# DNW TEST HIGHLIGHTS RELATED TO AIRCRAFT ENVIRONMENT

BY

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Abstract

A survey is given of environmental problem areas in aerospace. Noise and pollution emission are discussed and related aspects like pollution distribution, propulsion technology improvements, energy saving by drag reduction, and noise reduction of aircraft are analysed for potential applications of DNW. Typical examples of DNW tests are given in fields like noise reduction of aircraft, helicopters and propulsion units, integration of engines and airframe, and drag reduction by laminarization. Future activities will concentrate in these areas whereby research and technology programmes initiated by the aerospace industry sponsored partly from EC BRITE/EURAM funds, will play an important role.

## 1. INTRODUCTION

As result of the prognoses about the growth rates in civil air transportation the relation between aircraft and environment is becoming of increasing significance. Between 1980 and 1990 world air traffic has practically doubled and according to the 'Lotos' Study [1] it will triple again by today's standards in 2015. Inevitably this implies a considerable ecological burden by civil air transportation.
Typically, one may distinguish two problem areas in the relation air traffic and environment, i.e. noise hinder and exhaust gas emission.
Purpose of this paper is to illustrate the significance of DNW for the solution of aircraft environmental related problems by answering in particular two questions:

a. What kind of tests were carried out at DNW in the last ten years that contributed to the solution of environmental issues?

b. In which particular field can DNW make essential contributions and what are the future application areas?

## 2. FORMULATION OF NOISE AND POLLUTION EMISSION PROBLEMS

When we make a distinction between both emission types - noise and exhaust gases - it is possible to derive specific solutions which are partly closely interconnected, however. In Table 1 a survey is given for both types of emission inclusive potential measures which will be elucidated in the following.

| Type of Emission | NOISE | POLLUTION |
|---|---|---|
| Procedures/ Measures | Noise Reduction *(Source Identification)* | Expansion and Reaction of Pollutants[1] *(Identification and Objectification of Problems)* |
| | Noise Insulation *(active, passive)* | Low Pollution Propulsion Systems *(Improved Combustion, Fuel Consumption Reduction)* Drag Reduction of Airframe Components |

Noise Reduction: By discerning of noise sources and their resulting noise emission it is possible to attain direct improvements. Examples are: noise due to interaction between propulsors and airframes - in particular the integration with flap systems, noise from propulsion units and the impact of high by-pass ratio fans, and noise from helicopter rotors and the influence of higher harmonic control of the rotor blades. These subjects will be treated further on.

Noise Insulation: This comprises noise insulation measures in particular of buildings around airports, as well as measures to improve the comfort of passengers. While by insulation of buildings primarily passive measures are applied like noise absorbtive liners it is often possible to reduce internal aircraft noise by means of active dampers. Naturally, a more attractive and engineering like approach is the identification of noise sources and their elimination or reduction.

Distribution and Reaction of Pollutants: In Germany, the DLR has initiated a national Research and Development program "Pollutants in Aerospace", that in cooperation between Research Establishments and Industry will be executed [2]. This R&D program covers two problem areas, namely 'Research of the Atmosphere' and 'Propulsion Technolgy'. Hereto following information.

a. Research of the Atmosphere
Diagnosis of pollutant emissions and their effects with emphasis on the issues:
- Determination of pollutant emission
- Distribution of pollutant emission
- Effect of pollutants on the ozon and radiation contents.

b. Propulsion Technology
Reduction of pollutants with emphasis on the issues:
- Causes of pollutant emergence
- New combustion chamber concepts
- New propulsion concepts

Low Pollution Propulsors. Only the last issue 'New propulsion concepts' of the stipulated research areas is of relevance to DNW. An example is the propfan concept of MTU, the Counter Rotating Integrated Shrouded Propfan (CRISP). The deployment of these new energy saving engines and associated problem areas like for instance the integration of these engines with the airframe and the reduction of noise emission will be treated in chapter 3 and 4.

Drag Reduction of Airframes. By laminarization of the flow over aircraft components and by manipulation of turbulent boundary layer flows by for instance 'Lebus' (Large Eddies Brake-ups) or 'Riblets'. As DNW stands out by an excellent flow quality, the facility is virtually predestinated for drag reduction investigations (see also chapter 4.2).

## 3. INVESTIGATIONS FOR NOISE EMISSION OF AIRCRAFT AND HELICOPTER

For the discussion of noise emission problems it is necessary to distinguish between fixed wing aircraft and rotary wing aircraft (helicopter), as both the utility spectra and the technical aspects for these types of aircraft are principally different:

### 3.1 Noise Emission of Fixed Wind Aircraft

If supersonic and hypersonic air traffic are not taken into consideration rests for fixed wing aircraft primarily the noise hinder around airports. The introduction of new technologies in the fabrication of aircraft engines has thereby led to considerable reduction in noise levels. Due to the introduction of larger by-pass ratios, improved combustion chambers, acoustic absorbers in nacelles, and optimized integration of nacelles with airframes, reductions of 20 to 25 dB in noise levels have been obtained over the last thirty years (Fig. 1). Further noise reductions may be expected by continuation of these measures although new engines are primarily developed to obtain more favourable specific fuel consumptions. Expectations based on the development of both single and counterrotating propfans aim at fuel reductions of up to 30%. At present two versions have been tested in flight, i.e. at the Douglas MD91 and the Yakovlev Yak-42E-LL [3]. Important problems associated with the introduction of these new systems result from too high noise emission levels, which beside an environmental burden also lead to a serious dynamical loading of the airframe. Already in 1987, tests of this kind were carried out by Boeing in DNW (Fig. 2) with emphasis on the interaction between an unducted counter rotating propfan and the aft fuselage on noise generation. The test clearly demonstrated that installation effects of these engines effect both the noise emission and the dynamical loading of the airframe. As a logical consequence today, emphasis is given to the development of ducted propfans to investigate if this technique helps to fulfil the noise reduction requirements and to find protective measures against acoustic fatique. Moreover, ducting makes the armouring of fuselage parts which are endangered during the loss of a propeller blade, obsolete. During the development of 'Counter Rotating Ducted Propfans (UHBR) and engines with Very High By-pass Ratios (VHBR) problems are identified for which the DNW is ideally suited to find proper solutions. This comprises:

- o Acoustic and performance measurements of isolated propfans, UHBR and VHBR engines
- o Investigations to determine the interferences between these propulsion systems and the airframe.

The performance aspects of the latter are treated in chapter 4.1.

Investigations of Isolated Engines

What are the aerodynamic and aeroacoustic problem issues for new engines? In the last decennia two development trends are noticeable at the engines companies:

- o Augmentation of by-pass ratios of existing turbofan configurations
- o Development of ducted propfan engines like MTU's CRISP.

The up to 4m diameter large engines with relatively short nacelles are sensitive to sideflows or gusts which may lead to flow separations in the take-off and landing phase with associated losses in performance. Besides, the short nacelles shapes allow little internal space for noise absortive lining and enhance the external noise emission. First performance and acoustic measurements on a 'Ducted Contra Rotating Fan' were executed for Rolls-Royce in 1990 (Fig. 3). Similar tests were done for MTU with a 1:6.25 scale CRISP model in 1991. For the execution of these tests, DNW acquired beside an in-flow microphone traverse (stroke 12 m) a flexible floor based, model support system that can be used both in the open jet and in the parking hall. This so-called Common Support System (Fig. 4) consists of a 130° yawable turntable whose supporting structure can slide in mutually perpendicular directions over a stiff earthframe. The system is compatible with the DNW infrastructure and can support electrically, pneumatically and hydraulically driven engines up to 1 MW.

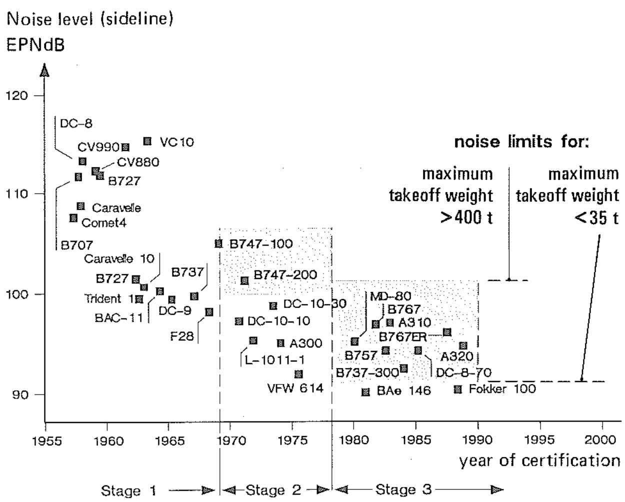


FIG. 1 Progress in Aircraft Noise Reduction from 1955 to 1990

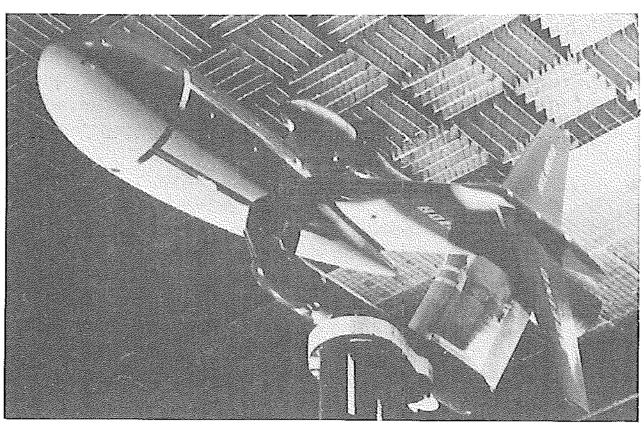

FIG. 2 Test set-up for the Investigation of Interaction Noise of an Aft Fuselage Unducted Propfan Model (GE 36) for Boeing

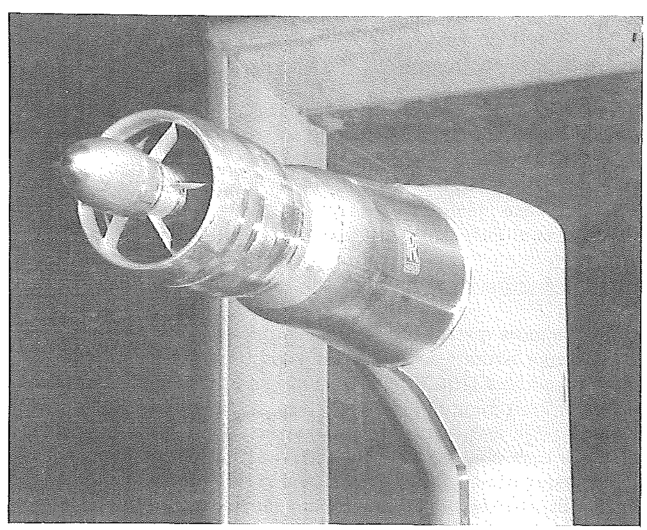

FIG. 3 Model of a Ducted Contra Rotating Fan of Rolls Royce for the Study of Performance Aspects and Noise Emission

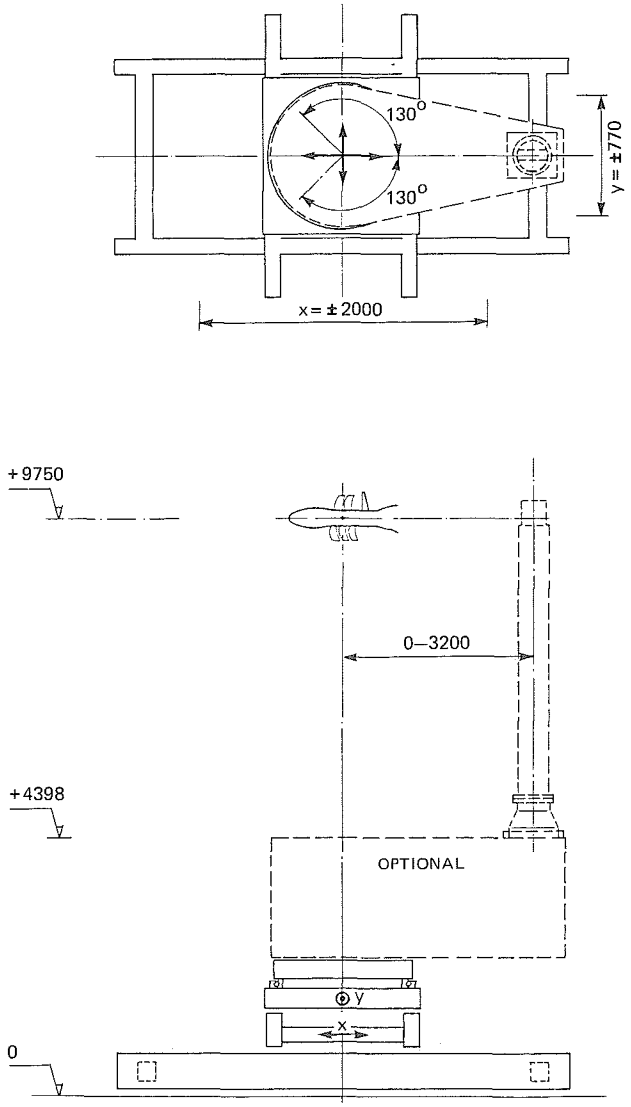


FIG. 4 Sketch of DNW Floor Based Support System for Testing Model Propulsors in the Open Jet Configuration

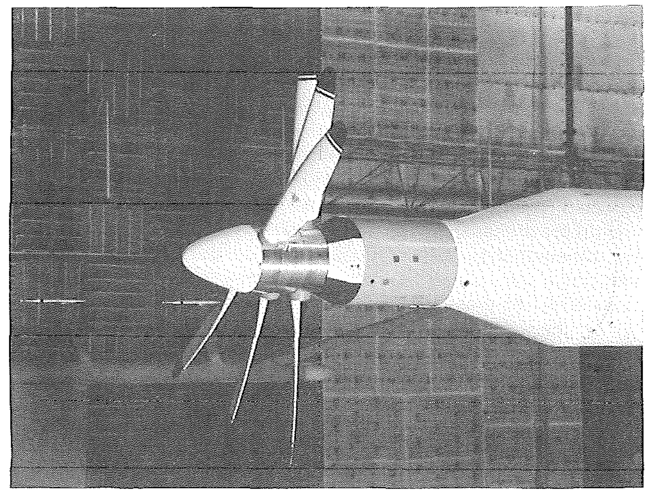

FIG. 5 Asymmetrical Blade Propeller Test by DLR

Investigations for Integration of VHBR-Turbofans and Propfans

Except for the mentioned tests of Boeing for the acoustic optimization of the integration of an unducted propfan, momentarily, all investigations concentrate on the performance aspects of the integration process in the take-off and landing phase. These tests are therefore treated under the topic 'Reduction of Pollutants' (chapter 4).

Noise Reduction for Propeller

Even in a more distant future propeller drives will still be used for short range aircraft as the lesser energy consumption leads to more favourable DOC (Direct Operational Costs) values. Propeller driven aircraft contribute nevertheless considerably to the overall noise hinder and, moreover, propellers contrary to turbofans create a high noise loading on the passenger cabin leading to a much lesser comfort of the flight guests. In the framework of the Fokker 50 development this lead for instance to the determination of cabin noise loadings by model experiments in the DNW. On the basis of these data, together with investigations of an isolated six-blade propeller solutions were found to obtain a much lower noise level in the flight cabin of the Fokker 50 [4].

One possibility to reduce the noise emission of propellers is the unsymmetrical arrangement of propeller blades like proposed by W. Dobrzynski of the DLR Institute for Design Aerodynamics in Braunschweig (Fig. 5). Investigations in the DNW confirmed that noise level reductions of 3 to 4dB with four- and six-bladed propeller with unsymmetrical blade configuration can be attained[5]. At present a European technology programme on propeller noise is under preparation. The programme called 'Study of Noise and Aerodynamics of Advanced Propellers' is incorporated in the EC BRITE/EURAM intermediate phase to provide a broader base to all research development activities and foresees in the execution of tests in the DNW under the direction of ALENIA.

### 3.2 Noise Reduction for Helicopter

Rotary wing aircraft have contrary to fixed wing aircraft, whose development and success in civil aviation was strongly influenced by military developments, not gained a dominant civil market share.
What are the reasons for this? No doubt, up to today, the helicopter is still an extremely complex technical system that - in comparision to an aeroplane - is difficult to fly. One reason for this is certainly the incomplete control of the instationary aerodynamics and its impact on the dynamical behaviour of the system. As a result of this flight mechanical problems can only be solved by means of complex flight control systems. Moreover, the use of the helicopter in the civil sector is strongly limited by its noise emission. Clearly, helicopters can make a valuable contribution to release the congestion of major airports.
In this respect is also the development of the tilt rotor important like the EUROFAR project. A condition for this no doubt is that considerable noise reduction for these types of aircraft are achieved. Contrary to propellers, the individual rotor blades experience no homogeneous flow conditions. Moreover for each rotor condition the local blade flow and thereby noise emission changes. Following noise phenomena can be recognized:

o High-Speed Impulsive (HSI) Noise
HSI noise occurs during fast forward flight and is noticeable especially in the forward quadrant. It is characterized by strong negative pressure spikes which grow in amplitude with the Mach number of the advancing blade. Because of high local absolute velocities shock waves are formed which for local Mach numbers in excess of 0.9 tend to separate from the blade (delocalization) and result in a highly intensive, impulsive type noise source.

o Blade-Vortex Interaction (BVI) Noise.
BVI noise is contrary to HSI noise characterized by pronounced positive pressure spikes and radiates mainly

in a downard/forward direction at low to mid frequencies. It occurs when the rotor blades interact with previously shed vortices in the rotor plane which is typically the case during descent flight.

- Broadband (BB) Noise
  BB noise is the result of stochastically fluctuating airforces like in wakes and turbulent boundary layers. It is the dominant noise in the mid to high frequencies. An example is the interaction between rotor blade and previously shed blade wakes which for instance at the retreating side, where the velocity reaches a minimum, may cause local flow separations.

- Loading and Thickness (L&T) Noise
  L&T noise is associated with the lift and drag forces on the individual blades in the rotating system.It is of a strong periodical nature and noticeable particularly in the low frequency range.

- Main Rotor - Tail Rotor Interaction (MTI) Noise
  This is caused by the interference between main rotor and tail rotor. The latter experiences extremely unsteady inflow and can account for much of the mid to high frequency noise at specific directivities.

An extensive description of the noise mechanisms was given by H. Heller in the Proceedings of the DNW colloquium 'Ten Years of Testing at DNW'[6]. This article contains further a survey of the most important results of helicopter model rotor measurements in DNW carried out by DLR in cooperation with colleagues of NASA-Langley, NASA-Ames, and US Army. In this respect it also forms an impressive documentation of ten years of collaboration with the USA. Already in 1988 a pilot rotor experiment was carried out that successfully demonstrated the potential of HHC (Higher Harmonic Control) - initially developed to alleviate vibrations - for rotor noise reduction. The basic idea thereby is to use HHC to obtain systematic changes in the local blade incidence angles, especially in the azimuthal angle range $\psi$ = 45° to 75° and $\psi$ = 270° to 300° where BVI noise is primarily generated (Splettstößer[7]). This leads to a reduction in the blade lift at the tip with subsequent reduction in vortex strength, and an increase of the blade vortex miss distance, resulting in a less blade vortex interaction and reduction in BVI-noise. A schematic representation as given by Brooks[8] is shown in Fig. 6.

Based on these promising results the DLR Institutes for Design Aerodynamics and Flight Mechanics initiated a further test to investigate the noise reduction potential of HHC. This was carried out in 1990 in cooperation with Aerospatiale Division Helicopteres, NASA Langley Acoustics Division and MBB Helicopter Division. The test was made possible due to the availability of the DLR rotor test rig (Fig. 7). The test program comprised higher harmonic cyclic pitch control schemes of 3 to 5 cycli per revolution with corresponding amplitudes and phase shifts for different rotor flight conditions.

The noise emission data were acquired by means of the DNW in-flow traverse provided with 11 microphones. The radiated noise field underneath the rotor was visualized by means of so-called directivity plots showing contours of identical noise levels (Fig. 8 from Reference 9).

Shown are directivities without and with HHC that illustrate clear noise maxima on the advancing and retreating side of the rotor, respectively, for a typical BVI condition. A comparison of the radiated noise levels shows a clear reduction of about 6 dB at the advancing side for the case with HHC. However, at the retreating side a slight increase could be noted. Moreover, it could further be assessed that the optimal HHC parameters for noise reduction and vibration reduction do not always coincide and that certain HHC phase shifts could also lead to a noise level increase. The application of this noise reduction measure therefore necessitates a precise tuning of the total higher harmonic controls whereby a form of computer supported closed loop HHC is required.

Another important activity for noise reduction of helicopters is the EC BRITE/EURAM program 'Helinoise'. This common European initiative aimes at a better understanding of the rotor blade noise mechanisms by means of extensive measurements in the wind tunnel. Objective is to measure the instationay pressures at 120

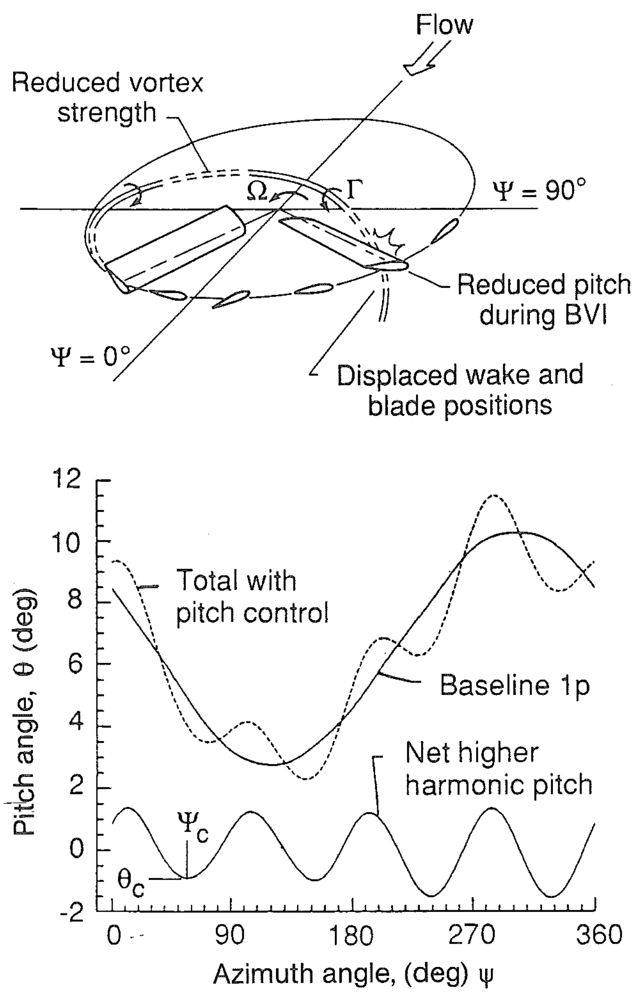


FIG. 6 Schematic Illustration of a Noise Reduction Concept by Higher Harmonic Control (NASA)

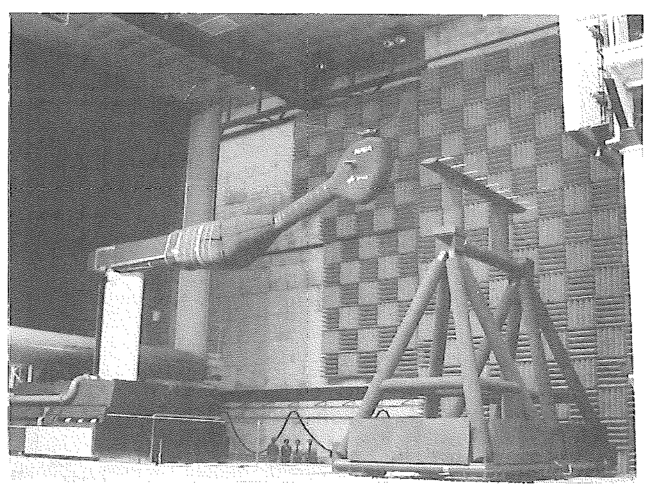

FIG. 7 Test Set-up for Main Rotor Fly-over Noise Measurements with a 40% Scaled Model of the BO 105 for NASA and DLR

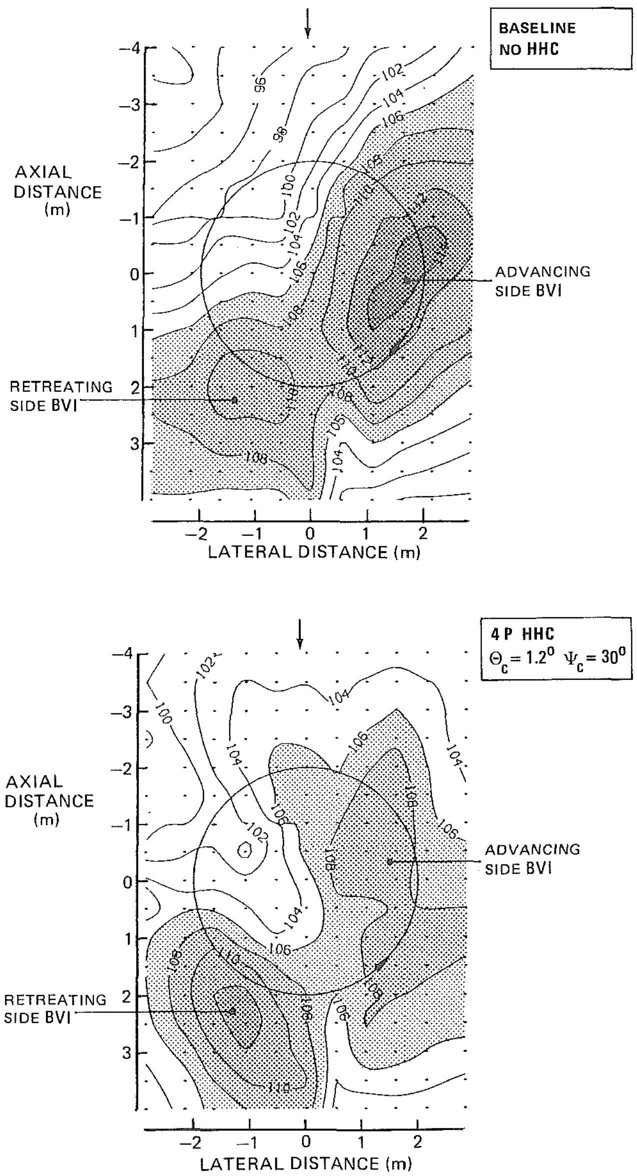


FIG. 8 Mid-frequency Noise Contours 2.4 m underneath a Model Rotor with and without HHC (DLR, NASA, AS, MBB)

pressure ports on a rotating blade for a great numbers of flight conditions in order to validate and to improve available computer codes. The involved 8 nations selected DNW as the most qualified aero-acoustic wind tunnel for this task.

## 4. REDUCTION OF POLLUTANT EMISSION BY ENERGY SAVINGS

For the solution of pollution problems two research areas are identified:

- o Improvement of combustion processes to reduce specific pollutant emissions
- o Reduction of fuel consumption

The first area is subject of the already quoted German national R&D program 'Pollutants in Aerospace' and is not treated here further. Reduction of fuel consumption can be obtained as well as by a direct improvement of the engines as by reduction of the drag of airframe.

### 4.1 Aspects of Engine Airframe Integration

For the optimal integration of engines with the airframe cooperative action of engine and airframe manufacturers is required. The installation effects of large by-pass ratio (BPR) engines as shown schematically in Fig. 9, partly counteract the fuel reduction savings due to the higher BPR (lower curve). The upper curve characterizes this trend as the sum of installation drag contributions like interference drag between engine-wing-fuselage, nacelle drag, inlet losses, and the larger engine weight, increases with BPR. It is expected that the net effect for aircraft reaches an optimum at a particular BPR. This optimum will depend on the aircraft configuration and utility spectrum. To diminish the development risks in this area for future aircraft a research program named DUPRIN (DUcted PRopfan INvestigations) was initiated in the framework of EC BRITE/EURAM. Objective is to create a data base on installation effects of ducted propfan engines and to make a comparison to existing turbofan engines. **

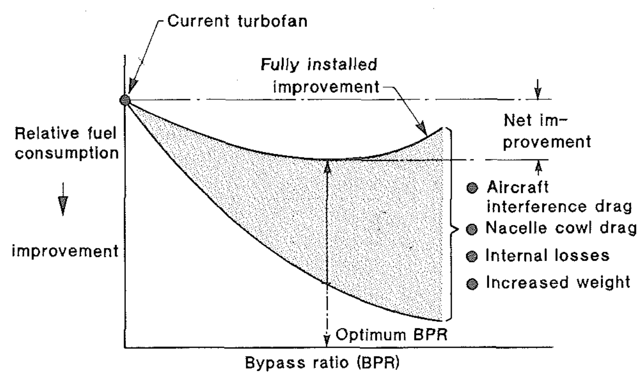


FIG. 9 Schematic Representation of Relative Fuel Reduction Consumption by Increase of the Engine By-pass Ratio and its Compensation by Installation Effects (Deutsche Airbus)

These fundamental research experiments will be carried out in DNW in 1992 and 1993, whereby the experiences gained already during engine integration tests with Airbus models like the A320, A330 and A340 will be highly beneficial. A survey paper about these experiences at DNW is written by W. Burgsmüller[10], who reports about the use of Through Flow Nacelles (TFN) and Turbine Powered Simulators (Fig. 10) for engine simulation applications. During tests with the Airbus A340 model not less than 3 TPS-units made by Deutsche Airbus, Bremen, were applied. The fourth engine was represented by a TFN unit to simulate as part of the test program an outboard engine failure during the second segment climb condition (Fig. 11).
Further investigations concentrated on

- o Force measurements in ground proximity for the determination of ground influence effects on performance and stability.
- o Pressure distribution measurements on wing/pylon/nacelle for the determination of important, interference data.
- o Force measurements in ground proximity with simulated thrust reverse with special emphasis on re-ingestion of the fan flow (Fig. 12).

** Another EC BRITE/EURAM program deals with the integration aspects of propeller and airframe, including so-called unducted propfans. DNW is also participating in this program named GEMINI (GEneric Model for wind tunnel test on airframe propulsion INtegration with emphasis on advanced propellers)

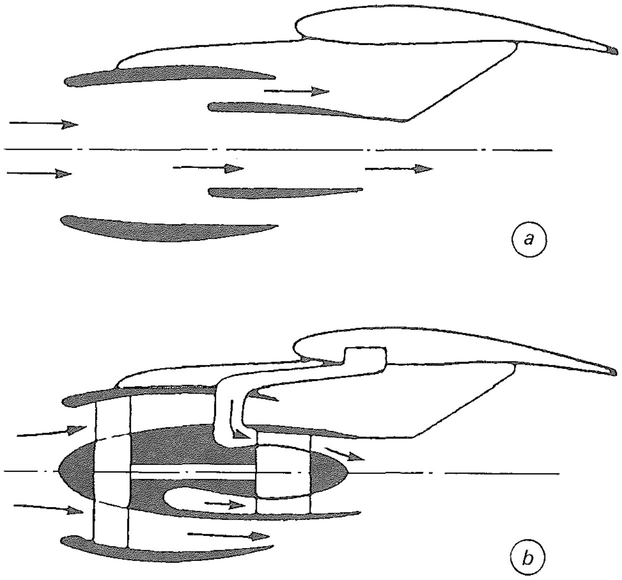


FIG. 10 Schematic Drawing of a Through Flow Nacelle (*a*) and a Turbine Powered Simulator (*b*)

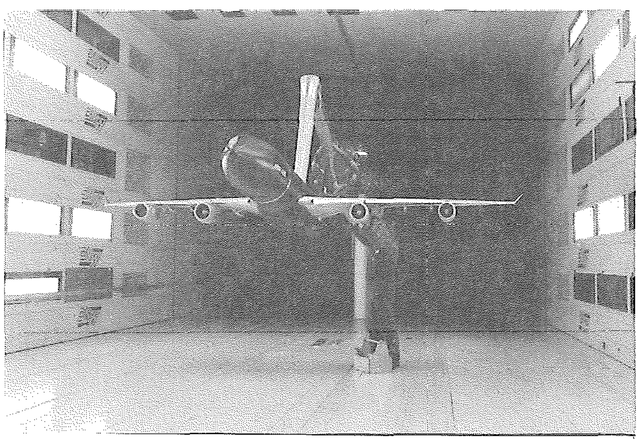

FIG. 11 Model of an Airbus A340 equipped with three Turbine Powered Simulators and one Through Flow Nacelle (Deutsche Airbus)

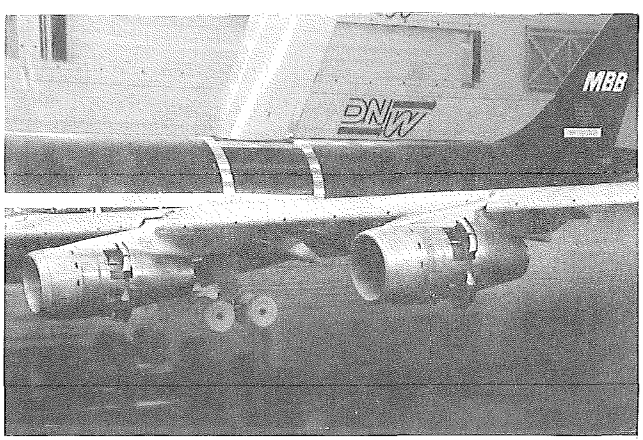


FIG. 12 Side-view of an Airbus A340 Model with Deployed TPS-Powered Thrust Reversers in Ground Proximity Simulated by Moving Belt (Aerospatiale)

With the availability of a moving belt ground plane for ground proximity tests in combination with engine simulation DNW has realized with the thrust reverse measurements one of the most complex tests in ten years of operation. The fact that these tests were carried out for Aerospatiale illustrates the international recognition of DNW in this field and the cooperation between Aerospatiale and Deutsche Airbus.

### 4.2 Fuel Reduction by Improved Airframe Aerodynamics

According to estimates of Deutsche Airbus the fuel reduction potentials measured by the technology status of 1986 amount:

- o Drag reduction by improved aerodynamics ≈ 36%
- o Less fuel consumption by new engines ≈ 23%
- o Weight savings by advanced design techniques ≈ 8%

The realization of these potentials is certainly a long term item and will require considerable R & D efforts.
From the drag reduction of airframes about 60% may be realized by laminarization of the boundary layer flow. By virtue of its excellent flow quality illustrated by an extremely low turbulence level DNW is one of the best large industrial low speed wind tunnel for simulating atmospheric flow conditions. In this respect an important contribution was made by the DLR Institute of Design Aerodynamics (DLR SM-EA) which carried out flight tests with a LFU 205 general aviation aeroplane to study the possibility of natural laminar flow on wings. To this purpose one half wing was equipped with a laminar flow 'glove' and after the flight tests examined in the DNW 8m x 6m test section under similar conditions as well (Fig. 13).

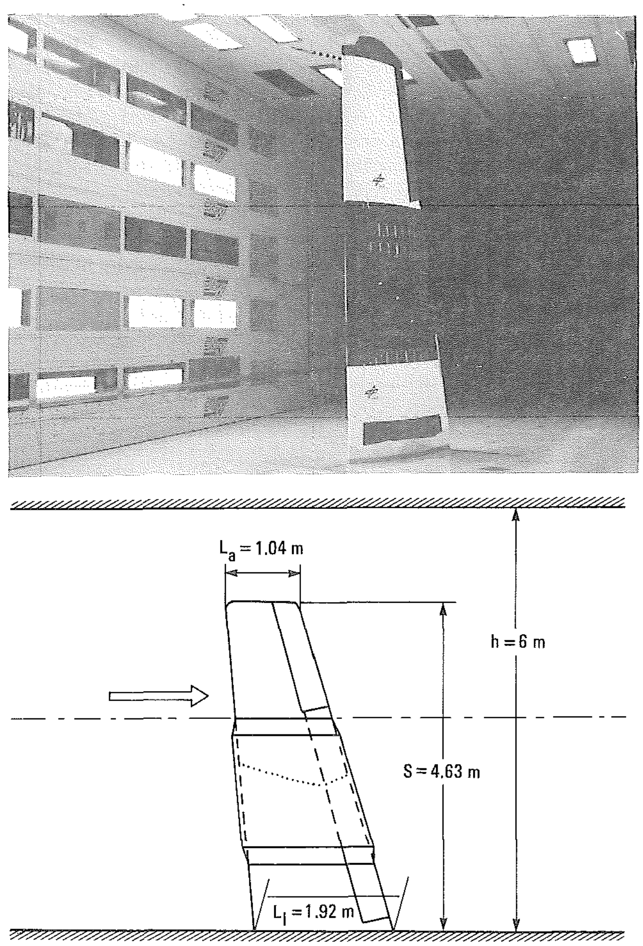


FIG. 13 Test Set-up for Laminar Flow Research on a LFU-205 Aricraft Wing by DLR

Dependant on flow velocity and angle of incidence laminar boundary layer flow could be attained over the greater part of the wing upper surface. The laminar turbulent transition locations were assessed by means of infra-red camera photography and formed together with measured pressure distributions the basis for boundary layer stability calculations. As result of these calculations Fig. 14 shows the so-called amplitude amplification factor N versus Reynolds number as derived from both flight and tunnel data. The N factors are a measure for the amplitude growth of Tollmien-Schlichting waves which as first regular disturbances appear in the initially laminar boundary layer. The excellent agreement in N factors for wind tunnel and flight measurements clearly confirms the proof of the good flow quality in the DNW[11,12].

For swept wings the flow becomes essentially three-dimensional and boundary layer transition will beside by Tollmien-Schlichting instabilities also be forced by other type of instabilities. In accelerated boundary layer flow a cross-flow instability occurs which is characterized by two disturbance modes in the form of stationary vortices and instationary waves. As observed by B. Müller and H. Bippes (DLR-SM) the amplitudes of the stationary waves decrease with increasing turbulence intensity of the outer tunnel flow[13]. If the experimental growth rates are compared to those obtained from the linear stability theory it can then be concluded that the first are obviously less strong. It was further observed that at higher turbulence intensities for the instationary waves the agreement improved. To clarify these phenomena more research is required whereby likely the secundary stability theory may enhance further progress.

These themes are subject of research in the framework of the German national program 'Transonic Laminar Wing'. In cooperation between DLR and DA (former MBB) a contour was developed which in the form of a laminar glove was attached to the DLR test plane ATTAS and accordingly tested in flight and as a 1:2 scale half model in the DNW and ONERA S1 wind tunnel (Fig. 15). The location of the laminar to turbulent transition in the boundary layer flow was detected by several techniques like surface hotfilms, piezo foils (TU Berlin), and infra-red photography. The results are reported in Ref. 14, 15. Fig. 16 shows the transition positions as experimentally found in both wind tunnels DNW and ONERA S1 for different sweep angles but equal Mach number. Considering the measuring accuracy it may be concluded that the measured transition locations correspond very well, taking into account that the Reynolds numbers in DNW are about 10% higher than in S1.

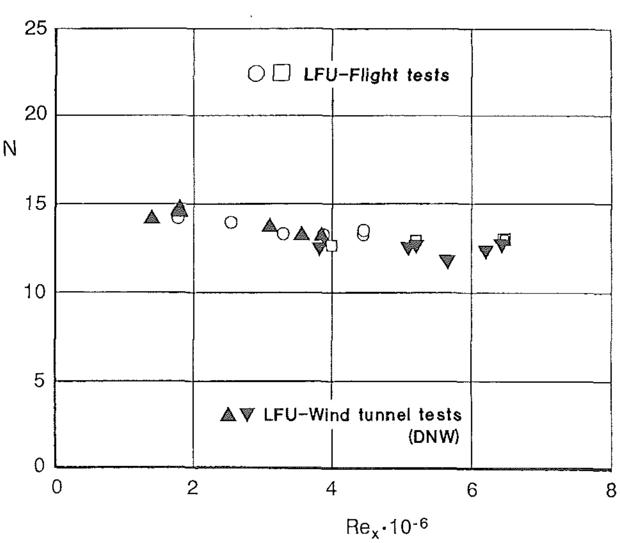


FIG. 14 Amplitude Amplification Exponents of Tollmien-Schlichting Waves Calculated by Linear Stability Theory from Measured Transition Positions and Pressure Distributions (DLR)

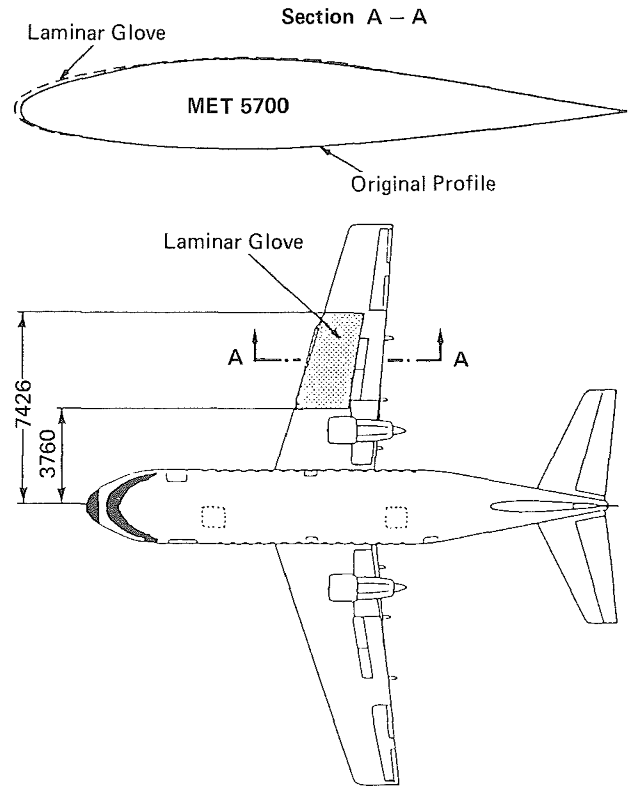


FIG. 15 Laminar Flow Profile and Arrangement on the Wing of DLR Test Aircraft ATTAS

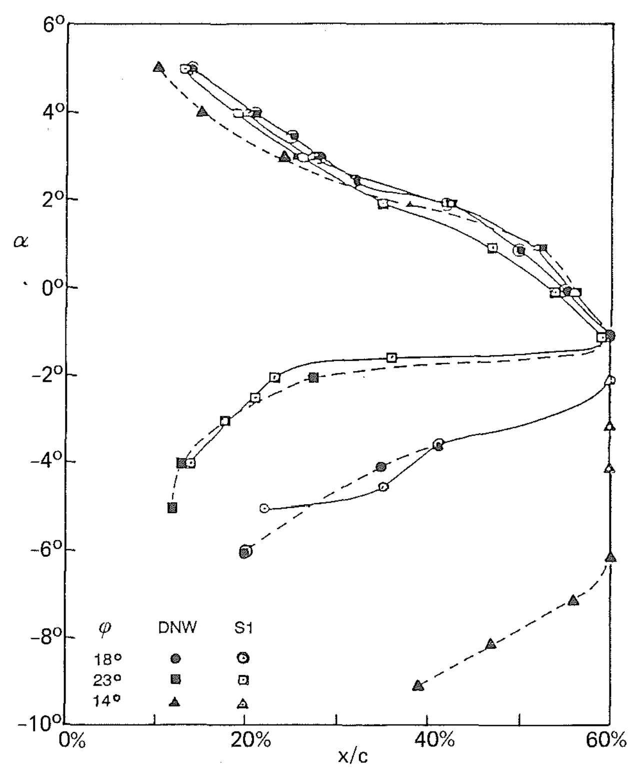


FIG. 16 Comparison of Experimentally Determined Boundary Layer Transition Positions at Equal Mach Number for Different Sweep Angles at the 1:2 Scale TLF Model in DNW and ONERA S1

The free stream turbulence intensities at constant Mach number differ from about 0.15% in DNW to 0.45% in S1, which may explain the observed tendencies. Nevertheless, it is noticeable that in spite of the different turbulence intensities no larger shifts in transition positions are found. The more since dependant on the angle of incidence either Tollmien-Schlichting or Cross-flow instabilities and Attachment Line Transition dominate. This result does not concur with axisymmetric flow investigations of the DLR ellipsoid Ref. 16 which showed large differences when tested at equal Reynolds number in various wind tunnels with different free stream turbulence levels, Fig. 17.
The laminar to turbulent transition at the ellipsoid at axisymmetric flow conditions is determined by Tollmien-Schlichting instabilities. For the improvement of calculation methods for the prediction of transition locations it is essential that these discrepancies and other questions are clarified and further tests are executed at larger Reynolds numbers in the DNW.

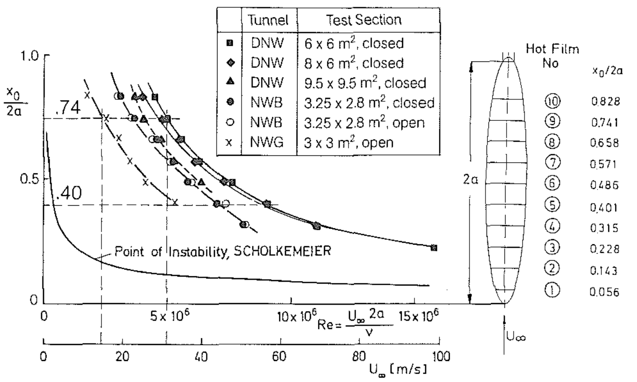


FIG. 17 Comparison of Boundary Layer Transition Positions on the DLR Axisymmetric Ellipsoid as Tested in Three Different Wind Tunnels with Six Different Test Section Configurations
(NWB - Low Speed Tunnel of DLR Braunschweig)
(NWG - Low Speed Tunnel of DLR Götting

## 5. SUMMARY

Several problem areas concerning the emission of noise and pollutants in aerospace are discussed and related aspects like pollution distribution, propulsion technology improvements, energy saving by drag reduction, and noise reduction of aircraft are analysed for potential applications of DNW. Typical examples of DNW investigations in fields like noise reduction of aircraft helicopter and propulsors, integration of engines with airframe, and drag reduction by laminarization are presented. Future activities in DNW will concentrate mainly in these areas whereby research and technology programmes initiated by the aerospace industry and sponsored partly from EC BRITE/EURAM funds will play an important role.

## 6. REFERENCES

[1] Flying Ahead, A View of the Future for Civil Aeronautics. Report of the Panel on Long Term Outlook for Aeronautics Research and Technology (LOTOS). Commission of the European Communities, Directorate-General for Science, Research and Development, Aeronautics Group. EUR 13334 EN, 1991.

[2] Schadstoffe in der Luftfahrt - Wirkung und Prävention. Vorschlag eines nationalen Verbundprogramms von Forschung und Industrie, DLR-Köln, 1990.

[3] Ryback, B.; Yakovlev Takes Propfan Lead. Flight International, Vol. 22, pp 27-28, 1991.

[4] Zandbergen, T; Propeller Noise Measurements in DNW on the Fuselage of a Twin Engine Aircraft Model. AIAA 84-2357, 1984.

[5] Dobrzynski, W.; Aeroacoustic Wind Tunnel Testing of Full-Scale Propellers with Unsymmetrical Blade Spacing. Proceedings Inter-Noise 90, pp. 475-478, Göteborg, Schweden, 1990.

[6] Heller, H.; Splettstößer, W.R. (DLR); Martin, R.; Brooks, T.; Marcolini, M. (NASA); Schmitz, F.; Boxwell, D. (US Army, Ames Research Center); Ten Years of Cooperative Helicopter Aeroacoustics Research in the DNW. Colloquium Proceedings Ten Years of Testing at DNW, 16. Oktober 1990.

[7] Splettstößer, W.R.; Lehmann, G.; van der Wall, B; Higher Harmonic Control of a Helicopter Rotor to Reduce Blade-Vortex Interaction Noise. Zeitschrift für Flugwissenschaften und Weltraumforschung 14, pp. 109-116, 1990.

[8] Brooks, T.F.; Booth, E.R.; Rotor Blade-Vortex Interaction Noise Reduction and Vibration Using Higher Harmonic Control. Conference Proceedings 16th European Rotorcraft Forum, Glasgow, UK, 18. bis 21. September 1990, Paper no. 9.3.

[9] Splettstößer, W.R.; Schultz, K.-J.; Kube, R. (DLR); Brooks, T.F.; Booth, E.R. (NASA, Langley Research Center), Niesl, G. (MBB); Stréby, O. (Aerospatiale); Noise Reduction by Higher Harmonic Pitch Control: Results of a Scaled Model Rotor Experiment in the DNW. Proceedings 17th European Rotorcraft Forum, Berlin, Paper no. 91-61, 1991.

[10] Burgsmüller, W.; Akkermann, E.; Kooi, J.W.; Engine Simulation with Turbo-Powered Simulators. Proceedings: Ten Years of Testing at DNW, 16. Oktober 1990.

[11] Horstmann, K.H.; Quast, A.; Redeker, G.; Flight and Wind-Tunnel Investigations on Boundary-Layer Transition. AIAA Journal Aircraft Vol. 27, No. 2, pp 146-150, 1990.

[12] Horstmann, K.H.; Redeker, G.; Miley, S.; Flight Investigations of Tollmien-Schlichting Waves on an Aircraft Wing. 17th Congress of ICAS, Paper 90-6.1.2,, Stockholm, 1990.

[13] Müller, B.; Bippes, H.; Experimental Study of Instability Modes in a Three-Dimensional Boundary Layer. Proceedings AGARD Symposium on Fluid Dynamics of Three-Dimensional Turbulent Shear Flows and Transition, 3. bis 6. Oktober, Çesme, Türkei, 1989.

[14] Henke, R.; Dreßler, U. (MBB); Horstmann, K.H.; Quast, A. (DLR); Untersuchungen am Flugversuchsträger ATTAS mit Laminarhandschuh und dessen 1:2 Großmodell im DNW und S1. DGLR Jahrbuch, 1989.

[15] Henke, R.; Münch, F.X.; Laminar Flow with a Large Half Model in Transonic Flow. 17th Congress of ICAS, Paper 3.6.4, Stockholm, 1990.

[16] Meier, H.U.; Michel, U.; Kreplin, H.-P.; Influence of Wind Tunnel Turbulence on the Boundary Layer Transition. Proceedings International Symposium: Perspectives in Turbulence Studies (Ed. H.U. Meier, P. Bradshaw), Springer Verlag Berlin, Heidelberg, pp. 26-46, 1987.