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THE INFLUENCE OF WINGLETS ON ROTOR AERODYNAMICS

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ABSTRACT

Impulsive noise emission and dynamic blade loads of helicopters are to some extend caused by Blade Vortex Interactions (BVI). In this paper a winglet arrangement is described, which will reduce the influence of BVI by increasing the distance between tip vortices and rotor blades at their first encounter. For hover flight a free wake analysis method has been developed to calculate the influence of the winglet. It is shown that a winglet can produce a smaller gradient of the spanwise load distribution leading to a higher spreading of the vorticity. Although it is expected that the winglet in forward flight could have an adverse influence due to large azimuthal variations of its incidence, the measured pressure variations are smaller. For this statement measurements have been conducted with a special rotor test facility with rotor blades equipped with pressure transducers. Calculations, based on the theory of NAUMANN and YEH, show a favourable influence of a winglet on the unsteady forces under certain flight conditions.

1. INTRODUCTION

In normal flight conditions of helicopters the main rotor blades pass close to the tip vortices of the preceding blades. Under certain conditions, even an intersection of blades with vortices will occur. These Blade Vortex Interactions (BVI) are to some extend responsible for impulsive noise emission, dynamic blade loads and a reduction in rotor performance.

A good knowledge of rotor aerodynamics is necessary for any improvement of the rotor characteristics. In the past several models of the rotor wake have been developed. In the case of hover flight the calculations are in quite a good agreement with experiments (Refs./1/,/2/,/3/). The simulation of forward flight is due to unsteady effects much more complicated and the agreement is not yet satisfactory (Refs./4/,/5/).

Therefore much remains to be done for a full understanding of the rotor wake phenomena in hover case and in forward flight. Nevertheless, it is considered worth doing some research on optimizing rotor blade tip shapes even at the present state of knowledge.

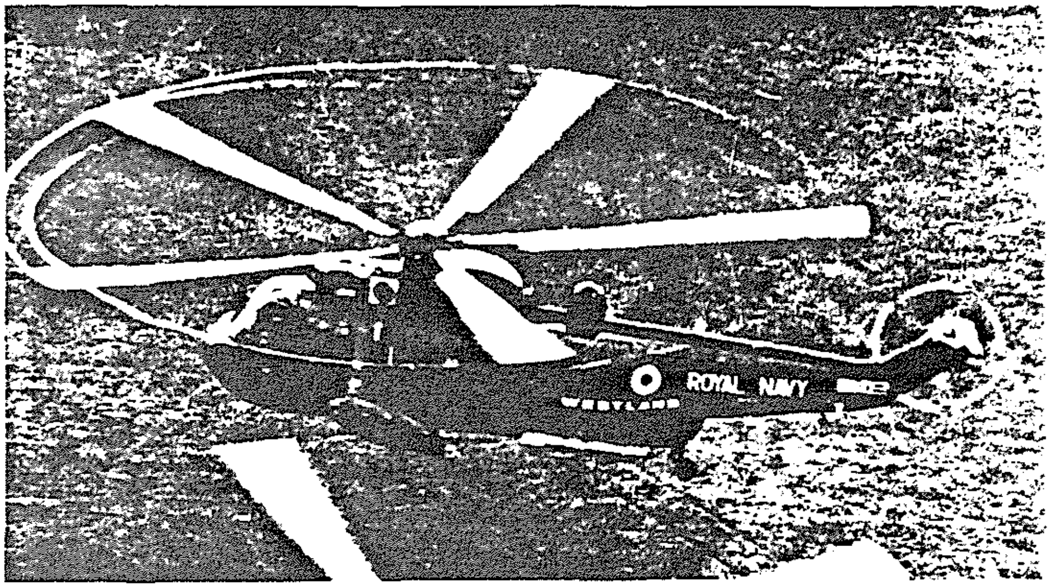


fig. 1 Vortex Path in Hover Case

Figure (1) shows the very close encounter of the vortices with the following blades in hover flight. In figure (2) the strong influence of the vortex of the preceding blade on the flow around the rotor blade tip as well as on its tip vortex path is explained. It is even possible to have a limited range of separation due to the immense upward velocity component of the close passing vortex. It is sensible that an increase of the distance between vortex and blade at the first encounter would decrease the interactions and improve rotor performance.

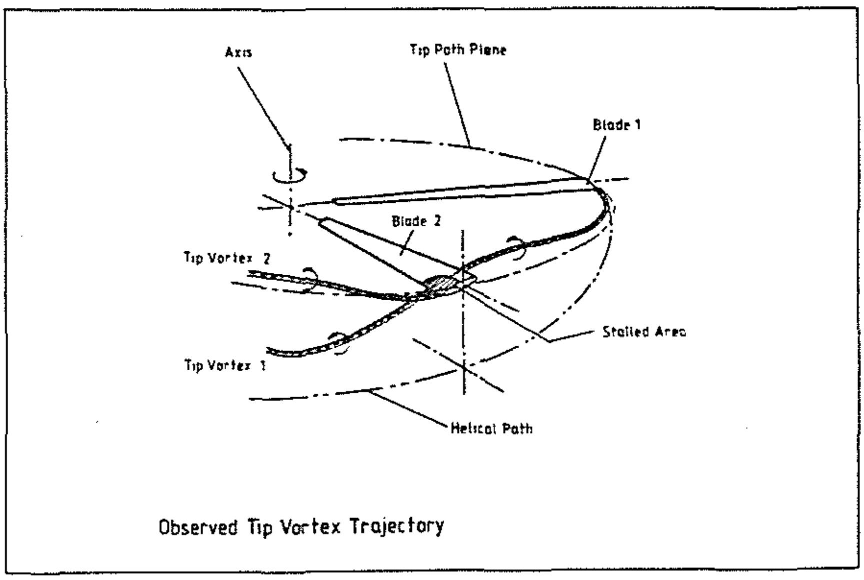
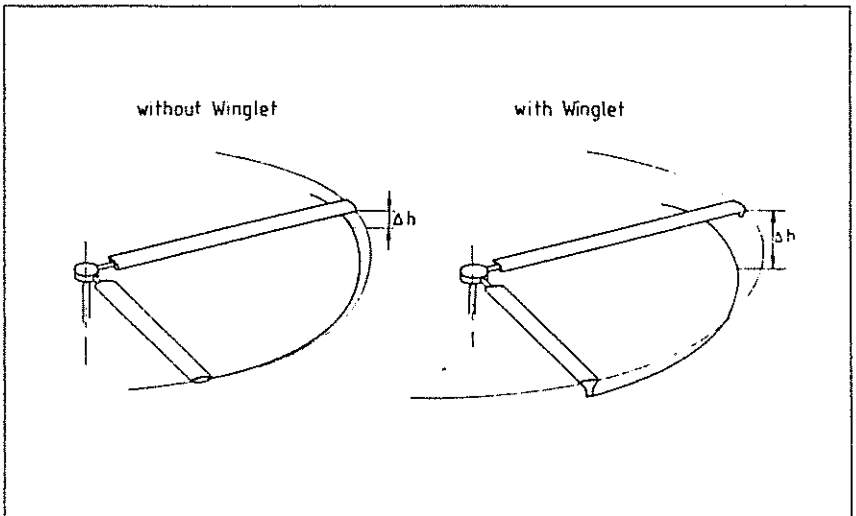


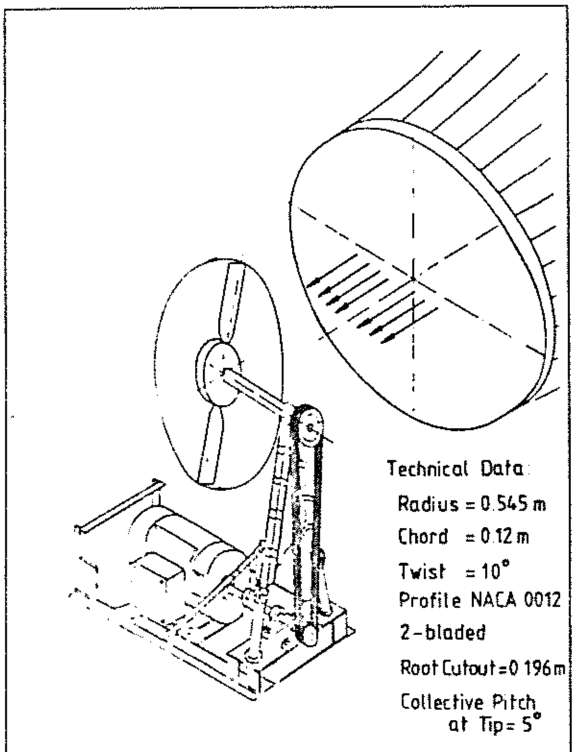
fig. 2 Vortex Path according to ref./10/

So the idea arose, to push down the vortex path with a downward pointing winglet installed at the tip of the rotor blade. The vortex path with and without winglet is shown schematically in figure (3). A rotor test facility (fig.(4)) has been used to investigate this behaviour more in detail. The vortex positions are made visible by a kind of smoke blown into a small sector of the wake. Three rotor tip shapes have been tested (fig.(5)) - two winglets, pointing up and down respectively, and a rectangular reference tip. The downward pointing winglet generates a double vortex, which reduces the maximum of the tangential velocity and results in a larger distance of the vortex to the following blade at the first encounter (fig.(6)). For comparison there are also the vortex paths for the reference tip and for the upward winglet.



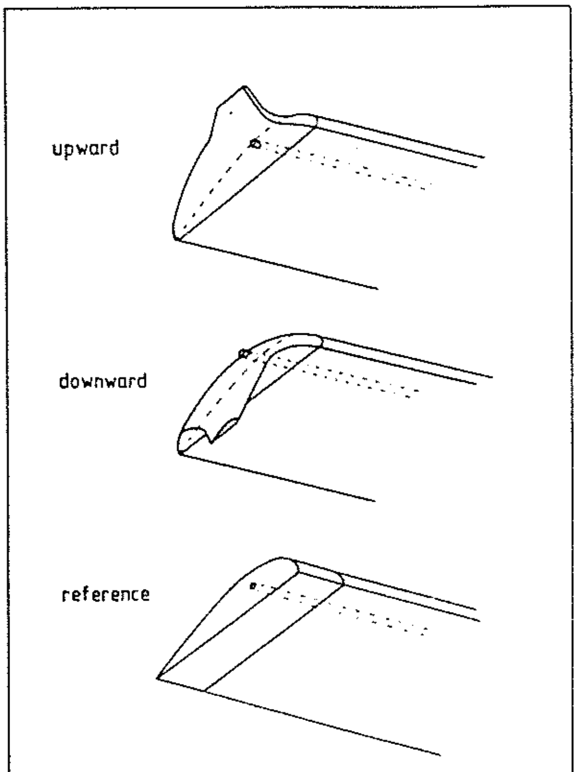
Vortex Path below the Rotorblade

fig. 3



Rotor Test Facility (SFB Rotor)

fig. 4



Various Tip Shapes (SFB Rotor)

fig. 5

A look at the expected distribution of circulation reflects directly the favourable influence of the larger distance between vortex and blade (fig.(7)). Both larger distance and smaller tangential velocities will smooth the spanwise load distribution. These effects are still more important for multibladed rotors, where the first encounter takes place just after the formation of the tip vortex.

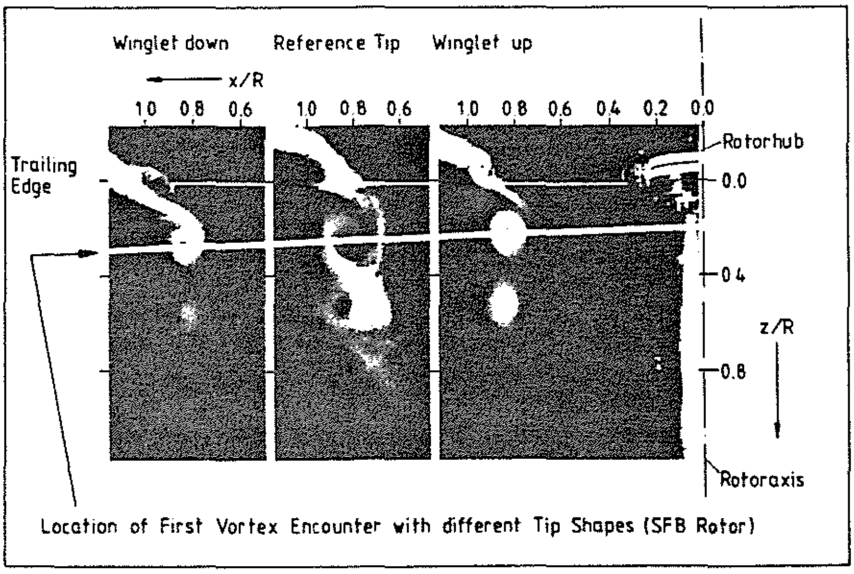


fig. 6

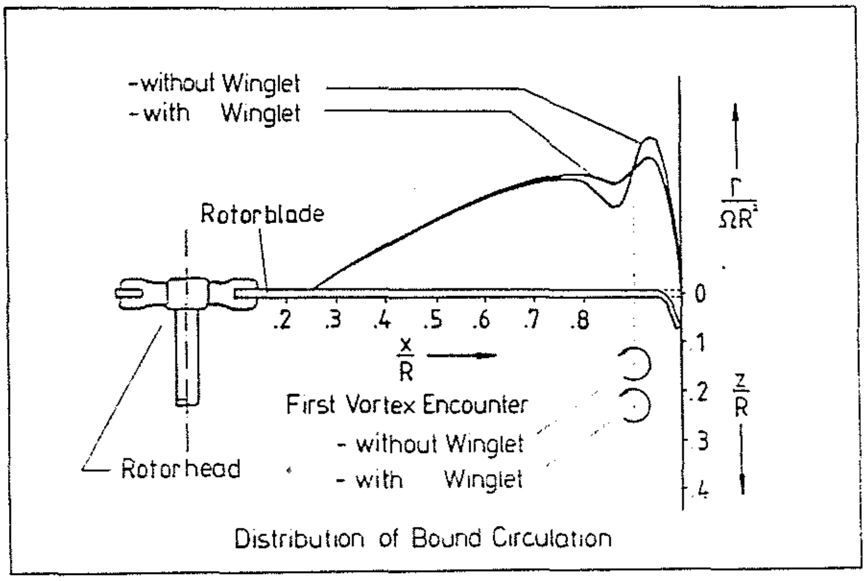


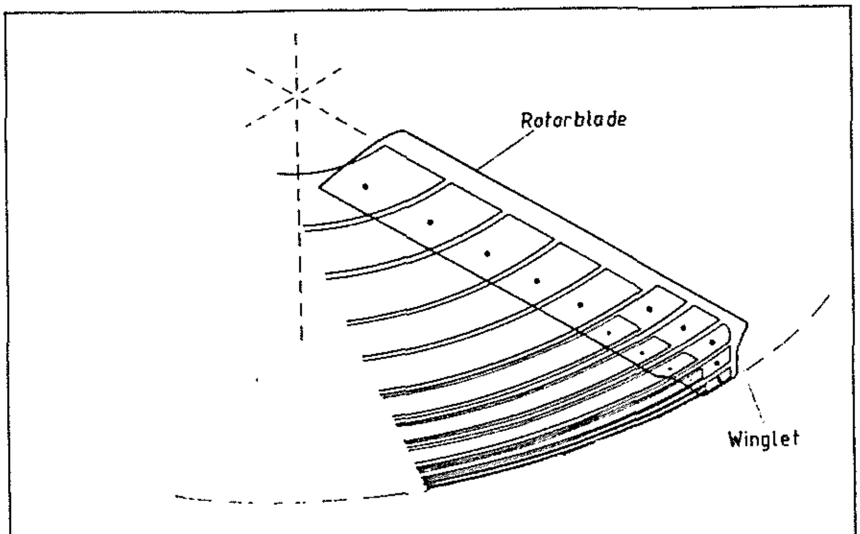
fig. 7

2. THE THEORETICAL MODEL

For the theoretical investigation of rotor - winglet configurations a suitable wake modelling is required. Wake models are usually divided into three parts:

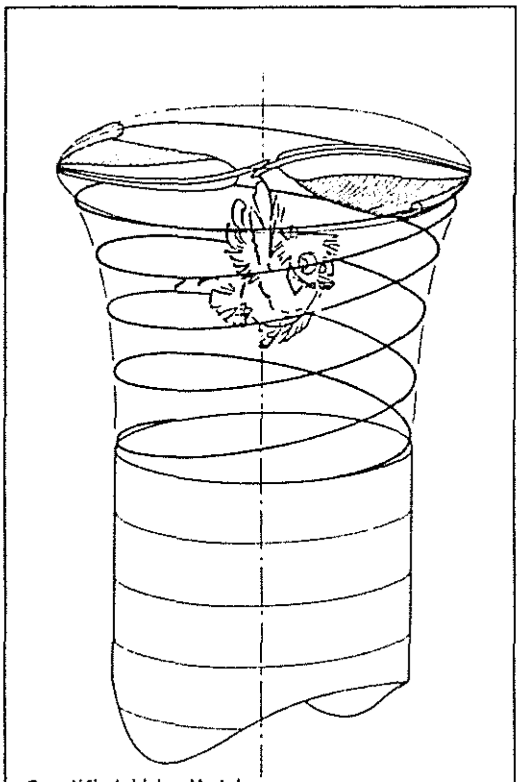
- near wake
- intermediate wake
- far wake

For the calculation of special tip shapes an accurate modelling of the near wake is essential. In this region a vortex lattice method is used (fig.(8)). The intermediate wake is modelled by some revolutions of vortex spirals, which start from the various centers of vorticity of the near wake - mostly two or three over the blade, a tip vortex, a mid vortex and a root vortex. Finally the far wake is simulated by vortex cylinders or several vortex rings (fig.(9)). The mid vortex, often postulated, has now been measured by LDA (fig.(10)). For this measurements a twisted fixed wing, distorted by a vortex simulating the tip vortex of the preceding blade, has been used. The circulation distribution on this test wing is very similar to that one of a rotor blade. So a comparison seems to be permissible.



Vortex-Lattice Method

fig. 8



Simplified Wake Model

fig. 9

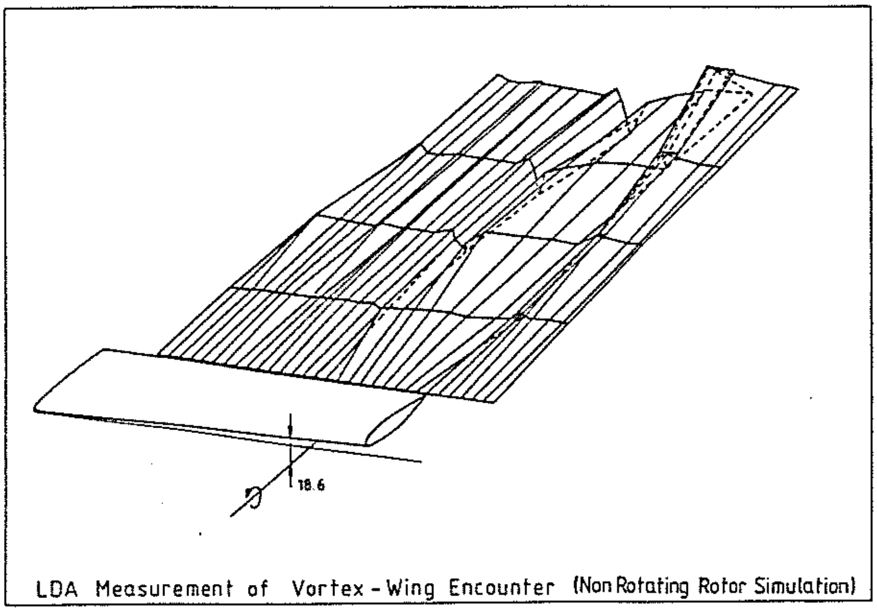


fig. 10

Calculations have been performed for test purposes for several rotor configurations without winglets, especially for the 2-bladed rotor of WAYNE JOHNSON /3/ and the 4-bladed rotor of FAVIER /2/, and the results have been compared with the respective measurements. In figure (11) the relative good agreement is shown for the 4-bladed rotor of FAVIER.

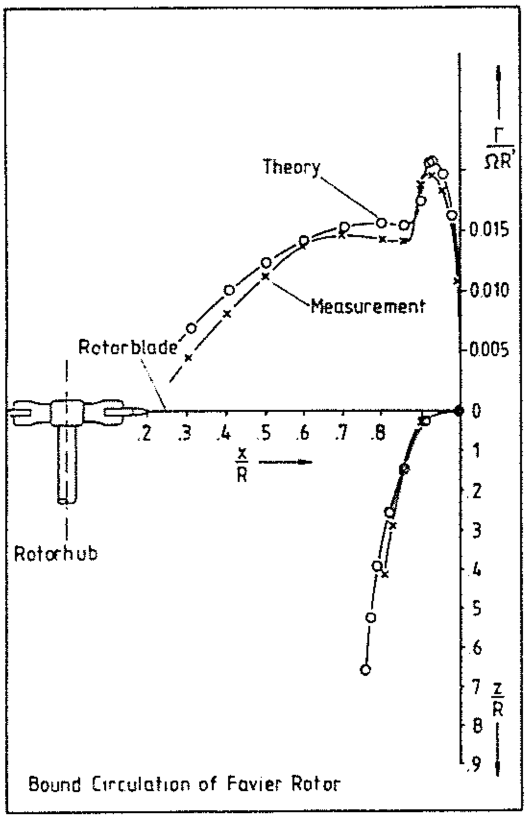


fig. 11

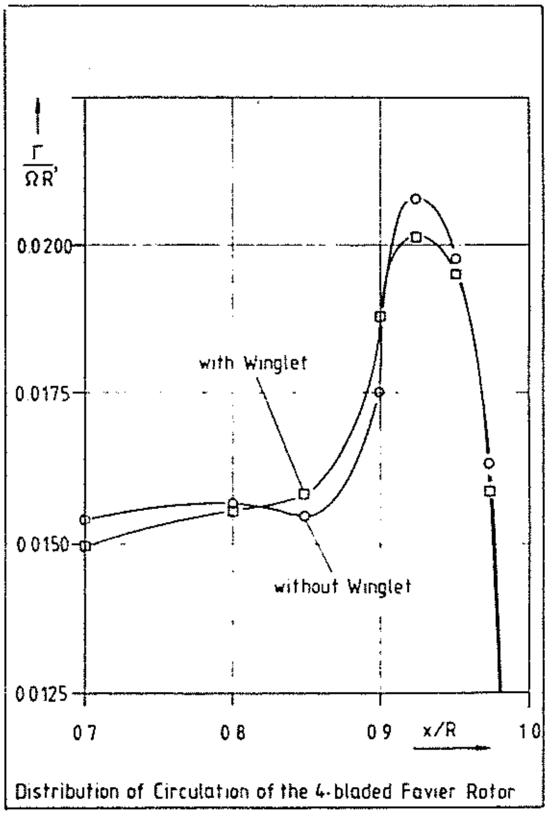
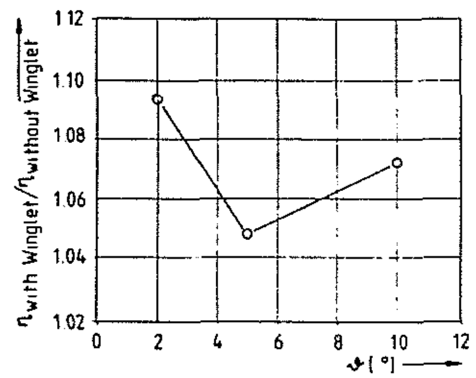


fig. 12

3. RESULTS

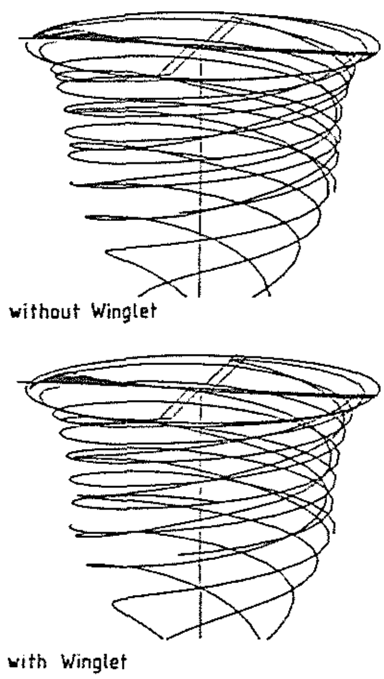
3.1 HOVER FLIGHT

Using the vortex lattice method it was possible to calculate different tip shapes. For first tests very simple shapes have been used. For the example of the FAVIER rotor the calculated influence of a tapered downward pointing winglet with a lenght of about 3% of rotor radius is shown in figure (12). Even this non-optimized simple winglet decreases the gradient of the circulation distribution remarkably. The intermediate and near wake with and without winglet are shown in figure (13) and (14). It is interesting to see that the double vortex, generated by the winglet, yielded by the calculation is similar to the double vortex in the visualization (fig. (6)). Measurements with the rotor of figure (4) yielded a bit lower thrust but a better figure of merit with the downward pointing winglet (fig.(15)).



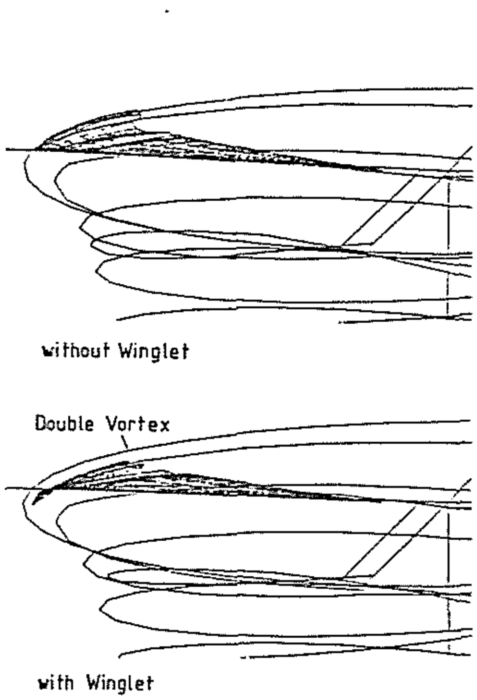
Relative Figure of Merit with Winglet (SFB Rotor)

fig. 15



4-bladed Favier Rotor

fig. 13



4-bladed Favier Rotor

fig. 14

3.2 FORWARD FLIGHT

The forward flight of a helicopter is more complicated than the hover flight due to unsteady effects. The wake behind the rotor rolls up into two strong vortices, which accumulate all vorticity (fig.(16)). Due to the lack of an acceptable wake model for forward flight the vortex paths in the wake have been determined by windtunnel measurements using a helicopter model (fig.(17)). This model was built with an arrangement to blow air out of the blade tips. A mixture of air saturated with water has been used for the visualization of the tip vortices. Configurations at different advance ratio have been photographed (figs.(18),(19),(20)). The vortices come still nearer to the blades than in hover flight and increase the strenght of the fluctuating forces on the blades. The vortices directly influence the forces on the blades as well as the paths of the remaining vortices (fig.(21)). In the figure a vortex crossing has been followed through several time steps and the photos illustrate the bending of the vortex paths and finally the global roll up mentioned above (fig.(16)).

Even a vortex bursting can be observed, as shown in landing configuration (fig.22)). This bursting is caused, however, not by the close encounter of a rotorblade, but by the influence of another vortex. Investigation on the behaviour of this bursted vortex at the arrival of the next blade need further photographs, which will be taken in the near future.

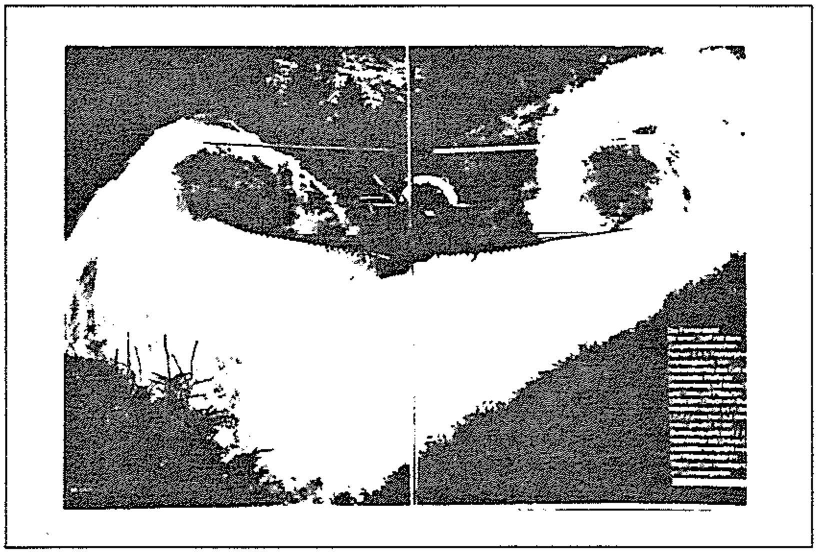
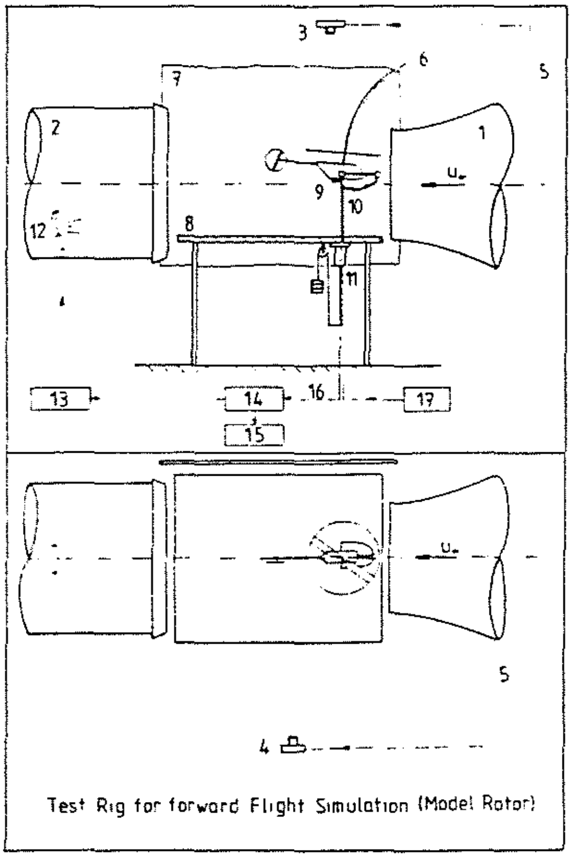


fig. 16 Visualisation of Vortex Roll-Up



Technical Data of Model Rotor

Radius = 0.5 m

Chord = 0.054 m

Twist = 0.0°

Profile NACA 0015

Number of Blades = 2

Rotor Hub Precone = 0.0°

Root Cutout = 0.11m

Rotor Speed 600 and 900 RPM

Collective Pitch at Tip = 11°

fig. 17

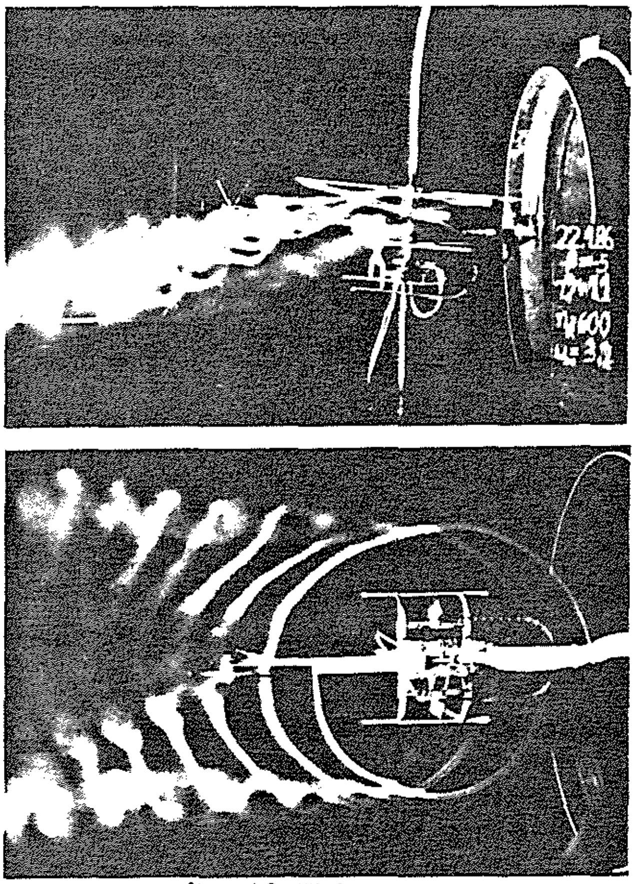


fig. 18 Wake at μ = 0.1

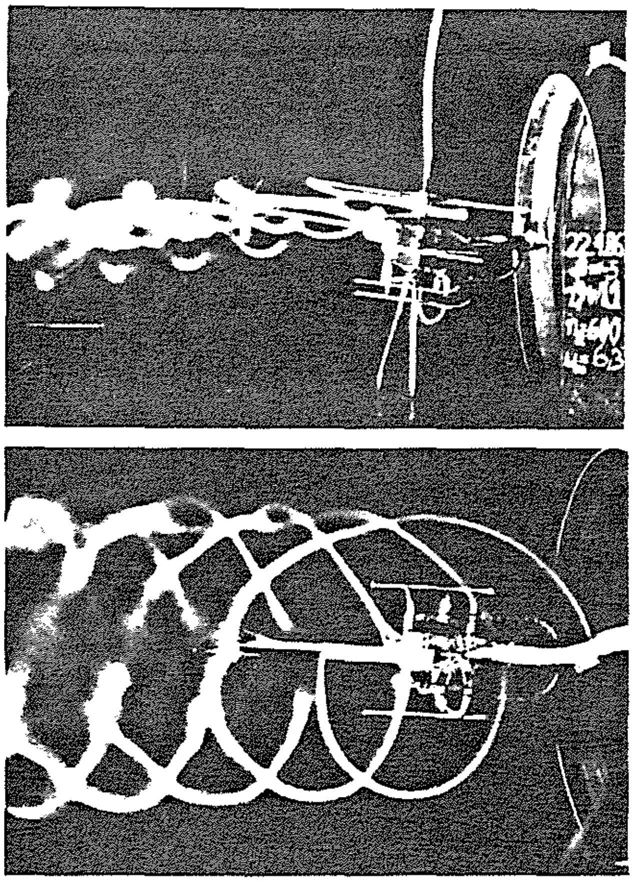


fig. 19 Wake at μ = 0.2

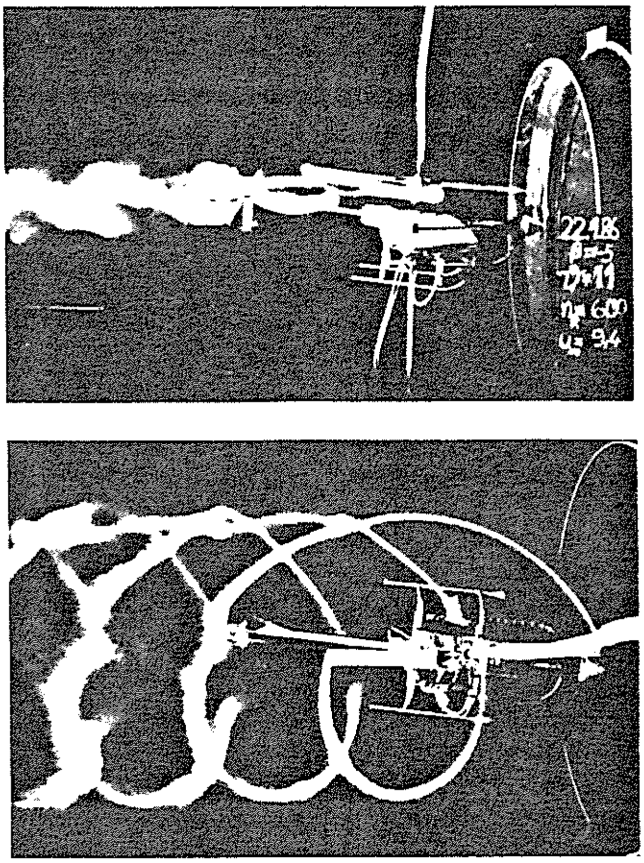


fig. 20 Wake at μ = 0.3

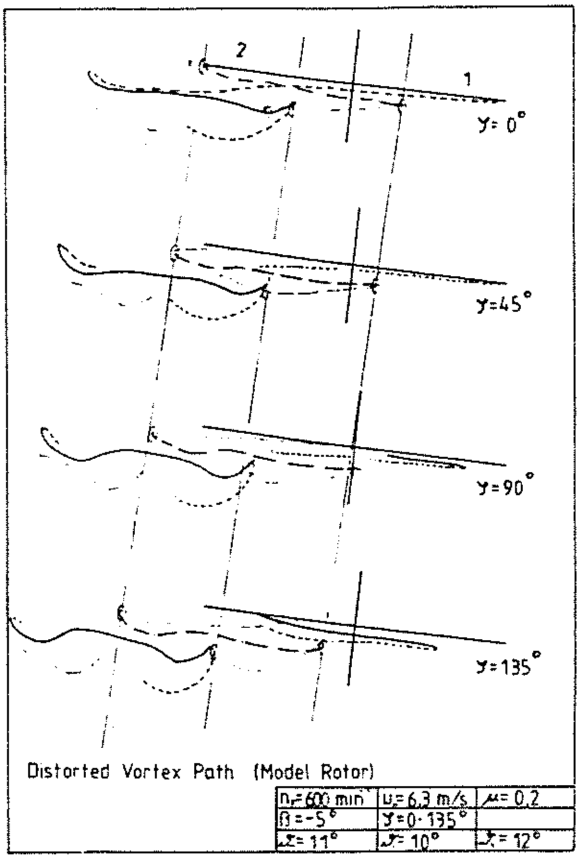


fig. 21

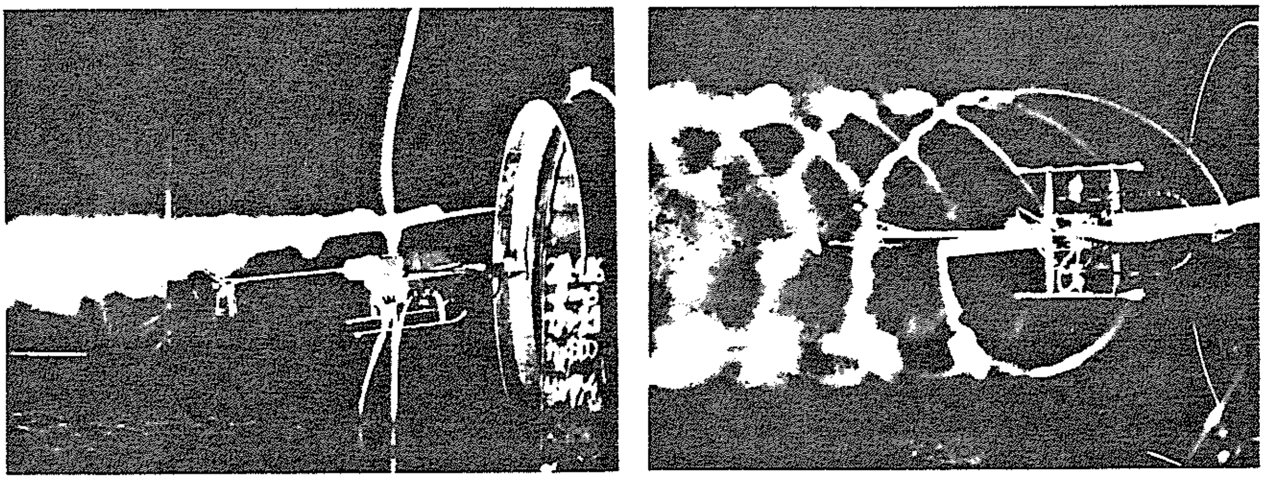


fig. 22 Vortex Bursting at Landing Configuration

The vortex paths shown by these photos can be used as an input to the calculations of the unsteady blade forces. This calculation method is shortly described by NEUWERTH and MÜLLER /6/. It is based on the unsteady theory of NAUMANN and YEH /7/, which has been modified and programmed by KELLNER /8/ and SCHREIER /9/. The main idea is shown in figure (23). The cambered airfoil is simulated by bound and free vorticity and the inflow is represented by a mean velocity and the Fourier components of the flow disturbances. Results of calculation of unsteady pressure are shown by NEUWERTH and MÜLLER /6/ and are found to be in good agreement with measurements using a special test arrangement, where the rotor inflow is distorted in hover and forward flight.

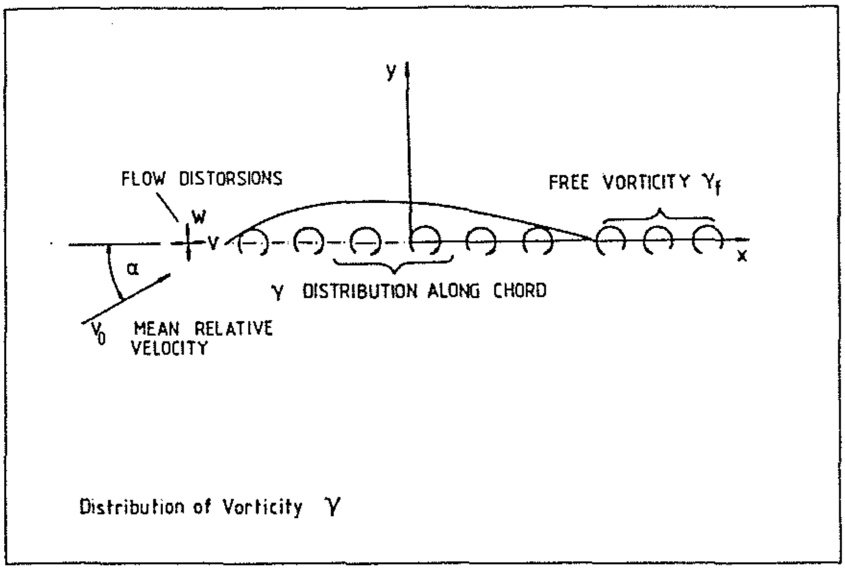


fig. 23

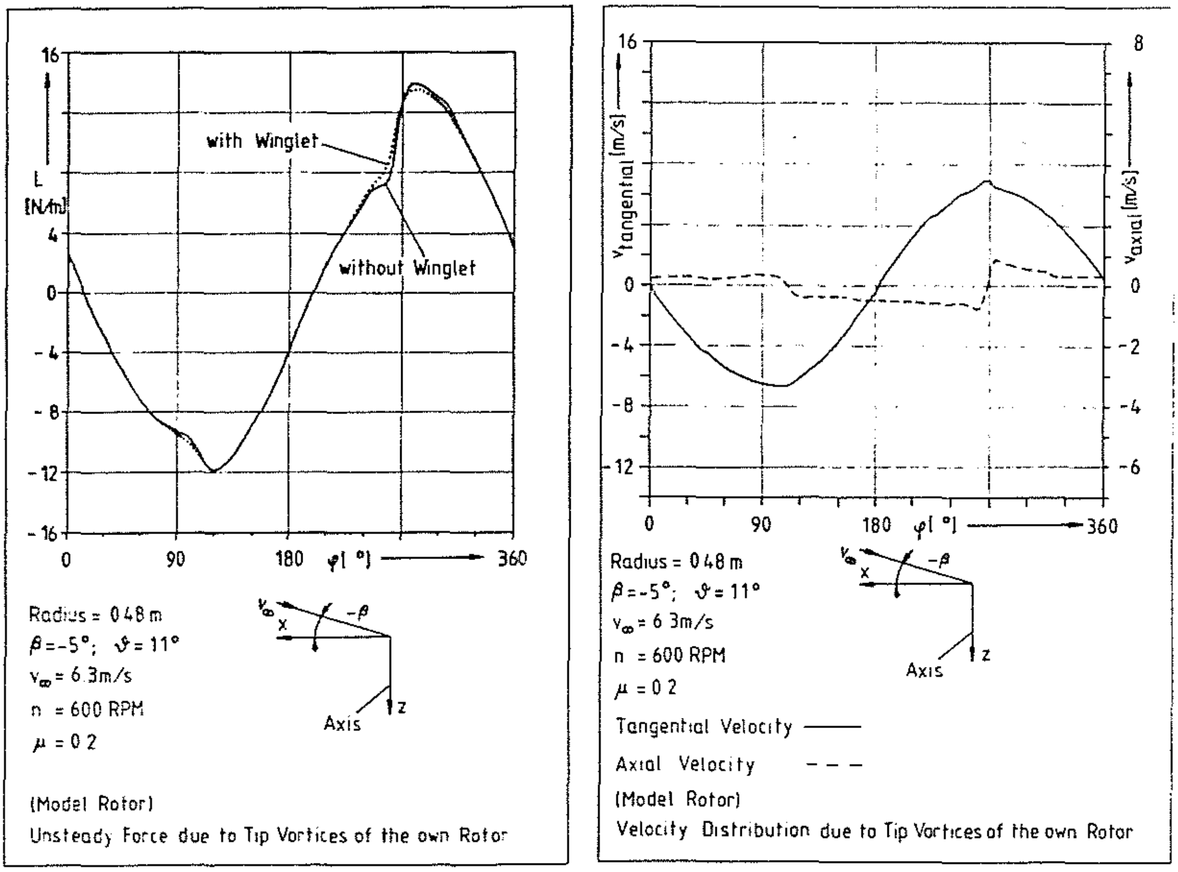


fig. 24

Applying this method to forward flight conditions and using the vortex path of the photos as an input, calculations yield the unsteady forces shown in figure (24). The calculation of the influence of winglets in forward flight requires the knowledge of the wake geometry generated by the winglet configuration. This data will be produced by further visualization studies or - in the future - by free wake analysis in forward flight. A shift of the wake downward by 2% of the rotor radius, which is obtainable by a winglet, will reduce the unsteady forces, also shown in figure (24). In this test calculation a spreading of the vortices is not yet regarded.

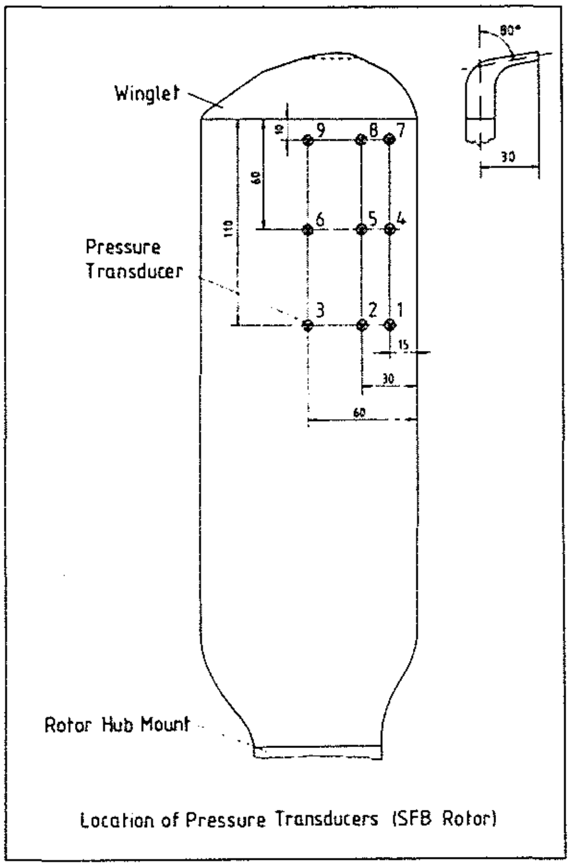
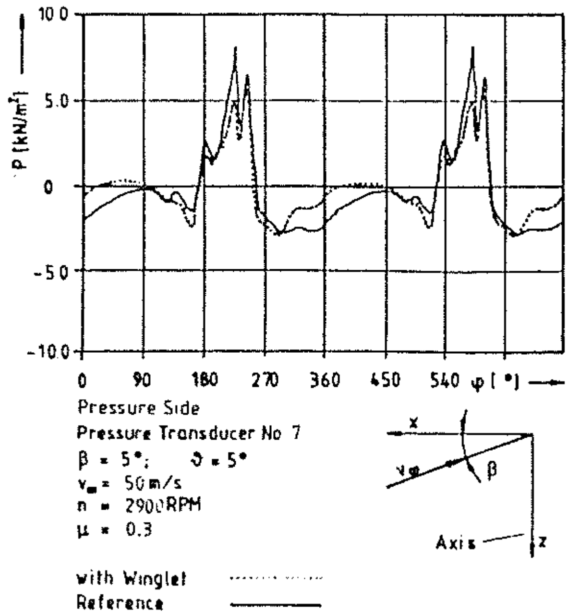
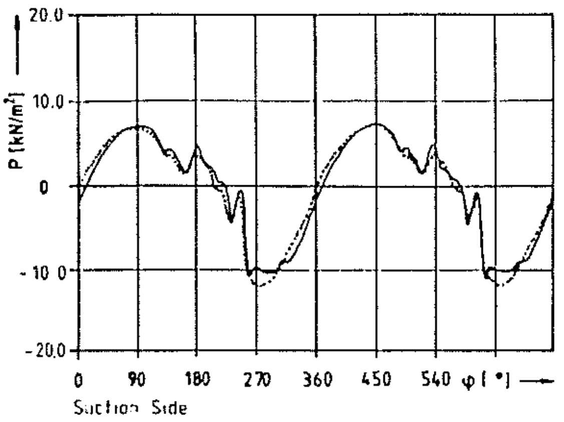


fig. 25

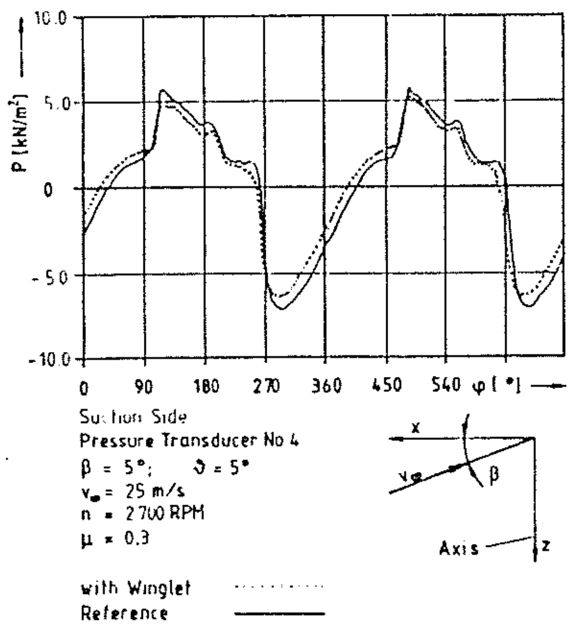
In forward flight, however, an adverse influence of the winglets may arise due to azimuthal variations of their incidence. Therefore an investigation of these effects has been conducted with the test facility of figure (4). One rotor blade has been equipped with nine pressure transducers at different radial and chordwise stations (fig.(25). The measurements with the winglets of figure (5) of the unsteady pressure course at advance ratio of $\mu = 0.15$ and $\mu = 0.30$ yield smaller fluctuations with the downward pointing winglet at the measured radial stations (figs.(26),(27),(28),(29)) - especially at the pressure side of the blade. But even at the suction side the peaks are lower. Important is, however, that no adverse influence of the winglets can be seen at these different rotor blade stations. Further investigation on the flow near the winglet bending is necessary yet.

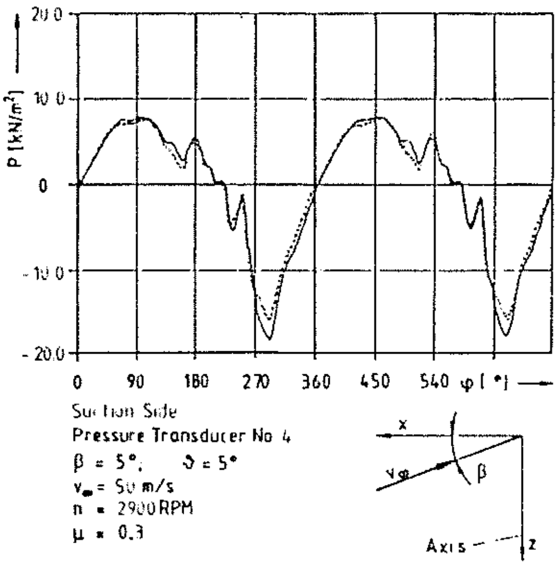




Pressure Fluctuations due to Tip Vortices of the own Rotor (SFB Rotor)

fig. 26 fig. 27





Pressure Fluctuations due to Tip Vortices of the own Rotor (SFB Rotor)

fig. 28 fig. 29

4. SUMMARY

In this paper winglet arrangements have been introduced to the rotor blades and its influence on the wake and on the unsteady blade forces has been presented. By experimental and theoretical investigation as

- visualization of the rotor wake and
- measurements of the unsteady pressure course

and by

- free wake analysis in hover flight and
- calculation of the unsteady forces with the theory of NAUMANN and YEH

the favourable influence on rotor aerodynamics has been proved even for a non-optimized Winglet. These first results promise an improvement of rotor performance, structural blade loading and noise emission and justify further experimental and theoretical investigation on the shape of winglets.

5. REFERENCE

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