

HF120 Turbofan Engine Development Test for Type Certificate

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ABSTRACT

Honda and General Electric Company have performed component certification tests, engine certification tests, as well as associated engineering tests, to verify conformity with regulations in order to obtain United States Federal Aviation Administration Type Certificate for the HF120 turbofan engine. The results of these tests confirmed that the HF120 turbofan engine satisfies the airworthiness requirements and exhaust emission regulation requirements of the United States Federal Aviation Regulations Title 14 of the Code of Federal Regulations Parts 33 and 34.

A total of 190 certification test plans and reports were submitted in the development of the HF120 turbofan engine, and on December 13, 2013, a Type Certificate was received from the United States Federal Aviation Administration.

1. Introduction

Honda initiated aircraft engine research and development in the late 1980s. In December, 2003, Honda developed the HF118 turbofan engine (HF118), and installed it on a HondaJet proof of concept vehicle and started flight tests. In October, 2004, Honda and General Electric Company (GE) established a joint venture company, realizing Honda's dream of entering aviation industry. In February 2007, an application was made to the Federal Aviation Administration (FAA) for Type Certificate of the HF120 turbofan engine (HF120), which is the mass-production engine successor to the HF118. Since submitted application to FAA in 2007, GE and Honda continued detail design work. The first engine test was started from October, 2009. A series of certification tests and engineering tests was started from 2010.

2. Classification of Tests

Federal Aviation Regulations (FAR) require substantiating engine compliances with the regulatory requirements for Type Certificate by test and/or analysis. Certification tests involve conducting substantiation tests with FAA representatives present to demonstrate engine compliance with regulatory requirements. Analysis substantiation is verification with a high confidence level analysis model. The analysis model is verified by well correlated component or engine test results.

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The next section explains the outline of various tests for acquisition of the turbofan engine Type Certificate.

2.1. Component Tests

Component tests are mainly classified into three types: a component test when the engine operating conditions can be well simulated on the component level, like a fire test; a component test with more severe conditions when the engine endurance test can not fully demonstrate a hardware capability, like an engine sensor test; and a component test to substantiate the correlation between an analysis and a test when a FAR requirement is complied with or supported by the analysis.

A total of forty-one component certification tests were conducted through the HF120 development program. Oil tank fire test, and Power Take Off (PTO) and Accessory Gear Box (AGB) endurance test are introduced herein as representative of the component tests.

2.2. Engine Tests

The engine tests consist of tests to confirm performance, function, and operability, such as steady-state tests and acceleration and deceleration tests to evaluate acceleration rate, surge, and flameout; tests to confirm engine soundness under severe conditions such as vibration tests, overheating tests, lubricant shut off tests and the like; tests in which foreign objects that could possibly be ingested during flight such as rainwater, hailstones, birds, ice and so on are actually fired into the engine; engine starting tests under

crosswind or tailwind conditions and high-altitude restart tests; fan blade containment tests in which a fan blade is purposely broken to confirm that there is no concern with airworthiness of the engine; and exhaust gas measuring tests. A total of 29 itemized engine certification tests were performed in the development of the HF120. Many of the engine tests were performed by GE, but the various engineering tests were also performed by Honda

As examples of these tests, this paper describes surge and stall tests, High Pressure Centrifugal Compressor (HPCC) impeller vibration response stress measurement tests, bird ingestion tests, and blade containment tests, including engineering tests.

Note that the bird ingestion tests were performed with the approval of the Honda Bioethics Committee.

3. Component Tests and Results

The oil tank fire test, and PTO and AGB endurance test are introduced in this chapter.

3.1. Oil Tank Fire Test

3.1.1. Certification requirement

The relevant FAR⁽¹⁾ requires that hardware which contains or conveys flammable fluid during normal engine operation must be fireproof or fire resistant. Fireproof is determined by neither having leakage of flammable fluid nor supporting fire during hardware exposure to fire. To substantiate compliance with this requirement, the oil tank fire test was conducted.

3.1.2. Method of substantiation

Substantiation that the oil tank complies with this FAR requirement was demonstrated by the component test. The test components are shown in Fig. 1. The HF120 oil tank is integrated into the intermediate case (IMC). The sight gauge for oil level monitoring and oil tank cap are mounted on the outer surface of the IMC.

Prior to the fire test, a flame impingement location was defined as the area which includes the oil tank cap and sight

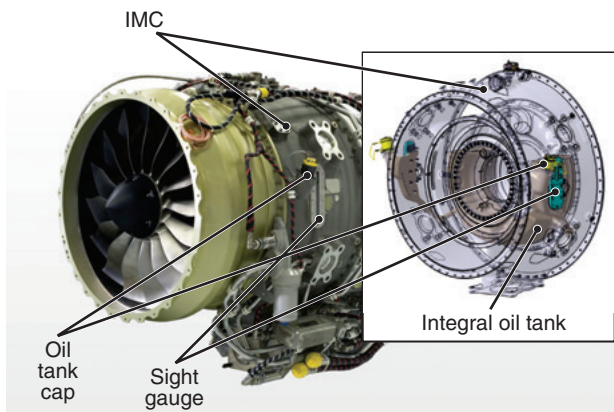


Fig. 1 HF120 oil tank system

gauge with or without flammable fluid, wall thickness, seal configuration, with or without fire protection feature, and with or without cooling flow.

Figure 2 shows the post-test condition of the area where flame was applied. No oil leakage and no flame growth were observed during the test and immediately after the completion of the test. Thus, the compliance with FAR requirement for fireproof of the oil tank was demonstrated.

In addition, the fire test sequence was as follows. First, a burner was calibrated prior to the test to confirm that flame temperature was 2000 °F and more and heat flux was 4500 BTU/h and more. Then the oil temperature inside of tank was increased up to the steady upper limit and flame applied to the defined impingement location for 5 minutes with simulated cooling flow and pressure at engine minimum idle condition, and for another 10 minutes with simulated cooling flow and pressure at engine windmill condition. After the completion of a total of 15 minutes flame impingement, the burner was calibrated to confirm that the calibration results were the same as the pre-test calibration results.

Windmill is a condition when the engine main shafts rotate by air from engine inlet while engine is not operating. The reason to include testing under windmill conditions was to verify no flame enhancement under the windmill condition. Figure 3 shows fire test configuration.

3.2. PTO and AGB Endurance Test

3.2.1. Certification requirement

The relevant FAR⁽²⁾⁻⁽⁴⁾ requires demonstrating the engine drive train endurance. Acceptance criteria for this requirement is that all test components are in a serviceable condition after the test completion. To demonstrate the endurance, drive train hardware endurance test was conducted. This test was the first certification test conducted by Honda.



Fig. 2 Fire exposure area of oil tank after test

3.2.2. Method of substantiation

Substantiation that PTO and AGB comply with this FAR requirement was demonstrated by the component test. The test components of PTO assembly, AGB, radial drive shaft and bevel gear for this test are shown in Fig. 4.

The endurance test was divided into the following two tests;

- (1) Static Torque Test: Figure 5 shows the test configuration. In this test, the maximum allowable static torque was applied on each accessory pad, and it was confirmed that no fracture occurred on each axis.
- (2) 150-hour Endurance Test: Figure 6 shows the endurance test setup. In accordance with the engine endurance test conditions in the FAR requirement, the test was conducted with a 25-cycle test, resulting in a total 150-hr and overload test. Oil temperature was kept at the steady upper limit of 290 °F and more throughout the test. In addition, tests with the oil temperature transient upper limit of 330 °F and more and with the minimum oil pressure were also conducted. The load on each accessory pad, which simulated the engine maximum load, was applied by hydraulic motor.

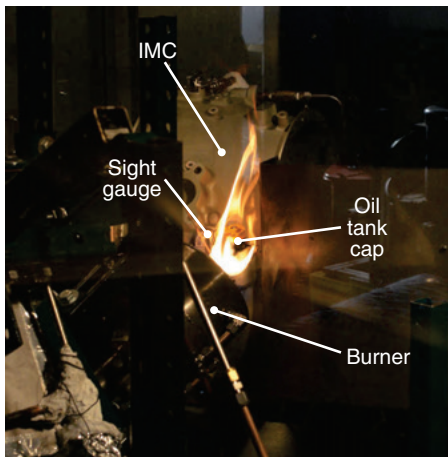


Fig. 3 Oil tank fire exposure

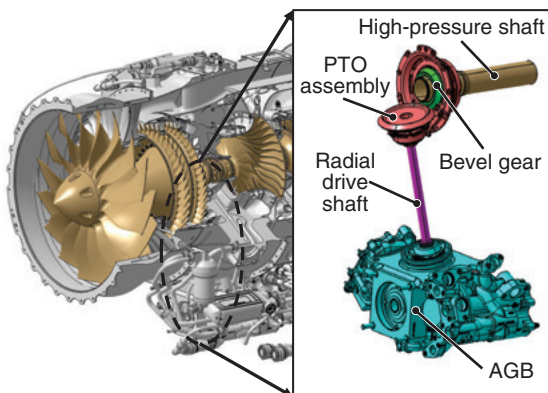


Fig. 4 Test components for PTO and AGB endurance test

As a result of the post-test tear down inspections, all test components were in a serviceable condition. Thus, compliance with the FAR requirements for engine drive train endurance was demonstrated.

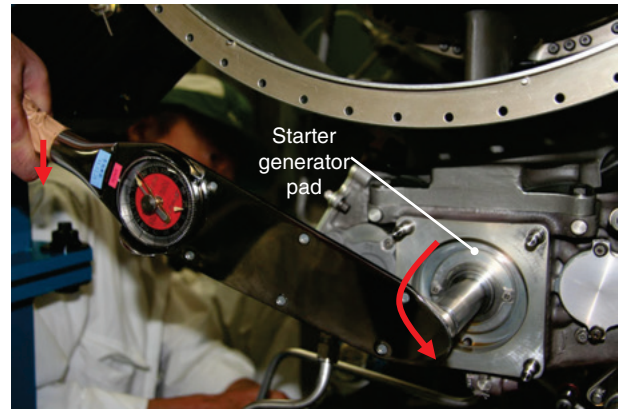


Fig. 5 Static torque test

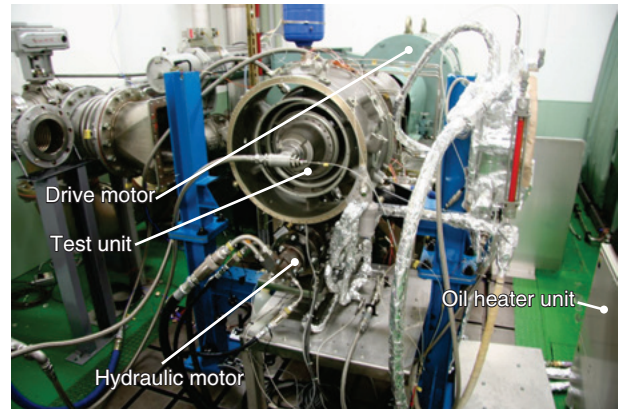


Fig. 6 PTO and AGB endurance test setup

4. Engine Test and Results

This chapter explains the surge and stall test, HPCC impeller vibration stress measurement test, bird ingestion test, and blade containment test.

4.1. Surge and Stall Test

4.1.1. Certification requirement

The operating limitations for an aircraft engine is defined as the operating envelope as functions of flight altitude and Mach number. FAR⁽⁵⁾ requires demonstration that an engine surge or stall that cause flameout, structural damage, component over-temperature or failure of engine to recover thrust does not occur within the operating envelope. Here, the terms surge and stall refer to the phenomena of instability of the airflow flowing through the compressor. The components that were evaluated were fan rotor, low-pressure compressor (LPC), and high-pressure centrifugal compressor (HPCC).

4.1.2. Method of substantiation

Compliance with the applicable regulations was demonstrated through a combination of engine certification tests and engine model analysis. The process involved is described below. Note that the engineering and certification tests described in this section were performed by GE.

4.1.3. Engineering and certification tests

The first step was to obtain the high-altitude performance of the test components at the GE Altitude Test Facility (ATF) with the aim of improving the accuracy of the engine model used in the analysis. At this facility, high-altitude flight conditions can be simulated by setting the engine inlet pressure and temperature, and the airspeed relative to the engine.

Next, engine tests were performed as certification tests to verify compliance with the regulations in the condition where external disturbances from a crosswind are present. Stall characteristics under crosswind were obtained using a large blower at the GE outdoor test facility shown in Fig. 7. As a result, it was confirmed that under the conditions of blowing a crosswind of up to a maximum of 40 kt at the engine, no surge or stall occurred. The degree of crosswind influence obtained from these test results was reflected in the analytical model, and the fact that surge and stall would not occur within the operating envelope was proven by analysis.

Also, for the HPCC, taking into account factors such as deterioration of performance and engine manufacturing variations, an engine operating line was defined by the analytical model, and by engine tests it was verified that surge or stall would not occur.

Furthermore, in order to decide engine start limit conditions, engineering tests were performed using the facility shown in Fig. 7. In start capability verification tests for ground conditions, tests were performed with crosswind and tailwind. For altitude conditions, restart characteristics tests were performed using the ATF.

From the results of these tests, a range of start capability and wind speed limits for no occurrence of surge or stall were set. In this way, the engine tests used in combination with the analytical model verified by the tests confirmed that surge and stall would not occur within the operating envelope, and it was demonstrated that the certification requirements of Federal Aviation Regulations were satisfied.

4.2. HPCC Impeller Vibration Stress Measurement Test

4.2.1. Certification requirement

With regard to the rotating blades, stationary blades, rotating discs, and rotating shafts that constitute the engine components, the FAR⁽⁶⁾ requires a vibration survey up to the maximum permissible engine rotational speed plus 3%, and in cases where signs of a new vibration response are observed within this plus 3% region, a further vibration

survey to a 2% higher rotational speed region, and with regard to all observed responses it must be verified that the stress levels of the combined static and dynamic stress are less than the material fatigue limits. This section describes the vibration stress measurement test of the HPCC impeller.

4.2.2. Method of substantiation

The HPCC impeller vibration stress, measured using strain gauges in the engine certification tests, was evaluated with respect to the fatigue limit and verified conformity with the regulations.

The HPCC impeller is shown in Fig. 8. Since the blade vibration response stress is evaluated from the response of strain gauges attached to the impeller blade surface, it is necessary to output the stress signal to the outside using slip rings.

The HF120 has a twin-shaft structure in which there

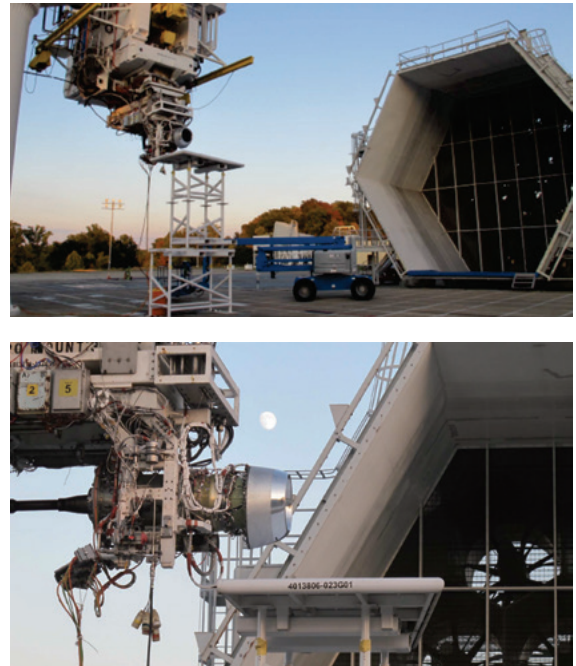


Fig. 7 Crosswind test setup

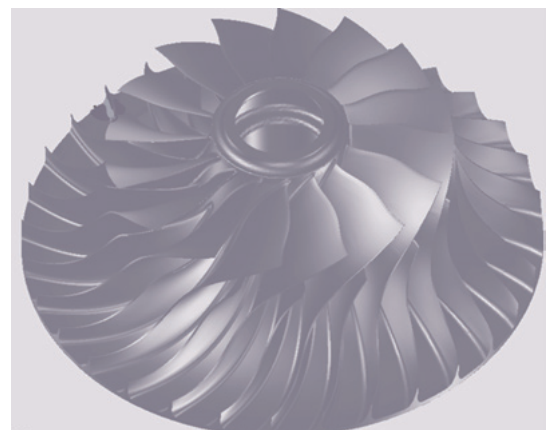


Fig. 8 HPCC impeller

is a high-pressure shaft section and a low-pressure shaft section. In order to access the HPCC impeller, the test was performed using a core-engine configuration comprising only the high-pressure section having the HPCC.

In this configuration, since the HPCC upstream fan rotor and LPC are not present, separate equipment was used to simulate the HPCC inlet conditions by feeding pre-compressed, heated air into the core engine intake.

In the evaluation of the strain gauge vibration response stress, since it is necessary to accurately measure a large number of vibration modes, it is desirable to efficiently obtain data from as many modes as possible in one strain measurement channel. Accordingly, instead of measuring all modes where the stress gradient is large and also the location where maximum stress is different for each mode, the strain gauge measuring points were chosen where the stress gradient is small and in locations with a possibility of multiple modes, making it possible to measure more accurately. For the choice of strain gauge location and the calculation of maximum vibration stress values, a ratio of subject point to measured point is used for each mode. In this case, a strain distribution based on a Finite Element Method (FEM) analysis was used. Furthermore, to verify the analysis probability, an individual vibration test was performed on the actual part. Figure 9 shows an example of typical mode deformation results for the HPCC impeller obtained in the individual vibration test.

Once these were prepared, the maximum vibration stress values during actual engine operation were obtained and combined with the static stress, and evaluated against fatigue limits obtained from a Goodman diagram.

4.2.3. Certification test

The engine test was performed by GE. A schematic of the engine test is shown in Fig. 10. Test results were obtained as a Campbell diagram, and from this Campbell diagram the blade surface strain gauge response levels, as well as the response rotational speeds and frequencies over the entire rotational speed operating range, can be read. For these results, combined with the FEM analysis, the vibration modes of the response and of the excitation source were identified and the maximum vibration responses were calculated. With regard to the maximum vibration stress values for all modes of the HPCC impeller obtained in these certification tests, combined with the static stress, the stress levels are less than the material fatigue limits, verifying that



Fig. 9 HPCC impeller mode shape

they satisfy the requirements of FAR.

4.3. Bird Ingestion Test

FAR bird ingestion requirements that are applicable to the HF120 engine include specific bird numbers and size, etc. This section explains medium-sized bird ingestion tests.

4.3.1. Certification requirement

The FAR⁽⁷⁾ for medium-sized bird ingestion tests requires verification that sustained thrust loss after the ingestion is not greater than 25%, that after bird ingestion a prescribed operating pattern is completed, that the engine can be shut down without issues, and that engine function and operability are acceptable.

4.3.2. Method of substantiation

Conformity with the regulations of medium-sized bird ingestion test was proven by engine certification tests. Also, the accuracy of the analytical model used to determine design specifications and the feasibility of the setup of test conditions are key points in the success of the certification tests. Therefore, engineering tests were performed by Honda in advance for the purpose of verification of the accuracy of the analytical model and confirmation of the feasibility of the certification tests. The certification tests were conducted by GE.

4.3.3. Core shot engineering test

The core shot test is a bird ingestion test aimed at the inner diameter side of the fan rotor. Figure 11 (a) shows the fan rotor bird ingestion target and Fig. 11 (b) shows a schematic of the test equipment. When a bird is ingested into the inner diameter side of the fan rotor of the HF120, surge is caused by blockage of a portion of the flow, and the pressure balance of the flow field fluctuates widely. At this time, some of the main aerodynamic parts may sustain damage having an effect on the thrust. Also, since the behavior inside the engine after bird ingestion is complex and changes within a short time, engineering tests using measuring technologies were run in order to gain detailed understanding of the events were conducted. As a result, it

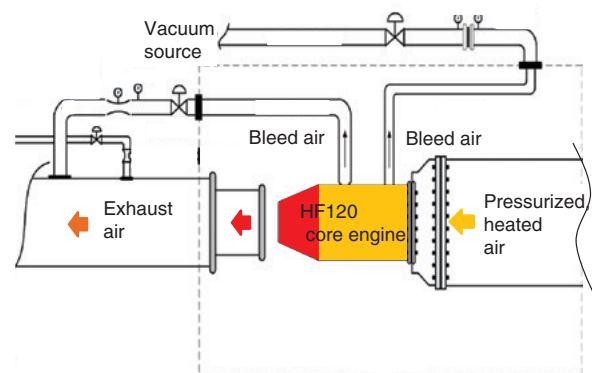


Fig. 10 HPCC stress survey core engine test

was possible to confirm the mechanism of the changes in thrust during the core shot.

Preliminary engine tests were conducted with the certification test specifications which were selected with this knowledge, and the thrust after bird ingestion was within the requirements.

4.3.4. Tip shot engineering test

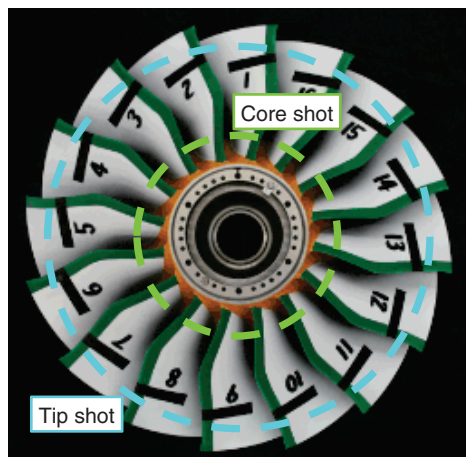
The tip shot is a bird ingestion test aimed at the outer diameter side of the fan rotor [Fig. 11(a)]. In this case, blade deformation is caused by bird collision with the fan rotor, affecting the thrust. For this evaluation, rather than using an engine test, a unit test was used in which appropriate test conditions could be set. The fan rotor was rotated at a specific rotational speed in the unit test rig shown in Fig. 12, and a tip shot test performed by letting a bird be ingested at the outer diameter side.

The post tip shot fan rotor was installed in the engine and the thrust before and after deformation was evaluated. The results provided an indication of satisfying the certification requirements.

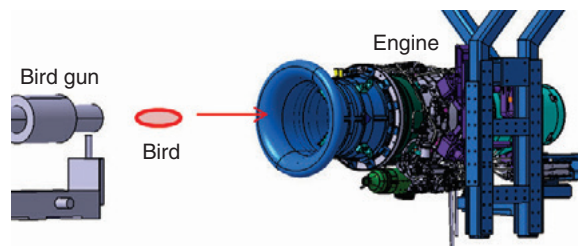
4.3.5. Certification test

The certification test was performed at the GE outdoor test site. The thrust after core shot satisfied the requirements, and the operation after ingestion was completed without issue. In this way, it was demonstrated that the FAR requirements were satisfied.

Regarding the tip shot, GE also performed a thrust



(a) Fan rotor target location



(b) Core shot test setup

Fig. 11 Target location and core shot test setup

verification test and it was confirmed that the requirements were satisfied.

4.4. Fan Blade Containment Test

4.4.1. Certification requirement

The relevant FAR⁽⁸⁾ requires substantiating that the engine is capable of containing damage from a fractured blade inside of the engine without catching fire and without damage to the engine mount system, and that the engine retains shut down capability after a blade fracture event occurs. FAR requires the most critical blade to be fractured. The most critical blade is a fan rotor blade in HF120. To verify conformance to this requirement, a fan blade containment test was conducted with an intentionally fractured blade during engine operation.

4.4.2. Method of substantiation

Fan blade containment compliance with the FAR requirement is demonstrated by engine certification test. Also, in the fan blade containment certification tests, as in the case of the bird ingestion tests, the accuracy of the analytical model used to determine design specifications and the feasibility of the setup of test conditions are key points in the success or failure of the certification tests. Engineering tests were therefore performed by Honda in advance for the purpose of verification of the analytical model and confirmation of the feasibility of the certification tests. The certification tests were then performed by GE.

4.4.3. Engineering test

In the engineering test, a fan rotor blade was broken off by wireless remote control from the test bench monitoring room. At the time the blade broke, the engine was running at the maximum permissible rotational speed.

Figure 13 shows a photo of the external appearance of the fan case after the engineering test. No evidence could be seen of the broken blade penetration on the fan case, and it was confirmed that damage was restricted to the interior of the engine. Neither catching fire, nor failure of the mount system was observed, and the engine had safe self shut-down after a blade fell. These results provided confirmation of satisfying the Federal Aviation Regulations requirements.

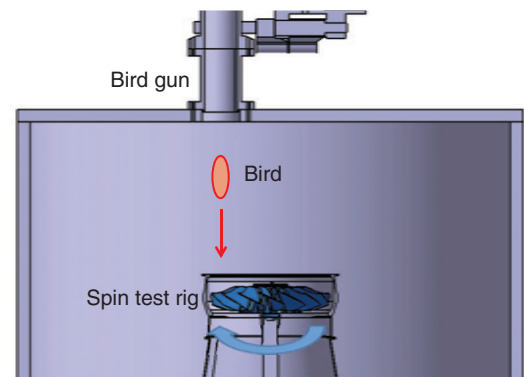


Fig. 12 Tip shot test setup

Also, detailed data such as strain data for each of the parts, necessary for verification of the analysis probability, was obtained.

4.4.4. Certification test

The certification test was conducted at the GE outdoor test facility. Figure 14 shows the blade containment test setup, the orange colored blade is the blade that was designed to fall. Figure 15 shows the fan rotor and fan case appearance after test completion. Same as the engineering test, no trace of fractured blade penetration appeared on the fan case, indicating that a fallen blade is contained inside the engine. The certification test also demonstrated safe self-shutdown after a blade fell, no catching fire, and no failure of the mount system, same as the engineering test, therefore substantiating compliance with FAR requirement.

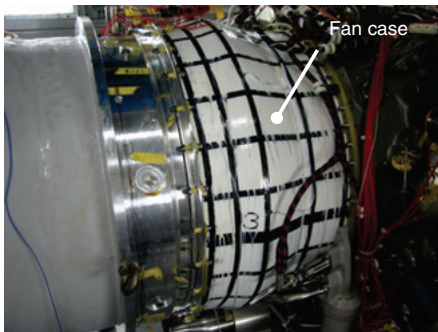


Fig. 13 Fan case after blade containment test

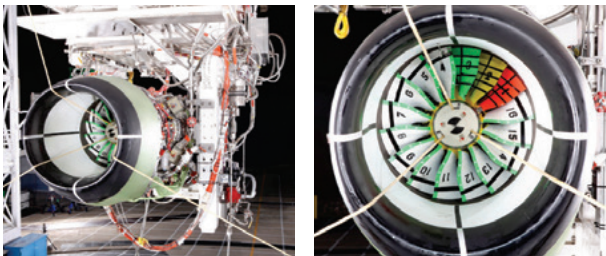


Fig. 14 Blade containment test setup

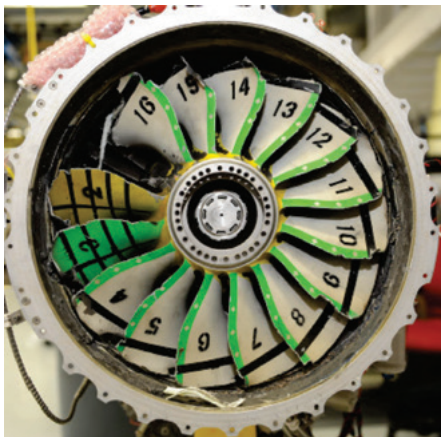


Fig. 15 Fan rotor and fan case after blade containment test

5. Conclusion

Through the HF120 development program, forty nine component certification tests and twenty nine engine certification tests were conducted, including the tests described in this paper. 190 certification test plans and reports were submitted to the FAA through the HF120 development program. GE and Honda finally received HF120 turbofan engine Type Certificate from the FAA in December 13, 2013.

A majority of the certification test was conducted by GE, while Honda conducted PTO and AGB endurance certification test and a number of engineering tests. These activities provided us not only technological outcomes but precise knowledge and experience.

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