EXPERIMENTAL STUDY OF SUPERSONIC INLET FOR SUPPRESSION OF BUZZ IN SUBCRITICAL OPERATION

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Abstract

Small supersonic transport is being examined as a target of technologies for supersonic aircraft in JAXA. Propulsion airframe integration technology is one of the key technologies for the supersonic aircraft. The noble concept to extend stable operation of a supersonic inlet is examined in this study. The concept consists of two considerations. One is suppression of the occurrence of buzz in subcritical operation, and another is reduction of spatial distortion in supercritical operation.

The basic idea of the concept is based on the experimental results that buzz is not observed when the subsonic diffuser is straight duct even in the condition that the shear layer from the triple point of shock system is ingested (Ferri criteria). In this paper, this idea was applied to the concept of the diffuser divided by splitter plate. The concept was verified by means of wind tunnel test using the supersonic inlet for jet-powered experimental airplane developed in JAXA.

1 Introduction

Small supersonic transport shown in fig.1 is being studied in JAXA. It is considered as the reference aircraft of the technologies which are important in order to realize the economy viable and environmentally acceptable SST. Main issues are how to reduce sonic boom, aerodynamic drag and airport noise. Propulsion airframe integration design is thought to be one of the key technologies for these problems.

For PAI design, it is important to deal with various layout of the nacelle on the airframe to meet the requirement from aerodynamic design. However, various layout sometimes causes serious problems. The layout of the top mounted nacelle in order to reduce the sonic boom, for example, makes inlet operation more unstable than the typical layout that the nacelle mounted under the wing. It is because distorted flow such as boundary layer developed on the airframe or vortices from the various portion are ingested into the inlet. Basically, buzz is more likely to occur for the subcritical operation of the inlet immersed in the distorted flow. Spatial distortion increases in supercritical operation as well[1]. Therefor, technologies to extend stable operation range of a supersonic inlet would be a important solution to make the nacelle layout more freely.

In order to extend stable operation range, mass flow control techniques such as variable ramp system have been applied to the inlet. However, these techniques usually require complex system. The main objective of this

Fig.1. Schematic of small supersonic transport

study is to create new concept to which any complex system is not necessary. Verifying the effect of the concept to extend stable operation range of inlet and its applicability to the inlet system by means of wind tunnel test is also the main part of this paper.

2 Basic idea

Figure 2 shows the simplified inlet model installed in JAXA supersonic wind tunnel. The ramp with the angle of 5 degrees is isolated from inlet duct in order to remove the effect of boundary layer being developed on ramp wall. This means the buzz of Dailey criteria[2] would be completely avoided. The inlet duct is being able to set to two kinds of area ratio. One is diffuser duct with area ratio of 1.3. Another is straight duct. The operation condition of the inlet is controlled from supercritical to subcritical by means of the flow plug, set downstream of the duct, with progress of time. Free stream Mach number is 2.0. It is enough condition that buzz of Ferri criteria[3] occurs.

The result of wavelet analysis for the pressure time history inside the diffuser duct shows strong pressure oscillation in subcritical operation range(fig.3(b)). This is caused by buzz of Ferri criteria that occurs when the shear layer is ingested into the duct (fig.3(a)). As seen in right photo of fig.3(a), the stream tube of lower side of the shear layer is extending as going downstream of the diffuser duct to balance the pressure across the shear layer in adverse pressure gradient.

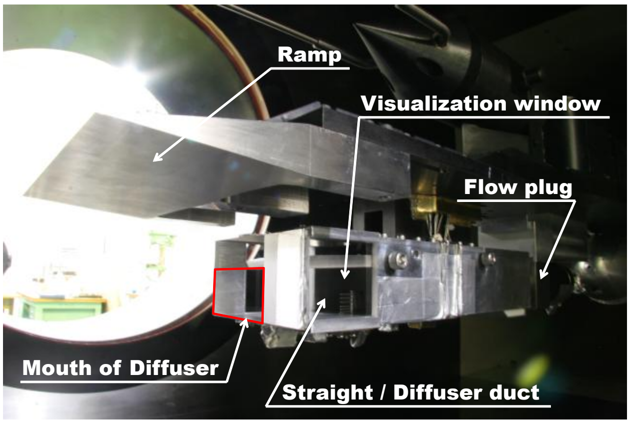
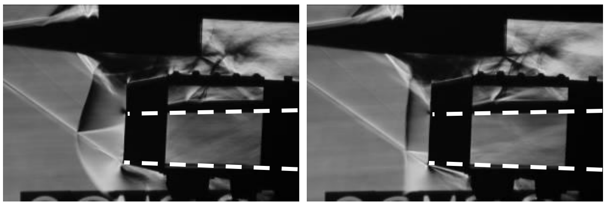
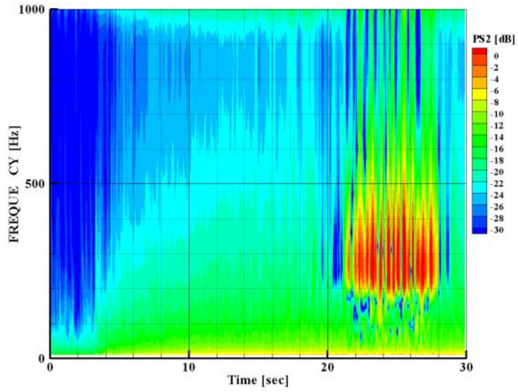


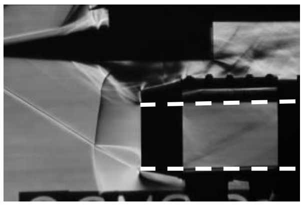
Fig.2. Simplified inlet model



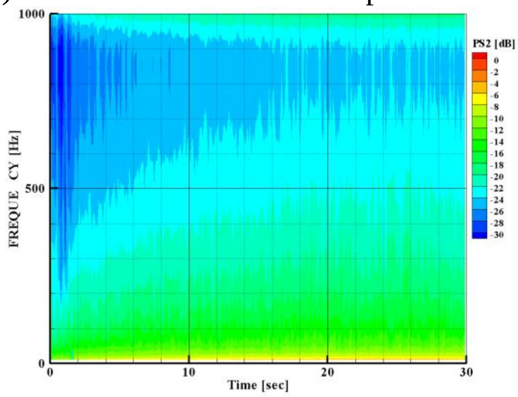
(a) Periodic shock oscillation in buzz condition



(b) Wavelet analysis for pressure oscillation
Fig.3. Flow of inlet with diffuser duct



(a) Stable flow in subcritical operation range



(b) Wavelet analysis for pressure oscillation
Fig.4. Flow of inlet with straight duct

Figure 4 shows the result for the inlet with straight duct. In this case, buzz of Ferri criteria is completely avoided. It is thought that the stream tube does not extend under the condition of zero pressure gradient. This important result, that the buzz is never observed for straight duct, is the basic of the new concept of the inlet to extend stable operation range.

3 Concept of diffuser duct devided by splitter plate

3.1 Configuration of inlet with splitter plate

As a concept of inlet diffuser to extend stable operation range, the subsonic diffuser was divided by the splitter plate. This concept was applied to the inlet for jet-powered experimental airplane shown in fig.5. Inlet is two dimensional external compression type. Design Mach number is 2.0. In order to avoid buzz in subcritical operation, mass flow control using variable ramp was applied[4]. Figure 6 shows schematic of the inlet with the splitter plate inside the subsonic diffuser. Two kind of configurations of splitter plate, plate A and plate B, were examined in this study. Hereafter, the diffuser duct without splitter plate is called “single duct”. The subsonic diffuser divided by plate A consists of straight duct and diffused duct. The straight duct is cowl side, where the shear layer which causes buzz occurrence is ingested. Whereas the diffused duct has larger area ratio than that of single duct. Plate B divides the area of the single duct equally. In this case, diffuse angle of divided duct become roughly half to single duct.

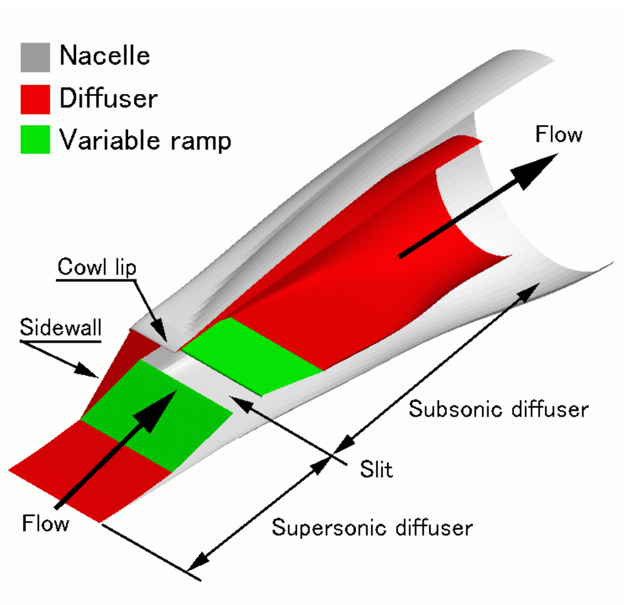
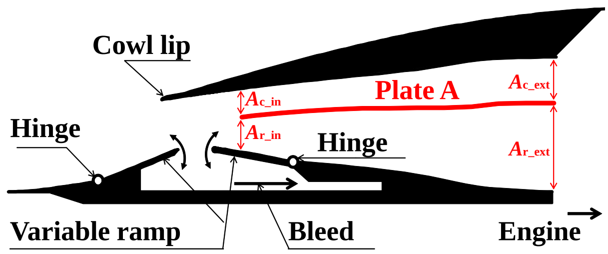
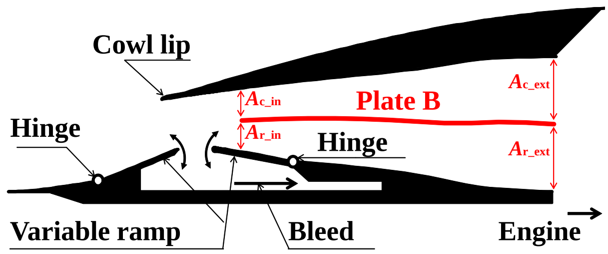


Fig.5 Supersonic inlet with variable ramp



(a) Configuration of splitter plate A



(b) Configuration of splitter plate B

Fig.6 Schematic of inlet

3.2 Wind tunnel test

Figure 7 shows experimental model using wind tunnel test at JAXA supersonic wind tunnle. Second and third ramp shown green in fig.5 is variable geometry, which is preset by changing ramp block. There is a slit between variable ramps where the boundary layer bleeding is applied. The quantity of the bleed is set to the appropriate value selected in the former project. Unsteady total pressure distribution at the exit plane of the inlet was measured by means of unsteady total pressure rake which consists of fifty pressure transducers. Mass flow ratio of the inlet is controlled by the flow plug. Experiment was carried out under the condition of free stream Mach number at 2.0. As a parameter of inlet configuration, three kind of diffuser configurations, single duct, plate A and plate B, were examined. About the angle of variable ramp, both larger value, 14.4 deg, and smaller value, 9.6 deg, than the value of design point, 12 deg, were examined as well. Duration of the wind tunnel is 30 seconds. In the meantime, flow plug was moved to change inlet operation condition from supercritical to subcritical. Flow field around the inlet was visualized by schlieren technique. Images were recorded on

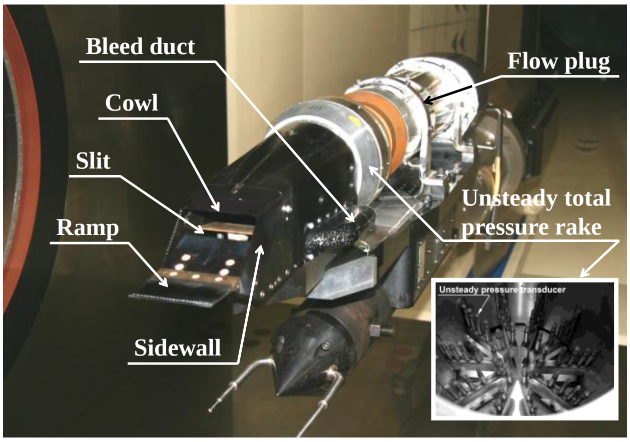


Fig.7 Experimental model

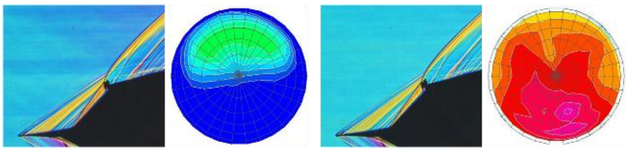
the still camera and the high speed video camera.

4 Evaluation of inlet performance

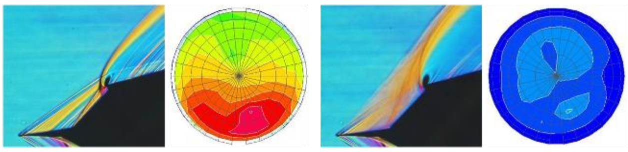
Figure 8 show a typical results, schlieren image, total pressure distribution and pressure recovery, obtained for single duct with nominal ramp angle 12 deg. Flow regime is basically distinguished into four stages having unique characteristics for each. First stage I is supercritical condition. In this stage, The spatial distortion is large and the distortion indices varies irregularly with time. Second stage II is typical engine operation range, in which stable flow with high pressure recovery is obtained. Third stage III is the range that buzz of Ferri type likely occer. In this stage, unstable flow accompany with shock oscillation appears. Spatial distortion indices also become larger than that of stage II. In final stage IV, buzz of Dailey type appears. Pressure distribution looks uniform, however, it was the result of averaging intense pressure oscillation. Shock pattern is not clear because of shock oscillation with large amplitude. Obviously, stage IV should be avoided for the safe engine operation.

There are several points which should be watched, to extend stable operation range of the inlet. First point is how spatial distortion is reduced in stage I. It is important to reduce not only the value of distortion indices, but also the variation of indices in time. Second point is suppression of Ferri type buzz in stage III. Third point is to shift the point of incidence of Dailey type buzz to the lower mass flow ratio. Final point is to keep the pressure recovery at high value in stageII. Because pressure recovery affects to the thrust of engine directly.

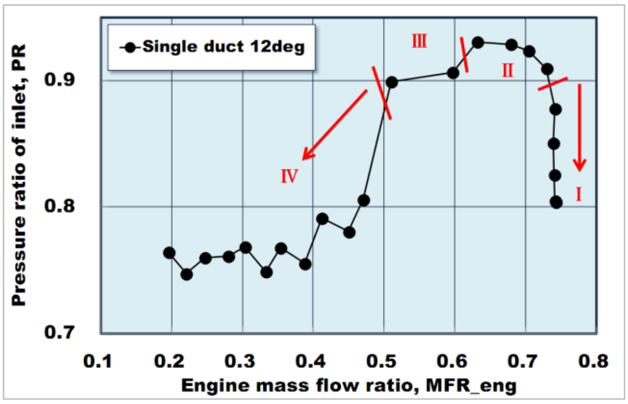
Spatial distortion is evaluated using circumferential index CDi and radial indices RDi_Hub and RDi_Tip prescribed in SAE guideline [5]. Total pressure oscillation is evaluated by averaged value of the root mean square values of pressure time history obtained from each pressure transducers. In order to express the matching to the engine operation, the value of mass flow ratio divided by pressure recovery was used.



(a) Stage I (b) Stage II



(c) Stage III (d) Stage IV



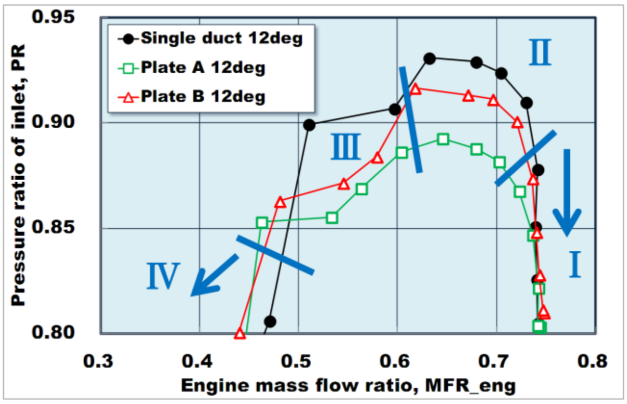
(e) Pressure recovery

Fig.8 Typical result of inle flow

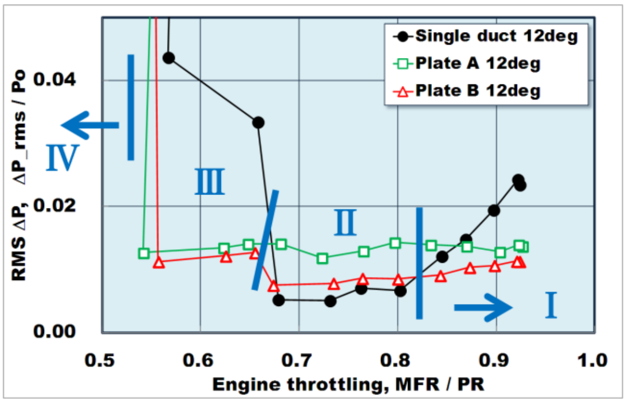
5 Improvement of inlet performance

5.1 Effect of splitter plate

Figure 9 shows aerodynamic performance for three kinds of inlet. Inlet with single duct is highest pressure recovery and is most stable in stage II. Thus this inlet has highest aerodynamic performance, however the stable operation range is not enough for wide engine operation [4]. In the stage I, rms value of total pressure oscillation become larger as engine throttling increases for the single duct inlet. Whereas the case for inlet with splitter plate, it remain almost constant at the value in stage II. This means that

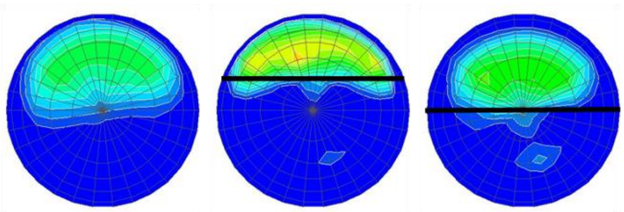


(a) Pressure recovery



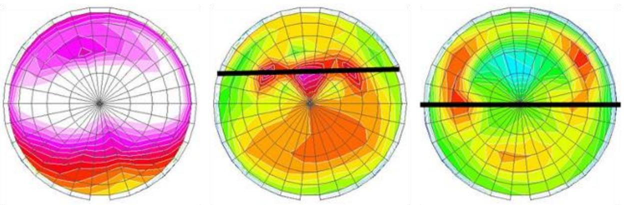
(b) Total pressure oscillation

Fig.9 Performance of inlet



(a) Total pressure distribution

(Left: single duct, center: plate A, right: plate B)



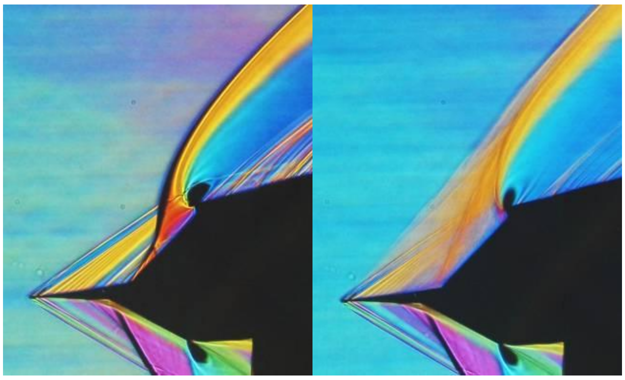
(b) Distribution of RMS value of total pressure oscillation

(Left: single duct, center: plate A, right: plate B)

Fig.10 Pressure distribution in stage I

the flow is stabilized by the splitter plate. As shown in fig.10, total pressure oscillation is large at mixing region between the flow core and the flow with low total pressure in single duct. Whereas the cases with splitter plate, the flow core is separated from the flow with low total pressure by the splitter plate. This is thought to result in the flow stabilization.

In stage III, Ferri type buzz occurs for the inlet with single duct. While in cases with splitter plate, buzz is suppressed. Even at the corresponding condition for single duct at incidence point of stage IV, flow is still stable for the case of the inlet with plate B as shown in fig.11. This is the most important result that the Ferri type buzz is completely avoided. Comparing the results for the case with different splitter plate, flow for plate B is stabler than that of plate A. It is thought to be the difference of area distribution of the duct. Diffuser duct with plate A is divided into straight duct and more diffused duct (fig.6(a)). The pressure oscillation in straight duct is very small even in case that shear layer is ingesting, because there is no adverse pressure gradient inside duct (Fig.12). However, in the duct of opposite side, adverse



(a) Plate B (b) Single duct

Fig.11 Comparison of shock pattern near the boundary of stage III and IV

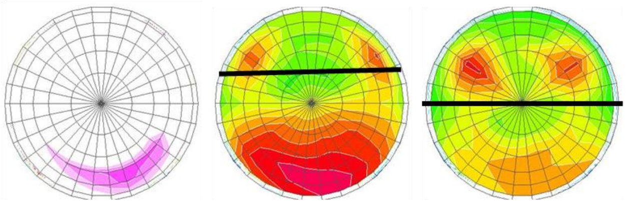
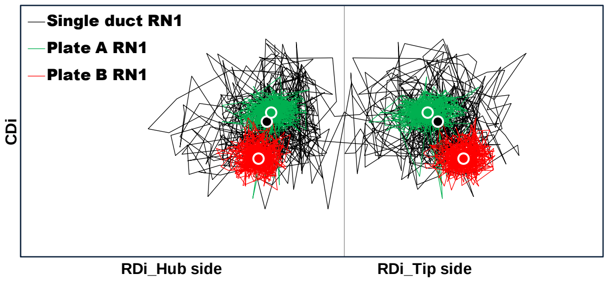


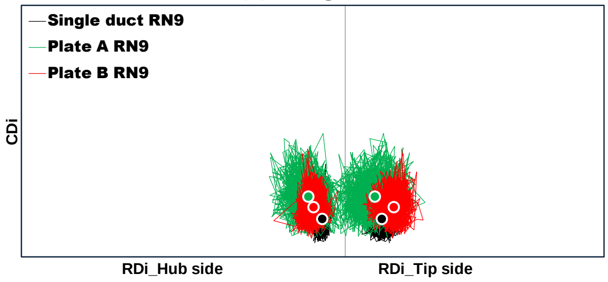
Fig.12 Distribution of RMS value of total pressure oscillation in stage III

(Left: single duct, center: plate A, right: plate B) pressure gradient is stronger than that of any other duct. Stronger adverse pressure gradient causes larger total pressure oscillation as shown in center figure of Fig.12. As a result of summation, total pressure oscillation of plate A is larger than that of plate B. Pressure recovery of plate B is smaller for a same reason.

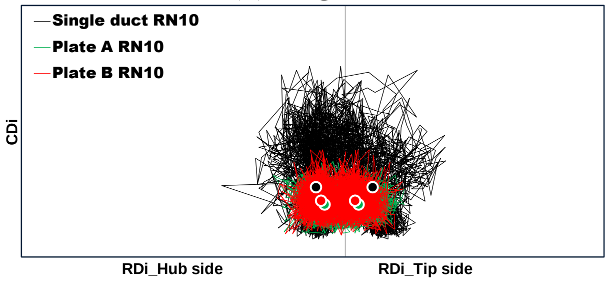
Figure 13 shows the change in relation of radial distortion indices and circumferential distortion index for each stage. Both averaged value of indices and temporal variation become smaller by applying splitter plate except in stage II. This is similar for the total pressure oscillation as shown in fig.9.



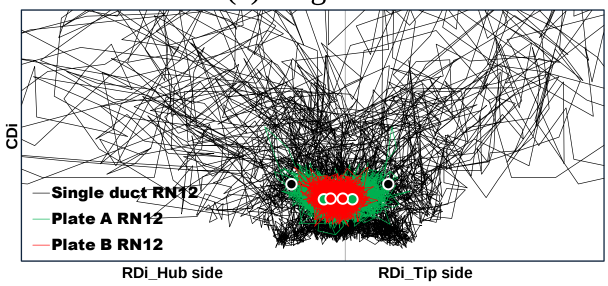
(a) Stage I



(b) Stage II



(c) Stage III



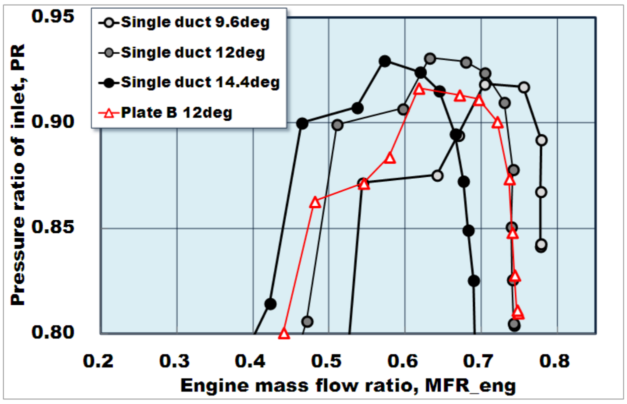
(d) Stage IV

Fig.13 Change in relation of radial distortion indices and Circumferential distortion index

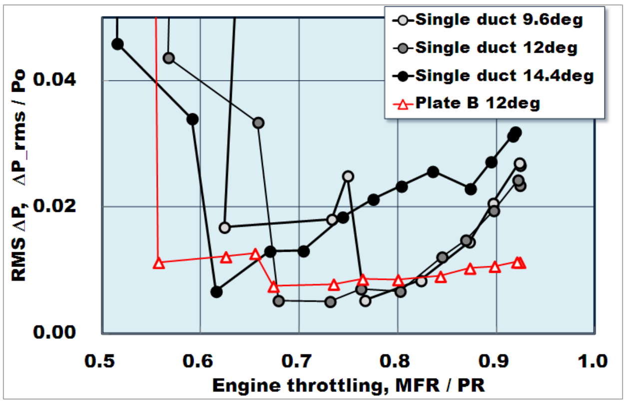
The inlet with plate B is thought to be the best to extend stable operation range of the inlet comprehensively. Stable operation region was extended roughly two times in terms of the operation of the engine. However, the pressure recovery was reduced about 1.5 percent. It is inevitable because inserting the plate into the flow means increase of wetted area which results in increase of viscous loss.

5.2 Comparison of the effect of splitter plate with variable ramp technology

Figure 15 shows the comparison the effect of the current concept, which is to extend stable operation region of the inlet, to the effect by means of variable ramp technology. Ramp angle for the single duct was varied from 9.6 degrees to 14.4 degrees to demonstrate the effect of the variable ramp technology. Comprehensive



(a) Pressure recovery



(b) Total pressure oscillation

Fig.15 Comparison of effect between current concept and variable ramp technology performance of the variable ramp should be thought the envelope curve of three performance curves.

About pressure recovery, variable ramp system has an advantage. By shifting performance curve using variable ramp, the ingestion of shear layer causing pressure loss is avoided. Similar effect is seen in supercritical condition as well. Whereas about total pressure oscillation, current concept has an advantage. Effect of stabilizing the flow in stage I and stage III is better than that for the variable ramp system.This means that the stable operation range of the inlet becomes much wider.

6 Conclusions

The new concept of the inlet, that the diffuser duct is divided by the splitter plate, in order to extend stable operation range was examined. The idea is based on the fact, obtained from wind tunnel test using the simplified inlet model, that the occurrence of buzz is avoided when the subsonic diffuser of the inlet is straight duct. The effect of the concept was verified in the wind tunnel test using two dimensional external compression inlet which design Mach number is 2.0. Stable operation range of the inlet is extended about two times in terms of the operation of the engine, which is wider than the result applied variable ramp system. The splitter plate also has the effect to reduce pressure recovery, however, it was found to be small. Comprehensively, applicability of the current concept to the inlet is thought to be promising.

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