Federal Aviation Administration

Handling Variability and Uncertainty in Flight Safety Analysis

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Chapter 1. INTRODUCTION

The material in this document is advisory in nature and does not constitute a regulation. This guidance is not legally binding in its own right and the FAA will not rely upon this guidance as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with this guidance document (as distinct from existing statutes and regulations) is voluntary only, and nonconformity will not affect rights and obligations under existing statutes and regulations. The material in this document does not change or create any additional regulatory requirements, nor does it authorize changes to, or deviations from, existing regulatory requirements.

There has been significant confusion in the community regarding the process to incorporate variability and uncertainty in the flight safety analysis process. This paper attempts to provide a logical framework to provide guidance on the requirements in three sections of the regulation:

Section 450.117(a) requires:

1. A set of trajectories to characterize **variability**. This set must describe how the intended trajectory **could vary due to conditions known prior to initiation of flight**; and
2. A set of trajectories to characterize **uncertainty**. This set must describe how the **actual trajectory could differ from the intended trajectory due to random uncertainties** in all parameters with a significant influence on the vehicle's behavior throughout normal flight.

Section 450.135(a) requires that the debris risk analysis demonstrates compliance with safety criteria in § 450.101, either—

1. **Prior to the day of the operation**, accounting for all foreseeable conditions within the flight commit criteria; or
2. During the countdown **using the best available input data**, including flight commit criteria and flight abort rules.

Section 450.13 requires the same as § 450.135, but for far field blast overpressure instead of debris.

These topics are discussed in AC 450.117-1 and AC 450.115-1A, and this paper is not intended to replace those discussions, but instead provide expanded practical guidance for application to the analysis sequence.

Chapter 2. BACKGROUND

2.1 Terminology Clarifications

The term "uncertainty" has led to some confusion, because variability is a form of uncertainty. Following the usage in Larson & Wilde, 2021, this paper will use the terms "incertitude" and "variability." Incertitude represents those uncertainties which are irreducible, either due to limitations of the models of the physics or the accuracy of data. Variability represents the range of factors which will be better known when the flight is initiated than they are at the time the analysis is performed, either due to decisions being made or better prediction or measurement of data. Thus, each variability trajectory is like a different potential nominal trajectory.[1]

The term "three-sigma trajectory" has no meaningful definition. It does not typically correspond to a statistical confidence interval, but instead has usually represented the operator's expectation of "normal" performance. The set of three-sigma trajectories have been used to represent incertitude, variability, and limits of a useful mission, which, in reality, are normally quite different. The differentiation of these is intended to increase safety (through improved fidelity of risk analysis) and provide more flexibility for operators.

In general, it is impossible to identify a "conservative" or worst-case dispersion. A change in the dispersion only relocates the hazard, it does not reduce it (it is valid to have a conservative casualty area or failure probability on the other hand). A dispersion can only be conservative in the context of what is exposed. As impact dispersions become smaller, the peak individual risk is higher and the hazard contours typically become longer and narrower. This may lead to different shape hazard areas. Thus, "worst case" for hazard areas may be the opposite of "worst case" for collective risk.

[1] Section 401.7 defines "nominal" to mean, in reference to launch vehicle performance, trajectory, or stage impact point, a launch vehicle flight for which all vehicle aerodynamic parameters are as expected, all vehicle internal and external systems perform exactly as planned, and there are no external perturbing influences other than atmospheric drag and gravity. Since wind leads to different drag effects, the expected wind field should be used to compute a nominal trajectory. This is consistent with standard industry practice. However, this is different than appears in the NPRM for the Part 450 promulgation and AC 450.117-1

2.2 Assumptions

2.2.1 Assumption 1: Reduction of Variability

Variability reduces as the time before the operation becomes smaller. This paper discusses only analyses required to comply with Part 450 for each flight[2] (i.e., after the vehicle design and mission objectives have been established). The three most significant variabilities in this context are the trajectory, the atmosphere, and the exposed population. See Larson & Wilde, 2021, for further discussion.

2.2.2 Assumption 2: Time

Mitigation strategies should be determined before wind forecasts are meaningful. The primary mitigation strategies are flight safety limits and hazard areas. Flight safety limits should be developed in time to validate, load into software/hardware, and verify on flight systems. Warning areas should be published in sufficient time to allow other users to plan, and surveillance areas should be identified in time to allocate and prepare surveillance platforms. These constraints typically entail finalization of mitigations at least 10 days prior to the operation. Currently, atmospheric forecasts are significantly better than historical statistics only a few days in advance for debris analysis and for far-field blast overpressure analysis.

2.2.3 Assumption 3: Off-Trajectory versus Malfunction Turn

There are fundamental differences between analysis of off-trajectory and on-trajectory failures. First, debris risk analysis of off-trajectory failures (e.g., malfunction turn) is much more computationally expensive than for on-trajectory breakups and loss-of-thrust failures. This is because many more failure trajectories should be modeled to obtain statistically meaningful results and the breakup scenarios are more complex. Second, the initial state at the time of the failure is less relevant to the outcome for off-trajectory than for on-trajectory failures. This is because the dispersion due to the failure flight is typically at least comparable to the normal trajectory variability and because the flight safety limits are fixed regardless of the initial nominal. These considerations lead to a key constraint that should be verified before the method described herein is applicable: **the dispersion of breakup states that result from violating flight safety limit should not be meaningfully different due to initiating from any trajectories in the variability set.**

[2] The results of this process must be submitted in accordance with § 450.213(b) for each flight under a license. For a license application, a representative analysis must be submitted that follows the same process as will be used for each flight.

2.2.4 Assumption 4: Incertitude Shift

For this method, we assume that there is no meaningful difference in the trajectory incertitude between any of the variability trajectories. Trajectory incertitude in this context is the variation in position and velocity and is often characterized as a covariance matrix (when a normal distribution of uncertainty is a good assumption). The random uncertainties should include mass properties, engine performance, atmosphere, aerodynamic coefficients (see AC 450.117-1). This means that the random uncertainties have the same statistical character regardless of which trajectory is the nominal.

There two important constraints when using uncertainties developed around one trajectory and translating them to another:

- The state vector uncertainty should be characterized with respect to events rather than absolute time, such as through time-scaling (see Larson & Gras, 2018), and applied to the new trajectory relative to its event times.
- The uncertainty should be defined in a coordinate system relative to the velocity vector at each event-relative time.

This assumption becomes less true the larger the difference between the variability trajectories. The variability trajectories should have the same sequence of events. A preliminary estimate of the allowable variation for this assumption is that the 99% confidence bound of direction of the velocity vector, at any event-relative time, is more than three degrees from the mean.

Chapter 3. MODELING NORMAL TRAJECTORIES

Section 450.117(b) requires that the final normal trajectory analysis be performed with a six-degree-of-freedom (6DOF) trajectory model. The conventional understanding of this is that all three elements of both position and orientation are outputs of the simulation. However, in some cases, an alternative approach, here called a 3+3 DOF, is a simulation where the vehicle orientation changes during flight, but is externally constrained, not controlled by physics. This lower-fidelity approach can be useful for exploring alternative guidance programs and wind conditions. However, it does not demonstrate that the vehicle control system can achieve the specified guidance program, and it cannot account for most uncertainties.

Thus, in order to model random uncertainties and to evaluate the final vehicle planned flight, use of a full 6-DOF is necessary, as required by § 450.117(b). A failure to properly simulate normal flight has been the cause of numerous vehicle failures and results incorrect input to risk analyses.

When the variability is significantly larger than the incertitude (and they are not the final flight plan), a 3+3 DOF simulation may be used for the variability trajectories instead. This is justified for two reasons:

1. The variation in flight plans is much larger than 6-DOF / 3+3-DOF effects.
2. These trajectories are not directly used as part of the evaluation of the safety criteria.

Chapter 4. ANALYSIS PROCESS

To satisfy part 450, there are typically three phases of flight safety analysis: validation of the limits of a useful mission, mitigation development, and the countdown. The validation of the limits of a useful mission is to satisfy § 450.108(d)(7): "Ensure that any trajectory within the limits of a useful mission that is permitted to fly without abort would meet the collective risk criteria…" Mitigation development is the determination of the hazard areas, in accordance with § 450.133, and flight safety limits in accordance with § 450.108. The countdown analysis is the final validation of the safety criteria in § 450.101, per § 450.135(a)(2) and § 450.137(a)(2). There are different technical products that are produced from these and different timelines for when they should be complete, and this is summarized in the table below.

Table 1. Analysis Overview

Analysis	Products	Timeframe	Part 450
Validation of limits of a useful mission	E_Cs	Before start of mitigation development	§ 108(d)(7)
Mitigation Development	Hazard areas Flight Safety Limits & CE_C vs time	Normally at least 10 days prior to flight (see Assumption 2: Time)	§ 133 § 108
Readiness Analysis[3]	E_Cs PC grids/contour (for validation of hazard areas and real-time ship risk)	0-3 days prior to flight	§ 135 & 137 showing compliance with § 101

Last, §§ 450.135(a)(2) and 450.137(a)(2) require an operator to demonstrate that the safety criteria are satisfied using the best available data during countdown, but it is not usually practical to change the mitigation strategies at this time.[4] Thus hazard areas should account for a range of possible conditions at launch because they are directly connected to the safety criteria in § 450.101. Flight safety limits are a means to meeting the safety criteria, but the constraints in § 450.108(d) are to be satisfied at the time the limits are developed, consistent with current practice.

Note: This paper does not discuss the process for validation of the limits of a useful mission.

4.1 Data Elements

The basic principle for variability analysis is to examine different scenarios where the variability is significant compared to the incertitude in the data and union the results, but to treat the variability as uncertainty when other uncertainties are comparable. A union result means taking the maximum result from a set of results (rather than the average), which for hazard area development means bounding the values from multiple analyses.

As discussed previously, there are typically three variabilities that should be considered during the mitigation, readiness analysis and/or countdown: trajectory, winds, and population.

Trajectory variability affects the breakup states and their uncertainty. The handling depends on whether OT/LT or off-trajectory scenarios are considered because of Assumption 3: OT vs MT. There is one important subtlety here: for off-trajectory failures, the uncertainty depends on the outcome. If the failure trajectory dynamics cause a structural failure or engine shutdown, then the uncertainty is related to the initial condition uncertainty. However, if the outcome is a result of conditions fixed to the external system (e.g., aerothermal breakup at a specific altitude, flight safety limits based on IIP), then the uncertainty is mostly related to the uncertainty in those conditions, not the initiating state. Thus, uncertainty due to the planned trajectory applies to only some off-trajectory breakup states.

Winds and population are handled differently for the near-site areas and for downrange areas. For downrange areas, variability can be treated as uncertainty except for sheltering. This is primarily because the combination of trajectory and population spatial incertitude is at least comparable to all the effects of all variability. The further from the launch/landing site, the greater the trajectory position/velocity incertitude. Furthermore, one has limited resolution of exactly where people are located; population is constantly changing, in some regions the data quality is poor, and the time-dependent factors lead to relatively small net movement in populations. However, the resolvable time-dependent effects of sheltering can be meaningful (on the scale of hours), so this should be accounted for. In the near-site area, however, the specific winds and population distribution are important. This is because the variability in hazard due to wind is significant relative to other uncertainties. And likewise, the net movement of people (especially spectators and controlled population) is significant relative to the effects of incertitude.

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[3] For risk analysis and derivation of day-of-launch risk products "readiness analysis" the is the analysis performed just days before a launch to complement a countdown analysis; it occurs when atmospheric conditions can be forecast sufficiently well that the uncertainty in analysis results due to the atmospheric data uncertainty is not meaningfully different than the uncertainty in the best available data at the launch commit decision time.

[4] In some situations, different sets of flight safety limits have been developed and selected based on winds in the countdown. This paper does not consider that concept of operations.

4.2 Mitigation Development

Flight safety analysis products are used in mitigation development: CE_C is needed for flight safety limits development, probability of casualty as a function of location is the basis for hazard areas, and E_C is used to identify the risk management strategy for controlled areas. It is important to remember that the analysis at this phase is not directly related to the safety criteria; the goal is to ensure the safety criteria are met at launch. Thus, there is room for some approximation and assumptions; an invalid approximation/assumption would only lead to a launch delay until criteria are satisfied.

During the process of mitigation development, there is typically variability in the trajectory due to wind, but there could be other remaining decisions that have yet to be made. If there are distinct mission plans (such as a re-entry initiating from different orbits), the two mission plans should be treated separately, and mitigations independently developed. For OT/LT, the variability is much larger than the incertitude, but for off-trajectory, this is generally not true. This means:

- For OT/LT, treat various trajectories spanning the range of the variability each as the nominal, and use the expected incertitude as the uncertainty, and union the results.
- For off-trajectory, two options:
  - (Preferred option) Initiate the malfunction trajectories by sampling from the variability set, use incertitude as the uncertainty, and average the results,
  - Initiate the malfunction trajectories from a median of the variability trajectories, use the covariance of the variability set as the uncertainty, and average the results.

Table 2. Mitigation Development Trajectory Data

	OT/LT	Off-trajectory Option 1	Off-trajectory Option 2
Breakup states	Several trajectories spanning the range of variability trajectories	Trapped states from malfunction trajectories initiating from variability trajectory samples	Trapped states from malfunction trajectories initiating from a median nominal
SV Uncertainty Source	Incertitude	Incertitude[3]	Variability
Statistical operation	Union	None (each sample has a probability)	

The atmosphere also affects the propagation of debris and focusing of blast waves. For downrange areas, it is sufficient to use an atmospheric data that is seasonally appropriate, with variability modeled as uncertainty. Monthly statistics are sufficient for seasonally appropriate, and it is reasonable to use the statistics from a neighboring month, such as if the operation date slips. In the launch/landing areas, it is best to use representative atmospheric samples and union the results: pre-selected sets of data that represent the range of conditions that might be present. For debris risk, wind power (see appendix to Larson & Wilde, 2021) can be used to identify representative winds. For far-field blast overpressure (FFBO), different conditions include inversion, gradient, and caustic profiles. A simplification may be appropriate for debris risk: seasonally appropriate statistical winds can be used (with variability used as uncertainty) and a buffer added, based on experience at the range.

For expected casualty calculations, there are differences between handling the local area and downrange population. For downrange areas, CE_C should be computed with two cases: everyone unsheltered and everyone sheltered in a weak structure, and the union taken, although a more specific time window could be used if the launch has a short window (e.g., less than an hour). For the local area, when computing CE_C and E_C, the maximum foreseeable population should be used at each location, accounting for mitigations and potential spectators. The maximum foreseeable population is generally the maximum that has ever occurred at a location, but if this is unduly constraining an operation, then data more specific to the time of the operation may be used.

For hazard areas determinations, the types of moving assets considered are also important. A range of vessel types and aircraft which are foreseeable in the regions at risk need to be considered to appropriately define evacuation, surveillance, and warning areas. Different areas may be developed for different classes of vessels and/or aircraft.

[3] It is normally acceptable to use no uncertainty in this case as this incertitude is generally insignificant compared to other effects.

Table 3. Mitigation Development Environment Data

	Local	**Downrange**
Winds for debris	Option 1: Multiple extreme winds, no uncertainty OR Option 2: Mean monthly wind with variability with additional buffer	Monthly statistics, with variability as uncertainty
Atmosphere for FFBO	Profiles for different conditions	n/a
Population	Maximum foreseeable	Maximum foreseeable sheltering
Statistical operation	Union	Union

4.3 Readiness Analysis[4]

In the countdown, flight safety analysis products are used for evaluating compliance with the safety criteria in § 450.101. For this paper, readiness analysis means the analysis performed with a meaningful weather forecast to supplement a countdown analysis. The collective risk (E_C) and probability of casualty (P_C) need to be evaluated, consistent with § 450.101(a)(1) and (2). The variability is much reduced, but may not be entirely eliminated, especially if the launch window has a significant duration. As in mitigation, if there remain fundamental differences in the mission plan, the different plans should be separately evaluated.

There may be remaining variability in the trajectory, such as if the trajectory changes meaningfully during the launch window or if there is a mobile launch platform. A meaningful change would be a difference in variability trajectories greater than the one-sigma rang e of the incertitude. The updated trajectory range normally significantly affects OT/LT failures. Ideally malfunction trajectories would be regenerated based on the updated nominal and/or variability range, but this usually does not produce a meaningfully different result and obtaining sufficient computational resources during the countdown is likely infeasible.

[4] Readiness analysis may be performed 2-3 days ahead of the mission, if the weather forecast is sufficiently accurate and no other variabilities will be reduced before countdown.

Table 4. Readiness analysis trajectory data

	OT/LT	Off-trajectory
Breakup states	Several trajectories spanning the range of variability trajectories (or single nominal if no remaining variability)	Same as was used for mitigation development (option 1 or option 2)
SV Uncertainty Source	Incertitude	
Statistical operation	Union	None

Atmospheric conditions are much simpler in the countdown. There typically remains no variability in the local area atmosphere, only incertitude. The exception is when there is an anticipated significant change in the conditions during or near the launch window, such as a front moving through. In the downrange area, a 3-D forecast is ideal, with minimal uncertainty, but seasonally appropriate wind statistics may be used.

For population data, there may be variability for two reasons. First, there may be last-minute observations of nearby areas (such as spectator locations). For these last-minute data, this risk can be computed based only on PC at the locations, equivalent to how real-time ship risk is performed. Second, there may be meaningful changes during the launch window. In the launch area, these changes could result in net population movement due to start or end of the workday. In the downrange area, the sheltering may change across the launch window.

[6] Readiness analysis may be performed 2-3 days ahead of the mission, if the weather forecast is sufficiently accurate and no other variabilities will be reduced before countdown.

Table 5. Readiness Analysis Environment Data

	Local	**Downrange**
Winds for debris	Best forecast(s), no (or small) uncertainty	3-D forecast, no (or small) uncertainty OR Monthly statistics, with variability as uncertainty
Atmosphere for FFBO	Best forecast(s)	n/a
Local population	General: different times in launch window Latest counts for locations with high variability	Different times in launch window
Statistical operation	Union	Union

Since most of the variabilities are a function of time within the launch window, the number of actual risk analysis runs to compute the results is usually small. Often it is sufficient to analyze the beginning and end of the launch window, and for hourly intervals in between, ensuring that safety criteria are satisfied across the window. Mobile platform variability may need to be handled separately.

Chapter 5. ANALYSIS STEPS

5.1 Site Specific Data Development

- Develop a sample set of wind profiles using wind power as a metric (see Appendix A of Larson & Wilde, 2021).
- Develop a sample set of atmospheric profiles using sound characteristics (e.g., inversion, gradient, caustic) as a metric.
- Develop list of spectator or other high-variance population locations.
- Develop an adequate set of representative vessels and aircraft, and the extent and resolution over which probability of casualty will be computed.

5.2 Preliminary Trajectory Development

- Incertitude Trajectories
  - Perform simulation to develop a reference nominal trajectory with 6DOF simulator.
  - Determine uncertainties in simulation input data that characterize those that would be present at the time of the final trajectory simulation for the operation.
  - Simulate a set of incertitude trajectories (at least 100, normally 300 or more) incorporating the uncertainties.
  - Develop statistics of the incertitude, using time-scaled trajectories, with the coordinate system based on the mean velocity vector at each time.
- Variability Trajectories
  - Identify the potential variability in mission plan.
  - Select representative atmospheric conditions, including the most extreme under which the operation could be attempted (the sample set of wind profiles may be used).
  - Simulate a set of variability trajectories that span the range of mission plan and atmospheric conditions. The range could be as simple as a left, right, hot, and cold, but if there is more complex variability, additional trajectories may be appropriate.
  - Develop statistics of the variability, using time-scaled trajectories, with the coordinate system based on the Earth.

5.3 Mitigation Development

(Option 1 in Table 2)

1. Trajectory Analysis

1.1. Generate off-trajectory failures that initiate from state vectors which sample variability trajectories ("Off-trajectory set").

1.2. Develop flight safety limits in compliance with § 450.108.

1.3. Trap the failure trajectories to produce breakup states.

1.4. For each variability trajectory, generate loss-of-thrust trajectories and trap to produce breakup states, along with on-trajectory breakup states ("OT/LT sets").

2. Debris Risk Analysis

2.1. Create baseline debris risk analysis.

2.1.1. Nominal debris, failure rate, thermodynamic profile.

2.1.2. Population data and downrange winds per Table 3.

2.2. Off-trajectory flight debris risk

2.2.1. Off-trajectory set of state vectors with incertitude statistics.

2.2.2. Either

2.2.2.1. Union over local wind conditions with no wind uncertainty OR

2.2.2.2. Mean monthly wind and monthly variability as uncertainty

2.2.3. Products for each failure mode: CE_C, probability of casualty grids, yield probability pairs.

2.2.4. Verify that CE_C meets the requirements of § 450.101(c) or § 450.108(b) and, when required, § 450.108(c)(4).

2.3. OT/LT Debris Risk

2.3.1. Union over each OT/LT set with either

2.3.1.1. Union over local wind conditions with no wind uncertainty OR

2.3.1.2. Mean monthly wind and monthly variability as uncertainty

2.3.2. Products for each failure mode: CE_C, probability of casualty grids, yield probability pairs

2.3.3. Verify § 450.108(c)(3) for which OT/LT CE_C can be used as a metric.

2.4. Add off-trajectory and OT/LT probability of casualty grids and yield probability pairs (if modes were run separately the results should be summed)

2.5. Develop hazard areas, identified by type (warning, controlled, surveyed)

2.6. Identify population locations that may require mitigation for individual risk and develop mitigation strategy (may depend on atmospheric conditions at launch)

3. FFBO Risk Analysis

3.1. Create baseline FFBO risk analysis

3.1.1. Population data per Table 3.

3.1.2. Yield probability pairs from debris risk.

3.2. Union risk over different atmospheric profiles

3.3. Identify population locations that may require mitigation for individual risk and develop mitigation strategy (may depend on atmospheric conditions at launch)

4. Develop Risk Mitigation Strategy

4.1. If collective risk criteria (combining debris, FFBO, and other applicable hazards) is potentially exceeded, develop strategy for mitigation. This may include relocating controlled population, restricting spectators, and/or implementing flight commit criteria based on atmospheric conditions at the time of the operation.

5.4 Example of Mitigation Development

An example of combined probability of casualty results for this phase of the analysis are shown in Figure 1 for off-trajectory (step 2.2.3), Figure 2 for OT/LT (step 2.3.2), and the combined result in Figure 3 (step 2.4).

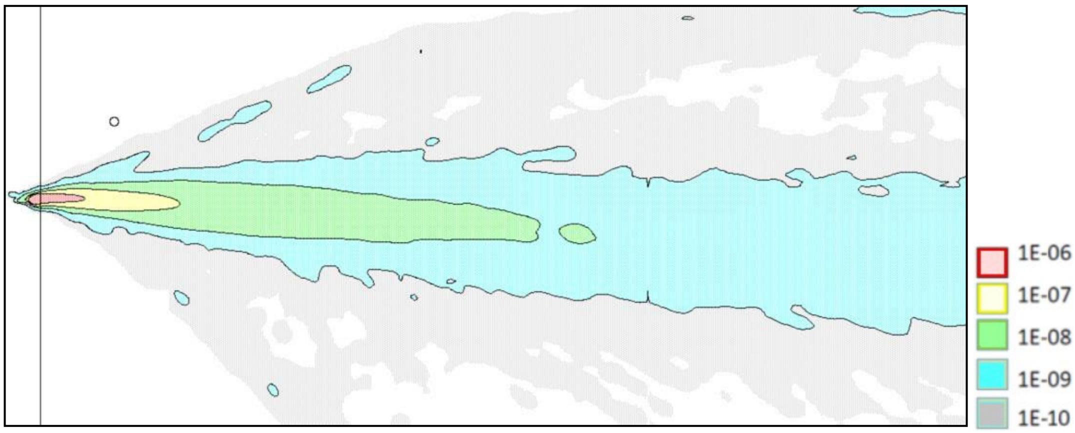

Figure 1 Example Mitigation Development Off-trajectory Probability of Casualty Contours

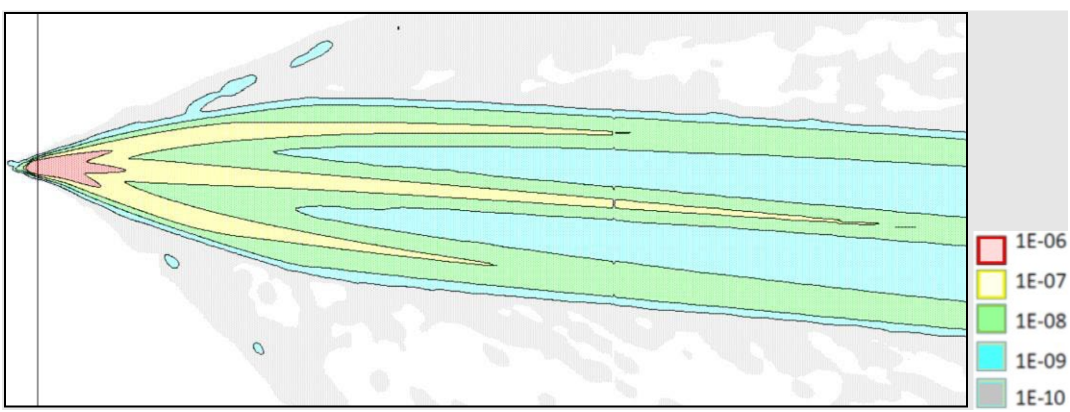

Figure 3. Example Mitigation Development Combined Probability of Casualty Contours

Sum (add) of union nominal failures (OT/LOT) and off nominal failures (MT &RA)

The 1E-7 contours extend further downrange for the nominal than the left and right because the left and right trajectories turn, so the debris is more spread out cross-range.

For example, a set of hazard area results are shown in Figure 4 (step 2.5). These include all four types of hazard areas:

- An evacuation area where no public is allowed (note: in general, the safety of operation-essential personnel are not regulated by the FAA (green on land and red at sea)
- A controlled area where only operation-essential and Neighboring Operations Personnel are allowed (yellow)
- A warning area for ships and boats, issued as a Notice to Mariners (dark green)
- Two surveillance areas
    - Active surveillance to verify that individual risk criteria are satisfied and the contribution of smaller vessels to collective risk (purple)
    - AIS surveillance to evaluate the contribution of passenger ships to collective risk (brown)

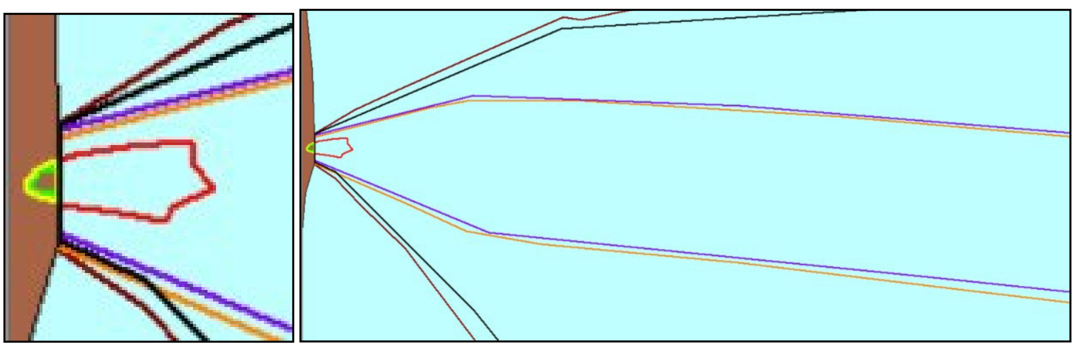

Figure 4. Example Hazard Areas

5.5 Final Trajectory Development

- Incertitude trajectories
    - Perform simulation to develop an updated nominal trajectory with 6DOF simulator
    - If there are meaningful changes in the simulation uncertainties, then
- Simulate a set of incertitude trajectories (at least 100, normally 300 or more) incorporating remaining uncertainties.
- Develop statistics of the incertitude, using time-scaled trajectories, with the coordinate system based on the mean velocity vector at each time.
- Variability trajectories
    - Identify any variability that remain to be made regarding the operation
    - Simulate a set of variability trajectories that span the range of variability

5.6 Readiness Analysis

1. Trajectory Analysis
   - 1.1. For each variability trajectory, generate loss-of-thrust trajectories and trap to produce breakup states, along with on-trajectory breakup states ("OT/LT sets").
   - 1.2. Generate incertitude-based velocity aligned covariance matrix for OT/LT breakups.
   - 1.3. Generate variability-based Earth aligned covariance matrix for off-trajectory breakups.
2. Debris Risk Analysis
   - 2.1. Create baseline debris risk analysis.
     - 2.1.1. Nominal debris, failure rate, thermodynamic profile.
     - 2.1.2. Downrange winds per Table 5.
     - 2.1.3. Latest local wind forecast with uncertainty.
     - 2.1.4. Risk runs – for each relevant time in operation window.
       - 2.1.3.1. Obtain static population model for the specified time.
         - 2.1.3.1.1. Downrange – sheltering
         - 2.1.3.1.2. Local area – time-dependent, include mitigations.
       - 2.1.3.2. Off-trajectory flight debris risk: Use prior set off-trajectory set of state vectors.
       - 2.1.3.3. OT/LT debris risk: Union over each new OT/LT set (often only one).
   - 2.2. Add risk off-trajectory and OT/LT.
   - 2.3. Products: Probability of casualty grids, collective risk by population center and population type, individual risk for spectator sites.
3. FFBO Risk Analysis.
   - 3.1. Create baseline FFBO risk analysis.
     - 3.1.1. Population data per Table 5.
     - 3.1.2. Yield probability pairs from debris risk.
   - 3.2. Union risk over different atmospheric profiles (if vary across the launch window).
4. Verification of safety – for each different time in the launch window.
   - 4.1. Verify mitigation strategies are still valid.

4.2. Evaluate static risk contributions
4.3. Calculate risk for special population locations with latest counts
4.4. Use probability of casualty grids for real-time ship risk
4.5. Evaluate collective risk against safety criteria
4.6. Validate controls are sufficient to satisfy individual risk safety criteria

5.7 Example of Readiness Analysis

In this example, it is assumed that there is a short launch window, such that there are no meaningful differences in the trajectory, atmospheric data, or special population locations across the duration.

An example probability of casualty result in a readiness analysis is shown in Figure 5. In this example, the left trajectory from the variability trajectories became the nominal between hazard area development and the readiness analysis.

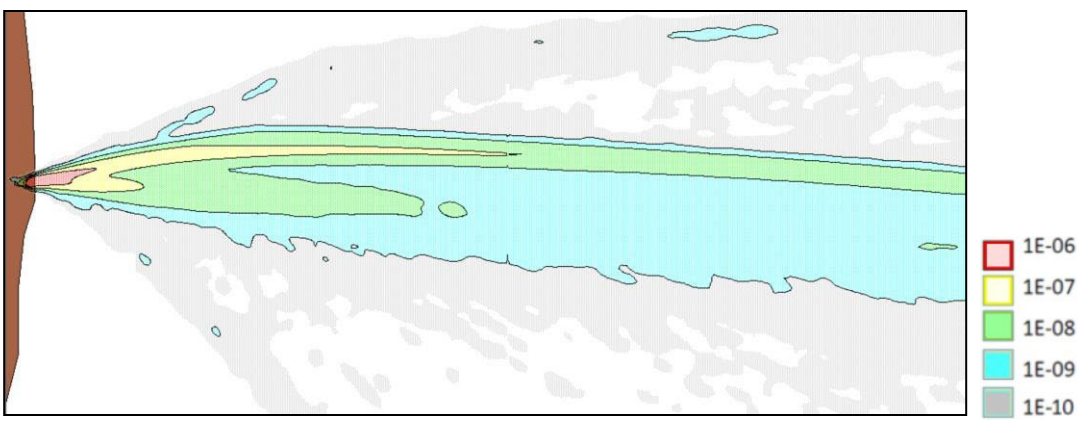

Figure 5. Example Probability of Casualty Contours for a Vessel in a Readiness Analysis

An example readiness analysis risk evaluation is shown in Table 6. In this example, the trajectory has little difference in the launch area as a function of launch time, but there are some changes downrange. Thus, the far-field E_C changes, but the near-site E_C (outside of flight safety lines) does not. The winds also change in the risk insides flight safety limits, changing the risk to spectators. A ship is assumed to be hazarded at the beginning of the window but is moving away and no longer has risk by the end of the window.

Table 6. Example Countdown Risk Evaluation

	Timeframe in launch window		
	Early	**Middle**	**Late**
Far-field E_C	70	60	50
Near-site baseline E_C	5	5	5
Spectator/Special locations			
Location 1 E_C/person	0.2	0.25	0.4
Location 2 E_C/person	0.12	0.13	0.14
Location 3 E_C/person	0.05	0.04	0.04
Location 1 Count	8		
Location 2 Count	25		
Location 3 Count	45		
Real-time-ship E_C	35	15	0
Total E_C	**117**	**87**	**64**