Flight Test to Validate Engine Surge-eliminating System Using disturbed board on Flight Test Bed

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Abstract: To prove the validity and reliability of engine surge eliminating system, surge test is conducted through disturbed board installed in nacelle inlet of flight bed. The test by installed the board blockage ratio of 30%, 40%, 50% on the ground and the board blockage ratio of 40% in the air were accomplished successfully. The results and date of experiment were discussed and analyzed in this paper.

Nomenclature

Ma Mach number
Φ Angle of throttle
n_l Low pressure rotor speed
n_h High pressure rotor speed
N_{2c} Corrected high pressure rotor speed
P_{3l} Total pressure at high pressure compressor exit
T_4 Turbine exit gas temperature
α_2 The angle of high pressure variable stator blade
P_{fse} Primary fuel passage pressure
P_{o2} Compensate oxygen pressure
S_{sig} Engine combustor igniting signal
S_{sur} Engine surge signal
S the ratio of board blockage

1. Introduction

Engine surge is instability state which is caused by airflow creating low frequency and high amplitude vibration along path of compression system, which can cause engine out of control, thrust descend abruptly, inlet duct and engine damaged mechanically, engine flameout stop and even to damage engine and safety of flight. A aero-engine Anti-surge/surge-eliminating system should make a significant contribution to prevent engine surge and flameout during maneuver flight and launch weapon. To prove the validity and reliability of engine surge eliminating system, it is important to adopt test procedure to cause engine into instability state during flight test, which is engine surge test in the air.

There are two kinds of test methods to cause engine surge. Interior disturbance is cause engine inlet temperature distortion by launching simulated missile or hydrogen burner or cause engine inlet pressure distortion by installed some facilities in engine inlet, such as disturbed screen or board, vortex generator and so on. Methods including stepping fuel of combustor, changing inner geometry of engine such as changing area of nozzle exit and angle of stator vane are called exterior disturbance. Those methods are used widespread in engine surge test on the ground. Only the way of launching simulated missile was used to cause engine into instability state in flight test on the flight test bed in the 1980’s, China.

In order to prove the validity and reliability of engine surge eliminating system, aero-engine surge test in the air was conducted through disturbed board installed in nacelle inlet of flight test bed.
2. Introduction of test devices and measurements

2.1 Aero-engine flight test bed

The aero-engine flight test bed is one high-altitude test facility, which is usually alternated by large-size transport plane. The tested engine is tested in high-altitude by mounted in retractable nacelle or replaced engine nacelle. True and used environment of engine is the particular merit of flight test bed. Because of safety of flight, some special projects which can not conduct on prototype plane are tested and verified on flight test bed.

The flight test bed which was used to verified the surge eliminating system of flight test engine has good flight ability with three-engine, that is to say, the flight test bed can guarantee the flight safety without the power of the flight test engine. To meet requests for engine flight test and assure normal work of the test engine, there are lots of alternate systems on the flight test bed, including, fuel oil system, operating system, cooling-fan installation, electrical control system and double fire-extinguishing system, and so on. The measurement parameter which the flight test bed can supply is more than 3000, there are airborne data real time process, monitor system and lift-support system for test flight engineer allocated on the flight bed.

2.2. Disturbed board and measurement

The disturbed facilities are made of six parts which are installed and fixed in nacelle inlet. According to the need of test, six different blockage ratios which are from 10% to 60% can be obtained using diverse quantitative board. The disturbed board is installed in special performed hole and fixed with clamping bolt in nacelle of the flight test bed. The disturbed board installed in nacelle is shown in Fig 1.

Six inlet static pressure measurement on nacelle inlet were used to determine the flow static pressure of engine inlet, the inlet pressure instrumentations at the same inlet compressor face were obtained with a special six-rake/36-prob apparatus. The apparatus consisted of six fixed, radially arranged rakes with five equal-area-weighted probes to measure total pressure and one probe to measure dynamic pressure. The apparatus was capable of being rotated clockwise through any angle up to and including an increment of 60°. The relative radial distance of total pressure probe was 0.408, 0.578, 0.707, 0.817 and 0.918 in turns. The relative radial distance of dynamic pressure probe was 0.9. The relative axial distance from disturbed board to the engine inlet measurement face was 2.74. The layout of measurement section in flight test bed is shown in Fig 2.

2.3. The test scheme

First of all, the engine ground test of symmetrical field is conducted without installed board to meet the requirement of inlet standard total pressure field.

Second, the engine surge test were accomplished by installed the board blockage of 30%, 40% and 50% on the ground.

In the end, the engine surge tests were achieved with installed board blockage ratio of
3. The test process

Based on the result of engine surge test on the ground, the critical speed of engine high compressor rotor at which engine surge occurs, with installed the certain area of disturbed board, should be selected. At the beginning of test, the engine high speed is requested to increase with increment of 5% by pulling throttle slowly from idle state. When the high rotor speed is near to the critical speed, the rate of pulling throttle is demand for adjusting the increment from 5% to 1%. Once the engine surge appear, it is important to fix the throttle first, after surge eliminating system is working and stall is appear again during engine recovery, then the low compressor rotor speed of engine is demanded to decrease 2% approximately at the speed of engine surge by dragging throttle. In order to verify the reliability of engine surge eliminating system, it is necessary to continue to engine test by pull throttle slowly again. For the safety of engine, it is important to set the maximum testing speed of engine high rotor, when engine suffer that speed and engine surge is not cause, stop engine surge test and consider increase area of disturbed board.

4. Results and analysis of the test

4.1. Results of test

- With installed the board blockage ratio of 30% on ground test, slowly push throttle from idle to n_L=83%, engine surge was not occurred.
- With installed the board blockage ratio of 40% on ground test, slowly push throttle from idle to n_L=85%, engine surge was not occurred.
- With installed the board blockage ratio of 50% on ground test, slowly push throttle from n_L=70 to n_L=83%, engine surge was occurred at n_L=76%, and the state of engine was resumed while LPC rotor speed was dropped to n_L=74%, the engine surge was occurred at n_L=76% during pushing throttle again. An example of the results of a engine surge typical analysis on the ground(s=50%) is shown in figure 3.
- With installed the board blockage ratio of 40% in flight test, the engine surge were occurred at n_H=93% under altitude of 5km and velocity of 550km/h and at n_H=89% under altitude of 8km and velocity of 530km/h. An example of the results of a engine surge typical analysis in the air(s=40%) is shown in figure 4.
4.2 Analysis of experimental results

The engine eliminating system is using surge pressure sensing device to sense the surge distinction of compressor previously. When eliminating system accepting the signal of engine stall, it can control engine to cut off oil automatically and change angle of stator blade and area of nozzle, adjust the law of inlet in order to eliminate engine surge.

Because of disturbed board installed in nacelle inlet, it is caused the engine inlet pressure distortion and deceased compressor stable margin during flying of flight test bed. With increase of engine state, disturbed flow is not meets the demand of engine stable working, engine is working into unstable zone slowly. Pressure differential surge sensor detected the pulsating signal of high pressure compressor exit, while the ratio of AC portion with DC portion exceeds the set threshold value of the engine eliminating system, surge signal is issued. The anti-surge module and automatic starting module of engine synthesis electronic controller give out command to correlated systems, and then it is to adjust gas path of physical dimension and oil flux, that is to say the engine eliminating system works. From fig 3 and fig 4, it can be in dictated while engine surge is occur, the pressure of oil main line is decreased, the angle of compressor stator blade is reduce, oxygen system and igniter body are work., LPC rotor speed and HPC rotor speed are decrease. Those phenomena indicate that surge is occur, oil supplying to main combustion is short-time cut off immediately. At the same time,
the angle of high compressor stator blade is reducing and automatic starting device is working. With the flow of fuel supply is reduce sharply, the temperature of combustion exit it is drop, LPC rotor speed and HPC rotor speed are decrease, compressor exit temperature and engine exhaust temperature are drop, the air flow from compressor is increase, engine surge is fade gradually.

The time of oil cut-off is about 0.5s. It is demand not to operate throttle during the course of engine surge, the flow of oil increase quickly after stopping oil cut-off, the angle of compressor stator blade, LPC rotor speed and HPC rotor speed and engine exhaust temperature are increase, that means engine is begin to acceleration.

From the design index of engine surge eliminating system: engine should have ability to recover stable working state. Because of disturbed board installed inlet, engine surge is occur again when engine state is increase, the state of engine is repeat from surge to working of surge eliminating system without operating throttle (fig 4). It is necessary to operate throttle to idle that engine surge is relieving. From the result of engine surge test on flight test bed, it is discovered that this method only can prove the working of engine surge eliminating system while surge occurred but cannot able to assess the reliability of engine surge eliminating system because the disturbed board fixed in inlet.

5. Summary of results

The test results show that the method using disturbed board on flight test bed can urge engine into surge during flight test. After analyzing the test results and data, it is discovered that this method only can prove the working of engine surge eliminating system while surge occurred but cannot able to assess the reliability of engine surge eliminating system because the disturbed board fixed in inlet.

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