Federal Aviation Administration

Memorandum

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To: SEE DISTRIBUTION

From: Manager, Engine and Propeller Directorate, Aircraft Certification Service

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Subject: **ACTION**: Use of Structural Dynamic Analysis Methods for Blade Containment and Rotor Unbalance Tests. [ANE-2006-33.94-2]

1. Purpose

This policy provides guidance for evaluating the use of structural dynamic analysis methods to show compliance with the requirements of Title 14 of the Code of Federal Regulations (14 CFR 33.94), "Blade containment and rotor unbalance tests". This policy specifically addresses compliance with paragraph (a) of § 33.94 for engine design and configuration changes, and follow-on model certification of the same type. This policy is derived from extensive Federal Aviation Administration (FAA) and industry experience in evaluating compliance with the relevant regulations. This policy does not create any new requirements, and does not specifically address new model type certification.

2. Background

This policy is superseding "Use of Structural Dynamic Analysis Methods for Blade Containment and Rotor Unbalance Tests", policy number ANE-2000-33.94-R0, dated March 8, 2001. The policy provided guidance for evaluating the use of structural dynamic analysis methods for compliance with the requirements of § 33.94. Application of the policy has shown the need for additional detail to define certification procedures, Engine and Aircraft Certification Office (ECO and ACO) coordination, define a standard set of terms, and refine the steps involved in engine modeling and validation. We changed the policy by adding sections 4) Certification Plan, 5) Engine Modeling and Analysis Methods, and 6) Engine Model Validation. Also, throughout this policy the modified engine is referred to as a derivative engine.

Engine manufacturers are developing and using various structural dynamic analysis methods to support both engine certification and aircraft manufacturer certification activities relevant to the § 33.94 blade out test requirements. These structural dynamic analysis methods include various types of mathematical models, such as two-dimensional and three–dimensional (3D) finite element models of the engine and installation. These models help in determining loads and performing structural dynamic analyses on engine rotating components, static structures, mounts, and other components, to simulate the effects of blade loss on the engine during a blade out test or on an aircraft installation.

One such aircraft level assessment examines windmilling imbalance using the methods described in the Aviation Rulemaking Advisory Committee (ARAC) report, "Engine Windmilling Imbalance Loads - Final Report," dated July 1, 1997, and the associated advisory circular (AC) 25.24 "Sustained Engine Imbalance," dated August 2, 2000. Although the ARAC report and AC state these dynamic analysis models should be validated by data obtained during a § 33.94 engine test, this validation is associated with certification requirements for airplanes. This validation does not substantiate the use of these dynamic analyses as a substitute for conducting the engine blade out tests required by § 33.94 for engines.

Section 33.94 requires an engine test to demonstrate failure of the most critical fan, compressor, or turbine blade. Typically, the engine test is run on the first model of an engine type during the type certification program. This certification test and type certified engine establish an acceptable baseline. When the manufacturer makes a major change to the engine, the manufacturer evaluates the effect of the change on the § 33.94 requirements to determine if the results from the baseline test are applicable. This process is referred to as reconciling the change with the baseline configuration. Dynamic analysis is one method used in this reconciliation process. When engine design changes cannot be appropriately reconciled with the baseline configuration, a new baseline test may be necessary, as an analysis cannot substitute for a baseline engine test.

3. General

When changes to an existing engine type design or derivative models are added to the type certificate, these changes must be reconciled to the baseline engine test. The analysis that reconciles the new configuration with the baseline engine test may vary from a qualitative engineering evaluation to the use of a complex dynamic model, depending on the extent of the modifications. In all cases the analysis must be validated for a given model type or series with a baseline engine test before it can be used for the new configuration. An analysis is validated by showing it can reliably predict results from engine tests or rig tests for changed products, within the scope of established analysis limitations. The analysis should consider the period from just before blade loss through the deceleration rundown for 15 seconds or until a self-induced shutdown.

To reconcile an engine change to the baseline configuration, you must follow the requirements of § 33.94. Therefore, the reconciliation must show that, following failure of the most critical fan, compressor, or turbine blade and when operated for 15 seconds or until a self-induced shutdown, the engine:

- Will not fail its mounting attachments;
- Will not catch fire; and
- Is capable of containing the damage.

The introduction of structural dynamic analysis methods into the certification compliance finding for a derivative engine should involve close and frequent coordination. This coordination is between the applicant, the ECO or the appropriate ACO as well as with the Engine and Propeller Directorate Standards Staff. Frequent coordination will serve to work out many modeling and certification issues (such as adding an equivalent level of safety finding to the certification basis when required). Additionally, you may contact the Chief Scientific and Technical Advisor for Engine Dynamics as needed. Early coordination should take place between the ECO or ACO and the applicant to establish a preliminary derivative engine certification plan and certification basis. This early planning should establish the foundation for a final certification plan acceptable to the FAA. The use of structural dynamic analysis is not without risk. If the applicant does not meet the FAA expectations expressed in this document and reconciliation of the shortfall is not feasible, then additional component testing or an engine demonstration test might be required.

4. Certification Plan

The following should be included in the certification plan and kept current throughout the project.

- A detailed description of the baseline engine, the § 33.94 test, and test results.
- A detailed description of the proposed changes to the baseline or derivative engine.
- The proposed certification basis including amendment levels, exemptions, equivalent level of safety findings, and special conditions as required.
- A description of how compliance will be shown to § 33.94.
- A list of analysis and test methods.
- The proposed method to validate the engine model and analysis methods.
- A list of all the components that will be affected by the engine changes and may effect compliance with § 33.94.
- The process used to evaluate and substantiate the engine components.
- The method used to address the capability of each relevant component. Capability means the component will behave as intended during the blade out event, and therefore will not invalidate the outcome of the baseline § 33.94 test when applied to the derivative engine.
- A program schedule including major milestones, and initial, interim, and final meetings with the FAA as required.
- A list of documentation that will be submitted to the FAA.

5. Engine Modeling and Analysis Methods

An engine structural model, relative to a baseline engine, typically includes a combination of analysis methods, test results, and empirical data, used to evaluate and reconcile the derivative engine's unique design characteristics. For example, the overall dynamic response of the engine may be modeled with 3D finite element analysis (FEA) to provide deflections and internal loads. The 3D FEA model may lack the detail required to calculate certain component stresses; therefore, separate models may be needed for those component stresses. Also, the 3D FEA model may require blade out event input data that was developed from engine, rig or component testing. Different methods and models are used because the engine is evaluated at both the macro and the component level. The engine model is therefore an auditable combination of analysis, test, and empirical procedures, which must be reviewed with and accepted by the FAA as an acceptable method to reconcile the derivative engine to the baseline engine.

The following analysis methods are typically used to assess hardware capability and behavior during a blade out event, depending on the complexity required to evaluate the engine changes:

- Comparative analysis - This is a method used when identical hardware or features from the baseline engine are used in the derivative engine. The loads are similar or lower, and there is a well characterized success or failure criteria. The applicant should show by comparison the part has at least equal capability in the derivative engine as compared to the baseline engine.
- Conventional analysis - This is a method used for identical or similar hardware or features that have a well characterized success or failure criteria, and have loads and margins that are close to the baseline. The analysis methods used should be a standard engineering analysis using a textbook approach, an empirically based design practice, or a conventional linear finite element model, or both. Minor non-linearities in the FEA results may also be included, if these are well understood and predictable, such as minor local yielding, gaps, etc.
- Correlated analysis - This is a method used when hardware, features, loads or margins differ from the baseline. The success or failure criteria for the hardware or features has been characterized. It also includes behavior which is significantly complex or non-linear to an extent beyond what could be considered in a conventional analysis, as described above. The analytical model should be correlated to an engine or component test that has loading and design features representative of the derivative engine behavior, thereby validating the analysis method. Analysis methods in this category include complex FEA, non-linear FEA, buckling analysis, etc. The applicant should establish that their analytical methods have been validated by testing, and are suitable for demonstrating hardware capability.
- Certification component test (for example, fan model rig test) - This is a method used when there are significant differences in hardware or features. Also, the 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. Loading and boundary conditions should be representative of the engine, and the test must be designed to encompass predicted failure. To accomplish this, the applicant should submit a test plan, including a request for part conformity, for FAA approval. Following the test plan approval and an FAA conformity finding, the applicant should conduct the test(s) and teardown inspection, both of which should be witnessed by an FAA representative.

Following the teardown, the applicant will need to submit a test report to the ECO or ACO. This report should include an evaluation of the test results and post-test teardown inspection results and a comparison of these results to the baseline engine.

6. Engine Model Validation

Before the manufacturer uses an engine model for certification purposes, the engine model, any auditable data, analysis and procedures that are used in combination with the engine model must first be validated and accepted by the FAA. Therefore, early involvement with the FAA is necessary. The validation of the engine model involves many steps related to the baseline engine test, historical background, and proven success. If derivative designs are anticipated, but details are not available during the baseline certification program, the applicant should attempt to conduct the appropriate analyses and collect the appropriate data to support future derivative analysis.

The applicant's validation of the baseline engine model should include, but not be limited to the following steps:

- A review with the FAA of the overall proposed baseline engine model and validation program, all applicable previous certification tests, analytical models, empirical models, rig tests, vibration tests, static tests, model correlation, etc., that will be used to develop and refine the model.
- For correlated analyses, review and establish with the FAA that analytical methods are validated and suitable for modeling the changed engine design characteristics. Include any relevant engine and rig test blade out experience that supports the use of proposed correlation and analytical methods. Engineering tests might be useful if it can be shown the test data meets certification quality standards. If it is anticipated that an engine test will be used for a baseline for validation purposes, then special, or additional engine test instrumentation might be required to assess the effects of unexpected test outcomes, such as failed load paths.
- Review with the FAA the pretest predicted baseline engine loads, deflections and test results before the § 33.94 baseline test is conducted. When the pretest predictions are not available, review with the FAA the background and reliability of applicable measured loads and the post test predictions to be used for model validation.
- Conduct a blade out test of the baseline engine in accordance with § 33.94, which is successful, or has minimal issues that are easily understood and addressed on the derivative engine. Review the § 33.94 blade out test results and pretest predictions and validated analysis with the FAA, and obtain their concurrence that the model is acceptable for use with the derivative engine program. Submit certification reports to establish the analytical methods have been validated and are suitable for modeling the derivative engine's response to the blade out test requirements.
- If the baseline or derivative engine containment and blade loss fraction will be determined by an engine blade out rig test, then it must be demonstrated the rig test adequately represents the relevant engine behavior. Historically, the baseline engine program has included an engineering blade out rig test before conducting the engine blade out test. When included, this engineering blade out rig test has provided significant

data for validating the results of a derivative engine blade out rig test. The blade out rig pretest predictions and the post-test results from blade out rig test used for the baseline engine should be reviewed with the FAA to demonstrate the rig is representative of the derivative engine.

- The engine model is usually validated when it can reliably predict results from engine tests, rig tests and the differences between both. Engine and component baseline and derivative model validation should include sensitivity studies to assess the robustness of the analysis.

Although the focus for the baseline program is on the blade out test outcome, the validation of the engine model for the derivative program may involve a correlation to other relevant baseline program tests. These could include rig tests, vibration tests, and static tests. As a result, you should discuss these baseline tests with the FAA, and come to agreement on the appropriate conformity and documentation requirements, so they can support the derivative engine analysis program.

7. Loads and Component Capability Evaluation

The reconciliation of a derivative engine design with the baseline configuration using analysis methods should involve an evaluation of loads and deflections. The baseline engine test loads should include the effects of the test configuration used to support the engine during the baseline blade out test. The derivative engine loads, also accounting for the test configuration effects, should be evaluated against the baseline engine test results. This evaluation should verify the derivative engine loads and the capability of each component are consistent with any applicable limitations (for example, engine or thrust reverser mount structure loads) noted within the installation instructions required under § 33.5 and the engine mount load limits established under § 33.23.

8. Mount Evaluation

The mount evaluation should focus on the loads imposed on, or transferred to, the mounts and the vibratory response of the engine. The analysis should show that proposed changes to the engine do not significantly modify mount loads relative to the baseline engine test results. If the resultant mount loads are higher than the baseline test results, further evaluation should be conducted to show the mounts have sufficient capability. 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. In this case a new blade out engine test may be required to show compliance with § 33.94.

9. Fire Evaluation

The fire evaluation generally focuses on the loads, deflections, and vibratory response of components that carry flammable fluids, such as fuel lines, oil lines, oil tanks, gearboxes, fuel pumps and lube pumps. The analysis should show the change to the engine will not increase the loads and response of these components, or reduce the capability of these components to endure the loads expected in the derivative application. The analysis, such as FEA, should show that fuel and oil lines do not become undone or otherwise fail and the engine has adequate drainage for fuel that could be ignited. If the loads and responses are increased, or the component capability is reduced, further evaluation of component capability should be conducted to show the components will not fail or catch fire.

10. Blade Loss and Containment Evaluation

Containment capability is dependent on the containment structure and blade loss interaction, including the extent of blade fragmentation and the resulting interaction between the blades and the case. The applicant should show by certification test, correlated analysis, or both, that changes to the blade or containment structure can be reconciled with the baseline engine test. Containment rig testing, combined with dynamic analysis, is one method that may provide the appropriate data to reconcile with the baseline engine test demonstrating both containment of the release blade, and the net unbalance from blade loss.

If the unbalanced loads are due to blade loss and are significantly higher than demonstrated during the baseline engine test, reconciliation of the change with the baseline test may not be possible. In those cases, a new engine test may be required by § 33.94.

Changes to the fundamental method of containment, such as changing from hard-wall containment to soft-wall containment, changing materials, or introducing design changes to the same case, may affect the containment capability of the engine. This may also affect the load transfer from blade fragmentation and the resulting interaction between the blades and the case. Therefore, it should be shown that, in addition to containment capability, the changes do not significantly affect the overall engine response and loads. This can be shown by a combination of rig test and dynamic system analysis that has been validated by showing that it can reliably predict event outcomes from similar changed products.

11. Static Structure

The analysis method should 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. Changes to the static structure may significantly alter the loads that are transmitted to the mounts. Therefore, the configuration should be analyzed, including changes to the engine support structure. For example, increasing the engine case stiffness and strut stiffness may result in higher loads to the engine mounts. The dynamic analysis should be sufficiently detailed to address these changes.

12. Applicable Changes

The use of analysis to reconcile derivative changes relative to a baseline § 33.94 engine test, requires engineering experience and judgment. Major engine changes include, but are not limited to the following:

- Blade count, blade mass, blade platform, blade retention or blade design;
- Materials in the blade, containment, or attachment structure;
- Maximum rotational speed;
- Containment structure;
- Static structures;
- Mount locations;
- Mount structures;
- Location or design of a component that carries flammable fluid;
- Significant change to engine system dynamics.

The baseline blade out engine model will need to be modified to reflect all design and configuration changes made after the baseline blade out test is completed. Assessing the effects of changes to the baseline engine model and the derivative engine and subcomponent models might require recalibration and additional validation testing.

13. Conclusion

The introduction of structural dynamic analysis as a method of compliance for certification of a derivative engine should involve close and frequent coordination between the applicant, the ECO or the cognizant ACO, and the Engine and Propeller Directorate Standards Staff. The Chief Scientific and Technical Advisor for Engine Dynamics should also be used as needed. We recommend early coordination between the cognizant ECO or ACO, and the applicant, to establish a preliminary certification plan and the derivative engine certification basis. This early planning should prepare the foundation for a certification plan and ensure a full understanding of the regulations.

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