEA, the FAA recently completed a programmatic Endangered Species Act (ESA) consultation with the NMFS for launch and reentry operations in the marine environment (NMFS 2022). NMFS concurred with the FAA's determination that the space launch and reentry activities presented in the programmatic consultation would not adversely affect ESA-listed species or designated critical habitat and issued a programmatic Letter of Concurrence (LOC) (NMFS 2022). The same impact mechanisms and effects described and assessed as part of the NMFS consultation are applicable to non-protected species. The prior consultation concluded with NMFS concurring that SpaceX's landing and recovery operations would be unlikely to adversely affect federally listed threatened and endangered species. Based on the same reasoning, it is unlikely that non-protected marine wildlife would be adversely affected. As stated in the 2022 PEA, the effects from ocean landing and recovery operations would be negligible. As stated in the 2022 LOC, it has been normal practice for decades for vertical rocket launches to involve expending one or more stages (or boosters) in the ocean with residual propellant resulting in a potential overpressure explosive event (FAA 2016; NASA 2013; NASA 2009; FAA 2020; USAF 2006).

Impact by Fallen Objects

Super Heavy would remain intact, and therefore, impacts would be the same as discussed in the 2022 PEA. Starship's intact impact with the ocean's surface and subsequent explosive event would generate debris. If there are reports of large debris, SpaceX would sink or recover, as necessary, any large floating debris. As stated in the 2022 PEA, non-recoverable debris would sink to the ocean bottom. The 2022 LOC notes that the likelihood of marine species encountering ingestible material once it has settled over the long-term is expected to be extremely unlikely to occur and thus discountable. Entanglement is not expected as parachutes and/or parafoils would not be utilized under the Proposed Action.

Direct strikes by debris from Starship are extremely unlikely for all species of concern, fish, sea turtles, and marine mammals. This is due to the small size of the components as compared to the vast open ocean. If debris from the vehicle struck an animal near the water's surface, the animal would be injured or killed. As stated in the 2022 PEA, given the low frequency of the Starship/Super Heavy ocean descent and landing operations, and the fact that marine wildlife, marine mammals, and special status species spend the majority of their time submerged as opposed to on the surface, it is extremely unlikely they would be impacted. The relative availability of these animals at the ocean surface, spatially and temporally, combined with the low frequency of the Proposed Action, reduce the likelihood of impacts to extremely low. Additionally, there are no known interactions with any of these species after decades of similar rocket launches and reentries. Further, the projected landing areas for both Super Heavy and Starship are well offshore where density of marine species decreases compared to coastal environments and upwelling areas (FAA 2017).

Exposure to Hazardous Materials

SpaceX expects residual LOX and methane to remain on both Starship and Super Heavy during descent and landing. Unlike other launch vehicle propellants and fuels, LOX and methane are not toxic pollutants. Because Super Heavy would remain intact, residual propellant would be retained and not released into the ocean but may eventually warm up, turn gaseous, and vent to the atmosphere through open valves. For the first launch, Starship is expected to experience an explosive event upon impact with the ocean's surface and subsequent vehicle failure. As all liquid fuel is likely to be consumed during vehicle breakup, only structural debris would remain. When Starship is not configured to survive atmospheric reentry, the vehicle would tumble and break apart as it descends through the atmosphere, and residual fuel would be dispersed and evaporated such that only structural debris would remain. Structural debris of both Starship and Super Heavy is made of inert materials, such as steel, carbon composite, silica heat tiles and is not anticipated to affect water quality. For these reasons, after considering the new information, the chance for marine species to be exposed to the residual propellant is still extremely low and therefore discountable, as the 2022 PEA concluded.

Exposure to Sonic Booms and Impulse Noise

A sonic boom is the sound associated with the shock waves created by a vehicle traveling through the air faster than the speed of sound. As described in the 2022 PEA, sonic booms that would occur during descent and landing would intercept the ocean's surface. However, exceptionally little energy from in-air noise is transmitted into water (FAA 2017). Due to the limited occurrences of ocean landings, the low magnitude of the sonic booms (no greater than 12 pounds per square foot [psf] for Super Heavy and 2 psf for Starship), the substantial attenuation of the sonic booms at the air/water interface, and the exponential attenuation with water depth, sonic booms would not result in impacts on marine species beneath the surface, even when the new information regarding the vehicle landings is considered.

Listed Marine Species

The 2022 LOC and the 2022 PEA considered an expendable Starship landing in the Pacific Ocean. Launch profiles that include Starships not configured to survive atmospheric reentry would be the same as those impacts described for expendable landings. Potential impacts on listed marine species from expendable Starship landings in the Pacific Ocean would be the same in the proposed expanded landing area as they would be in the previously analyzed landing areas the same species have the potential to be present in both locations.

The 2022 LOC and the 2022 PEA did not contemplate the potential effects of an explosive event near the ocean's surface for Starship's landing.[3] Consistent with the requirements of NEPA and Council on Environmental Quality (CEQ) NEPA-implementing regulations, SpaceX identified and used reliable, existing data and, when appropriate, best available, credible scientific evidence to evaluate the reasonably foreseeable environmental effects associated with a Starship intact impact with the ocean's surface and the subsequent explosive event. The FAA independently evaluated and approved an analysis methodology developed by SpaceX that relies on the robust application of scientific

[3] As previously stated, if Super Heavy completes the descent phases as nominally planned, SpaceX expects Super Heavy to land intact in the Gulf of Mexico and would sink. An explosive event is not expected for Super Heavy.

principles; a conservative estimation of the necessary coefficients based on available, existing reference data; and the application of appropriate species harassment thresholds taken directly from NMFS, which have been relied upon by the US Navy and US Air Force (NMFS 2023). The methodology, which is provided in as part of the 2023 consultation materials in Appendix A to this WR, identifies the affected area from the explosive event over which NMFS thresholds could be exceeded for ESA listed species, if present.

Calculating the potentially affected area, referenced in Appendix A, within which ESA-listed marine species could be harassed is one of the required inputs for conducting a quantitative analysis of potential impacts on listed species. Data on the abundance and distribution of the species in the potentially affected area is also required to conduct a quantitative analysis of potential impacts. According to previous consultations between the U.S. Navy and NMFS, the most appropriate metric for this type of analysis is density, which is the number of animals present per unit area (U.S. Navy 2018). Marine mammal and sea turtle density estimates are available for the area off of Hawaii where Starship would land (U.S. Navy 2017).[4] When density varied by seasons, the highest density was used in order to account for the potential for the proposed action to occur at any time of year. Table 1 provides the subset of species from the 2022 LOC that have the potential to be present in the originally analyzed and proposed expanded Starship landing areas. Table 1 also lists the NMFS hearing group associated with each species.

Table 1. ESA-listed Species Present in the Starship Landing Area

Species	NMFS Hearing Group
Blue Whale	Low Frequency (LF) Cetacean
False killer whale, Main Hawaiian Islands Insular DPS	Mid-Frequency (MF) Cetacean
Fin Whale	Low Frequency (LF) Cetacean
Sei Whale	Low Frequency (LF) Cetacean
Sperm Whale	Mid-Frequency (MF) Cetacean
Hawaiian Monk Seal	Phocid pinniped
Green Turtle Central Pacific DPS	Turtle
Hawksbill Turtle	Turtle
Leatherback Turtle	Turtle
Loggerhead Turtle North Pacific DPS	Turtle
Olive Ridley Turtle	Turtle
Giant Manta Ray	Fish[a]
Oceanic Whitetip Shark	Fish[a]

[a] The fish are an injury group, not a hearing group, since hearing-related injuries cannot be assessed in fish.

Using the potentially affected area within which ESA-listed marine species could be harassed, and the highest seasonal density (i.e., the most conservative) data available for the ESA-listed species that could be present, SpaceX calculated the number of marine mammals and sea turtles that could potentially be harassed by a Starship explosive event near the ocean's surface in the landing area (see Table 2). As shown in Table 2 below, the number of ESA-listed marine mammals and sea turtles

[4] Density estimates are not available for the two fish species that have the potential to be present in the Starship landing area.

expected to be harassed is less than one. Therefore, Starship descent and landing operations may affect, but are not likely to adversely affect, any ESA-listed marine mammals or sea turtles.

Very little published literature exists on giant manta ray occurrence and behavior in U.S. waters, and population trend information is not clear or available for the oceanic whitetip shark (NMFS 2019, U.S. Navy 2018). As density estimates are not available for these two fish species, it is not possible to conduct a quantitative effects analysis for these species. The United Nations Educational, Scientific and Cultural Organization Ocean Biodiversity Information System (UNESCO OBIS) provides distribution data for both species (UNESCO 2023). According to the UNESCO OBIS, the giant manta ray and oceanic whitetip shark have not been documented in the vicinity of the Starship landing area or the affected area where the harassment thresholds would be exceeded. Nearby sightings of both species around the Hawaiian Islands have been limited (UNESCO 2023). Further, the Starship landing area is well offshore where density of marine species decreases compared to coastal environments and upwelling areas (FAA 2017). Due to the limited area of ocean that may result in overpressure events from the Starship, the short time frame over which they would occur, the anticipated low densities of the giant manta ray and oceanic whitetip shark, and the low probability of these species being within the area at the time of the event, Starship descent and landing operations may affect, but are not likely to adversely affect, these species.

The Marine Mammal Protection Act (MMPA) requires that an incidental take authorization be obtained for the unintentional “take” of marine mammals (e.g., by harassment) incidental to otherwise lawful activities. As stated in the 2022 LOC, the action agencies and/or their commercial space partners are required to apply for an MMPA authorization from NMFS if their activities could subject marine mammals to “take” as defined by the MMPA. Using the same methodology developed to assess potential effects on ESA-listed species, SpaceX calculated the number of marine mammals protected under the MMPA that could potentially be harassed by a Starship explosive event near the ocean’s surface (see Table 3). As shown in Table 3 below, the number of marine species protected under the MMPA expected to be harassed is less than one. Therefore, the Proposed Action would not subject marine mammals to take as defined by the MMPA, and authorization is not required (16 United States Code 1361 et seq.).

Table 2. Species Harassment Results for Marine Mammals and Sea Turtles

Blast Inputs	
TNT Yield (kg)	1260
Surface Pressure in air (kPa)	6435
Transmission Coefficient	0.140
Water Peak Source Sound Level	
Surface Pressure in Water (kPa)	144465
Peak SPL dB (re 1 uPa)	283.2

Enter 4.5m Incident Pressure from: https://unsaferguard.org/un-saferguard/kingery-bulmash

INPUTS | CALCS | RESULTS

Species Data (Pacific)			NMFS Thresholds (dB re 1 uPa)		Harassment Area (km^2)		Species Harassment Results	
Species	**Type**	**Density (per km^2)**	**PTS**	**TTS**	**PTS**	**TTS**	**PTS**	**TTS**
Blue Whale	LF cetacean	0.00005	219	213	8.25	32.86	0.000413	0.001643
False killer whale	MF cetacean	0.000796	230	224	0.66	2.61	0.000522	0.002078
Fin Whale	LF cetacean	0.00006	219	213	8.25	32.86	0.000495	0.001972
Sei Whale	LF cetacean	0.00016	219	213	8.25	32.86	0.001321	0.005258
Sperm Whale	MF cetacean	0.001941	230	224	0.66	2.61	0.001273	0.005066
Hawaiian Monk Seal	Phocid pinniped	0.00003	218	212	10.39	41.37	0.000312	0.001241
Green Turtle Central North Pacific DPS*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Hawksbill Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Leatherback Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Loggerhead Turtle North Pacific DPS*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Olive Ridley Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Species	**Type**	**Density (per km^2)**	**Onset of Physical Injury (dB re 1 uPa)**		**Injury Area (km^2)**		**Species Injury Results**	
Giant Manta Ray	Fish	Unavailable	206		164.69		Unavailable	Unavailable
Oceanic Whitetip Shark	Fish	Unavailable	206		164.69		Unavailable	Unavailable

*These species are analyzed under the sea turtle guild due to a lack of reasonable in-water density estimates for individual sea turtle species.

Source: US Navy 2017.

Table 3. Species Harassment Results for Marine Mammals Protected Under the MMPA

Blast Inputs								
TNT Yield (kg)	1260							
Surface Pressure in air (kPa)	6435	Enter 4.5m Incident Pressure from: https://unsaferguard.org/un-saferguard/kingery-bulmash						
Transmission Coefficient	0.140							
Water Peak Source Sound Level								
Surface Pressure in Water (kPa)	144465		INPUTS	CALCS	RESULTS			
Peak SPL dB (re 1 uPa)	283.2							

Species Data (Pacific)			NMFS Thresholds (dB re 1 uPa)		Harassment Area (km^2)		Species Harassment Results	
Species	Type	Density (per km^2)	PTS	TTS	PTS	TTS	PTS	TTS
Bryde's whale	LF cetacean	0.000123	219	213	8.25	32.86	0.0010153	0.0040419
Minke whale	LF cetacean	0.005717	219	213	8.25	32.86	0.0471895	0.1878649
Blainville's beaked whale	MF cetacean	0.000966	230	224	0.66	2.61	0.0006334	0.0025215
Cuvier's beaked whale	MF cetacean	0.0003	230	224	0.66	2.61	0.0001967	0.0007831
Dwarf sperm whale	MF cetacean	0.00714	230	224	0.66	2.61	0.0046814	0.0186370
Longman's beaked whale	MF cetacean	0.00378	230	224	0.66	2.61	0.0024784	0.0098666
Pygmy sperm whale	MF cetacean	0.00291	230	224	0.66	2.61	0.0019080	0.0075957
Melon-headed whale	MF cetacean	0.002	230	224	0.66	2.61	0.0013113	0.0052204
Pygmy killer whale	MF cetacean	0.0044	230	224	0.66	2.61	0.0028849	0.0114850
Risso's dolphin	MF cetacean	0.01021	230	224	0.66	2.61	0.0066943	0.0266504
Short-finned pilot whale	MF cetacean	0.014449	230	224	0.66	2.61	0.0094736	0.0377151
Bottlenose dolphin	MF cetacean	0.005686	230	224	0.66	2.61	0.0037281	0.0148417
Fraser's dolphin	MF cetacean	0.021	230	224	0.66	2.61	0.0137688	0.0548147
Pantropical spotted dolphin	MF cetacean	0.009518	230	224	0.66	2.61	0.0062406	0.0248441
Rough-toothed dolphin	MF cetacean	0.00888	230	224	0.66	2.61	0.0058222	0.0231788
Spinner dolphin	MF cetacean	0.003062	230	224	0.66	2.61	0.0020076	0.0079925
Striped dolphin	MF cetacean	0.003724	230	224	0.66	2.61	0.0024417	0.0097205

Source: US Navy 2017.

On April 14, 2023 NMFS provided a letter of concurrence for the FAA's determination of may affect, but is not likely to adversely affect ESA-listed species and designated habitat when considering this additional information. Please see the letter in Appendix A.

The NMFS concurrence letter includes the following discretionary conservation recommendations:

- We recommend the FAA and SpaceX gather acoustic data on the explosive event expected for the first flight of Starship/Super Heavy. Sound source verification may help to more accurately determine the impacts of this near-surface explosion scenario in the future.
- During any nighttime vessel operations (e.g., vessel operations during 24–48 hour debris survey), in addition to the Vessel Operations PDCs, we recommend vessel speeds not to exceed 10 knots to reduce the risk of lethal or injurious vessel strike. We also recommend that dedicated observers (Education and Outreach PDCs) are equipped with nighttime visual equipment (e.g., night vision, thermal imaging, infrared binoculars) to identify protected species in the dark.
- In an off-nominal event where Super Heavy does not land at the landing location in the Gulf of Mexico, effort should be made to move any potential landing out of the Rice's whale core distribution area boundaries. Additionally, no vessel transit should take place in the Rice's whale core distribution area unless to specifically sink Super Heavy (in an off-nominal event where Super Heavy did not sink after landing) and then immediately exit at the nearest boundary edge while staying out of the core habitat area with depths of 100 meters to 425 meters, where the Rice's whale has been observed (Rosel et al. 2021).
- The action agency should coordinate with NMFS ESA Interagency Cooperation Division to foster collaboration with the NOAA Marine Debris Program (MDP), in order to evaluate how activities of the MDP may apply to debris that originates from space launch and reentry operations (e.g., expended vehicle components).

Essential Fish Habitat

The study area for essential fish habitat (EFH) would include the new areas shown on Figure 1. No additional EFH beyond those discussed in the 2022 PEA would be affected. As described in the 2022 PEA, in the event of a failure, there could be a potential impact on marine species and EFH as the launch vehicle debris would fall into the ocean areas.[5]

SpaceX expects most of the Starship launch vehicle would sink because it is made of steel. Super Heavy would soft water land and is expected to sink. As described in the 2022 PEA, expendable stage landings would not result in permanent changes to physical parameters (temperature, salinity, oxygen concentration, etc.) of the water column. The amount of propellant, metals, or other substances that could leach or dissolve into the water column or substrate after the vehicle sinks to the ocean floor would be minimal and would not result in detectable changes to water or sediment quality. Additionally, the probability an expended vehicle impacting EFH would be considered negligible given

[5] This could also occur during unassisted Starship descent, which is not considered a failure.

the small number of number (five) of landings per year in the study area; therefore, there would be no effects on EFH.

Lighter items (e.g., items not made of steel, such as composite overwrapped pressure vessels, which are lightweight storage vessels able to hold high pressurized gases and fluids) may float but are expected to eventually become waterlogged and sink. If there are reports of large debris, SpaceX would coordinate with a party specialized in marine debris to survey the situation and sink or recover as necessary any large floating debris. As stated previously, SpaceX expects all fuel onboard Starship to be consumed during vehicle breakup, as all residual propellant would be combusted. As all liquid fuel is likely to be consumed during vehicle breakup, only structural debris would remain. Structural debris is made of inert materials and are not anticipated to affect water quality. In summary, there may be temporary adverse effects to EFH, particularly in the event of launch failure involving the spread of debris and release of hazardous material (e.g., liquid propellant). The FAA consulted NMFS regarding this EFH adverse effect determination. NMFS provided two Conservation Recommendations pursuant to 50 CFR §600.920, which SpaceX and the FAA have agreed to implement:

- Conservation Recommendation 1: Prior to any in-water work (i.e., debris recovery or sinking), SpaceX will ensure all ballast and vessel hulls do not pose a risk of introducing new invasive species and that project implementation will not increase abundance of invasive species present at the project site. SpaceX will sanitize any equipment that has been previously used in an area known to contain invasive species prior to its use for project activities.
- Conservation Recommendation 2: The FAA will coordinate with NMFS in the case of a launch failure and any vessel grounding to determine if consultation re-initiation is appropriate.

Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant impacts on biological resources.

Climate

Climate impacts, taking into account the new information related to the Proposed Action, would be similar to those discussed in the 2022 PEA. As stated in the 2022 PEA, greenhouse gas (GHG) emissions from commercial space launch projects represent a small percentage of global GHG emissions. The 2022 PEA determined that estimated carbon dioxide emissions from annual operations of the Starship/Super Heavy program are significantly less than the total GHG emissions generated by the United States and the total carbon dioxide emissions generated worldwide. As described in the 2022 PEA, after Super Heavy lands, residual methane would eventually be released to the atmosphere. While SpaceX now expects the combustion of remaining propellant associated with Starship descent and landing activities, and that would result in GHG emissions, these impacts would be minimal when compared to the annual carbon dioxide emissions generated by the Starship/Super Heavy program, which were determined to be insignificant. For unassisted descents where the vehicle would break up during descent through the atmosphere, as described in the 2022 PEA for expendable missions, residual fuel would be dispersed and evaporate. Based on the anticipated infrequency of the descent and landing activities, and the short time frame over which they would occur, GHG emissions would be negligible.

The operation of the detonation suppression system for launch would not result in an increase in the amount of air pollutant emissions reported in the 2022 PEA.

Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant climate impacts.

Hazardous Materials, Solid Waste, and Pollution Prevention

Hazardous materials, solid waste, and pollution prevention impacts, taking into account the new information related to the Proposed Action, would be comparable to those discussed in the 2022 PEA. The 2022 PEA notes that Starship could contain residual methane upon landing depending on specific mission characteristics. Super Heavy is expected to land intact and sink and Starship would break apart in the open ocean. Structural debris of both Starship and Super Heavy is made of inert materials, such as steel, carbon composite, silica heat tiles and is not anticipated to affect water quality. As Super Heavy would remain intact, residual propellant and fuel would be retained and not released into the ocean but may eventually warm up, turn gaseous, and vent to the atmosphere through open valves. As described in the 2022 PEA, the residual methane vented to the atmosphere would evaporate within hours.

Starship is expected to experience an explosive event upon impact with the ocean's surface and subsequent vehicle failure. As all liquid fuel is likely to be consumed during Starship's breakup, only structural debris would remain. Structural debris is made of inert materials and is not anticipated to affect water quality. While not anticipated, SpaceX would respond to all accidental releases of polluting substances quickly and implement appropriate clean up measures in accordance with applicable laws to minimize impacts to the environment, as the associated mitigation measures in the 2022 PEA states. For unassisted descents where the vehicle would break up during descent through the atmosphere, residual fuel would be dispersed and evaporated such that only structural debris would remain, as described in the 2022 PEA. If there are reports of large debris, SpaceX would coordinate with a party specialized in marine debris to survey the situation and sink or recover, as necessary, any large floating debris.

The operation of the detonation suppression system for launch would not result in an increase in the amount of Hazardous Materials, Solid Waste, and Pollution Prevention reported in the 2022 PEA.

Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant hazardous materials, solid waste, and pollution prevention impacts.

Noise and Noise-Compatible Land Use

Noise and noise-compatible land use impacts, taking into account the new information related to the Proposed Action, would be comparable to those discussed in the 2022 PEA. The descent of both Starship and Super Heavy is anticipated to produce sonic booms. As described in the 2022 PEA, predicted sonic boom overpressures for Super Heavy descent and landing in the Gulf of Mexico range from 0.2 psf to approximately 12 psf. The modeled Super Heavy descent and landing sonic boom footprint is anticipated to be entirely over the Gulf of Mexico. Predicted sonic boom overpressures for Starship descent and landing in the Pacific Ocean are up to 2 psf. The modeled Starship descent and landing sonic boom footprint is entirely over the water.

Super Heavy would remain intact after impacting the ocean's surface. For the first launch, Starship would impact the ocean horizontally, where it would experience structural failure. For unassisted descents where the vehicle would break up during descent through the atmosphere, there would be no noise impacts as it would occur 50 km AGL. The vehicle's structural failure would allow the remaining LOX and methane to mix, leading to an explosive event above the water's surface that would result in complete vehicle break up and combustion of all remaining fuel. This explosive event would generate a blast wave, or overpressure. However, given the distance from the anticipated landing locations to the shore (and therefore any noise sensitive areas), the anticipated infrequency of these events, and the short time frame over which they would occur, the overpressure events would not result in significant noise impacts.

The operation of the detonation suppression system for launch would not result in an increase in the amount of noise impacts reported in the 2022 PEA.

Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant noise and noise-compatible land use impacts.

Water Resources (including Wetlands, Floodplains, Surface Waters, Groundwater, Ocean Waters, and Wild and Scenic Rivers)

Impacts on water resources, taking into account the new information related to the Proposed Action, would be comparable to those described in the 2022 PEA. Structural debris of both Starship and Super Heavy is made of inert materials, such as steel, carbon composite, silica heat tiles and is not anticipated to affect water quality. As Super Heavy would remain intact, residual propellant and fuel would be retained and not released into the ocean but may eventually warm up, turn gaseous, and vent to the atmosphere through open valves. For the first launch, Starship is expected to experience an explosive event upon impact with the ocean's surface and subsequent vehicle failure. The explosive event would be expected to consume all remaining fuel. As all liquid fuel is likely to be consumed during vehicle breakup, only structural debris would remain. For unassisted descents where the vehicle would break up during descent through the atmosphere, residual fuel would be dispersed and evaporated such that only structural debris would remain. As stated in the 2022 PEA, non-recoverable debris would sink to the ocean bottom. Accordingly, the data and analyses contained in the 2022 PEA remain substantially valid, and the Proposed Action would not result in significant impacts on water resources.

Impacts on water resources under the Proposed Action would be comparable to those impacts described in the 2022 PEA for operation of the detonation suppression system. There would be no impacts to Wild and Scenic Rivers. As stated above, a majority (if not all) of the water would be vaporized by the heat of the rocket engines. Any remaining water would be collected in a system of gutters and directed to an onsite lined sump pit that is pumped out and hauled offsite.

Conclusion

The 2022 PEA examined the potential for significant environmental impacts from Starship/Super Heavy launch operations at the Boca Chica Launch Site and defined the regulatory setting for impacts associated Starship/Super Heavy. The areas evaluated for environmental impacts in this WR included air quality; biological resources (marine wildlife); climate; hazardous materials, solid waste, and pollution prevention; noise and noise-compatible land use; and water resources (ocean waters).

Based on the above review and in conformity with FAA Order 1050.1F, Paragraph 9-2.c, the FAA has concluded that the issuance of a vehicle operator license for Starship/Super Heavy operations conforms to the prior environmental documentation, that the data contained in the 2022 PEA remains substantially valid, that there are no significant environmental changes, and all pertinent conditions and requirements of the prior approval have been met or will be met in the current action. Therefore, the preparation of a supplemental or new environmental document is not necessary to support the Proposed Action.

STACEY MOLINICH ZEE

Digitally signed by STACEY MOLINICH ZEE
Date: 2023.04.14 16:30:05 -04'00'

Responsible FAA Official: ___________________________________

Location and Date Issued: ___________________________________

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Appendix A. 2023 NMFS Consultation Letter, Consultation response, and Underwater Noise Analysis Methodology for Starship/Super Heavy

U.S. Department
of Transportation
Federal Aviation Administration

Office of Commercial Space Transportation

800 Independence Ave., SW.
Washington, DC 20591

April 4, 2023 (revised submittal – original dated March 6, 2023)

Consulting Biologist
Endangered Species Act Interagency Cooperation Division
Office of Protected Resources
National Marine Fisheries Service
Silver Spring, MD 20910

RE: Project Specific Review Request, OPR-2021-02908, Programmatic Concurrence for Launch Vehicle and Reentry Operations

Dear Consulting Biologist,

The Federal Aviation Administration (FAA) is requesting a project-specific review due for the Space Exploration Technologies Corp.'s (SpaceX) Starship/Super Heavy additional information regarding the federal action previously analyzed in consultation OPR-2021-02908. As stated in the January 31, 2022 National Marine Fisheries Service (NMFS) Letter of Concurrence (2022 LOC), NMFS issued a single programmatic LOC to the FAA for launch and reentry vehicle operations in the marine environment, which included Starship/Super Heavy launch vehicle operations at Space Exploration Technologies Corp.'s (SpaceX) Boca Chica Launch Site.

The FAA is continuing to evaluate SpaceX's proposal to operate its Starship/Super Heavy launch vehicle at its existing Boca Chica Launch Site in Cameron County, Texas. SpaceX's proposed operations include launches originating from this site, as well as landings at this site, in the Gulf of Mexico, or in the Pacific Ocean off the coast of Kauai, Hawaii. As further discussed below, SpaceX provided the FAA with additional information regarding vehicle reentry operations. This letter provides an update to the project description that details the operations and determination of effects on Endangered Species Act (ESA) listed species that could result from the project.

Project Description

The FAA's Proposed Action is the same as previously analyzed – to issue an experimental permit and/or vehicle operator license for Starship/Super Heavy operations. Since publication of the 2022 PEA, SpaceX provided the FAA with additional information regarding Starship and Super Heavy planned descents during the first launch. Based on Starship's hardware configuration, for the first launch, SpaceX plans to conduct a passive descent that would result in Starship's intact impact with the ocean's surface. Starship's planned landing location for the first launch is shown in Figure 1 below. Super Heavy would land intact in the Action Area described in the 2022 LOC and is shown below in Figure 2.

To provide SpaceX with additional launch planning flexibility for the first launch, SpaceX proposes to expand Starship's ocean landing area approximately 155 miles to the north of the one described in the

2022 PEA. The proposed expanded landing area, which is shown in yellow in Figure 1, does not equal the impact area from a single Starship landing; rather, it represents the area within which Starship could land. The nominal plan is to land in the passive descent landing location as shown in Figure 1. Any landing location within the green and yellow area other than the pinned location shown would not be considered nominal.

SpaceX also proposes to add an area southwest of Hawaii, uprange of the ocean landing area, to account for the potential Starship debris field for the second and third launches of Starship that are not configured to survive atmospheric reentry. The area of the debris field is determined by performing a debris analysis for an uncontrolled Starship entry. In this scenario the vehicle enters the atmosphere uncontrolled and breaks up above 70 km AGL and the resulting debris is propagated through the atmosphere to impact. The area is then generated to bound the debris impact locations from the debris analysis. It is theoretically possible for debris to land outside of this area, but the debris area shown is representative of a nominal uncontrolled entry based on flight modeling This area is shown in red in Figure 1. The depths for the areas in red, yellow and green are approximately 4,570 meters deep.

During Starship launches not configured to survive atmospheric entry (the second and third launches), this would be considered an expendable mission and the impacts consistent with those analyzed in the 2022 LOC. As described in the 2022 LOC, the vehicle is not expected to survive re-entry and any debris is expected to have sufficient mass to sink to the seafloor. For the first three launches, if telemetry-based evidence provided to SpaceX by on-board equipment on each vehicle stage or other information provided to SpaceX by other surveillance assets suggests large floating debris, SpaceX would act to mitigate the downrange debris in coordination with U.S. Coast Guard (USCG) to verify the debris sinks within 10 days as noted in the January 31, 2022 National Marine Fisheries Service (NMFS) Letter of Concurrence (2022 LOC).

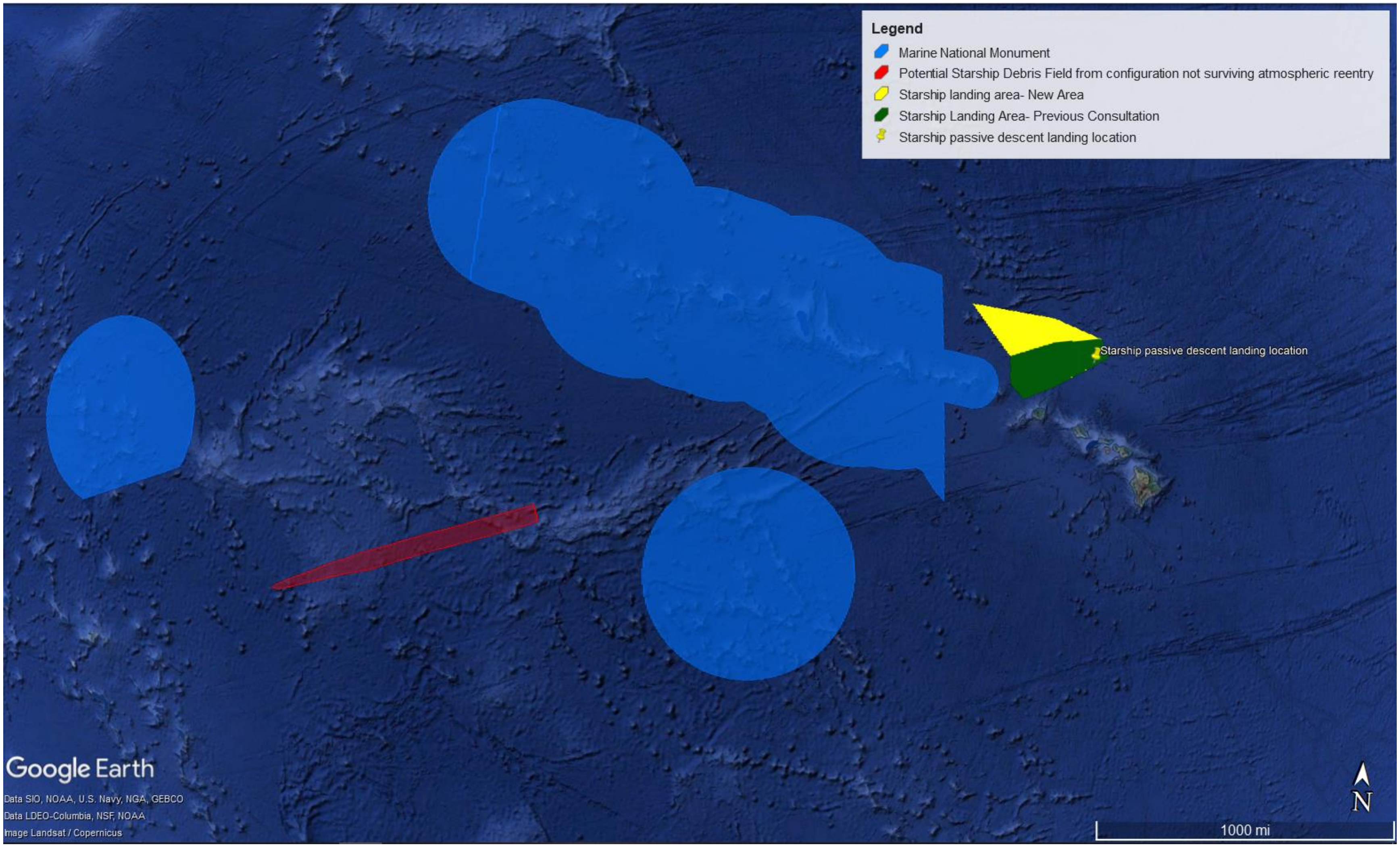

Figure 1: Starship Nominal Landing Areas

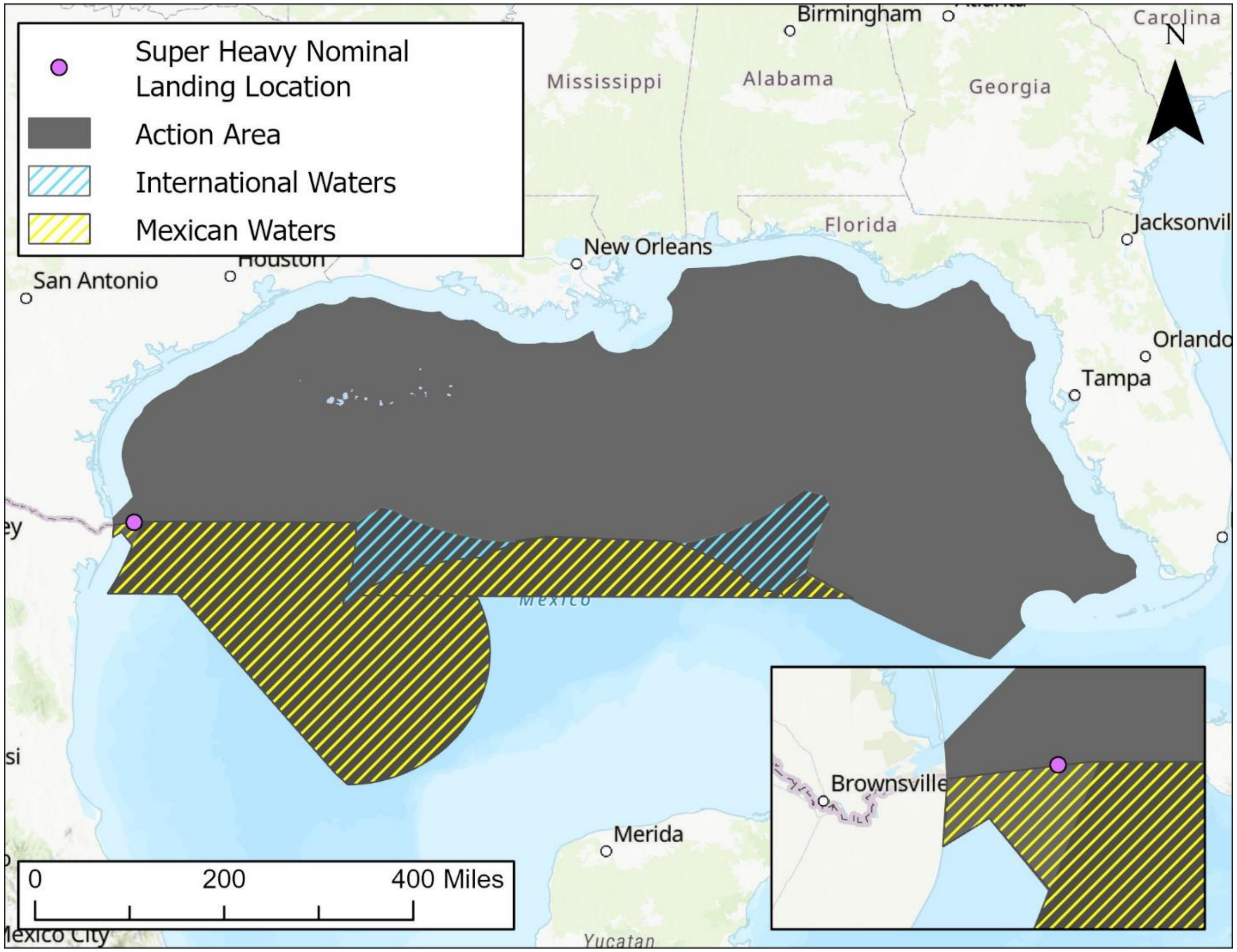

Figure 2: Starship Nominal Landing Areas

Starship/Super Heavy Ocean Landings

The following paragraphs provide additional detail that more clearly defines the launch profile for Starship's and Super Heavy's planned landings for the first launch. If Super Heavy completes the descent phases as nominally planned, SpaceX expects Super Heavy to land intact in the Gulf of Mexico and sink. If Starship completes the descent phases as nominally planned, SpaceX expects Starship would explode and break up upon impact with the Pacific Ocean's surface, where most debris would be expected to sink. As stated in the 2022 PEA, SpaceX would sink or recover as necessary and to the greatest extent possible any large floating debris. Additional detail regarding the events that would occur during descent is provided below.

Super Heavy: After stage separation of the Super Heavy from Starship, the flight plan is for Super Heavy to conduct a boost-back burn prior to descending into the atmosphere. After descent through the atmosphere, Super Heavy would conduct a landing burn to approximately the ocean's surface and then impact the water at approximately 8.5 meters/second. After the landing burn ends, the flight plan is for Super Heavy to impact the water vertically and intact. Then, within several seconds, Super Heavy would tip over and impact the water horizontally. The landing would impart forces onto the liquid oxygen (LOX) tank and methane tank; however, the tanks' structural capabilities allow it to withstand these forces. Therefore, the tanks would remain intact, and there would be no resultant interaction between the LOX and methane. Super Heavy is expected to remain intact. Following the landing burn, tank valves on Super Heavy would open causing the tanks to flood with sea water after landing. Super Heavy would sink at an angle (similar to a sinking ship). Sea water would flood the tanks through the fill drain valves near the bottom. As the tanks flood, the vehicle would become waterlogged and sink to the ocean floor. If an off-nominal event, Super Heavy did not sink, SpaceX would attempt to scuttle Super Heavy. The primary means of scuttling the vehicle is to remotely open the tank vents allowing water to ingress into the tank and sink the vehicle. If the vents are determined to be closed, SpaceX would attempt to command the valves open, inducing the flooding. Should SpaceX receive positive confirmation that the valves are open but the vehicle is not taking on water, SpaceX would attempt to orientate the vehicle in a manner that would be expected to induce sinking by using a vessel to physically interact with the vehicle and cause it to roll on its long axis. This could be accomplished with a vessel and tow line attached to the aft end of the vehicle or grid fins. During an off-nominal event where Super Heavy did not sink, additional methods for scuttling could be considered such as puncturing the outer shell of the vehicle using a firearm or remote operating vessel. Consistent with the 2022 LOC, it is SpaceX's goal to recover and reuse the Super Heavy boosters. However, during the first three launches, SpaceX may require landing the Super Heavy in the Gulf of Mexico intact and then sink.

Starship: For the first launch**,** after ascent engine cutoff, Starship would vent residual main tank propellant during the in-space coast phase of the launch at or above 120 kilometers AGL. Following the in-space coast phase, Starship would begin its passive descent. Some residual LOX (approximately 10 metric tons) and methane (approximately 4 metric tons) would remain in Starship, which is the minimum amount that can remain in Starship after venting to serve as ballast in order to successfully maintain trajectory to the landing location. The 14 metric tons of remaining propellant represents approximately 1.1 percent of the total fill levels for the Starship main tanks. Starship would impact the Pacific Ocean intact, horizontally, and at terminal velocity (i.e., the steady speed achieved by a freely falling object), and the impact would disperse settled remaining propellants and drive structural failure of the vehicle. The structural failure would immediately lead to failure of the transfer tube, which would allow the remaining LOX and methane to mix, resulting in an explosive event.

SpaceX would expend Starship (break up upon atmospheric entry) following the second and third launches. The Starships would be expended in the red area shown in Figure 1.

As required by 14 C.F.R. Chapter III, SpaceX would coordinate directly with the USCG to protect public health and safety prior to any launch or reentry activity licensed by the FAA that overflies or affects Navigable Waters. SpaceX and USCG have entered into the *Letter Of Intent (LOI) For Space Exploration Technologies Corp. (SpaceX) to Provide Information Related To Launch And Reentry Operations To The United States Coast Guard (USCG) For Launch And Reentry Operations In The Coast Guard Pacific Area (PACAREA) Area Of Responsibility (AOR) To Ensure Safety Of The Maritime Domain* (U.S. Coast Guard 2022) that outlines coordination efforts (Section 5 and 6 of the LOI) to ensure that any hazards to the environment or navigation are properly managed and mitigated[1]. These coordination efforts are described below.

Following the Starship breakup, SpaceX would have a vessel in the area of highest likelihood of debris that would identify large debris for salvage.[2,3] SpaceX would use the vessel to survey the debris field for approximately of 24 to 48 hours (using visual survey in the day and onboard vessel radar at night) depending on the outcome of the breakup. The initial survey area would be determined based on last known data location point received from the telemetry on the vehicle upon splashdown. Weather and ocean current data would be used to further characterize the debris field as the operation is conducted. During the operation SpaceX would coordinate findings and action items directly with the USCG Sector 14 to ensure all of the requirements of the LOI are met. SpaceX vessels would be equipped with multiple forms of communication equipment (Starlink, VHF, Sat phone) to enable communications directly with USCG representatives while offshore. As explained in the 2022 PEA and LOC, for all landing events in the

[1] Note, the current signed LOI is applicable for the first mission. Each subsequent mission, as required for the FAA license application, SpaceX will work with the USCG to develop agreement based on the mission.

[2] Text from the LOI, Section 5.b) states: Response Plans: SpaceX will provide current copies of a Response Plan to the PACAREA Prevention Branch and the applicable Coast Guard District's Waterways Management Branch(es). This Response Plan will include the procedures necessary to contain, minimize the adverse effects of, and respond to the foreseeable consequences of a mishap, as such term is defined in 14 C.F.R. § 401. 7, occurring in the conduct of the launch and/ or reentry, launch/reentry accident, launch/reentry incident, or other mishap, as such terms are defined in 14 C.F.R. § 401.5, occurring in the conduct of an FAA-licensed activity, and at a minimum, will include procedures to mitigate hazards to public health and safety and the contamination of waterways and adjacent coastline.

[3] Text from the LOI, Section 5.c) states: "Salvage Vessel(s): SpaceX has agreed to and shall arrange a contract with salvage vessel(s) of adequate size, strength, and capability for retrieval of any vehicle reentering PACAREA AOR, and shall do so at least one week prior to the launch. The salvage vessel(s) will be staged at the site of reentry at least the day prior to launch, approximately 16 nautical miles cross range from the nominal landing location. To look for debris, SpaceX will use last known telemetry and radar information to direct initial search location and then switch to relying on a visual search from the vessel(s). If the black boxes are transmitting their location, SpaceX will also use that information for guidance. The search will begin immediately after landing and continue for a minimum of 24 hours. SpaceX will report back any findings to the applicable District Waterways Management Branch(es) and Command Center Points of Contact. In addition, SpaceX shall notify the Coast Guard of any other salvage assets being used during this time period."

ocean, if debris is generated, SpaceX expects the majority of the Starship debris would sink because it is made of steel and will have sufficient mass to sink to the seafloor (U.S. Navy 2022). Debris is expected to sink within the nominal landing location (240 nm east of the Papahanaumokuakea Marine National Monument) and is not expected to drift into the Papahanaumokuakea Marine National Monument. Some lighter items (e.g., items not made of steel, such as composite overwrapped pressure vessels) may float but they are expected to become water-logged and sink. Though not expected and unlikely, if there is floating debris found by the vessel during the debris field survey, SpaceX would sink or recover any floating debris before it could drift into the Papahanaumokuakea Marine National Monument by physically removing the item or puncturing the item to cause it to sink. Methods to physically remove debris could include using a net or a boat hook. Methods for puncturing debris to help induce sinking would be the same as described above for Super Heavy. SpaceX would report debris findings to the USCG to determine the most appropriate method of recovery or sinking as described above and would be on a case-by-case basis depending on personnel safety, vessel safety, and capability. As mentioned earlier, SpaceX would act to mitigate the debris in coordination with U.S. Coast Guard (USCG) to verify the debris sinks within 10 days as noted in the January 31, 2022 National Marine Fisheries Service (NMFS) Letter of Concurrence (2022 LOC). If debris is still identified after the 24-48 hours survey and recovery efforts, SpaceX would use another method including, an aerial asset, an additional vessel or satellite imaging to confirm and characterize any debris and take appropriate action to retrieve or sink it. SpaceX would also attempt to locate the launch vehicle launch recording device (aka the "black box") which has a global positioning system (GPS) tracking signal. Should the recording device be located, scuba divers may be deployed to facilitate device retrieval.

As described in the 2022 LOC, any aircraft and surveillance vessels (watercraft) described above would comply with the Project Design Criteria (PDCs)'s environmental protection measures for vessel operations and/or aircraft procedures.

Determination of Effects

The 2022 LOC identifies potential stressors to ESA-listed species from the proposed activities; these include impact by fallen objects: spacecraft, rocket parts, radiosonde; exposure to hazardous materials; exposure to sonic booms (overpressure) and impulse noise generated during spacecraft reentry or stage landings in the ocean; ship strike; and harassment by aircraft overflight. The additional information provided by SpaceX regarding Starship reentry operations does not change any of the analysis or effects determinations for these stressors. Accordingly, these potential stressors are not addressed herein.

The 2022 LOC and the 2022 PEA considered an expendable Starship landing in the Pacific. Launch profiles that include Starships not configured to survive atmospheric reentry would be the same as those impacts described for expendable landings. The 2022 LOC and the 2022 PEA did not contemplate the potential effects of an explosive event near the ocean's surface for Starship's landing[4]. Consistent with the requirements of the National Environmental Policy Act (NEPA) and Council on Environmental Quality (CEQ) NEPA-implementing regulations, SpaceX identified and used reliable, existing data and, when appropriate, best available, credible scientific evidence to evaluate the reasonably foreseeable environmental effects associated with a Starship intact impact with the ocean's surface and the subsequent explosive event. The FAA independently evaluated and approved an analysis methodology developed by SpaceX that relies on the robust application of scientific principles; a conservative

[4]As previously stated, if Super Heavy completes the descent phases as nominally planned, SpaceX expects Super Heavy to land intact in the Gulf of Mexico and sink. An explosive event is not expected for Super Heavy.

estimation of the necessary coefficients based on available, existing reference data; and the application of appropriate species harassment thresholds taken directly from NMFS, which have been relied upon by the US Navy and US Air Force. This methodology, which is provided in Attachment 1 to this letter, identifies the affected area from the explosive event over which NMFS thresholds could be exceeded for ESA-listed species, if present.

Calculating the potentially affected area, referenced in Attachment 1, within which ESA-listed marine species could be harassed is one of the required inputs for conducting a quantitative analysis of potential impacts on listed species. Data on the abundance and distribution of the species in the potentially affected area is also required to conduct a quantitative analysis of potential impacts. According to previous consultations between the U.S. Navy and NMFS, the most appropriate metric for this type of analysis is density, which is the number of animals present per unit area (U.S. Navy 2018). Marine mammal and sea turtle density estimates are available for the area off of Hawaii where Starship would be expended (U.S. Navy 2017).[5] When density varied by seasons, the highest density was used in order to account for the potential for the proposed action to occur at any time of year. Table 1 provides the subset of species that have the potential to be present in the Starship landing area from those identified in the 2022 LOC. Table 1 also lists the NMFS hearing group associated with each species.

Table 1. ESA-listed Species Present in the Starship Landing Area

Species	NMFS Hearing Group
Blue Whale	Low Frequency (LF) Cetacean
False killer whale, Main Hawaiian Islands Insular DPS	Mid-Frequency (MF) Cetacean
Fin Whale	Low Frequency (LF) Cetacean
Sei Whale	Low Frequency (LF) Cetacean
Sperm Whale	Mid-Frequency (MF) Cetacean
Hawaiian Monk Seal	Phocid pinniped
Green Turtle Central Pacific DPS	Turtle
Hawksbill Turtle	Turtle
Leatherback Turtle	Turtle
Loggerhead Turtle North Pacific DPS	Turtle
Olive Ridley Turtle	Turtle
Giant Manta Ray	Fish[a]
Oceanic Whitetip Shark	Fish[a]

[a] The fish are an injury group, not a hearing group, since hearing-related injuries cannot be assessed in fish.

Using the potentially affected area within which ESA-listed marine species could be harassed, and the highest seasonal density (i.e., the most conservative) data available for the ESA-listed species that could be present, SpaceX calculated the number of marine mammals and sea turtles that could potentially be harassed by an explosive event near the ocean's surface (see Table 2). As shown in Table 2 below, the number of ESA-listed marine mammals and sea turtles expected to be harassed is less than one. Therefore, Starship descent and landing operations may affect, but are not likely to adversely affect, any ESA-listed marine mammals or sea turtles.

[5] Density estimates are not available for the two fish species that have the potential to be present in the Starship landing area.

Very little published literature exists on giant manta ray occurrence and behavior in U.S. waters, and population trend information is not clear or available for the oceanic whitetip shark (NMFS 2019, U.S. Navy 2018). As density estimates are not available for the two fish species that have the potential to be present in the Starship landing area, it is not possible to conduct a quantitative effects analysis for these species. The United Nations Educational, Scientific and Cultural Organization Ocean Biodiversity Information System (UNESCO OBIS) provides distribution data for both species (UNESCO 2023). According to the UNESCO OBIS, the giant manta ray and oceanic whitetip shark have not been documented in the vicinity of the Starship landing area or the affected area where the harassment thresholds would be exceeded. Nearby sightings of both species around the Hawaiian Islands have been limited (UNESCO 2023). Further, the Starship landing area is well offshore where density of marine species decreases compared to coastal environments and upwelling areas (FAA 2017). Due to the limited area of ocean that may result in overpressure events from Starship, the short time frame over which they would occur, the anticipated low densities of the giant manta ray and oceanic whitetip shark, and the low probability of these species being within the area at the time of the event, Starship descent and landing operations may affect, but are not likely to adversely affect, these species.

Table 2. Species Harassment Results for Marine Mammals and Sea Turtles

Blast Inputs	
TNT Yield (kg)	1260
Surface Pressure in air (kPa)	6435
Transmission Coefficient	0.140
Water Peak Source Sound Level	
Surface Pressure in Water (kPa)	144465
Peak SPL dB (re 1 uPa)	283.2

Enter 4.5m Incident Pressure from: https://unsaferguard.org/un-saferguard/kingery-bulmash

INPUTS | CALCS | RESULTS

Species Data (Pacific)			NMFS Thresholds (dB re 1 uPa)		Harassment Area (km^2)		Species Harassment Results	
Species	**Type**	**Density (per km^2)**	**PTS**	**TTS**	**PTS**	**TTS**	**PTS**	**TTS**
Blue Whale	LF cetacean	0.00005	219	213	8.25	32.86	0.000413	0.001643
False killer whale	MF cetacean	0.000796	230	224	0.66	2.61	0.000522	0.002078
Fin Whale	LF cetacean	0.00006	219	213	8.25	32.86	0.000495	0.001972
Sei Whale	LF cetacean	0.00016	219	213	8.25	32.86	0.001321	0.005258
Sperm Whale	MF cetacean	0.001941	230	224	0.66	2.61	0.001273	0.005066
Hawaiian Monk Seal	Phocid pinniped	0.00003	218	212	10.39	41.37	0.000312	0.001241
Green Turtle Central North Pacific DPS*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Hawksbill Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Leatherback Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Loggerhead Turtle North Pacific DPS*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Olive Ridley Turtle*	Turtle	0.0043	232	226	0.41	1.65	0.001779	0.007082
Species	**Type**	**Density (per km^2)**	**Onset of Physical Injury (dB re 1 uPa)**		**Injury Area (km^2)**		**Species Injury Results**	
Giant Manta Ray	Fish	Unavailable	206		164.69		Unavailable	Unavailable
Oceanic Whitetip Shark	Fish	Unavailable	206		164.69		Unavailable	Unavailable

*These species are analyzed under the sea turtle guild due to a lack of reasonable in-water density estimates for individual sea turtle species.

Source: US Navy 2017.

Conclusion

The FAA is requesting NMFS's written concurrence with our effect determinations. Thank you for your assistance in this matter. Please contact Amy Hanson, FAA Environmental Specialist, via email at Amy.Hanson@faa.gov or phone at 847.243.7609 to discuss any questions or concerns.

Sincerely,

[March 6, 2023 version signed by Stacey Zee]

Stacey Zee
Manager, Operations Support Branch

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Attachment 1. Underwater Noise Analysis Methodology for Starship Orbital Test Flight Vehicle

Underwater Noise Analysis Methodology for Starship Orbital Test Flight Vehicle

LIST OF SYMBOLS

P_s = Incident Pressure from explosion
A, B, C, D, E, F, G = Kingery-Bulmash empirically derived coefficients, values depend on scaled distance and desired output units for incident pressure
Z_s = Scaled distance
R = Range (distance)
W = TNT yield
I = Intensity, subscript represents medium e.g. air vs. water
T_c = Transmission coefficient
P = Local pressure, subscript represents medium
Z_I = Impedance, subscript represents medium
L = Sound Pressure Level (SPL), subscript represents type of SPL used e.g. peak vs. range
P_{ref} = Reference pressure used in SPL calculations
A = Area

This document presents a methodology for use in assessing the potential impacts of underwater noise that may result from an intact Starship vehicle impact (and resultant explosion) with the ocean's surface. Consistent with the National Environmental Policy Act's (NEPA) requirements, SpaceX identified credible scientific evidence that is relevant to evaluating the reasonably foreseeable environmental effects associated with an intact Starship ocean landing. SpaceX has developed and documented an analysis methodology that relies on the robust application of scientific principles; a conservative estimation of the necessary coefficients based on available, existing reference data; and the application of appropriate species harassment thresholds taken directly from the National Marine Fisheries Service (NMFS), which have been relied upon by the US Navy and US Air Force. This document provides a step-by-step guide and representative calculations as relevant to the identification of the area within which federally protected marine species protected under the Endangered Species Act (ESA) could be harassed, if present, given an explosive yield. Analysis and determinations relevant to the Marine Mammal Protection Act are provided in the Federal Aviation Administration's (FAA) draft Written Re-evaluation.

The intact Starship vehicle impact will have three events with the potential to create shockwaves: vehicle impact upon the surface of the water; rupture of fuel tanks; and an in-air explosive yield resulting from fuel explosion. This methodology is specifically focused on the noise impact associated with an in-air explosive yield resulting from the fuel explosion, as SpaceX expects the energy associated with this event will significantly exceed any shockwave from the vehicle impacting the water or the rupture of the fuel tanks. FAA analysis supports the fuel explosion creating the greatest explosive yield of the three events.

Step 1. Calculate the acoustic properties of the explosive event on the air side of the air/water boundary using the simplified Kingery-Bulmash equations as modified by Swisdack. These properties are calculated by propagating the blast wave from a height of 4.5 meters, the shortest distance between the transfer tube (explosive source) and the primary structure (water surface) at the time of impact, from the source through air.

While the outer radius of the vehicle is in contact with the water surface, SpaceX has demonstrated to FAA that the most likely and reasonably foreseeable origin of an explosion during an intact Starship ocean landing is from inside the vehicle. This explosion will occur at the point where fuel is transferred through the liquid oxygen tank. Consequently, there is space between the explosion and the surface of the water. The "object exploding" should be considered the inner transfer tube of the vehicle, and not the entire vehicle, as described below. The sequence of events leading to this explosion source, discussed below, is consistent with past real-world observations of Starship explosions resulting from impact with a surface, and with which FAA has concurred. Specifically, FAA has concurred that "the explosion due to impact likely initiates a small distance above the water's surface."[1] The modeled energy release from a fuel explosion, caused by an intact Starship's impact on the surface of the water, will significantly exceed the energy associated with the surface impact itself, also discussed below. Here again, FAA has concurred that the fuel explosion will create the greatest energy release of the three events involved, including the surface impact. While the Starship explosion at the transfer tube is best modeled by a spherical model, the use of a hemispherical model in this methodology is comparatively conservative and accounts for other sources of uncertainty, such as the effects of propagation through gaseous oxygen and the potential for blast reflection off of interior structures like the engine section.

Figure 1 shows the sequence of events that is analyzed to assess the potential underwater noise impacts from Starship's intact ocean impact. Figure 1 shows a cutaway of the aft section of the vehicle. The sequence of events is summarized below and explained in further detail in the corresponding sections of this memo.

1. **Vehicle Impact:** The Starship vehicle impacts the water at terminal velocity and at 90° angle of attack (horizontal). The impact disperses settled remaining propellants and drives structural failure.
2. **Structural Failure and Propellant Mixing:** The structural failure leads to cracks propagating throughout the structure at the speed of sound through steel. Cracks eventually lead to failure of the transfer tube, allowing fuel and liquid oxygen (LOX) to mix.
3. **Ignition and Explosive Event:** The mixed propellants find an ignition source in the proximity of the transfer tube and detonate.
4. **Blast Propagation to Air/Water Boundary:** The blast wave propagates outward towards the air/water boundary. In-air attenuation models are used to calculate the acoustic properties in the air on the air side of the boundary.
5. **Transmission Across Air/Water Boundary:** Assuming that the vehicle's steel structure is not blocking the air/water boundary, the acoustic properties on the water side of the boundary are calculated based on an estimated transmission coefficient for a near-surface explosion.
6. **Underwater Sound Attenuation Model:** Using the Sound Pressure Level (SPL) in the water directly below the explosion as the peak source sound level, SpaceX uses the NMFS recommendation of an omnidirectional source to calculate the sound attenuation in water.
7. **Calculation of Range of Threshold Exceedance:** SpaceX calculates the range at which the NMFS recommended Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) harassment thresholds are exceeded for the relevant species. The range of exceedance is then used to calculate impact areas for each impact type (PTS/TTS) for each species.

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[1] Email from Jacob Cantin, Federal Aviation Administration, to Matthew Thompson, SpaceX, November 3, 2022.

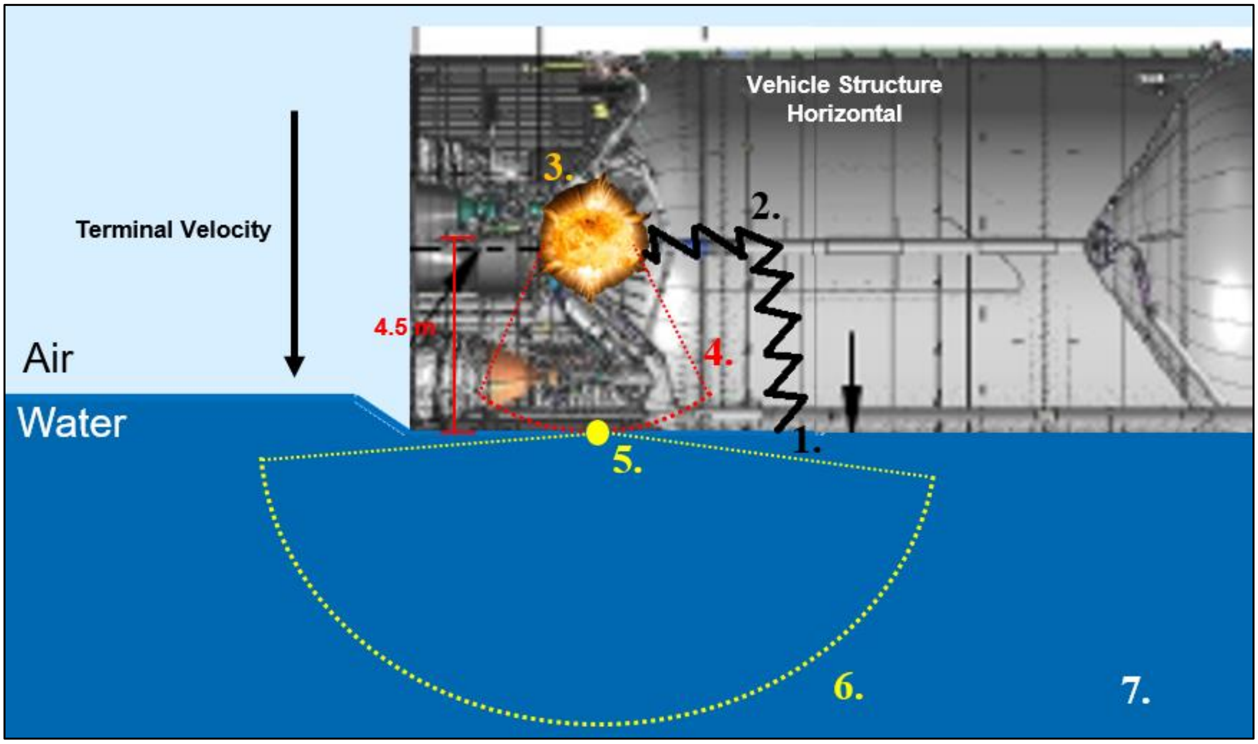

Figure 1: Sequence of events analyzed to assess potential underwater noise impacts from a Starship explosion

Items 1 through 3 in Figure 1 show the reasonably foreseeable sequence of events that would lead to an explosive event when the vehicle impacts the ocean surface at terminal velocity, in order to predict the location within the vehicle structure where the explosion is likely to originate. The conclusion, based on these events, is that the blast will initiate in the proximity of the fuel transfer tube and is most likely to originate from the aft end of the transfer tube, as pictured in Figure 1.

Figure 2 shows an internal cross section of the Starship vehicle immediately prior to impact with key vehicle hardware noted; station heights are given in millimeters relative to the full stack vehicle frame, which has an origin at the base of the Super Heavy booster. The location of residual liquid fuel (methane) is shown in the highlighted red region. During entry, the fuel main tank is isolated from the transfer tube such that liquid fuel residuals are fully contained within the approximately 13-meter long transfer tube that runs through the liquid oxygen (LOX) tank. The locations of residual LOX are shown in the highlighted blue regions. LOX residuals will exist in both the LOX main tank, the LOX header tank, and the LOX header tank feedlines. LOX main tank residuals will be mostly concentrated on the windward side of the tank due to the drag force experienced by the vehicle falling through the atmosphere.

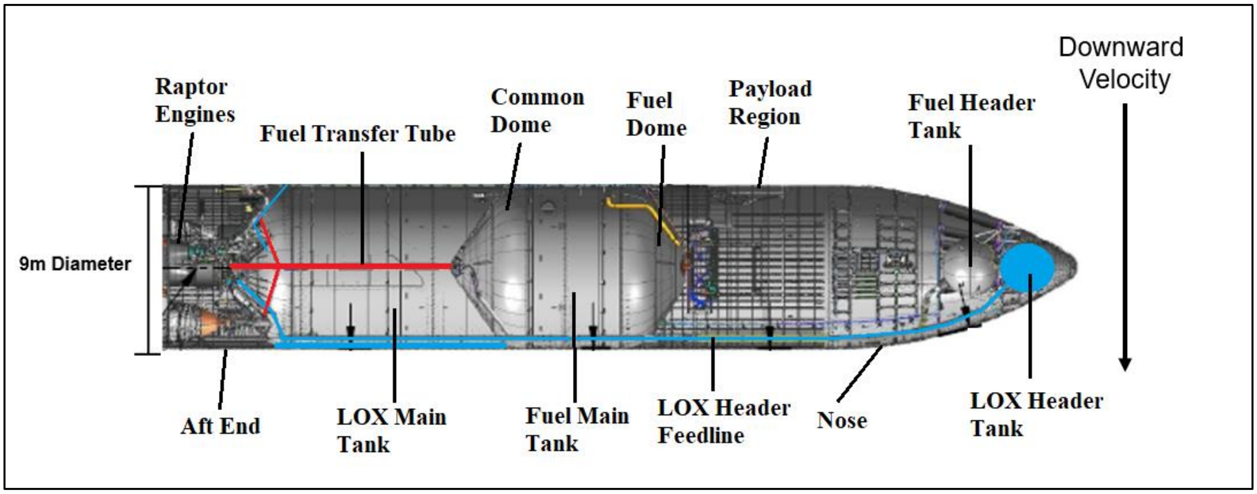

Figure 2: Starship internal cross section during terminal descent phase prior to impact

Figure 3 depicts the state of the vehicle immediately after impact. The LOX that was settled on the windward side of the LOX main tank will be fully dispersed throughout the tank by the force of the impact, while the fuel will remain confined within the transfer tube. There are three reasonably foreseeable failure modes for the fuel transfer tube, the first being denoted by the central crack. Given that the mass of the transfer tube is relatively high, it will have more inertia than the surrounding empty LOX tank. This will cause the transfer tube to flex through the central portion and exert stresses on the tube structure that it was not designed to handle. This could reasonably lead to a failure of the transfer tube in portion due to flex stresses. The other reasonable failure modes result from the propagation of main tank structural failures. At the point of impact, the main tank is expected to fail, resulting in large cracks that will propagate through the steel structure at the speed of sound (approximately 5,100 m/s for steel). There are two paths for these cracks to propagate to the transfer tube: 1) the aft end engine structure, or 2) the common dome. In either case, the cracks would propagate to the transfer tube and cause failure at the tube's structural interface with either the engine section or the common dome.

Irrespective of the specific failure scenario, the failure of the transfer tube is expected to occur instantaneously following Starship's impact with the water. This assumption is supported by the work summarized by Lambert et. al. which states that "shock simulations of impacting liquid propellant vehicles and considerations of the shock impedance of the vehicle materials led to the conclusion that for impact speeds greater than a few feet per second, shock waves capable of breaking apart the propellant tanks would travel much faster than the speed of the vehicle impacting the surface."[2] For this analysis the fuel propellant tank is the transfer tube.

[2] Lambert, R.R. et al. (2021). Distant Focusing Overpressure Risk Assessment Methods, 11th IAASS Conference, Rotterdam, Netherlands, October 2021.

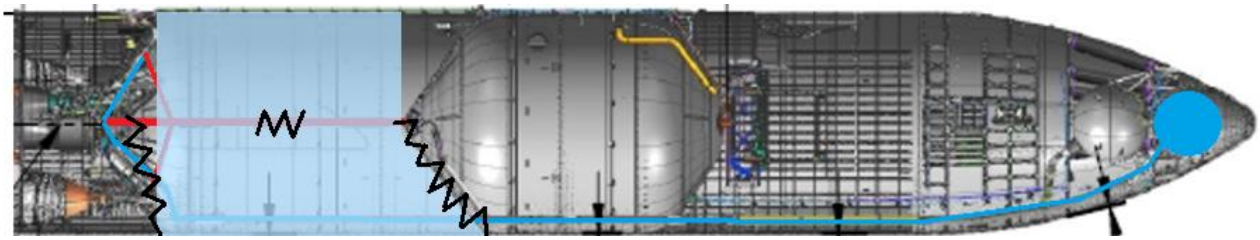

Figure 3: Starship internal cross section immediately after impact

Wherever the transfer tube failure occurs, the fuel will be released and will subsequently mix with the cloud of LOX now dispersed throughout the tank. This liquid LOX/methane mixture is expected to detonate immediately. Unlike gases that must transition from deflagration to detonation once ignited, the liquid mixture will behave as a high explosive, such that any ignition source, spark, flame, hot metal, and shock, will drive the bulk fluid to detonate within microseconds as a high explosive with any and all mixed propellant detonation at that moment. Here, components still at a high temperature from the orbital entry are expected to be the most likely ignition sources. Because the highest number of these components are located in the aft end, the aft end transfer tube interface is the most likely location for the explosive center. However, explosive centers at the central portion and the common dome interface are also considered reasonably foreseeable, potentially driven by auto-ignition or hot surfaces along steel cracks. Because the vehicle will be in a horizontal configuration at impact each potential explosive center is the same distance from the surface of the water. Figure 4 shows the potential explosive centers considered by SpaceX for this analysis, the water's surface in this figure would be parallel to the bottom of the figure. SpaceX's conclusions are also supported by the work summarized by Lambert et. al. which states that "the center of explosion at the interface between the fuel and oxidizer tanks would occur above any crater formed in an impact surface material into which the vehicle could penetrate."[3] Again, for this analysis, the interface between the fuel and oxidizer tanks is the region around the transfer tube.

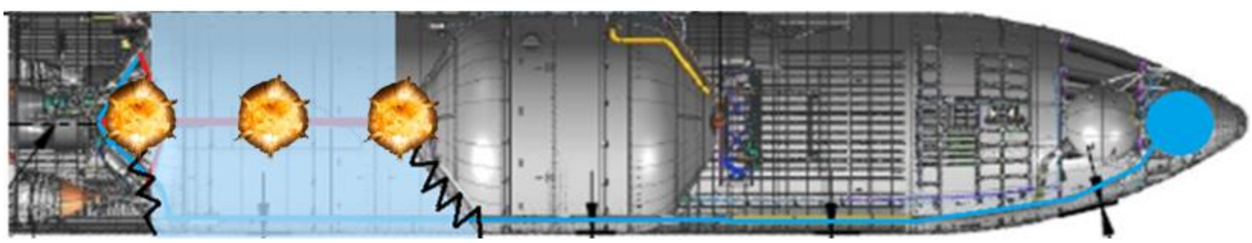

Figure 4: Starship internal cross section showing most likely locations of an impact driven explosion

SpaceX has been able to gather real-world evidence to further support the conclusion that the explosive source is near the transfer tube. For example, Figure 5 shows a frame-by-frame breakdown of Starship during the SN10 explosion: because this explosion happened on the ground, a few minutes after impact, SpaceX was able to focus high speed video cameras on the aft end of the vehicle. In the top row of images, an equal volume of gas can be seen coming out of vents on all sides of the vehicle, indicating an explosive source near the center. In the lower center image, there is a clear sign of an explosion within the vehicle when the tank begins to tear allowing the first light to pass through. Finally, the lower right image shows

[3] Ibid.

the effects of the explosion again being seen on both sides of the vehicle. After the lower right image, the vehicle structure fails fully and the image saturates.

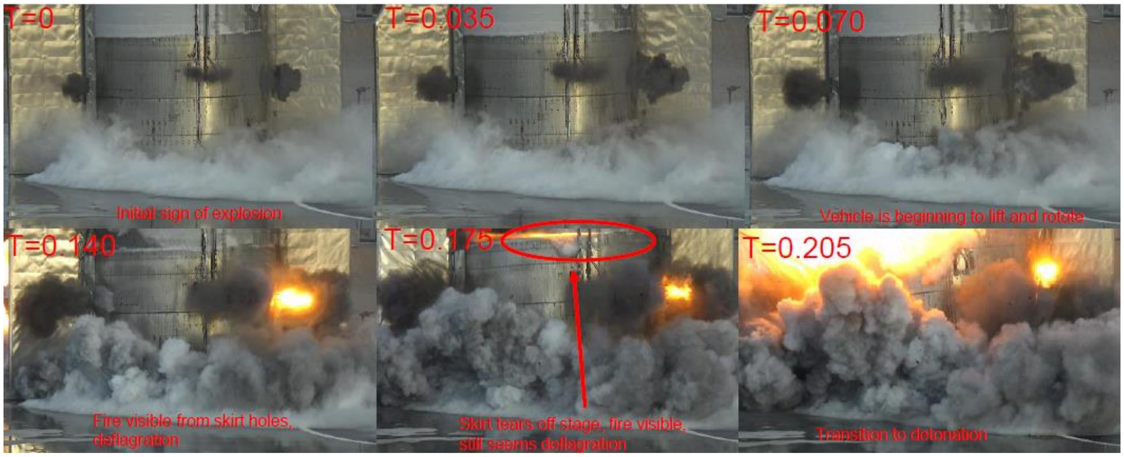

Figure 5: Frame-by-frame video review of SN10 explosion showing evidence of an internal explosive center

Given the above, SpaceX has determined that it is reasonably foreseeable that the explosive center is at the transfer tube and that the explosion occurs immediately following the ocean impact. While the aft end is the most likely location for the explosive center, the exact location along the transfer tube will not have an effect on the analysis, because the vehicle is in the horizontal configuration and so all locations along the transfer tube will be the same distance from the explosive center.

To calculate the acoustic properties, SpaceX uses the simplified Kingery-Bulmash equations as modified by Swisdack.[4] The Kingery-Bulmash equations are empirically derived from a vast set of experimental data and are commonly used in blast analysis to predict maximum incident blast overpressure and other blast parameters. In their simplified form, as used here, the equations can only be used to model a surface burst. While the Starship explosion at the transfer tube is best modeled by a spherical model, the use of a hemispherical model, as done in this methodology, is comparatively conservative as the hemispherical model directs all of the explosive energy downwards towards the water surface. This results in a greater overpressure prediction at the air/water interface than a spherical model. The use of a hemispherical model also accounts for other sources of uncertainty, such as the effects of propagation through gaseous oxygen and the potential for blast reflection off of interior structures like the engine section.

Additionally, guidance for how to calculate explosive parameters is provided in UFC-3-340, which is a Government-released document that is the standard for explosive parameter calculation in the industry. This document envelopes the information provided by Kingery-Bulmash and Swisdack.[5]

The simplified Kingery-Bulmash equation takes the form shown in Equation 1; the coefficients used to calculate incident peak overpressure are shown in Table 1. The equation uses a scaled distance, Zs, which is calculated using the equation shown in Equation 2, where R is the range in meters and W is the charge

[4] M. Swisdack, Simplified Kingery Airblast Calculations, Web, https://apps.dtic.mil/sti/pdfs/ADA526744.pdf, Accessed 15 November 2022.
[5] https://www.denix.osd.mil/ddes/denix-files/sites/32/2018/07/2018-06-11-DDESB-TP-202c-DDESB-Blast-Effects-Computer-Open-BEC-O2c-V...-1.pdf

weight in kilograms. The simplified Kingery-Bulmash equations have been shown to be accurate to within 1% of the conventional equations for scaled distances of 0.2 to 200 m/kg$^{1/3}$.

Equation 1: Swisdack's simplified Kingery-Bulmash equation

$$P_s = e^{\left(A+B\times \ln Z_s + C\times(\ln Z_s)^2 + D\times(\ln Z_s)^3 + E\times(\ln Z_s)^4 + F\times(\ln Z_s)^5 + G\times(\ln Z_s)^6\right)}$$

Table 1: Swisdack's equation coefficients for calculating incident peak overpressure for hemispherical surface bursts

Incident Peak Overpressure, P_s (Unit: kPa(psi))							
Z	A	B	C	D	E	F	G
0.2~2.9 (0.5~7.25)	7.2106 (6.9137)	−2.1069 (−1.4398)	−0.3229 (−0.2815)	0.1117 (−0.1416)	0.0685 (0.0685)	0 (0)	0 (0)
2.9~23.8 (7.25~60)	7.5938 (8.8035)	−3.0523 (−3.7001)	0.40977 (0.2709)	0.0261 (0.0733)	−0.01267 (−0.0127)	0 (0)	0 (0)
23.8~198.5 (60~500)	6.0536 (5.4233)	−1.4066 (−1.4066)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Equation 2: Scaled distance

$$Z_s = \frac{R}{W^{\frac{1}{3}}}$$

SpaceX's predicted peak overpressure results for the air side of the air/water boundary are given in Table 2. The predicted incident peak overpressure estimates can be verified using the calculator provided by UN SaferGuard[6]. This calculator can also be used to get peak overpressure results at different ranges or different yields, as long as they are within the valid range of scaled distances.

Table 2: Sample predicted peak overpressure values at air/water boundary

Yield	1,260 kg Explosive Weight (SN11's 9% Yield)
Incident Peak Overpressure @ 4.5 m	6,435 kPa

Note: 1,260 kg is the FAA supported estimate for explosive yield of the 14,000 kg of anticipated residual propellant at the time of S24's future intact impact of the water, based on data obtained from SN11's test flight on March 30, 2021.

Step 2. Calculate the transmission of the wave across the air/water boundary and the acoustic properties on the water side of the boundary. These properties are calculated by determining the portion of the acoustic wave that is transmitted into the boundary.

When an acoustic wave reaches a boundary, a portion of the wave reflects off of the boundary and a portion of the wave is transmitted into the boundary. The amount of reflection, defined by a reflection coefficient, is dependent on the angle of incidence and the magnitude of the impedance mismatch between the two materials. Since energy must be conserved across the boundary, the transmission coefficient is one minus the reflection coefficient. Air and water have a large impedance mismatch, as

[6] UN SaferGuard, Kingery-Bulmash Blast Parameter Calculator, Web, https://unsaferguard.org/un-saferguard/kingery-bulmash, Accessed 15 November 2022.

shown in Table 3, with water having approximately 3,600 times the impedance of air. The intensity reflection coefficient can be calculated as impedance mismatch, divided by the total impedance, squared; as shown in Equation 3. The intensity transmission coefficient is given by Equation 4.

An example of a normal acoustic wave reaching an air/water boundary is shown in Figure 6. The difference in impedance between air and water leads to an intensity reflection coefficient of 99.9% and an intensity transmission coefficient of 0.11%. This means that 99.9% of the wave intensity reflects off of the boundary back into the air and just 0.11% of the intensity is transmitted into the water. For any angle of incidence greater than 0 the transmission coefficient would be even lower, for transmission to be possible the angle of incidence must be less than the critical angle. For the air/water boundary this critical angle is approximately 13°.

Table 3: Impedance values for relevant materials

Material	Impedance (kg m^{-2} s^{-1})
Air	421.4
Water	1.5×10^6

Equation 3: Intensity reflection coefficient at boundary

$$R_c = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

Equation 4: Intensity transmission coefficient at boundary

$$T_c = 1 - R_c = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$

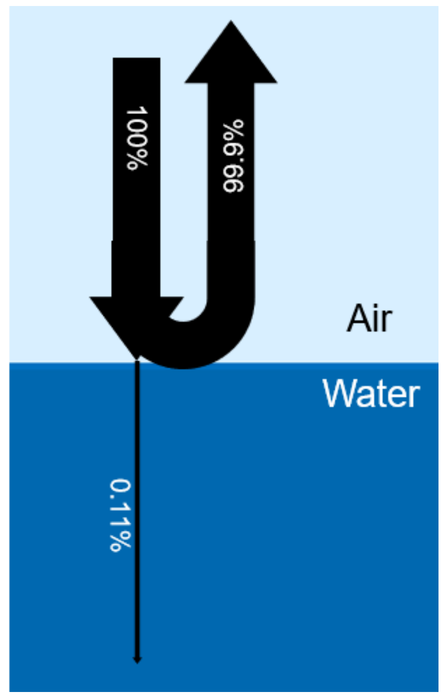

Figure 6: Air/water example

Acoustic intensity is defined as the pressure squared divided by the impedance, as shown in Equation 5.

Equation 5: Acoustic intensity

$$I = \frac{P^2}{Z}$$

For the transmission of the blast wave across the air/water boundary, the transmission coefficient from Equation 4 can be used to determine the intensity below surface, based on the intensity above the surface, and the intensity transmission coefficient, as shown in Equation 6.

Equation 6: Intensity in water based on intensity in air and transmission coefficient

$$I_w = I_a T_c$$

Substituting Equation 5 into Equation 6 and solving for the pressure in the water gives the relation shown in Equation 7. Since the ratio of impedance between water and air is roughly 3,600 and the transmission coefficient roughly 0.11%, most terms in Equation 7 can be combined to give a direct factor between the pressure in the air just above the surface and the pressure in the water just below the surface. Equation 8 shows that the pressure in the water would be roughly double the pressure in the air.

Equation 7: Pressure in water based on pressure in air and boundary transmission

$$\frac{P_w^2}{Z_w} = \frac{P_a^2}{Z_a} T_c$$

$$P_w = \sqrt{P_a^2 \frac{Z_w}{Z_a} T_c}$$

$$P_w = P_a \sqrt{\frac{Z_w}{Z_a} T_c}$$

Equation 8: Pressure in water for air/water boundary transmission

$$P_w = P_a \sqrt{\frac{1.5E6}{421} \times 1.1E-3} = 1.99 \times P_a$$

This analysis is consistent with the findings from the Air Force's sonic boom research, which concludes that "For plane waves incident at angles less than critical, the pressure in the water is approximately twice the pressure of the wave in the air. The transmitted intensity, however, is only about 0.11% of the incident intensity due to the impedance mismatch between the air and water."[7] However, the FAA concluded, and SpaceX agrees that, sonic boom research was not applicable to this scenario stating, stating that "an explosion event is different from a sonic boom" and that the research could not be used "because the air-water surface is within the near-field of the explosion, and there is likely significant coupling between the explosion and the water."[8] FAA's conclusion is supported when examining the scaled distances involved with sonic boom research, typically in the hundreds of m/kg$^{1/3}$ compared to the scaled distance of this scenario of 0.5 to 1 kg/m$^{1/3}$.

SpaceX assumes an intensity transmission coefficient of 14%, this represents a near-field transmission coefficient which is more than 100 times greater than the far-field air/water boundary transmission coefficient of 0.11%. This conservative transmission coefficient accounts for the limited scope of research into near-surface explosions and their transmission across the air/water boundary.

There are several factors that confirm that the 14% transmission coefficient will bound the real-world intensity transmission from a near-surface explosion. This value was selected based on research into the

[7] US Air Force, Supersonic Aircraft Noise At and Beneath the Ocean Surface: Estimation of Risk for Effects on Marine Mammals, https://apps.dtic.mil/sti/pdfs/ADA395062.pdf, Accessed 15 November 2022
[8] Email from Jacob Cantin, Federal Aviation Administration, to Matthew Thompson, SpaceX, November 3, 2022.

transmission coefficients derived from other near-surface explosive events. Based on available research, the 14% coefficient conservatively bounds the limited, applicable technical analysis that could be found.

For example, with respect to the existing research into the underwater effects of near-surface explosions, comprehensive studies were conducted by Lawrence Livermore National Laboratories (LLNL) between 1994 and 1998. These studies sought to determine if near-surface nuclear weapons testing could be detected by the underwater noise monitoring network set up to ensure enforcement of the terms of nuclear test ban treaties. The work began in 1994 with M. Kamegai and J. W. White developing a computer simulation model for both underwater and in-air nuclear blasts near the ocean surface.[9] Their analysis, looked at 1kt and 10kt at various heights/depths and calculated the predicted downward kinetic energy in the water. The results of this analysis are shown in Figure 7; the energy transferred to the water decreases rapidly as the explosion occurs at higher altitudes above the surface. For explosions above 20 meters altitude the effective transmission coefficient of energy across the water boundary appears close to the acoustic wave prediction of 0.001. At the surface, the effective transmission coefficient is approximately 2%; however, the authors of the paper do not clearly specify what the downward kinetic energy variable represents, and the fact that it has a maximum value of 15%, rather than 100%, indicates that it may not be fully accounting for the total energy transfer. Therefore, to ensure that SpaceX is applying the data in a reasonable manner, SpaceX assumed the relationship to be correct, but *increased* the maximum effective transmission coefficient to 100% for underwater blasts. This results in the shifted curve shown in the right of Figure 7 and is the first source of data for the transmission coefficient selected by SpaceX of 14%.

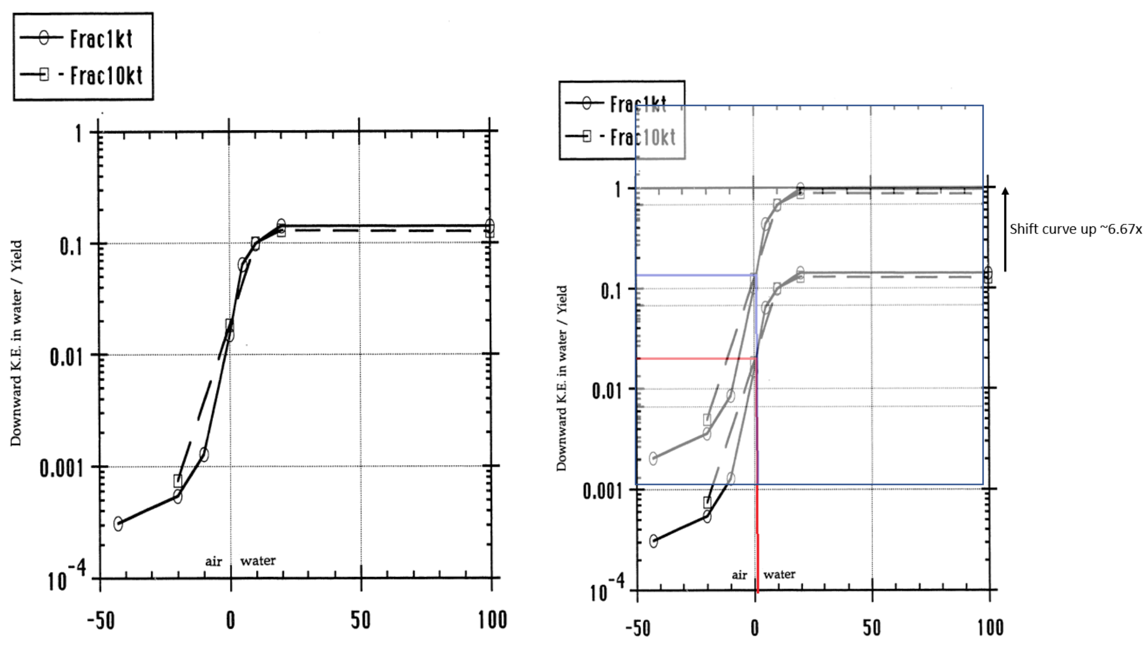

Figure 7: Original (left) and shifted (right) trend between downward energy and explosion height/depth[10]

[9] M. Kamegai and J. W. White, A Study of Near-Surface and Underwater Explosions by Computer Simulations, February 1994, https://www.osti.gov/servlets/purl/10137363, Accessed 7 November 2022
[10] Ibid.

Note that for a 1kt explosion, the altitudes that would result in an equivalent scaled distance to that of the Starship explosion (0.45 $m/kg^{1/3}$ to 0.97 $m/kg^{1/3}$) would be an altitude of 45m and 97m respectively. For a 10kt explosion these altitudes are 97m and 209m. In every case, the scaled distances involved would support the use of the lowest kinetic energy factors observed in the Figure 7 analysis.

An updated set of simulation results was published by J.W. White and D. Clarke in 1997.[11] This analysis looked at a larger range of burst depths/heights and expanded the simulations to model the outward motion of the blast waves, as opposed to the 1994 work that only looked at the downward energy. Figure 8 shows the simulation results for various 1kt explosion burst depths/heights in terms of the total wave energy in the water at 10 km range. The authors noted that the range of pressures associated with these results ranged from around 100,000 Pa to 200 Pa. The quoted ratio of 500 in pressure results matches up with the approximately 5 orders of magnitude decrease in wave energy shown in the results. Again, these more advanced simulation results show that the energy in the water decreases significantly for higher altitude explosions. For the equivalent Starship height of burst (45-100m altitude) the energy in the water would be over 4 orders of magnitude less than that of an underwater explosion. Again, the analytical results support 14% as a conservative transmission coefficient.

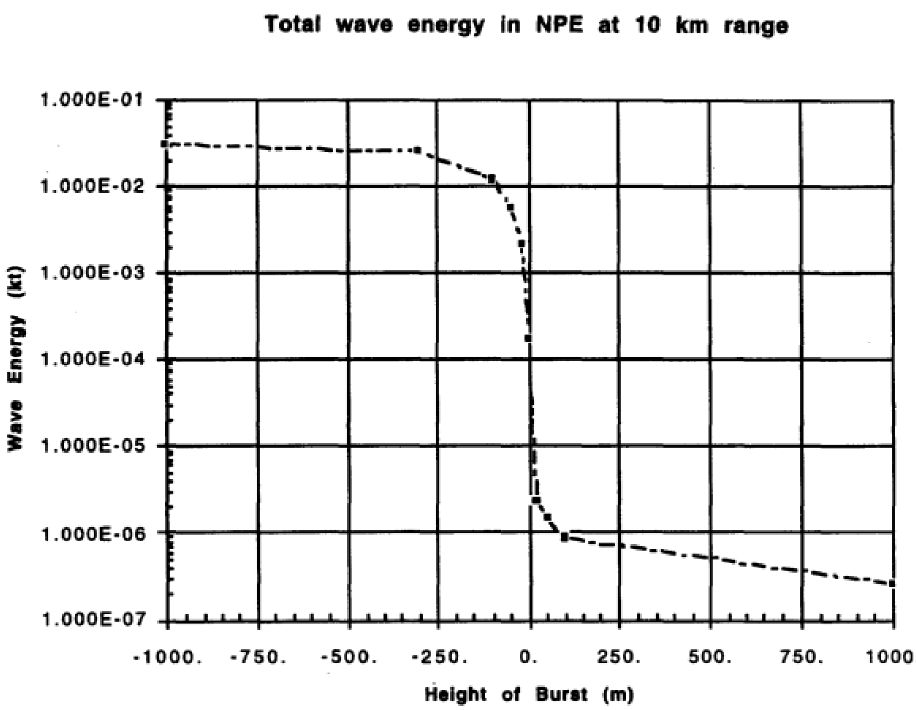

Figure 8: Simulation results for the total wave energy in the water at a range of 10 km from a 1kt explosion of varying depth/height[12]

[11] D. Clarke, J. W. White et. al., Energy Coupling of Nuclear Bursts in and above the Ocean Surface: Source Region Calculations and Experimental Validation, September 1997, https://digital.library.unt.edu/ark:/67531/metadc693831/m2/1/high_res_d/641356.pdf, Accessed 15 November 2022

[12] Ibid.

Perhaps the most important study conducted by LLNL was a series of experiments designed to validate their models. These experiments where conducted over an artificial lake in Wyoming and were documented in the 1998 report.[13] The findings as summarized in the paper's abstract stated that "Underwater signals from 6.82 kg charges were detected by a 30 m hydrophone string. Useful data were obtained at five burst locations: 5 m, 2 m zero, -2 m, and -15 m. Results from the experiments and new calculations support the predicted energy partitioning for above-surface explosions with model and experiment peak pressures agreeing within a factor of two over three orders of magnitude variation." Based on this information, it is reasonable that the previously developed computer simulations were validated and that the researchers obtained experimental data supporting the simulation results that above surface bursts resulted in orders of magnitude reductions in underwater pressures.

Finally, one additional source validates the SpaceX transmission coefficient of 14%. Independent analysis performed by M. Eneva and J. Stevens in 2001 using Russian hydroacoustic testing data that was also made available for the purposes of evaluating monitoring of nuclear test ban treaties.[14] The Russian data contained 29 explosive tests conducted in a shallow reservoir using 100 kg TNT cast spherical charges with 25 cm radius, detonated at various depths in a shallow 87 m long, 3 m deep reservoir. The test setup and burst locations are shown in Figure 9. A key finding of the research was that "[A] reduction of peak pressure by about 60-70% is observed in the measurements for half-immersed charges as compared with deeper explosions." Since intensity is proportional to the pressure squared, a 60-70% reduction in pressure would correspond to a 9-16% intensity transmission coefficient. Therefore, even for the half-submerged case in a shallow reservoir, the SpaceX transmission coefficient of 14% is close to the maximum value observed in the experimental data.

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[13] D. Clarke, D. Rock et. al. Validation of source region energy partition calculations with small scale explosive experiments, May 1998, www.researchgate.net/publication/265799582_Validation_of_source_region_ener_partition_calculations_with_small_scale_explosive_experiments, Accessed 15 November 2022

[14] M. ENEVA, J. L. STEVENS, B. D. KHRISTOFOROV, J. MURPHY, and V. V. ADUSHKIN, "Analysis of Russian Hydroacoustic Data for CTBT Monitoring," Pure and Applied Geophysics, 158, pp. 605–626, (2001).

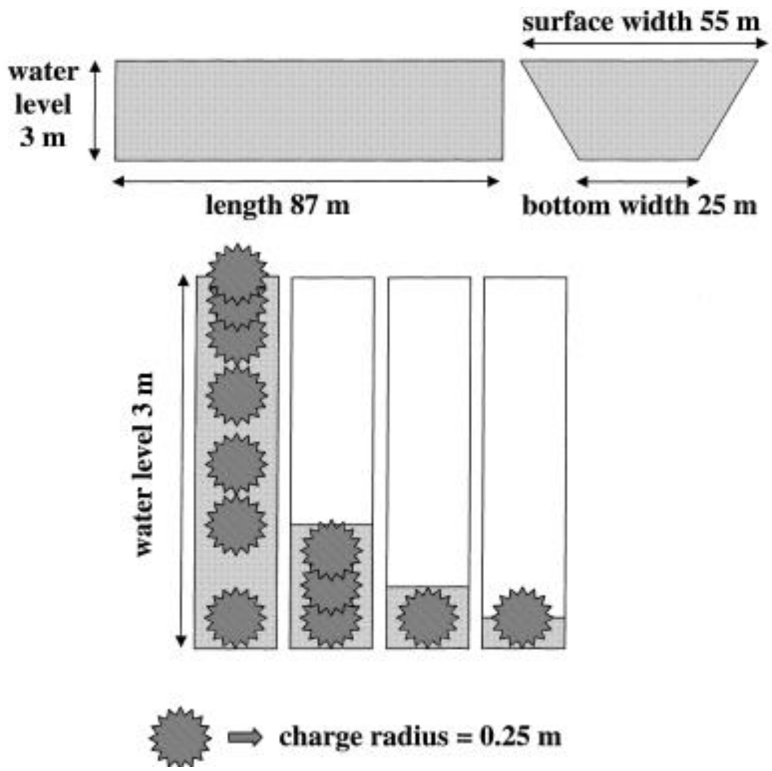

Figure 9: Test setup and burst locations for Russian hydroacoustic tests[15]

Based on the evaluation of the scientific principles surrounding wave transmission across the air/water boundary and the reliable, existing data from credible, scientific research into underwater pressure and energy from near-surface explosions, it is clear that SpaceX's selected intensity transmission coefficient of 14% clearly meets the reasonably foreseeable NEPA standard. Both the scientific principles and LLNL research would support a coefficient two orders of magnitude lower, and while the Russian hydroacoustic test data is consistent with the selected data it is for a much more conservative half-submerged condition that would be expected to produce much higher intensity in the water.

Substituting the SpaceX intensity transmission coefficient into Equation 7 results in Equation 9 and a pressure ratio between the water and the air at the air/water boundary of approximately 22.5. Multiplying the peak incident overpressure values for the air from Table 2 gives the peak incident overpressure value for the water shown in Table 4. Note that while the intensity has decreased across the boundary, the pressure will increase due to the impedance mismatch.

Equation 9: Pressure in water for air/water boundary transmission using SpaceX transmission coefficient

$$P_w = P_a \sqrt{\frac{1.5E6}{421} \times 0.14} = 22.45 \times P_a$$

[15] Ibid.

Table 4: Sample predicted peak overpressure value in the water just below the surface

Yield	1,260 kg (SN11's 9% Yield)
Incident Peak Overpressure in Water	144.5 MPa

Step 3. Calculate the noise attenuation underwater. These properties are calculated using the NMFS recommended assumption of spherical spreading for calculating the sound attenuation over distance. NMFS states that for deep water where there is little to no interaction between the sound and the ocean floor, a 20 log R model is appropriate. This model is given in Equation 10, where the noise is expressed as a Sound Pressure Level (SPL) defined by Equation 11. For all SPL calculations, SpaceX uses a reference pressure for water of 1 µPa.

Equation 10: NMFS 20 log R model for SPL decrease

$$L_{pk} - L_R = 20\ log\ R$$

Equation 11: Equation for SPL expressed in decibels

$$L = 20\ log\left(\frac{P}{P_{ref}}\right)$$

Finally, SpaceX takes Equation 10 and solves for range to get the expression given in Equation 12.

Equation 12: Solve for range to get equation used in NMFS spreadsheet tool

$$log\ R\ = \frac{L_{pk} - L_R}{20}$$

$$R = 10^{\left(\frac{L_{pk} - L_R}{20}\right)}$$

The peak source sound levels used in the NMFS attenuation model are calculated using Equation 11 with a 1 µPa reference pressure and the peak overpressure estimates at the water surface from Table 4. The resulting peak source sound levels are given in Table 5.

Table 5: Sample predicted water peak source sound level just below the surface

Yield	1,260 kg (SN11's 9% Yield)
Peak Source Sound Level (L_{pk} re 1 µPa)	283.2 dB

Step 4. Evaluate the impact area over which the NMFS thresholds are exceeded for species protected under the Endangered Species Act (ESA). With a peak source sound level and noise attenuation model established, the final analysis step is to evaluate the impact area over which the NMFS thresholds are

exceeded for the species protected under the ESA in the proposed Pacific impact area approximately 225 km north of Hawaii. Table 6 provides the subset of species that have the potential to be present in the Pacific impact area from those listed in Table 6 of the 2022 LOC [2]. Table 6 also lists the NMFS hearing group each species belongs to, based on the groups listed in the 2018 Revision to the 2016 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing [1].

Table 6: ESA-listed species present in the Pacific impact area

Species	NMFS Hearing Group
Blue Whale	Low Frequency (LF) Cetacean
False killer whale, Main Hawaiian Islands Insular DPS	Mid-Frequency (MF) Cetacean
Fin Whale	Low Frequency (LF) Cetacean
Sei Whale	Low Frequency (LF) Cetacean
Sperm Whale	Mid-Frequency (MF) Cetacean
Hawaiian Monk Seal	Phocid pinniped
Green Turtle Central North Pacific DPS	Turtle
Hawksbill Turtle	Turtle
Leatherback Turtle	Turtle
Loggerhead Turtle North Pacific DPS	Turtle
Olive Ridley Turtle	Turtle
Giant Manta Ray	Fish[a]
Oceanic Whitetip Shark	Fish[a]

[a] The fish are an injury group, not a hearing group, since hearing-related injuries cannot be assessed in fish.

The May 2022 NMFS summary of MMPA acoustic thresholds [3] provides a clear and concise summary of the information contained within their longer 2018 Revision to the 2016 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing [1]. NMFS defines two levels of harassment under the MMPA: Level A harassment/injury and Level B harassment. Level A harassment/injury is defined as any noise level that would be expected to result in a permanent (hearing) threshold shift (PTS) and/or lung or gastrointestinal (g.i.) tract injury; thus, covering all three types of marine mammal injury. Level B harassment is defined as any noise level that would be expected to result in a behavioral disturbance or a temporary (hearing) threshold shift (TTS).

NMFS defines four different types of noise sources: continuous, intermittent, impulsive, and non-impulsive. The noise generated by the Starship impact and explosive event is considered an impulsive sound source, in that it "produces sounds that are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and decay time" [3]. Additionally, the action described is an impulsive event of extremely rapid duration, which will not be repeated within any recommended accumulation periods. Such an event should only require that peak pressures be analyzed, as was done in this analysis. Here, the total positive phase pressure duration would be far less than one second, and the weighted cumulative sound exposure level will be significantly lower than the unweighted peak sound pressure. Based on this knowledge of the type of impulsive event under evaluation SpaceX determined that the unweighted peak sound pressure thresholds would result in the largest isopleths for calculating each threshold area.

Figure 10 gives the NMFS thresholds for an impulsive sound source for various marine mammal hearing groups. Per the NMFS guidance, “for a single detonation (within a 24-h period), NMFS relies on the TTS onset threshold to assess Level B harassment” [3]. Therefore, the behavioral thresholds listed in Figure 10 are not relevant to Starship analysis. Level A harassment/injury impacts are evaluated against the PTS threshold and Level B harassment impacts are evaluated against the TTS threshold. Additionally, because the explosion is a single event, it is evaluated against the peak sound pressure level thresholds, which all have a reference pressure of 1 µPa, the standard unit of acoustic pressure underwater [2]. The thresholds are also intended to be evaluated “unweighted” as signified by the “flat” subscript. SpaceX satisfied this by excluding any frequency weighting in the peak SPL calculations against those found in the technical documentation, Reference [1], and found them to be consistent.

Hearing Group	PTS Impulsive Thresholds	TTS Impulsive Thresholds	Behavioral Threshold (multiple detonations)
Low-Frequency (LF) Cetaceans	*Cell 1* $L_{p,0\text{-pk,flat}}$: 219 dB $L_{E,LF,24h}$: 183 dB	*Cell 2* $L_{p,0\text{-pk,flat}}$: 213 dB $L_{E,LF,24h}$: 168 dB	*Cell 3* $L_{E,LF,24h}$: 163 dB
Mid-Frequency (MF) Cetaceans	*Cell 4* $L_{p,0\text{-pk,flat}}$: 230 dB $L_{E,MF,24h}$: 185 dB	*Cell 5* $L_{p,0\text{-pk,flat}}$: 224 dB $L_{E,MF,24h}$: 170 dB	*Cell 6* $L_{E,MF,24h}$: 165 dB
High-Frequency (HF) Cetaceans	*Cell 7* $L_{p,0\text{-pk,flat}}$: 202 dB $L_{E,HF,24h}$: 155 dB	*Cell 8* $L_{p,0\text{-pk,flat}}$: 196 dB $L_{E,HF,24h}$: 140 dB	*Cell 9* $L_{E,HF,24h}$: 135 dB
Phocid Pinnipeds (PW) (Underwater)	*Cell 10* $L_{p,0\text{-pk,flat}}$: 218 dB $L_{E,PW,24h}$: 185 dB	*Cell 11* $L_{p,0\text{-pk,flat}}$: 212 dB $L_{E,PW,24h}$: 170 dB	*Cell 12* $L_{E,PW,24h}$: 165 dB
Otariid Pinnipeds (OW) (Underwater)	*Cell 13* $L_{p,0\text{-pk,flat}}$: 232 dB $L_{E,OW,24h}$: 203 dB	*Cell 14* $L_{p,0\text{-pk,flat}}$: 226 dB $L_{E,OW,24h}$: 188 dB	*Cell 15* $L_{E,OW,24h}$: 183 dB

Figure 10: NMFS PTS Onset, TTS Onset, and Behavioral Thresholds (Multiple Detonations) for Underwater Explosives [3]

The thresholds in Figure 10, along with the interpretation guidance in Reference [3], allows for the selection of Level A (PTS) and Level B (TTS) harassment thresholds for each marine mammal species in the Pacific impact area. Reference [3] does not include any guidance on assessing underwater noise impacts on the turtle and fish species that have the potential to be present in the Pacific impact. Therefore, SpaceX uses harassment thresholds consistent with those used by the Navy in their 2017 noise analysis [4], which derives thresholds for turtles based on the work of Popper et al. [5] and sets the TTS threshold for turtles as 226 dB re 1 µPa, which equals the highest threshold among the marine mammals (Otariid Pinnipeds).

The rationale begins with the Popper et. al. recommendation that an SEL-based threshold of greater than 186 dB re 1 µPa2s for TTS exposure to impact pile driving or seismic airgun impulses. However, Popper makes no recommendation for a single event peak SPL-based TTS threshold; as such the Navy assumed that the peak SPL-based threshold for sea turtle would likely be higher than that for marine mammals given the high hearing threshold measured for sea turtles and the high SEL-based TTS thresholds recommended by Popper. Since the TTS threshold should likely be higher than marine mammals the Navy concluded that it would be appropriate to set the sea turtle TTS threshold to be equal to the highest marine mammal threshold. The Navy then assumes that the same dB increase used to generate marine mammal PTS thresholds of +6 dB is also applicable to sea turtles. SpaceX concurs with these assumptions and therefore selected 232 dB re 1 μPa as the PTS threshold for sea turtles. Note that the sea turtle thresholds assumed by SpaceX match those most recently published by NMFS in January 2023 [6].

In the January 2023 publication titled "Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles)", Reference [6], NMFS provided onset of physical injury thresholds for fish species. SpaceX directly adopted the recommended onset of physical injury thresholds shown in Figure 11 for fish species.

	Onset of Physical Injury (Received Level)
Fish Size	**Impulsive**
Fishes ≥ 2 g	*Cell 1* $L_{p,0\text{-}pk,flat}$: 206 dB $L_{E,p,12h}$: 187 dB
Fishes < 2 g	*Cell 2* $L_{p,0\text{-}pk,flat}$: 206 dB $L_{E,p,12h}$: 183 dB

Figure 11: NMFS Onset of Physical Injury Thresholds for Fishes [6]

Based on the NMFS hearing type and the NMFS guidance for assessing the potential for harassment from single event impulsive sound sources, SpaceX identified the appropriate harassment and injury thresholds for each species potentially present in the Pacific impact area as shown in Table 7. All thresholds are given as peak SPL re 1 μPa.

Both ESA and MMPA prohibit the "take" of species under their protection. The ESA definition of take is broader than the MMPA definition of take. MMPS thresholds are used a surrogate to determine potentials impacts for ESA-listed species, and therefore considered encompassing of all potential impacts.

Table 7: PTS, TTS and/or Onset of Physical Injury Thresholds for Each Species

Species Data (Pacific)		Thresholds (dB re 1 u Pa)	
Species	**Type**	**Level A PTS (L_{PTS})**	**Level B TTS (L_{TTS})**
Blue Whale	LF cetacean	219	213
False killer whale, Main Hawaiian Islands Insular DPS	MF cetacean	230	224
Fin Whale	LF cetacean	219	213
Sei Whale	LF cetacean	219	213
Sperm Whale	MF cetacean	230	224

Species Data (Pacific)		Thresholds (dB re 1 u Pa)	
Species	Type	Level A PTS (L_{PTS})	Level B TTS (L_{TTS})
Hawaiian Monk Seal	Phocid pinniped	218	212
Green Turtle Central North Pacific DPS	Turtle	232	226
Hawksbill Turtle	Turtle	232	226
Leatherback Turtle	Turtle	232	226
Loggerhead Turtle North Pacific DPS	Turtle	232	226
Olive Ridley Turtle	Turtle	232	226
Species	**Type**	**Onset of Physical Injury (L_{Inj})**	
Giant Manta Ray	Fish	206	
Oceanic Whitetip Shark	Fish	206	

The total distance over which the TTS, PTS, or injury threshold would be exceeded can be calculated using Equation 12 where LR is the threshold SPL. The impact area can then conservatively be calculated as a circle with radius R, leading to the impact area equation in Equation 13. This approach is conservative as it calculates the impact area at the surface; for lower depths the impact area will be smaller as the radial distance will be smaller for equivalent ranges.

Equation 13: Impact area calculation in km2 for impact threshold Lthresh

$$A = \pi \left[0.001 \times 10^{\left(\frac{L_{pk} - L_{thresh}}{20}\right)} \right]^2$$

Impact area results are given in Table 8, using the peak source sound level values given in Table 5 and the species thresholds listed in Table 7.

Table 8: Sample results for Starship explosive event underwater noise analysis

Species Data (Pacific)		1,260 kg (SN11's 9% Yield)	
Species	Type	Level A PTS Area (km^2)	Level B TTS Area (km^2)
Blue Whale	LF cetacean	8.25	32.86
False killer whale, Main Hawaiian Islands Insular DPS	MF cetacean	0.66	2.61
Fin Whale	LF cetacean	8.25	32.86
Killer Whale, Southern Resident DPS	MF cetacean	0.66	2.61
Sei Whale	LF cetacean	8.25	32.86
Sperm Whale	MF cetacean	0.66	2.61
Hawaiian Monk Seal	Phocid pinniped	10.39	41.37
Green Turtle	Turtle	0.41	1.65

Species Data (Pacific)		1,260 kg (SN11's 9% Yield)	
Species	**Type**	**Level A PTS Area (km^2)**	**Level B TTS Area (km^2)**
Hawksbill Turtle	Turtle	0.41	1.65
Leatherback Turtle	Turtle	0.41	1.65
Loggerhead Turtle	Turtle	0.41	1.65
Olive Ridley Turtle	Turtle	0.41	1.65
Species	**Type**	**Onset of Physical Injury (km^2)**	
Giant Manta Ray	Fish	164.7	
Oceanic Whitetip Shark	Fish	164.7	

Figure 12 is provided as a reference for the relative size and location of the largest impact area given in the results table.

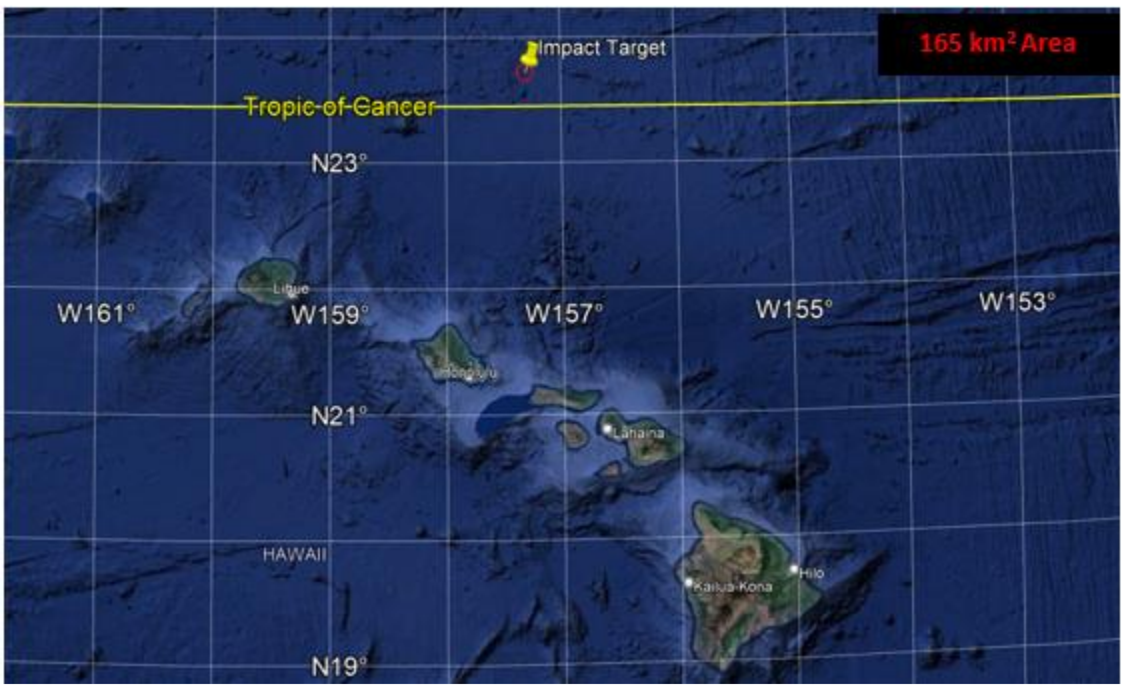

Figure 12: Reference map showing scale of Fish Onset of Physical Injury area

References

[1]. National Marine Fisheries Service, Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0), April 2018

[2]. NMFS (National Marine Fisheries Service). 2022. Programmatic Concurrence Letter for Launch and Reentry Vehicle Operations in the Marine Environment and Starship/Super Heavy Launch Vehicle Operations at SpaceX's Boca Chica Launch Site, Cameron County, TX. January.

[3]. NMFS (National Marine Fisheries Service). 2022. Summary of Marine Mammal Protection Act Acoustic Thresholds. https://media.fisheries.noaa.gov/2022-05/MM%20Acoustic%20Thresholds%20%28508%29_secure%20%28May%202022%29.pdf. Accessed 15 December 2022.

[4]. US Navy, *Criteria and Thresholds for U.S. navy Acoustic Explosive Effects Analysis (Phase III)*, https://www.hstteis.com/portals/hstteis/files/reports/Criteria_and_Thresholds_for_U.S._Navy_Acoustic_and_Explosive_Effects_Analysis_June2017.pdf, Accessed 7 November 2022

[5]. Popper, A. N., A. D. Hawkins, R. R. Fay, D. A. Mann, S. M. Bartol, T. J. Carlson, S. Coombs, W. T. Ellison, R. L. Gentry, M. B. Halvorsen, S. Løkkeborg, P. H. Rogers, B. L. Southall, D. G. Zeddies, & W. N. Tavolga. (2014). *Sound Exposure Guidelines for Fishes and Sea Turtles*.

[6]. NMFS (National Marine Fisheries Service). Jan 2023. Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles). https://www.fisheries.noaa.gov/s3/2023-02/ESA%20all%20species%20threshold%20summary_508_OPR1.pdf

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
1315 East-West Highway
Silver Spring, Maryland 20910

April 14, 2023
Refer to NMFS No: OPR-2023-00318

Ms. Stacey Zee
Manager, Operations Support Branch
U.S. Dept. Transportation, Federal Aviation Administration
Office of Commercial Space Transportation
800 Independence Ave SW, Suite 325
Washington, DC 20591

RE: Concurrence Letter for the Endangered Species Act Section 7 Consultation for FAA's Proposed Licensing of SpaceX Starship/Super Heavy Early Developmental Phase Launch and Reentry Operations for First Three Flights in the Gulf of Mexico and North Pacific Ocean

Dear Ms. Zee:

On March 6, 2023, the National Marine Fisheries Service (NMFS) received your request for a written concurrence that the Federal Aviation Administration's (FAA) licensing of the Space Exploration Technologies Corporation's (SpaceX) early developmental phase flights of Starship/Super Heavy in the Gulf of Mexico and the Pacific Ocean (limited to the first three flights), is not likely to adversely affect species listed as threatened or endangered or critical habitats designated under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 et seq.). This response to your request was prepared by NMFS pursuant to section 7(a)(2) of the ESA, implementing regulations at (50 CFR §402), and agency guidance for preparation of letters of concurrence.

This letter underwent pre-dissemination review using standards for utility, integrity, and objectivity in compliance with agency guidelines issued under section 515 of the Treasury and General Government Appropriations Act of 2001 (Data Quality Act; 44 U.S.C. 3504(d)(1) and 3516). A complete record of this informal consultation is on file at NMFS Office of Protected Resources in Silver Spring, Maryland.

1 Consultation History

- **October 2022:** The FAA informed NMFS that early developmental phase flights of Starship/Super Heavy could result in an explosive event upon Starship's impact with the Pacific Ocean, which is not covered under the existing programmatic concurrence for FAA for space launch and reentry (PLoC; OPR-2021-02908). NMFS provided technical assistance on acoustic thresholds, noise modeling, and exposure estimations related to the possibility of explosion and potential effects to ESA resources.
- **January 27, 2023:** The FAA provided a noise impact analysis methodology document to NMFS via email for review. NMFS reviewed the methodology and provided comments via email.

- **February 21, 2023:** The FAA sent a revised methodology via email to NMFS. NMFS reviewed the revised methodology and provided additional comments via email.
- **March 6, 2023:** NMFS received an email request for concurrence with the FAA's not likely to affect (NLAA) determination for species listed as threatened or endangered under the ESA for the early developmental phase flights of Starship/Super Heavy.
- **March 24, 2023:** NMFS requested via email more information regarding Starship's landing area location, expected debris, scuttling of Super Heavy, clarification on ESA-listed species in the action area, and transmission coefficient related to noise from the explosion.
- **March 28, 2023:** The FAA provided their response via email to NMFS' request for information, revised their consultation request, and revised methodology on early developmental phase flights of SpaceX's Starship/Super Heavy launch vehicle.
- **March 30, 2023:** In response to the information from FAA, NMFS requested via email additional information on the number of flights, debris, and coordination with the U.S. Coast Guard.
- **April 3, 2023:** The FAA provided their response via email to NMFS' request for information and further revised their consultation request on early developmental phase flights of SpaceX's Starship/Super Heavy launch vehicle.
- **April 4, 2023:** In response to the additional information from FAA, NMFS requested via email information on surveillance assets, puncturing of Super Heavy, and debris survey procedures.
- **April 5, 2023:** The FAA provided their response via email to NMFS' requests for additional information and further revised their consultation request on early developmental phase flights of SpaceX's Starship/Super Heavy launch vehicle. NMFS initiated the consultation.

2 PROPOSED ACTION AND ACTION AREA

2.1 Proposed Action

An action, for the purposes of the ESA, is all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States or upon the high seas (50 CFR §402.02). The FAA proposes to issue a vehicle operator license on SpaceX Starship/Super Heavy operations. The vehicle operator license would be limited to the first flight only. Any subsequent flights would require a vehicle operator license modification. As such, a vehicle operator license would be issued for each flight of Starship/Super Heavy and NMFS is consulting on the proposed actions that would be authorized under these three licenses. The first three flights of Starship/Super Heavy are part of the early program development phase to make the Starship/Super Heavy fully reusable. The following subsections provide a description of the proposed launch operations and launch system.

2.1.1 Launch System

SpaceX's Starship/Super Heavy launch vehicle is approximately 120 meters (394 feet) tall by nine meters (29.5 feet) in diameter and comprised of two stages: Super Heavy is the first stage (or booster) and Starship (the spacecraft) is the second stage. Super Heavy will land back on Earth shortly after launch (takeoff). Starship is a reentry vehicle, which is a vehicle designed to return from Earth orbit or outer space to Earth. Super Heavy operations are suborbital and are not considered by the FAA to be a reentry vehicle because they have not completed one orbit around the Earth. These first stage landings are considered part of a launch.

The Super Heavy is expected to be equipped with up to 37 Raptor engines, and the Starship will employ up to six Raptor engines. The Raptor engine is powered by liquid oxygen (LOX) and liquid methane (LCH_4). Super Heavy is expected to hold up to 3,700 metric tons of propellant and Starship will hold up to 1,500 metric tons of propellant.

2.1.2 Proposed Launch Operations

The first three flights of Starship/Super Heavy will launch from the SpaceX Boca Chica Launch Site. As these first three flights are part of the early developmental phase, Starship and Super Heavy will land in the North Pacific Ocean and Gulf of Mexico, respectively. In the first flight of Starship/Super Heavy, Super Heavy is expected to land intact and sink in the Gulf of Mexico, and Starship is expected to land in the North Pacific Ocean. An explosive event is expected to occur when Starship impacts the surface of the North Pacific Ocean. The second and third flights will result in Super Heavy landing intact and sinking in the Gulf of Mexico, and Starship breaking up upon atmospheric reentry with an expected debris field in the North Pacific Ocean.

Prior to launch, SpaceX will deploy weather balloons to measure weather data. The data, including wind speeds, is necessary to determine if it is safe to launch and land the vehicle. The weather balloons are made of latex with radiosondes attached to each balloon. A radiosonde, typically the size of a half-gallon milk carton, is attached to the weather balloon to measure and transmit atmospheric data to the launch operator. The latex balloon attached to each weather balloon typically has a diameter at launch of approximately four feet (approximately 1.2 meters). When a balloon is deployed, it rises to approximately 12–18 miles (approximately 19–29 kilometers) into the air and then bursts. The radiosonde and shredded balloon pieces fall back to Earth and are not recovered. The radiosonde does not have a parachute and is expected to sink to the ocean floor.

Vertical launches occur from launch pads located at a launch site. After liftoff, the rocket quickly gains altitude and flies over the ocean. At some point downrange, the rocket reaches supersonic speeds (which generates a sonic boom) and pitches over to attain its intended orbital trajectory. Depending on the rocket's orientation, it is possible for the sonic boom to intercept the Earth's surface. Given the altitude at which the rocket reaches supersonic speeds, most of the sonic boom footprint that reaches the Earth's surface is usually of small magnitude (one to two pounds per square foot [psf]), but there could be areas that experience a sonic boom up to eight psf. The area exposed to the higher overpressure (up to eight psf) is much smaller than the areas that experience lower overpressures. Sonic boom intensity, in terms of psf, is greatest under the flight path and progressively weakens with greater horizontal distance away from the flight track.

2.1.2.1 Super Heavy

For all three flights, Super Heavy's engines would cut off at an altitude of approximately 40 miles (approximately 64 kilometers) and the booster would separate from Starship. After stage separation from Starship, Super Heavy would conduct a boost-back burn prior to descending into the atmosphere. After descent through the atmosphere, Super Heavy would conduct a landing burn to approximately the ocean's surface and then impact the water at approximately 8.5 meters/second in the Gulf of Mexico landing location, approximately 31 kilometers off the coast of Texas. Any landing outside of the landing location would not be considered nominal. It is expected that Super Heavy would impact the water vertically and intact. Then, seconds later, Super Heavy would tip over and impact the water horizontally. The LOX tank and LCH_4 tank's structural capabilities would allow them to withstand the force of the impact. As such, the tanks would remain intact and there would be no interaction between the LOX and LCH_4. Super Heavy is expected to remain intact. Following the landing burn, tank valves on Super Heavy would open causing the tanks to flood with seawater after landing. As the tanks flood, Super Heavy would become waterlogged and sink at an angle (similar to a sinking ship) to the ocean floor. If, in an off-nominal event, Super Heavy did not sink, SpaceX would attempt to scuttle Super Heavy. To do this, SpaceX would remotely open the tank vents allowing water into the tank to sink the vehicle. If the tank vents are determined to be closed, SpaceX would attempt to command the valves open, inducing the flooding. If SpaceX receives positive confirmation that the valves are open but the vehicle is not taking on water, SpaceX would attempt to physically, using a vessel and towline, roll the vehicle on its long axis to induce sinking. Additional methods for scuttling could be considered such as puncturing the outer shell of the vehicle using a firearm or remote operating vessel. However, a scenario where Super Heavy does not sink is highly unlikely. Super Heavy landings would generate a sonic boom(s). The predicted overpressure from a sonic boom generated by a Super Heavy landing in the Gulf of Mexico is up to 15 psf at the ocean's surface.

2.1.2.2 Starship First Flight

For the first flight, after separation from Super Heavy, Starship's engines would start and burn to the target location just below orbital before beginning its descent. Starship is expected to land in the North Pacific Ocean, and the impact will result in an explosive event. After ascent engine cutoff, Starship would vent residual main tank propellant during the in-space coast phase of the launch at or above 120 kilometers above ground level. Following the in-space coast phase, Starship would begin its passive descent. Some residual LOX (approximately 10 metric tons) and LCH_4 (approximately four metric tons) would remain in Starship. This is the minimum amount that can remain in Starship after venting to serve as ballast in order to successfully maintain trajectory to the landing location. The 14 metric tons of remaining propellant represents approximately 1.1 percent of the total fill levels for the Starship main tanks. Starship would impact the Pacific Ocean horizontally, intact, and at terminal velocity (i.e., the steady speed achieved by a freely falling object; Figure 1). The impact would disperse settled remaining propellants and drive structural failure of the vehicle. The structural failure would immediately lead to failure of the fuel transfer tube, which would allow the remaining LOX and LCH_4 to mix. The mixture of LOX and LCH_4 in the fuel transfer tube will ignite resulting in an explosive event. Impact debris is expected to be contained within approximately one kilometer of the landing point. As Starship slows down through atmospheric resistance during its landing descent, a sonic boom(s) with a maximum predicted overpressure of approximately 2.2 psf will be generated; however, the actual overpressure will likely be lower. Water depth at the landing area is approximately 4,570 meters.

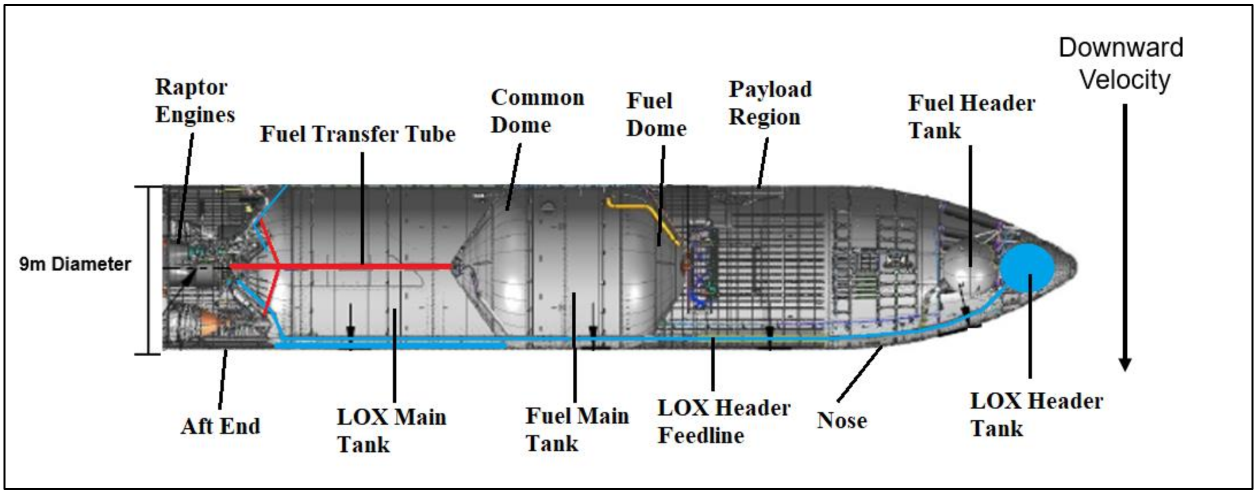

Figure 1. Starship vehicle and location of fuel transfer tube (source of explosion).

2.1.2.3 Starship Second and Third Flights

For the second and third flights, after separation from Super Heavy, Starship's engines would start and burn to the desired orbit location. Upon reentry, Starship is expected to break up and SpaceX proposed an area southwest of Hawai'i, to account for the potential Starship debris field. The area of the debris field is determined by performing a debris analysis for an uncontrolled Starship entry. In this scenario, the vehicle enters the atmosphere uncontrolled and breaks up above 70 kilometers above ground level and the resulting debris is propagated through the atmosphere to impact in the North Pacific Ocean. The locations of debris impact are then bounded to generate the debris field area. It is theoretically possible for debris to land outside of this area, but the debris area shown is representative of a nominal uncontrolled entry based on flight modeling. As Starship slows down during its landing descent, any noise from vehicle break up would be imperceptible because Starship will be at such a high altitude (at the edge of the atmosphere). Water depth at the debris field area is approximately 4,570 meters deep.

2.1.2.4 Debris Salvage Operations

SpaceX will coordinate directly with the U.S. Coast Guard (USCG) to protect public health and safety prior to any launch or reentry activity licensed by the FAA that overflies or affects Navigable Waters (14 CFR Chapter III). SpaceX and USCG have entered into a Letter of Intent that outlines coordination efforts to ensure that any hazards to the environment or navigation are properly managed and mitigated (Appendix I – Letter Of Intent)[1]. Coordination efforts regarding Starship reentry and debris are described below (see Appendix I – Letter Of Intent).

Following the Starship explosive event, SpaceX would have a vessel in the area of highest likelihood of debris that would identify large debris for salvage.[2] SpaceX would use the vessel to

[1] Note that the current signed Letter of Intent is applicable for the first flight. Each subsequent flight, as required for the FAA license application, SpaceX will work with the USCG to develop agreement based on the mission.

[2] Letter of Intent Section 5(c) states: "Salvage Vessel(s): SpaceX has agreed to and shall arrange a contract with salvage vessel(s) of adequate size, strength, and capability for retrieval of any vehicle reentering PACAREA AOR, and shall do so at least one week prior to the launch. The salvage vessel(s) will be staged at the site of reentry at least the day prior to launch, approximately 16 nautical miles cross range from the nominal landing location. To look for debris, SpaceX will use last known telemetry and radar information to direct initial search location and then

survey for debris for approximately 24 to 48 hours (using visual survey in the day and onboard vessel radar at night) depending on the outcome of the breakup. The initial survey area would be determined based on last known data location point received from the telemetry on the vehicle upon splashdown. Weather and ocean current data would be used to further characterize the debris field as the operation is conducted. During the operation, SpaceX would coordinate findings and action items directly with the USCG Sector 14 to ensure all of the requirements of the Letter of Intent are met. SpaceX vessels would be equipped with multiple forms of communication equipment (Starlink, VHF, Sat phone) to enable communications directly with USCG representatives while offshore.

SpaceX expects that the majority of Starship debris would sink because it is made of steel and will have sufficient mass to sink to the seafloor (U.S. Navy 2022). Debris is expected to sink at the nominal landing location (approximately 208 nautical miles [385 kilometers] east of the Papahānaumokuākea Marine National Monument) and is not expected to drift into the Papahānaumokuākea Marine National Monument. Some lighter items (e.g., items not made of steel, such as composite overwrapped pressure vessels) may float but they are expected to become waterlogged and sink. Though not expected and unlikely, if there is floating debris found by the vessel during the debris field survey, SpaceX would sink or recover any floating debris before it could drift into the Papahānaumokuākea Marine National Monument by physically removing the item using a net or boat hook, or puncturing the item using a firearm to cause it to sink. SpaceX would report debris findings to the USCG to determine the most appropriate method of recovery or sinking as described above and would be on a case-by-case basis depending on personnel safety, vessel safety, and capability.

If debris is still identified after the 24–48 hour survey and recovery efforts, SpaceX would use another method, including an aerial asset, additional vessel, or satellite imaging, to confirm and characterize any debris and take appropriate action to retrieve or sink it. SpaceX would act to mitigate the debris in coordination with USCG to verify that the debris sinks within 10 days. SpaceX would also attempt to locate the launch vehicle launch recording device (also known as the “black box”) which has a global positioning system (GPS) tracking signal. Should the recording device be located, scuba divers may be deployed to facilitate device retrieval.

During Starship launches not configured to survive atmospheric entry (the second and third launches), any debris is expected to have sufficient mass to sink to the seafloor. For the first three launches, if telemetry-based evidence provided to SpaceX by on-board equipment on each vehicle stage or other information provided to SpaceX by other surveillance assets suggests large floating debris, SpaceX would act to mitigate the downrange debris in coordination with USCG to verify that the debris sinks within 10 days.

2.1.2.5 Project Design Criteria Conditions

As a condition of the FAA’s proposed issuance of a vehicle operator license on SpaceX Starship/Super Heavy operations as described above, SpaceX must comply with Project Design

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switch to relying on a visual search from the vessel(s). If the black boxes are transmitting their location, SpaceX will also use that information for guidance. The search will begin immediately after landing and continue for a minimum of 24 hours. SpaceX will report back any findings to the applicable District Waterways Management Branch(es) and Command Center Points of Contact. In addition, SpaceX shall notify the Coast Guard of any other salvage assets being used during this time period.”

Criteria (PDCs) and Environmental Protections Measures, including general PDCs, Education and Observation, Reporting Stranded, Injured, or Dead Animals, Vessel Operations, and Aircraft Operations as described in the PLoC (Appendix II – Project Design Criteria).

The FAA, in coordination with SpaceX, will provide a report regarding SpaceX's Starship/Super Heavy operations within the action area of the first three flights of Starship/Super Heavy. The report will provide:

1. The dates and locations of all launches, including launch site, launch and reentry vehicles and any relevant license or permit that authorized the activities;
2. Contact information for the agencies and commercial entities involved in the events;
3. Details of launch and reentry operations that may affect the marine environment, such as booster stage landings at sea, and particularly those that involve entry of materials into the marine environment, such as spacecraft reentries;
4. Dates of reentry and recovery operations if different from launch date;
5. Approximate locations with GPS coordinates when available of all landing and debris areas. Information should also be provided regarding support vessels used during operations and transit routes, as well as aircraft activity associated with an event;
6. Any available information on the location and fate of unrecovered expended components and debris;
7. Any information regarding effects to ESA-listed species due to the activities; and
8. Sighting logs with observations of ESA-listed species with date, time, location, species (if possible to identify), number of animals, distance and bearing from the vessel, direction of travel, and other relevant information.

The report should be submitted electronically to nmfs.hq.esa.consultations@noaa.gov with the subject line "Report, OPR-2023-00318, Starship/Super Heavy Early Developmental Phase Launch and Reentry Operations for First Three Flights in the Gulf of Mexico and North Pacific Ocean."

2.2 Action Area

The action area is defined in 50 CFR §402.02 as "all areas to be affected directly or indirectly by the federal action and not merely the immediate area involved in the action." The proposed actions will take place in two ocean basins where launch and reentry operations are expected:

1. The Gulf of Mexico (Figure 2), at the Boca Chica Launch Site in Texas and Super Heavy landing location, 31 kilometers off the Texas coast, and
2. The North Pacific Ocean (Figure 3), at the Starship landing location, which is approximately 208 nautical miles (385 kilometers) from the boundary of the Papahānaumokuākea Marine National Monument; the Starship landing area, which is approximately 26 nautical miles (48 kilometers) from the boundary of the Papahānaumokuākea Marine National Monument at the closest point; and the Starship debris field for the second and third flights, which is approximately 980 nautical miles (1,815 kilometers) southwest of Kauai.

Starship/Super Heavy will launch from the Boca Chica Launch Site (Cameron Country, Texas). Super Heavy will land and sink at the Gulf of Mexico landing location (Figure 2). Any landing outside of the landing location would not be considered nominal.

For the first launch, Starship's nominal target landing location (passive decent landing location) is approximately 208 nautical miles (385 kilometers) from the boundary of the Papahānaumokuākea Marine National Monument. The Starship's landing area is approximately 26 nautical miles (48 kilometers) from the boundary of the Papahānaumokuākea Marine National Monument at the closest point, and approximately the same distance from Kauai (Figure 3). The Starship landing areas, areas in yellow and green in Figure 2, are not the impact area of the Starship landing but represent the area within which Starship could land. Any landing location within the yellow and green areas other than the nominal target landing location (yellow pin in Figure 3) will not be considered nominal.

For the second and third launches, Starship's expected debris field is estimated to be approximately 980 nautical miles (1,815 kilometers) southwest of Kauai (in red, see Figure 3).

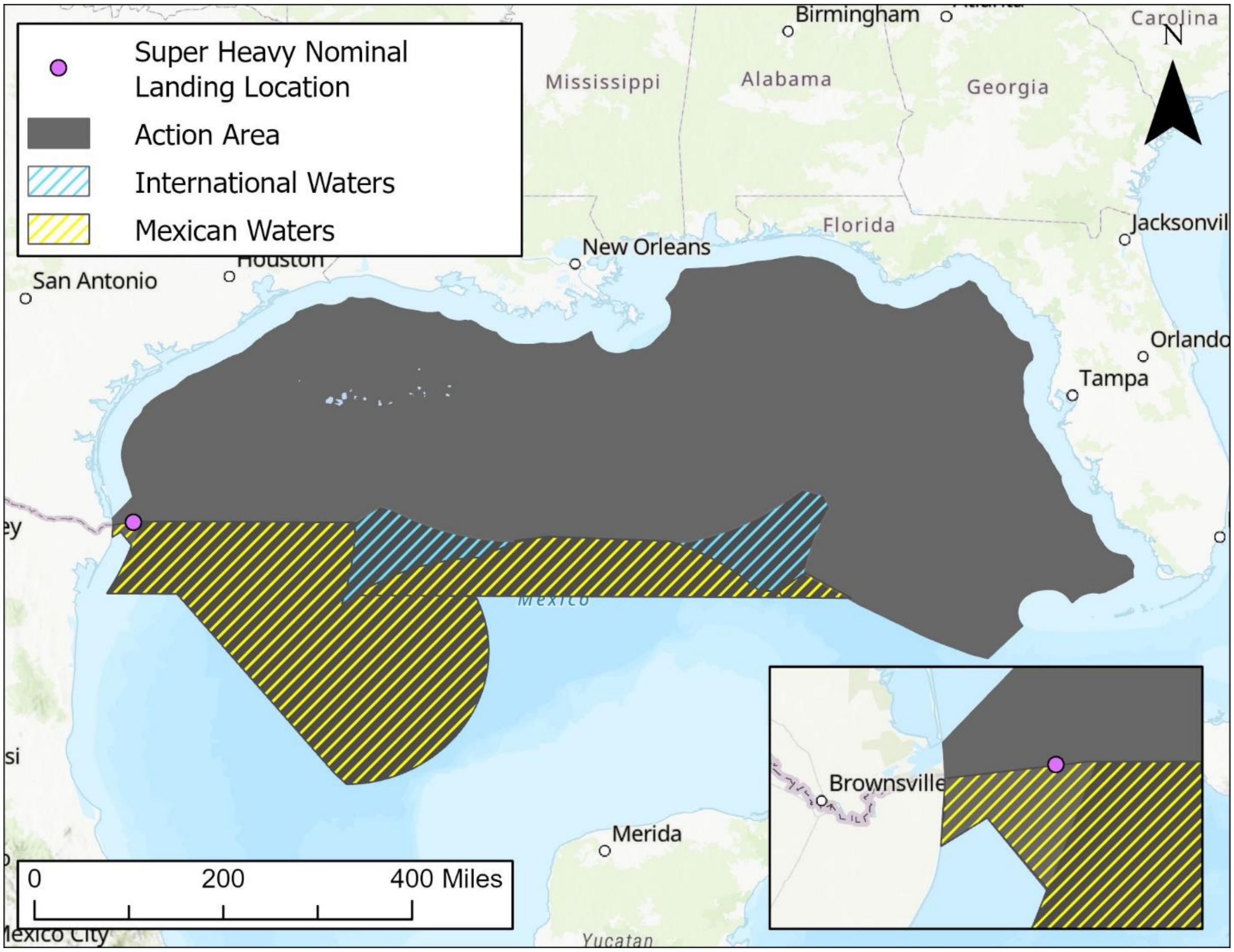

Figure 2. Super Heavy nominal landing location (purple circle) as described in the FAA's proposed authorization of a license to SpaceX for three early developmental phase launches of Starship/Super Heavy.

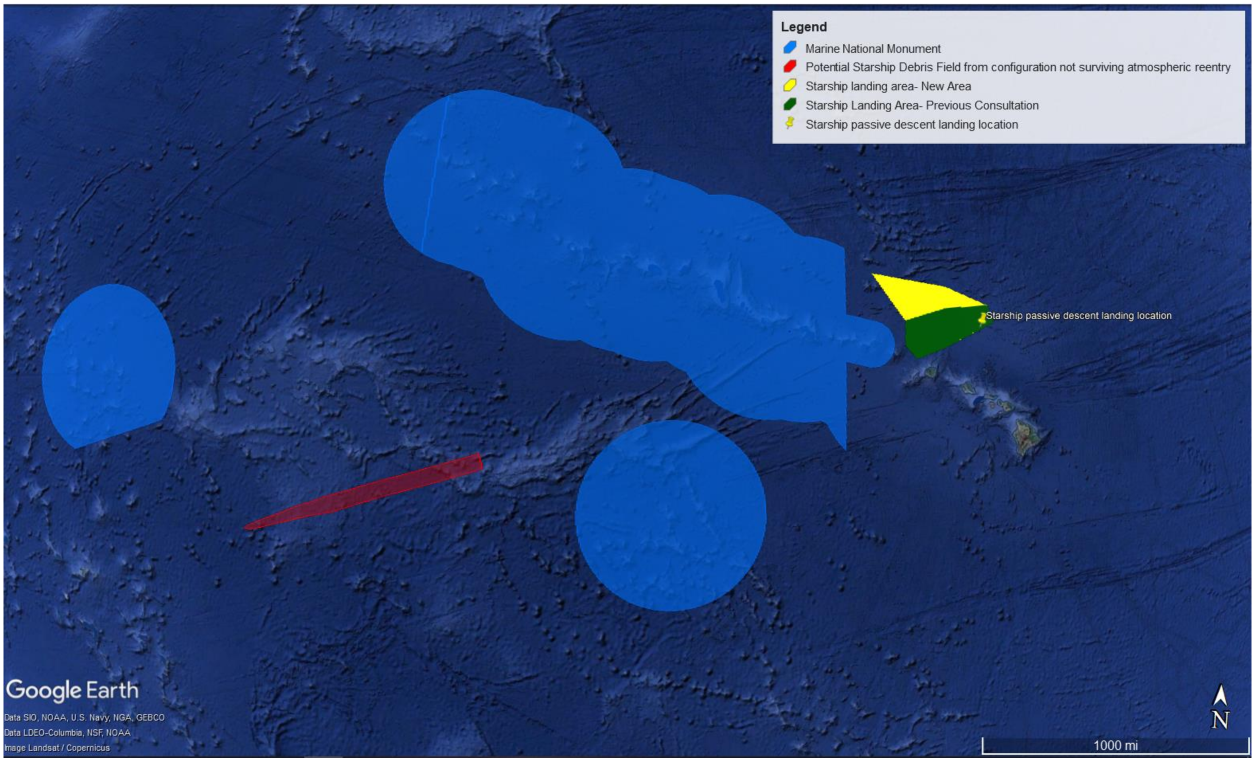

Figure 3. Starship nominal landing location (yellow pin), landing areas (yellow and green), and expected debris field (red) as described in the FAA's proposed authorization of a license to SpaceX for three early developmental phase launches of Starship/Super Heavy.

The launch and reentry activities will occur at least five nautical miles from shore, except for vessel operations when vessels are transiting to and from a port during surveillance. These vessel transit areas include marine waters that lead to the Port of Brownsville, Texas in the Gulf of Mexico and the Honolulu Harbor, Hawai'i in the North Pacific Ocean.

3 ESA-Listed Species and Critical Habitat in The Action Area

The ESA-listed threatened and endangered species under NMFS' jurisdiction listed in Table 1 are known to occur, or could reasonably be expected to occur, in the action area, and may be affected by stressors produced by the proposed action. Detailed information about the biology, habitat, and conservation status of the species listed in Table 1 can be found in their status reviews, recovery plans, Federal Register notices, and other sources at https://www.fisheries.noaa.gov/topic/endangered-species-conservation.

The Gulf of Mexico action area does not include nearshore areas where ESA-listed coral species occur. There is proposed critical habitat for three coral species in the Gulf of Mexico farther offshore (i.e., > five nautical miles). However, no launch operator will site a landing area in coral reef, and the location of the proposed critical habitat in the Gulf of Mexico is too far north of the Boca Chica Launch Site launch trajectories to be affected. Therefore, the FAA determined that launch and reentry operations will have no effect on ESA-listed coral species or their proposed critical habitat in the action area. As such, ESA-listed coral species and their proposed critical habitat are not included in Table 1.

Table 1. ESA-listed threatened and endangered species potentially occurring in the action area that may be affected by the FAA's proposed authorization of a license to SpaceX for three early developmental phase launches of Starship/Super Heavy.

Species	ESA Status	Critical Habitat	Recovery Plan
Marine Mammals - Cetaceans			
Blue Whale (*Balaenoptera musculus*)	E – 35 FR 18319	-- --	07/1998 11/2020
False Killer Whale (*Pseudorca crassidens*) – Main Hawaiian Islands Insular DPS	E – 77 FR 70915	83 FR 35062	86 FR 60615
Fin Whale (*Balaenoptera physalus*)	E – 35 FR 18319	-- --	75 FR 47538 07/2010
Rice's Whale (*Balaenoptera ricei*)	E – 84 FR 15446 E – 86 FR 47022	-- --	-- --
Sei Whale (*Balaenoptera borealis*)	E – 35 FR 18319	-- --	12/2011
Sperm Whale (*Physeter macrocephalus*)	E – 35 FR 18319	-- --	75 FR 81584 12/2010
Marine Mammals - Pinnipeds			
Hawaiian Monk Seal (*Neomonachaus schauinslandi*)	E – 41 FR 51611	80 FR 50925	72 FR 46966 2007
Marine Reptiles			
Green Turtle (*Chelonia mydas*) – North Atlantic DPS	T – 81 FR 20057	63 FR 46693	10/1991
Green Turtle (*Chelonia mydas*) – Central North Pacific DPS	T – 81 FR 20057	-- --	63 FR 28359 01/1998
Hawksbill Turtle (*Eretmochelys imbricata*)	E – 35 FR 8491	63 FR 46693	57 FR 38818 08/1992 – U.S. Caribbean, Atlantic, and Gulf of Mexico 63 FR 28359 05/1998 – U.S. Pacific
Kemp's Ridley Turtle (*Lepidochelys kempii*)	E – 35 FR 18319	-- --	09/2011
Leatherback Turtle (*Dermochelys coriacea*)	E – 35 FR 8491	44 FR 17710 and 77 FR 4170	10/1991 – U.S. Caribbean, Atlantic, and Gulf of Mexico 63 FR 28359

			05/1998 – U.S. Pacific
Loggerhead Turtle (*Caretta caretta*) – Northwest Atlantic Ocean DPS	T – 76 FR 58868	79 FR 39855	74 FR 2995 10/1991 – U.S. Caribbean, Atlantic, and Gulf of Mexico 05/1998 – U.S. Pacific 01/2009 – Northwest Atlantic
Loggerhead Turtle (*Caretta caretta*) – North Pacific Ocean DPS	E – 76 FR 58868	-- --	63 FR 28359
Olive Ridley Turtle (*Lepidochelys olivacea*) – All Other Areas/Not Mexico's Pacific Coast Breeding Colonies	T – 43 FR 32800	-- --	-- --
Fishes			
Giant Manta Ray (*Manta birostris*)	T – 83 FR 2916	-- --	-- --
Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)	T – 56 FR 49653	68 FR 13370	09/1995
Nassau Grouper (*Epinephelus striatus*)	T – 81 FR 42268	Proposed Rule (87 FR 62930)	8/2018- Outline
Oceanic Whitetip Shark (*Carcharhinus longimanus*)	T – 83 FR 4153	-- --	1/2023 - Draft
Smalltooth Sawfish (*Pristis pectinata*) – U.S. portion of range DPS	E – 68 FR 15674	74 FR 45353	74 FR 3566 01/2009

DPS=distinct population segment; ESU=evolutionarily significant unit; E=endangered; T=threatened; FR=*Federal Register*

4 Effects Analysis

The applicable standard to find that a proposed action is not likely to adversely affect ESA-listed species or designated critical habitat is that all of the effects of the action are expected to be discountable, insignificant, or wholly beneficial. Discountable effects relate to the probability of exposure. For an effect to be discountable, it must be extremely unlikely to occur. Insignificant effects relate to the probability of a response given an exposure and include those effects that are undetectable, not measurable, or so minor that they cannot be meaningfully evaluated. Insignificant is the appropriate effect conclusion when effects will not cause a response that can be measured or detected. Beneficial effects have an immediate positive effect without any adverse effects to the species or habitat.

The following subsections identify the potential stressors and analyze the potential effects of the FAA's proposed issuance of a license to SpaceX for three early developmental phase flights of Starship/Super Heavy on the ESA-listed species in the action area. Stressors are any physical, chemical, or biological agent, environmental condition, external stimulus, or event that modifies the land, water, or air occupied by an ESA-listed species or its designated critical habitat. Potential stressors to ESA-listed species from the proposed activities include the following:

- Direct contact from fallen objects: spacecraft, rocket parts, debris, radiosonde;
- Ingestion of material from weather balloon fragments, unrecovered floating debris;
- Vessel strike; and
- Acoustic stressors including vessel noise, exposure to sonic booms (overpressure), aircraft overflight, and explosive event upon Starship's landing in the North Pacific Ocean (first flight only).

Potential effects to the ESA-listed species from these stressors are discussed in the following sections.

4.1 Direct Contact from Fallen Objects

Super Heavy, Starship, and Starship debris falling and landing in the ocean have the potential to affect ESA-listed species in the action area. The primary concern is direct contact from an object landing on an ESA-listed marine mammal, sea turtle, or fish, because the impact of a vehicle or debris striking an ESA-listed species may result in injury or mortality to the individuals that are struck.

The action area where Super Heavy, Starship, and Starship debris would land is a relatively small area compared to the area over which species can be distributed in the Gulf of Mexico and North Pacific Ocean. Since ESA-listed species are distributed across these ocean basins, species densities are relatively low overall. For example, Roberts et al. (2016) modeled cetacean densities for groups of taxa in the Gulf of Mexico. For the group including ESA-listed sperm whales, the highest density was 0.04 individuals per square kilometer in the central northern Gulf and along the continental slope. However, sperm whale densities are likely lower than this because sperm whales were modeled with other species and only half of the sightings used in the model were sperm whale sightings. For sea turtles, the highest expected density is 0.02 individuals per square kilometer at the Super Heavy landing location (McDaniel et al. 2000). In the North Pacific Ocean, even lower densities are expected. The highest density for ESA-listed species is 0.0043 individuals per square kilometer for sea turtle species; U.S. Navy 2017). Given that Super Heavy is only 69 meters tall and nine meters in diameter, the probability of a direct impact to an ESA-listed species is extremely unlikely.

The same conclusion was reached when analyzing the Joint Flight Campaign missile testing from the Pacific Missile Range Facility (OPR-2021-02470). The Biological Evaluation for the Joint Flight Campaign utilized the best available density data for ESA-listed marine mammals and sea turtles, which is from the U.S. Navy's Marine Species Density Databases for training and testing areas in the Pacific (U.S. Navy 2017). Species densities were averaged across the study area within a proposed drop zone, and the highest estimated densities across seasons were used to represent animal densities in the entire drop zone. For a single flight test from the Pacific Missile Range Facility, the maximum number of estimated animal exposures for any ESA-listed species was for humpback whales, at 0.00001 individuals, corresponding to a one in 100,000 chance of contacting a humpback whale during a single test from the Pacific Missile Range Facility.

It is worth noting that materials have been expended from rocket launches for decades with no known interactions with any of the ESA-listed species considered in this Letter of Concurrence. We believe it would be extremely unlikely for an ESA-listed species to be directly struck by launch vehicle components, spacecraft, radiosondes, and any launching or landing-related debris; thus, the potential effects to ESA-listed species from a direct impact by those fallen objects are discountable. Therefore, we conclude that direct impact from fallen objects to ESA-listed marine mammals, sea turtles, and fish in the action area from the proposed action, may affect, but are not likely to adversely affect these species.

4.2 Ingestion

Weather balloon fragments and unrecovered floating debris in the ocean have the potential to affect ESA-listed species in the action area. Individuals of ESA-listed species who are foraging in the area may risk ingesting pieces of unrecovered weather balloon or floating debris from expended Starships.

Latex weather balloons typically have a diameter of approximately four feet at launch. When the weather balloon rises to approximately 19–29 kilometers, the volume of the balloon increases to the point where the elastic limit is reached and the balloon bursts. The temperature at this altitude range can reach negative 40 degrees Fahrenheit (°F) or even colder. Under these conditions of extreme elongation and low temperature, the balloon undergoes "brittle fracture", where the rubber actually shatters along grain boundaries of crystallized segments. The resultant pieces of rubber are small strands comparable to the size of a quarter (Burchette 1989). Researchers at the University of Colorado and NOAA confirmed this (University of Colorado and NOAA 2017). The small shreds then make their way back to the surface of the Earth and are expected to land in the ocean. Along the way, the pieces can be subject to movements in atmospheric pressure and wind as they sink through the air. This can cause the fragments to become scattered and disperse before landing on the surface of the ocean where they are subject to movement of surface currents, which can cause additional dispersion.

The balloon fragments would be positively buoyant, float on the surface, and begin to photo-oxidize due to UV light exposure. Studies have shown latex in water will degrade, losing tensile strength and integrity, although this process can require multiple months of exposure time (Pegram and Andrady 1989; Andrady 1990; Irwin 2012). Field tests conducted by Burchette (1989) showed latex rubber balloons are very degradable in the environment under a broad range of exposure conditions, including exposure to sunlight and weathering and exposure to water. The balloon samples showed significant degradation after six weeks of exposure (Burchette 1989).

The floating latex balloon fragments would provide substrate for algae and eventually be weighed down with growth of heavier epifauna, such as tunicates (Foley 1990). The degree to which such colonization (known as biofouling) may occur will correspond to the amount of time the balloon fragment remains at or near the ocean’s surface. Additionally, an area’s geographic latitude (and corresponding climatic conditions) has a marked effect on the degree of biofouling on marine debris. Fouling of the latex shreds could be confused with organic matter while ESA-listed species are foraging. Green sea turtles are herbivorous and a large study of green sea turtles that stranded in Texas between 1987 and 2019 discovered that 48 percent had ingested plastic, although there was no evidence of mortality related to the ingestion of the plastics (Choi et al. 2021). A study of latex balloon fragment ingestion by freshwater turtles and catfish found no significant impact on survival or blood measured indicators of stress response (Irwin 2012).

In addition to further degradation of the latex material, the embedded fouling organisms would cause the material to become negatively buoyant, making it slowly sink to the ocean floor. Studies in temperate waters have shown that fouling can result in positively buoyant materials (e.g., plastics) becoming neutrally buoyant, sinking below the surface into the water column after several weeks of exposure (Ye and Andrady 1991; Lobelle and Cunliffe 2011), or descending farther to rest on the seafloor (Thompson et al. 2004).

Given that the small weather balloon shreds are likely to be scattered and not concentrated, and that they should only be available in the upper portions of the water column for a matter of weeks, the potential for exposure of ESA-listed species to these shreds is extremely low and therefore discountable. Also, none of the ESA-listed species considered in this consultation forage at the seafloor; therefore, the likelihood of them encountering ingestible material once it has settled over the long-term is expected to be extremely unlikely to occur and thus discountable.

We conclude that the risk of ingesting pieces of weather balloons to ESA-listed marine mammals, sea turtles, and fish in the action area because of the proposed action may affect, but are not likely to adversely affect these species.

4.3 Vessel Strike

The ESA-listed marine mammals, sea turtles, and fish may be affected by vessel transit and operations in the Gulf of Mexico and North Pacific Ocean during the proposed action. The proposed action consists of relatively little vessel use, as the FAA proposes to issue a single vehicle operator license for up to three flights (with license modification) of Starship/Super Heavy. Vessels will mainly be used for debris survey and salvage; thus, vessels will be transiting relatively slowly to search for pieces of debris and to collect those pieces. ESA-listed marine mammals, sea turtles, and fish may spend time at or near the ocean surface but generally spend most of their time underwater. In addition, the debris survey and salvage will occur offshore, where densities of these species are generally low compared to nearshore areas where interactions with certain species (e.g., Hawaiian monk seal, Main Hawaiian Islands DPS false killer whale, and giant manta ray) are more likely. Given the anticipated low densities of ESA-listed species in the area, and that all vessels would be required to comply with the Environmental Protection Measures for vessel operations (requiring a dedicated observer on board, maintaining minimum safety distances, avoidance measures), vessel strikes are considered extremely unlikely to occur and therefore discountable. Based on previous operation reports provided as part of ESA section 7 consultations for similar operations, there have not been reported vessel collisions with ESA-listed marine species.

In an off-nominal event where Super Heavy lands outside of the landing location in the Gulf of Mexico, the Vessel Operations PDCs in the PLoC (Appendix II – Project Design Criteria) include additional measures to avoid Rice's whales. Rice's whale requires additional consideration due to its very low population size (likely < 50) and its ecology. The Rice's whale dives deep during the day to forage but at night tends to stay just below the surface, increasing the chance of the animal being struck at night. The Vessel Operations measures in the PLoC PDCs include the condition that recovery and vessel transit will not occur at night in the Rice's whale core distribution area. We have also recommended that every effort should be made to make sure that any off-nominal landing of Super Heavy does not land in the Rice's whale core distribution area. These restrictions will ensure the effects of vessel strike due to recovery vessel operations are discountable.

We conclude that the risk of ship strike to ESA-listed marine mammals, sea turtles, and fish in the action area due to the proposed action may affect, but are not likely to adversely affect these species.

4.4 Acoustic Stressors

Potential acoustic stressors to ESA-listed species from the proposed action include vessel noise, sonic booms, impulse noise from spacecraft or booster landings in the ocean, aircraft overflight, and expected explosive event upon Starship's impact on the surface of the North Pacific Ocean (first launch only).

NMFS uses acoustic thresholds to predict how an animal's hearing will respond to sound exposure (see https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-acoustic-technical-guidance).

For marine mammals, acoustic thresholds are different based on marine mammal hearing groups (Table 2). Marine mammal hearing groups are used to acknowledge that not all marine mammal species have identical hearing or susceptibility to noise-induced hearing loss. They are also used to establish marine mammal auditory weighting functions.

Table 2. Marine mammal hearing groups.

Hearing Group	Generalized Hearing Range*
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, Cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

***** *Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).*

4.4.1 Vessel Noise

Noise from debris surveillance vessels may produce an acoustic disturbance or otherwise affect ESA-listed species that spend time near the surface, such as marine mammals, sea turtles, and pelagic fishes, which may generally disrupt their behavior. Studies have shown that vessel operation can result in changes in the behavior of marine mammals, sea turtles, and fishes (Hazel et al. 2007; Holt et al. 2009; Luksenburg and Parsons 2009; Noren et al. 2009; Patenaude et al. 2002; Richter et al. 2003; Smultea et al. 2008). However, vessel noise will not exceed noise from the explosive event expected upon Starship's impact at the ocean's surface. Vessel noise will also not exceed that of larger commercial shipping vessels (up to 100 dB re 1 µPa in high shipping traffic areas; Haver et al. 2021), which do not cause a detectable response from any ESA-listed species. Additionally, while not specifically designed to do so, several aspects of the Vessel Operations PDCs will minimize effects associated with vessel acoustic disturbance (i.e., requiring protected species observer, maintaining distance from protected species, slowing to 10 knots or less around certain species and in specific areas; Appendix II – Project Design Criteria). For example, vessels are required to maintain 150 feet (approximately 46 meters) distances from sea turtles, and sea turtles only appear to show responses (i.e., avoidance behavior) at approximately 10 meters or closer to the vessel (Hazel et al. 2007).

Given the Vessel Operations PDCs and the relatively small contribution of the vessels associated with the proposed action to the overall soundscape, effects from vessel noise are expected to be so minor that they cannot be meaningfully evaluated and are thus insignificant.

We conclude that the risk of behavioral disturbance from vessel noise to ESA-listed marine mammals, sea turtles, and fish in the action area because of the proposed action may affect, but are not likely to adversely affect these species.

4.4.2 Sonic Booms

A sonic boom will be generated, due to the slowing of the vehicle in the atmosphere, during Starship landing (first flight) and Super Heavy landings in the ocean. Due to the shape and size of Starship/Super Heavy launch vehicle, as well as the altitude at which Starship would generate a sonic boom, the FAA do not expect the overpressure to exceed one to two psf. An overpressure of one psf is similar to a thunderclap. For a Super Heavy landing in the Gulf of Mexico, expected overpressures will be a maximum of 15 psf at the ocean's surface. Boom intensity, in terms of psf, is greatest under the flight path and progressively weakens with horizontal distance away from the flight track. Based on modeling, the area beneath the Super Heavy landing location (31 kilometers offshore) that will receive the maximum overpressure (up to 15 psf) as it is landing would be a maximum of 1.28 kilometers in diameter. The maximum overpressure for a Starship reentry is 2.2 psf.

Overpressure from sonic booms are not expected to affect marine species underwater. Acoustic energy in the air does not effectively cross the air/water interface and most of the noise is reflected off the water's surface (Richardson et al. 1995). Additionally, underwater sound pressure levels from in-air noise are not expected to produce a measureable response from ESA-listed species.

Previous research conducted by the U.S. Air Force supports this conclusion with respect to sonic booms, indicating the lack of harassment risk for protected marine species in water (U.S. Air Force Research Laboratory 2000). The researchers used a threshold for harassment of marine mammals and sea turtles by impulsive noise of 12 pound per square inch (psi) peak pressure and/or 182 dB re 1 µPa, which was the threshold used by NMFS and the Department of Defense at the time. The researchers pointed out that, to produce the 12 psi in the water, there needs to be nearly 900 psf at the water's surface, assuming excellent coupling conditions. They also noted that it is very difficult to create sonic booms that even approach 50 psf. Current NMFS thresholds for behavioral disturbance from impulsive acoustic sources are lower than the older threshold of 182 dB re 1 µPa (160 dB re 1 µPa for marine mammals and 175 dB re 1 µPa for sea turtles; as mentioned previously the 150 dB re 1 µPa for fishes is an informal threshold) but these current thresholds are root mean square (rms) values and not peak pressure values. The rms value is a square root of the average of sound signal pressures that have been squared over a given duration. Due to the squaring and averaging of sound pressure values (which tends to level out large values), the rms value results in a more conservative value than just a peak value. Still, what the U.S. Air Force research report illustrates is that it would take a tremendously greater sonic boom than what would be generated by either Super Heavy or Starship landings to create an acoustic impact underwater that would be likely to cause a measureable response in ESA-listed marine mammals, sea turtles, or fish. Therefore, any effect from the sonic booms on ESA-listed species while under water would be insignificant.

ESA-listed marine mammals and sea turtles could be exposed to the overpressures from sonic booms in the air when they are surfacing for air; however, the chances of both events happening at same time (i.e., species surfacing and a sonic boom occurring) is extremely unlikely, given the low species densities and especially considering the length of a sonic boom is less than one second (less than 300 milliseconds). The Hawaiian monk seal can spend time hauled out of the water and therefore may be affected by an in-air sonic boom. However, the Starship landing is not planned near areas where the Hawaiian monk seal hauls out. The magnitude of the sonic boom that has the potential to impact land areas where Hawaiian monk seals may be present is low (maximum 2.2 psf). The 2019 Marine Mammal Protection Act Letter of Authority for Vandenberg Space Force Base launch operations arrived at a similar conclusion (84 FR 14314). Over 20 years of monitoring data for pinniped species including harbor seals (*Phoca vitulina*), elephant seals (*Mirounga angustirostris*), and California sea lions (*Zalophus californianus*) at the Vandenberg Space Force Base and the North Channel Islands, showed that reactions to sonic booms one psf or lower tended to be insignificant. At overpressures one to two psf, some animals were alerted (lifted their heads) to the sound and others exhibited a startle response (flushed into the water). However, there were no behavioral responses beyond flushing into the water, which is a normal behavior. Although this data do not include the ESA-listed pinniped considered in this consultation, the long time series data for other species serve as a proxy, indicating that sonic booms one to two psf or lower do not result in significant disturbance for marine mammals that haul out of water. Therefore, the effect of these sonic booms is unlikely to create any significant disturbance for the Hawaiian monk seal when they are out of the water.

In summary, it is extremely unlikely that an ESA-listed marine mammal or sea turtle would surface close to Super Heavy or Starship at the exact moment to be exposed to a sonic boom in the air, therefore the effects are discountable. Acoustic effects from a sonic boom to ESA-listed marine mammals, sea turtles, or fishes underwater are not expected to be measurable; therefore, the effects are insignificant. The low level sonic boom (one to two psf) resulting from the Starship landing, is not expected to create any significant disturbance to hauled out ESA-listed pinnipeds and the effects are therefore insignificant. Therefore, sonic booms may affect, but are not likely to adversely affect ESA-listed marine mammals, sea turtles, and fish.

4.4.3 Aircraft Overflight

Noise from aircraft overflight may enter the water, but, as stated in relation to sonic booms, very little of that sound is transmitted into water. Sound intensity produced at high altitudes is reduced when it reaches the water's surface. At lower altitudes, the perceived noise will be louder, but it will decrease rapidly as the aircraft moves away. ESA-listed species that occur at or very near the surface (e.g., marine mammals, sea turtles, oceanic whitetip sharks, and giant manta rays) at the time of an overflight could be exposed to some level of elevated sound. There could also be a visual stimulus from the overflight that could potentially lead to behavioral response. Both noise and visual stimulus impacts would be temporary and only occur if an individual is surfacing or very close to the surface and an aircraft happens to be flying over at the same time.

Studies have shown minor behavioral effects (e.g., longer time to first vocalization, abrupt dives, shorter surfacing periods, breaching, tail slaps) in marine mammals exposed to repeated fixed wing aircraft overflights (Patenaude et al. 2002; Wursig et al. 1998; Richter et al. 2006; Smultea et al. 2008). However, most of these responses occurred when the aircraft was below altitudes of 820 feet (approximately 250 meters), which is below the altitude expected to be flown by aircraft during surveillance for the activities considered in this consultation. Species-specific studies on the reaction of sea turtles to fixed wing aircraft overflight are lacking. Based on sea turtle sensory biology (Bartol and Musick 2003), sound from low-flying aircraft could likely be heard by a sea turtle at or near the ocean surface. Sea turtles might be able to detect low-flying aircraft via visual cues such as the aircraft's shadow, similar to the findings of Hazel et al. (2007) regarding watercraft, potentially eliciting a brief reaction such as a dive or lateral movement. However, considering that sea turtles spend a significant portion of their time underwater and the low frequency and short duration of surveillance flights, the probability of exposing an individual to an acoustically or visually-induced stressor from aircraft momentarily flying overhead would be very low. The same is relevant for oceanic whitetip sharks and giant manta rays in the action area, considering their limited time near the surface and brief aircraft overflight.

Additionally, aircraft procedures stated in the PDCs require aircraft to maintain a minimum of 1,000 feet (approximately 305 meters) over ESA-listed species and to avoid any harassment-type behavior (e.g., flying in circles) over any marine mammals or sea turtles (Appendix II – Project Design Criteria).

The chances of an individual ESA-listed species being exposed to the proposed aircraft overflights are extremely low. Given the limited and temporary behavioral responses documented in available research, it is expected that potential effects on ESA-listed species, should they even occur, would be insignificant. We conclude that effects from aircraft overflight to ESA-listed marine mammals, sea turtles, and fish in the action area because of the proposed action may affect, but are not likely to adversely affect these species.

4.4.4 Noise from Starship Explosive Event

SpaceX’s expectation of the sequence of events leading to the Starship explosive event and subsequent acoustic calculations are as follows:

1. The Starship vehicle impacts the water at terminal velocity and at 90 degree angle (horizontal). The impact disperses settled remaining propellants and drives structural failure;
2. The structural failure leads to cracks propagating throughout the structure at the speed of sound through steel. Cracks eventually lead to failure of the transfer tube, allowing the LOX and LCH_4 to mix;
3. The mixed propellants find an ignition source in the proximity of the fuel transfer tube and detonate;
4. The blast wave propagates outward towards the air-water boundary. In-air attenuation models are used to calculate the acoustic properties in the air on the air side of the boundary;

5. Assuming that the vehicle's steel structure is not blocking the air-water boundary, the acoustic properties on the water side of the boundary are calculated based on an estimated transmission coefficient for a near-surface explosion;
6. Using the sound pressure level in the water directly below the explosion as the peak source sound level, SpaceX uses NMFS recommendations of an omnidirectional source to calculate the sound attenuation in water; and
7. SpaceX calculates the range beyond which no response would be observed for the relevant species. The range is then used to calculate ensonified areas relevant for each species.

The modeled energy release from a fuel explosion will significantly exceed the energy associated with the surface impact itself. This sequence of events is based on past real-world observations of Starship explosions resulting from impact with a surface. SpaceX developed this Underwater Noise Analysis Methodology for Starship Orbital Test Flight Vehicle (Appendix III – SpaceX Underwater Noise Methodology), relying on the robust application of scientific principles; a conservative estimation of the necessary coefficients based on available, existing reference data; and the application of appropriate species harassment thresholds from NMFS. This methodology is summarized below (for full methodology, see Appendix III – SpaceX Underwater Noise Methodology).

4.4.4.1 SpaceX In-Air Explosion Scenario

First, SpaceX calculated the acoustic properties of the explosive event on the air side of the air-water boundary using the simplified Kingery-Bulmash equations as modified by Swisdack[3]. This is calculated by propagating the blast wave from a height of 4.5 meters, which is the distance from the fuel transfer tube (source of explosion) to the vehicle's structure (Figure 4). The mixture of the propellants will behave as a high explosive with an explosive weight of 1,260 kilograms (Appendix III – SpaceX Underwater Noise Methodology).

[3] M. Swisdack, Simplified Kingery Airblast Calculations, Web, https://apps.dtic.mil/sti/pdfs/ADA526744.pdf, Accessed 15 November 2022. https://www.denix.osd.mil/ddes/denix-files/sites/32/2018/07/2018-06-11-DDESB-TP-202c-DDESB-Blast-Effects-Computer-Open-BEC-O2c-V...-1.pdf

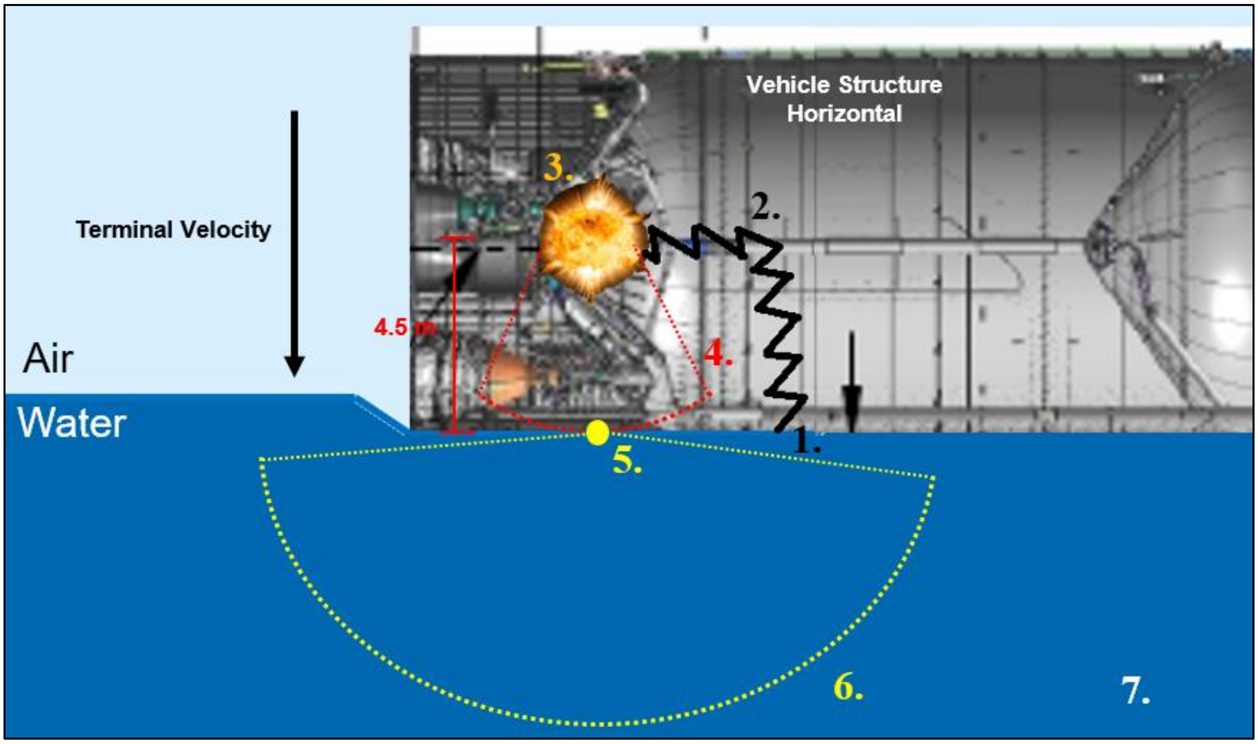

Figure 4. The sequence of events and subsequent analyses to assess potential underwater noise impacts from a Starship explosion. Item 1 – Starship impacts the ocean's surface; Item 2 – Structural failure and propellant mixing; Item 3 – Immediate explosive event; Item 4 – Blast propagation; Item 5 – Acoustic intensity transmission across the air-water boundary; Item 6 – Underwater sound attenuation; and Item 7 – Calculation of ensonified areas.

While the Starship explosion at the transfer tube is best modeled by a spherical model, the use of a hemispherical model, as done in this methodology, is comparatively conservative as the hemispherical model directs all of the explosive energy downwards towards the water surface. This results in a greater overpressure prediction at the air-water interface than a spherical model. The use of a hemispherical model also accounts for other sources of uncertainty, such as the effects of propagation through gaseous oxygen and the potential for blast reflection off of interior structures like the engine section.

Because the air-water surface is within the near-field of the explosion, there is likely significant coupling between the explosion and the water[4], and the portion of the acoustic wave intensity that is transmitted into the water will likely be higher than when a normal acoustic wave reaches the air-water boundary. Thus, SpaceX assumes an intensity transmission coefficient of 14 percent, because this represents a near-field transmission coefficient, which is more than 100 times greater than the far-field air-water boundary transmission coefficient of 0.11 percent. This conservative transmission coefficient accounts for the limited scope of research into near-surface explosions and their transmission across the air-water boundary (see Appendix III – SpaceX Underwater Noise Methodology). This results in a 283.2 dB re 1 μPa peak sound level. Using this value, SpaceX calculated the distance to insignificant response thresholds. The ensonified

[4] Email from Jacob Cantin, Federal Aviation Administration, to Matthew Thompson, SpaceX, November 3, 2022.

areas are then calculated as a circle. Insignificant responses would be anticipated outside of the ensonified areas listed in Table 3.

Table 3. ESA-listed species in the Starship landing area, hearing and species groups relevant to acoustic thresholds, maximum threshold for a response, and ensonified areas related to the explosive event.

Species	Hearing/Species Group	Maximum Threshold to Response* (dB re 1 μPa)	Ensonified Area (km^2)
Blue Whale	Low-frequency cetacean	219	32.86
False Killer Whale – Main Hawaiian Islands Insular DPS	Mid-frequency cetacean	230	2.61
Fin Whale	Low-frequency cetacean	219	32.86
Sei Whale	Low-frequency cetacean	219	32.86
Sperm Whale	Mid-frequency cetacean	230	2.61
Hawaiian Monk Seal	Phocid pinniped	218	41.37
Green Turtle –Central North Pacific DPS	Sea turtle	232	1.65
Hawksbill Turtle	Sea turtle	232	1.65
Leatherback Turtle	Sea turtle	232	1.65
Loggerhead Turtle – North Pacific DPS	Sea turtle	232	1.65
Olive Ridley Turtle	Sea turtle	232	1.65
Giant Manta Ray	Fish	206	164.7
Oceanic Whitetip Shark	Fish	206	164.7

** Note peak sound pressure thresholds are used.*

To estimate the number of exposures resulting from the explosive event, species densities were multiplied by the ensonified areas (Table 4). Species densities for marine mammals and sea turtles were obtained from the U.S. Navy Marine Species Density Database Phase III for the Hawaii-Southern California Training and Testing Study Area (U.S. Navy 2017). Densities for oceanic whitetip sharks and giant manta rays were only available through the NMFS Pacific Islands Regional Office’s fisheries observer data. The most recent year (2022) of data were obtained from the deep-set long line fisheries observer data, because fishing effort encompassed the Starship landing area. There were over 450 interactions with oceanic whitetip sharks in the Pacific Islands fishery in 2022 but only four occurred within the Starship landing area (93,054 square kilometers). The deep-set long line fishery operates year-round with 20 percent observer coverage (one in five fishing trips have an observer on board); thus, we extrapolated the four observed oceanic whitetip sharks to an estimated 20 observations in 2022. This is likely higher than what would be expected with standard survey data, because fishing vessels put out bait that attracts predators like the oceanic whitetip shark. These are also observations, not targeted surveys to identify species densities in an area. These observations were made over 12 months, representing individuals moving in and out of the Starship landing area, and are not representative of densities at any particular time each year. The Starship landing area is 93,054 square kilometers. Using this information, we can approximate daily oceanic whitetip shark densities for the Starship landing area as 20 divided by 93,054 divided by 365, which is approximately 0.0000006 individuals per square kilometer on any given day. Because the explosion will not generate sound for a full day, this is a very conservative density estimate. There were not enough data to determine densities for giant manta rays; however, there were no giant manta ray interactions in 2022 and only one interaction recorded in the Starship landing area in the time period that the deep-set long line fishery has been active (2004–2022; giant manta ray interaction inside the Starship landing area was recorded in 2004).

Table 4. ESA-listed species densities in the Starship landing area and calculations for the estimated number of exposures that would amount to more than insignificant related to the explosive event.

Species	Density* (individuals per km^2)	Ensonified Area (km^2)	Estimated Number of Exposures more than Insignificant
Blue Whale	0.00005	32.86	0.001643
False Killer Whale – Main Hawaiian Islands Insular DPS	0.000796	2.61	0.002078
Fin Whale	0.00006	32.86	0.001972
Sei Whale	0.00016	32.86	0.005258
Sperm Whale	0.001941	2.61	0.005066
Hawaiian Monk Seal	0.00003	41.37	0.001241
Green Turtle –Central North Pacific DPS	0.0043	1.65	0.007095
Hawksbill Turtle	0.0043	1.65	0.007095
Leatherback Turtle	0.0043	1.65	0.007095
Loggerhead Turtle – North Pacific DPS	0.0043	1.65	0.007095
Olive Ridley Turtle	0.0043	1.65	0.007095
Oceanic Whitetip Shark	0.0000006**	164.7	0.0001**

** Note sea turtle densities are based on the sea turtle guild (U.S. Navy 2017) because of a lack of reasonable in-water density estimates for individual species.*

*** Oceanic whitetip shark density is calculated as a daily density; thus, exposures are also daily estimates.*

Given the low estimated exposures that would amount to an effect beyond insignificant, we expect that potential effects of an explosive event, as calculated by SpaceX, on ESA-listed species to be extremely unlikely and therefore discountable.

4.4.4.2 NMFS Surface Explosion Scenario

While SpaceX categorizes Starship's explosive event as an in-air explosion, NMFS is uncertain whether this scenario aligns with previous ESA section 7 consultations involving in-air explosions. In this case, it is useful to examine the possibility of a surface explosion, in which the explosive center (fuel transfer tube) would be at the ocean's surface. The following describes NMFS' preliminary calculations for a surface explosion; first calculating the peak source level of an underwater explosion and then adjusting the source level based on the difference in pressure between an underwater and surface explosion.

For a fully submerged underwater explosion, with an explosive weight of 1,260 kilograms (Appendix III – SpaceX Underwater Noise Methodology), the peak overpressure can be found to be 852 MegaPascals (Dzwilewski 2014), at a distance of 1 meter. This corresponds to a peak source level of 298.6 dB re 1 µPa. However, because the acoustic energy will be split between air and water domains, only a fraction of the energy will be directed down into the water and propagate. An estimate of this energy splitting between domains can be found by using the experimental work of Eneva et al. (2001), where the authors measured the underwater sound from small explosives whose depths varied from near the surface, to depths at which nearly all the energy remained in the water. The measured underwater acoustic pressure for explosions near the surface in two experiments was found to be diminished by a factor of approximately 0.4 and 0.3, relative to measurements of deep water explosions. These ratios correspond to a reduction of approximately -eight and -10.5 dB, respectively, for the surface explosion scenario relative to deep water explosions. Applying the minimum of these two values, which is the most conservative choice, to the underwater source level calculated above (298.6 dB re 1 µPa), the peak source level can be estimated to be approximately 290.6 dB re 1 µPa, in the case of a detonation whose explosive center is at the surface. This value is approximately eight dB higher than the source level estimated for the in-air explosion modeled for the expected Starship explosive event. However, even with the increase in source level, exposure numbers that would be more than insignificant remain low (Table 5).

Table 5. Estimated exposures that would amount to more than insignificant for ESA-listed species from NMFS' preliminary calculations of a surface explosion scenario.

Species	Density* (individuals per km^2)	Ensonified Area (km^2)	Estimated Number of Exposures more than Insignificant
Blue Whale	0.00005	180.78	0.01
False Killer Whale – Main Hawaiian Islands Insular DPS	0.000796	14.36	0.01
Fin Whale	0.00006	180.78	0.01
Sei Whale	0.00016	180.78	0.03
Sperm Whale	0.001941	14.36	0.03
Hawaiian Monk Seal	0.00003	227.59	0.007
Green Turtle –Central North Pacific DPS	0.0043	9.06	0.04

Hawksbill Turtle	0.0043	9.06	0.04
Leatherback Turtle	0.0043	9.06	0.04
Loggerhead Turtle – North Pacific DPS	0.0043	9.06	0.04
Olive Ridley Turtle	0.0043	9.06	0.04
Oceanic Whitetip Shark	0.0000006**	164.7	0.0005**

** Note sea turtle densities are based on the sea turtle guild (U.S. Navy 2017) because of a lack of reasonable in-water density estimates for individual species.*

*** Oceanic whitetip shark density is calculated as a daily density; thus, exposures are also daily estimates.*

Given the low estimated exposures, we expect that potential effects on ESA-listed species would be discountable. We conclude that effects from the Starship explosive event to ESA-listed marine mammals, sea turtles, and fish in the action area because of the proposed action may affect, but are not likely to adversely affect these species.

4.5 Designated Critical Habitat

Critical habitat for Gulf Sturgeon, Main Hawaiian Islands Insular DPS false killer whale, Northwest Atlantic Ocean DPS loggerhead sea turtle, and Hawaiian monk seal occur in the action area. Designated critical habitat elements that may be affected by the proposed action is water quality: Gulf sturgeon and Main Hawaiian Islands Insular DPS false killer whale critical habitat include Physical and Biological Features (PBFs) for water quality. Potential effects to water quality could result from debris. Debris salvage and recovery would reduce the magnitude and duration of any impacts. Given the unlikely scenario that debris would be unrecovered, it is highly unlikely that water quality features would become degraded to the extent the conservation value of the critical habitats are impacted.

Most of the proposed operations would occur well offshore in deep waters. Landing and recovery operations would not occur within five nautical miles of the coast where most of the critical habitat for Gulf sturgeon occurs, except for Cedar Key, Florida, which is far away from flight trajectories from the Boca Chica Launch Site. Though possible, it is very unlikely that any landing of Super Heavy would occur within that portion of Gulf sturgeon critical habitat.

Migratory passage and adequate space for movement are features common to Main Hawaiian Islands Insular DPS false killer whale and Northwest Atlantic Ocean DPS loggerhead sea turtle critical habitats. As stated previously, no Starship/Super Heavy operations will occur in the immediate nearshore environment (< five nautical miles from shore), resulting in a considerable amount of those critical habitats not being affected by the proposed action. Landing operations will occur even farther from shore (31 kilometers for Super Heavy landing and at least 48 kilometers for Starship landing). Vessel transit to and from ports to the Starship and Super Heavy landing locations (North Pacific Ocean and Gulf of Mexico, respectively) will not affect migratory passage or space, as vessel transits associated with the proposed action are temporary with no long-term occupation or structures creating obstructions to movement. Thus, any potential effects are likely to be insignificant.

Prey and foraging areas are other common elements across several of the designated critical habitats in this consultation: Main Hawaiian Islands Insular DPS false killer whale and Hawaiian monk seal foraging areas. As previously stated, sound from sonic booms is not expected to enter the water with enough intensity to create any significant behavioral disturbances to ESA-listed species and the effects of this sound is also expected to be insignificant for zooplankton or small pelagic schooling fishes that are important prey species in these critical habitats. The explosive event is of relatively short duration and will be of sufficient distance away from any designated critical habitat that effects on any prey species in designated critical habitat will be undetectable. Pieces of weather balloons are not expected to be available to prey species in sufficient concentrations to measurably affect prey populations, and is not expected to reduce the conservation value of that PBF in any designated critical habitats. Therefore, the effect will be insignificant.

A unique PBF for Main Hawaiian Islands Insular DPS false killer whale critical habitat is sound levels that would not significantly impair false killer whales' use or occupancy. As previously stated, sound of any intensity that would create meaningful disturbance underwater is not an expected effect from proposed operations. Additionally, the explosive event, which will be the loudest sound source during the proposed actions in the North Pacific Ocean, will not ensonify nearshore areas where Main Hawaiian Islands Insular DPS false killer whale critical habitat occurs. The TTS ensonified area for this species is 41.37 square kilometers, and the explosive event will take place at least 48 kilometers from shore; thus, would not affect Main Hawaiian Islands Insular DPS false killer whale critical habitat.

Oceanographic conditions supporting *Sargassum* habitat having adequate abundance and cover for post hatchlings and prey is a PBF for Northwest Atlantic Ocean DPS loggerhead sea turtle critical habitat in the Gulf of Mexico. The degree and extent of Super Heavy landings are not large enough to affect boundary currents or areas of convergence that promote the aggregation of *Sargassum*. Any potential impacts to these features are expected to be very small and temporary, and therefore insignificant.

In summary, the effects associated with stressors from Starship/Super Heavy operations that are part of the proposed action may affect, but are not expected to adversely affect any of the designated critical habitats in the action area.

5 CONCLUSION

Based on this analysis, NMFS ESA Interagency Cooperation Division concurs with the FAA that the proposed action may affect, but is not likely to adversely affect ESA-listed species and designated critical habitat.

6 CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the ESA directs Federal agencies to use their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of the threatened and endangered species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on ESA-listed species or critical habitat, to help implement recovery plans or develop information (50 C.F.R. §402.02).

We make the following discretionary conservation recommendations that we believe are consistent with this obligation and therefore should be considered by the FAA and SpaceX in relation to their 7(a)(1) responsibilities. These recommendations will provide information for future consultations involving launch and reentry vehicle operations that may affect ESA-listed species.

- We recommend the FAA and SpaceX gather acoustic data on the explosive event expected for the first flight of Starship/Super Heavy. Sound source verification may help to more accurately determine the impacts of this near-surface explosion scenario in the future.
- During any nighttime vessel operations (e.g., vessel operations during 24–48 hour debris survey), in addition to the Vessel Operations PDCs, we recommend vessel speeds not to exceed 10 knots to reduce the risk of lethal or injurious vessel strike. We also recommend that dedicated observers (Education and Outreach PDCs) are equipped with nighttime visual equipment (e.g., night vision, thermal imaging, infrared binoculars) to identify protected species in the dark.
- In an off-nominal event where Super Heavy does not land at the landing location in the Gulf of Mexico, effort should be made to move any potential landing out of the Rice's whale core distribution area boundaries. Additionally, no vessel transit should take place in the Rice's whale core distribution area unless to specifically sink Super Heavy (in an off-nominal event where Super Heavy did not sink after landing) and then immediately exit at the nearest boundary edge while staying out of the core habitat area with depths of 100 meters to 425 meters, where the Rice's whale has been observed (Rosel et al. 2021).
- The action agency should coordinate with NMFS ESA Interagency Cooperation Division to foster collaboration with the NOAA Marine Debris Program (MDP), in order to evaluate how activities of the MDP may apply to debris that originates from space launch and reentry operations (e.g., expended vehicle components).

In order for NMFS to be kept informed of actions minimizing or avoiding adverse effects on ESA-listed species or their critical habitat, the FAA should notify the ESA Interagency Cooperation Division of any conservation recommendations implemented as part of activities included in this consultation. This information can be included in annual reports.

7 Reinitiation Of Consultation

Reinitiation of consultation is required and shall be requested by the federal agency, where discretionary federal involvement or control over the action has been retained or is authorized by law and:

1. New information reveals effects of the action that may affect an ESA-listed species or designated critical habitat in a manner or to an extent not previously considered;
2. The identified action is subsequently modified in a manner that causes an effect to the ESA-listed species or designated critical habitat that was not considered in this concurrence letter; or
3. A new species is listed or critical habitat designated that may be affected by the identified action (50 C.F.R. §402.16).

Please direct questions regarding this letter to Emily Chou, Consulting Biologist, at (301) 427-8483 or emily.chou@noaa.gov, or me at (301) 427-8493 or lisamarie.carrubba@noaa.gov.

Sincerely,

Lisamarie Carrubba, Ph.D.
Acting Chief
ESA Interagency Cooperation Division
Office of Protected Resources

Cc: Amy Hanson, FAA

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8 APPENDIX I – LETTER OF INTENT

LETTER OF INTENT (LOI) FOR SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX) TO PROVIDE INFORMATION RELATED TO LAUNCH AND REENTRY OPERATIONS TO THE UNITED STATES COAST GUARD (USCG) FOR LAUNCH AND REENTRY OPERATIONS IN THE COAST GUARD PACIFIC AREA (PACAREA) AREA OF RESPONSIBILITY (AOR) TO ENSURE SAFETY OF THE MARITIME DOMAIN

1) BACKGROUND.

   a) 14 C.F.R. Chapter Ill requires Commercial Space Operators to coordinate with the U.S. Coast Guard to establish procedures for the issuance of a Notice to Mariners, and any other measures the Coast Guard deems necessary, to protect public health and safety prior to any launch or reentry activity licensed by the FAA that overflies or affects Navigable Waters. The U.S. Coast Guard's authority to regulate Navigation and Navigable Waters is implemented in 33 C.F.R. Chapter I.

   b) SpaceX has applied for a license from the FAA to conduct a launch or reentry operation in the
   PACAREA AOR under 14 C.F.R. Part 450. PACAREA provides operational oversight of USCG Districts Eleven, Thirteen, Fourteen, and Seventeen for the purposes of this LOI. Launch operations include preparatory activities, namely readying and testing launch vehicle systems. Developmental vehicle hardware and testing, mission rehearsals, static fire tests, and other activities are conducted at or near the launch site. Reentry operations include the reentry of any vehicle, including hazardous debris, operated by SpaceX into the PACAREA AOR. These activities present potential hazards to commercial and recreational vessel activity both on the waters surrounding the launch site and offshore.

   c) SpaceX operations will have an effect on commercial vessel traffic to include fishing vessels, tugs/barges, tankers, freighters, recreational vessels, commercial facilities, and other entities utilizing the marine transportation system.

2) PURPOSE. This LOI is in response to a request made to PACAREA from SpaceX to establish procedures for issuance of Notices to Mariners and to provide other support of its operations in the PACAREA AOR (including launch, reentry, and recovery efforts involving the Starship Super Heavy) that may affect the safety and security of the maritime domain. The U.S. Coast Guard intends to exercise its statutory authorities and responsibilities to safeguard the maritime transportation system, public safety, and marine environment with regard to these activities and, consistent with its statutory authority, will issue Notices to Mariners in its discretion. This LOI does not address Air Traffic Control procedures, nor does it cover other notifications required for launch or reentry operations.

3) SCOPE. The information contained herein establishes PACAREA, and any applicable subordinate command, intent to issue Notices to Mariners in their discretion and monitor SpaceX's launch/reentry operations activity within the PACAREA AOR to ensure safety and security of the maritime domain. The geographical boundaries of the PACAREA AOR are described in 33 C.F.R. 3.04-3(b). The U.S. Coast Guard's intent is specific to the locations and proposed operations of the subject launch/reentry areas and is designed to establish Coast Guard conditions and coordination procedures for launch/reentry operations.

4) ABBREVIATIONS & DEFINITIONS.

a) Abbreviations:

i)	AST	Office of Commercial Space Transportation
ii)	BNM	Broadcast Notice to Mariners
iii)	COTP	Coast Guard Captain of the Port
iv)	FAA	Federal Aviation Administration
v)	GMT	Greenwich Mean Time
vi)	IIP	Instantaneous Surface Impact Point
vii)	LAA	Limited Access Area
viii)	LNM	Local Notice to Mariners
ix)	NAVTEX	NAVigation TEIeX
x)	NGA	National Geospatial-lntelligence Agency
xi)	NSRA	Navigation Safety Risk Assessment
xii)	RLV	Reusable Launch Vehicle

b) Definitions:

i) Captain of the Port (COTP): Captains of the Port and their representatives enforce, within their respective areas, port safety and security and marine environmental protection regulations. These regulations include, without limitation, the following: the protection and security of vessels, harbors, and waterfront facilities; anchorages; security zones; safety zones; regulated navigation areas; deep water ports; water pollution; and ports and waterways safety.

ii) Limited Access Area (LAA): Tool used to control movement of marine traffic and limit access to all or a portion of the waterway to provide safety and security for mariners, vessels, and maritime critical infrastructure, and manage the use of navigable waterways for commerce and environmental protection. LAAs could be a tool used to mitigate risks identified through a Navigation Safety Risk Assessment (NSRA).

iii) U.S. Coast Guard District: A Coast Guard District Commander is in command of a Coast Guard District and the District Commander's office may be referred to as a Coast Guard District Office.

iv) Navigation Safety Risk Assessment (NSRA): Tool used by the COTP when preparing input for the permitting agency regarding port or waterway safety issues associated with a project located on, over, or near the navigable waters of the United States. The assessment helps the COTP identify potential navigation risks and is the basis of any recommendation to the permitting agency.

v) Navigable Waters of the United States (navigable waterway): Navigable Waters refers to the territorial seas of the United States (all waters seaward of the baseline to 12 nautical miles (NM)); internal waters of the United States that are subject to tidal influence; internal waters of the United States not subject to tidal influence but that are or have been used, or have been susceptible for use, as highways for substantial interstate or foreign commerce, have been determined by a governmental or non-governmental body (having expertise in waterway improvement) that they are capable of improvement to constitute highways for substantial interstate or foreign commerce; and other waters over which the Federal Government may exercise Constitutional authority. See 33 C.F.R. § 2.36(a).

vi) NAVTEX: The International Maritime Organization has designated NAVTEX as the primary means for transmitting coastal urgent marine safety information to ships worldwide. In the United States, NAVTEX is broadcasted from Coast Guard facilities. NAVTEX is part of the Global Maritime Distress and Safety System (GMDSS), which has been incorporated into the International Convention for the Safety of Life at Sea, 1974, to which the United States is a party. All NAVTEX broadcasts are made on 518 kHz, using narrow-band direct printing 7-unit forward error correcting transmission.

vii) Notice to Mariners:

(a) Broadcast Notice to Mariners (BNM): Broadcast Notice to Mariners is the method by which important navigation safety information is disseminated in the most expedient manner. Two agencies within the United States, the U.S. Coast Guard and the National Geospatial-lntelligence Agency (NGA), are responsible for broadcasting navigation information. Each agency has a particular geographic area of responsibility.

(i) USCG: Broadcast Notice to Mariners are issued via voice and NAVTEX. As a general rule, VHF-FM voice broadcasts will contain all information that applies to inland waters and seaward to 20 nautical miles. Medium frequency (MF) broadcasts (out to 100 nautical miles) and high frequency (HF) broadcasts (out to 200 nautical miles), delivered via NAVTEX, duplicate the VHF-FM broadcasts.

(ii) NGA: In support of the GMDSS, NGA Broadcast Warnings are promulgated by the Worldwide Navigational Warnings Service (WWNWS) to provide rapid dissemination of information critical to navigation and the safety of life at sea. Navigational Warnings are issued regularly and contain information about persons in distress or objects and events that pose an immediate hazard to navigation. NGA broadcasts contain information that concerns ocean waters beyond approximately 150 nautical miles from shore.

(b) Local Notice to Mariners (LNM): The LNM is the Coast Guard's primary means for disseminating navigation safety information concerning aids to navigation, hazards to navigation, and other items of interest to mariners navigating the waters of the United States, its territories, and possessions. Each District Commander is responsible for issuing a Local Notice to Mariners each week containing information that contributes to navigation safety and maritime security within the boundaries of the District.

(c) Notice to Mariners: The Notice to Mariners is published weekly by the NGA and prepared jointly by the USCG, National Ocean Service, and the NGA. It is intended to advise mariners of new hydrographic discoveries, changes in channels and navigational aids, and information concerning the safety of navigation. It also contains information to update charts and publications, information from Local Notices to Mariners published by USCG Districts, and information compiled from foreign notices to mariners, ship reports, and similar cooperating observer reports.

5) SpaceX Requirements. For each launch or reentry operation, SpaceX will:

a) Operations Plans: SpaceX will provide current copies of the following plans to the Coast Guard:

i) Ship Hazard Area, as defined through Range Commanders Council, Common Risk Criteria Standards for National Test Ranges 321, section 3.4. This includes a Ship Hazard Area diagram describing the projected impact area of debris fragments;

ii) Mishap Plan that includes all information to facilitate the immediate notification of primary points of contact listed in Appendix A, in the event of a launch or reentry site accident over or adjacent to navigable waters, and/or within the applicable Coast Guard District areas of responsibility.

b) Response Plans: SpaceX will provide current copies of a Response Plan to the PACAREA Prevention Branch and the applicable Coast Guard District's Waterways Management Branch(es). This Response Plan will include the procedures necessary to contain, minimize the adverse effects of, and respond to the foreseeable consequences of a mishap, as such term is defined in 14 C.F.R. § 401.7, occurring in the conduct of the launch and/or reentry, launch/reentry accident, launch/reentry incident, or other mishap, as such terms are defined in 14 C.F.R. § 401.5, occurring in the conduct of an FAA-Iicensed activity, and at a minimum, will include procedures to mitigate hazards to public health and safety and the contamination of waterways and adjacent coastline.

c) Salvage Vessel(s): SpaceX has agreed to and shall arrange a contract with salvage vessel(s) of adequate size, strength, and capability for retrieval of any vehicle reentering PACAREA AOR, and shall do so at least one week prior to the launch. The salvage vessel(s) will be staged at the site of reentry at least the day prior to launch, approximately 16 nautical miles cross range from the nominal landing location. To look for debris, SpaceX will use last known telemetry and radar information to direct initial search location and then switch to relying on a visual search from the vessel(s). If the black boxes are transmitting their location, SpaceX will also use that information for guidance. The search will begin immediately after landing and continue for a minimum of 24 hours. SpaceX will report back any findings to the applicable District Waterways Management Branch(es) and Command Center Points of Contact. In addition, SpaceX shall notify the Coast Guard of any other salvage assets being used during this time period.

d) Scheduling and Notification Activities:

i) SpaceX will annually provide the PACAREA Commander a launch and reentry schedule forecast for the fiscal year, as it is known at the time, by 30 September.

ii) SpaceX will provide notice of the launch and reentry schedule not less than 10 business days in advance of any launch, to the extent reasonably practicable.

iii) (Reentry (R)-30 days) SpaceX will submit reentry information, where applicable, at least 30 days prior to scheduled reentry or as soon as practicable for contingency reentry.

(a) SpaceX will provide this reentry information to:

(i) PACAREA Prevention Operations Planning Branch;

(ii) The applicable Coast Guard District's Waterways Management Branch(es), which will request an LNM article; and

(iii) Any applicable Sector Waterways Management Division(s).

(b) Reentry information should include the following:

(i) Mission Designator;

(ii) Vehicle type and reentry description;

(iii) Primary, secondary, and contingency reentry dates and times in GMT;

(iv) Ship Hazard Area perimeter coordinates in degrees, minutes, and seconds to three decimal places, if applicable;

(v) Recovery Officer contact information; and

(vi) Any on water asset information (name, call sign, and contact information).

v) NLT R-IO days SpaceX will contact the relevant Sector Waterways Management Division(s) and Sector Command Center to provide launch and reentry information for the LNM.

vi) (NLT R-72 hours) SpaceX will contact the following:

(a) Relevant Sector Level: Any applicable Sector Waterways Management Division(s) and

Sector Command Center(s), to request issuance of a Broadcast Notice to Mariners (BNM) to provide launch and reentry information and any other specific information needed by mariners. This communication is important because it will, subject to the discretion of the Coast Guard Captain of the Port, result in the Coast Guard issuing a NAVTEX broadcast;

(b) Relevant District Level:

(i) Relevant District Waterways Management Branch(es) to confirm launch and reentry information for the I-NM;

(ii) District Command Center(s), to ensure general awareness and monitoring and to trigger LNM issuance, at the discretion of the applicable District Commander, for launch and reentry activities occurring within 150 miles from shore;

(c) NGA may issue Navigation Area XII or HYDROPAC warning notifications for launch/reentry activities occurring over water seaward of 150 nautical miles offshore. Reentry infonnation should be sent to navsafety@nga.mil and may also be relayed via voice at (571) 557-5455.

(d) Chain of communications: SpaceX will inform PACAREA's Prevention Branch of all communications with an engaged District (dpw) and will inform the relevant District of all communications with an engaged Sector.

vii) Limited Access Area (LAA) activation, coordination and enforcement: SpaceX will notify all relevant Coast Guard entities as soon as possible of any location or timeline change.

6) Coast Guard Intent.

a) Upon timely receipt of the information relating to any launch, reentry, or recovery operation from SpaceX, PACAREA intends to:

i) Assess the information received, with relevant Districts and Sectors for potential effects in or to the maritime domain; and promptly communicate any concerns to the FAA.

ii) Discuss the information received with relevant Districts and Sectors to allow local Coast Guard leaders to make a risk-based assessment of the need for resources;

iii) Conduct a risk assessment to determine what, if any, assets are appropriate to ensure public safety and that commerce is not adversely affected by the launch, reentry, or recovery;

iv) Issue appropriate public advisories, such as Notices to Mariners (e.g. LNM and BNM), for SpaceX launches, reentries, and recoveries; and

v) Communicate Coast Guard actions in response to SpaceX's planned recovery operations to SpaceX and other stakeholders, as appropriate.

vi) Limitations: The Coast Guard cannot commit a specific number or type of asset(s) because of the dynamic nature of Coast Guard operations, the potential for competing missions, and vessel or personnel limitations. Upon notification of an imminent launch and reentry, the Coast Guard will determine asset availability based on factors that include, but are not limited to, the following: whether the spacecraft is crewed and by whom, weather and sea state at the splashdown location, competing or ongoing missions, potential hazards to Coast Guard personnel and the public, anticipated public presence at the splashdown location, and the presence of private resources arranged for the operation.

b) Applicable Waterways Management Branch intends to engage in the following scheduling and notification activities:

i) Receive and review annual forecast of scheduled launches and reentries provided by SpaceX;

ii) Endeavor to publish launch and reentry information at least 7 days prior to launch and reentry in the Local Notice to Mariners at the discretion of the operational commander and subject to operational limitations;

iii) Fulfill any other statutory responsibility pertaining to USCG jurisdiction and authorities subject to the discretion of the relevant District Commander;

iv) Consult with SpaceX on all matters related to navigation safety pertaining to space transportation as appropriate.

c) When determined necessary for the safe operation of the event, the Coast Guard may, consistent with law and regulation, promulgate a LAA and coordinate enforcement with SpaceX.

d) Irrespective of SpaceX fulfilling all requirements of paragraph 5, Coast Guard Area, District, Sector, or local unit commanders may exercise their discretion to take necessary action, consistent with law and regulation, to protect the safety and security of lives and property in areas and aboard vessels in which the Coast Guard may exert jurisdiction. The FAA's issuance of a license to SpaceX in no way limits the Coast Guard's ability to exercise such discretion.

7) POINTS OF CONTACT. The primary points of contact for this Letter of Intent will be the Chief, Prevention Operations Planning Branch (PAC-54) of Coast Guard Pacific Area; Eleventh District Waterways Management Branch; Thirteenth District Waterways Management Branch; Fourteenth District Waterways Management Branch; Seventeenth District Waterways Management Branch; and SpaceX's primary contact. Contact details are in Appendix A.

8) OTHER PROVISIONS.

a) SpaceX will immediately notify the Coast Guard in the event it is unable to fulfill any of the requirements covered by this Letter.

b) This Letter represents the entire intent of the Coast Guard and supersedes any prior letters, arrangements, or agreements between the Coast Guard and SpaceX with respect to the subject matters referenced in this Letter.

c) No provision of this Letter of Intent should be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341. Furthermore, no provision of this Letter of Intent is intended to conflict with current law or regulation or the directives of the U. S. Coast Guard or Department of Homeland Security. If a term of this Letter is inconsistent with such authority, then that term shall be invalid, and is severable from the rest of this Letter.

ISSUED BY:

10/25/22

RADM Matthew W. Sibley
Deputy Commander, Coast Guard Pacific Area Date

ACKNOWLEDGED BY:

October 18, 2022

Allison Crutchfield Date
Senior Manager, Regulatory Affairs, SpaceX

Appendix (A) Primary Points of Contact

LETTER OF INTENT

Appendix A — Primary Points of Contact

OFFICE	NUMBER	RESPONSIBILITY
SpaceX Primary Contact Allison Crutchfield-Sr. Manager, Regulatory Affairs allison.crutchfield@spacex.com	310-978-2306	Regulatory Affairs
SpaceX Recovery Officer TJ Binotto-Operations Support Coordinator Terence.Binotto@spacex.com	310-970-8555	Operations Support Coordinator/Sr. Launch Engineer
Coast Guard Pacific Area Prevention Operations Planning Branch D 1 1-DG-M-PacArea-PAC54@uscg.mi1	510437-5839 510437-3813	Chief, Prevention Operations Planning Branch
Coast Guard District Eleven Waterways Management DI I-SMB-DI I-LNM@uscg.mil	510437-2968	Chief, Waterways Management
Coast Guard District Eleven LNM Editor DI I-SMB-DI 1-LNMtauscg.mi1	510437-2980	Publication of Local Notice to Mariners
Coast Guard District Eleven Marine Transportation System Officer	510437-2978	Commercial Space Liaison Officer

Coast Guard District Eleven Command Center RCCAlamedaI@uscg.mil	510437-3701	Emergency contact number for all Search and Rescue in DI I
Coast Guard Sector Los Angeles - Long Beach Waterways Management DI 1 -SMB-SectorLALB-WWM(ûusc u .mil	310-521-3860	Chief, Waterways Management
Coast Guard Sector Los Angeles - Long Beach Command Center D 1 1 -SMB-SECTORLALB-SCC@uscg.mil	310-521-3815	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard Sector San Diego Waterways Management D 1 1 MarineEventsSDûtuscg.mil	619-278-7656	Chief, Waterways Management
Coast Guard Sector San Diego Command Center DI 1 -SMB-SectorSD-JHOCu. uscg.mil	619-278-7031	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard District Thirteen Waterways Management D13-SMB-D13-DPW@uscg.mil	206-220-7273	Chief, Waterways Management
Coast Guard District Thirteen LNM Editor DI 3-SMB-D13-LNM@uscg.mil	206-220-7280	Publication of Local Notice to Mariners
Coast Guard District Thirteen Command Center D13.CC@uscg.mil	206-220-7004	Emergency contact number for all Search and Rescue in DI 3
Coast Guard Sector Puget Sound Waterways Management SectorPuoetSoundWWMQž)usc '.mil	206-217-6042	Chief, Waterways Management
Coast Guard Sector Puget Sound Command Center SectorPugetSoundCC auscg.mil	206-217-6002	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard Sector Columbia River Waterways Management MSUPDXWWM@uscg.mil	503-240-9333	Chief, Waterways Management
Coast Guard Sector Columbia River Command Center D 13-SMB-C01umbiaRiverCC@uscg.mil	503-861-6212	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard District Fourteen Waterways Management D14-DG-PJ-dpwfâuscg.mil	808-535-3411	Chief, Waterways Management

Coast Guard District Fourteen LNM Editor D 14-DG-PJ-dpw@uscg.mil	808-535-3408	Publication of Local Notice to Mariners
Coast Guard District Fourteen Command Center JRCCHonolulu@uscg.mil	808-535-3333	Emergency contact number for all Search and Rescue in D14
Coast Guard Sector Honolulu Waterways Management D 14-SMB -SecHono-MarineEventPermits@uscg.mil	808-5414359	Chief, Waterways Management
Coast Guard Sector Honolulu Command Center SCCHonoIulu auscu.mil	808-842-2600	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard Sector Guam Waterways Management WWMGuam(ajuscg.mil	671-3554866	Chief, Waterways Management
Coast Guard Sector Guam Command Center RCCGuam@uscg.mil	671-3554821	Emergency contact number for all Search and Rescue in COTP zone
Coast Guard District Seventeen Waterways Management DI 7-SG-M-JUN-DI 7-DPW@uscg.mil	907463-2263	Chief, Waterways Management

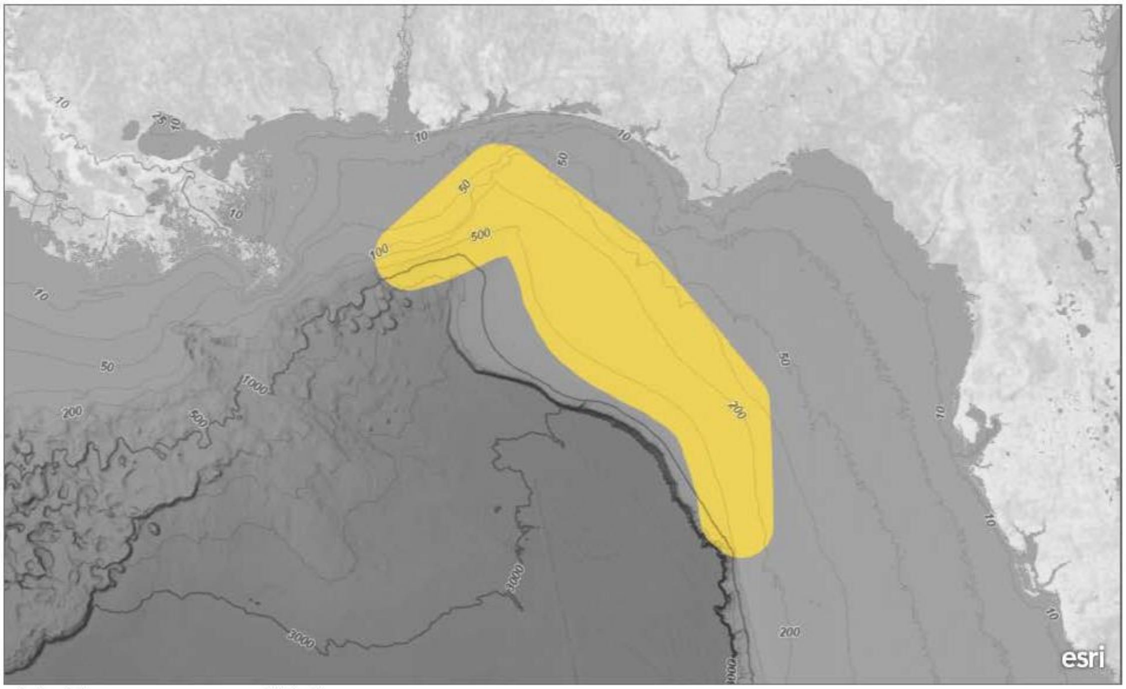
Coast Guard District Seventeen LNM Editor D17-PF-D17-LNM@uscg.mil	907463-2269	Publication of Local Notice to Mariners
Coast Guard District Seventeen Command Center JRCCJuneau@uscg.mil	907463-2000	Emergency contact number for all Search & Rescue in DI 7
Coast Guard Sector Anchorage Waterways Management Anchorage.Waterways@uscg.mil	9074284189	Chief, Waterways Management
Coast Guard Sector Anchorage Command Center Sector.Anchorage@uscg.mil	9074284101	Emergency contact number for all Search & Rescue in COTP zone
Coast Guard District Eleven Waterways Management DI I-SMB-DI1-LNM@uscg.mil	510437-2968	Chief, Waterways Management

9 Appendix II – Project Design Criteria

Project design criteria (PDCs) are identified as part of a programmatic consultation and are applicable to future projects implemented under the program. In the case of this consultation, PDCs include environmental protection measures developed by the FAA to limit the effects of launch operations. These environmental protection measures will lead to avoidance and minimization of effects to ESA-listed species and designated critical habitat in the action area to assist in the conservation of these resources.

General PDCs applicable to this consultation:

- Launch and reentry operations will be conducted by the USSF, NASA, or an FAA-licensed (or permitted) commercial operator from a launch site identified in Table 1. Launch preparations will occur in compliance with standard operating procedures and best management practices currently implemented at these existing launch vehicle facilities.
- Launch operations will utilize launch vehicles identified in Table 3.
- Launch activities, including suborbital landings and splashdowns, and orbital reentry activities will occur in the proposed action area at least 5 NM offshore the coast of the United States or islands. The only operations component that will occur near shore will be watercraft transiting to and from a port when recovering spacecraft or launch vehicle components, or possibly for surveillance.
  - No launch operator will site a landing area in coral reef areas.
  - No activities will occur in or affect a National Marine Sanctuary unless the appropriate authorization has been obtained from the Sanctuary.
- Landing operations will not occur in the aquatic zone extending 20 NM (37 km) seaward from the baseline or basepoint of each major rookery and major haul-out of the Western Distinct Population Segment (DPS) Steller sea lion located west of 144° W.
- Launch abort testing will only occur in the Atlantic Ocean from CCAFS or KSC as previously analyzed (SER-2016-17894, FPR-2017-9231). In addition:
  - It will not occur in designated critical habitat for the North Atlantic right whale.
  - It will not occur during the North Atlantic right whale winter calving season from November to mid-March.
- Utilize all feasible alternatives and avoid landing in Rice's whale core habitat distribution area as much as possible. No more than one splashdown, reentry and recovery of the Dragon capsule, will occur in Rice's whale core habitat distribution area per year. No other operations, spacecraft, launch or reentry vehicle landings, or expended components will occur in Rice's whale core habitat distribution area. The Rice's whale core habitat distribution area map (**Error! Reference source not found.Error! Reference source not found.**) and GIS boundary can be accessed here: https://www.fisheries.noaa.gov/resource/map/rices-whale-core-distribution-area-map-gis-data.



Rice's whale core area transparent with bathmetry

General Bathymetric Chart of the Oceans (GEBCO); NOAA National Centers for Environmental Information (NCEI)

Figure 5. Rice's Whale Core Distribution Area in the Gulf of Mexico.

Education and Observation

- Each launch operator will instruct all personnel associated with launch operations about marine species and any critical habitat protected under the ESA, and species protected under the MMPA that could be present in the operations area.[5] The launch operator will advise personnel of the civil and criminal penalties for harming, harassing, or killing ESA-listed and MMPA-protected species.
- Each launch operator will provide a dedicated observer(s) (e.g., biologist or person other than the watercraft operator that can recognize ESA-listed and MMPA-protected species) that is responsible for monitoring for ESA-listed and MMPA-protected species with the aid of binoculars during all in-water activities, including transiting marine waters for surveillance or to retrieve boosters, spacecraft, other launch-related equipment or debris.
    - When an ESA-listed or MMPA-protected species is sighted, the observer will alert vessel operators to apply the Vessel Operations protective measures.
    - Dedicated observers will record the date, time, location, species, number of animals, distance and bearing from the vessel, direction of travel, and other relevant information, for all sightings of ESA-listed or MMPA-protected species.
    - Dedicated observers will survey the launch recovery area for any injured or killed ESA-listed or MMPA-protected species and any discoveries will be reported as noted below.

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[5] The FAA is responsible for ensuring ESA compliance. The launch operator is responsible for MMPA compliance. Measures to protect all marine mammals are included here for animal conservation purposes.

Reporting Stranded, Injured, or Dead Animals

- Each launch operator will immediately report any collision(s), injuries or mortalities to, and any strandings of ESA-listed or MMPA-protected species to the appropriate NMFS contact listed below, and to Cathy Tortorici, Chief, ESA Interagency Cooperation Division by e-mail at cathy.tortorici@noaa.gov.
  - For operations in the Gulf of Mexico and Atlantic Ocean: 727-824-5312 or via email to takereport.nmfsser@noaa.gov, and a hotline 1-877-WHALE HELP (942-5343).
  - For operations on the west coast/Pacific Ocean: 562-506-4315 or via email to Justin.Viezbicke@noaa.gov, and a hotline for whales in distress 877-767-9245.
  - For operations near Alaska, statewide hotline: 877-925-7773.
  - Additional regionally organized contact information is here: https://www.fisheries.noaa.gov/report.
- In the Gulf of Mexico and Atlantic Ocean waters near Florida, each launch operator will report any smalltooth sawfish sightings to 941-255-7403 or via email Sawfish@MyFWC.com.
- Each launch operator will report any giant manta ray sightings via email to manta.ray@noaa.gov.
- In the Atlantic Ocean, each launch operator will report any injured, dead, or entangled North Atlantic right whales to the U.S. Coast Guard via VHF Channel 16.

Vessel Operations

All watercraft operators will be on the lookout for and attempt to avoid collision with ESA-listed and MMPA-protected species. A collision with an ESA-listed species will require reinitiation of consultation. Watercraft operators will ensure the vessel strike avoidance measures and reporting are implemented and will maintain a safe distance by following these protective measures:

- Maintain a minimum distance of 150 ft from sea turtles.
- In the Atlantic Ocean, slow to 10 knots or less and maintain a minimum distance of 1,500 ft (500 yards) from North Atlantic right whales.
- In the Gulf of Mexico, slow to 10 knots or less and maintain a minimum distance of 1,500 ft (500 yards) from Rice's whale [formerly Gulf of Mexico Bryde's whale]. If a whale is observed but cannot be confirmed as a species other than a Rice's whale, the vessel operator must assume that it is a Rice's whale.
- Maintain a minimum distance of 300 ft (100 yards) from all other ESA-listed and MMPA-protected species. If the distance ever becomes less than 300 ft, reduce speed and shift the engine to neutral. Do not engage the engines until the animals are clear of the area.
- Watercraft operators will reduce speed to 10 knots or less when mother/calf pairs or groups of marine mammals are observed.
- Watercraft 65 ft long or longer will comply with the Right Whale Ship Strike Reduction Rule (50 CFR §224.105)[6] including reducing speeds to 10 knots or less in Seasonal Management Areas or in Right Whale Slow Zones, which are dynamic management areas established where right whales have been recently seen or heard.

[6] See: http://www.fisheries.noaa.gov/pr/shipstrike/.

    - The Whale Alert app automatically notifies when entering one of these areas.
- Check various communication media for general information regarding avoiding ship strikes and specific information regarding North Atlantic right whale sightings in the area. These include NOAA weather radio, U.S. Coast Guard NAVTEX broadcasts, and Notices to Mariners.
    - There is also an online right whale sightings map available at https://apps-nefsc.fisheries.noaa.gov/psb/surveys/MapperiframeWithText.html.
- Attempt to remain parallel to an ESA-listed or MMPA-protected species' course when sighted while the watercraft is underway (e.g., bow-riding) and avoid excessive speed or abrupt changes in direction until the animal(s) has left the area.
- Avoid vessel transit in the Rice's whale core distribution area. If vessel transit in the area is unavoidable, stay out of the depth range of 100 m to 425 m (where the Rice's whale has been observed; Rosel et al. 2021) as much as possible and go as slow as practical, limiting vessel speed to 10 knots or less.
- No operations or transit will occur at night in Rice's whale core distribution area.

Aircraft Procedures

Spotter aircraft will maintain a minimum of 1,000 ft over ESA-listed or MMPA-protected species and 1,500 ft over North Atlantic right whales. Additionally, aircraft will avoid flying in circles if marine mammals or sea turtles are spotted to avoid any type of harassing behavior.

10 APPENDIX III – SPACEX UNDERWATER NOISE METHODOLOGY

Underwater Noise Analysis Methodology for Starship Orbital Test Flight Vehicle

LIST OF SYMBOLS
P_s = Incident Pressure from explosion
A, B, C, D, E, F, G = Kingery-Bulmash empirically derived coefficients, values depend on scaled distance and desired output units for incident pressure
Z_s = Scaled distance
R = Range (distance)
W = TNT yield
I = Intensity, subscript represents medium e.g. air vs. water
T_c = Transmission coefficient
P = Local pressure, subscript represents medium
Z_I = Impedance, subscript represents medium
L = Sound Pressure Level (SPL), subscript represents type of SPL used e.g. peak vs. range
P_{ref} = Reference pressure used in SPL calculations
A = Area

This document presents a methodology for use in assessing the potential impacts of underwater noise that may result from an intact Starship vehicle impact (and resultant explosion) with the ocean's surface. Consistent with the National Environmental Policy Act's (NEPA) requirements, SpaceX identified credible scientific evidence that is relevant to evaluating the reasonably foreseeable environmental effects associated with an intact Starship ocean landing. SpaceX has developed and documented an analysis methodology that relies on the robust application of scientific principles; a conservative estimation of the necessary coefficients based on available, existing reference data; and the application of appropriate species harassment thresholds taken directly from the National Marine Fisheries Service (NMFS), which have been relied upon by the US Navy and US Air Force. This document provides a step-by-step guide and representative calculations as relevant to the identification of the area within which federally protected marine species protected under the Endangered Species Act (ESA) could be harassed, if present, given an explosive yield. Analysis and determinations relevant to the Marine Mammal Protection Act are provided in the Federal Aviation Administration's (FAA) draft Written Re-evaluation.

The intact Starship vehicle impact will have three events with the potential to create shockwaves: vehicle impact upon the surface of the water; rupture of fuel tanks; and an in-air explosive yield resulting from fuel explosion. This methodology is specifically focused on the noise impact associated with an in-air explosive yield resulting from the fuel explosion, as SpaceX expects the energy associated with this event will significantly exceed any shockwave from the vehicle impacting the water or the rupture of the fuel tanks. FAA analysis supports the fuel explosion creating the greatest explosive yield of the three events.

Step 1. Calculate the acoustic properties of the explosive event on the air side of the air/water boundary using the simplified Kingery-Bulmash equations as modified by Swisdack. These properties are calculated by propagating the blast wave from a height of 4.5 meters, the shortest distance between the transfer tube (explosive source) and the primary structure (water surface) at the time of impact, from the source through air.

While the outer radius of the vehicle is in contact with the water surface, SpaceX has demonstrated to FAA that the most likely and reasonably foreseeable origin of an explosion during an intact Starship ocean landing is from inside the vehicle. This explosion will occur at the point where fuel is transferred through the liquid oxygen tank. Consequently, there is space between the explosion and the surface of the water. The "object exploding" should be considered the inner transfer tube of the vehicle, and not the entire vehicle, as described below. The sequence of events leading to this explosion source, discussed below, is consistent with past real-world observations of Starship explosions resulting from impact with a surface, and with which FAA has concurred. Specifically, FAA has concurred that "the explosion due to impact likely initiates a small distance above the water's surface."[7] The modeled energy release from a fuel explosion, caused by an intact Starship's impact on the surface of the water, will significantly exceed the energy associated with the surface impact itself, also discussed below. Here again, FAA has concurred that the fuel explosion will create the greatest energy release of the three events involved, including the surface impact. While the Starship explosion at the transfer tube is best modeled by a spherical model, the use of a hemispherical model in this methodology is comparatively conservative and accounts for other sources of uncertainty, such as the effects of propagation through gaseous oxygen and the potential for blast reflection off of interior structures like the engine section.

Figure 1 shows the sequence of events that is analyzed to assess the potential underwater noise impacts from Starship's intact ocean impact. Figure 4 shows a cutaway of the aft section of the vehicle. The sequence of events is summarized below and explained in further detail in the corresponding sections of this memo.

1. **Vehicle Impact:** The Starship vehicle impacts the water at terminal velocity and at 90° angle of attack (horizontal). The impact disperses settled remaining propellants and drives structural failure.
2. **Structural Failure and Propellant Mixing:** The structural failure leads to cracks propagating throughout the structure at the speed of sound through steel. Cracks eventually lead to failure of the transfer tube, allowing fuel and liquid oxygen (LOX) to mix.
3. **Ignition and Explosive Event:** The mixed propellants find an ignition source in the proximity of the transfer tube and detonate.
4. **Blast Propagation to Air/Water Boundary:** The blast wave propagates outward towards the air/water boundary. In-air attenuation models are used to calculate the acoustic properties in the air on the air side of the boundary.
5. **Transmission Across Air/Water Boundary:** Assuming that the vehicle's steel structure is not blocking the air/water boundary, the acoustic properties on the water side of the

[7] Email from Jacob Cantin, Federal Aviation Administration, to Matthew Thompson, SpaceX, November 3, 2022.

boundary are calculated based on an estimated transmission coefficient for a near-surface explosion.

6. **Underwater Sound Attenuation Model:** Using the Sound Pressure Level (SPL) in the water directly below the explosion as the peak source sound level, SpaceX uses the NMFS recommendation of an omnidirectional source to calculate the sound attenuation in water.
7. **Calculation of Range of Threshold Exceedance:** SpaceX calculates the range at which the NMFS recommended Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) harassment thresholds are exceeded for the relevant species. The range of exceedance is then used to calculate impact areas for each impact type (PTS/TTS) for each species.

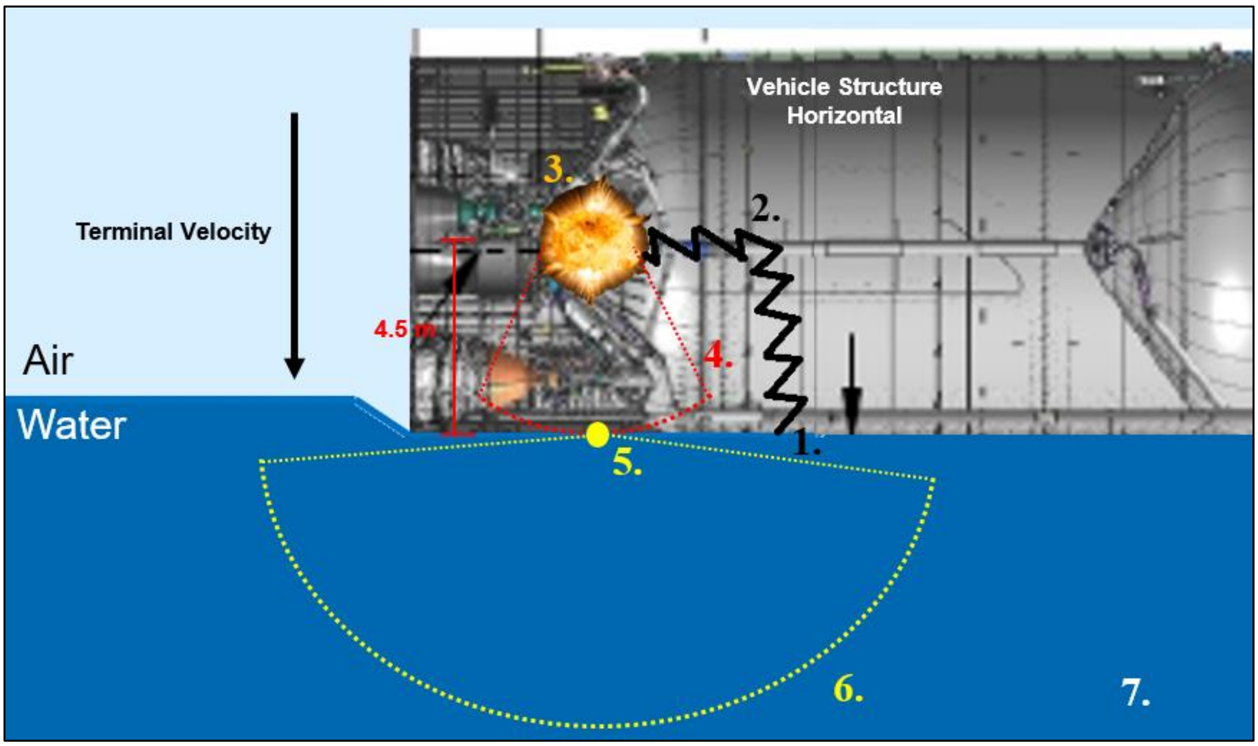

Figure 6: Sequence of events analyzed to assess potential underwater noise impacts from a Starship explosion

Items 1 through 3 in Figure 4 show the reasonably foreseeable sequence of events that would lead to an explosive event when the vehicle impacts the ocean surface at terminal velocity, in order to predict the location within the vehicle structure where the explosion is likely to originate. The conclusion, based on these events, is that the blast will initiate in the proximity of the fuel transfer tube and is most likely to originate from the aft end of the transfer tube, as pictured in Figure 4.

Figure 7 shows an internal cross section of the Starship vehicle immediately prior to impact with key vehicle hardware noted; station heights are given in millimeters relative to the full stack vehicle frame, which has an origin at the base of the Super Heavy booster. The location of residual liquid fuel (methane) is shown in the highlighted red region. During entry, the fuel main tank is isolated from the transfer tube such that liquid fuel residuals are fully contained within the approximately 13-meter long transfer tube that runs through the liquid oxygen (LOX) tank. The locations of residual LOX are shown in the highlighted blue regions. LOX residuals will exist in both the LOX main tank, the LOX header tank, and the LOX header tank feedlines. LOX main tank residuals will be mostly concentrated on the windward side of the tank due to the drag force experienced by the vehicle falling through the atmosphere.

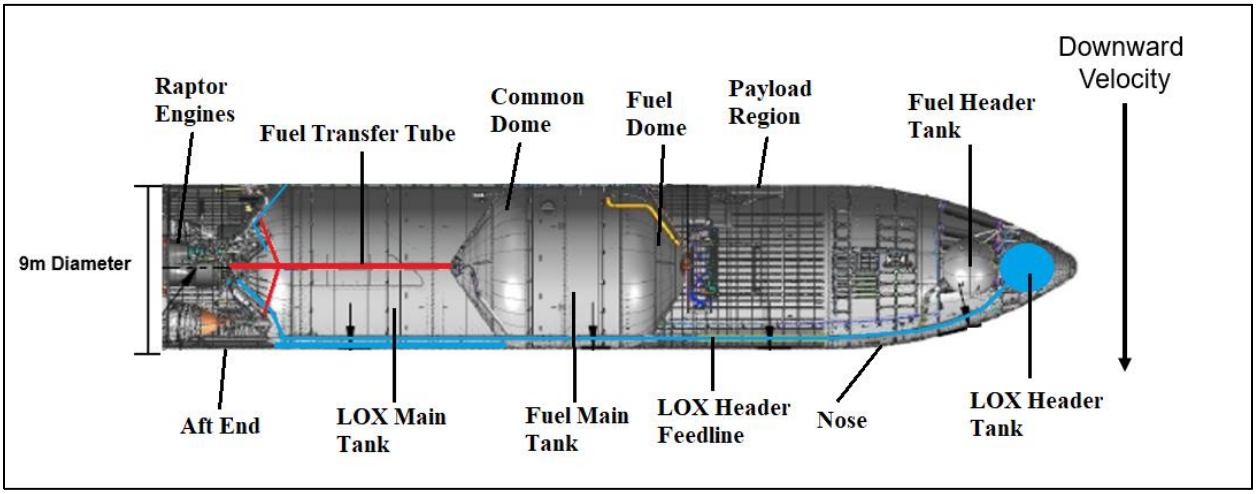

Figure 7: Starship internal cross section during terminal descent phase prior to impact

Figure 8 depicts the state of the vehicle immediately after impact. The LOX that was settled on the windward side of the LOX main tank will be fully dispersed throughout the tank by the force of the impact, while the fuel will remain confined within the transfer tube. There are three reasonably foreseeable failure modes for the fuel transfer tube, the first being denoted by the central crack. Given that the mass of the transfer tube is relatively high, it will have more inertia than the surrounding empty LOX tank. This will cause the transfer tube to flex through the central portion and exert stresses on the tube structure that it was not designed to handle. This could reasonably lead to a failure of the transfer tube in portion due to flex stresses. The other reasonable failure modes result from the propagation of main tank structural failures. At the point of impact, the main tank is expected to fail, resulting in large cracks that will propagate through the steel structure at the speed of sound (approximately 5,100 m/s for steel). There are two paths for these cracks to propagate to the transfer tube: 1) the aft end engine structure, or 2) the common dome. In either case, the cracks would propagate to the transfer tube and cause failure at the tube's structural interface with either the engine section or the common dome.

Irrespective of the specific failure scenario, the failure of the transfer tube is expected to occur instantaneously following Starship's impact with the water. This assumption is supported by the work summarized by Lambert et. al. which states that "shock simulations of impacting liquid propellant vehicles and considerations of the shock impedance of the vehicle materials led to the conclusion that for impact speeds greater than a few feet per second, shock waves capable of breaking apart the propellant tanks would travel much faster than the speed of the vehicle impacting the surface."[8] For this analysis the fuel propellant tank is the transfer tube.

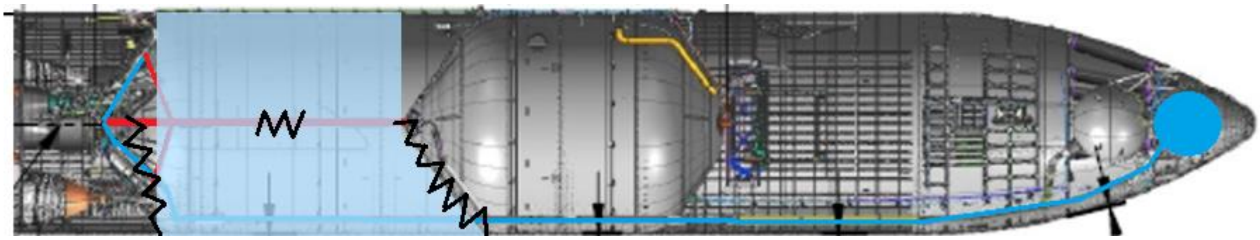

Figure 8: Starship internal cross section immediately after impact

Wherever the transfer tube failure occurs, the fuel will be released and will subsequently mix with the cloud of LOX now dispersed throughout the tank. This liquid LOX/methane mixture is expected to detonate immediately. Unlike gases that must transition from deflagration to detonation once ignited, the liquid mixture will behave as a high explosive, such that any ignition source, spark, flame, hot metal, and shock, will drive the bulk fluid to detonate within microseconds as a high explosive with any and all mixed propellant detonation at that moment. Here, components still at a high temperature from the orbital entry are expected to be the most likely ignition sources. Because the highest number of these components are located in the aft end, the aft end transfer tube interface is the most likely location for the explosive center. However, explosive centers at the central portion and the common dome interface are also considered reasonably foreseeable, potentially driven by auto-ignition or hot surfaces along steel cracks. Because the vehicle will be in a horizontal configuration at impact each potential explosive center is the same distance from the surface of the water. Figure 9 shows the potential explosive centers considered by SpaceX for this analysis, the water's surface in this figure would be parallel to the bottom of the figure. SpaceX's conclusions are also supported by the work summarized by Lambert et. al. which states that "the center of explosion at the interface between the fuel and oxidizer tanks would occur above any crater formed in an impact surface material into which the vehicle could penetrate."[9] Again, for this analysis, the interface between the fuel and oxidizer tanks is the region around the transfer tube.

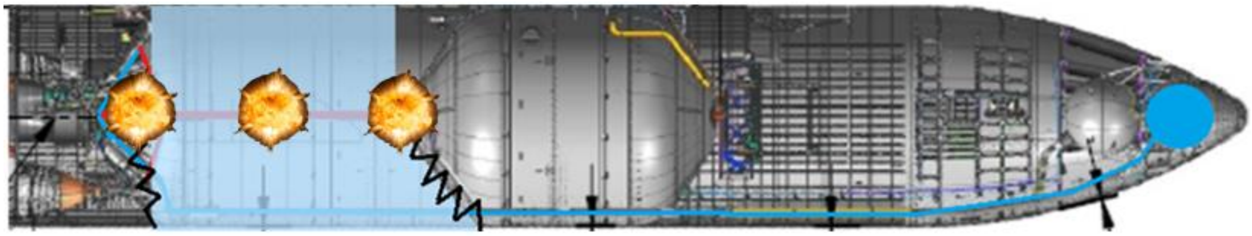

Figure 9: Starship internal cross section showing most likely locations of an impact driven explosion

SpaceX has been able to gather real-world evidence to further support the conclusion that the explosive source is near the transfer tube. For example, Figure 10 shows a frame-by-frame

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[8] Lambert, R.R. et al. (2021). Distant Focusing Overpressure Risk Assessment Methods, 11th IAASS Conference, Rotterdam, Netherlands, October 2021.

[9] Ibid.

breakdown of Starship during the SN10 explosion: because this explosion happened on the ground, a few minutes after impact, SpaceX was able to focus high speed video cameras on the aft end of the vehicle. In the top row of images, an equal volume of gas can be seen coming out of vents on all sides of the vehicle, indicating an explosive source near the center. In the lower center image, there is a clear sign of an explosion within the vehicle when the tank begins to tear allowing the first light to pass through. Finally, the lower right image shows the effects of the explosion again being seen on both sides of the vehicle. After the lower right image, the vehicle structure fails fully and the image saturates.

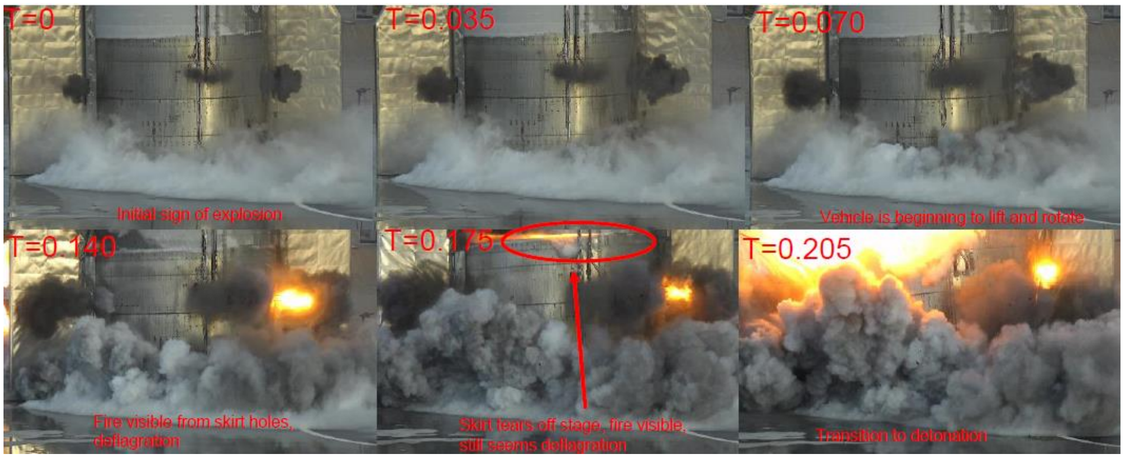

Figure 10: Frame-by-frame video review of SN10 explosion showing evidence of an internal explosive center

Given the above, SpaceX has determined that it is reasonably foreseeable that the explosive center is at the transfer tube and that the explosion occurs immediately following the ocean impact. While the aft end is the most likely location for the explosive center, the exact location along the transfer tube will not have an effect on the analysis, because the vehicle is in the horizontal configuration and so all locations along the transfer tube will be the same distance from the explosive center.

To calculate the acoustic properties, SpaceX uses the simplified Kingery-Bulmash equations as modified by Swisdack.[10] The Kingery-Bulmash equations are empirically derived from a vast set of experimental data and are commonly used in blast analysis to predict maximum incident blast overpressure and other blast parameters. In their simplified form, as used here, the equations can only be used to model a surface burst. While the Starship explosion at the transfer tube is best modeled by a spherical model, the use of a hemispherical model, as done in this methodology, is comparatively conservative as the hemispherical model directs all of the explosive energy downwards towards the water surface. This results in a greater overpressure prediction at the air/water interface than a spherical model. The use of a hemispherical model also accounts for other sources of uncertainty, such as the effects of propagation through

[10] M. Swisdack, Simplified Kingery Airblast Calculations, Web, https://apps.dtic.mil/sti/pdfs/ADA526744.pdf, Accessed 15 November 2022.

gaseous oxygen and the potential for blast reflection off of interior structures like the engine section.

Additionally, guidance for how to calculate explosive parameters is provided in UFC-3-340, which is a Government-released document that is the standard for explosive parameter calculation in the industry. This document envelopes the information provided by Kingery-Bulmash and Swisdack.[11]

The simplified Kingery-Bulmash equation takes the form shown in Equation 1; the coefficients used to calculate incident peak overpressure are shown in Table 6. The equation uses a scaled distance, Zs, which is calculated using the equation shown in Equation 2, where R is the range in meters and W is the charge weight in kilograms. The simplified Kingery-Bulmash equations have been shown to be accurate to within 1% of the conventional equations for scaled distances of 0.2 to 200 m/kg$^{1/3}$.

Equation 1: Swisdack's simplified Kingery-Bulmash equation

$$P_s = e^{\left(A+B\times ln\, Z_s + C\times(ln\, Z_s)^2 + D\times(ln\, Z_s)^3 + E\times(ln\, Z_s)^4 + F\times(ln\, Z_s)^5 + G\times(ln\, Z_s)^6\right)}$$

Table 6: Swisdack's equation coefficients for calculating incident peak overpressure for hemispherical surface bursts

Incident Peak Overpressure, P_s (Unit: kPa(psi))							
Z	A	B	C	D	E	F	G
0.2~2.9 (0.5~7.25)	7.2106 (6.9137)	−2.1069 (−1.4398)	−0.3229 (−0.2815)	0.1117 (−0.1416)	0.0685 (0.0685)	0 (0)	0 (0)
2.9~23.8 (7.25~60)	7.5938 (8.8035)	−3.0523 (−3.7001)	0.40977 (0.2709)	0.0261 (0.0733)	−0.01267 (−0.0127)	0 (0)	0 (0)
23.8~198.5 (60~500)	6.0536 (5.4233)	−1.4066 (−1.4066)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Equation 2: Scaled distance

$$Z_s = \frac{R}{W^{\frac{1}{3}}}$$

SpaceX's predicted peak overpressure results for the air side of the air/water boundary are given in Table 7. The predicted incident peak overpressure estimates can be verified using the calculator provided by UN SaferGuard[12]. This calculator can also be used to get peak overpressure results at different ranges or different yields, as long as they are within the valid range of scaled distances.

[11] https://www.denix.osd.mil/ddes/denix-files/sites/32/2018/07/2018-06-11-DDESB-TP-202c-DDESB-Blast-Effects-Computer-Open-BEC-O2c-V...-1.pdf

[12] UN SaferGuard, Kingery-Bulmash Blast Parameter Calculator, Web, https://unsaferguard.org/un-saferguard/kingery-bulmash, Accessed 15 November 2022.

Table 7: Sample predicted peak overpressure values at air/water boundary

Yield	1,260 kg Explosive Weight (SN11's 9% Yield)
Incident Peak Overpressure @ 4.5 m	6,435 kPa

Note: 1,260 kg is the FAA supported estimate for explosive yield of the 14,000 kg of anticipated residual propellant at the time of S24's future intact impact of the water, based on data obtained from SN11's test flight on March 30, 2021.

Step 2. Calculate the transmission of the wave across the air/water boundary and the acoustic properties on the water side of the boundary. These properties are calculated by determining the portion of the acoustic wave that is transmitted into the boundary.

When an acoustic wave reaches a boundary, a portion of the wave reflects off of the boundary and a portion of the wave is transmitted into the boundary. The amount of reflection, defined by a reflection coefficient, is dependent on the angle of incidence and the magnitude of the impedance mismatch between the two materials. Since energy must be conserved across the boundary, the transmission coefficient is one minus the reflection coefficient. Air and water have a large impedance mismatch, as shown in Table 8, with water having approximately 3,600 times the impedance of air. The intensity reflection coefficient can be calculated as impedance mismatch, divided by the total impedance, squared; as shown in Equation 3. The intensity transmission coefficient is given by Equation 4.

An example of a normal acoustic wave reaching an air/water boundary is shown in Figure 11. The difference in impedance between air and water leads to an intensity reflection coefficient of 99.9% and an intensity transmission coefficient of 0.11%. This means that 99.9% of the wave intensity reflects off of the boundary back into the air and just 0.11% of the intensity is transmitted into the water. For any angle of incidence greater than 0 the transmission coefficient would be even lower, for transmission to be possible the angle of incidence must be less than the critical angle. For the air/water boundary this critical angle is approximately 13°.

Table 8: Impedance values for relevant materials

Material	Impedance (kg m^{-2} s^{-1})
Air	421.4
Water	1.5×10^6

Equation 3: Intensity reflection coefficient at boundary

$$R_c = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

Equation 4: Intensity transmission coefficient at boundary

$$T_c = 1 - R_c = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$

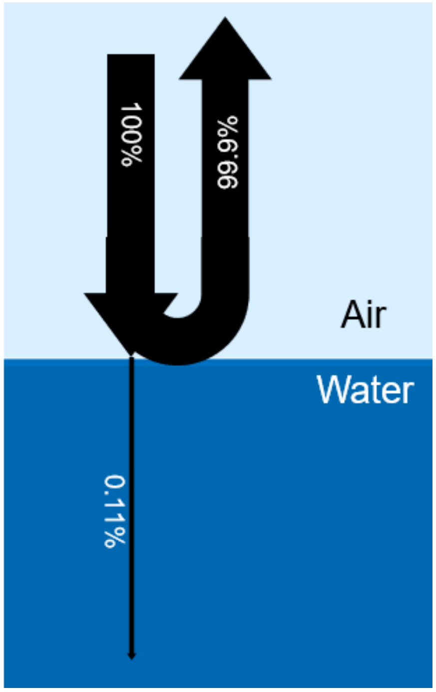

Figure 11: Air/water example

Acoustic intensity is defined as the pressure squared divided by the impedance, as shown in Equation 5.

Equation 5: Acoustic intensity

$$I = \frac{P^2}{Z}$$

For the transmission of the blast wave across the air/water boundary, the transmission coefficient from Equation 4 can be used to determine the intensity below surface, based on the intensity above the surface, and the intensity transmission coefficient, as shown in Equation 6.

Equation 6: Intensity in water based on intensity in air and transmission coefficient

$$I_w = I_a T_c$$

Substituting Equation 5 into Equation 6 and solving for the pressure in the water gives the relation shown in Equation 7. Since the ratio of impedance between water and air is roughly 3,600 and the transmission coefficient roughly 0.11%, most terms in Equation 7 can be combined to give a direct factor between the pressure in the air just above the surface and the pressure in the water just below the surface. Equation 8 shows that the pressure in the water would be roughly double the pressure in the air.

Equation 7: Pressure in water based on pressure in air and boundary transmission

$$\frac{P_w^2}{Z_w} = \frac{P_a^2}{Z_a} T_c$$

$$P_w = \sqrt{P_a^2 \frac{Z_w}{Z_a} T_c}$$

$$P_w = P_a \sqrt{\frac{Z_w}{Z_a} T_c}$$

Equation 8: Pressure in water for air/water boundary transmission

$$P_w = P_a \sqrt{\frac{1.5E6}{421} \times 1.1E-3} = 1.99 \times P_a$$

This analysis is consistent with the findings from the Air Force's sonic boom research, which concludes that "For plane waves incident at angles less than critical, the pressure in the water is approximately twice the pressure of the wave in the air. The transmitted intensity, however, is only about 0.11% of the incident intensity due to the impedance mismatch between the air and water."[13] However, the FAA concluded, and SpaceX agrees that, sonic boom research was not applicable to this scenario stating, stating that "an explosion event is different from a sonic boom" and that the research could not be used "because the air-water surface is within the near-field of the explosion, and there is likely significant coupling between the explosion and the water."[14] FAA's conclusion is supported when examining the scaled distances involved with sonic boom research, typically in the hundreds of $m/kg^{1/3}$ compared to the scaled distance of this scenario of 0.5 to 1 $kg/m^{1/3}$.

SpaceX assumes an intensity transmission coefficient of 14%, this represents a near-field transmission coefficient which is more than 100 times greater than the far-field air/water boundary transmission coefficient of 0.11%. This conservative transmission coefficient accounts for the limited scope of research into near-surface explosions and their transmission across the air/water boundary.

There are several factors that confirm that the 14% transmission coefficient will bound the real-world intensity transmission from a near-surface explosion. This value was selected based on research into the transmission coefficients derived from other near-surface explosive events. Based on available research, the 14% coefficient conservatively bounds the limited, applicable technical analysis that could be found.

For example, with respect to the existing research into the underwater effects of near-surface explosions, comprehensive studies were conducted by Lawrence Livermore National Laboratories (LLNL) between 1994 and 1998. These studies sought to determine if near-surface nuclear weapons testing could be detected by the underwater noise monitoring network set up to ensure enforcement of the terms of nuclear test ban treaties. The work began in 1994 with

[13] US Air Force, Supersonic Aircraft Noise At and Beneath the Ocean Surface: Estimation of Risk for Effects on Marine Mammals, https://apps.dtic.mil/sti/pdfs/ADA395062.pdf, Accessed 15 November 2022

[14] Email from Jacob Cantin, Federal Aviation Administration, to Matthew Thompson, SpaceX, November 3, 2022.

M. Kamegai and J. W. White developing a computer simulation model for both underwater and in-air nuclear blasts near the ocean surface.[15] Their analysis, looked at 1kt and 10kt at various heights/depths and calculated the predicted downward kinetic energy in the water. The results of this analysis are shown in Figure 12; the energy transferred to the water decreases rapidly as the explosion occurs at higher altitudes above the surface. For explosions above 20 meters altitude the effective transmission coefficient of energy across the water boundary appears close to the acoustic wave prediction of 0.001. At the surface, the effective transmission coefficient is approximately 2%; however, the authors of the paper do not clearly specify what the downward kinetic energy variable represents, and the fact that it has a maximum value of 15%, rather than 100%, indicates that it may not be fully accounting for the total energy transfer. Therefore, to ensure that SpaceX is applying the data in a reasonable manner, SpaceX assumed the relationship to be correct, but *increased* the maximum effective transmission coefficient to 100% for underwater blasts. This results in the shifted curve shown in the right of Figure 12 and is the first source of data for the transmission coefficient selected by SpaceX of 14%.

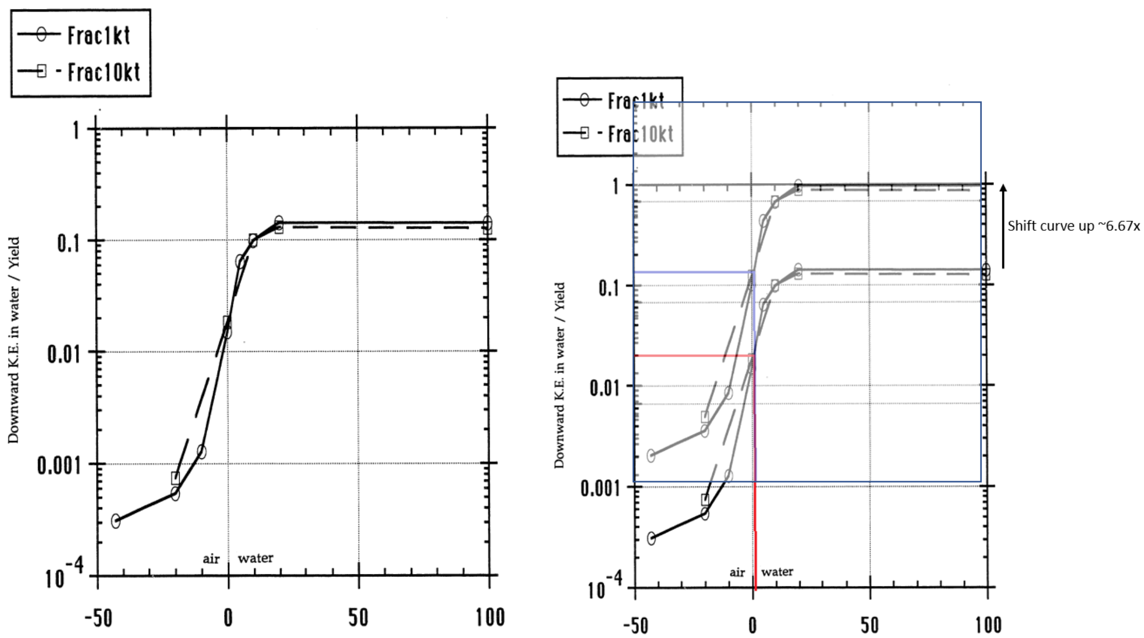

Figure 12: Original (left) and shifted (right) trend between downward energy and explosion height/depth[16]

Note that for a 1kt explosion, the altitudes that would result in an equivalent scaled distance to that of the Starship explosion (0.45 m/kg$^{1/3}$ to 0.97 m/kg$^{1/3}$) would be an altitude of 45m and 97m respectively. For a 10kt explosion these altitudes are 97m and 209m. In every case, the scaled distances involved would support the use of the lowest kinetic energy factors observed in the Figure 12 analysis.

[15] M. Kamegai and J. W. White, A Study of Near-Surface and Underwater Explosions by Computer Simulations, February 1994, https://www.osti.gov/servlets/purl/10137363, Accessed 7 November 2022

[16] Ibid.

An updated set of simulation results was published by J.W. White and D. Clarke in 1997.[17] This analysis looked at a larger range of burst depths/heights and expanded the simulations to model the outward motion of the blast waves, as opposed to the 1994 work that only looked at the downward energy. Figure 13 shows the simulation results for various 1kt explosion burst depths/heights in terms of the total wave energy in the water at 10 km range. The authors noted that the range of pressures associated with these results ranged from around 100,000 Pa to 200 Pa. The quoted ratio of 500 in pressure results matches up with the approximately 5 orders of magnitude decrease in wave energy shown in the results. Again, these more advanced simulation results show that the energy in the water decreases significantly for higher altitude explosions. For the equivalent Starship height of burst (45-100m altitude) the energy in the water would be over 4 orders of magnitude less than that of an underwater explosion. Again, the analytical results support 14% as a conservative transmission coefficient.

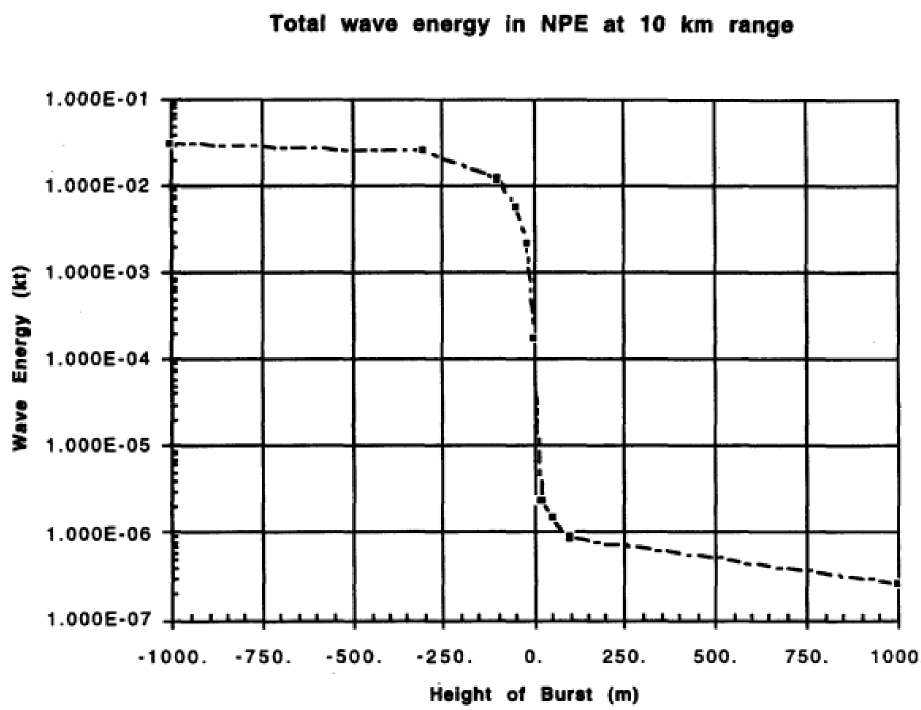

Figure 13: Simulation results for the total wave energy in the water at a range of 10 km from a 1kt explosion of varying depth/height[18]

Perhaps the most important study conducted by LLNL was a series of experiments designed to validate their models. These experiments where conducted over an artificial lake in Wyoming and were documented in the 1998 report.[19] The findings as summarized in the paper's abstract

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[17] D. Clarke, J. W. White et. al., Energy Coupling of Nuclear Bursts in and above the Ocean Surface: Source Region Calculations and Experimental Validation, September 1997, https://digital.library.unt.edu/ark:/67531/metadc693831/m2/1/high_res_d/641356.pdf, Accessed 15 November 2022

[18] Ibid.

[19] D. Clarke, D. Rock et. al. Validation of source region energy partition calculations with small scale explosive experiments, May 1998, www.researchgate.net/publication/265799582_Validation_of_source_region_ener_partition_calculations_with_smal

stated that "Underwater signals from 6.82 kg charges were detected by a 30 m hydrophone string. Useful data were obtained at five burst locations: 5 m, 2 m zero, -2 m, and -15 m. Results from the experiments and new calculations support the predicted energy partitioning for above-surface explosions with model and experiment peak pressures agreeing within a factor of two over three orders of magnitude variation." Based on this information, it is reasonable that the previously developed computer simulations were validated and that the researchers obtained experimental data supporting the simulation results that above surface bursts resulted in orders of magnitude reductions in underwater pressures.

Finally, one additional source validates the SpaceX transmission coefficient of 14%. Independent analysis performed by M. Eneva and J. Stevens in 2001 using Russian hydroacoustic testing data that was also made available for the purposes of evaluating monitoring of nuclear test ban treaties.[20] The Russian data contained 29 explosive tests conducted in a shallow reservoir using 100 kg TNT cast spherical charges with 25 cm radius, detonated at various depths in a shallow 87 m long, 3 m deep reservoir. The test setup and burst locations are shown in Figure 14. A key finding of the research was that "[A] reduction of peak pressure by about 60-70% is observed in the measurements for half-immersed charges as compared with deeper explosions." Since intensity is proportional to the pressure squared, a 60-70% reduction in pressure would correspond to a 9-16% intensity transmission coefficient. Therefore, even for the half-submerged case in a shallow reservoir, the SpaceX transmission coefficient of 14% is close to the maximum value observed in the experimental data.

l_scale_explosive_experiments, Accessed 15 November 2022

[20] M. ENEVA, J. L. STEVENS, B. D. KHRISTOFOROV, J. MURPHY, and V. V. ADUSHKIN, "Analysis of Russian Hydroacoustic Data for CTBT Monitoring," Pure and Applied Geophysics, 158, pp. 605–626, (2001).

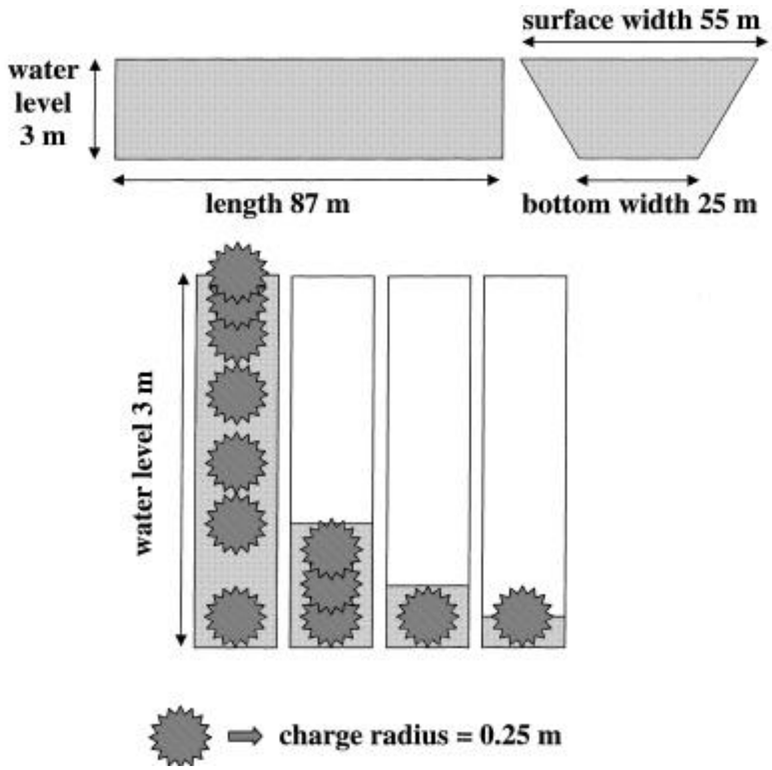

Figure 14: Test setup and burst locations for Russian hydroacoustic tests[21]

Based on the evaluation of the scientific principles surrounding wave transmission across the air/water boundary and the reliable, existing data from credible, scientific research into underwater pressure and energy from near-surface explosions, it is clear that SpaceX's selected intensity transmission coefficient of 14% clearly meets the reasonably foreseeable NEPA standard. Both the scientific principles and LLNL research would support a coefficient two orders of magnitude lower, and while the Russian hydroacoustic test data is consistent with the selected data it is for a much more conservative half-submerged condition that would be expected to produce much higher intensity in the water.

Substituting the SpaceX intensity transmission coefficient into Equation 7 results in Equation 9 and a pressure ratio between the water and the air at the air/water boundary of approximately 22.5. Multiplying the peak incident overpressure values for the air from Table 7 gives the peak incident overpressure value for the water shown in Table 9. Note that while the intensity has decreased across the boundary, the pressure will increase due to the impedance mismatch.

Equation 9: Pressure in water for air/water boundary transmission using SpaceX transmission coefficient

$$P_w = P_a \sqrt{\frac{1.5E6}{421} \times 0.14} = 22.45 \times P_a$$

[21] Ibid.

Table 9: Sample predicted peak overpressure value in the water just below the surface

Yield	1,260 kg (SN11's 9% Yield)
Incident Peak Overpressure in Water	144.5 MPa

Step 3. Calculate the noise attenuation underwater. These properties are calculated using the NMFS recommended assumption of spherical spreading for calculating the sound attenuation over distance. NMFS states that for deep water where there is little to no interaction between the sound and the ocean floor, a 20 log R model is appropriate. This model is given in Equation 10, where the noise is expressed as a Sound Pressure Level (SPL) defined by Equation 11. For all SPL calculations, SpaceX uses a reference pressure for water of 1 μPa.

Equation 10: NMFS 20 log R model for SPL decrease

$$L_{pk} - L_R = 20\ log\ R$$

Equation 11: Equation for SPL expressed in decibels

$$L = 20\ log\left(\frac{P}{P_{ref}}\right)$$

Finally, SpaceX takes Equation 10 and solves for range to get the expression given in Equation 12.

Equation 12: Solve for range to get equation used in NMFS spreadsheet tool

$$log\ R\ = \frac{L_{pk} - L_R}{20}$$

$$R = 10^{\left(\frac{L_{pk} - L_R}{20}\right)}$$

The peak source sound levels used in the NMFS attenuation model are calculated using Equation 11 with a 1 μPa reference pressure and the peak overpressure estimates at the water surface from Table 9. The resulting peak source sound levels are given in Table 10.

Table 10: Sample predicted water peak source sound level just below the surface

Yield	1,260 kg (SN11's 9% Yield)
Peak Source Sound Level (L_{pk} re 1 μPa)	283.2 dB

Step 4. Evaluate the impact area over which the NMFS thresholds are exceeded for species protected under the Endangered Species Act (ESA). With a peak source sound level and noise attenuation model established, the final analysis step is to evaluate the impact area over which the NMFS thresholds are exceeded for the species protected under the ESA in the proposed Pacific impact area approximately 225 km north of Hawaii. Table 6 provides the subset of species

that have the potential to be present in the Pacific impact area from those listed in . Using this value, SpaceX calculated of the 2022 LOC [2]. Table 6 also lists the NMFS hearing group each species belongs to, based on the groups listed in the 2018 Revision to the 2016 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing [1].

Table 11: ESA-listed species present in the Pacific impact area

Species	NMFS Hearing Group
Blue Whale	Low Frequency (LF) Cetacean
False killer whale, Main Hawaiian Islands Insular DPS	Mid-Frequency (MF) Cetacean
Fin Whale	Low Frequency (LF) Cetacean
Sei Whale	Low Frequency (LF) Cetacean
Sperm Whale	Mid-Frequency (MF) Cetacean
Hawaiian Monk Seal	Phocid pinniped
Green Turtle Central North Pacific DPS	Turtle
Hawksbill Turtle	Turtle
Leatherback Turtle	Turtle
Loggerhead Turtle North Pacific DPS	Turtle
Olive Ridley Turtle	Turtle
Giant Manta Ray	Fish[a]
Oceanic Whitetip Shark	Fish[a]

[a] The fish are an injury group, not a hearing group, since hearing-related injuries cannot be assessed in fish.

The May 2022 NMFS summary of MMPA acoustic thresholds [3] provides a clear and concise summary of the information contained within their longer 2018 Revision to the 2016 Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing [1]. NMFS defines two levels of harassment under the MMPA: Level A harassment/injury and Level B harassment. Level A harassment/injury is defined as any noise level that would be expected to result in a permanent (hearing) threshold shift (PTS) and/or lung or gastrointestinal (g.i.) tract injury; thus, covering all three types of marine mammal injury. Level B harassment is defined as any noise level that would be expected to result in a behavioral disturbance or a temporary (hearing) threshold shift (TTS).

NMFS defines four different types of noise sources: continuous, intermittent, impulsive, and non-impulsive. The noise generated by the Starship impact and explosive event is considered an impulsive sound source, in that it “produces sounds that are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and decay time” [3]. Additionally, the action described is an impulsive event of extremely rapid duration, which will not be repeated within any recommended accumulation periods. Such an event should only require that peak pressures be analyzed, as was done in this analysis. Here, the total positive phase pressure duration would be far less than one second, and the weighted cumulative sound exposure level will be significantly lower than the unweighted peak sound pressure. Based on this knowledge of the type of impulsive event under evaluation SpaceX determined that the unweighted peak sound pressure thresholds would result in the largest isopleths for calculating each threshold area.

Figure 15 gives the NMFS thresholds for an impulsive sound source for various marine mammal hearing groups. Per the NMFS guidance, "for a single detonation (within a 24-h period), NMFS relies on the TTS onset threshold to assess Level B harassment" [3]. Therefore, the behavioral thresholds listed in Figure 15 are not relevant to Starship analysis. Level A harassment/injury impacts are evaluated against the PTS threshold and Level B harassment impacts are evaluated against the TTS threshold. Additionally, because the explosion is a single event, it is evaluated against the peak sound pressure level thresholds, which all have a reference pressure of 1 μPa, the standard unit of acoustic pressure underwater [2]. The thresholds are also intended to be evaluated "unweighted" as signified by the "flat" subscript. SpaceX satisfied this by excluding any frequency weighting in the peak SPL calculations against those found in the technical documentation, Reference [1], and found them to be consistent.

Hearing Group	PTS Impulsive Thresholds	TTS Impulsive Thresholds	Behavioral Threshold (multiple detonations)
Low-Frequency (LF) Cetaceans	*Cell 1* $L_{p,0\text{-pk,flat}}$: 219 dB $L_{E,LF,24h}$: 183 dB	*Cell 2* $L_{p,0\text{-pk,flat}}$: 213 dB $L_{E,LF,24h}$: 168 dB	*Cell 3* $L_{E,LF,24h}$: 163 dB
Mid-Frequency (MF) Cetaceans	*Cell 4* $L_{p,0\text{-pk,flat}}$: 230 dB $L_{E,MF,24h}$: 185 dB	*Cell 5* $L_{p,0\text{-pk,flat}}$: 224 dB $L_{E,MF,24h}$: 170 dB	*Cell 6* $L_{E,MF,24h}$: 165 dB
High-Frequency (HF) Cetaceans	*Cell 7* $L_{p,0\text{-pk,flat}}$: 202 dB $L_{E,HF,24h}$: 155 dB	*Cell 8* $L_{p,0\text{-pk,flat}}$: 196 dB $L_{E,HF,24h}$: 140 dB	*Cell 9* $L_{E,HF,24h}$: 135 dB
Phocid Pinnipeds (PW) (Underwater)	*Cell 10* $L_{p,0\text{-pk,flat}}$: 218 dB $L_{E,PW,24h}$: 185 dB	*Cell 11* $L_{p,0\text{-pk,flat}}$: 212 dB $L_{E,PW,24h}$: 170 dB	*Cell 12* $L_{E,PW,24h}$: 165 dB
Otariid Pinnipeds (OW) (Underwater)	*Cell 13* $L_{p,0\text{-pk,flat}}$: 232 dB $L_{E,OW,24h}$: 203 dB	*Cell 14* $L_{p,0\text{-pk,flat}}$: 226 dB $L_{E,OW,24h}$: 188 dB	*Cell 15* $L_{E,OW,24h}$: 183 dB

Figure 15: NMFS PTS Onset, TTS Onset, and Behavioral Thresholds (Multiple Detonations) for Underwater Explosives [3]

The thresholds in Figure 15, along with the interpretation guidance in Reference [3], allows for the selection of Level A (PTS) and Level B (TTS) harassment thresholds for each marine mammal species in the Pacific impact area. Reference [3] does not include any guidance on assessing underwater noise impacts on the turtle and fish species that have the potential to be present in the Pacific impact. Therefore, SpaceX uses harassment thresholds consistent with those used by the Navy in their 2017 noise analysis [4], which derives thresholds for turtles based on the work of Popper et al. [5] and sets the TTS threshold for turtles as 226 dB re 1 μPa, which equals the highest threshold among the marine mammals (Otariid Pinnipeds).

The rationale begins with the Popper et. al. recommendation that an SEL-based threshold of greater than 186 dB re 1 μPa2s for TTS exposure to impact pile driving or seismic airgun impulses. However, Popper makes no recommendation for a single event peak SPL-based TTS threshold; as such the Navy assumed that the peak SPL-based threshold for sea turtle would likely be higher than that for marine mammals given the high hearing threshold measured for sea turtles and the high SEL-based TTS thresholds recommended by Popper. Since the TTS threshold should likely be higher than marine mammals the Navy concluded that it would be appropriate to set the sea turtle TTS threshold to be equal to the highest marine mammal threshold. The Navy then assumes that the same dB increase used to generate marine mammal PTS thresholds of +6 dB is also applicable to sea turtles. SpaceX concurs with these assumptions and therefore selected 232 dB re 1 μPa as the PTS threshold for sea turtles. Note that the sea turtle thresholds assumed by SpaceX match those most recently published by NMFS in January 2023 [6].

In the January 2023 publication titled "Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles)", Reference [6], NMFS provided onset of physical injury thresholds for fish species. SpaceX directly adopted the recommended onset of physical injury thresholds shown in Figure 16 for fish species.

	Onset of Physical Injury (Received Level)
Fish Size	**Impulsive**
Fishes ≥ 2 g	*Cell 1* $L_{p,0\text{-}pk,flat}$: 206 dB $L_{E,p,12h}$: 187 dB
Fishes < 2 g	*Cell 2* $L_{p,0\text{-}pk,flat}$: 206 dB $L_{E,p,12h}$: 183 dB

Figure 16: NMFS Onset of Physical Injury Thresholds for Fishes [6]

Based on the NMFS hearing type and the NMFS guidance for assessing the potential for harassment from single event impulsive sound sources, SpaceX identified the appropriate harassment and injury thresholds for each species potentially present in the Pacific impact area as shown in Table 12. All thresholds are given as peak SPL re 1 μPa.

Both ESA and MMPA prohibit the "take" of species under their protection. The ESA definition of take is broader than the MMPA definition of take. MMPS thresholds are used a surrogate to determine potentials impacts for ESA-listed species, and therefore considered encompassing of all potential impacts.

Table 12: PTS, TTS and/or Onset of Physical Injury Thresholds for Each Species

Species Data (Pacific)		Thresholds (dB re 1 u Pa)	
Species	Type	Level A PTS (L_{PTS})	Level B TTS (L_{TTS})
Blue Whale	LF cetacean	219	213

False killer whale, Main Hawaiian Islands Insular DPS	MF cetacean	230	224
Fin Whale	LF cetacean	219	213
Sei Whale	LF cetacean	219	213
Sperm Whale	MF cetacean	230	224
Hawaiian Monk Seal	Phocid pinniped	218	212
Green Turtle Central North Pacific DPS	Turtle	232	226
Hawksbill Turtle	Turtle	232	226
Leatherback Turtle	Turtle	232	226
Loggerhead Turtle North Pacific DPS	Turtle	232	226
Olive Ridley Turtle	Turtle	232	226
Species	**Type**	**Onset of Physical Injury (L_{Inj})**	
Giant Manta Ray	Fish	206	
Oceanic Whitetip Shark	Fish	206	

The total distance over which the TTS, PTS, or injury threshold would be exceeded can be calculated using Equation 12 where LR is the threshold SPL. The impact area can then conservatively be calculated as a circle with radius R, leading to the impact area equation in Equation 13. This approach is conservative as it calculates the impact area at the surface; for lower depths the impact area will be smaller as the radial distance will be smaller for equivalent ranges.

Equation 13: Impact area calculation in km2 for impact threshold Lthresh

$$A = \pi \left[0.001 \times 10^{\left(\frac{L_{pk} - L_{thresh}}{20}\right)} \right]^2$$

Impact area results are given in Table 13, using the peak source sound level values given in Table 10 and the species thresholds listed in Table 12.

Table 13: Sample results for Starship explosive event underwater noise analysis

Species Data (Pacific)		**1,260 kg (SN11's 9% Yield)**	
Species	**Type**	**Level A PTS Area (km^2)**	**Level B TTS Area (km^2)**
Blue Whale	LF cetacean	8.25	32.86
False killer whale, Main Hawaiian Islands Insular DPS	MF cetacean	0.66	2.61
Fin Whale	LF cetacean	8.25	32.86
Killer Whale, Southern Resident DPS	MF cetacean	0.66	2.61

Sei Whale	LF cetacean	8.25	32.86
Sperm Whale	MF cetacean	0.66	2.61
Hawaiian Monk Seal	Phocid pinniped	10.39	41.37
Green Turtle	Turtle	0.41	1.65
Hawksbill Turtle	Turtle	0.41	1.65
Leatherback Turtle	Turtle	0.41	1.65
Loggerhead Turtle	Turtle	0.41	1.65
Olive Ridley Turtle	Turtle	0.41	1.65
Species	**Type**	**Onset of Physical Injury (km^2)**	
Giant Manta Ray	Fish	164.7	
Oceanic Whitetip Shark	Fish	164.7	

Figure 17 is provided as a reference for the relative size and location of the largest impact area given in the results table.

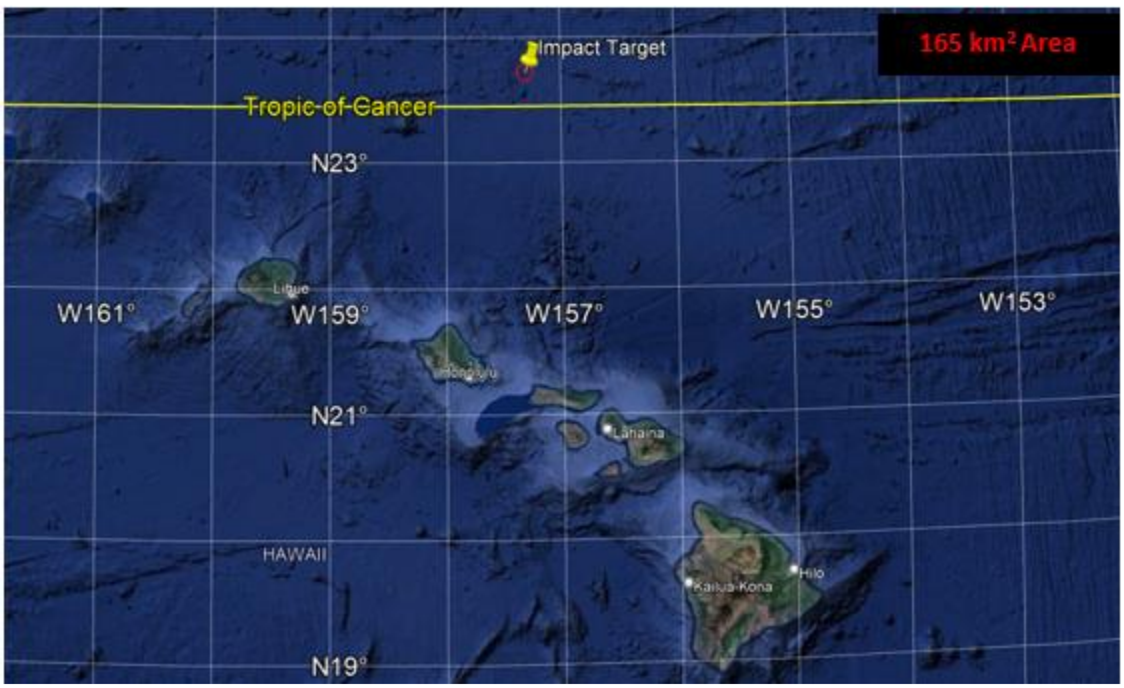

Figure 17: Reference map showing scale of Fish Onset of Physical Injury area

References

[1]. National Marine Fisheries Service, Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0), April 2018

[2]. NMFS (National Marine Fisheries Service). 2022. Programmatic Concurrence Letter for Launch and Reentry Vehicle Operations in the Marine Environment and Starship/Super Heavy Launch Vehicle Operations at SpaceX's Boca Chica Launch Site, Cameron County, TX. January.

[3]. NMFS (National Marine Fisheries Service). 2022. Summary of Marine Mammal Protection Act Acoustic Thresholds. https://media.fisheries.noaa.gov/2022-05/MM%20Acoustic%20Thresholds%20%28508%29_secure%20%28May%202022%29.pdf. Accessed 15 December 2022.

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[5]. Popper, A. N., A. D. Hawkins, R. R. Fay, D. A. Mann, S. M. Bartol, T. J. Carlson, S. Coombs, W. T. Ellison, R. L. Gentry, M. B. Halvorsen, S. Løkkeborg, P. H. Rogers, B. L. Southall, D. G. Zeddies, & W. N. Tavolga. (2014). *Sound Exposure Guidelines for Fishes and Sea Turtles*.

[6]. NMFS (National Marine Fisheries Service). Jan 2023. Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles). https://www.fisheries.noaa.gov/s3/2023-02/ESA%20all%20species%20threshold%20summary_508_OPR1.pdf