Use of Structural Dynamic Analysis with 33.94 Compliance Policy

Presented to: Certification by Analysis
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What does 33.94 Blade containment and rotor unbalance tests require?

“it must be **demonstrated by engine tests** that the engine is capable of containing damage without catching fire and without failure of its mounting attachments when operated for at least 15 seconds, …….

(1) Failure of the most critical compressor or fan blade while operating at maximum permissible r.p.m. ………”

When has analysis been used with 33.94 compliance?

- Post 33.94 certification test to fix test shortfalls
- With major and minor design changes in the same engine model:
  - Mount changes
  - Accessory changes
  - Casing, rotor, or plumbing changes
- With derivative engine models (amended TC's):
  - Modified containment
  - New fan section

What is Considered Analysis?

- Analysis takes on many forms:
  - Comparative analysis when compliance is shown by comparison to similar designs
  - Simple hand calculations
  - Standard linear FEA modeling
  - Complex non-linear static or dynamic modeling
  - Comparison to component testing
  - Complex non-linear analysis such as LS-DYNA

Background Examples

- In the past for engines with smaller fans a new test was not often required for top to side engine mount changes.
- Post test re-design often acceptable without re-test.
- There are numerous examples of pre- and post-certification engine changes that did not require a full 33.94 blade out test.

External Pressure to Use Analysis vs Test

- EASA CS-E 810 permits analysis.
- Improvements in dynamic modeling methods.
- Engine Manufacturers are building tool kits of validated methods to show compliance.
- Engine Manufacturers requesting to use analysis.

EASA CS-E 810 Compressor and Turbine Blade Failure

- CS-E 810 is the equivalent EASA blade failure rule.
- EASA rule permits compliance by:
  - Engine Test
  - Similarity to other engines
  - Other acceptable means

FAA Policy Developed for Analysis Use

- The policy provides FAA engineers with a structured method to use with an applicant when analysis is proposed.
- Limitations:
  - Analysis is only permitted for a derivative engine from a baseline engine that has undergone 33.94 certification testing.
  - Analysis use is permitted on a case by case basis.
  - Analysis methods must be validated.
    - Validation should be tied to the parent engine FBO certification test, other relevant experience can support validation demonstration

Policy Memo Outline

- The policy presents a structured approach with information in each of the sections:
  - General
  - Certification Plan
  - Engine Modeling and Analysis Methods
  - Engine Model Validation
  - Loads and Component Capability Evaluation
  - Mount Evaluation
  - Fire Evaluation
  - Blade Loss and Containment Evaluation
  - Static Structure

General Section Content

- Outlines FAA and applicant coordination
- This involves:
  - Determining feasibility of analysis use
  - Determine if a rule modification is needed by; Equivalent Level of Safety (ELOS), Exemption, or Special Conditions.
  - ELOS would most likely be applied to;
    - Wing to side mount changes
    - Substantial fan modification
    - Substantial containment modification

Engine Modeling & Analysis Methods

- An engine structural model typically includes a combination of analysis methods, test results, and empirical data.
- Typical model elements:
  - Empirical fan rundown rate based on engine and rig test results
  - Engine dynamic FEA model for deflections and loads
  - Detailed FEA models for component stresses
- The engine model is an auditable combination of analysis, test, and empirical procedures, which must be reviewed with and accepted by the FAA.

Analysis methods used for compliance

Comparative analysis (Example: Simple comparison)

- Identical hardware or features
- Well characterized success or failure criteria
- Equivalent or lower loads

Analysis methods used for compliance (cont.)

- Conventional analysis (Example: Simple stress analysis to basic NASTRAN)
  - Identical or similar hardware or features.
  - Well characterized success or failure criteria.
  - Loads and margins that are close to the baseline.
  - Standard engineering analysis; textbook approach, empirically based design practice, conventional finite element model.
  - Model methods follow applicant company practices (traceable to company practice validation documents).

Analysis methods used for compliance (cont.)

- Correlated analysis (Example: Validated LS-Dyna analysis)
  - Differences in hardware or features, loads and margins.
  - Well characterized success or failure criteria.
  - Complex or non-linear analysis; Analytical model should correlate to an engine or component test, Analysis methods in this category include complex FEA, non-linear FEA, buckling analysis, etc.

Analysis methods used for compliance (cont.)

- Certification component test (Example: Blade out rig test)
  - Significant differences in hardware or features.
  - Loads and margins and the complexity of the behavior results in a situation where the analytical prediction of success or failure cannot be made with high confidence.
  - Applicant should submit a test plan.

Correlated Analysis Example

- Component on derivative engine is unique so the baseline 33.94 test is insufficient to substantiate compliance.
- Component is a complex structure modeled with NASTRAN. The model complexity requires validation.
- NASTRAN model is validated with correlation to a test that simulates the 33.94 blade out loads using the component in question.
- The test may or may not be a certification test. It is a model validation test.
- Compliance is shown by Correlated Analysis.

Engine Model Validation

- The applicant must show that the engine model predicts outcomes.
- Validation is established by Pre-test predictions and post test comparisons.
  - Differences are expected but must be shown to have little or no effect on compliance.
  - When differences exist a sensitivity study may be needed.
- Post test calculations are not sufficient for validations.
- Post test model refinement is expected and encouraged. Refinements should be based on physics, not tweaks to give better answers.

Engine Mount Evaluation

- Focus on the loads imposed on, or transferred to the mounts and the vibratory response of the engine.
- Show that proposed changes to the engine do not significantly modify mount loads.
- Mount loads and load distributions that are significantly higher than the baseline engine test results generally indicate the new configuration cannot be reconciled to the baseline engine test.

Fire Evaluation

Fire evaluation is often an analysis of all fluid carrying components, tubes, hoses, and fitting

- Legacy engine failure modes should be examined.
- Parts are subjected to analysis (Stress analysis for gearboxes and fuel controls and stretch for tubes and hoses).
- Design criteria should be established.
- No Fire as a result of flammable fluids leaks .
- Large components cannot be liberated:
    - Servo Valves, FADEC, Heat Exchangers

Blade Loss and Containment Evaluation

- Rig tests are often used for derivative engine programs.
- The rig test can be instrumented and modeled to augment validation programs.
- Purpose for a rig test:
  - Unbalance
  - Containment
  - Fuse and other hardware behavior
  - Damping and rundown rates

Static Structure Evaluation

- Model the loads and the load transfer through the engine structure for 15 seconds after the blade out event, or until a self-induced shutdown occurs.
- Testing may be required to validate the analytical methods used to address the static structure (buckling).
- The effect on the engine mounts of engine case stiffness changes should be assessed.

Things to Consider with Analysis Use

- Will the overall engine dynamics change:
  - Case stiffness/mass
  - Rotor/shafting stiffness/mass
  - Bearing support stiffness/damping
  - Weight changes (hard wall to soft wall containment)
  - Mount locations
  - Rear frame supports

- Will the blade out loads change:
  - Number and/or geometry fan blades
  - Metal vs composite blades
  - Load reduction devices
  - Will trailing blades fail the same way

Things to Take into Account

- The engine support structure should be taken into account in model validation and for reconciliation of the derivative to the baseline engine.
- Blade release angle should be taken into account. Examine multiple release angles to determine the worst case.

Things that are Difficult to Model

- Engine RPM run down rates.
- Blade and containment case fragmentation and interactions.
- Load reduction device fuse failure timing.
- Containment
- Bearing stiffness

Questions

- **<u>Policy Issued:</u>** 33.94, Use of Structural Dynamic Analysis Methods for Blade Containment and Rotor Unbalance Tests [ANE-2006-33.94-2].
- **<u>Issue Date:</u>** April 20, 2009
- http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgPolicy.nsf/