ENGINE STARTING PERFORMANCE EVALUATION AT STATIC STATE CONDITIONS USING SUPERSONIC AIR INTAKE

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Abstract

The air intake and engine matching is quite important design problem in supersonic aircraft propulsion system because the air flow requirement of the engine and the capacity of air intake often disagree in wider range of flight speed regime. The air intake suitable for supersonic flight has such sharp lips at the mouth that possibly causes harmful flow distortion to the stable engine operation at subsonic flight or ground taxing. Unfortunately there is neither good estimation method nor appropriate database.

In this study, we have conducted engine test at test facility of Japan Aerospace Exploration Agency (JAXA), using a YJ69-T-406 turbojet engine along with a supersonic two dimensional external compression intake of a jet powered experimental aircraft to evaluate the influence of supersonic air intake on engine ground operation.

1. Purpose of test

The air intake system of this small supersonic experimental aircraft (Jet-SST) is designed to provide maximum performance at Mach number 1.7. For this reason the ramp and cowl edge of Jet-SST are sharp.

On the other hand, airflow from this edge tends to separate more easily at subsonic air speed or steady static condition. The less engine inlet airflow and increase of inlet distortion may have an influence on stable engine operation.

However, accurate evaluation of aerodynamic performance of this supersonic air intake at steady state ground condition using computational fluid dynamics (CFD) or wind tunnel testing is very difficult.

In this test, we made a full scale supersonic air intake and installed it to the engine. Then we have conducted an engine ground run using a test cell and evaluated the engine starting performance at static state conditions with the supersonic air intake.

2.Test model

2.1 Summary of Supersonic Air Intake System

The Jet-SST which is being developed by JAXA for future SST civil aircraft development, is designed to operate over a range of air speed, from steady static condition to Mach number 2.2 . The Jet-SST has a two dimensional external compression air intake. The artist impression of Jet-SST is shown in figure1. The arrangement of supersonic air intake is shown in figure2.

Figure1 Small Supersonic Jet Experimental Aircraft

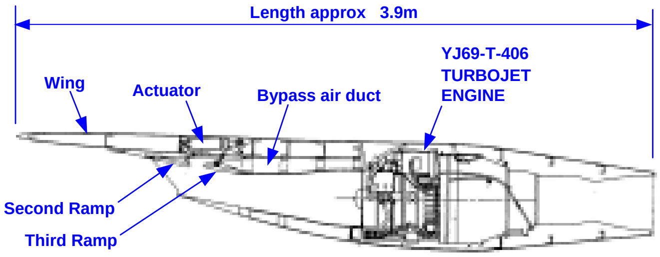

Figure2 Supersonic Intake system view

The second and the third ramp are movable according to the flight Mach number and engine thrust using an electric actuator and mechanical link.

A Teledyne Continental made YJ69-T-406 turbojet engine is used in conjunction with this supersonic air intake system. At supersonic flight condition, excess inlet airflow other than engine aspiration is ejected out of the intake through a bypass air duct.

2.2 Explanation of Supersonic Intake Test Model

This intake test model consists of the following three major parts:

(1) FWD intake that has a sharp edge and made of aluminum metal
(2) CFRP intake duct made of carbon fiber reinforced plastic
(3) Rake duct where pressure is measured

The figure and picture are shown in figure 3-1, 3-2, 3-3 and 3-4.

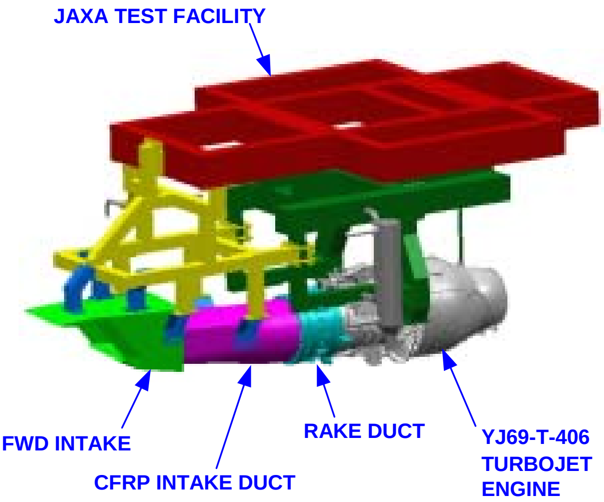

Figure3-1 Supersonic Intake Test Facility
(CATIA MODEL)

Figure3-2 Supersonic Intake Test Facility

Figure3-3 Supersonic Intake front view

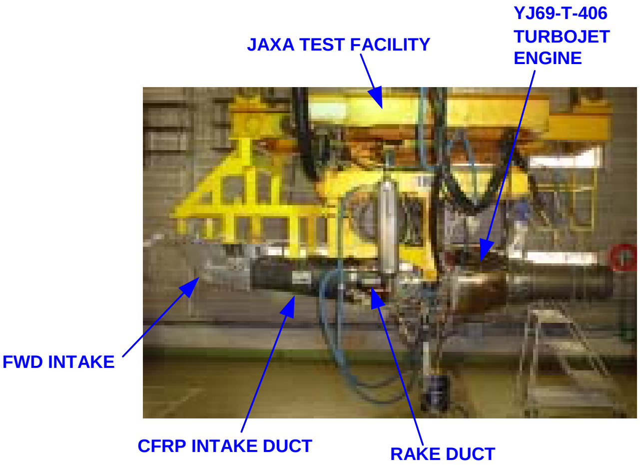

Figure3-4 Supersonic Intake side view

(1)The sharp edge of FWD intake is designed based on the intake mold line of the Jet-SST, but the right and left side, and up and down face are simplified from the original mold. These faces are made flat because they have no negligible influence on the evaluation of this test.

The auxiliary air inlet is located on the upper face of the supersonic air intake system.

The bypass air duct is located aft of the intake and bypass airflow is discharged as the actual aircraft intake system. Both the auxiliary air inlet and the bypass duct outlet are opened to the test atmosphere to allow air to be suctioned in case the airflow through the main inlet is insufficient.

(3) 49 total pressure sensors, 48 total temperature sensors, and 8 static state pressure sensors are attached to the rake duct. Total inlet pressure recovery and distortion level are calculated based on these data.

3 static state pressure sensors and 2 total pressure sensors are attached to the bypass duct to measure reverse airflow.

The ramp angle is fixed mechanically at Mach number 1.4 position which is the minimum height position of the intake system. This is different from the actual Jet-SST intake system that uses electric actuators for ramp angle control.

2.3 Explanation of Engine Test Facility

This test is conducted at test cell of JAXA.

In this test cell, YJ69-T-406 engine can be remotely operated while measuring pressure, temperature, and engine thrust. Pressure data of rake duct is measured and used to calculate inlet distortion level at the same time. During the test, special attention is paid not to exceed the inlet distortion limit of engine by monitoring these destortion data.

3.Contents of test

3.1 Test case

Ramp angle is set at Mach number 1.4 position while the auxiliary air inlet area and the bypass air inlet area are varied in three steps (Full Open, Medium Open, Full Close).

After engine start is completed, the engine revolution speed is kept at 85%rpm.

The auxiliary air inlet and bypass air inlet are shown in figure4. Test cases are shown in table1.

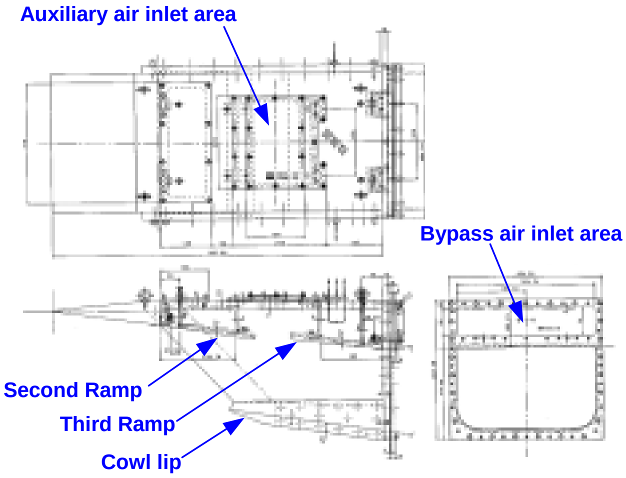

Figure4 FWD intake detail view

Table1 Test Case

Test Case	Auxiary air inlet area	Bypass air inlet area
Case1	Full Open	Full Open
Case2	Midium open	Full Open
Case3	Full Close	Full Open
Case6	Full Close	Midium open
Case9	Full Close	Full Close

3.2 Test Result

(1) Variation of Inlet Distortion

For all test cases, the distortion level does not exceed the limit of the engine.

Test result is shown in figure 5.

The case that shows the highest calculated KD2 is observed at the auxiliary air inlet full open case.

On the other hand, the case that shows the lowest calculated KD2 is observed at the auxiliary air inlet full close case.

This result indicates that when the auxiliary inlet is opened, airflow is added from the auxiliary inlet. This flow partially separates when going around the tip of the third ramp.

As a result, the distribution of pressure just in front of the engine becomes unequal, causing the distortion level to deteriorate.

(2) Change of Engine Inlet Total Pressure Recovery

The case that the auxiliary air inlet area and bypass air inlet area is full open shows engine inlet total pressure recovery to be maximum. On the other hand, the case that the auxiliary air inlet area and bypass inlet area is at its minimum shows engine inlet total pressure recovery to be minimum.

See figure 6 for test result. See figure 7 for total pressure recovery distribution data.

The pressure distribution in figure 7 shows that when the auxiliary intake is opened and air starts to flow in, the flow separation from the lip of the third ramp becomes apparent which indicated by the total pressure recovery ratio of the upper half(ramp side) being lower than that of the cowl side.

On the other hand, when the auxiliary air intake is fully closed and the airflow from the FWD intake becomes the primary flow, flow separation from the cowl lip becomes apparent. This is shown by the deterioration of the total pressure recovery ratio in the cowl side.

Due to the decline of engine inlet total pressure recovery, the engine thrust decreases by 10% and exhaust gas temperature is 40 degrees higher when compared to a test result from a test using a standard bell mouth inlet.

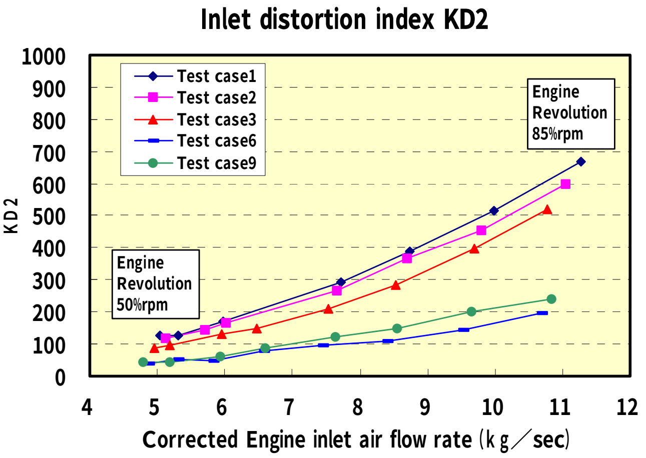

Figure5

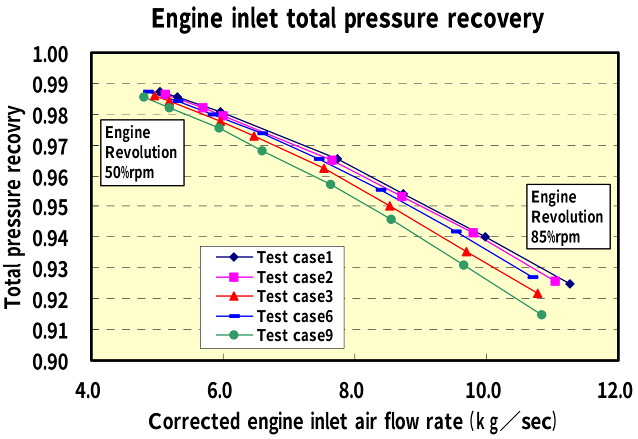

Figure6

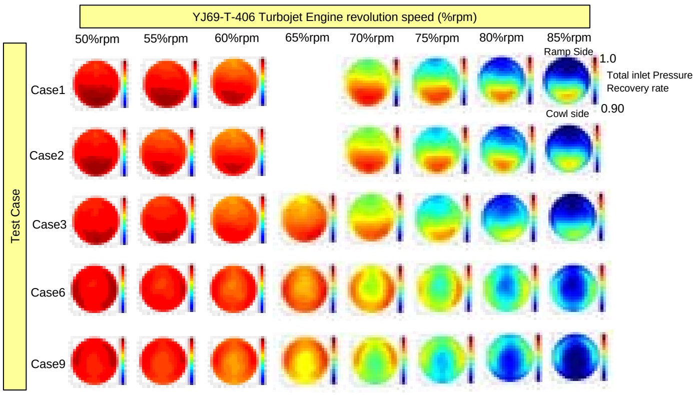

Figure7 Pressure Distribution

4.Conclusion

(1) It is found that it is possible to conduct an engine ground run of a supersonic air intake without using a special device designed to prevent flow separation.

(2) Jet SST development can be continued without major design change since no modification such as additional device or auxiliary air inlet attachment to the wing is found to be necessary

(3) The engine performance shows a slight decrease in thrust and slight increase in engine exhaust temperature. However, these are not major influence on engine performance.

The distortion level remained within limit and the engine operation was very stable.

(4) Domestically, the intake performance including distortion are mainly evaluated in wind tunnels test, therefore, the evaluation of this study that the engine is conjunction with intake is first time.

Finally, the supersonic air intake system of the Jet SST is especially designed to the demand of least drag and superior performance in the supersonic flight regime, therefore, its intake forward lip is very sharp when compared to those of other aircraft. For this reason, effect of airflow separation at the cowl lip has on engine ground starting performance was our major concern in Jet SST development. However, this engine ground run enabled proper evaluation of engine ground starting performance and allowed us to obtain valuable data. The significant result for propulsion system design was obtained.