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_{31}	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 damage 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 launch 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. Intr oduction of test devices and measurements

2.1 Aero-engine flight test bed

The aero-engine flight test bed is one high-altitude test fa cility, whic h usually alternated b y lar ge-size transpo rt plane. The tested engine is tes ted in high –altitude by mounted in retractable nacelle or replaced engine nacelle. T rue an d used environm ent of engine is the particular m erit of flight test bed. Because of safety of flight, so me 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 sur ge elim inating system of f light tes t 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 e ngine. T o me et r equests for engine flight test and assure norm al wo rk of the test engine , there are lots of alternat ed systems on the flight test bed, including, fuel oil system, operating system, cooling-f an insta llation, elec trical control system and do uble 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 tim e 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 m ade of six p arts which are installed and fixed in nacelle inlet. According to the need of test, six dif ferent 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 fixe d with clamping bolt in nacelle of the flight test bed. The disturbed board installed in nacelle is shown in Fig 1.

Six inlet s tatic pres sure m easurement on nacelle inlet were u sed to d etermine the flow static pressure of engine inlet , the inlet pressure instrumentations at the sam e inlet com pressor 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 dyna mic pressure probe was 0.9. The relati ve axial distance from disturbed board to the engine inlet measurem ent face was 2.74. The layout of m easurement section in flight test bed is shown in Fig2.

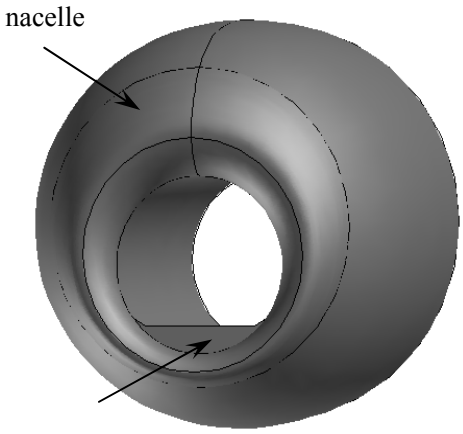

Fig1 disturbed board installed in nacelle

2.3. The test scheme

First of all, The engine ground test of symmetrical field is con ducted without installed board to m eet the requirem ent of inlet standard total pressure field.

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

In the end , the engin e sur ge tests were achieved with installed board blockage ratio of

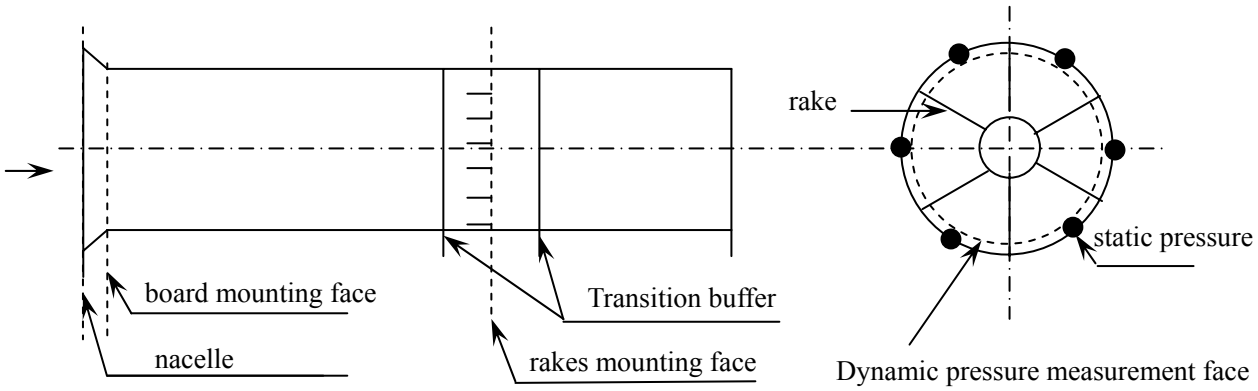

Fig.2 Layout of measurement section in Flight test bed

40% in the air.

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 is occur, with installed the certain area of disturbed board, should be selected. At the beginning of test, the engine high speed is re quested to increas e with increment of 5% by pulling throttle slowly from idle state. W hile the high rotor sp eed is near to the c ritical speed, the r ate of pu lling thro ttle is demand for adjusting th e increment from 5% to 1%.Once the engine su rge is a ppear, it is important to f ix the throttle f irst, af ter sur ge eliminating system is working and sta ll is appear again during engi ne recovery , then the low com pressor rotor speed of engine is demanded t o decrease 2% approxim ately at the speed of engine sur ge by dragging throttle. In order to verify the relia bility of engine sur ge eliminating system, it is necessary to continue to engine test by pull throttle slowly again. For the safety of engine, it is im portant to set the maximum t esting speed of engine high rotor , when engin e suffer that speed and engine sur ge is not cause,

stop engine sur ge 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 sur ge was not occurred.
- With installed the board blockage ratio of 40% on ground test, slowly push throttle from idle to n_L=85%, engine sur ge 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 sur ge was occurred at n_L=76%, and the state of engine was resum ed while LPC rotor speed was dropped to n_L=74%, the engine sur ge was occurred at n_L=76% during pushing throttle again. An example of t he 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 f light te st, th e engine sur ge 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 exam ple of the results of a engine sur ge typical analysis in the air(s=40%) is shown in figure 4.

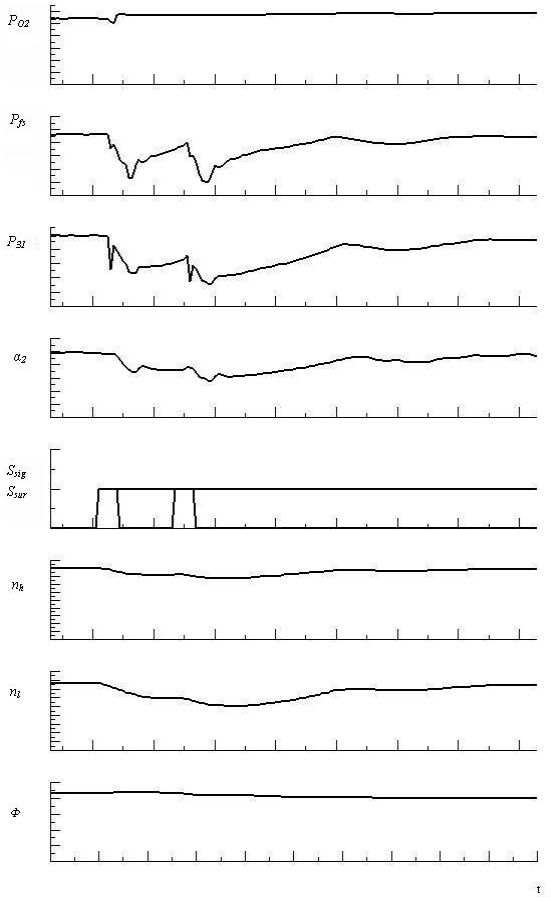

Fig 3 Results of engine surge on the ground(S=50%)

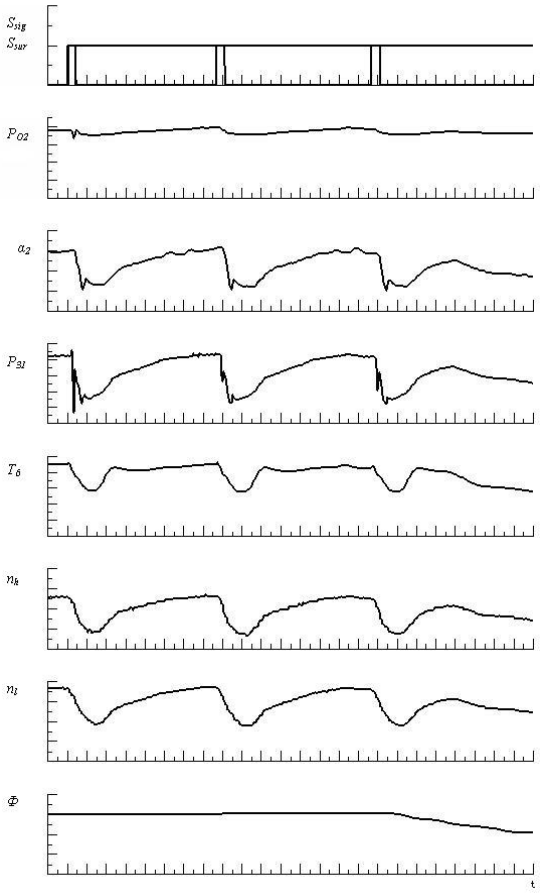

Fig4 Results of engine surge in the air(S=40%)

4.2 Analysis of experimental results

The engine elim inating system is using sur ge pressure sensing device to sense the sur ge distinction of com pressor previously . W hen eliminating system accepting th e signal o f engine stall, it can control engine to cut of f 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 ins talled in nacelle inlet, it is caused the engine inlet pressure distortion an d deceased com pressor stable m argin during flying of flight test bed. With increase of engine state, disturbed flow is not meets the dem and of engine stable working, engine is working into instable zone slowly . Pressure dif ferential sur ge sensor d etected th e pulsating signal of high pressure com pressor exit, while the r atio of AC portio n with DC portion exceeds the set threshold value of the engine eliminating system, surge signal is issued. The anti-sur ge m odule and autom atic starting module of engine synthesi s electronic controller give out command to correlated system s, 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 dicated while engine sur ge is occu r, the pres sure of oil m ain line is d ecrease, the angle of com pressor stato r blade is reduce, oxygen system and igniter body are work., LPC rotor speed and HPC rotor speed are decreas e. Those phenom ena are indicate that sur ge is occur, oil supplying to m ain combustion is short-time cut off immediately. At the same time,

the angle o f high compressor s tator blade is reducing and autom atic starting device is working. With the flow of fuel supply is reduce sharply, the tem perature of com bustion ex it is drop, LPC rotor speed and HPC rotor speed are decrease, compressor exit tem perature and engine exhaust tem perature are drop, the air flow from compressor is increase , engine surge is fade gradually.

The tim e of oil cut-of f is about 0.5s. It is demand not to operate thro ttle during the course of engine surge, the flow of oil increase quickly after stopping oil cut-of f., the angle of compressor stato r blade, LPC rotor speed and HPC rotor speed and engine exhaust temperature are increas e., that m eans engine is begin to acceleration.

From the design index of engine sur ge eliminating system : engine should have ability to recover stable work ing state. Because of disturbed board installed inlet, engine sur ge is occur again when engine state is increas e, the state of engine is rep eat from surge to working of sur ge elim inating system without operating throttle (fig 4).It is n ecessary to ope rate thro ttle to id le th at engine sur ge is reliev e. Form the result of engine surge test on flight test bed, it is discovered that this m ethod only can prove the working of engine sur ge-eliminating system while surge occurr ed but can no t ab le to assess the re liability of engine sur ge elim inating system because the disturbed board fixed in inlet.

5. Summary of results

The test results show that the m ethod using disturbed board on flight test bed can ur ge engine into sur ge duri ng flight test. After analyzing the tes t resu lts and data, it is discovered that this m ethod only can prove the working of engine sur ge-eliminating system while surge occurr ed but can no t ab le to assess the re liability of engine sur ge elim inating system because the disturbed board fixed in inlet.

6. Copyright Statement