Workshop on AC 450.115-1

High-Fidelity Flight Safety Analysis

AST Commercial Space Transportation
Go for launch.

Presented by:

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faa.gov/space

Federal Aviation Administration

Agenda

- Background
- Additional forthcoming ACs
- Chapter by chapter review of the Advisory Circular
  - Brief overview
  - Key points
  - Response to submitted comments
  - New questions

Background on Advisory Circulars

Advisory Circulars (ACs) are being used to supplement streamlined regulations by the Federal Aviation Administration (FAA), Commercial Space Transportation (AST).

Their goal is to assist license applicants in two ways:

- Further explain the meaning of the regulatory text and its intent/goal
- Provide **a** means of compliance

The ACs are guidance, not a regulation, and compliance is voluntary.

Background on AC 450.115-1

Expands on the *AST Flight Safety Analysis Handbook* (2011).

A complete description of high-fidelity approach to debris risk analysis (most of subpart C) is too broad for one AC.

Status	ACs That Cover Flight Safety Analysis Topics
Published	AC 450.101-1 High Consequence Event Analysis
	AC 450.115-1 High-Fidelity Flight Safety Analysis
In Development	AC 450.117-1 Normal Trajectory Analysis
	AC 450.119-1 High-Fidelity Malfunction Trajectory Analysis
	AC 450.108-1 Flight Abort Rule Development
	AC 450.123-1 Population Exposure Analysis
	AC 450.131-1 Probability of Failure Analysis
	AC 450.133-1 Flight Hazard Areas
	AC 450.137-1 Far-field Blast Overpressure Analysis
	AC 450.139-1 Toxic Release Hazard Analysis

Plan to have two additional ACs on simpler approaches

Physical Containment	**Medium-Fidelity FSA**

Chapter 4 –Terms & Definitions

ACs normally only define terms not defined in part 401.7, so check there for definitions too.

Definitions provide the scope for terms used in the AC text.

Comment 1: What is hazardous debris for jettisons?

Response:

There is an existing definition:

> **Hazardous debris** means any object or substance capable of causing a casualty or loss of functionality to a critical asset. Hazardous debris includes inert debris and explosive debris such as an intact vehicle, vehicle fragments, any detached vehicle component whether intact or in fragments, payload, and any planned jettison bodies.

Chapter 11 contains more specific quantitative thresholds.

Chapter 4 – Terms & Definitions

Comment 2: Add definition of "statistically valid."

Response:

A new definition has been added:

> A "**statistically valid**" analysis is the result of a sound application of mathematics and accounts for the uncertainty in any statistical inference due to sample size limits, the degree of applicability of data to a particular system, and the degree of homogeneity of the data. The specific approach to establish statistical validity depends on the context of the particular analysis, as described in this AC and others.

Chapter 4 – Terms & Definitions

Comment 2: Add definition of “foreseeable failure mode.”

Response, part 1:

A new definition has been added for failure mode, in the context of flight safety analysis:

> A **failure mode** is a category of potentially hazardous events that share significant similarity in system response, prior to consideration of mitigations or hazard control strategies.

A failure mode is not an outcome (breakup type) or a failure cause, but a collection of similar vehicle response (for example, trajectory type).

Example: “loss-of-thrust” is a failure mode

- Multiple causes: guidance error, engine failure
- Multiple outcomes: aero breakup, intact impact, FTS, abort

Chapter 4 – Terms & Definitions

Response, part 2:

A footnote was added to chapter 1:

> In the context of launch and reentry vehicle analysis, reasonably foreseeable events and failures are those identifiable through a system safety process, including all relevant failures that have occurred for prior vehicles.

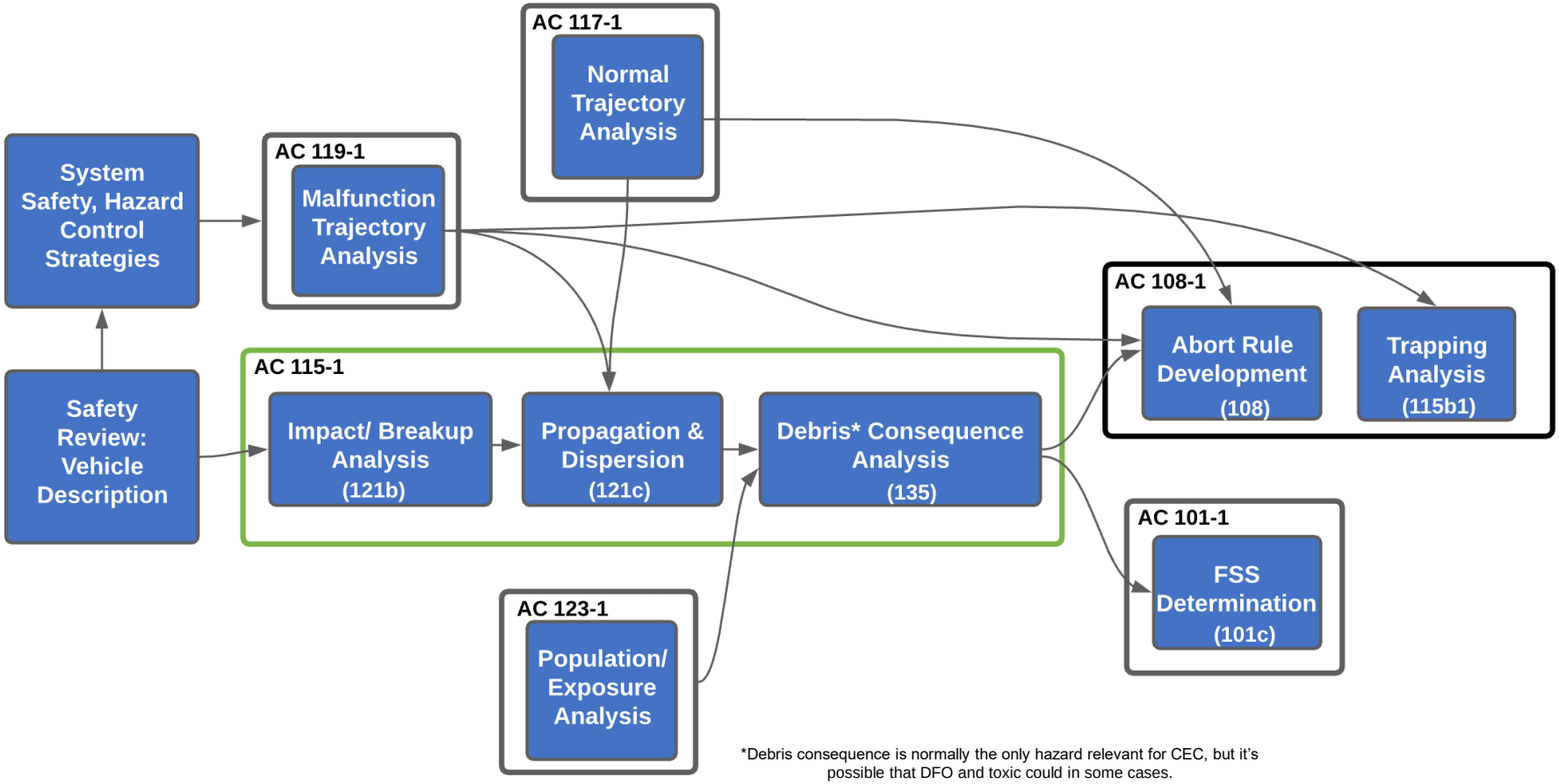
Additionally, **not** foreseeable would include:

- Failures that are not physically possible for the subject vehicle, e.g. a turbo-pump failure for a solid rocket motor
- Unknown-unknowns

Chapter 4 – Terms & Definitions

Please type your question into the Q&A chat box in Zoom,
in chat on YouTube or send an email to ASTWorkshops@faa.gov

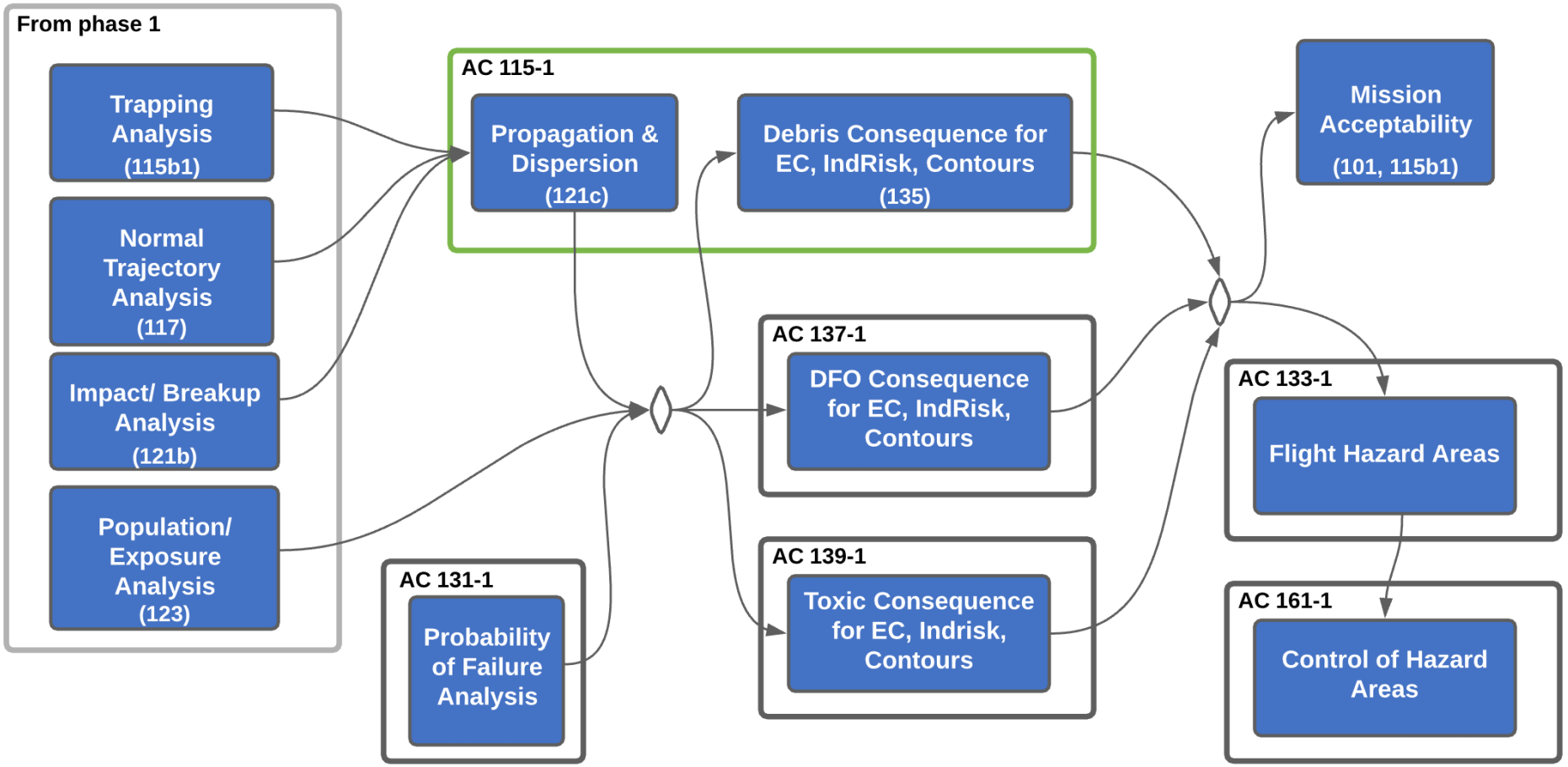
Chapters 5 & 6 – Overview



*Debris consequence is normally the only hazard relevant for CEC, but it's possible that DFO and toxic could in some cases.

This flow chart illustrates phase 1:
Use of FSA to develop abort limits or determine FSS is not needed

Chapters 5 & 6 – Overview



This flow chart illustrates phase 2:
Computing risk metrics and hazard areas

Chapters 5 & 6 – Overview

Comment: One-second interval on trajectories is excessive.

Response: This is only for *normal* trajectory data; it is required by 450.117. AST believes 1 Hz or higher frequency is reasonable for normal trajectory data.

Three comments will be answered in other ACs:

- Trajectory file formats – in 450.117-1 and 450.119-1
  - No specific format will be specified, but expectations will be detailed
- Limits of a useful mission – in 450.119-1
- Flight mission limits – in 450.117-1 and 450.119-1

Chapters 5 & 6 – Overview

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Chapter 7 – Hazardous Scenarios

- Intact impact – often highest consequence
  - Explosion
  - Toxic release
  - Gliding impact
- Mid-air explosion
  - Characterizing small debris important for aircraft
- Flight termination action
  - Includes both destruct and thrust termination
  - Abort flight is part of malfunction trajectory analysis
- Aerodynamic breakup
  - Observed 100s to 1000s of fragments
- Aerothermal breakup
  - Depends on design – vehicles designed to survive can produce a lot of fragments

FAA/AST is considering expanding debris list development guidance in an additional AC

Chapter 7 – Hazardous Scenarios

Comment: Add expectations regarding debris based on historical data.

Response: The FAA has performed analysis of historical debris lists and has added a new paragraph 8.8 to the AC, which includes guidelines of:

- number of fragments greater than 300g and
- total basic casualty area

For:

- Mid-air explosive breakup of a fully loaded liquid-fueled motor, exclusive of other motors, interstage, etc.
- Aero-thermal breakup of vehicles designed to re-enter from orbit

There is insufficient history to generalize for other scenarios.

Chapter 7 - Hazardous Scenarios

Two comments on 7.1.4 Determining Population and Geographic Areas Affected by Hazardous Debris.

Response 1: The title of this paragraph was misleading. It has been changed to be “Debris Characterization for Consequence Evaluation.”

Comment: Provide references for population data.

Response 2: There will be more guidance on population data in AC 450.123-1.

Comment: Provide references for aviation traffic density data.

Response 3: Air traffic densities are not applicable to compliance with the regulation. Hazard areas are used to control aircraft risk, which is only measured on an individual (not collective) basis.

Chapter 7 - Hazardous Scenarios

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Chapter 8 – Debris Characteristics

Chapter discusses the determination of quantitative values for debris data

- Initial conditions – position and velocity distribution at breakup
- Aerodynamic properties – for ballistic propagation
- Material properties – for aerothermal demise
- Hazard properties – for consequence calculation
- Debris grouping – for statistical purposes, reduces computation requirements

The FAA is interested in more empirical data regarding debris characteristics

Chapter 8 – Debris Characteristics

There were no comments submitted.

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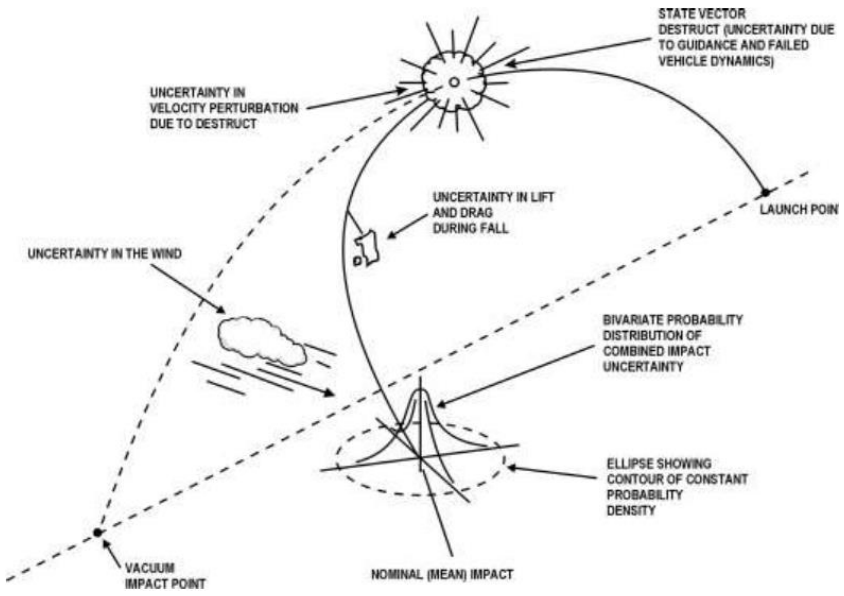
Chapter 9 - Propagation



Important about atmospheric data

- In near vicinity of operation launch/landing need to look at wind as a variability, not monthly averages with uncertainty.
- High altitude (above 100km) density important for re-entry

- Atmospheric data
- Failure & planned event state vectors
- Statistical trajectory set
- Simulation mathematics

- Special topics
  - Residual thrust
  - Directed lift
  - Progressive breakup
  - Aerothermal demise

Chapter 9 - Propagation

There were no comments submitted.

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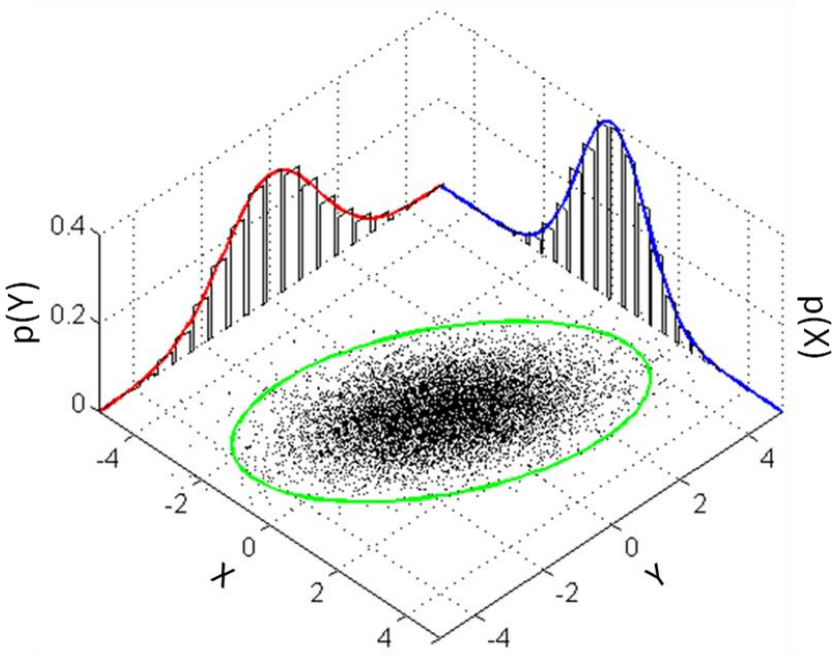
Chapter 10 – Probability Distribution

- Definition of impact probability
- Gaussian distributions
- Skewed distributions
- Histogram
  - Kernel Density Estimation
- 3-D distributions
  - Needed for aircraft hazard areas



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Chapter 10 – Probability Distribution

There were no comments submitted.

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Chapter 11 - Consequence

- Definition of consequence measures
  - Casualty
  - Casualty area
  - Probability of casualty
- Consequence vs. structure type
  - Unsheltered
  - In buildings, ships, aircraft
- Consequence for debris types
  - Inert
  - Explosive
  - Toxic
  - Burning
  - Intact

Image Credit: Sino Defense

Chapter 11 - Consequence

Comment on paragraph 11.8, People in Aircraft:

Provide clarification that this analysis does not apply to published/controlled flight hazard volumes which are assumed to be clear of aircraft during effective time of the hazard.

Response:

Modeling of consequence to people in aircraft **is needed** to calculate the extent of airspace that needs to be cleared. This is used in the determination of the hazard areas to satisfy 450.133.

Chapter 11 - Consequence

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Chapter 12 – Risk Computation

Risk metrics

Conditional Expected Casualties (CE_C)

- Further discussed in AC 450.101-1

$$CE_C(M,t) = \sum_{Regions} \sum_{frags} \frac{P_I(M,t,R,f) A_C(M,f) N_R}{A_R}$$

Expected casualty

$$E_C = \sum_{Mode} \int_{time} P_F(M,t) CE_C(M,t)$$

Maximum individual probability of casualty

Probability of impact

- Always associated with area/structure and fragment characteristic

Analysis Approaches

Availability study

Countdown analysis

Chapter 12 – Risk Computation

There were no comments submitted.

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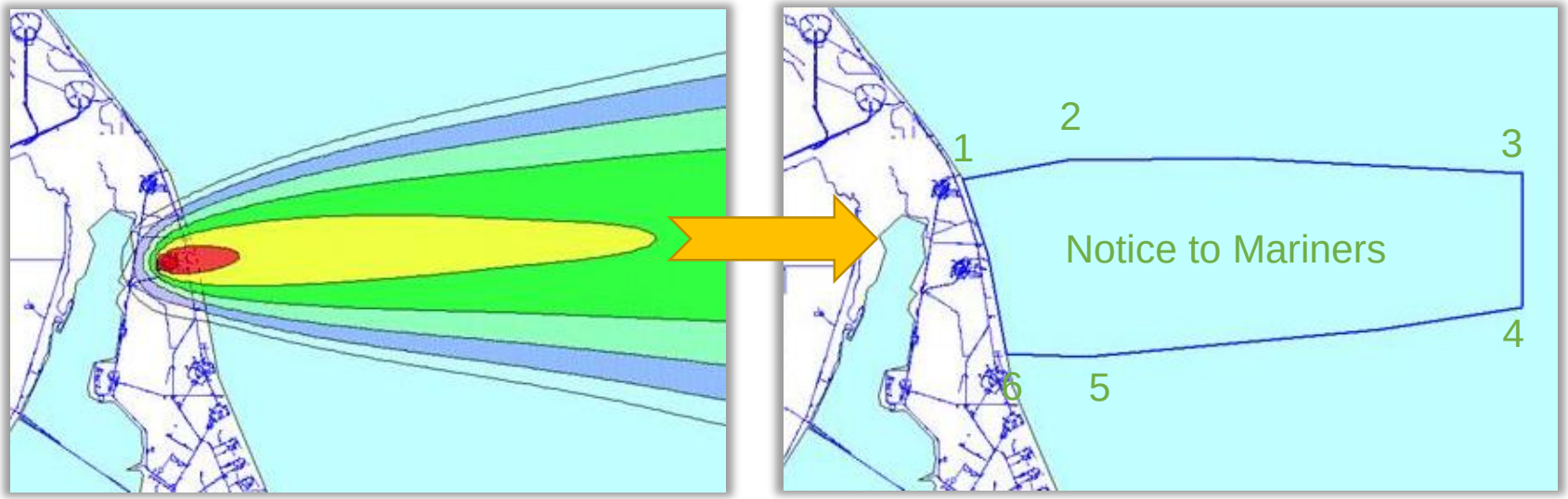
Chapter 13 - Hazard Areas

- Purpose of hazard areas
- Regions: Land, Water, Airspace
- Types: Warning, Exclusion
- Calculation: Grids & Contours

FAA is considering expanding hazard area development guidance in an additional AC



Chapter 13 - Hazard Areas

Comment: Clarify that aircraft hazard analysis within US airspace may be performed by FAA.

Response:

AST does not plan to perform the aircraft hazard area analysis. This is an operator function, per part 450.133. Operators often contract with the Federal site operator to accomplish this. AST may validate results, but does not in general perform or duplicate applicant analyses.

Chapter 13 – Hazard Areas

There were no comments submitted.

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Chapter 14 – Application Requirements

- Currently overlaps with other in development ACs
  - Likely to be revised as other ACs are published.
- Key unique elements to this AC:
  - Debris list development
  - Propagation methodology
  - Consequence analysis
  - Risk results

Key takeaways:

- A license may cover multiple launches and launch locations
- Applicant should submit description of
  - the analysis process used for all operations
  - representative results for one operation
- **Per operation** requirements are specified in § 450.213 Pre-flight reporting.

Chapter 14 – Application Requirements

There were no comments submitted.

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Part 450 Advisory Circular Process

- Develop Advisory Circular
- AST management review, Common Standards Working Group (CSWG) review, legal review
- Office of the Secretary of Transportation and Office of Management and Budget review, if significant
- Publish as draft with a 30 day comment period
- Receive comments and hold industry workshop
- Update based on comments
- AST, CSWG, and legal review
- Publish as final (Note: ACs are open for comment indefinitely and can be updated as needed.)

Part 450 Advisory Circular Releases

Published with part 450:

- AC 450.115-1 High Fidelity Flight Safety Analysis
- AC 450.101-1 High Consequence Event Protection
- AC 450.141-1 Computing Systems and Software

Released approximate to Effective Date:

- AC 450.108-1 Flight Abort Rule Development
- AC 450.107-1 Hazard Control Strategy Determination
- AC 450.143-1 Safety Critical Systems

Part 450 Advisory Circular Releases

Released near to Transition Period (90 days after effective date):

- AC 450.173-1 Mishap Reporting, Response, and Investigation
- AC 450.103-1 System Safety Program
- AC 450.109-1 Flight Hazard Analysis
- AC 450.117-1 Normal Trajectory Analysis
- AC 450.161-1 Control of Hazard Areas
- AC 413.5-1 Pre-Application Consultation

Part 450 Advisory Circular Releases

Released near end of Fiscal Year 2021:

- AC 450.137-1 Distance Focusing Overpressure Risk Analysis
- AC 450.139-1 Toxic Hazards Analysis and Thresholds
- AC 450.167-1 Tracking
- AC 450.169-1 Collision Avoidance Analysis
- AC 450.179-1 Ground Safety
- AC 450.141-2 Mission Data Loads (MDL)
- AC 450.113-1 Flight Safety Analysis: Levels of Rigor
- AC 450.XXX Hybrid Launch Systems
- AC 450-119-1 High-Fidelity Malfunction Trajectory Analysis

Part 450 Advisory Circular Releases

Released near end of Fiscal Year 2021 (Cont.):

- AC 450.110-1 Physical Containment Flight Safety Analysis (Low Fidelity)
- AC 450.131-1 Probability of Failure
- AC 450.123-1 Population Exposure
- AC 450.115-2 Medium Fidelity Flight Safety Analysis

Questions/Discussion

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