Analytical Methods in Aerospace Applications

Decision Making

Presented to: FAA M&S Workshop

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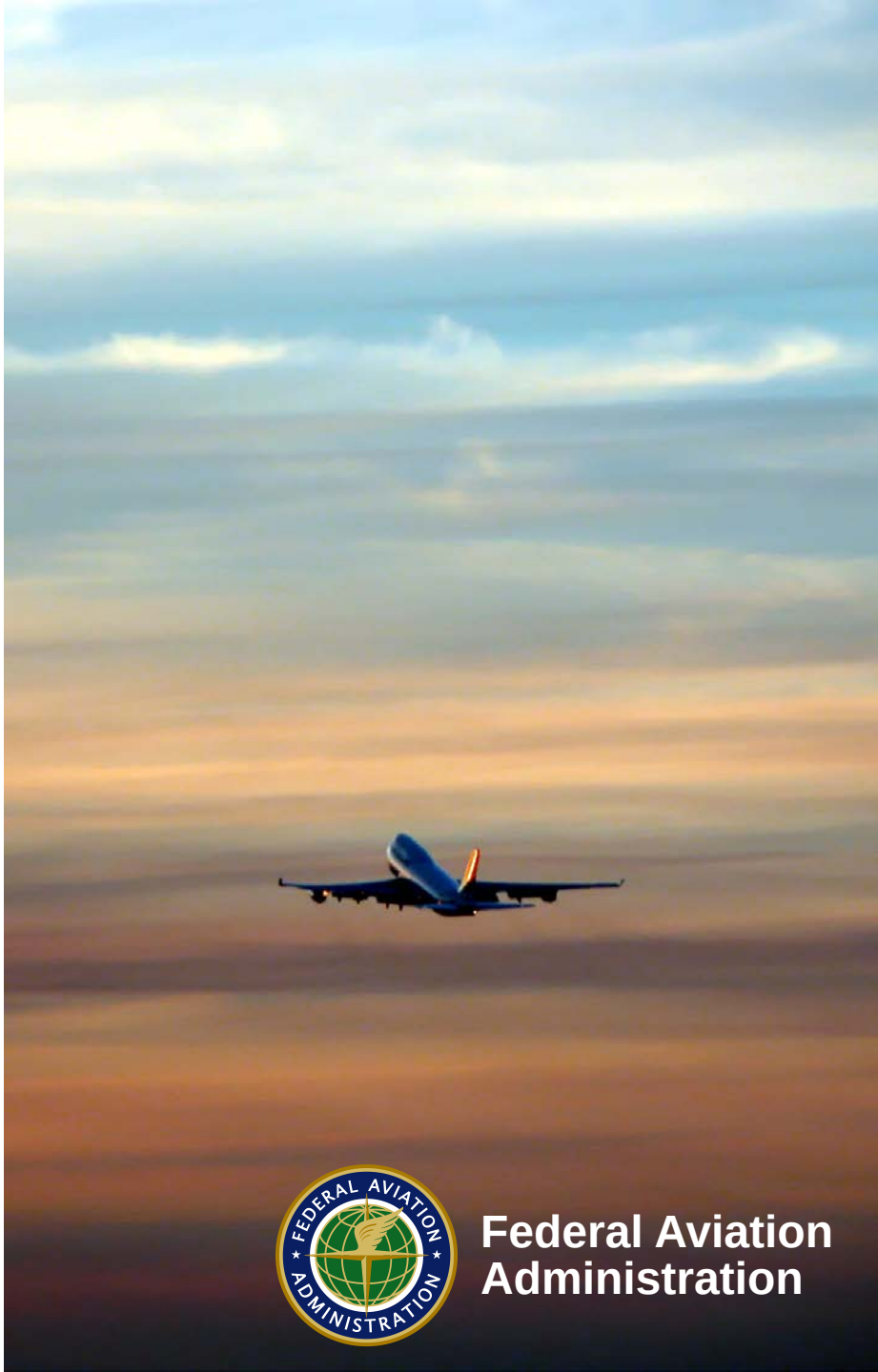
Date: August 2019



Background

- **Will use lots of regulatory references and acronyms!**
  - Derived mainly from Transport Airplanes
- **Seats will be discussed – as an example**
- **Methods are generally applicable**
  - Birdstrike
  - Engine related impact failure
  - Other parts for which dynamic analysis may be used
- **Developed guidance material**
  - Have been used in other areas

Outline

- Certification process
- Certification by analysis
- Questions
- Conservatism
- FAA activity

Certification of Aircraft Articles

- **How do you certify an article?**
  - Demonstrate compliance with the applicable regulations
  - Sometimes in a single step and can be part of certification at aircraft level
  - Oftentimes, articles approved to an industry standard, then compliance to the applicable regulation is later demonstrated
    - Technical Standard Order (TSO)
  - Generally compliance through physical testing!

Who Makes the Certification Decision?

- **Applicants**
  - Stating that they have met the requirements
- **Engineers within directorates**
  - Authors of the policies
- **Engineers within Aircraft Certification Offices (ACOs)**
  - Ultimately sign the approval

What is a TSO?

- **A Technical Standard Order (TSO) is a Minimum Performance Standard, defined by the FAA, used to evaluate an article.**
  - An article can be a material, part, component, process, or appliance.
  - Each TSO covers a certain type of article.
- **When authorized to manufacture an article to a TSO standard, this is referred to as a "TSO Authorization." Receiving a TSO Authorization is both a design and production approval.**

What is a TSO?

- **Receiving a TSO Authorization is not an approval to install and use the article in the aircraft. It means that the article meets the specific TSO and the applicant is authorized to manufacture it.**

Compliance with TSO

- **21.616 *Responsibility of holder***
  - *(c)* ***Ensure that each manufactured article*** *conforms to its approved design, is in a condition for safe operation, and* ***meets the applicable TSO***
  - If TSO specifies a specific substantiation method, applicant **must** use that specified method unless approval is obtained for a deviation per 21.618
    - Must show article maintains an equivalent level of safety using this alternate method

TSO Holder

- **Responsible for all it’s suppliers**
  - Ensure they have a quality management system
  - Must use tools that meet the requirements of this system
  - Maintain documentation in the event of any audits
  - Applicable to M&S and not just the analysts, but the tools that they use as well!

Compliance with TSO (cont'd)

- **If TSO states testing *OR* analysis, applicant can use analytical modeling without a deviation**
- **AC 20-146A provides guidance for seats on:**
  - How to validate the computer model
  - Under what conditions the model may be used in support of TSO authorization and design changes
  - If proposing to model vs. test, supply data proving model represents testing conditions/environment
- **FAA considering development of general M&S guidance**

Example – Emergency Evacuation Slides, Ramps, Ramp/Slides, and Slide/Rafts

- **TSO-C69**
  - "The device must be demonstrated by tests or analysis, or a combination of both, to be seaworthy in an open sea condition with maximum sustained winds of 17 to 27 knots and waves of 6 to 10 feet… If analysis is used, the analysis must be approved by the manager of the FAA office having purview of the manufacturer's facilities…"
- **Deviation not required**
- **Analysis needs to be approved by FAA**
  - M&S is an acceptable analysis method

Example – Seats

- **TSO-C127b requirement – SAE AS 8049 Para 5.**
  - *"Initial qualification of a seat shall be performed by static and dynamic tests. Subsequent qualifications related to design changes to seats of a similar design may be performed by rational analysis based on existing qualification test data."*
- **Using M&S for initial qualification would require a deviation**
- **M&S can be beneficial to assist in:**
  - Identifying critical case test scenarios
  - Evaluating minor changes to a tested configuration

Identification of Critical Test Cases - Seats

- **M&S allowed**
  - TSO new design
  - TSO major change
  - TSO minor change
- **Determination of worst-case scenario for a seat design**
- **Determination of worst-case scenario for a seat installation**
- **Determination of occupant strike envelope**
- **Evaluating minor changes to a tested configuration**

Substantiation of Minimum Performance Standards - Seats

- **M&S allowed**
  - TSO minor change
- **Deviation required for initial seat qualification**
  - With FAA involvement
  - Perform Static and Dynamic testing for baseline seat
  - Recommend building your test / model libraries (including failures), integrate into your design and development procedures, and validate your models to receive the full benefit of M & S

Certification by Analysis

- **The FAA approves the data, not the analytical technique**
- **The FAA holds no list of acceptable analyses, approved computer codes, or standard formulas**
  - Use of a well established analysis technique is not enough to guarantee the validity of the result
  - The applicant must show the data are valid
  - The FAA or our designees must find the data accurate and applicable, and that the analysis does not violate the assumptions of the problem

(Refer to FAA Order 8110.4C Type Certification, Paragraph 2-6g)

FAA Initiative to Promote Analytical Modeling in Seat Certification

- **Congressional mandate to evaluate streamlining certification**
  - HR 1000 Section 757
- **Ultimate Goals**
  - Reduce cost and improve safety through more thorough design and qualification
  - Develop broader understanding and acceptance of modeling internal to FAA
  - Update FAA policies accordingly

Questions from Analyst for V&V

- **Code and calculation verification**
- **Mesh quality**
- **Sensitivity**
- **Testing uncertainty**
- **Comparator metrics**

Code Verification

- **TSO holder is responsible for ensuring that their supplier provides a quality product**
- **Applicant is responsible for ensuring that they have access to the QA procedures, etc., to determine if the product meets the applicant's quality process**
- **The applicant defines their process then verifies they meet it, i.e. they decide what level of code verification is necessary**

Decision Making

- **How much V&V does the decision maker need to know**
- **What details about the model does the decision maker need**
- **How is credibility assessed (credibility separate just the accuracy of the model)**
- **Decision making based on M&S results, etc..**

Aircraft Certification Office

- **Certification decisions are made by Aircraft Certification Office (ACO) engineers**
  - Experts on regulations, policy, orders, etc.
  - Typically have a structural qualification
    - e.g. mechanical or aerospace engineering background
  - Typically not a modeler
- **In a typical (physical) certification test, an FAA witness can inspect the physical test article and observe the test**
- **In certification by analysis, the ACO must rely solely on the Validation and Analysis Report to make a decision**
  - Documentation must stand-in for the ability to view a physical seat
- **Ability to use FAA subject matter experts to assist in the decision-making process**

Questions from ACO

- **Assume applicant followed quality procedure**
- **Source of data**
  - Material characterizations
  - Standard or in-house test methods
  - ACOs understand material allowables and factors of safety
- **Model assumptions and limitations**
- **“Sniff” test**
- **Conservative models encouraged!**

Quality Procedure

- **The user/applicant should have a developed quality procedure for which they follow**
- **Describes**
  - Verification and Validation
  - Quality control
  - Acceptability
  - Document process
- **May contain many details, the decision maker is interested to know that you have a quality procedure and that you follow it!**

Quality Procedure

- **The procedure will describe your pass/fail criteria**
- **The decision maker will then determine acceptability based upon the guidelines that are set and agreed upon**
- **If you don’t meet your own guidelines, don’t expect someone else to!**

How does V&V help the ACO

- **ACOs require more information to be comfortable**
  - Consult with subject matter experts
- **They want to see**
  - Compliance with regulatory requirements
  - Factor of safety
  - Confidence
- **Becomes part of the quality procedure**

Conservatism

- **What is a conservative model?**
  - One that includes an overload factor?
  - One that always overpredicts a response?
- **"Conservative simulation results are encouraged, but not required. In the context of simulation, conservatism relates to the model over predicting a particular response or under predicting a particular strength…"**
- **Not always straightforward, think at the system level**

General Validation Criteria Guidance

- **Validate against dynamic tests**
- **Validation and model use conditions should be similar**
- **Consider accuracy of test data**
- **Applicant and ACO should agree on application specific validation – prior to program initiation**

Conservatism Example

- **Regulatory requirement of HIC < 1000**
- **To account for testing uncertainty**
  - Assumed variance of ± 200 units
  - 95% confidence of meeting regulation if test HIC is ≤ 890
- **Only original designs with test response ≤ 890 eligible**
- **Model should be within 100 units**
- **Encourage conservative models**

Conservative Example– Model Use Limits

- For modified configuration/installation, only model predictions ≤ 890 eligible
- Extrapolation limit a function of the degree of conservatism seen in Validation
- For model that under-predicts the test result, the predicted HIC must not exceed 890 minus the magnitude of the under-prediction.

	Validation	Model Use
Model under predicts	Test = 850, Model = 800	Model = 840 or less
Model over predicts	Test = 850, Model = 900	Model = 890 or less

Test Data

- **The utility of comparator data for validating the simulation results can be affected by several factors, including the precision, accuracy, repeatability, and reproducibility of the measurement system, and the extent to which the test conditions and test articles have been characterized**
- **Source of test data**
  - Industry methods, ASTM
  - In-house methods

Validation Testing

- Typical certification testing is deterministic
- Validation of the model requires precision testing
- Component level and full system level
- Additional measurements, both pre-test and time histories, are typically required
- Test design should be coordinated with the modeling group

Limitations

- **“Regardless of what we might think and say…**

  M&S can’t do it all”

- **Bound the use for the model**
- **Once the limitations are identified, will need to identify Alternative Means of Compliance for those items**

Other Considerations

- **Total cost includes model development (including physical tests), V&V, and documentation**
- **V&V (documentation) is about demonstrating, not simply claiming, credibility**
- **Model fidelity vs accuracy vs credibility**
  - Valid for one use doesn't necessarily mean valid for a different use
- **Verification of model inputs and outputs**
  - User entered values

Challenges

- Expanded use of complex (including explicit codes) finite element models for certification compliance
- Flow down of requirements from compliance finders to analysts
- Need to build experience base of compliance finders
- Need more communication between FAA and applicant
- FAA and applicant expectations
- Standardization

FAA Activity

- **Internal and external webinars to review certification requirements and compliance**
- **FAA (designee and internal) training**
  - Bird strike certification for external modifications (new, available)
  - Finite element analysis for certification compliance (in work)
- **Workshops – Such as this one**

Resources

- AC 20-146A [rgl.faa.gov]
- SAE ARP 5765A [standards.sae.org/arp5765]
- ASME V&V 10 [asme.org/products/codes-standards/v-v-10-2006-guide-verification-validation]
- LS-Dyna Aerospace Working Group [awg.lstc.com]
- Joseph Pellettiere [joseph.pellettiere@faa.gov]
- David Moorcroft [david.moorcroft@faa.gov]

Conclusions

- **With proper planning and coordination, analytical methods can be inserted in the certification process**
- **Seats discussed as an example of how this methodology was applied**

Questions?