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AERODYNAMIC CONCEPTS FOR FUEL-EFFICIENT TRANSPORT AIRCRAFT

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ABSTRACT

The rapid inflation of jet fuel prices in the last decade contributes largely to the growing operating expenses of the airlines and to a disproportionate share of the Direct Operating Costs (D.O.C.) as well, wherein the fuel share is already dominant. This report describes the influence of the increasing fuel costs on the aircraft design and explains the manner in which the lift/drag ratio as design parameter is steadily increasing in importance compared to the weight. The evaluation of the fundamentals for a new fuel efficient aircraft is a challenge for both, designer and aeronatical research. On the other hand there still exist potentials for performance improvements in terms of L/D for most of the current aircraft in service, as they were generally designed for minimum weight performance. This paper gives examples for aircraft modifications for performance improvement and shows potentials for future designs in the field of aerodynamics.

NOMENCLATURE

c	airfoil wing chord
c_D	drag coefficient
c_L	lift coefficient
c_m	moment coefficient
c_p	pressure coefficient
c_Q	suction coefficient
D	drag, engine diameter
L	lift
M	Mach number
R_N	Reynolds number
s.f.c	specific fuel consumption
T	thrust
u	velocity component
v	aircraft speed
v_j	jet velocity
W	weight
x	streamwise coordinate
x_e, x_T	engine exit behind wing leading edge
α	angle of attack
y	spanwise coordinate
Γ	circulation

Suffix

Tr	trim
max	maximum

1. Introduction

The development of civil air transport has made rapid advance with the introduction of new technologies. The significant strides made in aeronautical research and technology, such as the innovation of the swept wing and turbojet engines, have accentuated the rapid progress in aviation by providing increased flight speed and reduction in cruise time, and together with increased passenger capacity, contributed to major technological improvements in world-wide communications.

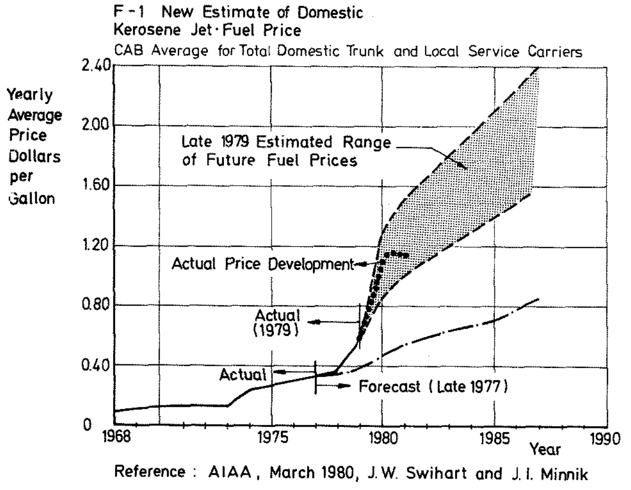
The technological development trend of flying higher and faster coincides with the passenger preference for shorter flight time, the block time reduction, a major factor in flight economy, and with the profit impetus of the airlines. However this trend of flying faster was limited by the sonic barrier, not as a technical but an economic limitation. The first steps into the supersonic regime as taken by the Concorde, despite outstanding technical performance and prospects, was economically unsuccesful. Herefore, besides a number of unsolved environmental problems, the inflatory jet fuel prices were responsible. Considering the air transport of the western hemisphere, the operating expenses up-to recent times were balanced between aircraft price, crew, maintenance and fuel price, in the last decade however, the rising fuel price increasingly dominates the airlines Direct Operating Costs (D.O.C.), setting consequences for the aircraft design philosophies. The reduction of specific fuel consumption s.f.c. with reduced flight Mach number, illustrates the trend to lower cruising speeds and make other propulsive systems with low s.f.c., e.g. prop-fans, attractive for the future. The design of the airframe also undergoes a reassessment with the inflative fuel prices. The aircraft weight which dominates the design in recent times, with its effects on fuel consumption, production and maintenance and crew costs is giving way to the gaining emphasis of aerodynamic efficiency, defined as lift/drag ratio. More shall be discussed on this topic subsequently in section 3 of this paper.

Considering that the fuel price situation can force the airlines into financial difficulties and without an acceptable economical air transportation, the further development of civil aircraft is at stake. To labour on a solution for this problem is a challenge for the aircraft design as well as for aeronautical research. Therefore extensive programmes in reseach and technology are planned and executed in Europe and USA with emphasis on configurations with improved performance capability and economic fuel consumption. In Germany, the work in the aerodynamic field is concentrated in a cooperative programme between the aircraft companies, the DFVLR and the ONERA in France. An outline of this programme - sponsored by the German Ministry of Research and Technology - with some results produced recently are presented in section 5.1.

The cost of research and development during an aircraft design has little influence on D.O.C. and proportionately decreases further with fuel price increase. This is an important consideration for the assessment of aeronautical research and for the application of new technology.

2. Fuel Price Increase and Operating Costs

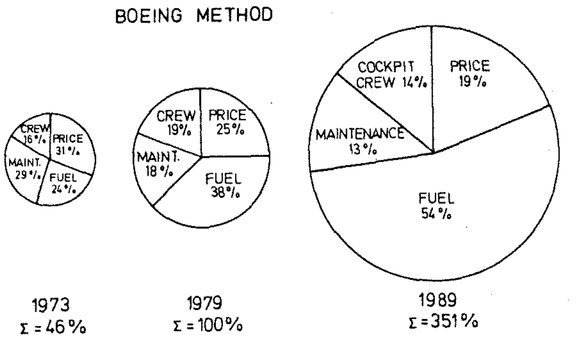
The increase of fuel price shown in FIG. 1 valid for the USA, and taken from Boeing [1], shows the rapid cost increase with the uncertainty for estimating the fuel price development. The forecast of 85 cents/gallon for the decade in 1977 was corrected 2 years later in 1979 to nearly 2 - 3 times the price, i.e. 160 - 240 cents/gallon. The cost inflation steps at 1973 and 1978/79 - the result of the world-wide oil price inflation - can be clearly seen. The dotted line gives the real price increase up to the end of March 1982.



Reference : AIAA, March 1980, J.W. Swihart and J.I. Minnik

FIG. 1 Increase of Fuel Price

The rapid fuel price increase considerably effects the direct operating costs D.O.C. directly and contributes to the disproportionate increase of the fuel costs in the D.O.C. FIG. 2 shows the cost development as estimated by Airbus Industry in 1979 [2]. From the different methods used in this forecast only the results from Boeing are shown because of its simplicity (4 parameters), and it strongly reflects the fuel costs within the D.O.C. In the EURAC method however, the fuel costs represent about 2/3 of the Boeing estimate. The fuel cost price development corresponding to FIG. 2 is based on the lower broken curve in FIG. 1.



Reference : 1979 ATA Engineering and Maintenance Forum, J. Thomas

FIG. 2 Increase of Operating Expenses with Time and Change of Distribution

Taking into consideration the upper line forecast from 1979, FIG. 1, the fuel costs share is considerably greater for the forecast up to 1989 [1]. A rough estimate leads to an amount of 64 %.

3. Influence of Fuel Price Increase on Aircraft Design

A proportionate change within the cost items of the D.O.C., as shown in FIG. 2, has a considerable effect on aircraft design. To elaborate this, the fuel consumption as determined by the main aircraft and engine parameters have to be analysed. FIG. 3 contains a simplified basic formula for mission fuel efficiency, defined as trip fuel burned per distance. The first term, the ratio of specific fuel consumption to cruise speed is defined as propulsive efficiency, and the second term is the airframe efficiency with aircraft weight to lift/drag ratio. Considering the latter, L/D to weight ratio must be as large as possible for fuel efficient flight.

The dominant part of the aircraft weight in aircraft design is relaxed by the growing influence of trip fuel on D.O.C., wherein the lift/drag ratio plays a more important economical role. The example under chapter 3.1 will explain the above.

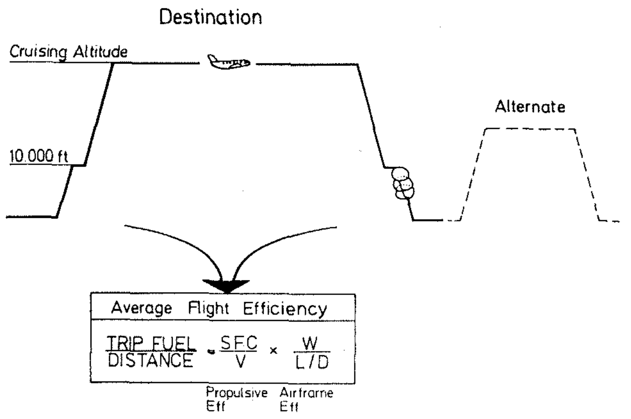


FIG. 3 Mission Fuel Efficiency

3.1 Influence of Aerodynamic Improvements on D.O.C.

Taking the following assumptions into consideration:

- o 10 % L/D increase is possible with 5 % higher aircraft weight.
- o 5 % weight increase leads to 5 % higher aircraft price.

Derived from Boeing method, is:

- o 5 % weight increase results in 2.5 % higher crew costs.
- o 5 % weight increase gives 1.5 % higher maintenance costs.

  For a large transport aircraft at medium ranges (≈ 1000 nm)

Using these assumptions and D.O.C. scaling factors with the D.O.C. subdivision as shown in FIG. 2 and estimating a fuel consumption according to FIG. 3, the cost increment effects on D.O.C. are:

+ 5 % weight increase	1973	1979	1989
+ 10 % L/D increase	Change in D.O.C. %		
Price (+ 5 %)	+ 1.6	+ 1.3	+ 1.0
Crew (+ 2.5 %)	+ 0.4	+ 0.5	+ 0.4
Maintenance (+ 1.5 %)	+ 0.4	+ 0.3	+ 0.2
Fuel (- 5 %)	- 1.2	- 1.9	- 2.7
Total change in D.O.C. %	+ 1.2	+ 0.2	- 1.1

This simplified example demonstrates the changing influence of aircraft weight and lift/drag ratio on the D.O.C. with increasing fuel prices. With an improvement of 10 % L/D by a 5 % aircraft weight increment, the direct operating costs show a downward trend over the years. Starting with a 1 % D.O.C. increase for 1973, nearly constant for 1979, the D.O.C. shows a 1 % decrease in 1989. As the above example is based on fuel price increase corresponding to the lower broken curve in FIG. 1 the balance shift is more pronounced using the upper curve of fuel price development prognosis.

3.2 Influence on Aircraft Wing Design

Since the lift/drag ratio is positively affected by an increase in aspect ratio, consequently the evaluation of the important parameters L/D and weight must be analysed for wing design with the objective of reducing the operating costs. This advantage of a larger aspect ratio opens new targets for various fields in aircraft engineering. The importance of direct weight saving with new constructive methods using advanced composite materials is outweighted by the possibility of producing a flutter free wing of large span with low weight penalties. Furthermore, active controls are a valuable implement to realize large span wings with limited design loads. The aerodynamics has the need to develop efficient large span wings and take up the challenge of engine-wing interference, besides suggest alternatives for new configuration concepts. Side by side to a new aircraft design, the result of re-evaluation of the effects of weight and lift/drag ratio on the D.O.C. can be exploited for performance improvements on current aircraft.

4. Potential for Performance Improvements of In-Service Aircraft

As many of the current aircraft are designed for minimum aircraft weight, fuel reduction through advanced aerodynamics is achievable at the expense of structural weight increase: Some possible modifications on the wing are sketched in FIG. 4. To determine are the L/D gains and the resulting weight penalties on wing and other aircraft sections eg. fuselage and tail.

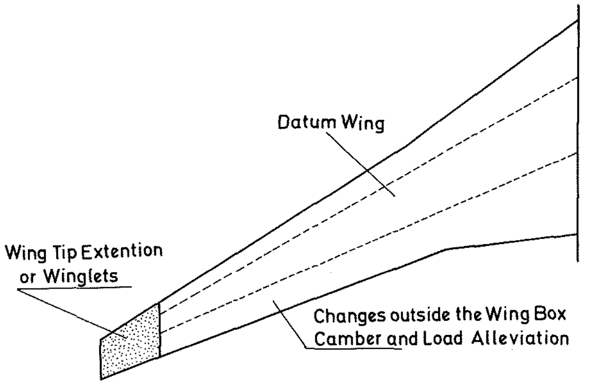


FIG.4 Wing Modification to Improve Aircraft Performance

The second important parameter for aircraft performance is the buffet boundary. The successful aerodynamic development of new transonic rear loaded aerofoils, as sketched in FIG. 5, resulted in major gains in buffet boundary. Increasing aerofoil rear end camber for lift gains can be used for improving the buffet boundary with relative small structural changes aft the wing box.

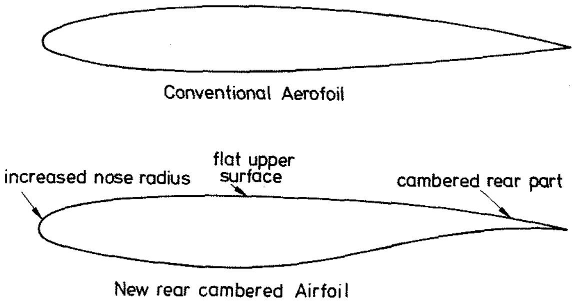


FIG.:5 Change of Aerofoil Geometry

4.1 Wing Modification aft the Rear Spar

The effects of wing modification on performance constraints was investigated on transport aircraft configurations as in FIG. 4. The aim was specifically to raise the cruise buffet limits by an acceptable lift/drag ratio development. A typical transport wing of current aircraft was the starting point for the investigation. The pressure distribution on the inner wing as designed for cruise configuration is shown in FIG. 6. This pressure distribution type has some development potential with aft wing camber. Theoretical calculations including boundary layer effects gave about 30 % lift enhancement for the inboard wing section, see FIG. 6. This was achieved mainly by extending the supercritical region without additional nose suction and increasing lift at the rear part of the aerofoil. The disadvantageous increase of pitch-down moment of 50 % results in higher tail loads. The type of spanwise modification depends on the spanwise lift distribution of the datum wing and on structural design criteria.

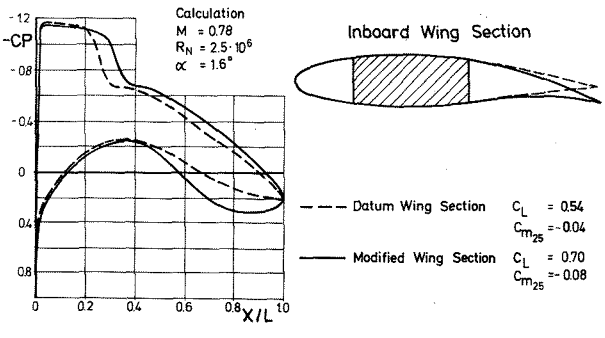


FIG. 6 Change of Pressure Distribution due to Wing Section Modification

4.2 Wind-Tunnel Tests in the NLR-High Speed Tunnel

After theoretical calculations for the required pressure distribution, the wind-tunnel model was modified accordingly. FIG. 7 shows the area and type of modification which was done with consideration of minimal structural changes and cost penalties. The modification consists of 3 ° flap and 2 ° wing rear end deflection with the upper wing surface lofted to the new flap position. This new flap position was faired spanwise to the outboard flap in the region of the inboard aileron. The wind-tunnel wing model had exchangeable parts aft the wing box for test comparison between the modified and the datum wing.

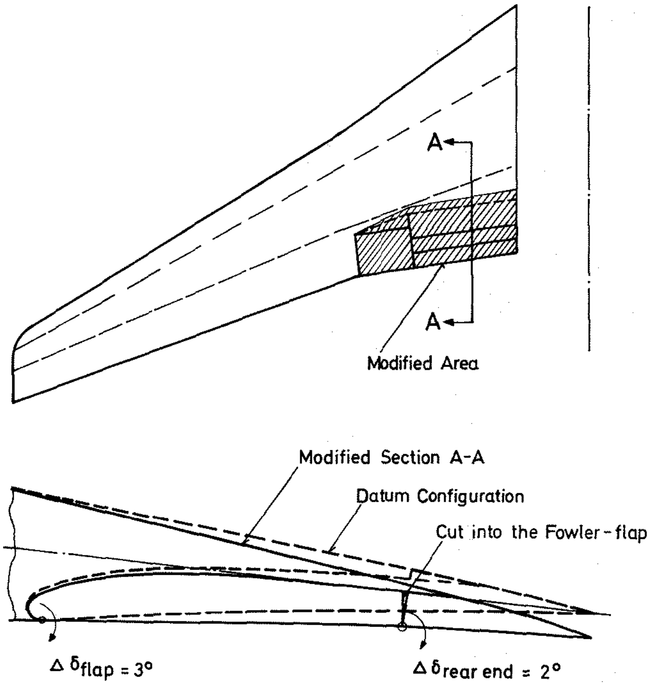


FIG.7 Inboard Wing Modification

The test programme covered three-component force measurements and flow visualization pictures. The tests were run in the NLR-HST at $R_N = 2.5 \times 10^6$ with transition band fixed at 7 % on the upper and lower wing surface. FIG. 8 shows the lift curves for the modified wing in comparison with the datum configuration at three Mach numbers. Besides a nearly parallel shift in the lift curves, the characteristics remain unchanged over the Mach number and angle of attack range. The lift increment results in higher buffet onset roughly estimated at $\Delta c_L = 0.08$ for the untrimmed curves. The pitching moments are given in FIG. 9. Similar to the lift curves the characteristics are unchanged, however, an increase in nose down pitching moment of $\Delta c_m = 0.02$ is observed, resulting in higher tail loads and trim losses. FIG. 10 contains the drag polars for both configurations. A $\Delta c_{D_{min}}$ of the order of 10 counts is measured due to the additional camber of the modified wing, however, a remarkable decrease of lift dependant drag is noticed leading to a crossover of the drag polars at about the design-C_L at M = 0.78 of the datum wing, leading to a favourable drag reduction at higher C_{L}s.

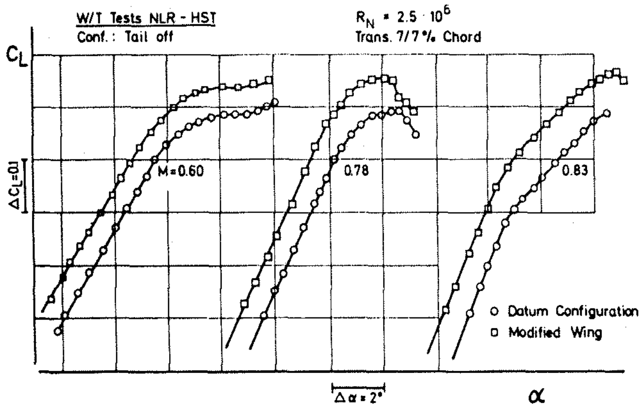


FIG. 8 Change in Lift Characteristics due to Inboard Wing Modification

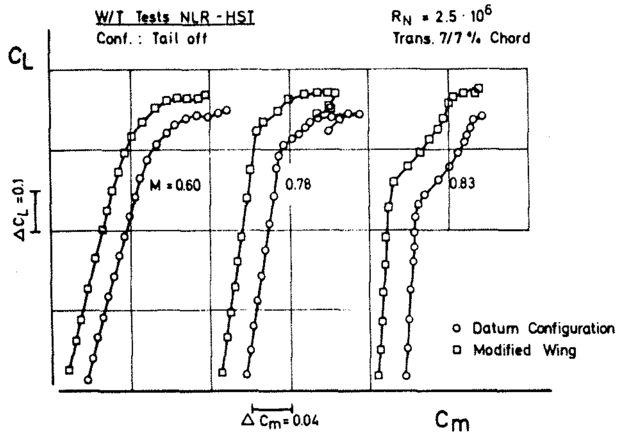


FIG. 9 Change in Pitching Moments due to Inboard Wing Modification

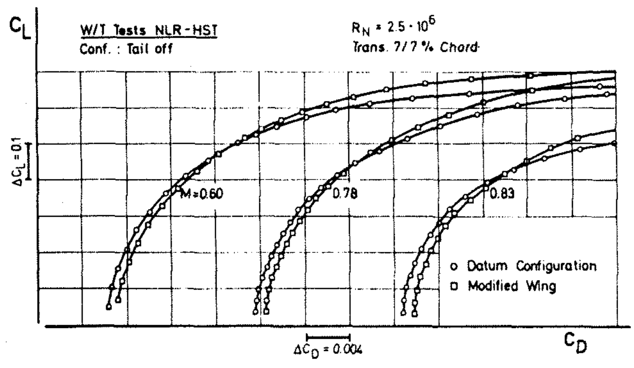


FIG. 10 Change in Drag Characteristics due to Inboard Wing Modification

4.3 Data Transformation for a Typical Transport Aircraft Configuration

The wind-tunnel test results were trimmed and transformed to an aircraft configuration of the current standard of civil transports. FIG. 11 upper section, shows a Δc_L = 0.05 improvement of the buffet boundary which corresponds to 6 % - 10 % in the cruise range, depending on Mach number and datum aircraft buffet limit. This improvement can be used to fly the aircraft either at higher altitudes, or to increase the aircraft weight, e.g. with additional passenger payload.

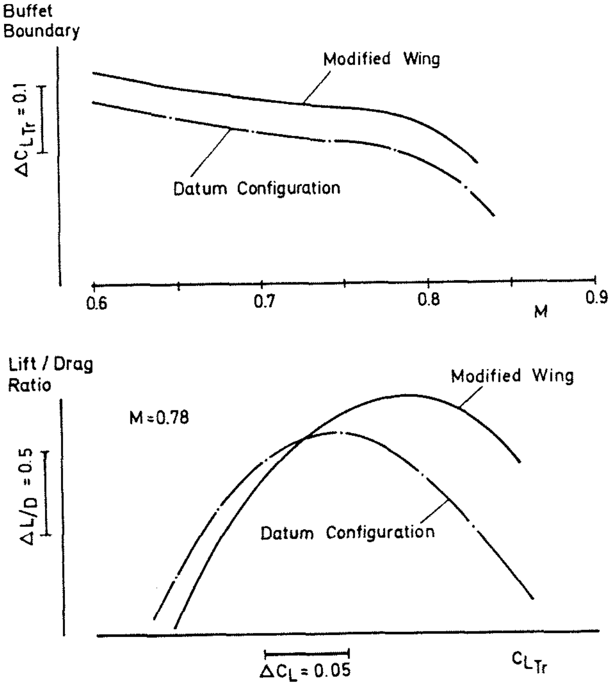


FIG. 11 Influence of Inboard Wing Modifications on Performance Boundaries

The change in trimmed lift/drag ratio is presented in FIG. 11 lower section, for a typical cruise Mach number. An improvement of maximum lift/drag of Δ L/D = 0.25 is gained which represents an increase of about 1.5 % refering to current aircraft standards. The maximum L/D is shifted to higher c_L-values which fits the buffet onset gain shown in the upper section of the figure. The lower L/D at smaller lift coefficients is disadvantageous and should be avoided. The aircraft designer may improve this lift/drag ratio by increasing camber at the outboard wing to achieve a smoother spanwise lift distribution.

Besides the change in chordwise pressure distribution, the inboard wing modification also generates a change in spanwise lift distribution, shown in FIG. 12. This data is estimated on the basis of reasonable good agreement between measured and calculated pressure distribution for the datum wing. The shift of wing loading results in an 8 % lower

1 g wing bending moment, which corresponds to a reduction of the design wing root bending moment of 2 % - 3 %.

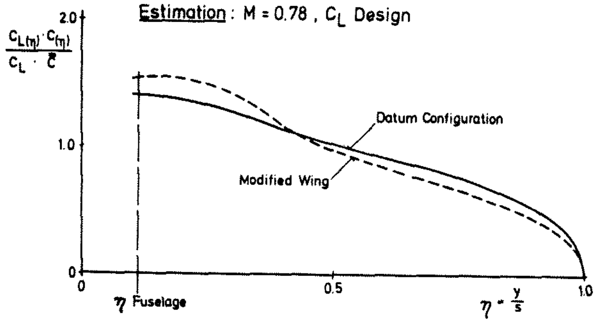


FIG. 12 Change of Spanwise Lift Distribution due to Inboard Wing Modification

4.4 Conclusions for In-Service Aircraft Modifications

The considerable performance betterments with the above modifications depend primiarily on the basic aircraft and comparison of the aircraft performance to the costs for the innovation. Stretching the aircraft to increase passenger payload is a classical method for achieving lower D.O.C. per seat, however, this is limited by the lowering of buffet altitude, restricting the operation flexibility of the aeroplane.

This limit can be further extended because the lift/drag ratio improves with higher lift coefficients when the buffet limit is raised by camber modification.

Further gains in lift/drag ratio are ensured by increasing aspect ratio with tip extension or winglets. This makes structural reinforcement necessary to counteract the bending moment increments at the root.

FIG. 12 shows that the inboard wing modification with the displaced lift distribution is an aid to reduce the bending moments at the root.

5. Future Transport Aircraft Concepts and Technology

The rapid inflation of jet fuel prices as predicted in FIG. 1, constitutes a great challenge for both aeronautical research and aircraft design. The two steps in 1973 and 1978 and even the optimistic price forecast at the lower curve, can raise the impression that all current aircraft concepts are obsolete and should be replaced by more economic ones, however, the major capital investment necessary and the timelag for service introduction, make the derivatives and modifications of current aircraft economically interesting.

The example of wing modification, as discussed in the previous section, with rear loaded transonic aerofoils show a way for improving current aircraft.

Future designs governed by the formula in FIG. 3, suggest the trend of raising the lift/drag ratio by primarily implementing an aspect ratio increase, even at the cost of weight penalties. This naturally involves all fields of aeronautics.

> Aerodynamics, to develop efficient transonic wings with high lift/drag values, evolved from substantially thicker sections for a given initial drag divergence Mach number which can be utilized for larger aspect ratios. For any design Mach number in the transonic regime, the smaller permissible sweep angle or higher wing thickness increase the effective wing stiffness, favourable for the aeroelastic problems of high aspect ratio, and reduce the basic wing weight level.
>
> New materials e.g. composites, and constructional methods could reduce aircraft weight and condition the structure for large aspect ratios. The composites offer superior strength and stiffness to density ratios compared to conventional aluminium and steel alloys, and are considerably advantageous for usage in the primary structure of high aspect ratio wings as their high elastic modulus reduce weight penalties arising from aeroelastic constraints caused by increased wing span.
>
> Active Control Technology to reduce gust and manoeuvre loads of high aspect ratio wings. For example the reduction of manoeuvre loads could lower the critical design loads with outboard aileron deflections causing an inboard wing load shift, and the reduction of gust loads by dumping lift with outboard and inboard ailerons and spoilers. The reduction of gust loads extends fatigue life and may even allow the structure to be dimensioned for lower maximum loads. In the case of critical manoeuvre loads, manoeuvre load control will lower the critical design loads.

5.1 Research in Aerodynamics of Transport Aircraft

All over the world work on technological advances contributing to the reduction of fuel consumption is being done. In Germany this research is included in the Civil Component Programme (Ziviles Komponenten Programm - ZKP -), sponsored by the German Ministry of Research and Technology. This cooperative programme which includes the aircraft companies, the DFVLR and the ONERA in France, is divided into development stages of 4 years duration. In the first, ZKP I for 1975 - 1978, the supercritical wing was the objective for the aerodynamics, wherein considerable contribution to the A 310 wing development was made.

In the present programme, ZKP II [3, 4] for 1978 - 1982, the objectives outlined in FIG. 13, to be achieved are: -

- o High aspect ratio wing
- o Propulsion - Airframe integration
- o High lift devices
- o Manoeuvre load control
- o Relaxed static stability.

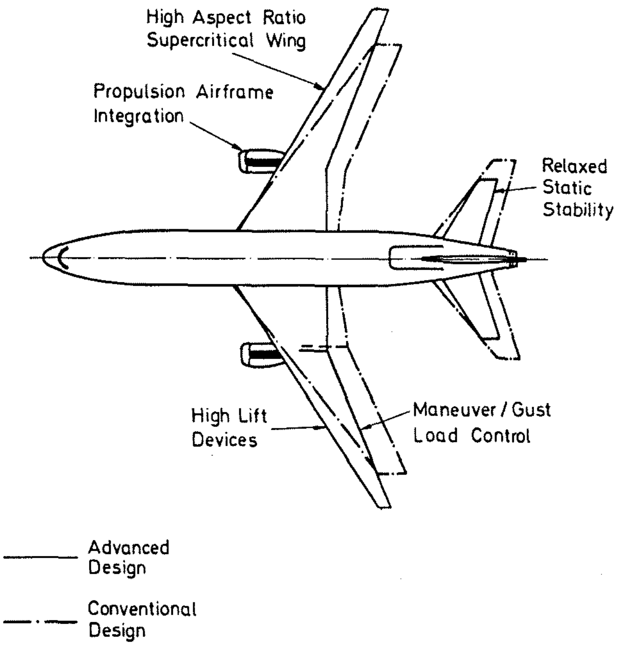


FIG.13 Civil Component Programme ZKP II Objectives

The tasks set are in good agreement with the NASA Aircraft Energy Efficiency Programme (ACEE), having similar views on future research in the field of new technology transports [5].

Some main points of research in the field of transonic wing aerodynamics are outlined in FIG. 14. One objective is the improvement of 2-D section performance as basis for high aspect ratio wings. Besides a stepwise aerofoil improvement and considering high and low speed requirements, great improvements were achieved by boundary layer suction at the shock [6, 7] .

FIG. 15 shows the single slot suction concept, which after theoretical investigations at VFW, was tested in cooperation with the DFVLR in the Göttingen wind-tunnel.

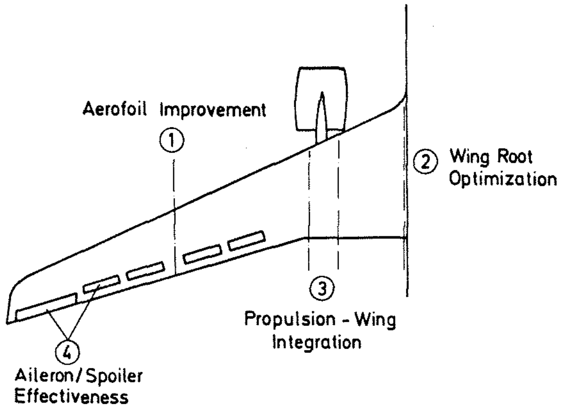


FIG. 14 Future Research in Transonic Aerodynamics

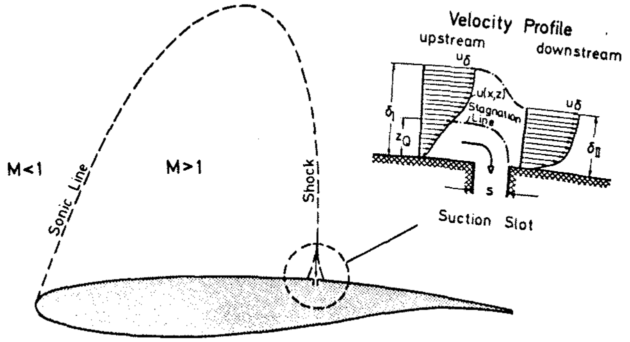


FIG. 15 Supercritical Aerofoil Single Slot Suction Concept

FIG. 16 contains the lift curve and the drag polar with and without suction at M = 0.76, which is slightly above the design Mach number for the Va2 aerofoil. Maximum lift is increased from $c_L = 0.86$ to $c_L = 0.99$ using a suction coefficient of 0.0006. The results show only small improvements over $c_Q = 0.0004$, which is also demonstrated in FIG. 17, containing the pressure distribution with and without suction operating. The suction influence on the boundary layer profile is shown in FIG. 18. In this case separation occurs without suction at x/c = 0.9, showing a thick boundary layer developing far upstream. This condition is changed with suction. One observes a thin boundary layer before the shock, a small separation bubble behind the suction slot at x/c = 0.65 and reattached flow down to the trailing edge.

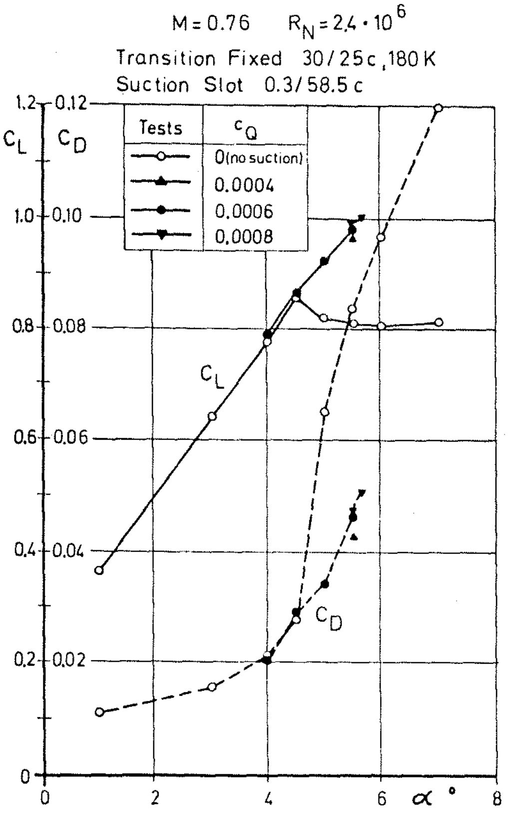


FIG. 16 Va-2 Section Lift Curve and Drag Polar with and without Slot Suction

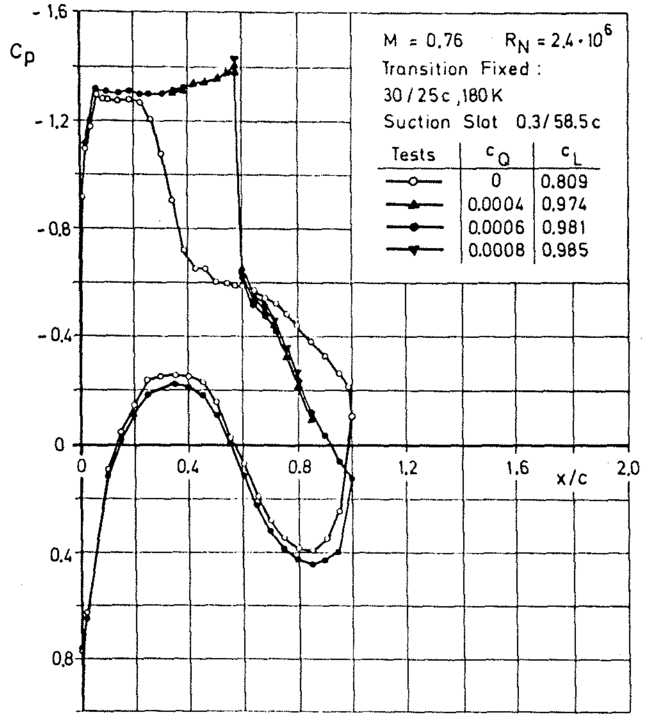


FIG. 17 Va-2 Aerofoil Pressure Distribution with and without Slot Suction

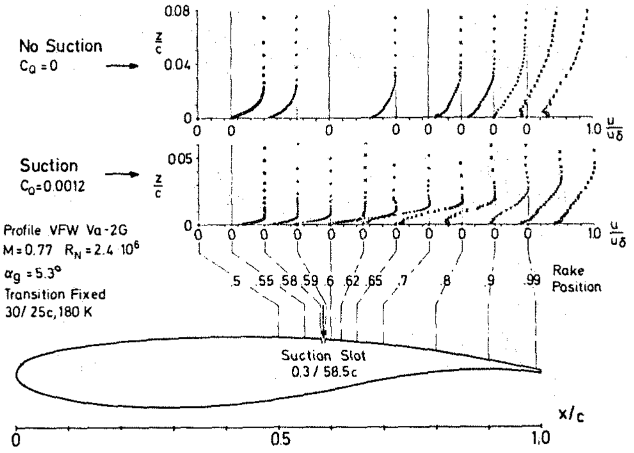


FIG. 18 Suction Influence on Boundary Layer Profile

Contrary to the distributed suction with minislots or miniholes needed for flow laminarization, this slot concept seems to be practicable without too much structural complication. Low suction quantities are sufficient to achieve good improvements in maximum lift and buffet boundary showing the possibility for practical application in production aircraft.

A further task in transonic aerodynamics is the wing- engine integration, as shown in FIG. 14. The change of wing pressure distribution on both sides of the engine, represented by a through-flow double-body nacelle, taken from NLR-HST tests, is given in FIG. 19. The lower wing surface inboard of the engine is considerably effected whilst, outboard the engine, the influence is on both wing surfaces. To separate the combined pylon-nacelle effects, tests were run with the large ZKP half-model at ONERA, shown in FIG. 20, where the nacelle was fixed on a sting mounted on the tunnel floor[8].

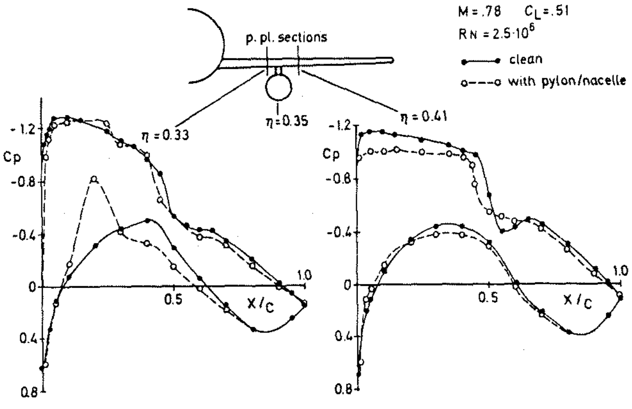


FIG. 19 Windtunnel Tests at NLR-HST, Wing B10.3V

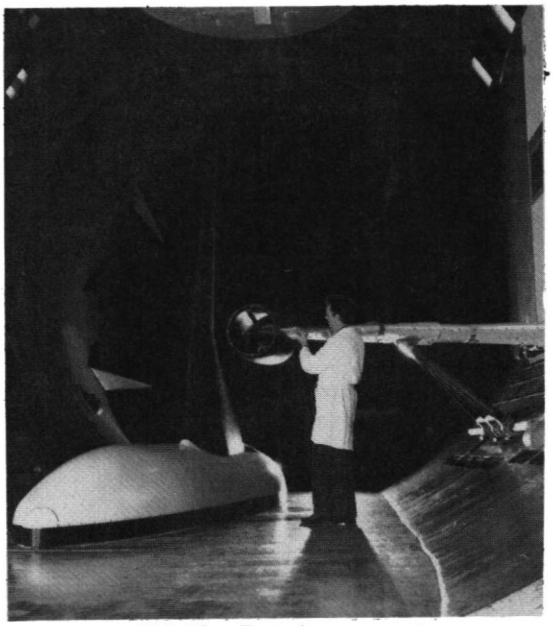


FIG. 20 Test Arrangement

The results in FIG. 21 show, that the pod alone has the main influence on the upper surface distribution, therefore, the change of pod position relative to the wing can be taken as a measure for the change of pressure distribution on the upper wing surface, which is important for the wing design.

FIG. 22 shows the corresponding figure for a more rearward and slightly lower nacelle position. The effect is quite similar though slightly smaller. Starting from this position the nacelle was moved to the wing in three steps with the results presented in FIG. 23. The Δc_p is recorded as difference of the pressure at the new positions [2] ,[7], ⑥ against the pressure at position ⑧ over the wing chord up to the shock. At the shock, as Δc_p increases considerably for any small change of the shock position, it is therefore not representative for nacelle-wing interference. Behind the shock region, the change of the wing pressure distribution caused by the nacelle is small and is therefore omitted in FIG. 23.

A comparison with FIG. 22 shows, that the main effect at the forward wing is to increase the upper surface c_p by the same order of magnitude (10%), as produced by the pod in its lowest position. The maximum shift in nacelle position from ⑧ to ⑥ is in the order of wing thickness at the pod station. For this magnitude of shift we can conclude, that interference effects can be taken into account during the wing design without changing the basic wing geometry, i.e. twist or dihedral over span.

For better engine representation, the jet simulation has to be included. The TPS technique is provided for future ZKP tests. For the conventional engine location, the jet is expected to enforce the through-flow nacelle effects.

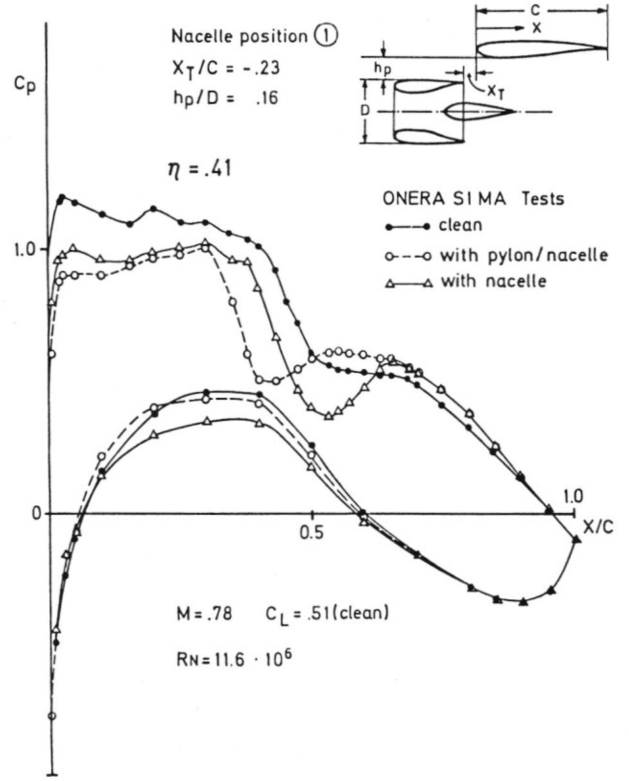


FIG. 21 Pylon/Nacelle Influence on Wing B10.3V Pressure Distribution

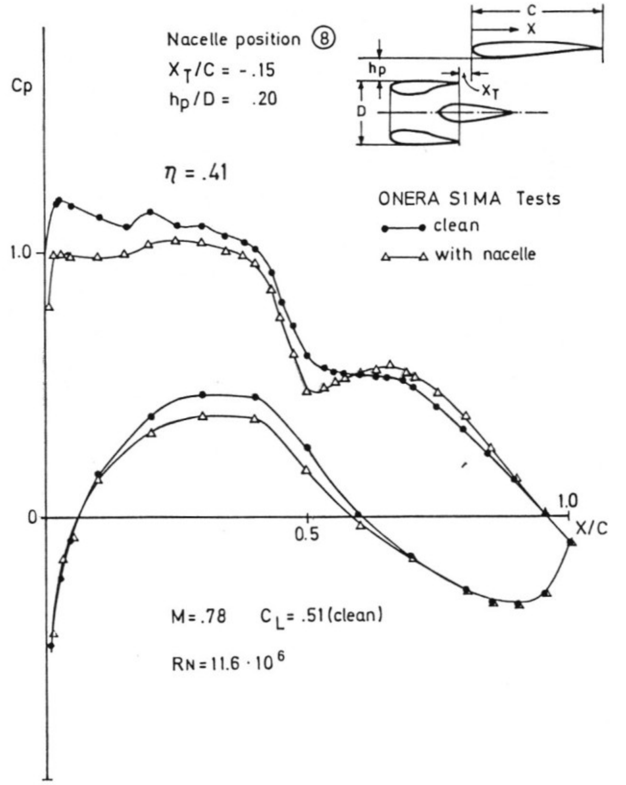


FIG. 22 Pylon/Nacelle Influence on Wing B10.3V Pressure Distribution

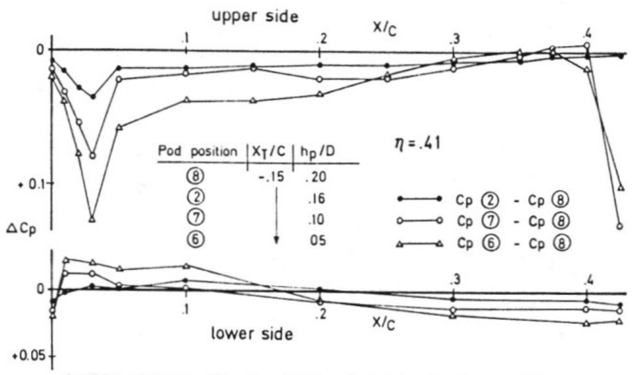


FIG. 23 Change of Wing Pressure Distribution due to decreasing Nacelle Distance from Wing

5.2 Advanced Concepts for Transport Aircraft

The interference studies with the classical underwing engine position aim at minimizing interference drag. The development of high aspect ratio wings with thick sections and high by-pass engines with large diameters aggravates the propulsion-wing interaction problem still further. The problem for the reduction of interference between engine and airframe must also be seen in connection with new engine types having low fuel consumption with large airflows, e.g. prop-fans.

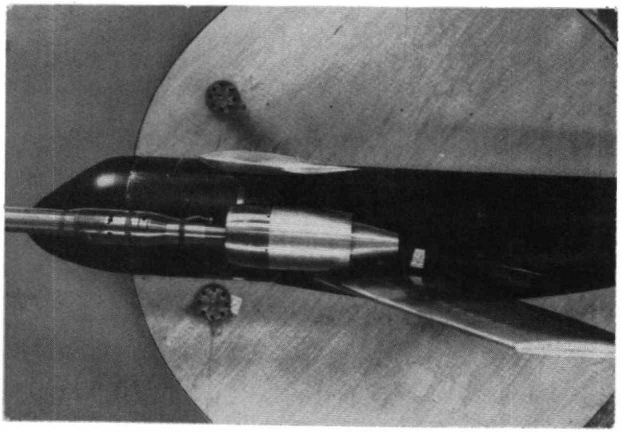


FIG. 24 Test Arrangement

A concept with a wing isolated engine which sustains the natural circulation of the wing was investigated by VFW. FIG. 24 shows the model setup in a subsonic wind-tunnel. The engine model is located above the wing. As the engine is isolated from the wing-fuselage model, only the nacelle-jet effects on the wing and not the reaction forces on the engine are measured. Initially blowing nacelles were used for wake simulation, later ejector engines as shown in the picture. The engines were manufactured by the DFVLR, working in close collaboration with VFW. The jet of the model is in good agreement with a typical By-pass engine jet, as comparable tests have shown.

The ejector engine effects on the lift/drag ratio and maximum lift are presented in FIG. 25.

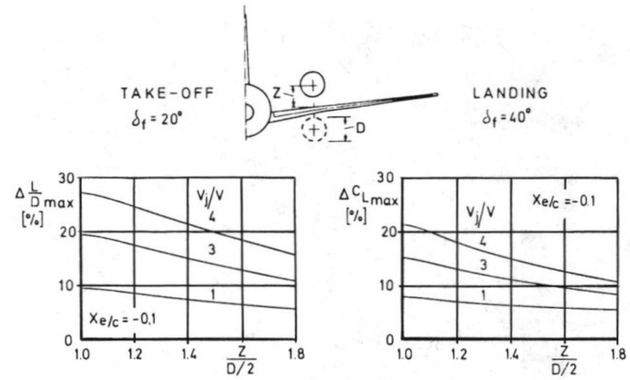


FIG. 25 Improvement of Low Speed L/D and $C_{L_{max}}$ due to Engine Over-Wing Position

The results are refered to the wing without jet influence. This wing was designed for an underwing engine installation. For the reference tests, the trailing edge flaps in the engine wake were fowlered at 6°. The tests with jet effects were conducted with full span flap deflection. At take-off flap settings - shown on the left side of the figure - there is a remarkable improvement in L/D, dependant on nacelle position above the wing. This can be considered partly due to better flap efficiency for the case with nacelle/jet on, as there is no interruption of the flaps. This value can be obtained from the curve $v_j/v = 1$ where the asymptotic value is of the order of 5%. For the engine positions close to the wing, rather high benefits are obtained, however, strong adverse effects can be expected in the high speed flight regime, which can hardly be rectified by modification of the basic wing geometry. For the landing case where $C_{L_{max}}$ is of major importance, the jet effects are smaller and the better $C_{L_{max}}$ results from the superior continuous flap system of the advanced configuration.

First results of recent wind-tunnel measurements using the TPS-technique are presented in FIG. 26. The test setup is shown in FIG. 27. The engine is fitted to a stub-wing i.e. forces and moments on the engine are included in the measurements. The main wing is a modern transonic wing designed for underwing engine installation. The L/D_{max} improvement due to the jet influence only is of the same order of magnitude as with the ejector engine. The $C_{L_{max}}$ improvement shows another characteristic in the clean wing configuration. In this case the wing is more sensitive against the engine interference at lower distances between engine and wing.

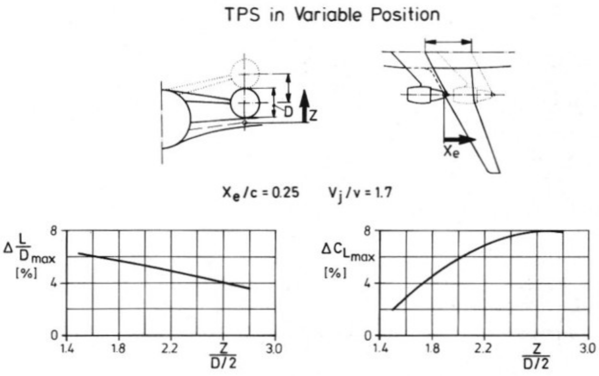


FIG. 26 Improvement of L/D and $C_{L_{max}}$ for Clean-Wing-Configuration with TPS in Ower-Wing Position

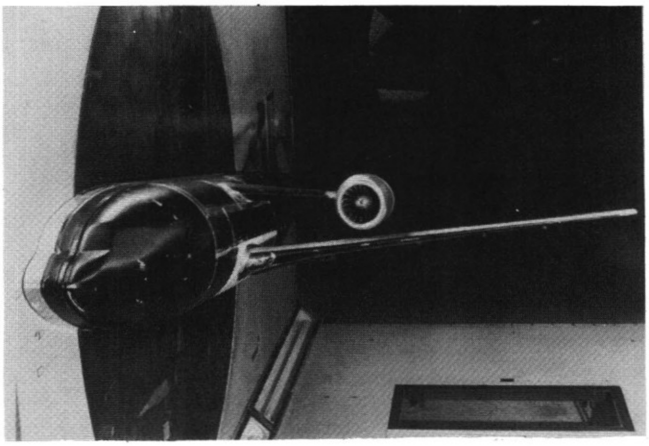


FIG. 27 Test Arrangement with Turbine Powered Simulator (TPS)

The benefits to which aerodynamic performance can be used in an advanced aircraft design are illustrated in FIG. 28 as an example. The jet wake sustains the wing circulation flow with improved momentum distribution in the wake. To avoid the strong pylon wing interference effects of wing mounted configurations, the engines are fixed to the fuselage. The forward wing appears advantageous for stepwise introduction of CCV techniques, with a design potential for other propulsive systems such as propfans, etc, where over-wing installations bring disadvantages with wing-engine interaction.

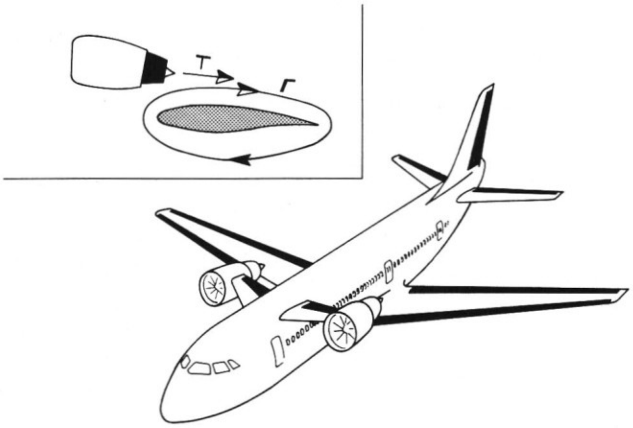


FIG.28 Advanced Engine Over-Wing Configuration

However, the negative aspects of this type of concept must mentioned: Cabin noise with limited passenger view; ground handling and engine maintenance; fuel flow to the engines; forward wing wake effects and jet influence on the tail.

Further work is necessary with engine simulation (TPS) in the high speed and low speed regimes to fathom the implications and the limitations of the encouraging low speed test results. For this purpose wind-tunnel measurements are proposed with TPS of the GE-CF6 engine.

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