EXPERIMENTAL AND NUMERICAL INVESTIGATION ON LIPLETS FOR WING/NACELLE INTERFERENCE DRAG REDUCTION

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Abstract

Transonic wind tunnel test and three dimensional Euler calculation were carried out on wing/nacelle interference for transonic transports with nacelles under the wing. To reduce the interference drag, a new aerodynamic device, Liplet, was developed. Liplet is a small wing installed on both sides of the pylon just downstream of the upper part of the nacelle fan cowl trailing edge, to control the flow in the interference region between wing and nacelle.

A wing-body configuration half model with an ejector powered nacelle was tested in Fuji Heavy Industries' 61cm high speed wind tunnel. Several shapes of liplets were designed and tested at transonic cruise condition. Drag reduction by installing the liplet was observed by the measurement of three-component force and wing surface pressure distribution.

Three dimensional Euler calculation was also carried out. A finite volume code using overlapped grid method was successfully applied to calculate the flow field around the wing-nacelle/liplet configuration. The numerical result reveals the effect of the liplet to the wing surface pressure and detailed flow field.

1. Introduction

Underwing nacelle is a conventional way of installation for transport aircrafts as discussed in many publications, and it is known that aerodynamic interference occurs between the wing and the nacelle. [1], [2]

The nacelle position relative to the wing is the main factor to the interference drag. The engine positioning chart published by the Boeing company shows the region for the acceptable installation drag level derived mainly from wind tunnel methodology, and it also shows that almost all existing transports is inside this region. [3] It shows that conventional way to suppress the interference drag is to set the nacelle position away from the wing leading edge.

Recently, large diameter high bypass ratio turbofan engines are developed to improve the efficiency. In case of such an engine, especially for small aircrafts, the nacelle position has to be closer to the wing to keep the ground clearance, or longer landing gear length is required. This causes the increament of interference drag or weight penalty.

Additional fairing on the wing/pylon or nacelle is also applied to assist the interference drag reduction, but it requires fairly big shape modification to the wing and nacelle configuration.

The authors have developed an aerodynamic device, liplet, to reduce the interference drag between the wing and nacelle. [4] It does not require big shape modification, but is just an addition of a small wing-like shape device. This paper presents the wind tunnel test results along with the CFD results on the liplet effect.

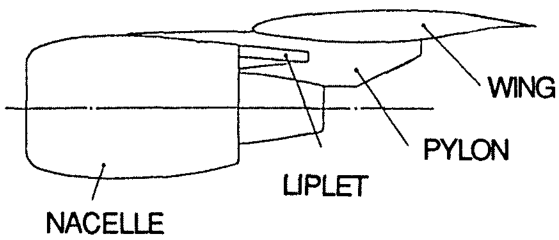


FIGURE 1. LIPLET

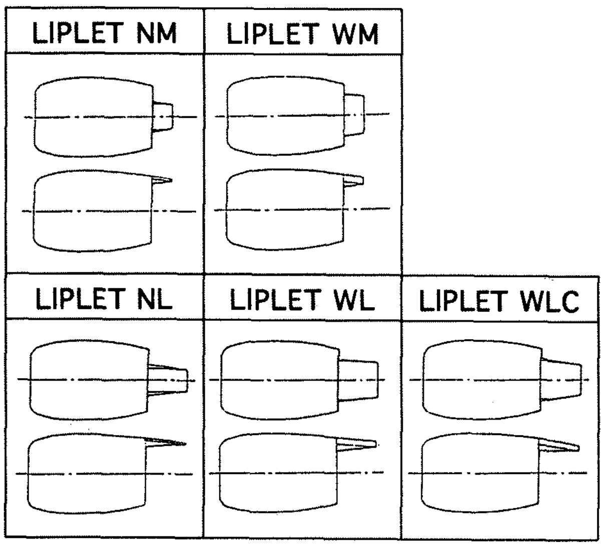


FIGURE 2. LIPLET CONFIGURATIONS

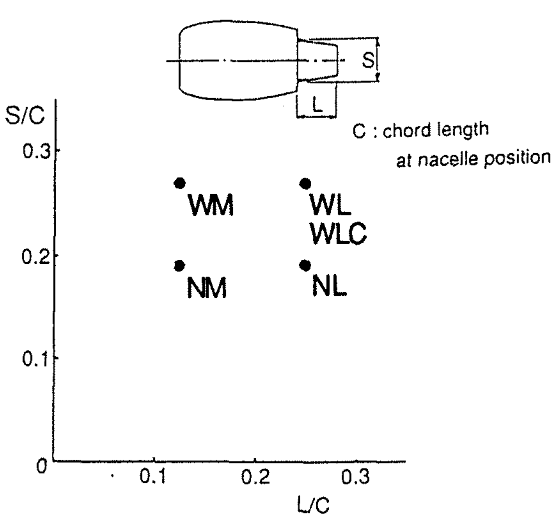


FIGURE 3. LIPLET SIZE

2. Liplet Concept

To reduce the interference drag, a new aerodynamic device, liplet, was developed. Liplet is designed to control the flow in the interference region locally; the engine outflow and the flow around the wing.

Figure 1 shows the schematic sketch of the liplet. The liplet is a small wing installed on the pylon just downstream of the upper part of the nacelle fan cowl trailing edge and its shape is smoothly contoured from the nacelle fan cowl.

Liplet length was derived by the consideration of the nacelle positioning chart. In this study, nacelle is located at the position close to the wing, outside the acceptable interference drag level region. Lipet length is set so as to move its trailing edge position into the region. And its width was set to about the half of the fan exit diameter.

Figure 2 shows the plan and side view of the lipet configurations designed and tested in this study, and thier size normalized by the wing chord length at nacelle position are shown in figure 3.

3. Wind Tunnel Test

Test Facility and Test Model

Wind tunnel test was carried out in Fuji Heavy Industries 61cmx61cm high speed wind tunnel (figure 4). Wind tunnel test model is a transonic transport wing-body configuration half model, with a nacelle under the wing and is mounted on the sidewall balance. Figure 5 shows a picture of the model installation in the wind tunnel. To simulate the engine power effect, an ejector type nacelle was used. The nacelle was

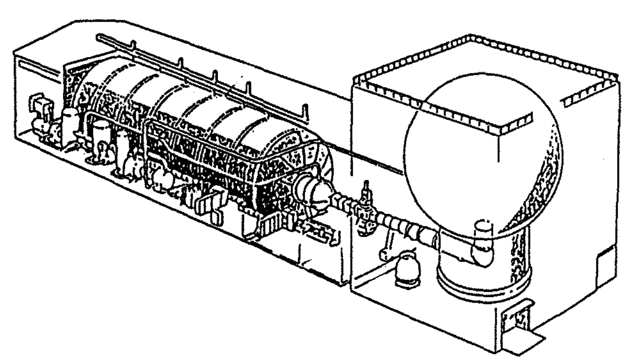


FIGURE 4. FHI 61cm HIGH SPEED WIND TUNNEL

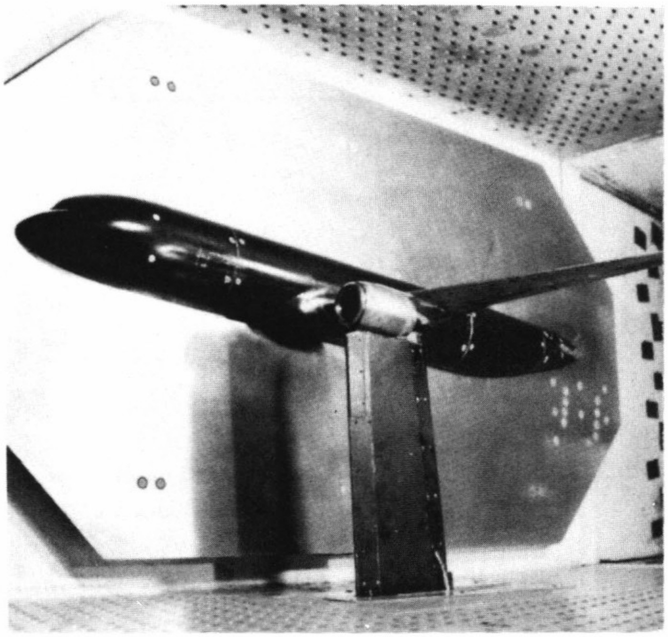


FIGURE 5. MODEL INSTALLATION

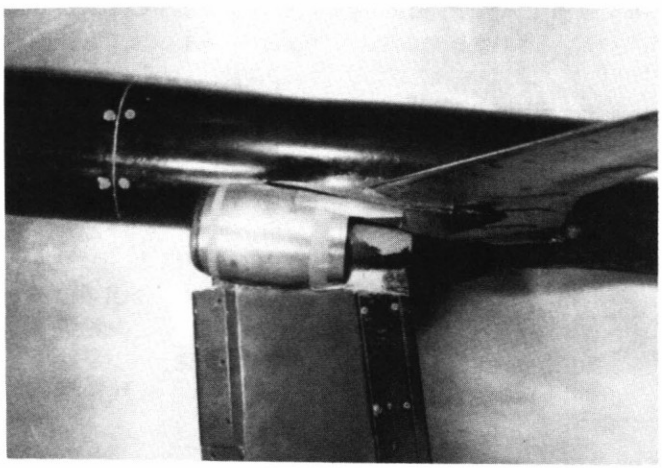


FIGURE 6. NACELLE WITH LIPLET

mounted on a strut from the wind tunnel lower wall to supply the high pressure air to the ejector. Liplet was installed on the nacelle trailing edge, several shapes of liplet were tested, two types of length and two types of width and different cambers shown in figure 2 and 3. Figure 4 shows a closeup view of the nacelle installation with the liplet.

Five rows of wing surface pressure distribution and three component force by the sidewall balance were measured. The sidewall balance measures the force acting on wing, body and pylon. The nacelle and liplet are not metric, because they are mounted on the strut from the tunnel lower wall.

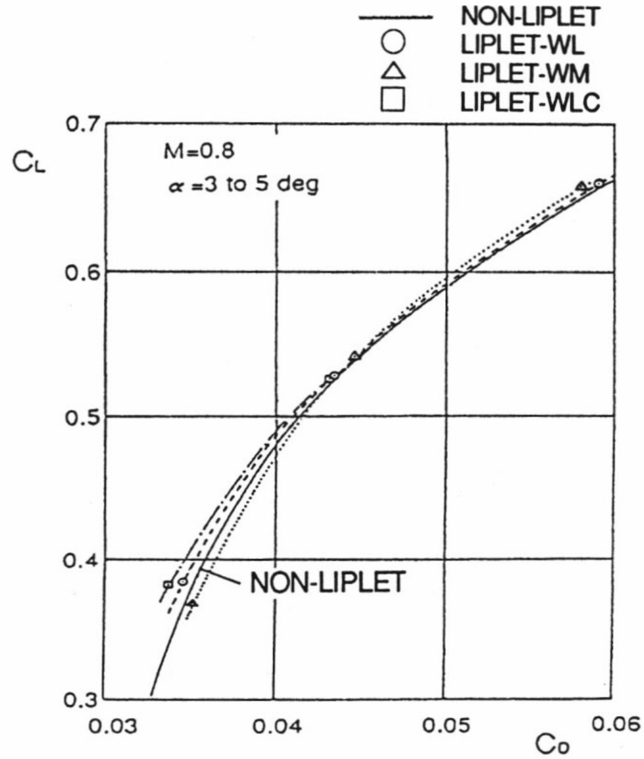


FIGURE 7. DRAG REDUCTION EFFECT BY INSTALLING THE LIPLET

Test Condition

Test condition was set to simulate the typical cruise condition of transonic transport aircrafts; Mach number was from 0.6 to 0.9, and the angle of attack from 3 to 5 degrees around cruise CL. Reynolds number based on the wing chord length is around 1×10^6. The pressure of the ejector air was chosen to simulate the typical fan engine at transonic cruise condition.

Test Results

Figure 7 shows the comparison of drag polar at the condition of Mach=0.8 and angle of attack from 3 to 5 degrees. Solid line shows the non-liplet configuration, and others are three types of liplet configurations; WL, WM and WLC. In this figure, the result of the wider type liplets are shown as a typical case. Design condition of the wing tested is CL=0.5. Liplet WL and WLC shows several counts of the drag reduction at the wide CL condition, and liplet-WM at high CL condition. The narrow type liplets, NM and NL, are not shown in this figure, but they showed less effective to the drag reduction.

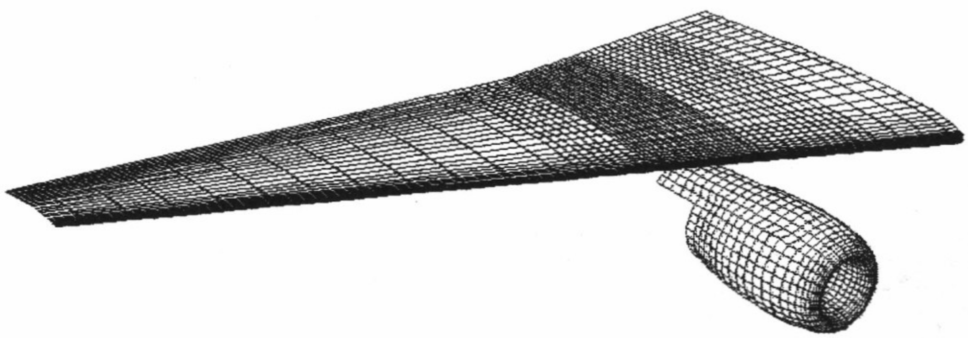


FIGURE 8. NUMERICAL MODEL / SURFACE GRID FOR LIPLET-WL CONFIGURATION

4. Numerical Analysis

Besides the experimental approach, CFD is an effective method to examine the flow field around the aircraft. But it requires huge computational time and special technique to treat the flow field around the complex geometry. According to the progress of super computer and numerical scheme, CFD method has been recently applied to the engine/airframe integration.

In this study, we also carried out a numerical analysis to calculate the flow field caused by the liplet and examine its effect.

Computation Model

Wing/nacelle configurations with and without the liplet were chosen as a computational model. Liplet-WL was chosen as the liplet configuration, because it showed the drag reduction in the wind tunnel test. The shape of the computational model is basically same as the wind tunnel test model. But the nacelle was treated as a flow-through type and pylon was not installed, because of the simplification of the calculation. Figure 8 shows the computational model / surface grid system for liplet-WL configuration.

Numerical Method and Grid system

The governing equations, time dependent three dimensional Euler equations, are solved with a cell centered finite volume algorithm and the flux vector splitting method of Van Leer is used for space discretization. [5] The equations are advanced in time using two stage Runge-Kutta method, and local time stepping is used for convergence acceleration to the steady state.

Overlapped grid method is applied to calculate the flow field around complex geometry like wing and nacelle configuration. Computational grid is generated for each component, and the flow calculation is carried out on each grid system. And then interpolation of the flow field is carried out for the interconnecting regions. As cell centered finite volume method is applied, variables are interpolated based on the coordinates of C.G. of the each cell in the interconnectiong region. [4], [6]

Two grid systems are generated around the wing and the nacelle. Grid system used is 121x 71x80 CH-type for the wing, 57x33x20 CO-type for then nacelle without liplet and 67x33x20 for the nacelle with liplet. Total number of grid points is about 700000. Overall grid system is shown in figure 9 and the detail at the nacelle center line position is shown in figure 10.

Numerical Results

Figure 11 shows the comparison of pressure coefficient contours on the surface and nacelle centerline plane at the condition of Mach 0.8, angle of attack 3 degrees; (a) non-liplet configuration, (b) Liplet-WL. Figure 12 also shows the detail of the pressure contours at the nacelle centerline plane. Comparing these figuers, the flow field above the wing is almost same but small change caused by the liplet can be seen in the flow field under the wing.

Figure 13 shows the comparison of wing surface pressure distribution at nacelle center line position. Dashed line is non-liplet, and solid line is Liplet-WL configuration. Lower surface pressure distribution is significantly changed by installing the liplet.

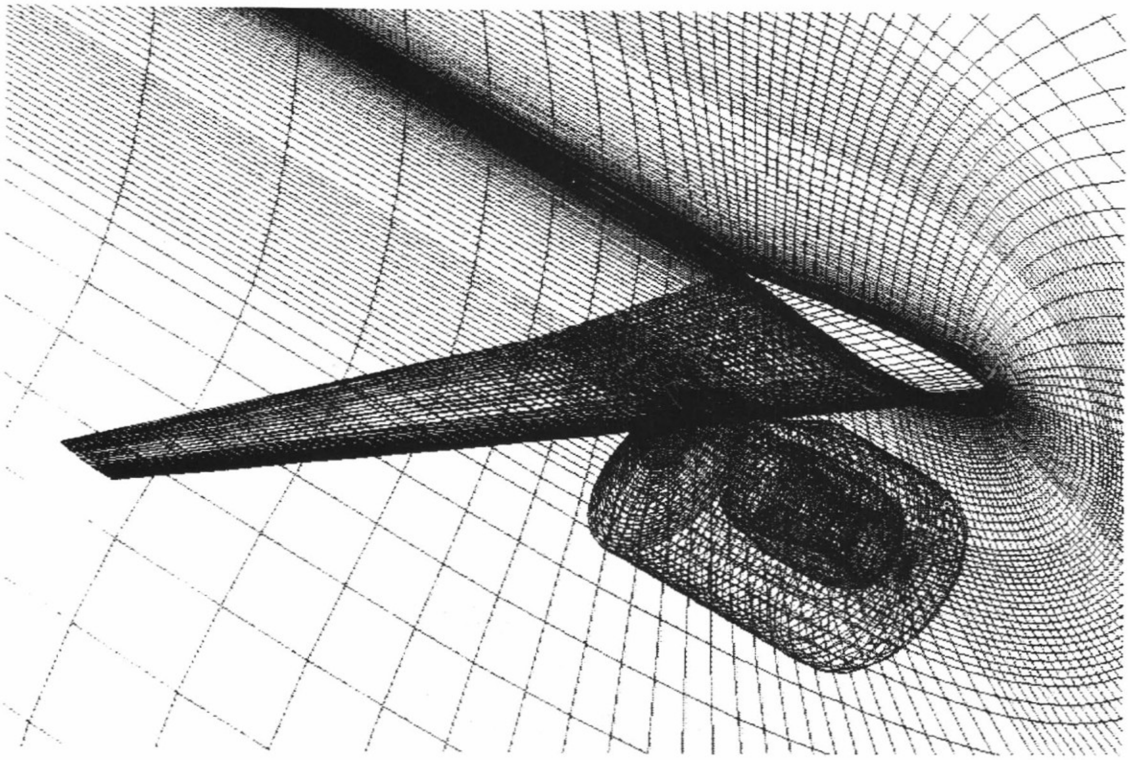


FIGURE 9. NUMERICAL GRID AROUND WING/NACELLE WITH LIPLET CONFIGURATION

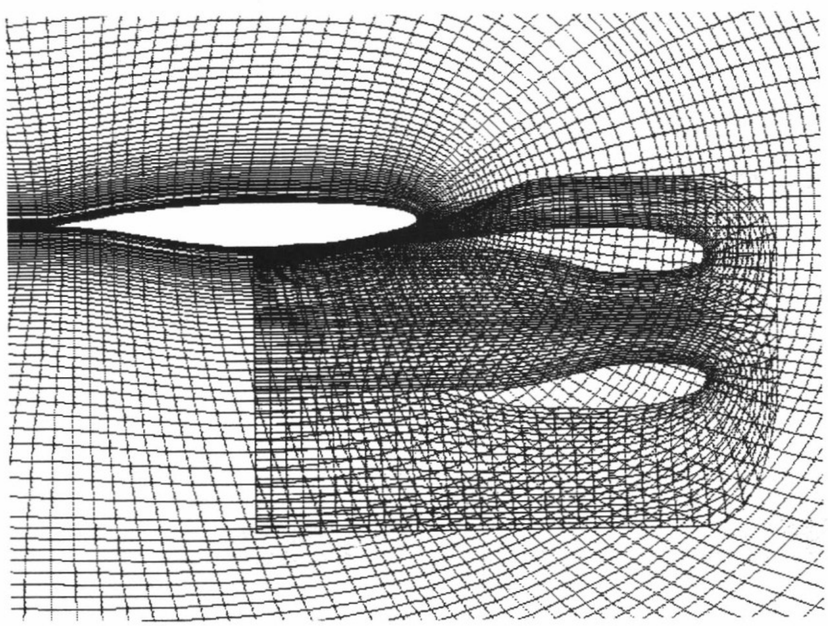
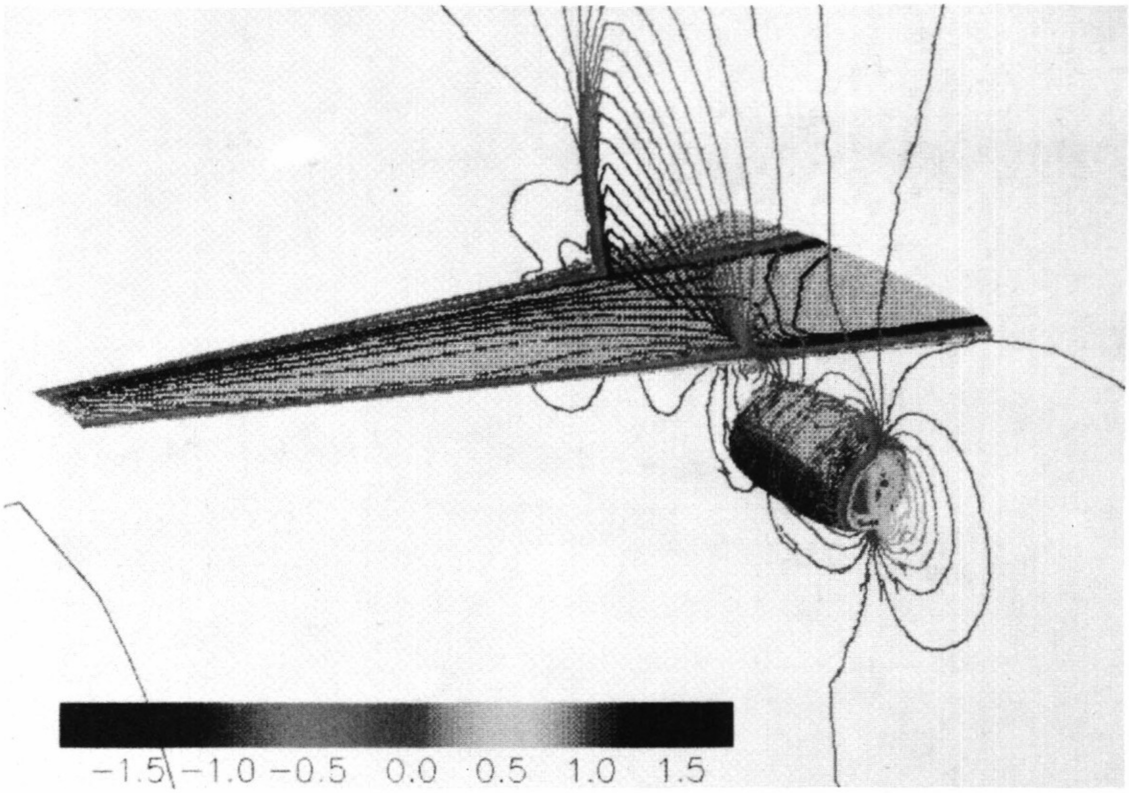
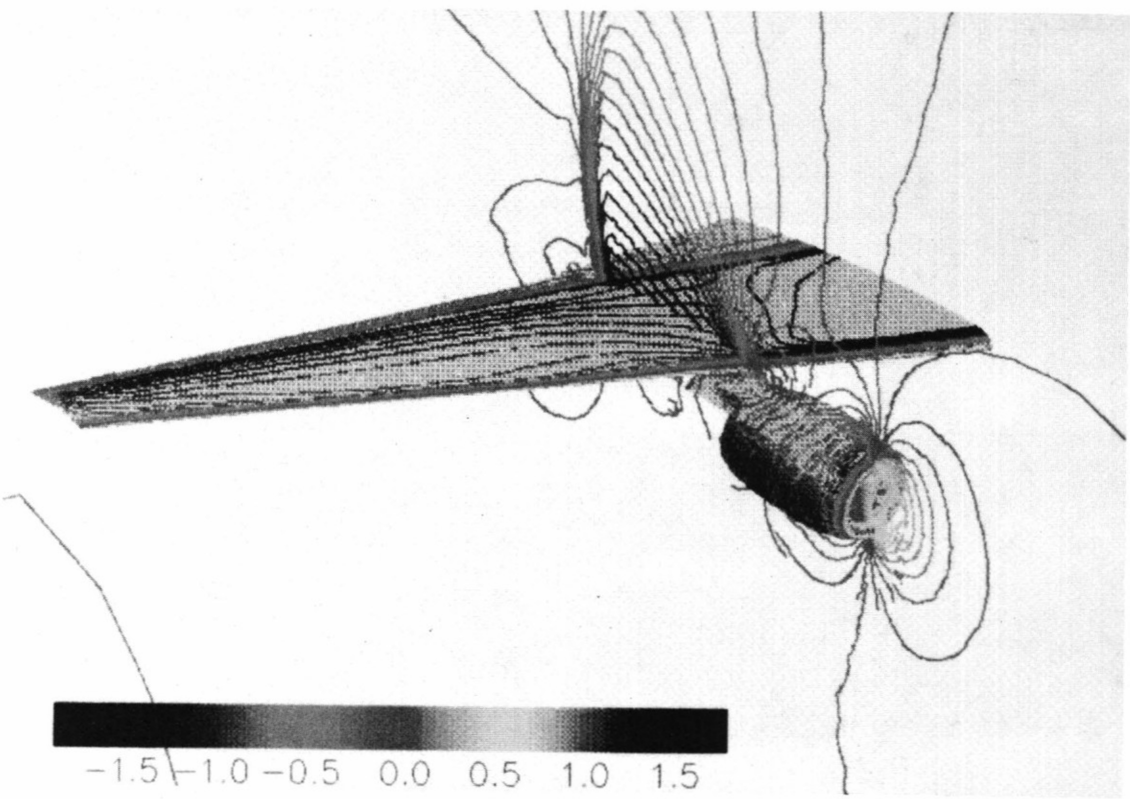


FIGURE 10. OVERLAPPED GRID AT NACELLE CENTERLINE PLANE



(a) NON-LIPLET CONFIGURATION



(b) LIPLET-WL CONFIGURATION

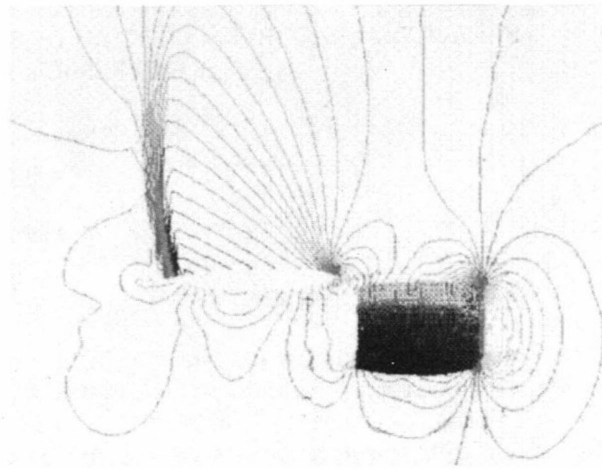
FIGURE 11. PRESSURE CONTOURS ON SURFACE AND NACELLE CENTER LINE PLANE
Mach = 0.8 α=3 deg

5. Concluding Remarks

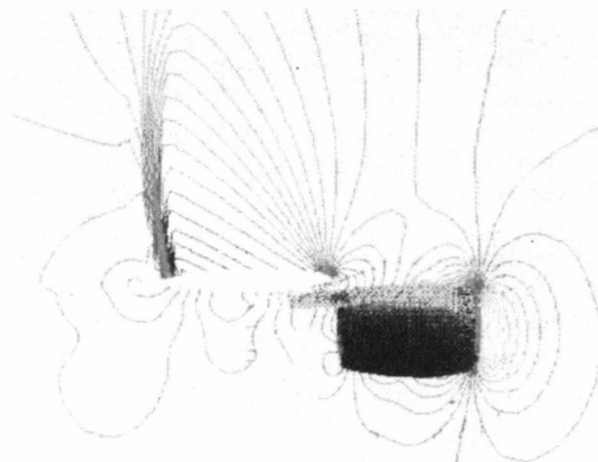
To reduce the interference drag for the nacelle installation problem to the airframe, there are two conventional ways; one is to keep the clearance between the wing and nacelle position, and another is modification of wing/pylon/nacelle shape.

In this study, a new aerodynamic device, liplet, is proposed to reduce the intreference drag. This method is an addition to the nacelle/airframe configuration.

Wind tunnel test and three dimensional Euler calculation were carried out on the liplet, and the result shows the effectiveness of the liplet to the reduction of the interference drag. Wind tunnel test result shows the drag reduction by the liplet is several counts at transonic cruise condition, and three dimensional Euler calculation shows the flow field change caused by the liplet.



(a) NON-LIPLET CONFIGURATION



(b) LIPLET-WL CONFIGURATION

FIGURE 12. PRESSURE CONTOURS AT NACELLE CENTER LINE PLANE, M=0.8 α=3 deg

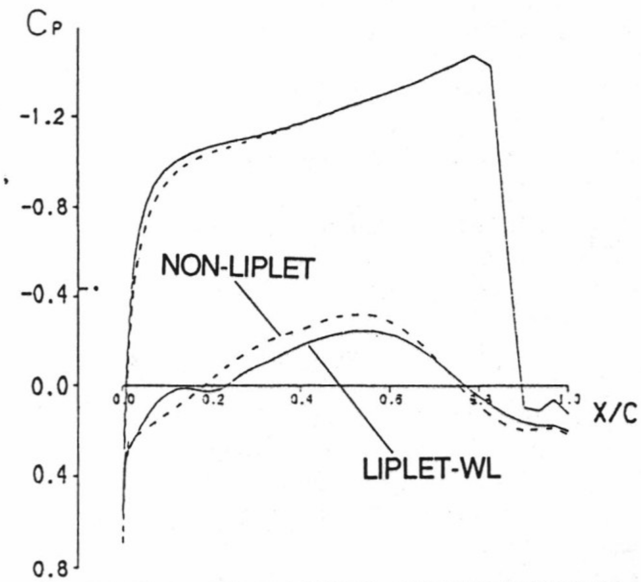


FIGURE 13. COMPARISON OFWING SURFACE PRESSURE DISTRIBUTION, M=0.8 α=3deg

6. References

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