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COMPARISON OF COMPUTATIONAL RESULTS OF A FEW REPRESENTATIVE THREE-DIMENSIONAL TRANSONIC POTENTIAL FLOW ANALYSIS PROGRAMS

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16. Abstract

The development of transonic aerodynamic computation methods and specific examples, as well as examples of three-dimensional transonic computation in design are discussed. The case of the transonic transport and the case of the small transport are analyzed. Requirements for programs of the future are itemized.

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COMPARISON OF COMPUTATION RESULTS FROM VARIOUS ANALYSIS PROGRAMS ON THREE-DIMENSIONAL TRANSONIC FLOW

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1. INTRODUCTION

In recent years, thanks to the dramatic upgrading of the capability of computers and the rapid development of the associated computation aerodynamics, the computational analysis program(s) on the flow around airframes in flight at transonic speed which heretofore was considered extraordinarily difficult is becoming feasible. The matching of the computational results obtained from these programs with experimental results has become quite favorable; and as a method to supplement and further expand upon the wind tunnel testing which is greatly constrained by factors such as cost and time, these computation methods have already become an important tool in the aerodynamic design of aircraft.

2. DEVELOPMENT OF TRANSONIC AERODYNAMIC COMPUTATION METHODS AND SPECIFIC EXAMPLES

Before proceeding into the primary subject, we will initially provide an overview of the steps through which transonic computation methods have developed. Figure 1 traces the transonic flow computation method in a summary chronology table format, divided into three areas: Around a two-dimensional wing form; around a three-dimensional wing form; around a three-dimensional combined wing fuselage form. Ever since the mid-60's when NASA announced the supercritical wing form, research on transonic wing shapes progressed rapidly; however, this progress coincided with the period during which the computation method

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around a transonic wing form also made great strides; therefore, it can be said that the progress of the computation method contributed heavily to the development of high performance wing forms. Also, in the mid-70's, the computation program around the three-dimensional wing became feasible and indications are that the most advanced transports--the B767 and the A300--utilized this computation method from its early design phase. In the present era, a computation program for analysis around a combined wing fuselage form is about to make its appearance and it can be believed that from here on, as the computation method progresses further, we will advance toward a design capability that will permit us to optimize the entire airframe configuration.

Figure 1 illustrates the computation methods for non-viscous flow. At the present, the calculation by the Navier Stokes equations which are the basic equations for viscous flow, is yet in the research stage and the mainstream effort on a feasible program for design purposes is a non-viscous computation based on the assumption of potential flow. A few among the programs mentioned above that are actually being utilized at our company are indicated in Table 1.

Firstly, the FLO-22 which computes the field around the three-dimensional wing, based on total potential equations, has been evaluated as having a stability and accuracy in its solutions and has been used widely for design purposes for several years. This method evolved from the FLO-27 whose analysis capability includes infinite cylindrical fuselage, to the FLO-30 which can handle "real" fuselages of finite length. Further, although the method of calculating the total potential equations by approximating small disturbances is said to be of somewhat lower accuracy compared with the total potential, it does have the advantage of being less constrained in accommodating grid generation and boundary conditions; and there have already appeared several

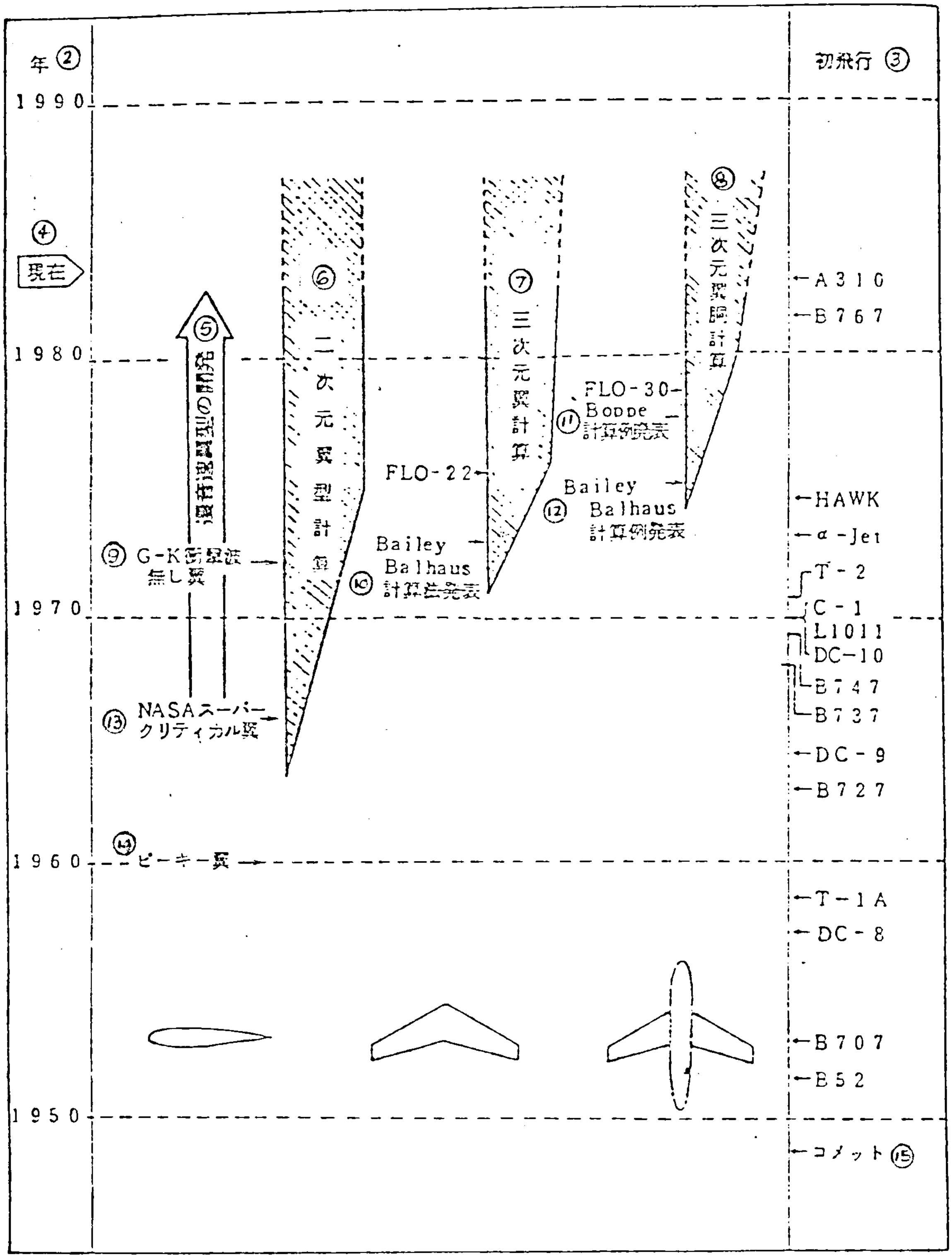
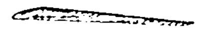
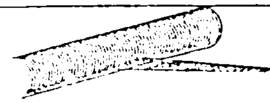


Figure 1. Trace of transonic aerodynamic computation method (non-viscous).
1--Aerospace Technical Research Lab. Special Data; 2--year; 4--present; 3--initial flight; 5--development of the transonic wing form; 6--2-dimensional wing form computation; 7--3-dimensional wing computation; 8--3-dimensional wing fuselage computation; 9--wing without G-K shock wave; 10--Bailey Ballhaus computation method announced; 11--Bloppe prototype computation announced; 12--Bailey Ballhaus prototype computation announced; 13--NASA supercritical wing; 14--Bii-Kii wing; 15--Comet

TABLE 1. Examples of transonic flow analysis programs (non-viscous)

①基礎方程式	②プログラム	③解析形態	
⑤完全ポテンシャル	FLO-22	④翼	
	FLO-27	⑥翼+円柱	
	FLO-30	⑨翼+胴体	
⑦微小擾乱ポテンシャル	MASON他※⑧		
	BOPPE※		

⑩※境界層計算つき

1--basic equation; 2--program; 3--configuration analyzed; 4--wing; 5--total potential; 6--wing + circular rod (cylinder); 7--small disturbance potential; 8--Mason, et al.*; 9--wing + fuselage; 10--*with boundary layer computation

procedures that provide for calculation of relatively complicated wing fuselage configurations. One of these programs is the code by Mason, et al. [1] which is currently being used regularly for design purposes. This has been further developed into the BOPPE code [2] which is considered to be among those with the highest configuration (format) flexibility. Further, these two programs which are based on small disturbance potential are capable of performing computation while correcting the non-viscous results through boundary layer computations.

We will next discuss the advantages/disadvantages and problems of the various computation methods by illustrating examples of using the programs during the design phase.

3. EXAMPLES OF THREE-DIMENSIONAL TRANSONIC COMPUTATION IN DESIGN

(1) Case of the transonic transport /159

Figure 2 shows the comparison between the experimental values and computed values of the pressure distribution at five span-wise cross sections in the airfoil direction for transport aircraft currently being planned. Two computations were used: the small disturbance potential wing fuselage, and the total potential wing computation. Especially in the case of the wing fuselage computation, the match to the experimental value was extremely good. In the wing computation, since the wing fuselage interference is not taken into account, an accurate evaluation could not be expected for all regions in the wing span direction. By this example, the shock wave position on the outer wing is somewhat out of phase. However, since the wing fuselage interference is not particularly large for a configuration having a large aspect ratio and a simple form, as is the case for a transport, if parameters such as the angle of attack are adjusted to some degree, it is possible to make computations that are close to the experimental value over a considerably wide portion of the external wing merely from computation on the wing only.

Figure 3 shows the example of a design performed for the purpose of thickening the internal wing through the aggressive use of the wing fuselage interference on a transport baseline. Both the small disturbance and total potential used the wing fuselage computation as a computing method. It is said that the computational accuracy of the small disturbance is somewhat inferior to that of total potential; and in particular, the accuracy deteriorates at the point(s) where the direction of localized flow breaks away largely from the free stream direction. In this example, too, at the external wing area where the leading edge radius is small, the small disturbance match is poor for the experimental value for the total potential flow compared with the vicinity of the leading edge; other than this case, the match is not especially in disagreement. Further, since this configuration is a low wing arrangement, the fuselage interface becomes subtle in the vicinity of the maximum thickness of the main wing lower surface, and it appears that for the total potential, the grid structure for this section is not particularly favorable, thus

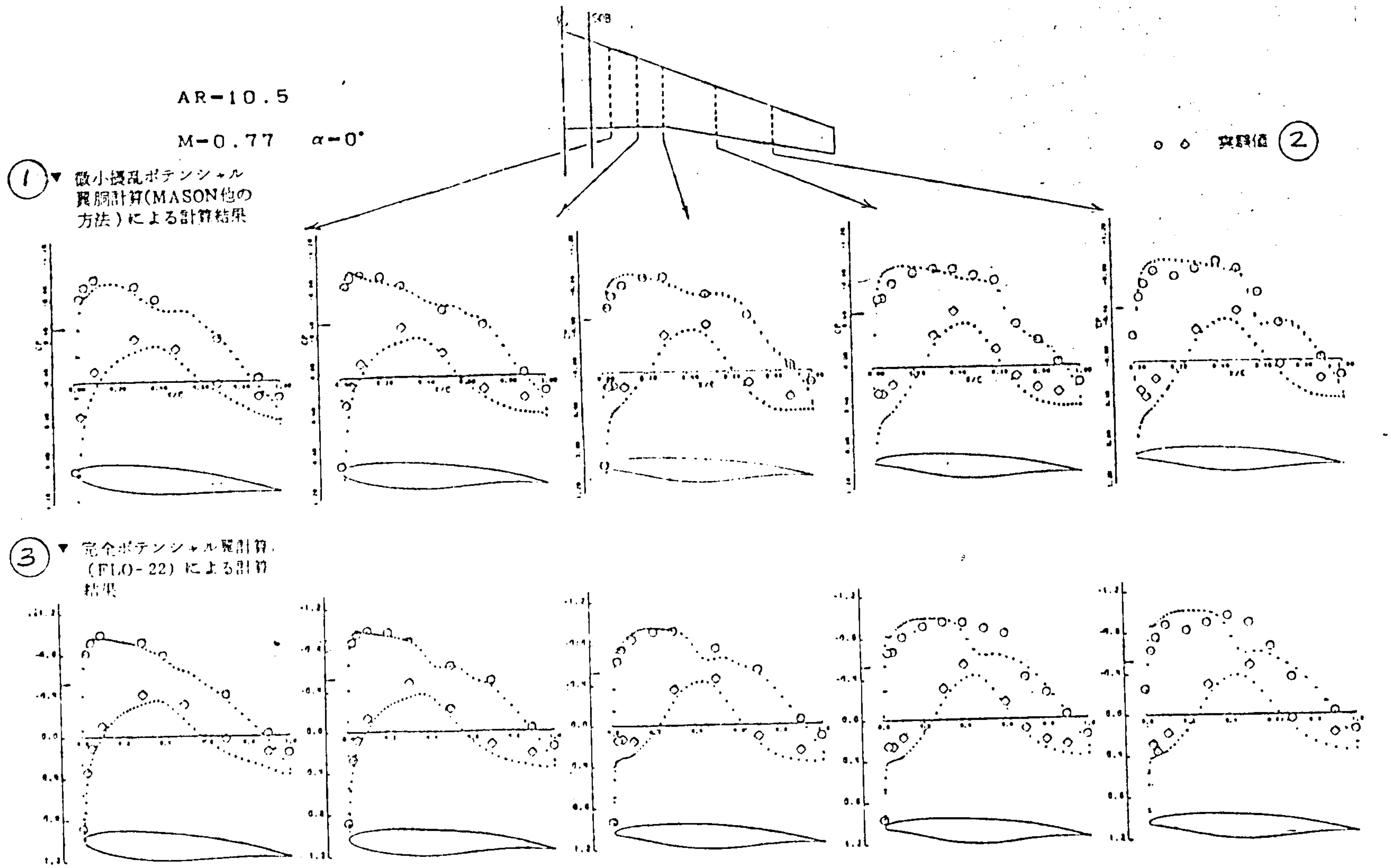


Figure 2. Examples of computation for transonic transports (1) comparison between wing fuselage computation and wing-only computation.

1--results from small disturbance potential wing fuselage computation (method of Mason, et al.); 2--experimental values; 3--results from total potential wing computation (FLO-22).

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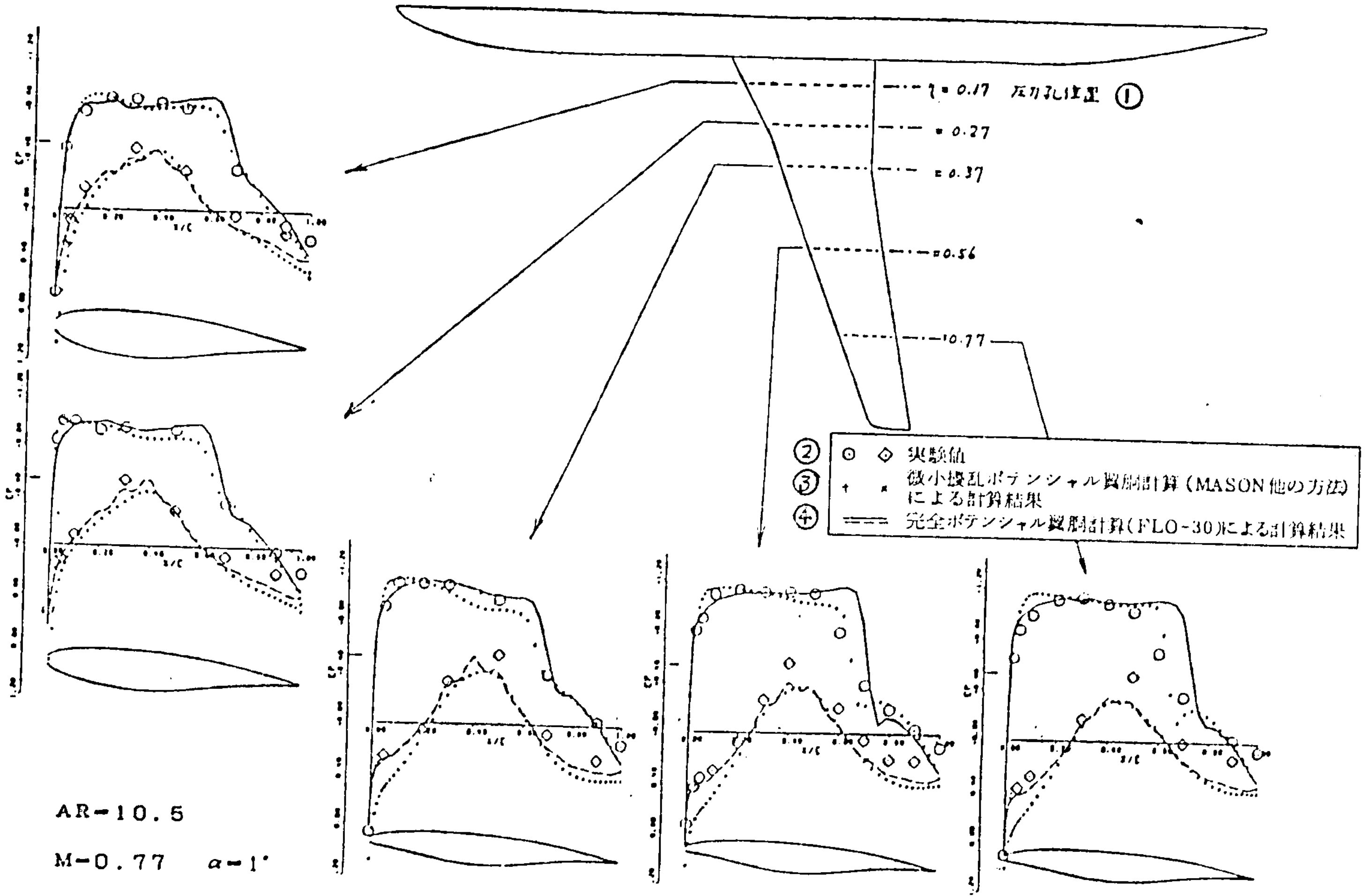

Figure 3. Examples of computation for transonic transports (2)--comparison between small disturbance and total potential

1--pressure port stations; 2--experimental values; 3--results of small disturbance potential wing fuselage computation (method of Mason, et al.); 4--results of total potential wing fuselage computation (FLO-30)

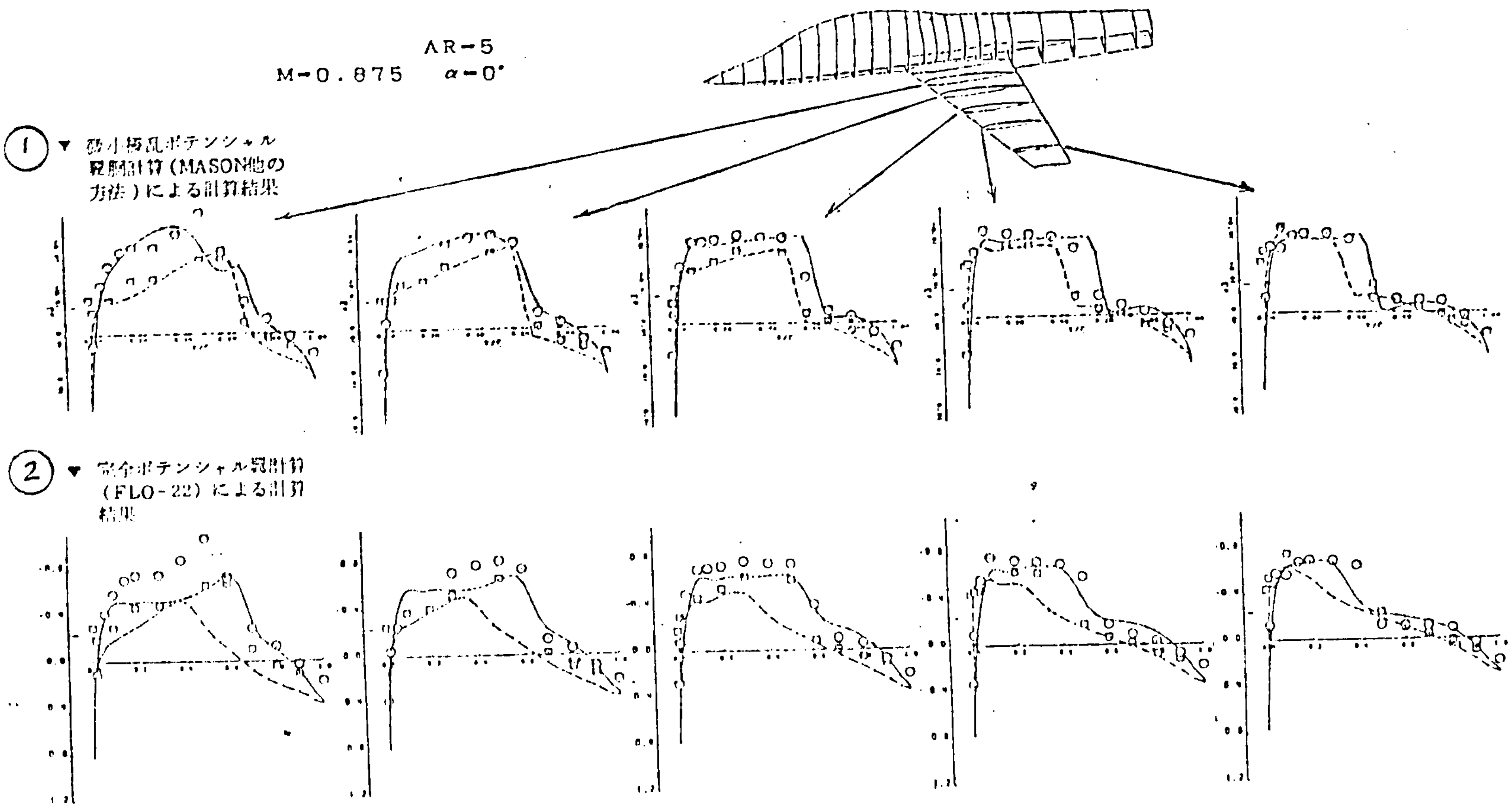

FIGURE 4. Examples of computation for small transonic aircraft--Comparison between wing fuselage computation and wing alone computation.

1--results of small disturbance potential wing fuselage computation (method of Mason, et al.); 2--results of total potential wing computation (FLO-22)

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the stability of the solution deteriorates. In Figure 3, such a sign is indicated by the fluctuations in the vicinity of the peak pressure on the lower surface. For a similar reason, if the fuselage configuration is made even a little complex under a total potential, a stable solution cannot be obtained, and it can be said that the small disturbance is more difficult as an aircraft design tool at the present time.

(2) <u>Case of the small transport</u>

Figure 4 is the example of (a) small transonic with an aspect ratio of about 5. It shows the results for the small disturbance potential wing fuselage computation and the total wing only computation. In comparison with the case of the transport aircraft, it possesses a relatively large fuselage, has a complex fuselage shape, and is characterized by a fairly large wing fuselage interference. For this reason, there occurs a great discrepancy in the wing-only computation, especially near the fuselage, and the shock wave on the external sector tends to a projection of a weaker value. On the other hand, the wing fuselage computation shows considerably favorable results, making it possible to evaluate quite adequately a wing fuselage computation even for a configuration of this type; and it becomes apparent that a large error in evaluation results from a computation limited to a wing-only configuration. Furthermore, at the present when a program capable of performing analysis of a wing fuselage configuration is beginning to make its appearance, it can be said that the /163
issue of whether or not the fuselage effects can be accurately evaluated will hold the key to determining the level of the program's feasibility.

(3) <u>Evaluation of computation of the area rule effects</u>

Next, we will introduce [3] the computed value and the experimental value for the case of applying the area rule to the transport type airframe as an example of the evaluation obtained from a transonic computation of the effects of the fuselage configuration on the aerodynamic characteristics of the main wing. As shown on the right side of Figure 5, the small disturbance potential wing fuselage computation (method of Mason, et al.) and the wind tunnel testing were conducted on (A), an ordinary transport having a continuous fixed cross sectional form in the middle fuselage section as a baseline configuration; and (B), an area rule conformed configuration designed to assume a shape whose cross-sectional area distribution is smooth over the entire aircraft in the direction of the airframe longitudinal axis, derived by reducing the fuselage in the vicinity of the main wing which is the same main wing as in (A). By applying the area rule, a delay is incurred in the sudden increase of the wave generation drag which accompanies the increase in the Mach number; the drag dissipation Mach number, M_{DD}, increases, making it possible to project an increase in the cruise Mach number and an increase in its transport efficiency. Figure 6 shows the comparison of the pressure distribution computed values for both configurations at two Mach numbers in the M_{DD} range, for the purpose of seeking the mechanism by which the effects of the M_{DD} increase occur. The shock wave on the external wing section is mitigated to some degree by the application of the area rule; but where the difference between the pressure distribution of the two configurations is more conspicuous, is the internal wing section. As the Mach number increases from 0.79 to 0.82 for the baseline configuration (A), the so-called rear shock which is generated at 70-80% wing chord suddenly expands. In contrast, in the case of configuration (B) with its application of the area rule, a comparatively large pressure peak is generated near the leading edge from low Mach number, resulting in the generation of a strong front-shock at 30-40% wing chord; however, the strength of that shock increases very little even on the increase of the Mach number, and it can be thought that this is a major cause for delaying the drag dissipation.

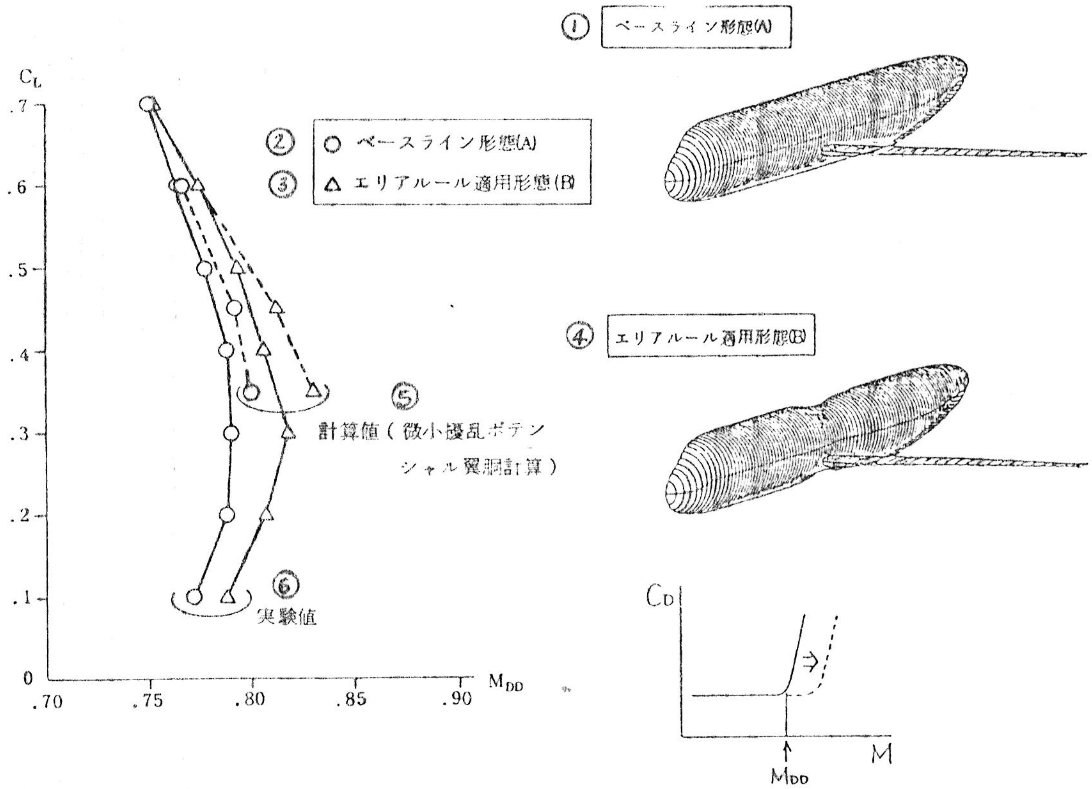

Figure 5. Effects of area rule on M_{DD} (comparison of experimental and computed values).
1--baseline configuration (A); 2--baseline configuration (A); 3--area rule (applied) configuration (B); 4--area rule configuration (B); 5--computed values (small disturbance potential wing fuselage configuration); 6--experimental values

The above described are the analysis results from the computed results; however, in conducting the corresponding wind tunnel tests, experimental results were obtained which matched well with the computed values, as shown in Figure 7. Further, the comparison with experimental values, of the M_{DD} (Mach number for drag dissipation), from the aerodynamics (lift and drag forces) obtained from differentiating the computed values of pressure distribution, /166 is shown in Figure 5. There is observed a mismatching between the computed value and the experimental value thought to have been due to the fact that the computation did not take viscosity into account; and it can be readily seen that the computations provide a good portrayal of the condition characterized by the effects of M_{DD} increasing from proper application of the area rule, and the reduction in those effects as the lift force increases. By using the transonic wing fuselage computation as described above, it has become fully possible to analyze the mechanism of wing fuselage

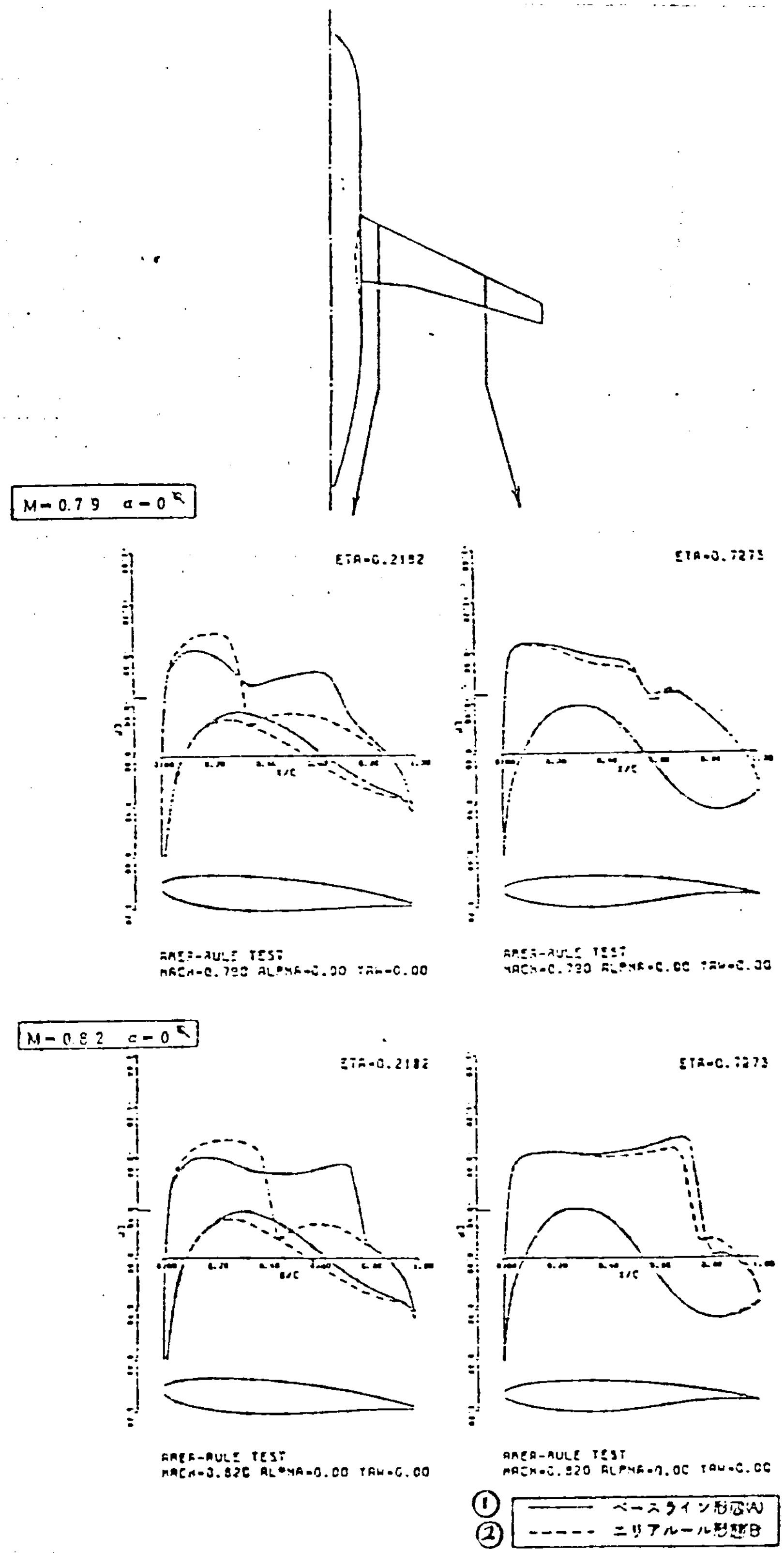

Figure 6. Effects of area rule on pressure distribution (small disturbance potential wing fuselage computed values). 1--baseline configuration (A); 2--area rule configuration (B)

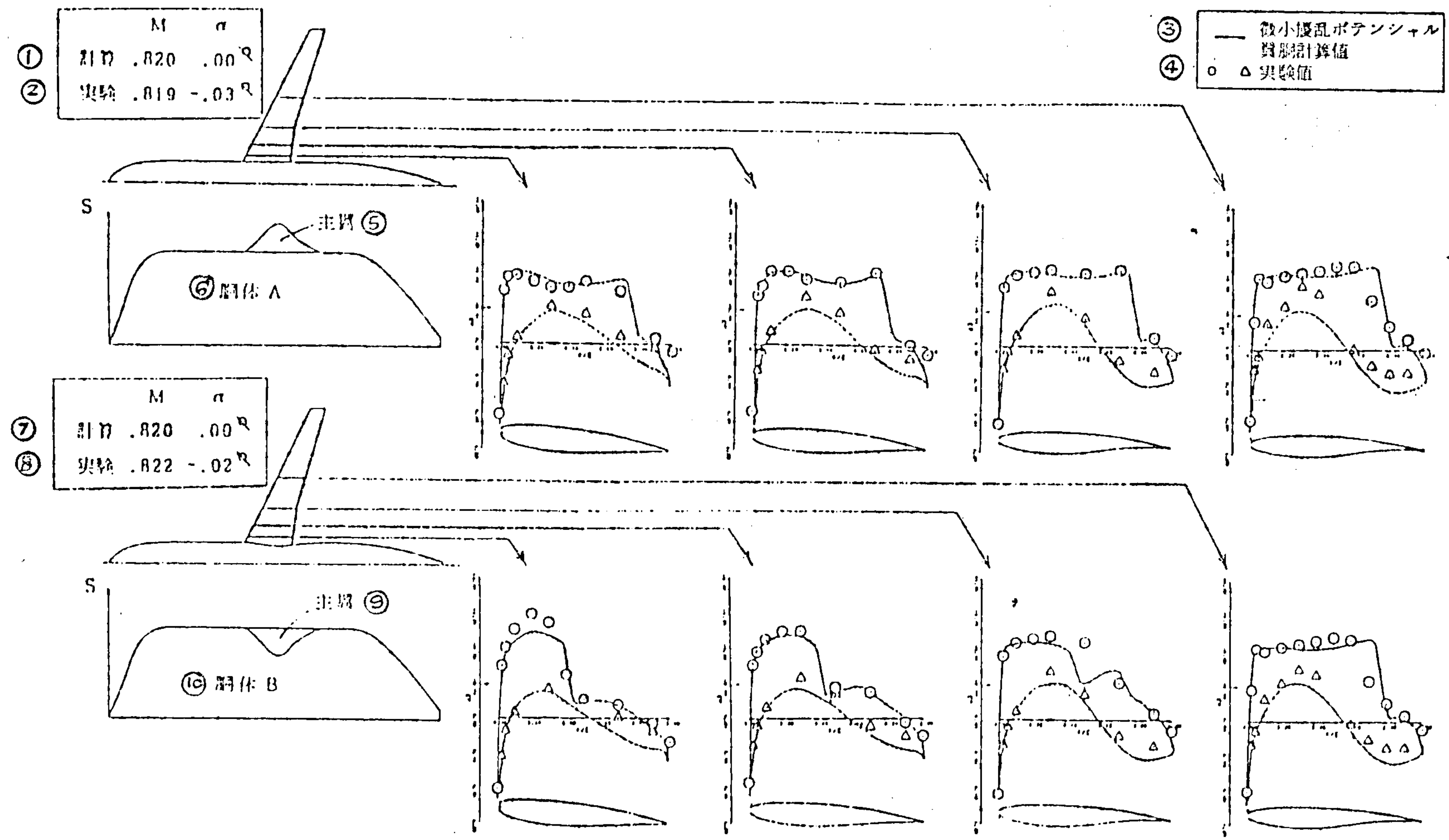

Figure 7. Effects of area rule on pressure distribution (comparison between experimental and computed values)

1--computed; 2--experimental; 3--small disturbance potential wing fuselage computed values; 4--experimental values; 5--main wing; 6--fuselage; 7--computed; 8--experimental; 9--main wing; 10--fuselage

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interference that heretofore was undefined, and to deduce the effects that this interference imposes on the airframe.

Furthermore, in the examples shown here, it cannot be said that a good design necessarily results since although by combining a fuselage to which the area rule has been applied, with a main wing that was initially designed for a "straight line" fuselage, the pressure peak occurs mainly in the vicinity of the internal wing's leading edge thereby improving the M_{DD}; this, in reverse, increases the drag effects and generates the creep phenomenon. However, it is projected that by further tightening the individual wing fuselage configurations, the optimum aerodynamic configuration for the combined wing-fuselage can be designed; and it can be thought that because of this the transonic design method demonstrates its formidability.

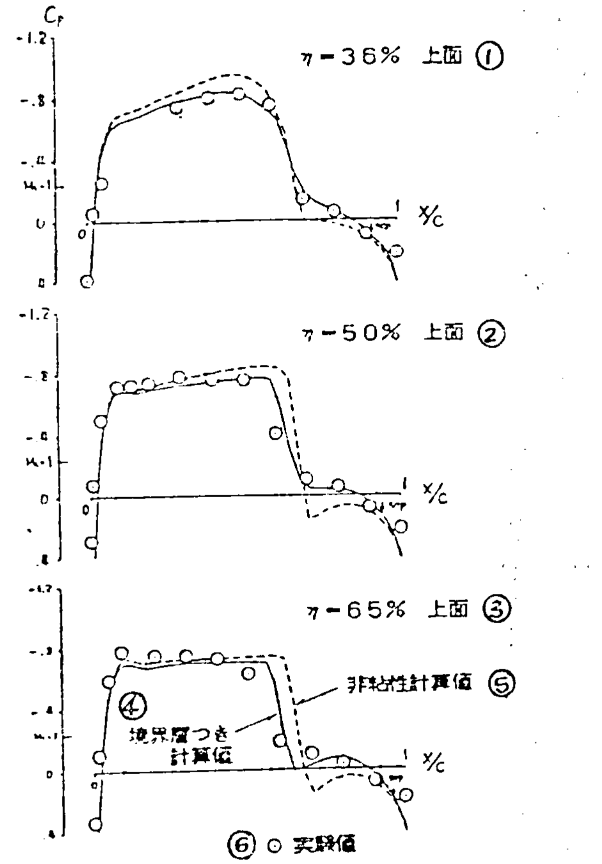

FIGURE 8. Effects of boundary layer computation (small transport)
1,2,3--upper surface; 4--computed value for attached boundary layer; 5-- computed value for non-viscous case; 6--experimental value

(4) Effects of boundary layer computation

At the present, those transonic programs that are feasible for aircraft design are based on non-viscous computation but by supplementing with boundary layer computation, a method is implemented that incorporates the viscous effects. By Mason et al.'s code, an operation can be repeated whereby the point at which non-viscous computation is to some extent made, a boundary layer computation is performed and the results adjusted, resulting in the initiation of a non-viscous computation. We introduce below the computed results from this methodology.

Figure 8 shows the comparison between the pressure distribution for a small transonic craft for the cases when the boundary layer is computed and when it is not. By computing the boundary layer, it is seen that the computational accuracy is enhanced on evaluating the generation point and strength of shock waves and the associated pressure recovery from the generated shocks. Also the boundary layer computation permits the projection of the separation point; Figure 9 shows the computed results on the separation points for the case where the area rule is applied to the previously discussed transport aircraft. By applying the area rule, a strong forward shock wave is generated on the internal wing section; however, it is judged from the computation that this will not instigate a separation immediately thereafter. This has been verified by wind tunnel oil flow tests. It is thought that this is due to the generation of the shock wave at points where the boundary layer is still robust; and the fact that the application of the area rule makes it difficult for the internal wing to be separated, too, may contribute to delaying drag dissipation.

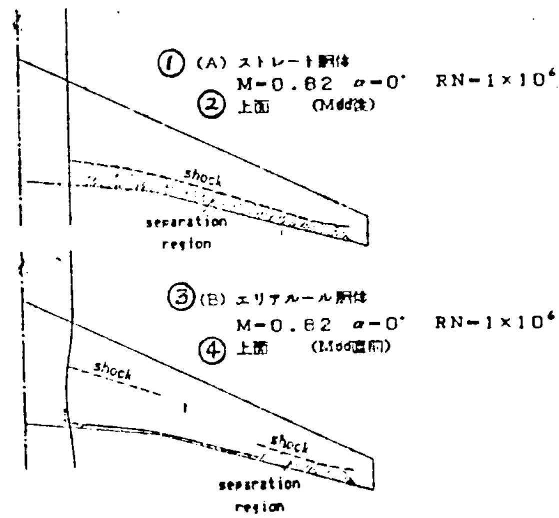

FIGURE 9. Computation of separation position (for area-rule applied transport).
1--(A) straight fuselage; 2--upper surface (post M_{DD}); 3--(B) area rule fuselage; 4--upper surface (pre M_{DD})

By performing boundary layer computation in this fashion, /167
various effects can be acknowledged, but at the cost of large increase in computing time. Therefore, further investigation is required on the extent to which the transonic computing method, augmented by boundary layer computation, can be incorporated into actual design.

4. REQUIREMENTS DESIRED ON PROGRAMS OF THE FUTURE

As discussed above, it has become possible to analyze by the transonic computation method a considerable portion of the flow around an airframe in the transonic regime which heretofore could only be performed by the conventional wind tunnel tests. And currently, even though there are some problems, the computing accuracy is relatively good, and the aerodynamic design technique of main wings by application of these methods has made an order of magnitude advancement. It is predicted that in order to perform design of ever increasing accuracy, the programs will become ever important. Therefore, we will try to summarize the requirements desired of programs to be developed in the future.

(1) Should be capable of analyzing the total airframe configuration

It is believed that development will be toward a design that will aerodynamically optimize the total airframe structure, including the interference of nacelles and canards. For this purpose, a program is necessary that is capable of analyzing not only the total airframe configuration but an airframe that is as close as possible to the true configuration, and performing an accurate evaluation including the interference between and among all components of the entire airframe. It is also important that the input/output of complex flow diagrams are devised that will allow for simple and accurate processing.

(2) Must be capable of handling viscous flow and non-steady flow

It is anticipated that computations will be possible on separated flow, buffeting, etc.

(3) Must be capable of obtaining stable solutions (answers) within practical computing time

For effective design, it is as important to reduce the computing time and obtain a stable solution at all times, or even more important critically, than to attain computing accuracy. The target time is CPU 10 minutes to, at the most, 30 minutes.

(4) Must be developed domestically

From the standpoint of technology upgrade and the availability of programs, it is desirable that development be accomplished domestically.

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