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MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

WIND TUNNEL TECHNOLOGY FOR AERONAUTICAL DEVELOPMENT
PART 1 WIND TUNNEL TESTING TECHNIQUE
(SURVEY; SOME SELECTED HIGHLIGHTS)

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ABSTRACT

Aeronautical research and development require the same as ever a lot of wind tunnel testing work although the computational possibilities have grown up extremely during the last two decades. Both, experiment and computation, complete each other in an ideal manner, since mathematical methods can describe aero-mechanical functions and tendencies, verified by significant experiments under selected conditions.

This paper deals with aerodynamic experiments, in general, as far as they have to be applied for aircraft development, shown with the vertical take-off and landing (VTOL) fighter VAK 191 B as an example, which has been developed in Germany, successfully. With this complex system as a guide, the experimental steps from the lay-out up to the completion of the flight test period are shown.

Tests in Low and High Speed Wind Tunnels and in special test facilities, such as Reingestion Test Rig, have been conducted.

Overall forces and moments, pressure distributions, sectional loads, jet decay characteristics and reingestion temperature distributions have been measured and analysed in order to get reliable predictions on longitudinal and lateral flight performances, manoeuvrability and hovering as well as on structual load estimation.

Some kinds of flow visualization techniques are described, supporting the comprehension of flow mechanisms, in detail.

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INTRODUCTION

Strategic considerations are predominant in developing military aircraft, in order to attain to a project which covers the required regime of operation, as well as possible. Civil transport airplane designs follow - first of all - to the customers requirements in cost effectiveness and in market analysis. In any case, the operational requirements are the priorities in judging the performance criteria. Usually the main factors of valuation are

for combat aircraft : manoeuvrability, maximum speed, take-off and climb performances,
for civil airplanes : cruising drag and high lift performances in take-off, climb and landing,
the high lift criteria especially for short and mid-range airplanes.

In the very early stage of a development phase of a project wind tunnel tests are to be conducted with a first model which enables a rough-scattered parameter variation of main geometric dimensions. Those tests are limited to six component force measurements compared with computational performance predictions. Furthermore, the calculations allow a reliable interpolation of the rough-scattered parameter study.

In this phase we have a special advantage if the "closed loop" of the main aerodynamic performance data of a well-known and near-related aircraft from the layout up to the finished flight testing period, is available. The reliability of performance prediction procedures for the full scale aircraft and the probability of successful geometric modifications are increased by this method.

The special aircraft type for VTOL (vertical take off and landing) characteristics is signified by the additional possibility of completely spatial motions. The investigation of the aerodynamic characteristics within the angle of incidence range from -90° to +90° and the angle of sideslip range from 0° to 180° is required, therefore.

Although strongly different between military and civil aircrafts, the next important criterion is the influence on aerodynamic characteristica of the engines to be installed. For military designs the dominant items are the thrust-supported performance increments, such as : maximum speed, rate of climb and manoeuvrability. For aircraft with vertical take-off and landing capabilities the jet-induced aerodynamic downwash is an additional main effect. For transport airplanes the mutual engine-airframe interactions are of main interest.

In the following the arbitrarily selected example of the VAK 191 B is the guide introducing into the development process of an aircraft from first layout up to the final flight tests, as far as concerned with wind tunnel testing technique, as a survey. The VAK is one of the VTOL combat aircraft, which have been developed successfully in Germany before cancelation by military reasons due to strong changes of strategic defense concepts.

SPECIFICATION OF THE REQUIRED AIRCRAFT

A close-to-ground operating combat and reconnaissance fighter was required, with transonic speed, VTOL capabilities and high manoeuvrability, supporting about 2,5 tons payload in the single- and two-seater versions. The typical VTOL advantages in relation to the operational behaviour of a conventional aircraft are the higher availability and flexibility, which had to be applied, consequently. The connected disadvantages, such as jet-induced downwash and the tendency to reingest hot exhaust gas in ground closed hovering, were the main points of investigation in order to minimize.

LAYOUT OF THE VAK 191 B

An extensive information on all relevant engine types (existing or under development) was gathered. With this some possible jet group combinations have been computationally investigated with respect to the relation of required and available thrust vectors in all flight conditions, including the inevitable lift thrust losses induced by downwash effects. By experiments the decay and spreading of the jet group combinations (avoiding strong hot gas fountains) have been analysed. The most sufficient configuration was (as will be shown later) the six jet group, formed by four swivel nozzles of the combined lift-cruise engine and two vertically mounted lift engines in the fuselage. After a lot of development investigations the conceptual design was fixed. Its realization is shown under flight testing condition in fig. 1.

AERODYNAMIC TESTS

Between layout and final flight tests an immense number of aerodynamic tests had to be conducted, about 8000 wind tunnel hours and 2000 hours for reingestion testing. The main part of the wind tunnel tests has been engaged with stationary aerodynamics and the deducible performances, hereof.

Wind Tunnel Tests

In addition to the conventional low speed tests the forces and moments of a VTOL aircraft are to be measured for all spatial wind directions. The covering of these extremely wide fields is only possible with interchangeable model suspensions which induce different interferences to the model at different flow conditions. These disturbances have to be eliminated by calibrations.
Figures 2 to 4 give a survey on the test arrangement in a LSWT. Remarkable are the typical VTOL results as shown in figures 5 to 7. The overlaps in these pittoresque curves, produced by different suspensions, show the relatively big and different influences of the suspensions on the model. Another important group of low speed tests are the forces measurements with actively simulated and separately controlled engine jets in order to quantify the jet-induced downwash and ground effects. In principle, the relevant test installation is shown in figure 8 . A three-channel-pipe for separate pressed air supply of the engines is used as a model support. An internal strain gage balance connects the model with the support. The nozzles penetrate the fuselage contour, free of contact. Gaps between nozzles and fuselage are sealed by thin rubber diaphragms. Reaction forces induced by the sealings are eliminated computationally by using the measured local pressure distributions.

Typical test results [1] are shown with figures 9 and 10. Fig. 9 gives a survey on jet-induced downwash effects for some possible jet arrangements, fig. 10 shows the equivalent ground influence on some configurations. It becomes evident that the selected fighter configuration with the Six Jet Group generally increases the lift thrust close to ground.

Such kinds of tests are to be conducted, with respect to the abundance of the parameters to a great extent, also for different settings of high lift devices, ailerons, elevator, rudder and other controls. Longitudinal as well as lateral motion are to be investigated.

Pressure distribution measurements of about 1000 stations dispersed all over the surface must be done for the final loads and stress calculation of the aircraft. But this should be delayed until the configuration design has been fixed. So long as the optimization process of the aircraft has not yet been concluded, a special test method is very advisable, which we have developed with the VAK, at first : the Sectional Loads Technique [2] . This technique allows in a simple manner estimations of loads of structual parts and of mutual interactions. The prinziple, shown in fig. 11 is: a central skeleton supports a couple of special strain gage balances. Each of them is connected separately with a structual section. If there is any need to modify the structure, the corresponding section can be easily exchanged. Moreover, the complete model is supported with the tunnel balance, conventionally. The sum of total forces and sectional loads measured for complete model, fuselage only and wing only, shown in the scheme, enables the estimation of all partial structure loads as well as all mutual interferences. This method we have applied since its first approval, regularly.

Reingestion Tests

Near field recirculation of hot exhaust gases is a symptomatic VTOL problem, which is to be investigated, carefully. Reingestion of hot and oxygen-starved gases decreases the produced engine thrust, strongly heated inlet strands can destroy combustion chamber and turbine parts, and finally it must be avoided, that the external fuselage structure, landing gear and bomb racks will be heated, excessively. Starting, procedures of the engines and taking influence on geometric details of the aircraft may minimize those problems below the danger threshold. But this can only be demonstrated by relevant experiments. Figure 12 gives a survey on a typical test arrangement for this kind of investigation, with the model horizontally supported by the hot gas feedings supplying all six jets, and with the suction pipes of the engines inlet flow. A hydraulically movable plate simulates ground clearance, attitude and roll angle. A very copious instrumentation on model, groundplate and circular rake is shown with some hundreds of pressure and temperature probes, acquired and evaluated to a complete image of the near field flow status.

A very interesting flow visualization technique, we have developed with the VAK, results in the impressive footprint pattern pictures, shown in fig. 13 to 15. Geometry and power settings are the same for the 2 jet group of the lift engines, the 4 jet group of the lift-cruise engine and for the combination of all 6 jets. In connection with the plenty of pressure and temperature measurements these ground streamlines give rich informations on existence and susceptibility of hot gas fountains in the near field flow.

Shortly to mention are in this connection some of the important aerodynamic tests, which have to be conducted, even if here is no place to discuss more detailed, such as : dynamic tests with elastically similar wind tunnel models, experiments in a vertical wind tunnel to investigate the spin behaviour as well in its stationary phase as regarding spin recovering procedures, non-stationary test to estimate damping derivatives.

SOME RECENT TEST TECHNIQUES

The natural request for best possible aircraft and - with the same importance - for most exact prediction methods of the promised performance data requires extraordinary exertions and effects from aerodynamic test techniques. The actual data accuracy requirements are described in [3] . Each feasibility to increase performance data accuracy must be used by application of improved model manufacturing procedures as numerically controlled machining, by increments of Reynolds Number in pressurized or cryogenic wind tunnels, by careful investigations of differences in load-depending deformations between model and aircraft [4] , or by flow visualization methods, which help decisively to understand the physical causes of experimentally demonstrated effects. To this category belongs the ""Graphical Wake Imaging System" developed by J. Crowder [5] . Its application in the MBB-LSWT has proven as an exellent tool in analysing of drag sources and its location [6] . With this method, a probe, sensing total pressure losses of a wake, is traversed through the flowfield. A colored signal light, controlled by a voltage level detector, whose various colors are coordinated with preset pressure ranges, produces on a photograph a colored picture of isobars. The recent outgrowth of this system is the "Electronic Wake Imaging System". It uses a low cost microcomputer and a video monitor, which allow a much more detailed resolution of pressure ranges by the feasibility of much more colores.

CONCLUSION

The aerodynamic testing technique in general is a field with extremely high requirements, steadily growing up. The design margins become close and closer, but on the other hand, the technology is going to be improved. So we have the tools to take up the challenge, in order to obtain an optimum result. The most protruding tool of wind tunnel instrumentation is an accurate and reliable wind tunnel balance, which is described more detailed in part 2 of this joint paper.

FIRST A.S.A.T. CONFERENCE
14-16 May 1985 , CAIRO

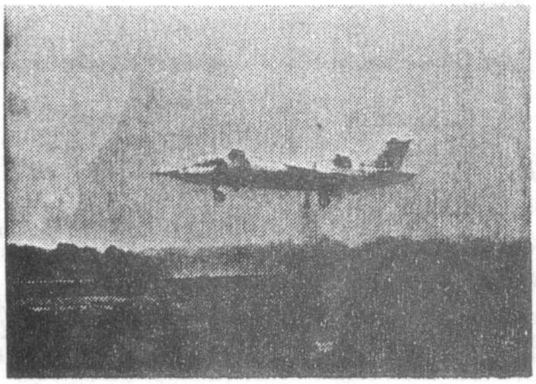

Fig. 1 VAK 191 B in Flight Testing

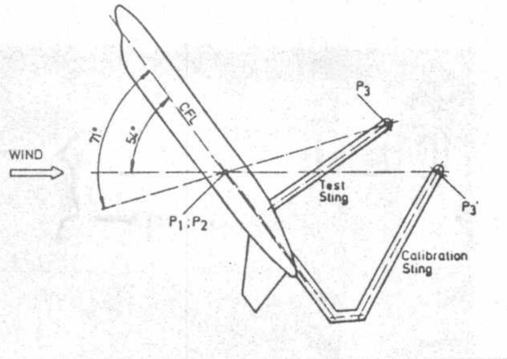

Fig. 2 Model Suspension I (-90°≤ α ≤-45°)

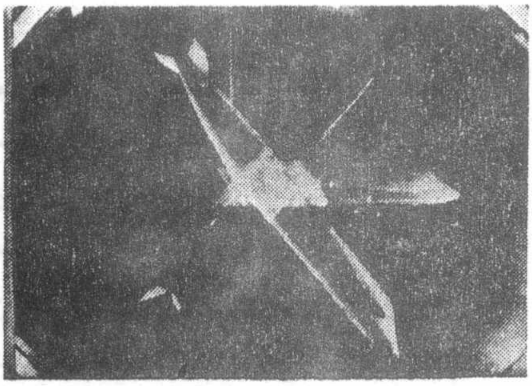

Fig. 3 Model Suspension II (-47,5°≤ α ≤47,5°)
(Triple Exposed Photo)

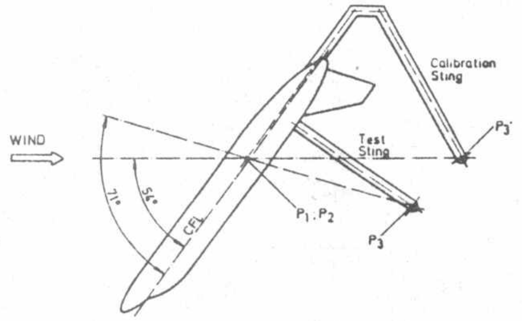

Fig. 4 Model Suspension III (42,5°≤ α ≤92,5°)

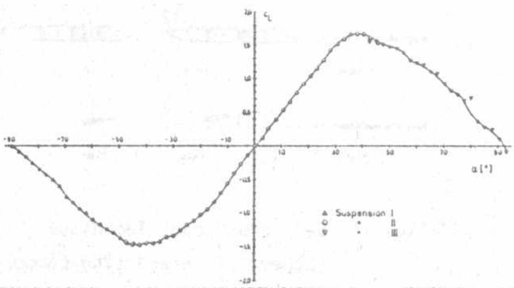

Fig. 5 Lift vs. Incidence (β=0°)

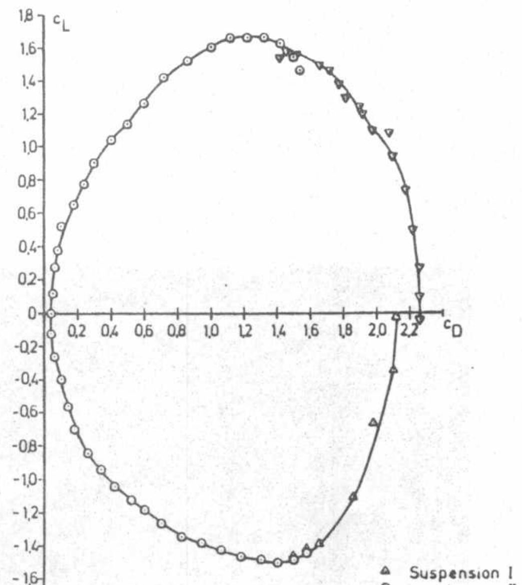

Fig. 6 Drag Polar (β=0°)

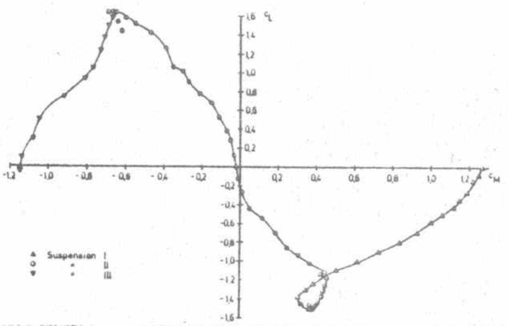

Fig. 7 Pitching Moment (β=0°)

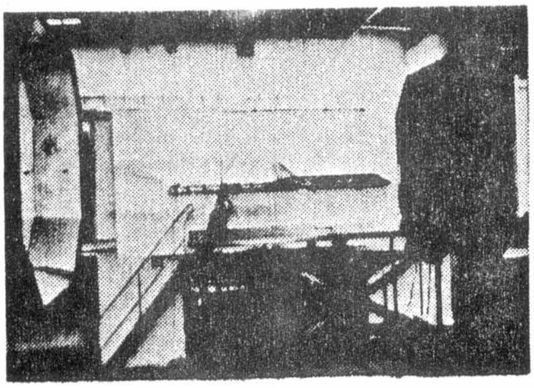

Fig. 8 Jet Effects Model

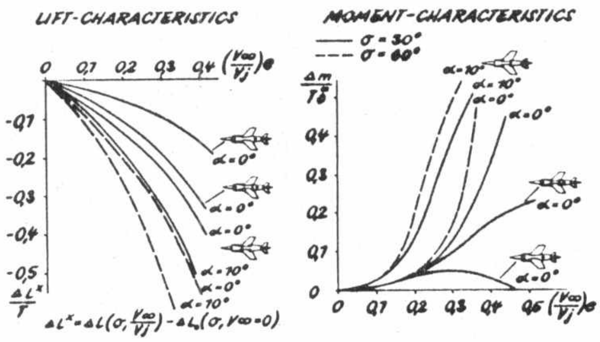

Fig. 9 Jet Effects (STOL/Transition)

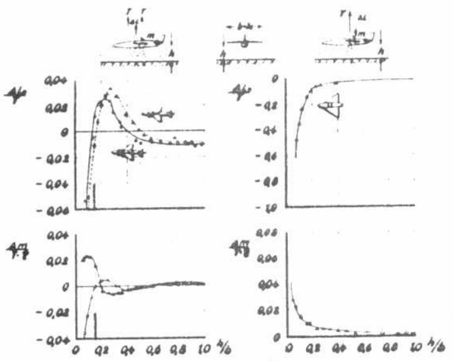

Fig. 10 Ground Effects (VTOL/Hovering)

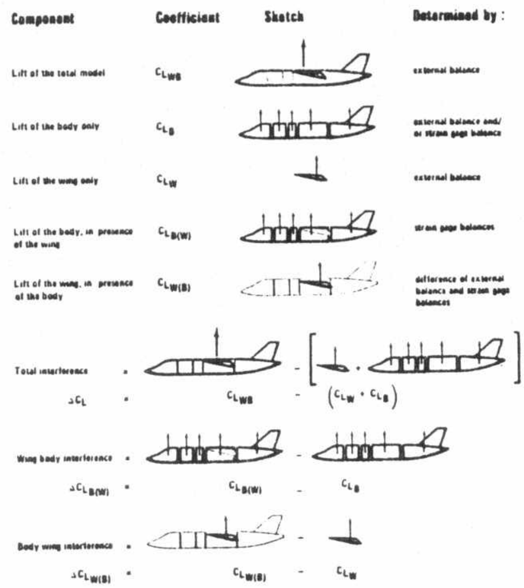

Fig. 11 Sectional Loads Technique
(Scheme of Interacting Components)

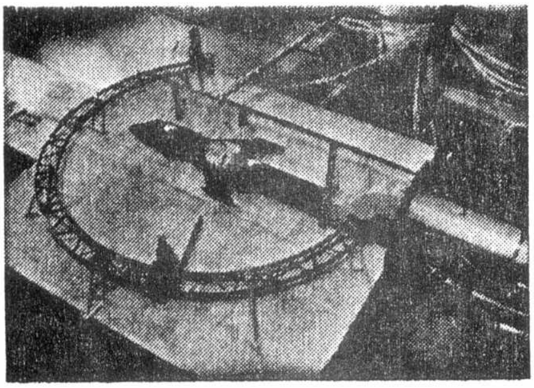

Fig. 12 Reingestion Test Arrangement

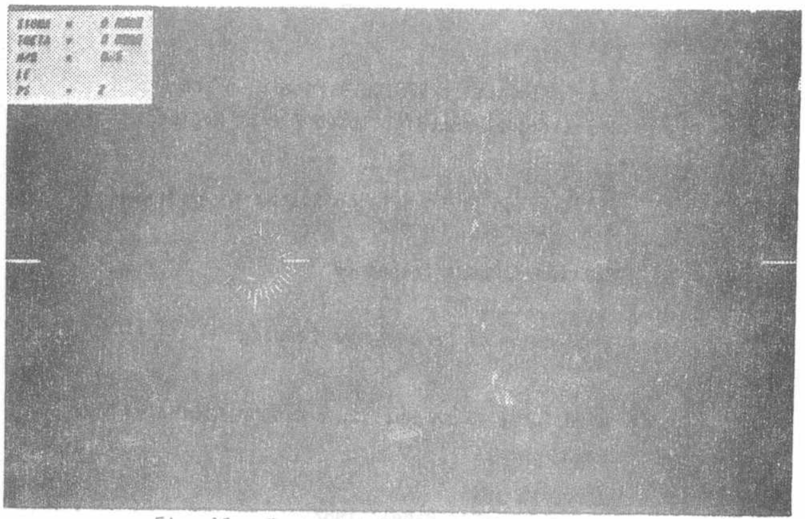

Fig. 13 Footprint Pattern (Two Jet Group)

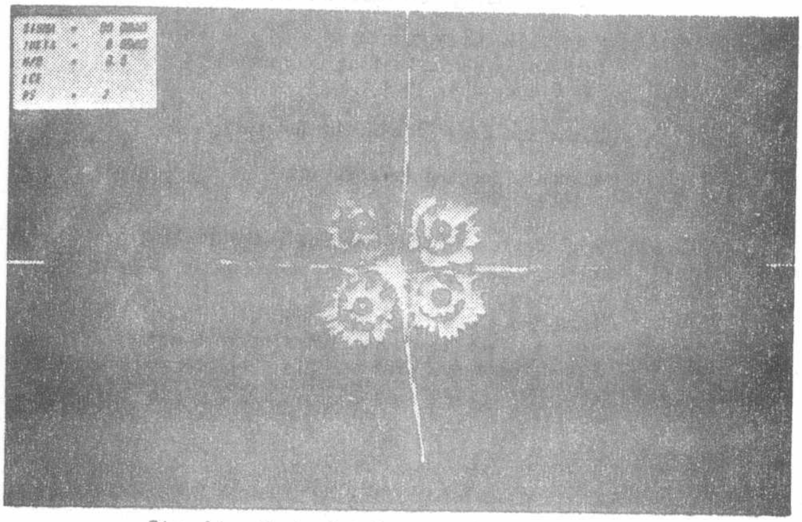

Fig. 14 Footprint Pattern (Four Jet Group)

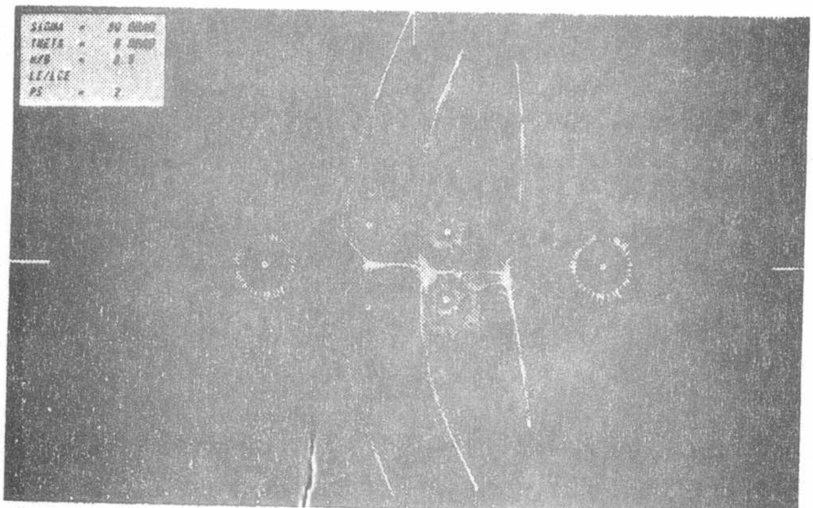

Fig. 15 Footprint Pattern (Six Jet Group)

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NOMENCLATURE

Abbreviations

b	wing span
$\bar{c}$	aerodynamic mean chord
CFL	center fuselage line
h	ground clearance
LCE	lift-cruise engine
LE	lift engine
PS	power setting
P1, P2, P3	model suspension points
T	thrust
v	velocity
α	angle of incidence
β	angle of sideslip
ΔL	lift loss
Δm	change in pitching moment
σ	nozzle swivelling (LCE)
Θ	ground inclination

Coefficients

c_D	drag coefficient
c_L	lift coefficient
c_M	pitching moment coefficient

Subscripts

∞	free stream condition
o	at $v_\infty = 0$ (hovering)
B	body
W	wing
(B)	in presence of the body
(W)	in presence of the wing
j	jet condition