LAH-MAIN ROTOR MODEL TEST AT THE DNW

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Abstract

In the context of a Feasibility and Cost Definition Study for the A129 LAH a wind tunnel experiment was executed in the German-Dutch Windtunnel DNW on a dynamically and Mach scaled model of the main rotor. The tests aimed at getting more reliable answers as to the question which of the proposed rotor configurations would fulfil the stringent flight performance requirements of the new helicopter best.

The rotor diameter amounted to 3.5 m. Four different rotor configurations were examined, the variations being either in the blade tip shape or in the twist distribution along the span of the blade. The rotor drive system along with the data acquisition and data processing equipment was supplied by the Deutsche Forschungsanstalt für Luft- und Raumfahrt DLR.

It has been found that the dynamic characteristics of the various blade configurations agree reasonably well. An exception in this respect should only be made for those blade configurations that have swept back tips. These specific blades exhibit definitely lower torsional frequencies than comparable blades with straight tips.

The rotor torque measured on the model rotor correlates up to 130 kts really good with the torque as determined during flight tests.

Comparing the different rotor configurations considered during the present test, the high twist blade set is found to produce the highest vibration levels at the higher advance ratios (mu>0.1).

1. Introduction

In the course of 1987 the Government of the Netherlands, the United Kingdom, Italy and Spain decided to enter the A129 LAH Feasibility and Cost Definition (F.C.D.) Study. The execution of this study was the prime task of the Joint European Helicopter (JEH). This organisation was formed by members of the respective national aerospace firms, i.e. Fokker Aircraft B.V., Westland Helicopters, Gruppo Agusta and Construcciones Aeronauticas S.A. (CASA).

One of the questions put forward in this feasibility study was to define a main rotor system, that should fulfil the stringent flight performance requirements of the new helicopter. The group of experts handling this subject, came to the conclusion, that this question could not be solved satisfactorily by only theoretical means, but that an experimental study would be beneficial and very helpful to come to more reliable answers to the questions posed.

Additional funds made available by the Netherlands MoD, enabled JEH to have a wind tunnel experiment executed on a model of a main rotor. The model rotor had a diameter of 3.5 m and was a dynamically and Mach scaled version of an existing four-bladed rotor. In fact four different rotor configurations were investigated in the present test: a set of basic rotor blades could be equipped with three differently shaped exchangeable tips, while the second set of rotor blades represented the basic rotor but with double twist along the span. The experiments were carried out in the closed test section of the German-Dutch Windtunnel (DNW) in the fall of 1989.

The present paper will first of all dwell on the description of the model, its support and drive system and the data acquisition and processing. A preliminary analysis of the test data will focus on the following points:

- analysis of the dynamic characteristics of the various model rotor configurations
- analysis of some aerodynamic performance characteristics for the different rotor configurations

- comparison of model scale wind tunnel test data with available flight test results
- comparison between wind tunnel test data and results from an analytical study.

2. Test set up

2.1 Main rotor blades

The model rotor was a dynamically and Mach scaled version of an existing four bladed rotor. The diameter of the model rotor amounted to 3.5 m. The basic plan view of the blades is shown in fig. 1. The constant chord part extends from about 30 % to about 95 % of the span and measures 115 mm in depth. From 25 % span out to about 73 % span the blade has a constant airfoil, which through a linear transition transfers into a different airfoil that stays constant from 95 % span out to full span. The twist distribution along the span consists of two linear parts; staying at 0 degr. up to 15 % span the twist raises up to +4 degr. at 30 % span and decreases from there linearly to a value of -2.225 degr. at the tip of the blade.

Since the rotor blades had to meet certain dynamic characteristics, specific expertise was required to design and fabricate these blades. This specialty not being available at NLR or any other of the participating firms, it was decided to have the rotor blades made by Dynamic Engineering Inc. at Newport News, Va.

As with the full scale blade the model rotor blade also was fabricated from composite material. A general idea about the way the model rotor blade was built up is given in fig. 2. The essential part of the blade is the so-called D-shaped spar. This element accounts for both the strength and the stiffness of the blade. It is composed of layers of carbon fibre and glass fibre. By properly selecting the number and the orientation of the various layers the required stiffnesses (flapping, lagging and torsion) can be achieved. The core of the D-spar is filled up with balsa which helps to sustain the aerodynamic shape of the D-spar. Near the leading edge space is left open to accommodate small tungsten weights. These serve a twofold purpose, viz. adjustment of the mass distribution of the blade and proper positioning of the sectional c.g.-position. The aft end of the blade consists of a glassfibre shell internally supported by a honeycomb.

In total two different sets of rotor blades were manufactured. The first set of four blades represented existing rotor blades, but with the double twist along the span of the blade (fig. 1). This blade set was called therefore: the high-twist blade. A second set of blades differed in two ways from the high-twist blade: the twist distribution equalled that of the existing blade and further these blades were provided with exchangeable tips. To that end the outer 16 % of the blade span could be removed and replaced by blade tips of different shape. Three tip shapes were defined and manufactured (fig. 3).

2.2 Hub

In essence the main part of the hub was a geometrically scaled down replica of an existing hub (fig. 4). The four legs of the hub were foreseen with large openings in which the elastomeric bearings were located that provided the adequate root stiffness and damping (flapping, lagging and torsion) to the blades. A cuff ensured the connection between each elastomeric bearing and its corresponding blade. No lead-lag dampers were installed because of the following two reasons: it was expected, that the elastomeric bearings would provide sufficient damping and further the manufacturing of reproduceable dampers at such a small scale was considered to be too complicated. Through a flange coupling the hub was connected to the rotor drive shaft, while the blades were hooked up to the swashplate via pitch links.

2.3 Rotor drive system

The model rotor was mounted on top of the rotor-test-rig of the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) at Braunschweig. This compact test rig on its turn was installed through a sting on the sting-support system of the DNW.

The major components of the DLR rotor test rig are: a hydraulic motor that drives the rotor, a six-component balance system to determine the loads on the rotor and a 32-channel Pulse Code Modulation (PCM)-system to get test data from the rotary part of the system down to earth via five sliprings.

The 115 kW-hydraulic motor got its oil supply from a power source located underneath the test section. Two kinds of balance force transducers were used: the static loads were measured with strain-gauged force transducers, while piezo-electric type force transducers were applied to determine the dynamic loads. In addition to that the torque meter provided the power transferred to the rotor shaft.

2.4 Windtunnel

The main part of the tests was executed in the closed 8x6 m^2 test section of the DNW. This atmospheric low speed facility is of the closed return type. Apart from being the largest low speed wind tunnel in Europe it possesses a very special feature in that it has interchangeable test sections available. The dimensions of these test sections and hence the maximum attainable wind speeds range from a closed 6x6m^2 test section with maximum wind speed up to 152 m/s, via a closed 8x6m^2 with 116 m/s to a closed 9.5x9.5m^2 test section with a top speed of 62 m/s. In addition to that the test section can be converted to an open jet having a nozzle of 8x6m^2 and a maximum speed of 80 m/s.
More elaborate information on this unique testing facility, including also data on flow quality, can be found in ref. 1 and especially for rotor tests in ref. 2.

2.5 Instrumentation

The major objectives served by the measuring instrumentation in the present test, can be described as: determination of the loads on the rotor and further determination of the load conditions of the blades.
The first part of the information was obtained with the help of the balance system and the torque meter in the rotor test rig.
The second set of data all had in common that they were generated in the rotary part of the system. Within this set the following elements could be discerned: measuring signals being proportional to the position of the blades with respect to the hub, load transducers measuring the control load in the pitch link rod and finally a fairly large number of strain gauge bridges (flapping, lagging and torsion) that gave an impression about the elastic characteristics of the blades. Each of the two sets of blades, the modular and the high-twist blades, were equipped with the same amount of strain gauge bridges. These measuring elements, 19 in total per blade set, were distributed over two blades. The other two blades were provided with dummies to prevent as much as possible an unbalance of the rotor system.
The signals originating in the rotary part of the system were first amplified and filtered, then multiplexed and after A/D-conversion sent down to earth via a two-channel slipring.
The hub system was further provided with three accelerometers located on the fixed part near the swashplate. The blade flap angle was separately measured by a device directly connected to the elastomeric bearing.

2.6 Data reduction

The data reduction being so closely related to the actual running of the rotor test rig, was also taken care of by the DLR-crew.
In short the data reduction supplied information on the time-averaged values of all test signals and for as far as appropriate also a decomposition of the unsteady part of the measured signals as to amplitude and phase for up to the 8th harmonic of the rotor-rpm.

3. Discussion of some results

3.1 Dynamic behaviour of the blades

The primary research goal of the present experiment was to find out which rotor configuration would fulfil the requirements, like performance and vibrational behaviour, best. Since the aerodynamic characteristics of a flexible rotor system however do not rely on only the outer shape of the blades but also on the vibrational characteristics of the rotor system, it thus was quite essential that all the rotor configurations investigated in this experiment, would have a similar vibrational behaviour.
Basic information as to the natural frequencies of a blade can most easily be obtained from a non-rotating blade. By clamping the blade at its root the so-called cantilevered frequencies can be determined. This can be done by exciting the blade with a variable frequency exciter or more simply by executing a pulse excitation. The response of the blade can be measured with a low-mass accelerometer and by performing a

frequency analysis of this signal the various natural frequencies can be obtained. This testing procedure has been performed on the various blades and the results of these vibration tests are presented in table 1.
At first the data for the high-twist blade set are considered. With the relatively simple excitation procedure only five vibrational modes could be excited, viz. the lower three blade flapping modes plus the fundamental modes for torsion and for chordwise bending. A comparison of the results of the four blades within this set reveals that the frequencies of the five natural modes agree fairly well. The larger deviation with respect to the average is in all cases caused by only one blade, which on its turn is also not always the same one.
Performing the same sort of analysis to the modular blade one first should consider the set of blades when equipped with the standard tip. Here again a similar good agreement between the frequencies of the four blades was found. Only the second and the third flapping mode of blade 2 exhibits a somewhat larger deviation, the second flapping mode having a somewhat lower frequency while the third flapping mode possesses a higher than average frequency.
The modular blade when equipped with either the swept tip or the paddle type tip, was only checked for blade 1 and 2. As a consequence there is a tendency for the deviation to become a bit larger, since it is only based on two values. Taking this effect into consideration one however may still conclude, that the agreement for the various natural frequencies is rather good.
Comparing finally the natural frequencies for the five vibration modes concerned for all four blade configurations, shows a very satisfactory result. There only is one exception and that is the torsional vibration mode: with the swept tip or, even more pronounced, with the paddle type tip on the natural frequency for this specific mode drops drastically below the comparative value for the high twist blade and the modular blade with standard tip. The other frequencies, as already mentioned, agree fairly well which means, that the mass of the swept and the paddle type tip apparently was scaled very well. The sweep-back of these two tips however caused the c.g.-position to change to a more aft location, thus causing the torsional frequency to drop below the corresponding value of the other two blade configurations.
In evaluating the quality of a set of rotor blades with respect to its dynamic characteristics it is one thing to make a comparison between the appropriate parameters, e.g. natural frequencies, as they have been realized on the various blade sets. Another thing however is to make the comparison between what has come out and what should come out. The results of this comparison are gathered in table 2. The measured natural frequencies are the overall-averaged values, while the calculated values are obtained by applying a lumped-mass method on a rotor blade having a mass and stiffness distribution which is scaled down from the full-scale values. Except for the third flapping mode the natural frequencies agree fairly well. Had it been felt necessary to improve the agreement on a specific frequency, it would have been possible, but very likely this would have caused a disprovement on the remaining others.

3.2 Aerodynamic performance characteristics

3.2.1 Model hover tests

Once having determined the dynamic characteristics of the various blades, actual tests could commence. The four rotor configurations were tested for hover conditions in the so-called "assembly" or "preparation" hall outside the wind tunnel, where wall interference effects can be considered to be small. Hover tests were performed at constant blade tip Mach number and various collective blade pitch settings. In order to keep the blade tip Mach number constant, small changes to the rotor rpm had to be applied to compensate for temperature changes.
Fig. 5 shows torque coefficients versus thrust coefficients for all four blade configurations in hover. At low thrust coefficients the differences in torque between the various tip configurations are negligibly small. At high thrust values however, small differences can be identified. The rotor configurations with standard tips (ST) consume slightly more power (i.e. torque) than the high twist blade set (HT).
As to the effects swept (SW) and paddle type (PA) tip blades have in this respect it should be noted, that this information cannot be deduced fully from the apparent plot. This is caused by the fact, that the solidity effect has not been considered. As can be learned from ref. 3, 4 and

5 this parameter may have a distinct influence on the value of the torque coefficient.

3.2.2 Forward flight wind tunnel tests

After having completed the hover tests, the test stand was moved to the 8*6 m closed test section of the DNW.

The tunnel test program was based on available flight tests and prediction analysis. Tests were conducted at three thrust coefficients (Ct = 0.0051, 0.0055 and 0.0059) and increasing advance ratio (up to mu = 0.3). Furthermore the rotor propulsive force was set by tilting the rotor shaft in such a way, that it represented various full scale equivalent flat plate drag area configurations. For the high twist blade only also pitching moment and rotor rpm were varied.

A summary of all test points is plotted in fig.6 in terms of thrust and drag variations.

To make a comparison of wind tunnel test data with available flight test data possible, the model rotor propulsive force and vertical force (helicopter weight) were adjusted to set the test points. Although this test methodology is rather time consuming, it is to be preferred above the adjustment of control angles, since these are difficult to be measured accurately. The forces and shaft angle have to be adjusted iteratively, which leads to a certain data scatter for the various tip configurations (fig. 6). As such however, no conclusions can be drawn directly from this set of data.

Hence, suitable test points taken from fig. 6 have been used to compare the rotor torque of the different tip and rotor configurations as a function of tunnel speed (fig. 7). The swept tip blade, as compared to the standard blade, shows some 3 % lower power consumption, whereas the paddle type tip tends to have less favourable power consumption characteristics.

In fig. 7 also results of some calculations are plotted (solid symbols). Due to the fact, that only differences in geometric and not in aerodynamic characteristics of the blade tips were modelled, only small discrepancies could be identified.

Both from the wind tunnel tests and from the analytical results the swept tip blade looks slightly better in terms of performance in forward flight conditions.

The offset in rotor torque between wind tunnel test data and analytical results is probably caused by the application of inaccurate wind tunnel corrections and/or analytical downwash models.

3.2.3 Model rotor vibration characteristics

The data reduction system supplied information on both the static and the dynamic parts of the loads measured, making it thus possible to analyse also the dynamic rotor characteristics. Some remarkable results can be seen in figs. 8 and 9.

The 4/rev component of the rotor thrust (fig. 8) and the amplitude of the pitch link load (fig. 9) are plotted versus tunnel speed. The high twist blade set (twice as much twist as the twist of the standard blade) shows a significantly higher vibration level, whereas blade tip shape hardly has any influence on these dynamic characteristics.

As to the vibratory pitch link loads a variation in blade configuration does not have much effect either, except for the higher speeds where the high twist blade (HT) exhibits a much higher dynamic load in the pitch link.

It should be noted that for the vibratory pitch link loads the contribution of the longitudinal and lateral cyclic control angles (i.e. 1/rev loads) are filtered out to make a better comparison with flight test results possible.

3.3 Comparison of wind tunnel data with flight test data

The main objective of the wind tunnel test program was to support the decision making process for the design of the A129 LAH main rotor in terms of blade twist and tip shape.

To be able to predict full scale rotor characteristics a number of test runs was performed with the standard A129 blade to make a direct comparison possible. Scaled down gross weight, lift to drag ratio and speed usually don't coincide exactly with flight test configurations. Repeatability (attitude, control settings for trimmed flight and weight) and measurement accuracy (low speed) are more difficult to deal with during flight tests than in wind tunnel tests.

Therefore, and since the number of wind tunnel test data with the standard blade were limited, special adaptation procedures had to be applied.

A regression curve was fit through the flight data of main rotor torque versus speed using 31

flight data points (fig. 10).
Resemblance between the regression curve and equivalent wind tunnel results is remarkably good.
The inter/extrapolation procedure used to adapt the wind tunnel data, plotted in fig. 10, is visualized in fig. 11. For a given flat plate drag area of the aircraft the drag (this is the horizontal force in the wind tunnel) was calculated at different forward flight speeds. Applying this scaled down drag to the wind tunnel plot curve "drag versus tilt angle" gives the equivalent shaft tilt.
This value corresponds to a specific torque extracted from the plot "torque versus shaft tilt angle". As the equivalent thrust was not measured in the wind tunnel, the curve "thrust versus torque" yields a correction factor to be applied to the torque. All values are related to the standard atmosphere. Wind tunnel correction factors have not been applied.

4. Conclusions

In the framework of the A129 LAH program model rotor test, funded by the Netherlands MoD, have been conducted in the DNW. The main objective of the study to support the decision-making process for the design of the A129 LAH main rotor was met. Four main rotor configurations (standard, swept and paddle tip, high twist blade) have been tested and a large amount of data has been gathered.
The scope of this test campaign was much more complex and complete than similar experimental activities in Europe so far. This because of the inclusion of rotor hub and flapping, lagging and torsional blade elasticity.
At present detailed interpretation of the data is still going on. Preliminary analyses have been focussed on the model blade dynamic characteristics, rotor performance in hover and forward flight and comparisons with analytical and available flight test data.

In the near future more effort will be spent in the analysis of these test results, which are of high quality and unique for European standard. Especially dynamic and elastic characteristics and control loads will be dealt with in more detail, to get a better understanding of the influence of blade twist and tip shape on dynamic rotor behaviour.
Furthermore the data are very well suited to validate mathematical tools in order to better predict rotor characteristics.

Acknowledgement

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References

1. Anon., Compilation of Calibration Data of the German Dutch Wind Tunnel, DNW. DNW-publication MP 82-01.

2. Hamel, P., Gmelin, B., Langer, H.-J., and Braun, D., Rotorcraft model testing at DNW, Coll. Ten Years of Testing at DNW, Oct. 1990

3. Amer, K.B., High speed rotor aerodynamics, Technical Note. Journal of the American Helicopter Society, Vol. 34, No. 1, January 1989

4. Perry, F.J., The contribution of planform area to the performance of the BERP rotor (Reply to K.B. Amer), Technical Note. Journal of the American Helicopter Society, Vol. 34, No. 1, January 1989

5. Amer, K.B., Closure, Technical Note. Journal of the American Helicopter Society, Vol. 34, No.1, January 1989

TABLE I

Natural frequencies of rotor blades in Hz

a. High-twist blade

HIGH-TWIST BLADE						
VIBRATION MODE	BLADE 1	BLADE 2	BLADE 3	BLADE 4	AVERAGE	DEVIATION (%)
Fundamental flap	5.75	5.5	5.5	5.5	5.56	-1/+3.4
2nd flap	32.38	32.0	31.0	32.0	31.85	-2.7/+1.7
3rd flap	77.5	77.75	74.5	77.0	76.68	-2.8/+1.4
Fundamental torsion	107.5	106.0	109.0	104.5	106.75	-2.1/+2.1
Fundamental chord wise	21.63	21.87	21.5	21.63	21.66	-.7/+1

TABLE 1 Continued

b. Modular blade

VIBRATION MODE	MODULAR BLADE													
	STANDARD TIP						SWEPT TIP				PADDLE TYPE TIP			
	BLADE 1	BLADE 2	BLADE 3	BLADE 4	AVERAGE	DEVIATION (%)	BLADE 1	BLADE 2	AVERAGE	DEVIATION (%)	BLADE 1	BLADE 2	AVERAGE	DEVIATION (%)
fundamental flap	5.5	5.5	5.5	5.5	5.5	0	5.5	5.0	5.25	± 4.8	5.5	5.5	5.5	0
2nd flap	32.75	29.5	32.0	31.5	31.44	-6.2/+4.2	33.25	30.0	31.63	± 5.2	32.5	30.5	31.5	± 3.2
3rd flap	79.0	83.0	79.5	79.0	80.1	-1.4/+3.6	80.75	85.0	82.88	± 2.6	81.0	79.0	80.0	± 1.3
fundamental torsion	105.0	105.5	105.5	105.0	105.25	-.2/+.2	101.0	98.0	99.5	± 1.5	76.75	77.5	77.13	± 0.5
fundamental chord wise	22.5	21.5	22.0	21.5	21.87	-1.7/+2.8	22.25	21.5	21.88	± 1.7	22.0	21.5	21.75	± 1.2

TABLE 1 Concluded

c. High-twist vs. modular blade

VIBRATION MODE	HIGH TWIST	MODULAR STANDARD	MODULAR SWEPT	MODULAR PADDLE TYPE	AVERAGE	DEVIATION (%)
fundamental flap	5.56	5.5	5.25	5.5	5.45	-3.7/+2
2nd flap	31.85	31.44	31.63	31.5	31.6	-.5/+.8
3rd flap	76.68	80.1	82.88	80.0	79.92	-4.1/+3.8
fundamental torsion	106.75	105.25	99.5	77.13	-	-
fundamental chord wise	21.66	21.87	21.88	21.75	21.79	-.6/+.4

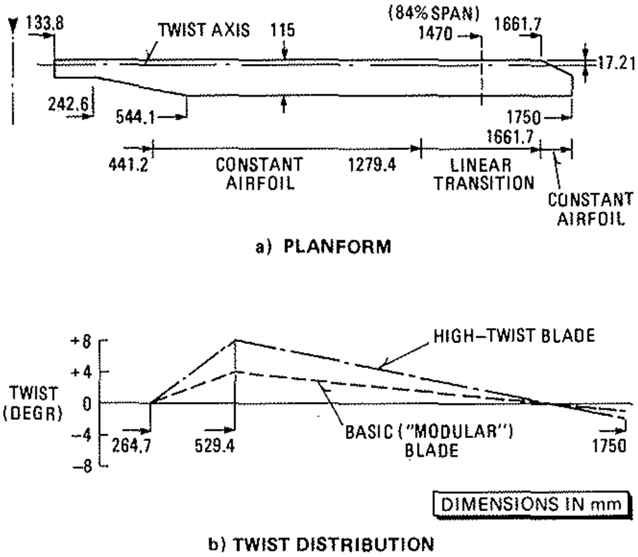

Fig. 1 Planview and twist distribution of basic rotor blade

TABLE 2

Comparison between measured and calculated natural frequencies in Hz

VIBRATION MODE	MEASURED (AVERAGE)	CALCULATED	DEVIATION (%)
fundamental flap	5.45	5.72	-5.1
2nd flap	31.6	30.33	+4.2
3rd flap	79.92	71.28	+12.1
fundamental torsion	106 *)	99.5	+6.5
fundamental chord wise	21.79	22.49	-3.1

*) exclusive swept tip and paddle type tip

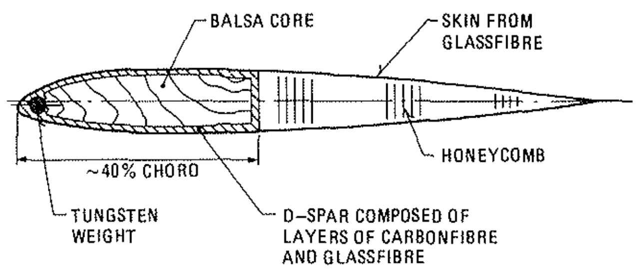

Fig. 2 Schematic composition of rotor blade

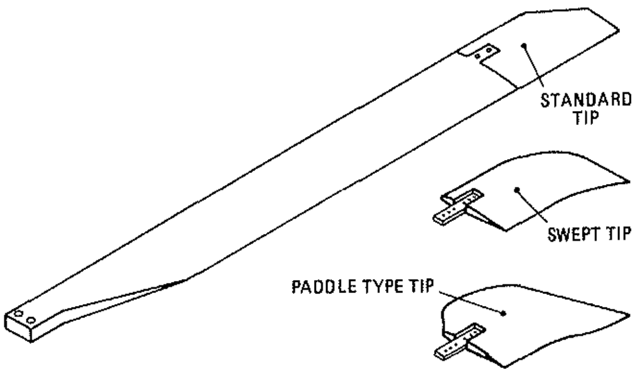

Fig. 3 Modular rotor blade with three different, exchangeable tips

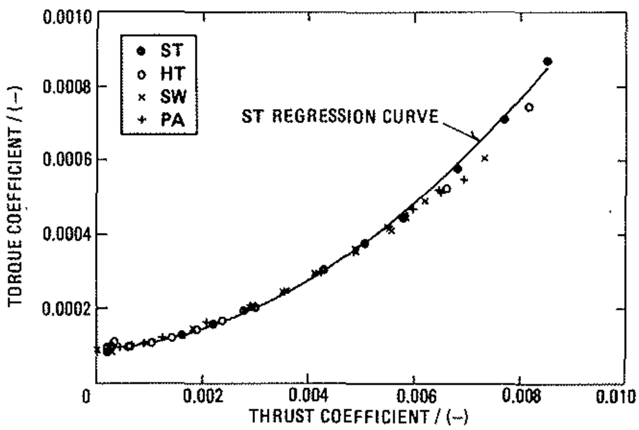

Fig. 5 Rotor shaft torque vs. thrust; data from tests in DNW "model assembly hall" (ST-standard tip, HT-high twist blade set, SW-swept tip, PA-paddle tip)

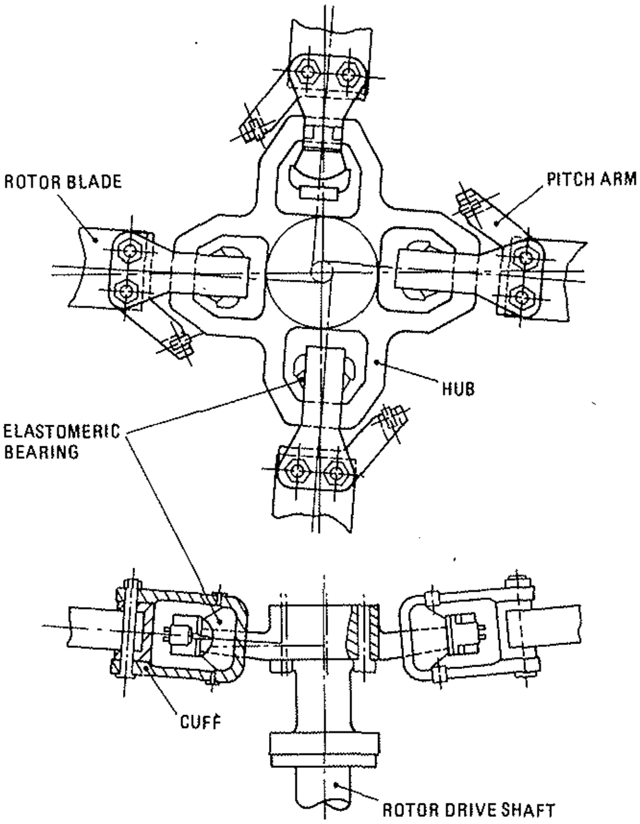

Fig. 4 Schematic drawing of hub and blade attachment

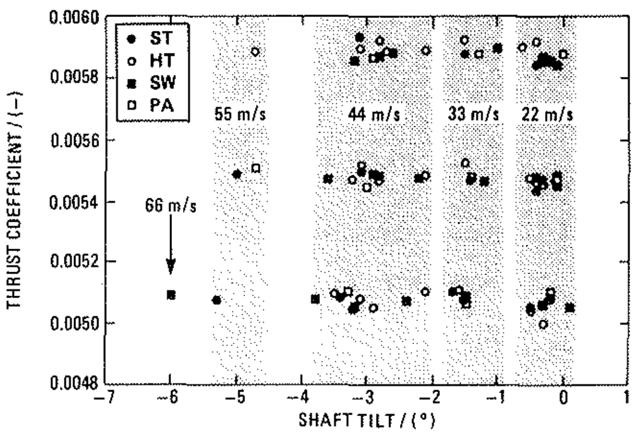

Fig. 6 Test points set in the DNW 8 m × 6 m closed test section (ST-standard tip, HT-high twist blade set, SW-swept tip, PA-paddle tip)

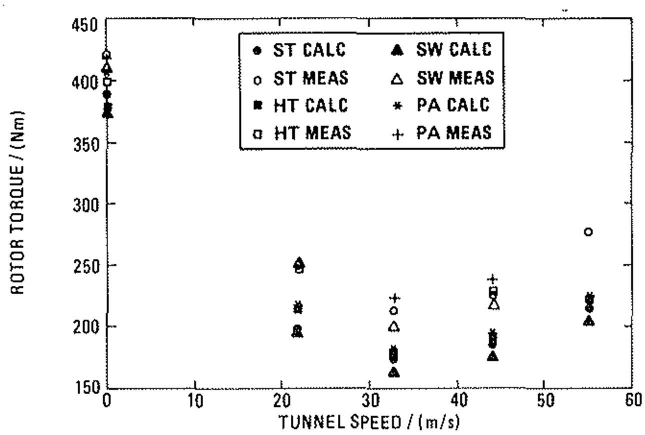

Fig. 7 A comparison of measured and calculated test points. Measured test points extracted from fig. 6 (C_T = 0.0055)

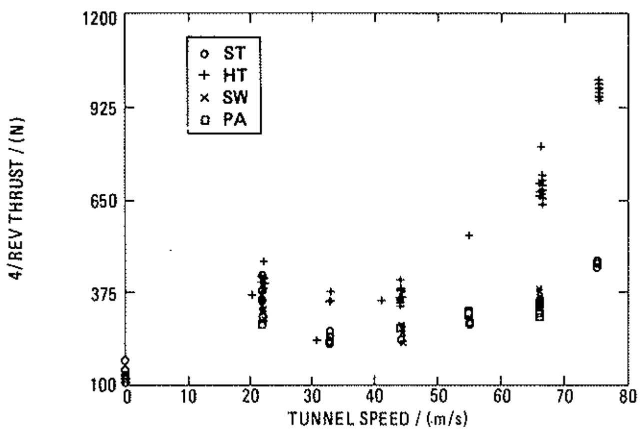

Fig. 8 4/rev thrust for different blade tips and high twist blade set ($0.0051 \leq C_T \leq 0.0061$)

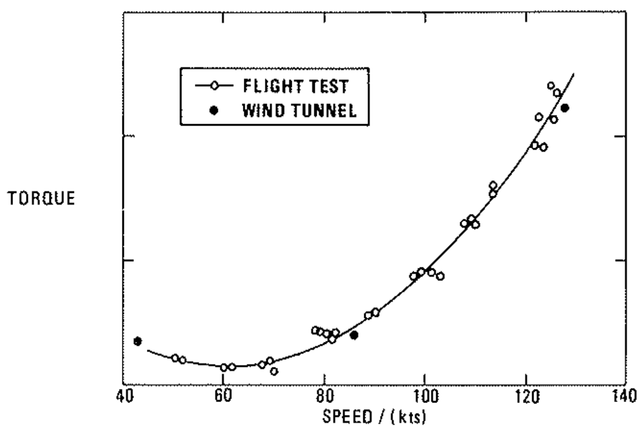

Fig. 10 A comparison of flight test data and wind tunnel data; flight test curve by regression of approx. 30 flight test points

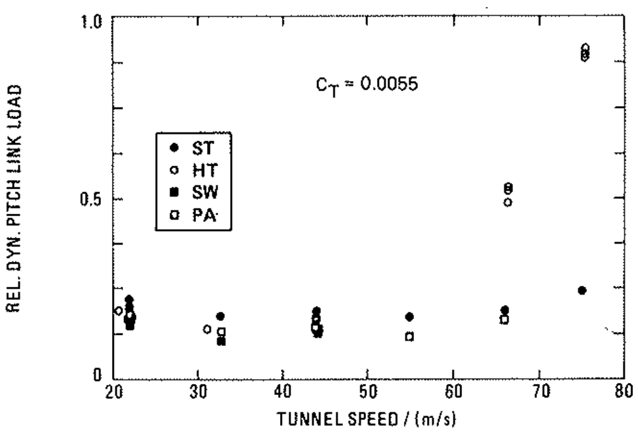

Fig. 9 Dynamic pitch link loads for different blade tips and high twist blade set (1/rev filtered out)

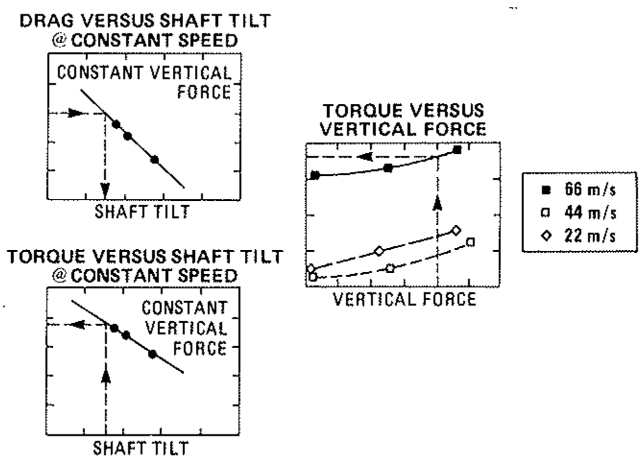

Fig. 11 Procedure to adapt flight data to wind tunnel data and vice versa