THE FAA'S APPROACH TO QUALITY ASSURANCE IN THE FLIGHT SAFETY ANALYSIS OF LAUNCH AND REENTRY VEHICLES

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ABSTRACT

The U.S. Federal Aviation Administration (FAA) Office of Commercial Space Transportation's safety mission is to ensure protection of the public, property, and the national security and foreign policy interests of the United States during commercial launch and reentry activities. As part of this mission, the FAA issues licenses to the operators of launch and reentry vehicles who successfully demonstrate compliance with FAA regulations. To meet these regulations, vehicle operators submit an application that contains, among other things, flight safety analyses of their proposed missions. In the process of evaluating these submitted analyses, the FAA often conducts its own independent analyses, using input data from the submitted license application. These analyses are conducted according to approved procedures using industry developed tools. To assist in achieving the highest levels of quality in these independent analyses, the FAA has developed a quality assurance program that consists of multiple levels of review. These reviews rely on the work of multiple teams, as well as additional, independently-performed work of support contractors. This paper describes the FAA's quality assurance process for flight safety analyses. Members of the commercial space industry may find that elements of this process can be easily applied to their own analyses, improving the quality of the material they submit to the FAA in their license applications.

1. INTRODUCTION

The FAA Office of Commercial Space Transportation (AST) provides safety oversight to the Commercial Space Transportation industry through its issuance of licenses, experimental permits, and safety approvals to applicants meeting the requirements of Title 14 Code of Federal Regulations part 400. Under these requirements, the prospective operators of launch and reentry vehicles and launch and reentry sites must demonstrate that risks posed to the public by the proposed operations do not exceed acceptable limits. In the licensing regime, this demonstration generally takes the form of quantitative risk analyses, also known as flight safety analyses, which compute the collective risk to the public and the risk to an individual member of the public.

During its license application evaluation process, AST determines whether or not the submitted analyses constitute sufficient demonstrations of acceptable risk. To aid in this determination, AST often conducts its own analyses, using input data describing the vehicle and the proposed operation provided in the license application. Given the use of common inputs, the applicant's submitted analyses and AST's analyses are otherwise intentionally independent, in that AST generally employs different tools than those used by its applicants and that AST identifies and applies analytical assumptions and methods without regard for those used by the applicant.

The results of AST's independent analyses, when compared with those computed by the applicant and other parties, serve to improve the characterization of the risks to the public posed by the proposed operation. Resulting risk values and the values of key intermediate parameters, such as the probability of a vehicle failure at a particular location or time or the probability of an impact within a particular area, can be compared directly. These comparisons provide AST with confidence in the applicant's use of mathematics, data, and analytical assumptions. They also serve to identify the influence of the various analytical assumptions and methods used, calling attention to those with the largest effect on public safety.

For this process to be most effective, AST's analyses must be conducted according to standardized procedures and be subject to rigorous quality assurance standards. This paper describes those procedures and the quality program that supports them.

2. OVERVIEW OF AST'S INDEPENDENT ANALYSIS APPROACH

The responsibility for conducting these independent analyses falls on members of the AST Tools and Analysis Program. This Program has developed a standardized process for the conduct and review of its analytical work. This process has been established to meet three primary goals:

- To instil an additional level of consistency and quality assurance in AST's analytical work,

- To provide a standard mechanism through which to achieve Tools and Analysis Program concurrence on analytical approaches, products, and results, and
- To facilitate additional training opportunities by review.

The content of the analysis and quality assurance process described in this paper was based on the inputs and collective experience of members of the AST Tools and Analysis Program. It focuses on the use of "best practices" to solve analytical problems and the need to appropriately identify, support, and obtain team concurrence on the use of the analytical assumptions employed. The process is flexible enough to accommodate all of the projects within its scope of application, conducted on any timeline. This scope includes:

- Flight safety analyses,
- Explosive safety analyses,
- Maximum probable loss determinations, and
- Analyses and research conducted in support of the work that lies within this scope.

2.1. Use of Best Practices

All AST analyses are performed according to approved, documented procedures. These procedures represent "best practices," where they exist. Best practices are those practices based on the collective experience of the safety community. These include analytical methods and approaches documented in safety standards, guides and handbooks, including those of the Range Commanders Council and the Common Standards Working Group (composed of representatives of the FAA, NASA, and the U.S. Air Force), peer reviewed journals, and those of other U.S. government agencies

Best practices also represent those practices identified and employed in the independent review of AST's work conducted by qualified external parties. AST routinely calls upon its safety partners and qualified contracted resources to independently conduct analyses and to review AST analyses in a number of circumstances, including:

- First time use of a particular method or tool,
- First time analysis of a particular vehicle or vehicle configuration,
- First time analysis of a mission profile that potentially results in a significant increase in risk compared to previous analyses of the same vehicle along different profiles (e.g. a change in launch inclination that results in a significant increase in population over-flight), and
- Analyses pertaining to spectator events.

Once identified, best practices are documented in detailed AST internal procedures. Once AST gains sufficient experience in using these procedures, the procedures are included in guides for use by the commercial space transportation industry and published on AST's web site.

In the absence of best practices, alternate analytical means are employed. Situations in which this becomes necessary include those in which sufficient data does not exist with which to employ a best practice. For example, a best practice for determining the total probability of failure for a launch vehicle may require a tally of the successes and failures of that vehicle on previous launch attempts or a tally representing the outcomes of launch attempts of a similar vehicle. However, if the vehicle being analyzed has never flown before and it cannot be characterized as similar to any other previously launched vehicles, another method for determining its probability of failure must be identified and used. In situations such as these, an alternate method must be employed that accounts for the outcome of all previous launches of vehicles developed and launched in similar circumstances.

2.2. Use of Multiple Tools and Teams

Where available, AST strives to employ multiple tools and teams to perform independent analyses. Applying more than one tool to a particular problem provides several benefits. First, where the tools utilize common methods, the intermediate and final results can be checked against each other for potential errors. In areas where the tools use different methods, analysts can more readily identify elements of the analyses to which the results are most sensitive. In the future, AST intends to use multiple tools to assist in the characterization of model uncertainty.

Analysts choose a primary safety tool for an analysis task from among the available heritage safety tools. Heritage safety tools are those tools used as primary or secondary tools by other safety organizations. These tools have been successfully and rigorously tested against other available tools. Secondary tools for use in an analysis are either alternate heritage tools or tools developed within AST.

Multiple teams internal to AST, as well as safety contractor teams hired by AST, are often used for first time analyses and analyses pertaining to spectator events, as discussed previously. AST strives to keep a degree of independence between multiple teams as a means to ensure that raw input data are converted into high quality and useful inputs and that a variety of analytical assumptions and methods are considered for application in areas where best practices may not exist.

AST's use of multiple teams assists in the characterization of model input data uncertainty and the associated uncertainty in the results. The use of both

multiple tools and multiple teams provides additional scrutiny to the inputs used, helping to identify potential errors and to ensure consistency of the inputs with the assumptions used in the analysis..

2.3. Use of Trained Analysts

Analysts in AST's Tools and Analysis Program receive classroom training on analysis theory as well as hands-on training on specific tools. Prior to leading an analysis effort, analysts receive on-the-job training in analytical skills as members of an analysis team.

3. THE PEER REVIEW PROCESS

The process begins with a planning meeting, extends through the analysis work itself, and culminates in the documentation and presentation of the methods used and the pertinent findings. Each of these steps is described in detail below.

3.1. Planning Meetings

Prior to initiating an analysis, the Analysis Team holds a Planning Meeting. The purposes of the Planning Meeting are to:

- Identify the available resources,
- Identify potential constraints (deadlines for the receipt of data, training needs, tool acquisitions, contractor support, etc.),
- Introduce the task to the Tools and Analysis Program at large and develop concurrence on the Preliminary Strategy, and
- Identify the individuals who will serve on the Peer Review Panel.

The Preliminary Strategy defines the plan for the accomplishment of the analysis task. The scope and level of detail of the Preliminary Strategy varies based on its complexity. However, at a minimum the strategy should look to identify the top-level approaches and desired level of fidelity of the analysis, as well as the potential tools to be applied. The basic steps in the analysis task should be covered as well, including the planned steps to accomplish input data verification, the potential risk analysis assumptions and supporting rationale, and the potential sensitivities to be examined.

The Analysis Team identifies more detailed assumptions regarding the task as the analysis progresses. The application of these assumptions is left to the discretion of the Lead Analyst. As the individual responsible for the successful and timely completion of the task at hand, the Lead Analyst is knowledgeable of documented procedures, prior approaches, and best practices. Where best practices do not exist, the Lead Analyst seeks the advice of members of the Tools and Analysis Program and associated subject matter experts. Informal intermediate reviews are helpful in these situations, to obtain preliminary concurrence from the Peer Review Panel.

Members of a Peer Review Panel are identified from among the attendees of the Planning Meeting. While the Analysis Team's analytical products are made available for review by anyone in AST, members of this Panel volunteer their time to perform the official review, in the capacity described below. The Peer Review Panel membership is separate from the Analysis Team, and includes multiple members of the Tools and Analysis Program and appropriate subject matter experts, and at least one other person not involved in the licensing effort.

The Analysis Team takes detailed minutes of the Planning Meeting. These notes include the Preliminary Strategy and the names of the Peer Review Panellists. All concerns and issues are recorded in these minutes and addressed in subsequent meetings or the revised report.

3.2. Analysis

The analytical approach applied to a given task is a function of the available input data, the time with which to complete the work, and the desired level of fidelity.

At the outset of an analysis, the origin of all input data is identified and documented. Supporting analyses and reports from which data has been extracted are also reviewed. Assumptions contained in these analyses and reports that are used to generate this data are checked to ensure that they agree with the assumptions used in the document in which they are cited.

Likewise, tools used to produce data for input to an analysis are identified and documented. Limitations of these tools are identified and accounted for in the use of the data.

All input data, regardless of its origin, must be verified for consistency and reasonableness. Inconsistent data does not agree with the assumptions with which it was produced or the assumptions by which it is being applied. Reasonable data agree with the physics of the problem being analyzed.

The Analysis Team may need to conduct supporting analyses to assist in the verification of input data. Often, a simple plot of key variables, such as weight, thrust, or velocity versus time, may yield potential discrepancies in supplied data sets. However, more sophisticated analyses may be required. For example, the Analysis Team may use vehicle characteristics and mission constraints to independently generate trajectory or other data that can be compared against data provided by an applicant.

The level of fidelity of the analysis may vary from low to high based on a number of factors. For example, rough estimate or "screening" analyses are often employed when sufficient time, data, or tools with which to conduct more extensive analysis are unavailable. Although care should be taken to handle the results of such analyses in this context, it is possible to demonstrate acceptable risk on the basis of a rough estimate analysis. 14 CFR Part 400 and its subparts require an applicant to submit a demonstration of acceptable risk, not a computation of precise risk values. Accordingly, the Tools and Analysis Program's acceptance of an independent analysis is based on the same standard. If the simplifying assumptions used in a rough estimate analysis demonstrate sound engineering judgment and are sufficiently conservative such that the results provide a clear and convincing demonstration that the risk is below the allowable threshold, a higher-fidelity analysis may not be necessary.

Even in circumstances where a lower-fidelity analysis is capable of demonstrating acceptable risk, the Tools and Analysis Program advocates the use of multiple analyses of increasing levels of fidelity, ideally undertaken using multiple tools, whenever time and other constraints allow. Regardless of the conservative or simplifying nature of the assumptions used, some degree of uncertainty in the results always exists. Multiple analyses using different methodologies and assumptions, used in concert with sensitivity and parametric studies, can provide further insight to help characterize this uncertainty.

3.3. Analysis Report

Every AST independent analysis used in support of a licensing or permitting evaluation is documented. This documentation focuses on the verification of the input data used, the application of the analytical assumptions used, the rationale cited for the use of these assumptions, and the sensitivity of results to variations in these assumptions.

To that end, the documentation strives to address all four elements of the Transparency, Clarity, Consistency, and Reasonableness Model of risk characterization used by the U.S. Environmental Protection Agency in its Risk Characterization Policy, described below:

- Transparency provides explicitness in the analysis process. It ensures that any reader understands all the steps, logic, key assumptions, limitations, and decisions in the analysis, and comprehends the supporting rationale that lead to the outcome.
- Clarity refers to the analysis product. Making the product clear makes the analysis free from obscurity and easy to understand by all readers inside and outside of the analysis process.
- Consistency provides a context for the reader and refers to the presentation of the material in the analysis. For example, are the conclusions of the analysis characterized in harmony with relevant policy, procedural guidance, and scientific rationales? If not, why do the conclusions differ? Also, does the analysis follow precedent with other related actions or why not? However, consistency should not encourage blindly following the current analytical guidance at the expense of stifling innovation.
- Reasonableness refers to the findings of the analysis in the context of the state-of-the science, the default assumptions, and the science policy choices made. It demonstrates that the analysis process followed an acceptable, overt logic path and retained common sense in applying relevant guidance. The analysis should be based on sound judgment.

3.4. Final Review

A Final Review is required of all tasks within the scope of this process. The Final Review is the forum through which the Analysis Team presents its accomplishments to the Peer Review Panel. The basis for a Panel's acceptance of the results of an analysis lies in the Analysis Team's subsequent successful resolution of all significant issues raised by or to the Panel prior to or at the Final Review. Accordingly, during the Final Review, a member of the Analysis Team records all action items for tracking toward resolution.

Prior to the meeting, the Peer Review Panel reviews all of the products associated with the analysis task. This includes the Analysis Report, as well as the input and output data sets of intermediate, supporting, and final analyses.

All members of the Peer Review Panel are present at the Final Review. Other invitees for the Final Review include members of the Analysis Team and the Tools and Analysis Program, as well as any additional personnel with an involvement or interest in the task, including subject matter experts and leads of other AST teams and programs.

During the review, the Analysis Team makes a formal presentation of all the work it has conducted. This presentation summarizes the contents of the Analysis Report. It revisits the Preliminary Strategy, noting any changes that were made during the analysis, summarizes the analysis methods and key findings, and provides any additional material required to give the necessary context to those findings.

After the Final Review is complete, the Peer Review Panel approves the resolution of all action items. The

Analysis Team assembles a tracking matrix from the notes of the Final Review meeting. This matrix is provided to all members of the Peer Review Panel and the Tools and Analysis Program Lead. In addition to relevant information regarding the task and lists of the Analysis Team members and Panellists, this matrix contains a listing of all issues raised, even those resolved at the meeting. All Peer Review Panel members initial each item listed in the matrix in the appropriate column as the corresponding issue is resolved. Resolution may include updates to the report document. Once all issues have been resolved to the satisfaction of the Peer Review Panel, the Analysis Team, Peer Review Panel members, and Tools and Analysis Program Lead sign the matrix, denoting the completion of the task.

3.5. Standards of Review

When developing the analytical approach, the Analysis Team should be conscious of the criteria by which the resulting analysis will be deemed acceptable. Namely, that:

- All results shall be supported by analysis, and
- All of the assumptions employed shall be clearly identified, applied consistently, and supported appropriately.

Unsupported or inadequately supported results are not acceptable. Likewise, unsupported or inadequately supported assumptions are also not acceptable. Acceptable rationale for the application of an analytical assumption includes one or more of the following:

- Similarities with historical data or trends,
- The results of supporting analyses or previous studies,
- Expert opinion, including externally developed approaches published in accredited papers or journals, as well as the application of current practices of respected external entities, including other government agencies and domestic and international technical organizations or societies, and
- Sound engineering judgment.

Engineering judgment is considered sound when it is supported by analyses that gauge the sensitivity of the results to variations in the assumptions used. Sensitivity analyses are also conducted and documented for input parameters exhibiting a relatively large amount of uncertainty in their value.

4. MANAGEMENT REVIEW

Upon its successful completion of the Peer Review process, the Analysis Team presents a summary of its analyses and results to an AST Management Review Board. Prior to the presentation, the Board receives and reviews all of the evaluation documentation, including the Analysis Team's report of AST's flight safety analysis efforts.

The Management Board is composed of all of the AST frontline and executive managers. Typically, the Management Review covers the entire evaluation of a license or permit application. In that regard, the flight safety analyses are just one element of the review, and they are presented at an executive summary level, focusing on the results and key findings. The evaluation of the applicant's analyses and any analyses performed by a third party, such as contracted resource, are also presented.

Action items are tracked at this level, and worked to resolution in advance of the evaluation determination. Actions involving AST's flight safety analyses are assigned to the Analysis Team. These actions may include the application of an alternate assumption to one that was used in the original analysis or the conduct of additional sensitivity studies. The Peer Review Panel reviews any additional work produced as a result of these actions, prior to reporting them back to the Management Review Board. Once all action resolutions have been accepted by the Management Review Board, the analysis processes, and its supporting series of reviews, are complete.

5. CONCLUSION

Independent analyses play an important role in the license and permit evaluation process, providing AST with a verification of an applicant's analysis, as well as additional insight into potential uncertainties and the aspects of a proposed operation that contribute the most to the overall risk. Based on the importance of this role, AST has established a quality assurance program consisting of multiple levels of review to ensure that its analyses are conducted using approved processes and tools and appropriate data. Elements of this process are easily transferable to other organizations performing such analyses, including members of the Commercial Space Transportation industry.