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INVESTIGATIONS OF BLADE-VORTICES IN THE ROTOR-DOWNSTREAM

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Abstract

The flow field of a rotor consists of induced downwash, the mixing area of this downwash with the free stream, and last not least, the strong rotorblade-vortices. The paper deals with the investigation of those vortices. The trace and the diameter of the vortex were identified by a simple measuring method. This technique will be presented. The measuring equipment was set up on both sides of the DFVLR-Rotor-Test-Stand, and in a short time it was able to cover the whole area under and behind the rotordisc. The tests were conducted in the DNW-Wind-Tunnel using the closed 8 x 6 m test section.

Some remarkable results are presented and discussed. During the tests, data of vortex diameter, trace, and vortex location with respect to the fuselage and especially to the tail-rotor were measured. These test results provide a better understanding of the rotor downwash structure and are very helpful for preparation of hot-wire probe measurements at selected points.

1. INTRODUCTION

Extensive knowledge about the structure of the downwash is nessesary for the theoretical comprehension and the understanding of aerodynamic procedures with the rotor. Mainly it is the more or less big vortex, springing from each blad tip which exerts a decisive influence. Contrary to the fixed-wing aircraft the tip vortex does not swim away in a straight line, but gets a helical trace because of the rotating rotorblades. It looks like a twisted cycloid with increasing advance ratio. On the one hand the interference between these vortices and the following rotorblades is important, on the other hand it is also the interference with the helicopter tail-groups, the stabilizing fin as well as the tail rotor.

The rotor blade interference is a dominating factor for the periodical load changes of the rotor, which will be noticable because of vibrations. Also acoustic appearances are caused by the blade interference. In dependence on the flight conditions, the rotorblades hit or pass very close the vortices in parts of the rotorlevel. In both cases one can find a strong variation of the angle of attack in the vortex areas. Therefore it is important for the calculation of the rotor to know something about the tip vortices, in addition to the knowledge of the downwash components. This paper will present a simple measuring method to investigate the trace and the size of a vortex.

To make extensive research in the rotor downwash, a measuring equipment was build up. With hot-wire probes it is able to measure the components of the flowfield under the rotor of the DFVLR-Rotor-Test-Stand. Because the probe does not measure continuously over the area, but only in defined points, it is necessary to use the described method to locate the tip vortices. With the help of these results it was possible to put the hot wire probe into the correct location. All measurements took place in the closed 8 x 6 m test section from the German Dutch Wind Tunnel (DNW).

2. MEASURING EQUIPMENT

The facility to measure the downwash is installed on both sides of the test stand. The probes are moving over a sliding carriage system in the x- and y-direction. A telescopic mast provides the movement in the z-direction. A view of the measuring equipment is presented in Figure 1. An impression of the original facility in the test section is given by a photograph (Figure 2). The driving range of the probe includes the rotor area with an enlargement in the rear zone, the helicopter tail region. Figure 3 showns the measuring range of the probes. Of course, it is only possible to measure below the rotor disc. The measurement region in the z-direction changes with the adjustment of the angle of attack of the rotordisc. The sliding carriage for the x- and y-movements are driven with chains from regular alternating-current motors with brakes. The z- drives are spindel mechanisms with the same type of motors. The positions of the support and therefore the positions of the probes are measured by potentiometers. The supports are controlled in all directions with a maximum position error of ± 5 mm. This inaccuracy is given by the type of the motors. The error of position measurement by the potentiometer is in the range of 1 mm. With regard to the size of the rotor, the control error can be ignored. Only with a stepmotor it is possible to have a more accurate control. This will be more expensive but not rather more effective.

3. THE PROBE SYSTEM AND THE MEASURING PRINCIPLE

At the top of the telescopic mast an arm is installed, pointing towards the centerline of the rotor, holding the respective probe. To investigate the vortex trace, many dynamic pressure probes have been installed in one row, one above each other (Figure 4). The original idea to use those pressure probes to determine the vortices was the fact, that the pressure is very low inside the center of a vortex. The suggestion for these investigations was initialized by an article of the "AVIATION WEEK" (ref. 1).

Because of the low pressure it is possible, that vortices, which are passing the probes, are determinable by the measured signals. The probe consists of a pressure transducer, installed at the top of a tube and is measuring the total pressure. The magnitude of the signal provides informations about the location of the vortex related to the position of the sensor. If the probe moves continuously across the vortex field, it is possible to determine the location of the center and the size of the vortex.

Contrary to the fixed-wing airplanes the vortex of a helicopter is always moving away, that means, conforming to the rotorphase it moves to another place. So it is sufficient to drive only one probe slowly through the downwash below the rotor at one z-level. With 4 rotorblades rotating with more than 1000 rpm, about 70 vortices per second will flow along. The vortices will always take the same trace if the rotor test condition is not changed.

The other probes are used to eximine the further trace of the vortices in the downwash. So it is easy to get a time history of the vortex signal in the probe direction. In the latest wind tunnel tests, the pressure probes were placed at those levels and traces, to examine the positions for the hot wire probes.

Parallel to the pressure signals the position of the rotorblades as well as the position of the probes were recorded on two analog tape recorders and on-line printed out with two slow moving u-v-paper writers. For each side of the rotor one tape recorder and one paper writer was used. The interesting field below the rotor was separated into several traces (Figure 5) which were continously driven through by the probes. The recording time for one of those trace was about 45 sec. The whole field with 17 traces and 6 levels was measured in nearly 13 minutes.

4. DATA INTERPRETATION

For a quick look the u-v-strip charts are used. The strip charts gives in a compregnated form of the signals of 6 probes on a paper length of 11 cm (4 inch) (Figure 6). In addition, on the lowest trace informations about the position of the sensors are marked. To look at the vortex immediately is of interest, because the hot-wire probes for the downwash measure at fixed points.

The signal peaks, pointing downwards, are representing a low pressure. The vortex center is located in the signal maximum. The data recorded on the analog tape recorders are later digitized and evaluated on a large digital computer. Currently the sampling time is 0.4 msec. This time is short enough to resolve the signals up to 500 Hz in a good manner. The problem of this rate is the large quantity of data that comes together during a record time of 45 sec. Previous tests were scanned with 2 msec, which is the upper limit, because the vortex signals were, for the most parts, just to identify. Of course, some of the maximal values were not sampled. But to have a roughly view over the whole flow field this data evaluation is enough sufficient, indeed.

Before looking for details of the vortex signal, some figures will give an overview of the measurements. Figure 7 shows the results of one complete test with 6 levels and 17 traces. The upper probe was kept in a distance of 150 mm to the idealized horizontal rotorlevel.

The bending of the rotordisc could not yet be measured. The distance of the following probes was 100 mm. Because of the distance of the first sensor to the rotorlevel, only in trace 5 a vortex signal is visible. This is the lower front boundary of the downwash cylindre. The other traces are reaching deeper into the region of downwash. In trace 14 the backside is reached. The upper probe has already left the region of downwash in trace 15.

In Figure 8 this downwash cylinder is shown in front of a BO 105 helicopter which is drawn into the measuring field. In the front rotor area the vortices are close to the rotor. Also most rotor-vortex interferences are to find in this region. A range of high signal activity is noticeable beginning in trace 12 outside of the tip vortex. This range keeps its orientation later on. The windtunnel velocity interferes with the vortices in the outside of the downwash cylinder. That is why there are big rolling-up areas in this region.

Figure 9 shows the signals of the level $z/R = 0.175$.

The vortices can produce two different signal forms. Figure 10 shows those two types. The signal of vortex A has the expectet form, where the pressure decreases towards the vortex center. The signal form of vortex B also has a low pressure area but directly in the neighborhood an area with higher pressure can be noted. How can this be explained?

Imagine the vortex like a rotating disc (Figure 11). Probe A is in a rectangular position to this disc, it points in direction towards the vortex shaft. If now the probe A moves through the vortex in y-direction, the angle between the upward pointing velocity vector and the probe is the same as the angle of the downwards pointing vector. In the center there is a calm and low pressure zone. When driving the probe through the flow field, many vortices are moving in z-direction. Then the signal reduces to the value of the free stream and increases again with the next vortex. The more the probe moves towards the center, the more the pressure decreases. So far the interpretation of the view A of the vortex.

If the probe is not pointing towards the vortex, the rotating velocity vector of the vortex will hit the one side of the probe a little bit from behind but on the other side the vector blows into the probe. This results in a high pressure signal. The change between low pressure in the center and high pressure of the highest velocity vector of the vortex is shown in case B.

Which one of those pressure areas is on the right or left side is dependent on the sense of vortex rotation, if the probe's position is constant.

With the help of type B it is possible to say something about the core of the vortex. It is possible to measure an area, in which a higher velocity is induced by the vortex. The distance to the low pressure area could be measured. In this illustration the core diameter is 20 to 25 mm.

Between the vortex illustrations A and B you should not make any comparisons. Both vortices are derived from different tests and positions. Vortex A may have a diameter of 30 mm if it is measured at the point of 30% loss of pressure.

The magnitude of the vortex velocity vector is not so easy to investigate, because the probe needs to point quite exactly toward the vector. The magnitude of the vortex vector depends on different factors. Besides the geometrie of the rotorblade and the blade tip, the angle of attack of the blade influences the vortex structure. With increasing advance ratio, the vortex formation is greater at the retreating blades than at the rotorside with the advancing blades.

Experiments were made with the probe angle of attack. Originally the vortex signals should be of type A in figure 10, as shown in the results of the first test (Figure 12). But at the following test the vortex type B was found. In the meantime a new probe rake was built and the probes were adjusted at a new angle of incidence. The probes should point parallel to the streamline of the downwash cylinder. In the first test they were adjusted parallel to the wind tunnel axis. However, the type B gives more interesting informations. The angle of incidence was 30 degrees to the horizontal plane. Perhaps with an angle of 90 degrees the information about the magnitude of the vortex vector will become more accurate.

The velocity condition at the probe also depends on the rotor thrust, the advanced ratio, and the angle of attack of the rotor disc. As presented in figure 12, small peak signals inside the downwash field were found in the neighborhood of the strong blade vortices of type A. The more detailed analysis shows two small single vortices springing from one rotorblade only during one revolution (Figure 13). The reasons for these small vortices were little trim tabs at the trailing edges of the rotorblades. One of them had a great angle of incidence. The small vortex signals could be assigned to the corresponding rotorblade.

Figure 14 presents the marginal vortices of another test. In this case, like in figure 13, it is possible to measure the time between the probe signals. With the known distance it is possible to calculate the downwash component in the z-direction. The results could be compared exactly with the following hot-wire measurements. In Figure 14 the distance between probe 3 and 2 is twice the size of the distance of probe 2 to probe 1.

The signals do not need to lay beneath each other, the trace also could have a strong diagonal direction. In this case the following probes recieve the vortex only if the support moves in y-direction. The relation between the probe signals is given by the revolution signal of the rotor. Depending on this signal the running time will be measured.

5. CONCLUSION

The method to investigate the helicopter downwash for vortices with dynamic pressure probes is explained. A mechanical support makes it possible to move the probes to every position below the rotor.

The vortex, springing from the blade tip, presents itself as a steady low pressure system. The vortices are changing their position dependant on the rotorphase. One after the other, like a chain, they are running in a steady trace.

The data presentation on u-v-strip-charts gives at once a quick look of the flow conditions and the vortex trace. This is important for immediately following hot-wire probe measurements at selected points. The evaluation of the analog data from the tape needs a high sampling rate for digitizing. To achieve good results, the sampling time should be about 0.4 msec. The disadvantage of a too high sampling rate is the amount of data, because one trace takes about 30-45 sec.

From the data of all traces and levels it is possible to get a three-dimensional view of the downwash cylindre. The trace of the tip vortex can be measured exactly. Based on these results conclusions can be made for the interference with parts of the helicopter tail.

The size of a vortex core can be found with the pressure signals. The vortex may have two different signal types. When the probe is parallel to the vortex axis the first signal type is a pressure signal, which is only pointing in the lower pressure area. The other type has a low pressure area in the vortex center and a high pressure area in the neighborhood at the point of the maximum vortex velocity. In this case the probe is not pointing into the vortex axis. Only on one side of the vortex, it blows into the tube, because of the rotating velocity vector.

Especially at the second vortex presentation, the diameter of the vortex core can be calculated. The core radius is defined by the distance between the pressure maximum and the pressure minimum.

The downwash component in the z-direction can be calculated out of the time between two probe signals and the distance of the probes. This was proven by comparing the following hot-wire measurements.

The measuring system is suitable for the desired measurements. Vortex investigations in the short range field of the rotor and on the rotorblades will be started in the future.

References

1) Aviation Week & Space Technology, page 121, Nov. 8, 1982

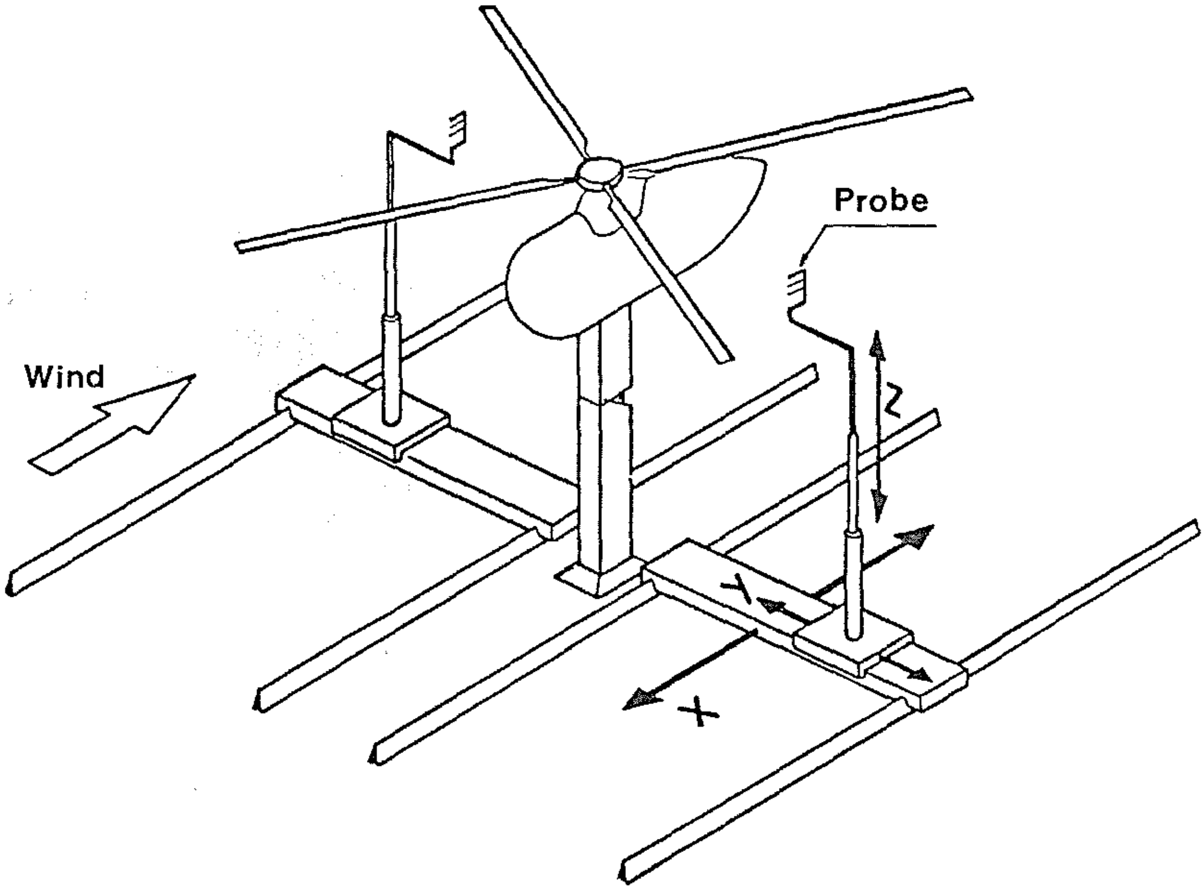


Figure 1. DFVLR-Rotor-Teststand with the downwash measuring equipment

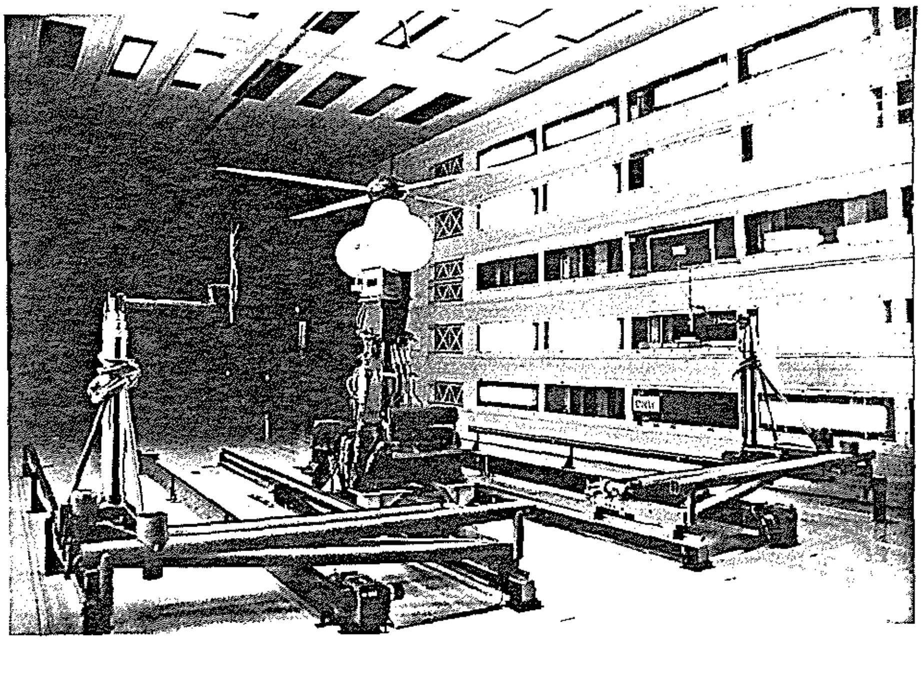


Figure 2. DFVLR-Rotor-Teststand in the German Dutch Windtunnel

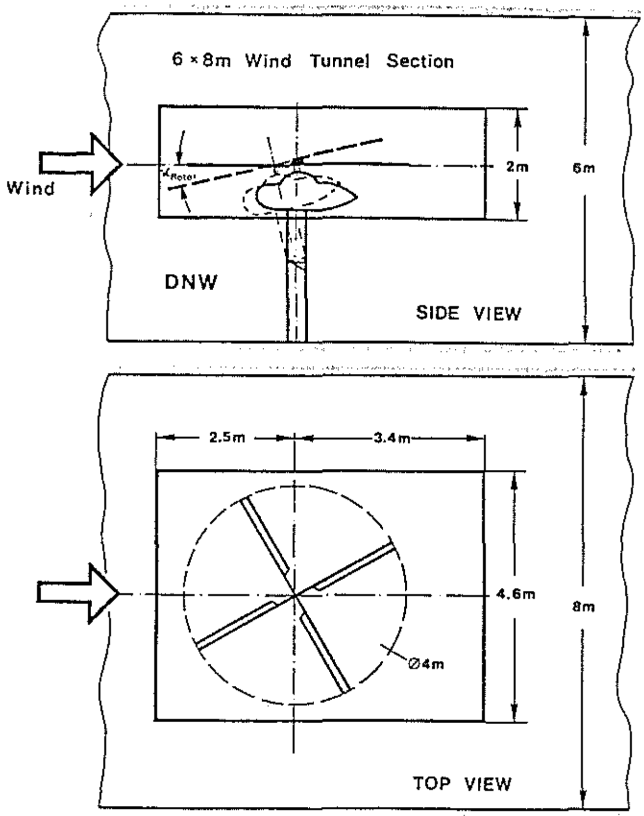


Figure 3. Measurement range of the probes

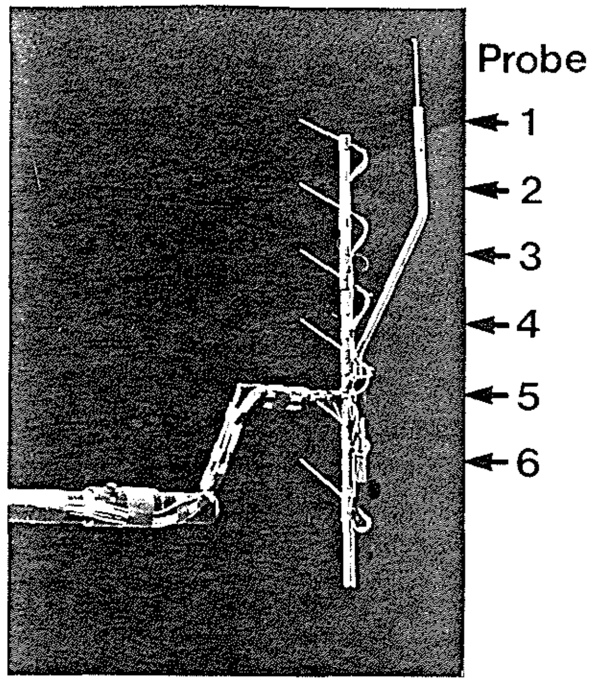


Figure 4. Dynamik pressure probe rake

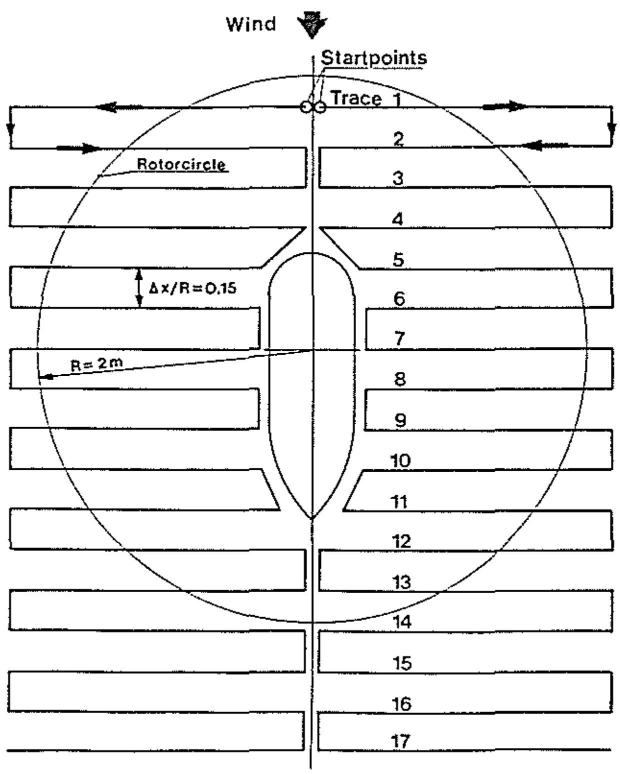


Figure 5. Traces of the probes below the rotor

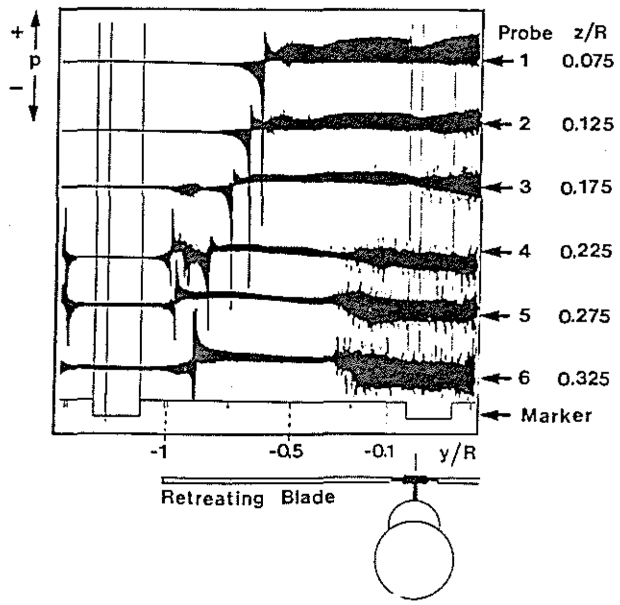


Figure 6. Probe signals on U-V-paperstrip

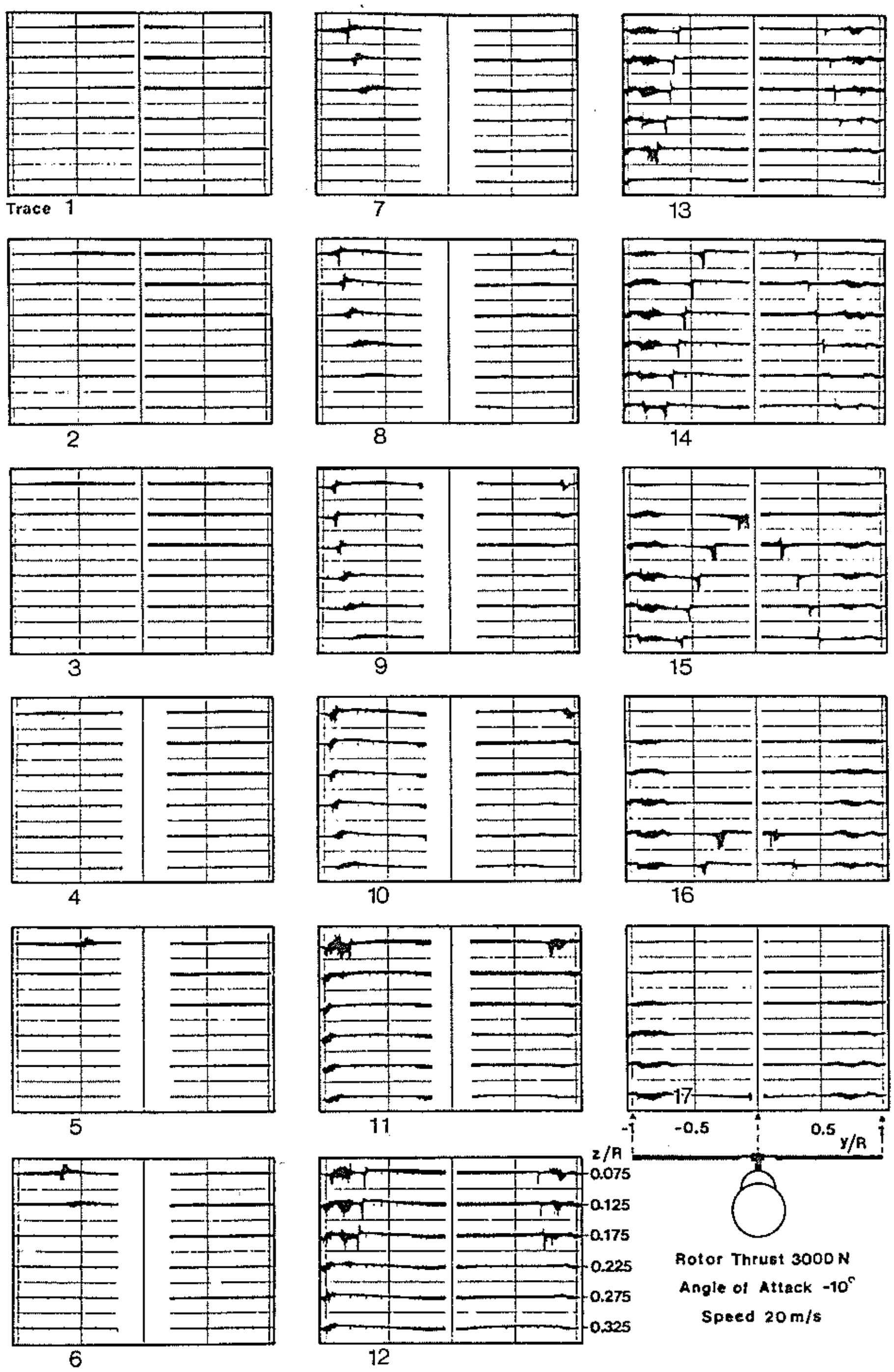


Figure 7. Results of 6 probes and 17 traces

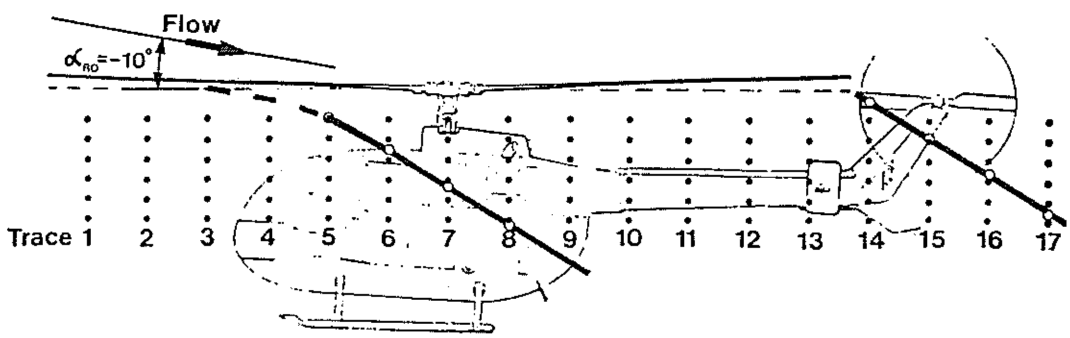


Figure 8. Side view of the downwash cylinder

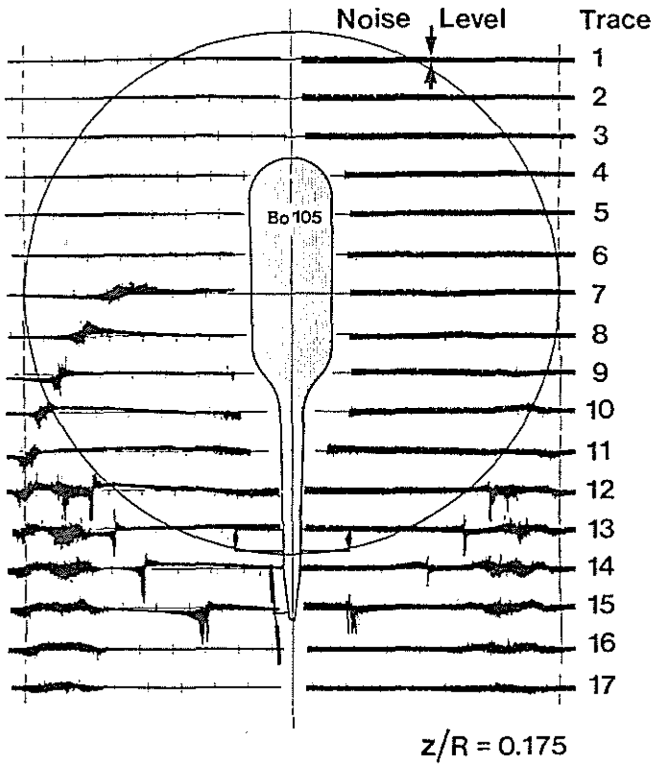


Figure 9. Pressure signals in a specific distance

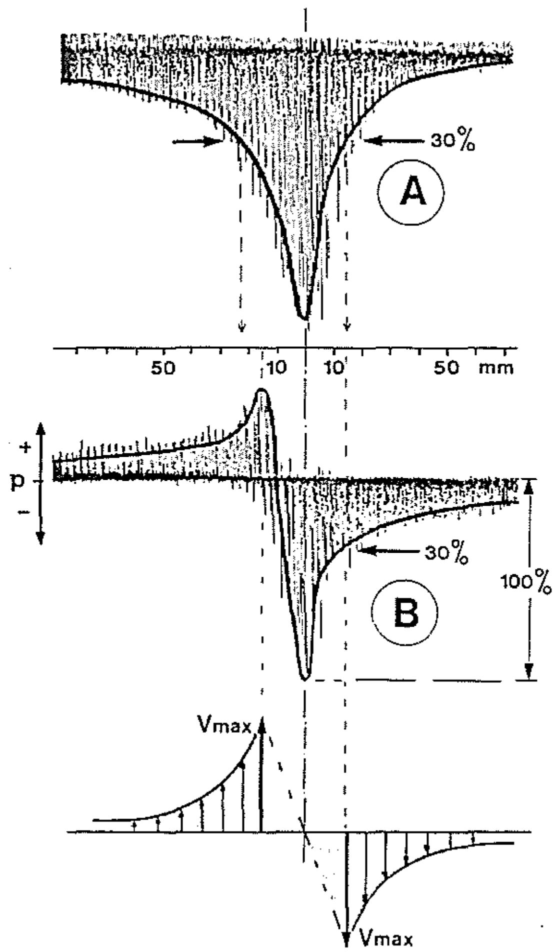


Figure 10. Two different measured pressure signals and a theoretical velocity distribution of a vortex

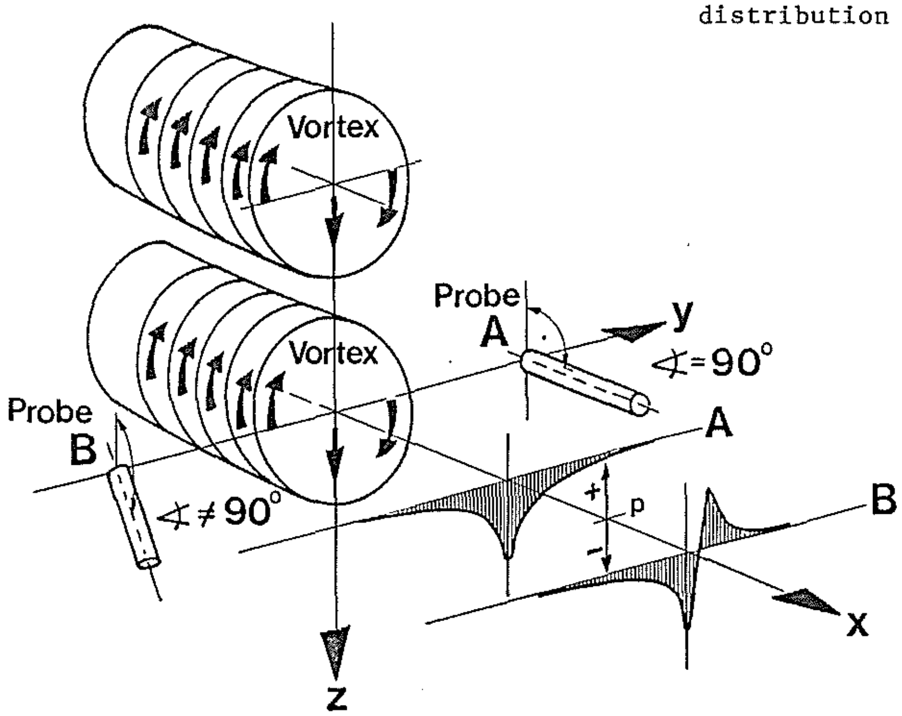
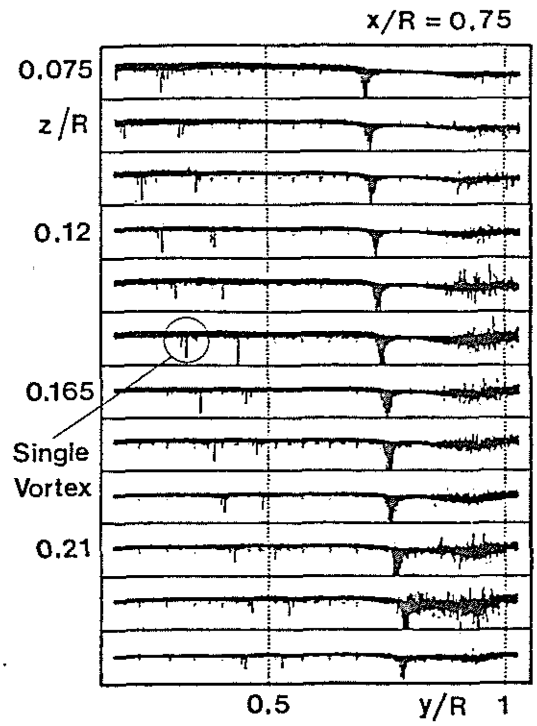


Figure 11. Greation of the two vortex signals



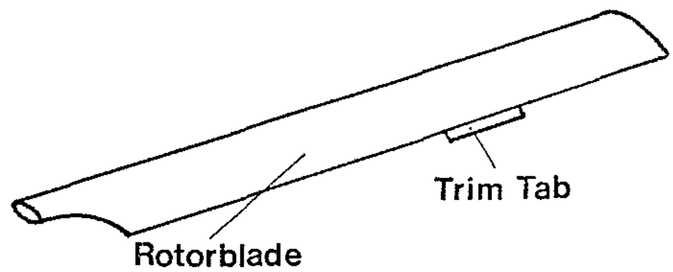


Figure 12. Vortex signal of a trim-tab in the downwash

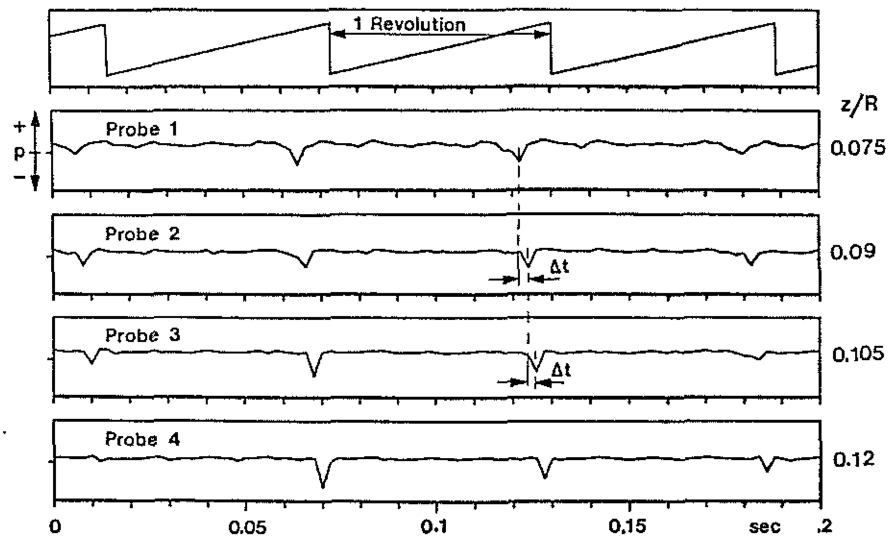


Figure 13. Probe signals of the trim-tab vortex

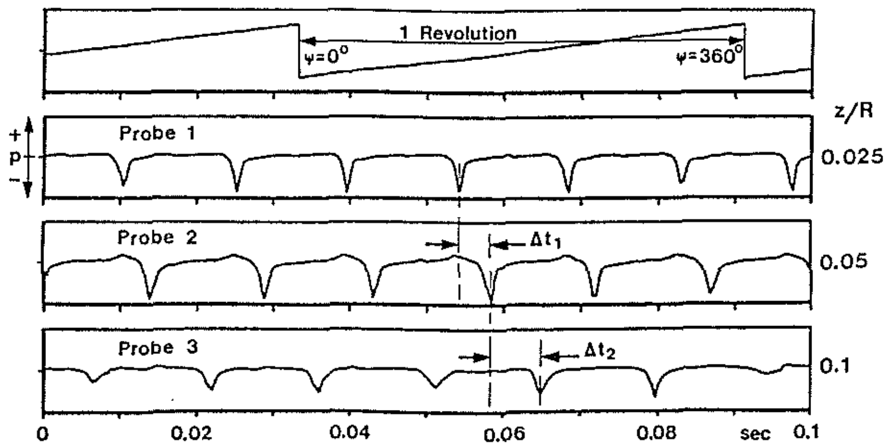


Figure 14. Probe signals of the blade vortices