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DEVELOPMENT OF INTAKE SWIRL GENERATORS FOR TURBO
JET ENGINE TESTING

by

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ABSTRACT

The main objective of this investigation is to assess the influence of different types and magnitudes of swirl on the performance and compatibility of turbo jet engines. The generation of intake swirl, typical for many supersonic combat aircraft, is described. Essentially two basic types, i.e. twin swirl and bulk swirl of varying strength and also combinations thereof, have been selected in order to simulate these swirl patterns by subscale swirl generators in a model wind tunnel. The swirl patterns measured behind these generators show good agreement with the target patterns selected at the beginning. The small scale swirl generators are being rebuilt at full scale for subsequent testing in front of a Larzac engine under static conditions with a bellmouth inlet at the engine test facility of the Jet Propulsion Institute at the Universität der Bundeswehr München.

LIST OF SYMBOLS

D	duct diameter	(mm)
\dot{m}	air flow	(kg/s)
n	rotor speed	(rpm)
α	angle of incidence	(degree)
δ_2	angle of subsonic intake ramp	(degree)
θ	angle of circumferential position	(degree)
τ	angle of swirl	(degree)
π	total pressure ratio	(...)
φ_0	leading edge sweep angle	(degree)

LIST OF INDICES

B	bulk swirl
HPC	high pressure compressor
LPC	low pressure compressor
max	maximum
T	twin swirl

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1. INTRODUCTION

The design aim of advanced turbo jet engines and intakes is to achieve good installed performance for all power settings across the aircraft flight envelope. This requires high intake and engine performance and also sufficient intake/engine compatibility. Sufficient compatibility means that the intake flow quality is always better than that which the engine can tolerate (engine sensitivity). Intakes and engines have to be developed separately at first, before the compatibility of intake and engine can be measured directly. Only the specified compatibility parameters like pressure and temperature distortion, turbulence and swirl can be checked at the aerodynamic interface plane during the development wind tunnel model tests. The engine itself has to be developed behind a bellmouth intake. Special simulators or generators located between bellmouth intake and engine compressor face simulate typical intake flow patterns which yield the levels of the specified compatibility parameters up to the engine limits.

A comparison of the real and the simulated intake air flow pattern showed differences. These differences between the real and the simulated intake air flow pattern caused substantial time delays in many aircraft projects. For example, during the flight test phase of the aircraft F-111 additional model and full scale tests had to be performed. A reduction of the dynamic intake distortion was particularly addressed in order to solve these problems. Another example is the multi role combat aircraft TORNADO. Also, additional model and full scale tests were necessary. Flight operations at higher angles of incidence produced swirl in the air intake which caused the engine to surge. An intake fence was finally adopted and completely eliminated the problem. The intake fence reduced mainly the intake swirl. A reduction of the pressure distortion and the pressure turbulence was also measured.

Both examples and the experience from other past aircraft developments shows also that swirl intake flow simulators or generators shall be used during engine development as soon as possible. A big part of the time delays described above had to be used for the design and manufacture of intake flow pattern generators. The generator development began with distortion screens and later also with secondary air injection. These types of generator produced air intake flow patterns with different pressure and temperature distortion (steady state and instantaneous distortion) in front of the engine compressor. The TORNADO experience has shown again that a swirl generator is necessary in addition to the pressure and temperature distortion generator for future aircraft and engine projects. A swirl generator is not only necessary for the development of engines without inlet guide vanes (IGV's) in front of the engine fan, like TORNADO engine RB199, it is also necessary for future engine projects with IGV's in front of the engine. The development of such swirl generators will be shown in this report.

2. SOURCES AND TYPES OF INTAKE SWIRL DISTORTION

Experiments and theoretical considerations have shown that all supersonic intakes of present combat aircraft produce essentially two types of swirl components of varying magnitude, i.e. twin and bulk swirl (see ref.1). This is based on the similarity of these aircraft intakes and their flight envelopes. Such intakes normally require S - shaped diffusers because of the off-set of the engine relative to the intake. The wall boundary layer produces the well known twin swirl when the flow is turned through a simple bend. The same holds for a double bend (S - shaped duct), see paragraph 2.1. An additional type of swirl occurs if separation takes place at the entrance of the intake with subsequent turning of the flow passage. Such a separation can happen e.g. at higher angles of incidence in unshielded intakes at subsonic flights or at too strong diffusions downstream of the (variable) throat in supersonic flight, see paragraph 2.2. Depending on the sensitivity of the engine towards such disturbances serious intake/engine compatibility problems may arise, as for example engine surge and fan flutter.

2.1 Twin Swirl (ref.1)

The existence of twin swirl in flows through curved pipes has been well known: centrifugal forces push the higher energy stream lines towards the outer radii of the bend while the low energy stream lines are in turn forced to move inwards, fig.2. For example, in a thesis by Detra in 1953 (ref.2) this phenomenon was investigated as well experimentally as theoretically (inviscid) and its effect on engines, as regards performance degradation, pointed out.

The intake models and in full scale intakes (see fig.1 and ref.5), which all had the same S - shaped intake diffuser, this twin swirl could be identified. It proved to be the most stable component of the total swirl pattern measured at the engine face. That is, it was little affected by internal intake modifications like flow straighteners.

2.2 Bulk Swirl (ref.1)

Bulk swirl is defined here as the circumferential mean value of the flow angles for each radius $R = \text{const}$. For the TORNADO aircraft, this type of swirl was found to be similar to a solid body type rotation; its generation can be explained in the same way as above if only one half of the "twins" is considered:

A region of low kinetic energy (low total pressure) located asymmetrically at one portion of the intake duct perimeter, e.g. either at the intake cowl or at the ramp (fig.1), is pushed towards the inner radius of the bend while the high energy air is moved outwards by centrifugal forces, as shown in fig.3.

Fig.3 also explains why the bulk swirl is contrarotational to the fan at subsonic speed and high angles of incidence in the left hand engine and at supersonic speed and low angles of incidence in the right hand engine respectively.

In contrast to the twin swirl, bulk swirl is rather sensitive, i.e. it changes considerable in magnitude and also in sign for varying external flow conditions (fig.3) which define the position and size of the region of low kinetic energy flow.

2.3 Combination of Twin and Bulk Swirl

Typical supersonic intake flow patterns as shown in fig.5, 6, 7 and 8 show a combination of twin and bulk swirl. Fig.4 illustrates the superimposing of these two basic intake swirl components.

2.4 TORNADO Intake Swirl (ref.1)

At subsonic speeds both the twin and the bulk swirl increase (fig.5): The extremes in deviation from the mean value, the local maximum and minimum values at the outermost measuring station $R = 0.87 \cdot R(\max)$, are a measure of the strength of the twin swirl, which is more than doubled towards the high incidence end. The swirl being contrarotational to the fan rotation of the left hand engine and obviously co-rotational to the right hand engine.

At subsonic speed, Mach = 0.7, fig.7 shows the influence of the engine mass flow. Reducing the engine mass flow at intermediate incidences produced swirl angles of similar magnitude, however, of opposite sign, fig.7 (shaded area).

At supersonic speeds an analogous dependence of swirl versus second ramp angle (β) of the intake shock system was found, fig.6. The swirl being now largely contrarotational to the fan rotation of the right hand engine and obviously co-rotational to the left hand engine.

A comparison between model and full scale data was made under static conditions. As shown in fig.8, the flow angles at the duct wall of TORNADO prototype obtained by the oil flow technique agree quite well with the flow angles measured in a TORNADO wind tunnel model by a rotatable 8 arm rake having 24 five-hole probes. This agreement was also found in paragraph 4.1 and 4.2 (Moveable Swirl Generator). More details about the TORNADO model and full scale tests are described in ref.1.

3. SIMULATION OF INTAKE SWIRL

In the past only steady state and instantaneous (dynamic) pressure distortion were particularly attended during air intake and engine compatibility investigations. In 1977 tests with a twin swirl generator in front of a compressor were published by the DFVLR (ref.3). After that Rolls Royce performed RB199 engine rig tests with fixed bulk swirl generators (ref.4). Swirl angles of τ (bulk, max) = $\pm 5^\circ$ and $\pm 10^\circ$ were simulated. These swirl generators (DFVLR and Rolls Royce) simulated either twin or bulk swirl.

The simulation of typical supersonic aircraft intake flow patterns, as shown in fig.5, 6, 7 and 8 for example, is the objective of the present work. These flow patterns with some simplifications will be simulated by fixed and moveable swirl generators.

Fixed swirl generators simulate selected specific intake flow patterns at the static test rig. The advantages of a fixed swirl generator are their greater simplicity as compared with moveable ones and also the simulation of the swirl distribution with nearly no total pressure disturbances. The effects on the engine of the pressure and swirl distortion can be measured separately.

Moveable swirl generators simulate as well selected specific intake swirl patterns as time variant intake swirl patterns which correspond to the flow patterns measured for all ground and flight conditions. The main advantage of a moveable swirl generator, as described below, is the fact that the magnitude of the swirl can be continuously varied by the remote controlled variation of the wing incidence. This is important in an emergency situation, as for example, during a severe engine surge which requires immediate removal of the swirl disturbance.

4. MODEL INVESTIGATIONS

4.1 Model Simulation of Intake Swirl Distortion Model Wind Tunnel and Testing Technique

The model investigations were made in a low speed wind tunnel, installed in the engine test facility of the Jet Propulsion Institute at the Universität der Bundeswehr München. Fig.9 is a detailed sketch of its arrangement which consists of an orifice plate, a 90° bend, a 3° diffuser, a plenum chamber, a nozzle reducing the circular cross section to an internal diameter of 200 mm, the model swirl generator and the measuring section. In front of and in the plenum chamber screens and honeycombs are mounted in order to obtain uniform flow conditions over the whole cross section.

The air is supplied by a screw compressor with a pressure ratio of 2,8 and a constant mass flow rate of 3,7 kg/s. Part of this mass flow rate can be blown off through a regulating valve, so that the mass flow rate through the wind tunnel easily can be changed.

The device for measuring the flow patterns behind the model swirl generator consists of three 5-hole-probes with pyramidal probe heads (see fig.10). These probes are equally positioned in the circumferential direction of the measuring plane and can be traversed in radial direction. In addition wall static pressure holes are located midwise between the 5-hole-probes.

The fastening of the model swirl generator between nozzle and measuring section is constructed in such a way that it can easily be turned around the center-axis. In this way the whole flow field behind the swirl generator can be measured with the three 5-hole-probes. The distance between swirl generator and measuring plane can be varied by different lengths of pipes. In addition to these measurements tests were made by using the oil flow technique for getting informations about the flow conditions near the wall. This technique is based on the assumption that small droplets of high viscosity are moving slowly in the direction of the passing air flow. Thus a lot of small droplets of a suspension of oil and dye were applied at the duct wall in the plane to be measured. Then the model wind tunnel was set in operation and kept at the desired mass flow rate for about five minutes. After shutting-down the air supply a copy of the trails of the droplets was obtained by pressing a sheet of paper on the cylindrical duct wall. In this way it was possible to obtain the wall flow pictures at different distances behind the swirl generator.

Model Swirl Distortion Generators

The aim of this investigation was not primarily to simulate exactly the flow conditions measured in the Tornado intake (refer, Chapt.2), but to carry out basic investigations by generating two basic swirl types and also combinations thereof of different magnitudes. Therefore the following model swirl generators were designed:

FIXED SWIRL GENERATOR:

With this type of swirl generator the flow deflection is generated by guide vanes which are individually cambered with respect to the desired flow deflection. For this purpose the flow fields of the two basic swirl types are described in simple theoretical swirl models: According to its definition bulk swirl is similar to a solid type rotation. Thus the corresponding guide vane have to generate a flow deflection which is linearly increasing in radial direction to a maximum value $\tau_{B,MAX}$ (see fig.11). The twin swirl is a counter rotating double swirl which is approximated by a swirl model as shown in fig.12a. The model for determination of the local flow deflection uses concentric semicircles and straight lines which define the direction of the cross flow. The flow deflection along the x-axis corresponds to a cosine-distribution with the maximum at $\tau_{T,MAX}$. The flow deflection along the semicircles and the straight parts follows also a cosine-distribution with the corresponding maximum at the point of intersection with the x-axis. In this way the flow deflection is defined in each point of the cross section. As examples for the resulting theoretical flow deflections, the distributions along the 45, 135, 225 and 315°-directions are shown in fig.12b.

Combinations of the two basic swirl types result from the superposition of these both swirl models specifying the values of $\tau_{B,MAX}$ and $\tau_{T,MAX}$. Fixed model swirl generators were designed to simulate the following swirl configurations, assuming zero deviation of the guide vanes as a rough approximation:

Twin swirl	Bulk swirl
20°	0°
15°	5°
10°	10°
5°	15°
0°	20°

Depending on the strength of the maximum deflection caused by bulk swirl and twin swirl, the combinations thereof have a different number of swirl centers. There exists only one swirl center if $\tau_{B,MAX} > \tau_{T,MAX}$, two centers if $\tau_{B,MAX} < \tau_{T,MAX}$ and finally three centers if $\tau_{B,MAX} = \tau_{T,MAX}$ (i.e. the maximum flow deflections of bulk swirl and twin swirl are equal).

As an example fixed model swirl generators for the swirl configurations $\tau_{B,MAX} = 15^\circ$, $\tau_{T,MAX} = 5^\circ$ and $\tau_{B,MAX} = 0^\circ$, $\tau_{T,MAX} = 20^\circ$ (i.e. pure twin swirl) are shown in fig.13 and fig.14.

MOVEABLE SWIRL GENERATOR:

A slender sharp-edged delta wing generates two symmetrical vortex sheets above its upper surface at specific angles of attack α (see fig.15). The vorticities are generated by flow separation at the sharp leading-edges of the wing.

Therefore a sharp-edged delta wing with trapezoidal cross section was used as a moveable swirl generator. Its geometry is shown in fig.16. The main data are the leading-edge sweep angle of 60° (i.e. an aspect ratio of 2,3), the maximum thickness ratio of 0,03 and the vertex angle of the bevelled leading-edges of about 8°.

The adjustment of the angle of attack is carried out by two moveable sticks. For aerodynamical purposes these sticks are covered by suitable shaped fairings (see fig.17).

This mechanism allows to change the angle of attack from 0° to 24° in steps of 3°.

4.2 Results of the Model Wind Tunnel Tests

As was explained before the main objective of the model investigations was to generate defined swirl patterns with the present subscale swirl generators and to investigate the influence of the distance between swirl generator and measuring plane on the stability of the generated flow field.

FIXED SWIRL GENERATORS

For the fixed swirl generators the following program of measurements using 5-hole-probes was conducted:

fixed swirl generators for the following swirl combinations	distance between swirl generator and measuring plane		
	1,5 D	2,5 D	4,5 D
$\tau_{B,MAX} = 20^\circ, \tau_{T,MAX} = 0^\circ$	X		X
$\tau_{B,MAX} = 15^\circ, \tau_{T,MAX} = 5^\circ$	X	X	X
$\tau_{B,MAX} = 10^\circ, \tau_{T,MAX} = 10^\circ$	X		X
$\tau_{B,MAX} = 5^\circ, \tau_{T,MAX} = 15^\circ$	X		X
$\tau_{B,MAX} = 0^\circ, \tau_{T,MAX} = 20^\circ$	X	X	X

Some of the results are presented in fig.18a to 19. The flow pattern for the swirl combination $\tau_{B,MAX} = 15^\circ, \tau_{T,MAX} = 5^\circ$ and the distance between swirl generator and measuring plane of 1,5 D is shown in fig.18a. According to the design of this swirl generator there is a clockwise cross flow with one swirl center caused by the dominating bulk swirl. For different distances between swirl generator and measuring plane very similar cross flow patterns were measured behind this swirl generator (see fig.18b and 18c). This means that the generated swirl configuration and also the magnitude of the flow deflection is tolerably stable. Regarding the locations of the swirl center in each of the flow patterns it can be found that the swirl center is clockwise turning around the center-line with increasing distance of the measuring plane. In fig.19 the cross flow pattern of the pure twin swirl is shown. The counter-rotating double swirl can clearly be recognized being symmetrical with respect to the y-axis. In fig.20 the flow deflection curves along the x-axis resulting from the theoretical twin swirl model (see Chapt. 3.1), the geometrical blade exit angles, and the measured values are shown. According to the desired cosine-shaped flow deflection of the theoretical swirl model the trailing-edges of the guide vanes had to obtain a corresponding contour. However, it was not possible to realize this contour because of manufacturing problems. Thus guide vanes were built with linearly approximated contours at the trailing-edges assuming zero deviation. A comparison of the measured values with the desired flow distribution shows that the desired magnitudes could not be generated close to the theoretical maximum and minimum flow deflection. Nevertheless the tendency of the distributions is comparable even though further research in this subject seems to be necessary. New considerations should take into account also the deviation between the geometrical blade exit angles and the real flow angles.

MOVEABLE SWIRL GENERATOR

In order to investigate the flow deflections behind the moveable swirl generator the oil flow technique as well as 5-hole-probes were used. Wall flow pictures applying the oil flow technique were produced for several angles of attack, varying measuring plane distance and mass flow rate according to the following test program:

α (°)	distance: generator-measuring plane		mass flow rate (kg/s)	measurement technique oil flow	5-hole-probe
	1,5 D	2,5 D			
0		X	3,7	X	
6		X	3,7	X	
12		X	3,7	X	
15		X	3,7	X	X
18	X	X	3,7	X	
18	X	X	3,49	X	
18	X	X	3,0	X	
21		X	3,7	X	

Some of these results are shown in fig.21 and fig.24.

The flow deflections at the wall are shown in fig.21 as a function of the circumferential position for three angles of attack (0, 6, 18 degrees). A comparison of the three curves emphasizes the augmentation of the flow deflection by increasing the angle of attack. This increase of the maximum flow deflection at the wall depending on the angle of attack is shown in fig.22. It results from the development and augmentation of the vortex sheets on the upper surface of the delta wing.

In order to gain confidence in the oil flow technique a comparison was done between the wall flow picture obtained by the oil flow technique and the distribution of the flow deflection measured with the 5-hole-probes at 95% radius. The result is shown in fig.23. Both curves agree well. This shows that the oil flow technique is a good tool for measuring the flow deflection at the wall and can save effort and cost. In addition a cosine-distribution is plotted which describes the theoretical flow deflection at the wall for a pure twin swirl. It can be seen that the locations of the maximum and minimum flow deflection and the zero passages are coinciding well, but between these locations the measured and theoretical distributions show a distinct difference which may be attributed to this type of swirl generation.

In order to show the vortex sheets the measurement of the whole flow field behind the moveable swirl generator was carried out at an angle of attack of 15° and a distance between swirl generator and measuring plane of 2,5 D and resulted in the cross flow pattern shown in fig.24. Similar to the flow field behind the fixed swirl generator for the pure twin swirl (see fig.19) the two symmetrical counter-rotating swirls can clearly be perceived. A comparison of the two swirl patterns shows that behind the moveable generator the swirls are more concentrated around the swirl centers while the fixed generator produces a flow deflection which is spread over the whole cross section.

5. FULL-SCALE INVESTIGATIONS

General Test Arrangement and Testing Technique

The model investigations described in the previous section were preliminary tests for the full-scale simulation of intake swirl. The full-scale investigations consist of engine tests which are in preparation at this time. The object of these tests is to get more information about the influence of different types and magnitudes of swirl configurations on the engine behavior under static conditions.

The tests will be conducted in the engine test facility of the Jet Propulsion Institute at the Universität der Bundeswehr München. The test facility is designed for turbo jet engines up to an maximum thrust of 30kN and a maximum mass flow rate of 60 kg/s. A side view of this facility is shown in fig.25.

The test facility containing intake splitters and primary and secondary air intake silencer provides a smooth air flow for the rig-mounted engine inside the test cell which is 4,5 m wide, 13,4 m long and on the average 6,2 m high. In order to reduce the temperature of the exhaust jet it is mixed with cold secondary and tertiary air before it passes through the exhaust silencer.

As a test object a Larzac 04 turbofan engine was chosen which is used as propulsion in the Alpha Jet aircraft. This two-spool engine features a two-stage fan ($\pi_{LPC} = 2,3$, $n_{LPC} = 17000$ 1/min), a four-stage high-pressure compressor ($\pi_{HPC} = 4,6$, $n_{HPC} = 22750$ 1/min), each driven by a single-stage turbine, and a fixed-area exhaust nozzle. The total mass flow rate is about $m = 28$ kg/s, the bypass ratio 1.13:1, and the maximum thrust about 13,2 kN for sea-level static conditions.

Although no intake swirl distortion occurs at the practical application of this engine it is well suited for these investigations because of the absence of inlet guide vanes which have normally a flow straightening effect.

The main components of the test setup are shown in fig.26. The original intake configuration designed as a bellmouth inlet had to be extended by a swirl generating unit and a measuring device which allows the measurement of the flow field over the whole cross section in front of the engine. This measuring device consists of a swirl rake mounted in a rotatable intake segment (see fig.27). The swirl rake is designed as a diagonal strut which can be traversed in radial direction. Thus the intake segment needs only be turnable by 180° in order to sweep over the whole cross section. In order to allow rotation it is carried and guided on six rollers in two guide-rails. It is plugged up very carefully against the non-moving intake parts. The swirl rake carries eight 5-hole-probes which had to be calibrated very carefully in built-in condition.

The first full-scale investigations will be carried out with a delta wing as a swirl generator /9/. This delta wing and its fastening inside the intake (see fig.28) is geometrically similar to the subscale model used at the previous wind tunnel tests (fig.16). The variation of the angle of attack is carried out with the help of a rod drive. A spring is used to turn the delta wing quickly back into the starting position in case of surge of the compressor. In this case the driving mechanism can be disengaged very quickly. The system is designed for continuous variation of the angle of attack up to a maximum of 25°.

In order to obtain a fully developed swirl the measuring plane has to be at a distance of about 1,5 D behind the swirl generator according to the model test results.

6. CONCLUSIONS

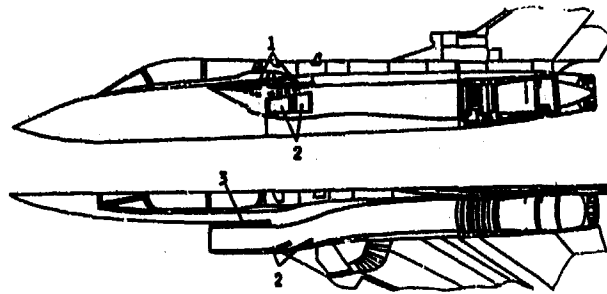
On the basis of a detailed investigation of the engine inlet flow pattern behind a typical supersonic intake of a military fighter aircraft it has been shown that also swirl distortions have to be considered as dominant influence parameters on engine performance and intake/engine compatibility. Two basic types, i.e. twin swirl and bulk swirl and also combinations thereof had to be considered. Model tests with fixed and moveable generators have proven their ability to reproduce those swirl distortions, and they showed good agreement with the target patterns. The engine performance investigations with full scale generators will be performed with a Larzac 04 low by-pass engine in the engine test facility using comprehensive instrumentation for flow field measurements in the inlet duct as well as engine performance measurements.

7. REFERENCES

- /1/ Aulehla, F.
Intake Swirl - a Major Disturbance Parameter in Engine/Intake Compatibility
ICAS/AIAA, -82-4.8.1, Seattle, August 1982
- /2/ Detra, R. W.
The Secondary Flow in Curved Pipes
Thesis, ETH Zürich 1953
- /3/ Lecht, M., and Weyer, H. B.
Unsteady Rotor Blade Loading in an Axial Compressor with Steady-State Inlet
Distortion
AGARD CP 248-30, Cleveland, Oct. 1978
- /4/ Yates, B., and Eagles, C.
Engine 3/23B Gauze and Swirl Tests
Rolls Royce Ltd. Bristol, 1979 (Restricted)
- /5/ Stocks, C. P., and Bissinger, N. C.
The Design and Development of the Tornado Engine Air Intake
AGARD CP 301-10, Toulouse, May 1981
- /6/ Staudacher, W.
Auslegung eines Delta-Flügels
MBB-LKE 127, 1985
- /7/ Hummel, D., and Srinivasan, P. S.
Vortex Breakdown Effects on the Low-Speed Aerodynamic Characteristics of
Slender Delta Wings in Symmetrical Flow
J. Royal Aero.Soc., Vol.71, 1967, pp 319-322
- /8/ Hummel, D.
On the Vortex Formation over a Slender Wing at Large Angles of Incidence
AGARD CP 247, 1978
- /9/ Pazur, W.
Entwurf einer Drallsimulationseinrichtung vor dem Triebwerk Larzac 04
Unibw-München, Institut für Strahltriebwerke
Diplomarbeit Nr. 86/11, 1986

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- 1 = variable ramps
- 2 = auxiliary air intake doors (AAID)
- 3 = boundary layer diverter

Figure 1. Tornado Inlet Geometry

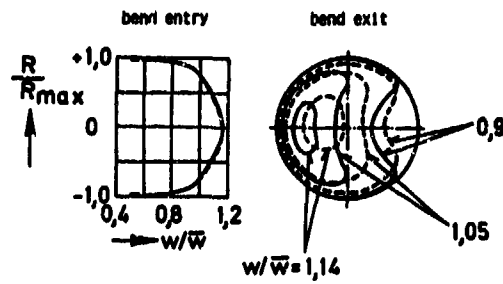


Figure 2. Comparison of Computed (Solid Lines) and Measured Twin Swirl (Dashed Lines) in a 21° Bent Pipe. Lines of Constant Axial Velocity Ratios; $\bar{w} = 41,6 \text{ m/s}$; Ref.2

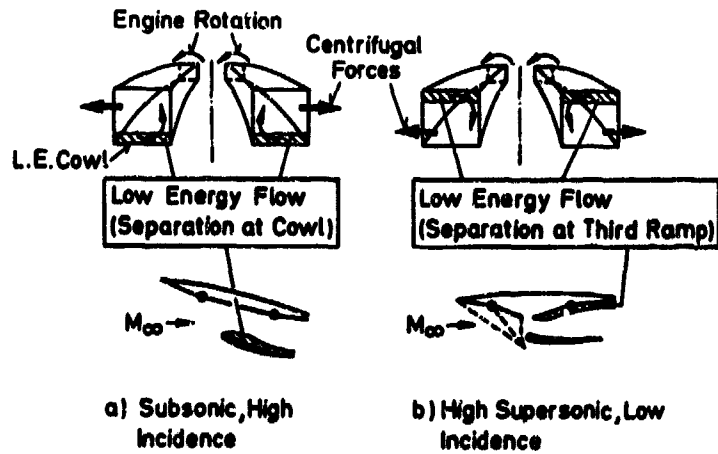


Figure 3. Generation of Intake Swirl, Ref.1

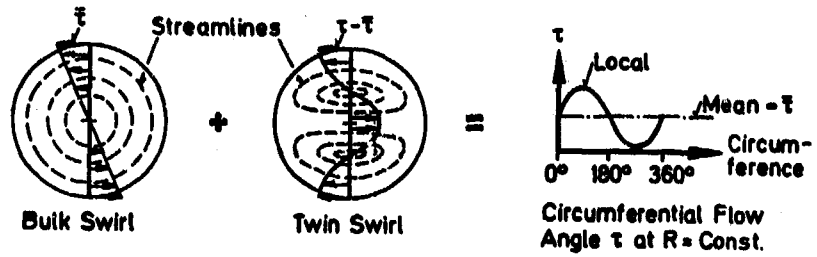


Figure 4. Superimposing of Bulk and Twin Swirls

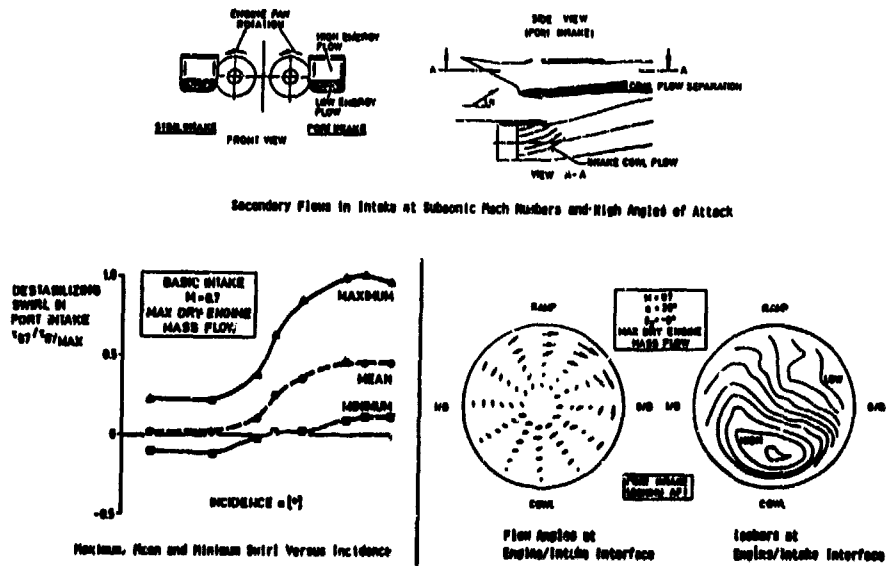


Figure 5. Tornado Inlet Swirl at High Angle of Attack (Subsonic Flight) , Ref.5

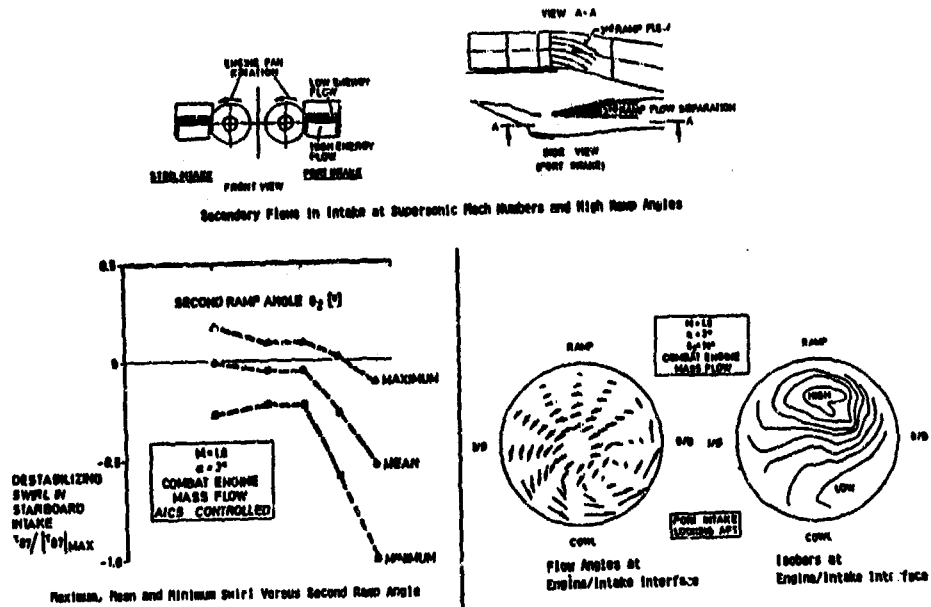


Figure 6. Tornado Inlet Swirl at High Ramp Angles (Supersonic Flight), Ref.5

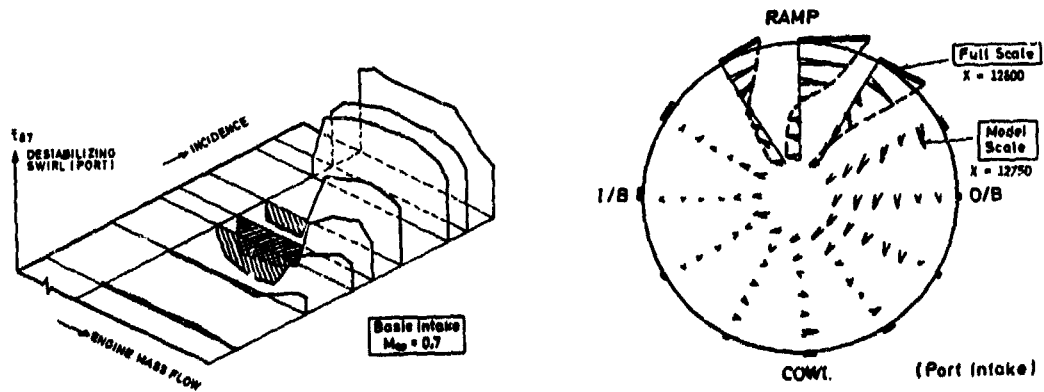


Figure 7. Effect of Incidence and Engine Mass Flow on Mean Swirl ($R = 0.87 \cdot R_{max}$), Ref.1

Figure 8. Model / Full Scale Comparison of Intake Swirl at $M_{\infty} = 0$

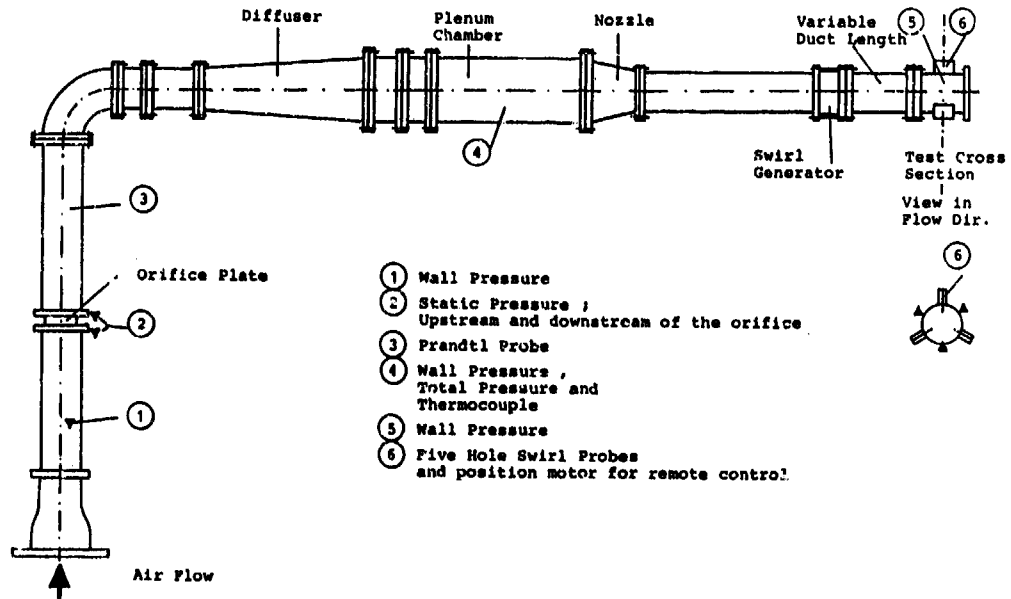


Figure 9. Arrangement and Instrumentation of the Low Speed Model Wind Tunnel

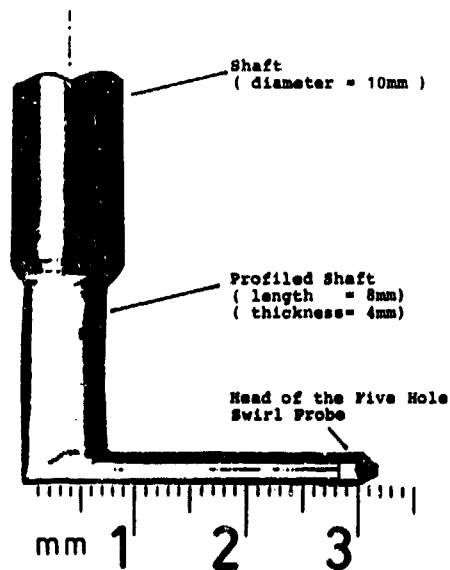


Figure 10. Five Hole Swirl Probe

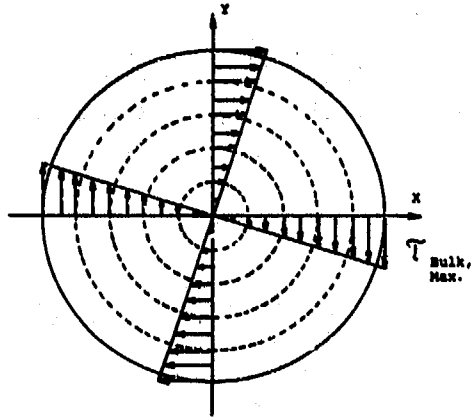


Figure 11. Theoretical Model for Bulk Swirl

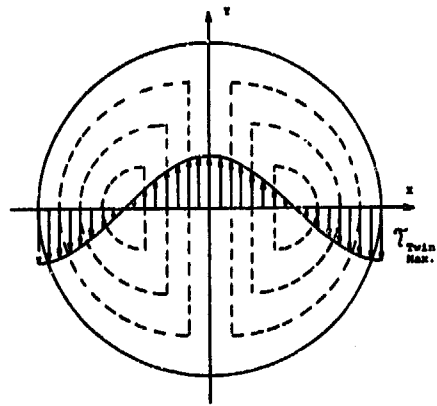


Figure 12a. Theoretical Model for Twin Swirl, Flow Deflection Along the x-Axis

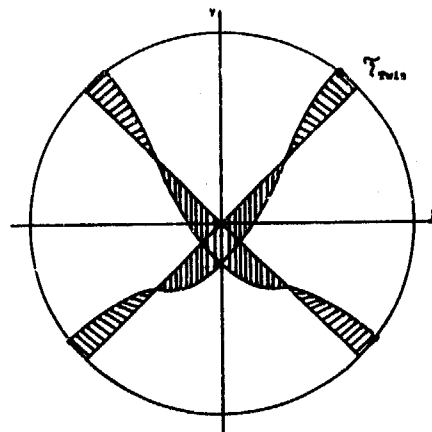


Figure 12b. Theoretical Model for Twin Swirl

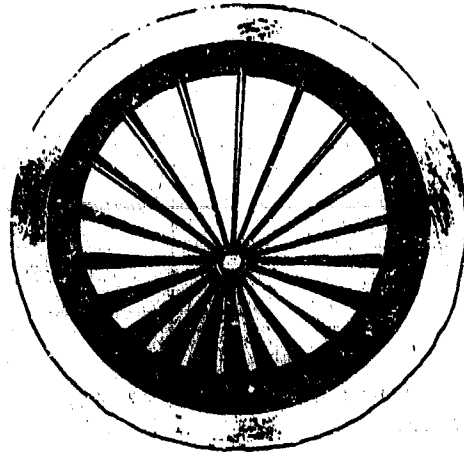


Figure 13. Model Fixed Swirl Generator for Simulation
of Swirl Combination
 $\tau_{B,max} = 15^\circ$ $\tau_{T,max} = 5^\circ$

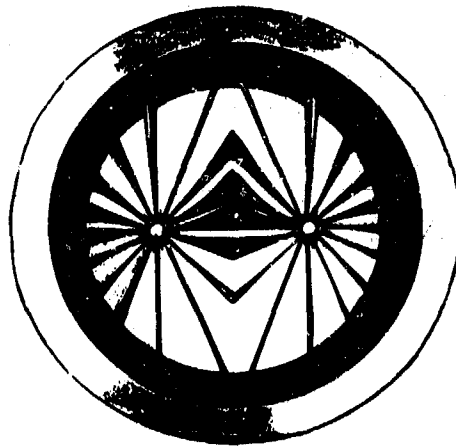


Figure 14. Model Fixed Swirl Generator, Twin Swirl
 $\tau_{T,max} = 20^\circ$

18-14

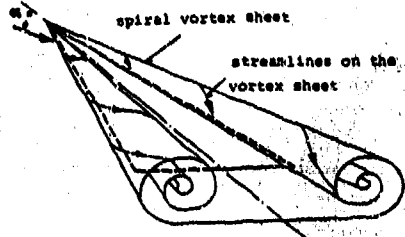


Figure 15. Vortex Formation Over a Sharp-Edged Slender Delta Wing (Ref.7)

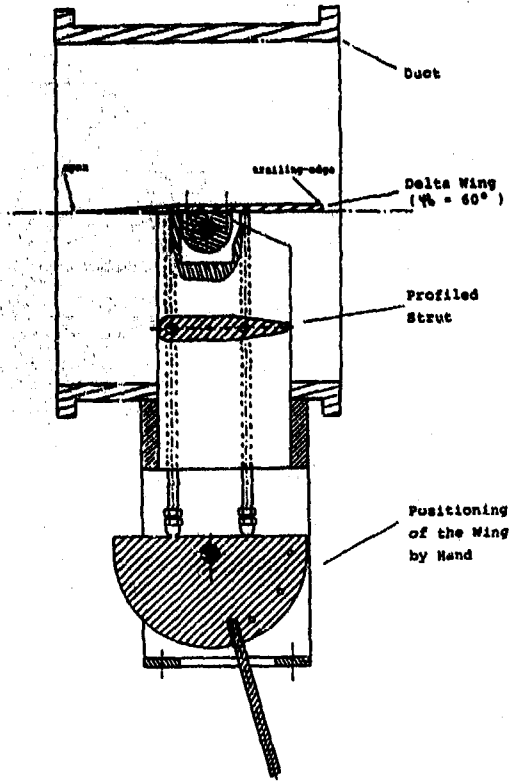


Figure 17. Fastening and Mechanism for Positioning of the Subscale Moveable Swirl Generator

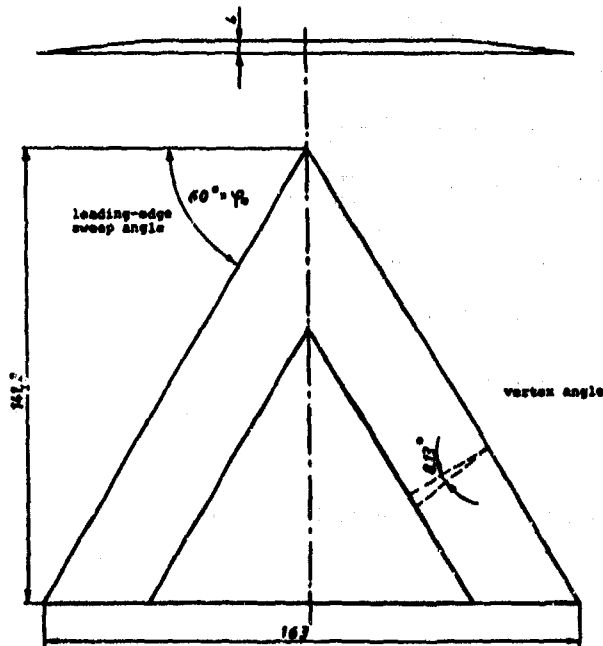
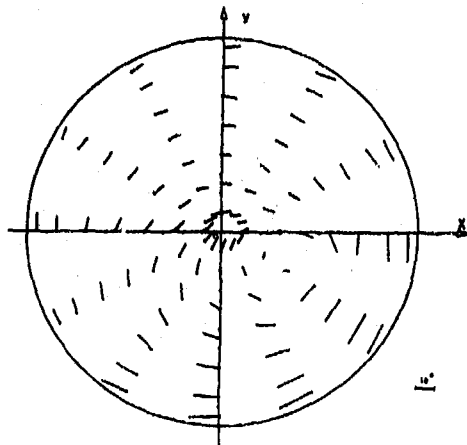
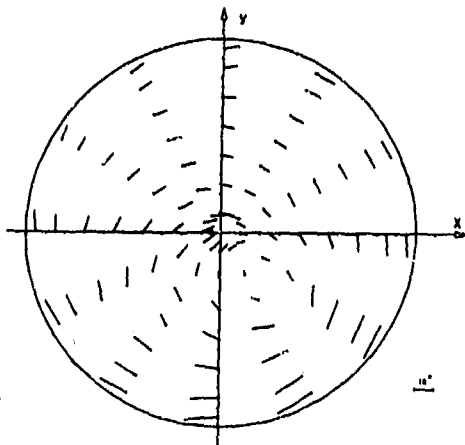


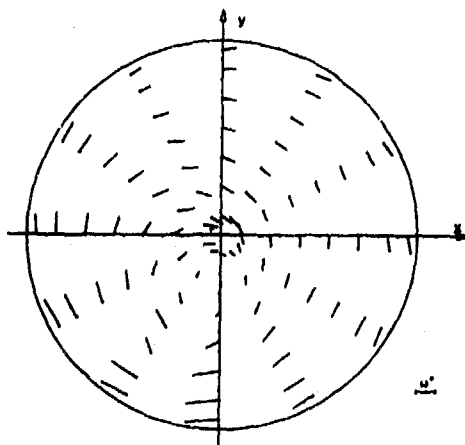
Figure 16. Geometry of the Model Delta Wing - Moveable Swirl Generator -



a) Distance Swirl Generator / Rake Plane
 $= 1,5 \cdot D = 300 \text{ mm}$

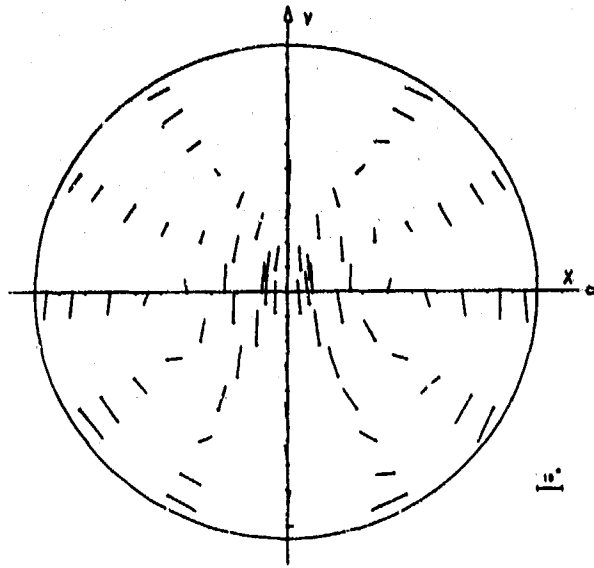


b) Distance Swirl Generator / Rake Plane
 $= 2,5 \cdot D = 500 \text{ mm}$



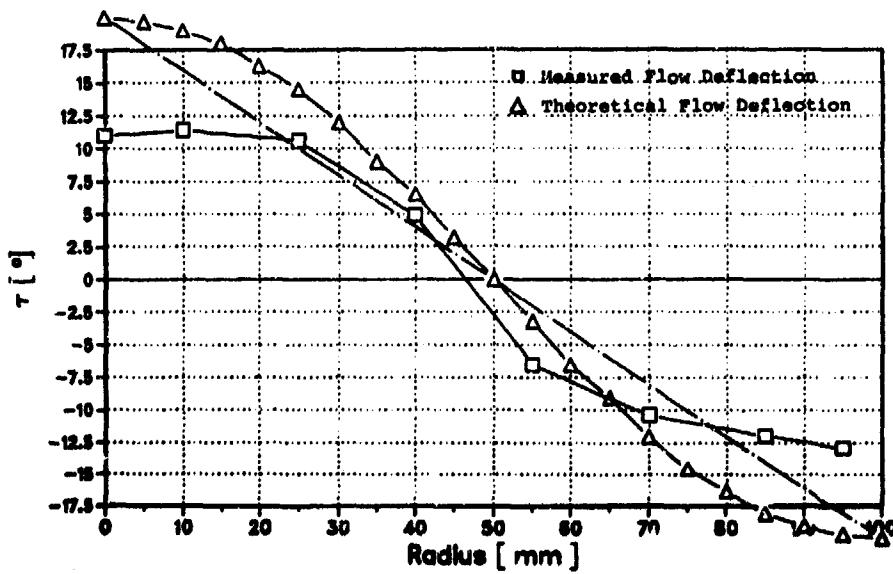
c) Distance Swirl Generator / Rake Plane
 $= 4,5 \cdot D = 900 \text{ mm}$

Figure 18. Cross Flow Pattern behind the Fixed Swirl Generator
 $\tau_{B,\max} = 15^\circ$, $\tau_{T,\max} = 5^\circ$



Distance Swirl Generator / Rake Plane
 = $1,5 \cdot D = 300 \text{ mm}$

Figure 19. Cross Flow Pattern behind the Fixed Twin Swirl Generator
 $\tau_{T,max} = 20^\circ$



Distance Generator / Rake Plane
 = $1,5 \cdot D = 300 \text{ mm}$

Figure 20. Comparison of the Flow Deflections along the X-Axis ($\theta = 0^\circ$), $\tau_{E,max} = 0^\circ$, $\tau_{T,max} = 20^\circ$

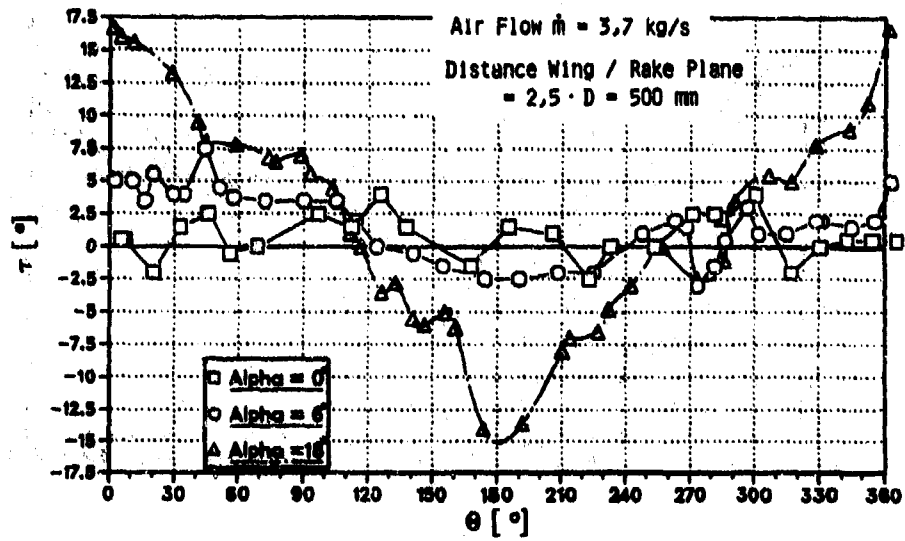


Figure 21. Wall Flow Picture behind the Moveable Swirl Generator, 60° Delta Wing, for Different Angles of Incidence (Alpha)

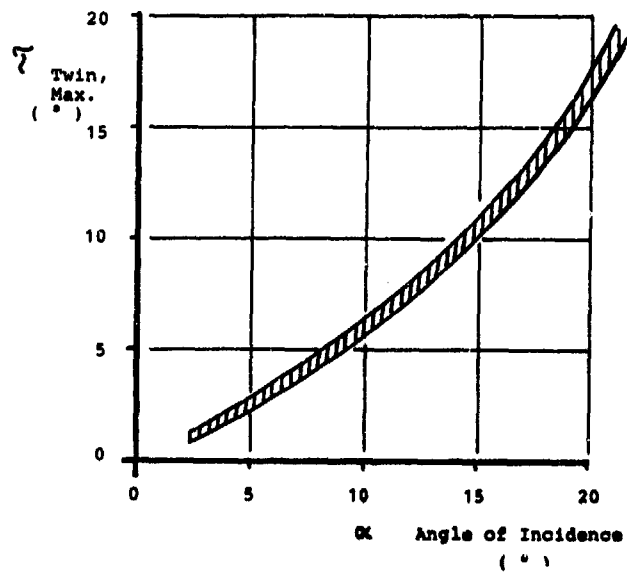


Figure 22. Maximum Flow Deflection behind the Moveable Swirl Generator as a Function of the Angle of Incidence

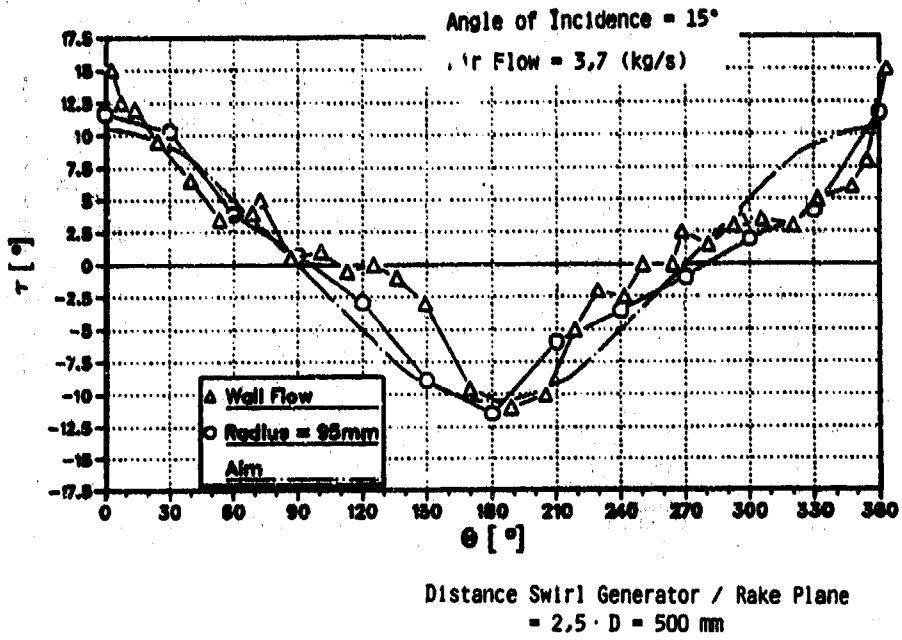


Figure 23. Comparison of the Measurement Techniques - Oil Flow Picture, Five Hole Swirl Probes

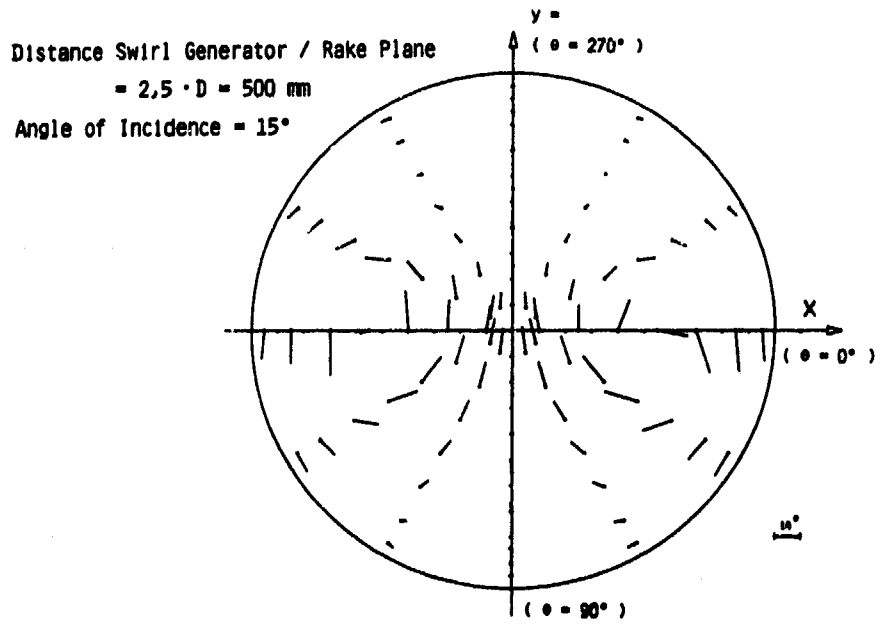


Figure 24. Cross Flow Pattern behind the Moveable Swirl Generator, Delta Wing 60°

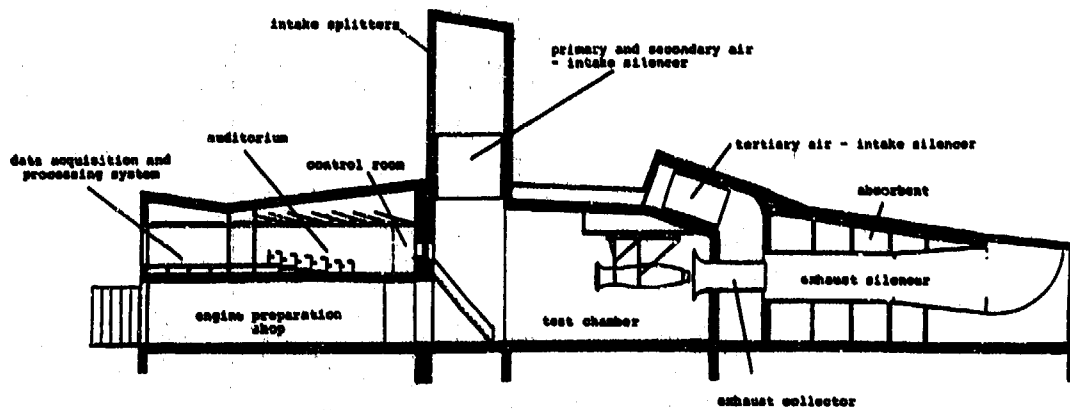


Figure 25. Side View of the Engine Test Facility

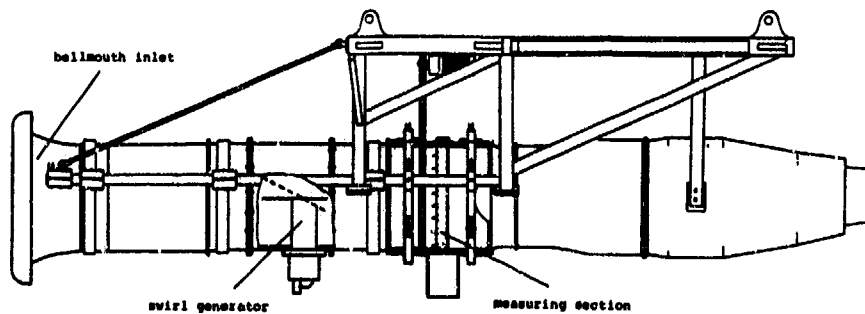


Figure 26. Test Arrangement of the Full Scale Investigations

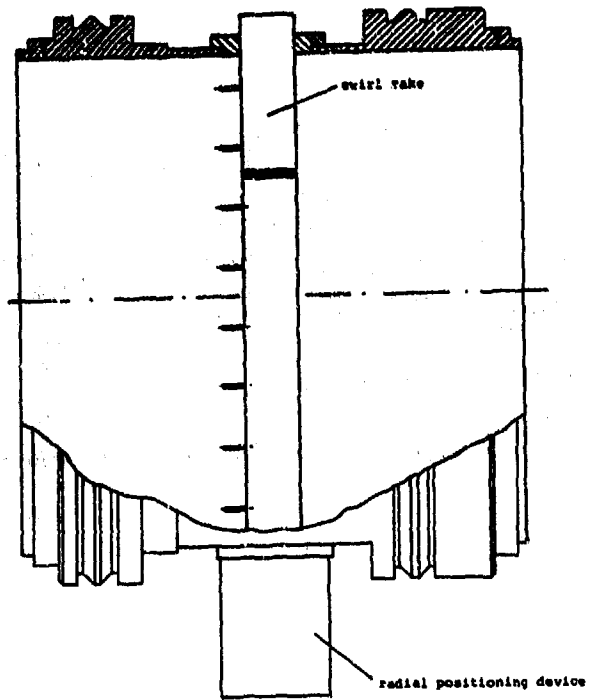


Figure 27. Device for Measuring the Flow Conditions
in Front of the Engine
(equipped with 8 five hole swirl probes)

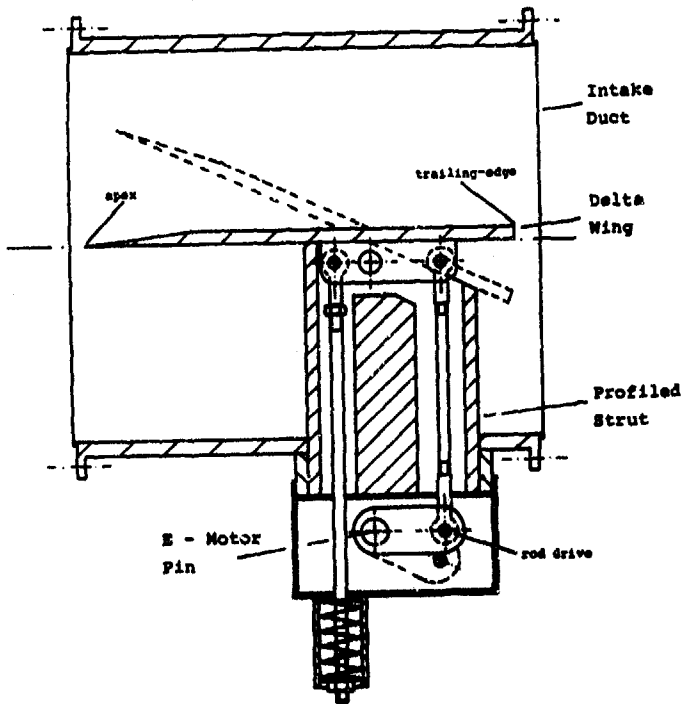


Figure 28. Moveable Swirl Generator for the Full Scale Investigations

DISCUSSION

Ph.Kamette, Fr

How do the distortions caused by a fixed twin-swirl generator and a moveable-swirl generator compare and which one do you think would give the best simulation of the actual distorted flow in the intake of an engine in the same flight case? I am thinking about distortion and turbulence.

Author's Reply

We could not find turbulence during our test but we have started only with model tests. The engine tests will be carried out in the immediate future.

Ph.Kamette, Fr

The first part of my question was: which kind of swirl generator would you prefer?

Author's Reply

We started with the moveable one, the delta wing.

M.Dupelaff, Ge

Could you say something about the pressure loss of the different kinds of swirl generators, especially the circumferential distribution of the loss?

Author's Reply

Would you like to have the distortion values? The DC(60) for the moveable-swirl generator is less than 0.1. About 0.05 or 0.06, I do not know exactly at the moment.

R.G.Hercock, UK

Do you propose to test the engine with total-pressure distortion as well as swirl? If so how are you to generate it?

Author's Reply

At first we will start with swirl generators only, as it was our clear intent to investigate the two disturbances separately.

That is, we simulate either swirl or pressure distortions measured for a typical case in the real inlet flow. In order to get the engine response (surge) either the simulated disturbances will be increased (proportionally) or the engine will be made more surge prone, eg by reducing the throat of the thrust nozzle. The simultaneous simulation of swirl and pressure distortion may then not be necessary, but could be accomplished as outlined in Reference 1.

