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DESIGN STUDY OF SHORT RANGE TRANSPORT WING

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Abstract

The wing shape for short range transport was studied using numerical tools and high speed wind tunnel tests.

In two dimensional sense, rear loading wing, front loading wing and front-and-rear loading wing were designed and tested.

Results show that rear loading wing has some advantages in M_{DD} (drag divergence mach number) but not so good for subsonic C_D. Among above three types of wing, front-and-rear loading wing were most promising both in M_{DD} and subsonic C_D.

In three dimensional approach, numerical analysis shows that extended leading edge of root section can bring very thick root and can reduce the root incidence which results relative large reduction of pressure drag at root. Transonic wind tunnel test shows very encourageous results on lowering C_D for this wing model.

1. Introduction

The requirements for wing design of short range fuel efficient transport are somehow different from long range cruise transport. The short range transport uses more fuel during climb segment than high speed cruise segment. Example of the break down of fuel burn are shown in Fig.1. Also, the requirement of cruise speed is not so high as for long range cruise transport because the speed-up of cruise segment brings little improvement of block time and fuel burn in case of short range transport (Fig.2).

From these fact, one can realize that good subsonic C_D is much important than high M_{DD}. Especially for twin engine transport, requirement for maximum thrust level is often determined by one-engine-out ceiling performance, so, if C_D level is reduced, engine size can become smaller that brings smaller fuel burn and DOC, then the merits of low C_D become two fold. In this study, possible wing shape for low drag but with high M_{DD} are looked for.

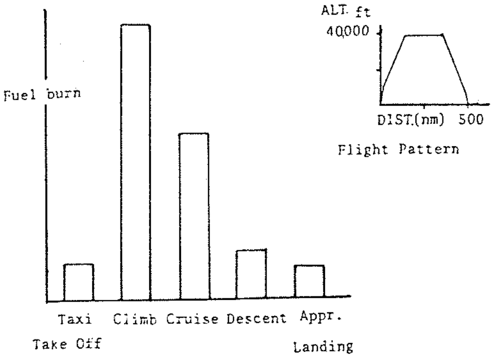


Fig.1 Fuel burn in each flight segment. (500nm. flight)

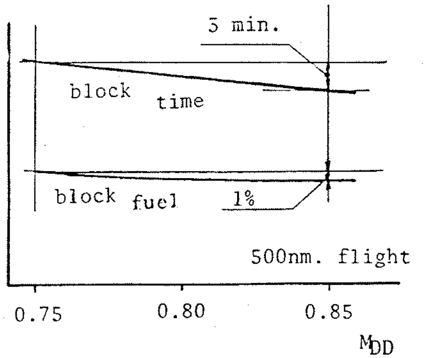


Fig.2 Effects of M_{DD} improvement (Geometris parameter unchanged)

2. Design approach

Because of rapid progress of numerical tools for the design of transonic wing shape, it has become rather easy to design high M_{DD} wing.

Though, getting high M_{DD} brings not so great reduction of fuel burn or DOC, as stated before, it can possible to get several different shapeswith almost same M_{DD} performance, and such studies were thought to be useful for getting the trade-off relation of C_D level and M_{DD}.

(1) Two-dimensional study

In designing two dimensional section of transonic transport wing, large portion of upper surface Cp distribution is determined by shock strength of high subsonic condition. Most strong method to get good upper surface Cp distribution is using the criteria based on local mach number shown as Fig.3 . If the local mach number become just larger than this criteria, M_{DD} or M_{BO} (Buffet Onset Mach Number) is equal to those main stream mach number.

These criteria were choosed from several literatures and from boundary layer caluculation then verified with Garabedian-Korn[2] program and finally checked by wind tunnel tests.

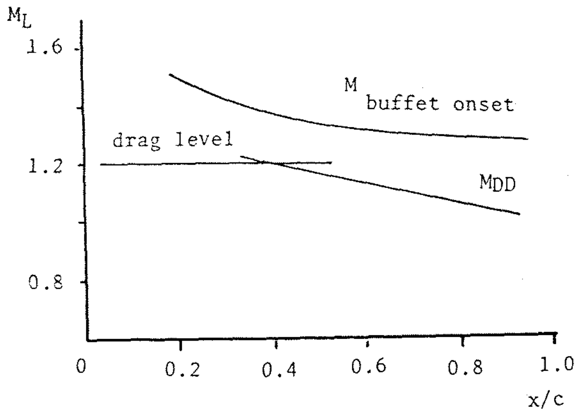
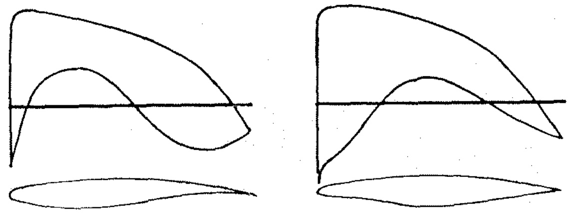


Fig.3 Local Mach number (M_L) criteria

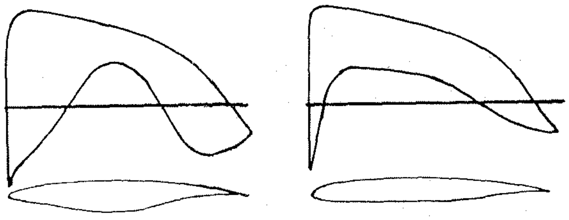
The most effective upper surface Cp distribution for high C_L condition occupies the area inside this criteria as large as possible. So choice of upper surface Cp distribution of transonic section becomes some monotonic manner.

In contrast with this monotonious of upper surface, the lower surface has some varieties in its Cp shape . Fig.4 shows the candidates of shapes for actual use. Shock free rear loading type seems most prevailing for the transport wing, but this section tends to give thin trailing edge also high Cmo that makes the heavy aft fuselage structure. If one use relative large twist in three dimensional design, this Cmo level can be reduced but there may be some penalty of drag level. In contrast with this shape, front loading section tends to give small leading edge radius and thick trailing edge. This type is advantageous in Cmo but generally the lift that can be carried by front camber is not so large as rear loading type, then this type of airfoil may be just behind rear loading section in M_{DD} performance. Considering the shape effect for C_D level, front loading seems favorable because drag area around leading edge can be make small, so in case that 'thrust pressure' of succeeding part of section cannot be attained due to three dimensional viscous flow etc, this type can still maintain low Cd level than rear loading section.(Fig. 5) There may be the third shape that has both front-and-rear loading in single section. (Fig.4c)

To clarify these shape effect, three sections that have characteristics stated above were designed two and three dimensionally and tested in high speed wind tunnel. These three wings were named W-3, W-4 and W-7, respectively.

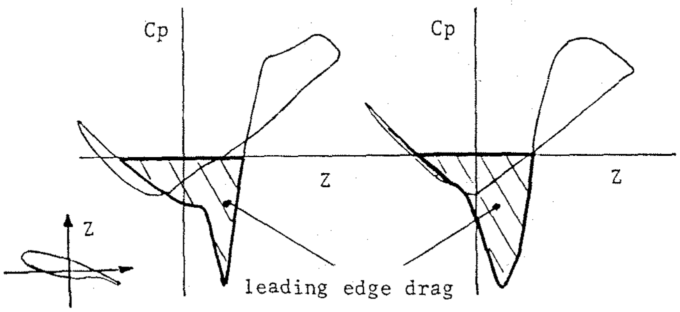


a) rear loading b) front loading



c) front and rear loading d) constant loading (small t/c)

Fig.4 Typical Cp distributions of transonic airfoils.



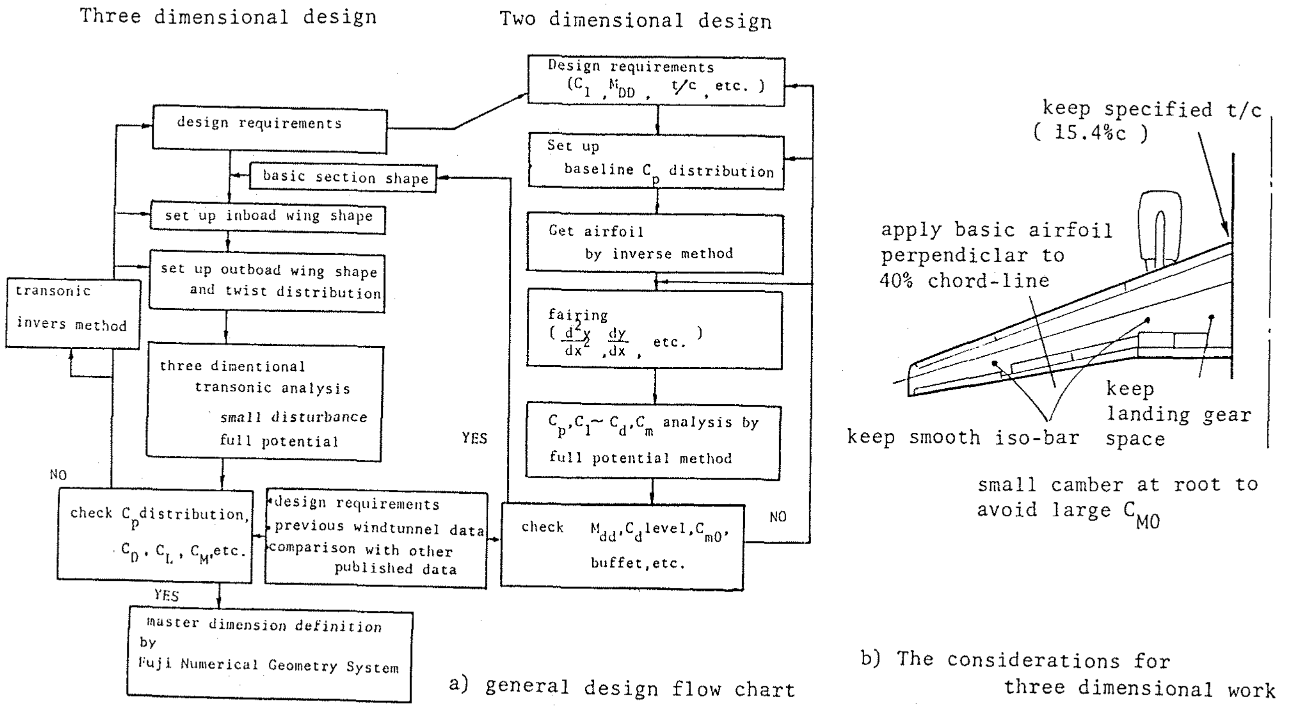
a) front loading type b) rear loading type

Fig.5 Comparison of leading edge pressure drag

Design process was shown as Fig.6 . The numerical tools used are two dimensional small disturbance method(design and analysis mode)[1], full potential method(analysis mode)[2], three dimensional small disturbance method includ body effect[5], three dimensional full potential method(FLO-22, 30)[3],[4] and later three dimensional inverse method[6] was used.

Two dimensional design conditions were with constraint of t/c 12%c, Cl design arround 0.6.

After the two dimensional design work, using these airfoils as outer wing basic sections, three dimensional wings were designed, which have same thickness distribution and same planform each other. During the three dimensional work, upper surface Cp distribution of each section of wings are tuned to keep similar shape from root to tip. The considerations given are illustrated as Fig.6 b).



a) general design flow chart

b) The considerations for three dimensional work

Fig.6 Design process for Transonic wing

(2) Three dimensional studies

Apart from two dimensional works, the three dimensional drag reduction idea were looked for. Generally, it has been believed that to get good performance, the pressure distribution of wing, at least upper surface, should be close to that of basic two dimensional pressure distribution at each station. And the lift distribution should be close to the elliptical distribution at design condition. These approach seems basically right but there may be other approachs. For example, elliptical lift distribution is drag-minimum according to lifting-line concept, but same theory shows that the penalty of drag is not so large even if one use different distribution.

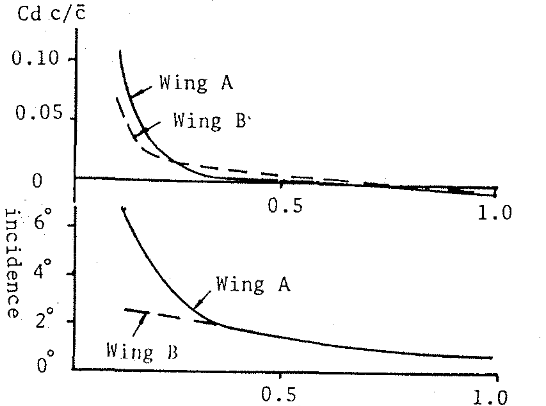


Fig.7 drag distribution and twist effects.

Recent numerical tools has ability to predict drag distribution of wing. From typical example of calculation, one can easily realize that the great part of pressure drag is brought by inner part of wing (Fig.7, Wing A) . Though this root drag can be reduced by lowering the incidence of root section, in this case, outer part of wing become to carry more drag and total drag kept actualy the same level. If the incidence of root section is reduced with root chord extention to recover the lift , the total pressure drag should be able to be reduced. But there should be one more idea to reduce the friction drag due to enlargement of wetted area. Fortunatly, root leading edge extention can bring very thick root section because area distribution of wing itself has peak after the maximum thickness position of root section.

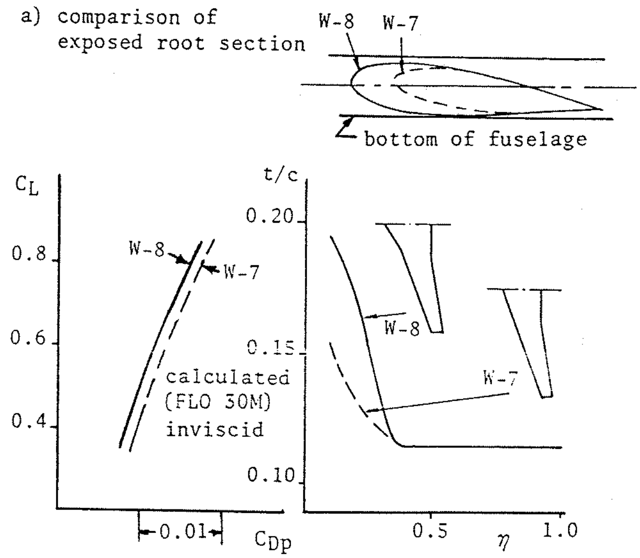
If one use thick root, the wetted area of body is reduced then total wetted area of wing-body become very close to that of baseline unextended wing.

Then one more wing was designed that has same out board shape as W-7, that is the rear and aft loading wing, and has root chord leading edge extention also has very thick root t/c.

Design process was same as stated before.

Fig.8 shows thickness distribution and calculated pressure drag of this wing(W-8). The drag level was expected cut down compare with W-7.

Root t/c become about 20%c based on its actual chord length. If one measured t/c based on baseline W-7 chord length its value become 23.5%c. This thick root can carry more fuel and is effective in reducing the wing weight.



b) $C_D \sim C_L$ (calculated)   c) t/c distribution

Fig.8 design of thick root wing W-8

Other idea of drag reduction was to apply the conical camber to the transonic transport wing. This idea is similar to two dimensional approach stated before that drag reduction which can be gotten around leading edge may be attainable in case of poor pressure recovery.

Numerical calculation shows its effectiveeness for the high aspect ratio low sweep wing(Fig.9). The advers effect of conical camber was considered to lie in stronger shock due to high curveture of upper surface. But inverse solution of shock free, straight iso-bar wing, shows more curveture is needed near tip if one want to modify the wing that has constant section shape from kink to tip.

So, the moderate comical camber is excepted to be rather preferable from the point of shock formation.

The wing that has conical camber was also designed and tested.

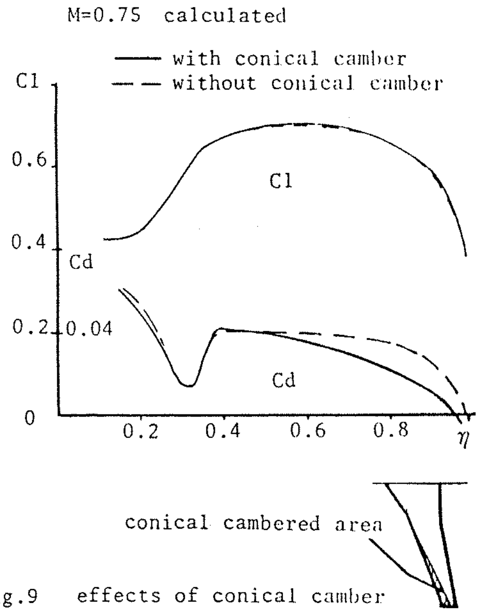


Fig.9 effects of conical camber

3. Windtunnel Test

Most of wings were tested by half model. Tests were conducted in 0.6×0.6^m FHI* TRI Sonic Indruft Wind Tunnel, at RN=1.0X10^6, M=0.6~1.0, α=-2°~6°. Forces of wing-body combination and pressure distribution of wing surface were measured.

Half model tests were used because these series of tests aimed to compare the performance of different wing shape, not the exact perfomance. Before the series of these tests, comparison of half model test data and full model test data were done.

Half model tests data and full model tests data show good correlation in drag rise characteristics and pressure distributions (Fig. 10).

General arrangement of windtunnel tests are shown in Fig.11 .

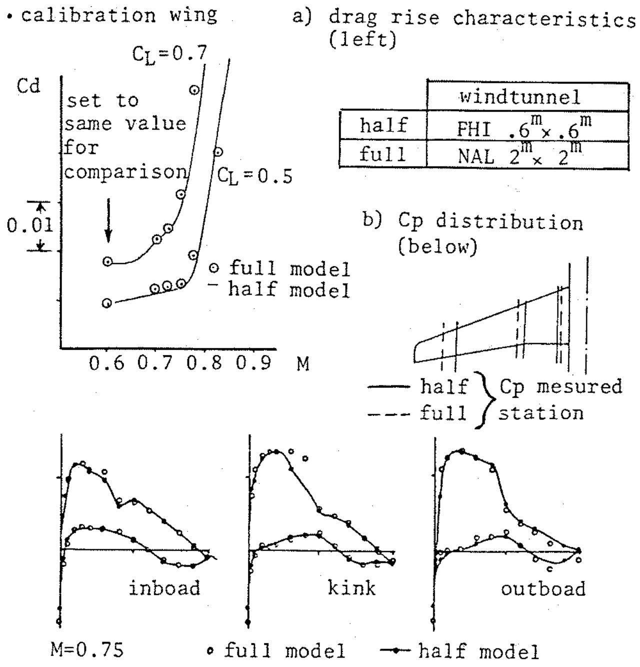


Fig.10 Comparison of half model and full model

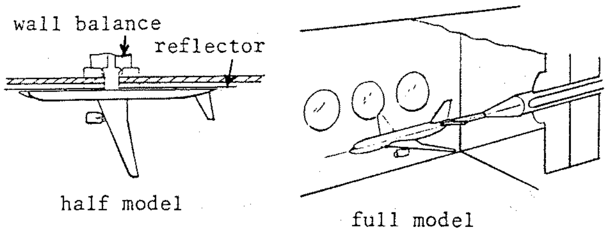


Fig.11 Wind tunnel test model

wing model	contour
W-3	rear loading
W-4	front loading
W-7	rear-and-front loading
W-8	thicker root, outboad same as W-7
W-10	modification of W-8

Table 1. Test wings

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* FHI : Fuji Heavy Industries

4 . Tests Results

Fig.12 shows the tests results of three wings. As expected from the numerical calculation, the front-and-rear loading type wing(W-7) shows most promising in both drag divergence performance and drag level. (Fig.12a and Fig.12c)

Front loading tends to low drag, low M_{DD} and rear loading tends to high C_D and high M_{DD}. Though relative large twist was used for rear loading type wing, which also the cause of high drag level, Cm became larger than other two wings. The corelation of numerical analysis and wind tunnel tests results was fairly good in Cp distribution. (Fig.12d)

Fig.13 shows the test results of two wings which are same at outboard contour and different at inboard. The wing which has root chord extension and large thickness ratio(W-8) shows drag level reduced as intended, but M_{DD} performance needs some improvement. In this case also, the corelation of Cp distribution between calculated and tested was good.

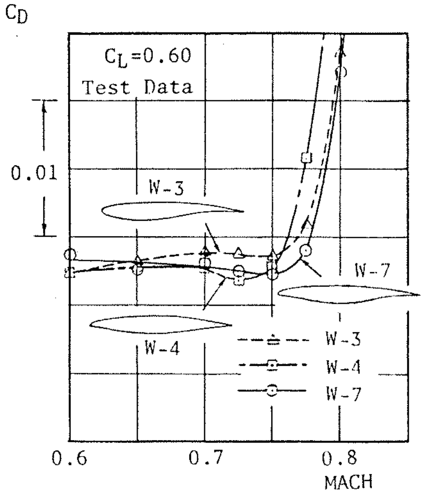


Fig.12a comparison of $C_D \sim M$

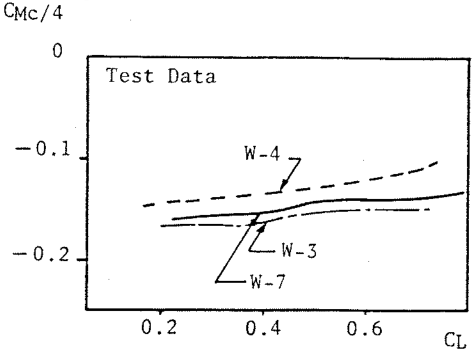


Fig.12b $C_{Mc/4} \sim C_L$

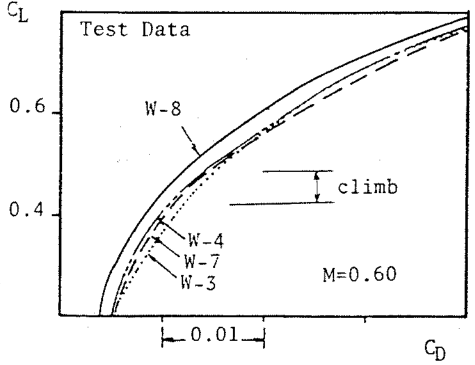


Fig.12c subsonic drag

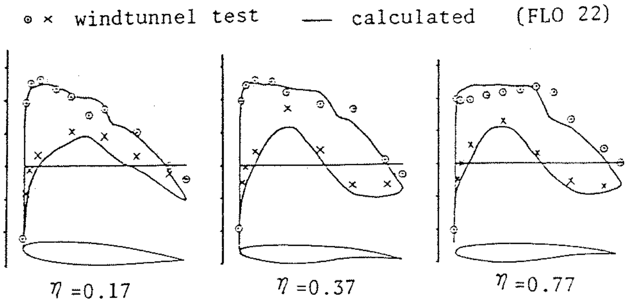


Fig.12d Cp distribution (W3) M=0.79

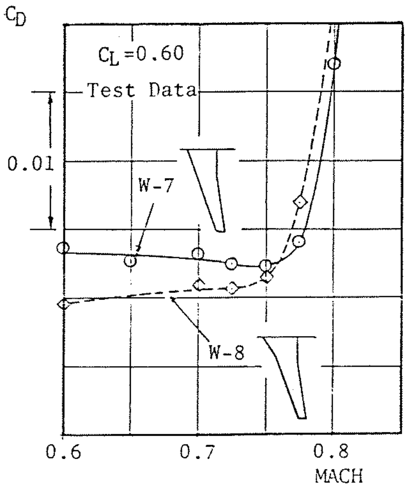
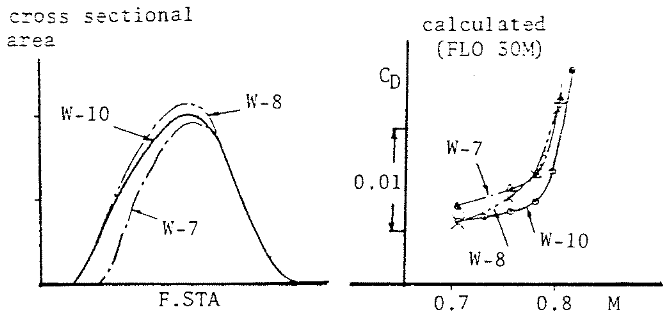


Fig.13 comparison of two wings

Judging from Fig.12a,Fig.12c and Fig.13, three dimensional approach seems more effective than two dimension-lke approach for lowering drag level.

Another windtunnel test was conducted, one of the purpose of this test was to confirm the possibility of improving MDD of W-8.

In this time inboad section was carefully tailored to have good area distribution. (Fig.14) At same time conical camber was added at outboard.



a) comparison of area distribution of wings.

b) calculated performance

Fig.14 design of W-10 wing.

This wing (W-10) was testes in full model, not half model, at NAL* $2^m \times 2^m$ transonic wind tunnel, $RN=1\times10^6$.

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* National Aerospace Laboratory

Fig.15 shows the results of this test. M_{DD} performance is improved as intended. Also, it was confirmed that adding conical camber do not harm the M_{DD} performance.

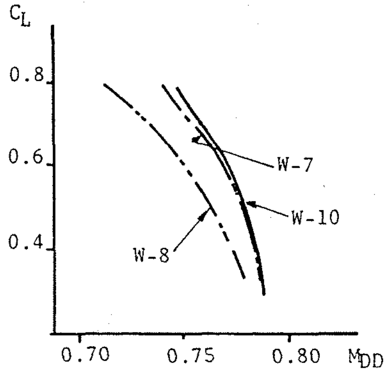

Fig.15 windtunnel test results of M_{DD} performance.

5. Conclusion

The possibility of low drag level and high drag diergence mach number of front-and-rear loading wing is discussed based on numerical study and experimental study analysis.

Also in three dimensional approach, extended leading edge of root section can bring very thick root which results relative large reduction of drag without hurt the drag divergence performance.

These studies were done in accordance with YXX project, i.e. next generation 150 passenger class short range transport under planning by JADC(Japan Aircraft Development Corp).

Reference

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