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HELICOPTER MODEL NOISE TESTING AT DNW STATUS AND PROSPECTS

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1. Introduction

Helicopter noise is a subject of growing concern due to the annoyance it forms for the public community. This is particularly illustrated by the introduction of the ICAO-"Standard" for noise certification in 1981 [1] following up the CAN 6 meeting. Although this standard forms subject of continuing debate and study [2] and has been amended since then in 1983 (CAN 7), it greatly stimulated the onset of noise research programs like the NASA $(NR)^2$ program in 1983 [3]. Apart from this also for military applications noise emission and subsequent detection has gained considerable importance [4] and will most likely effect future design of rotors.

Helicopter noise is mainly composed of main rotor and tail rotor contributions (Fig. 1). Both categories can be distinguished after their origins in impulsive and broadband noise types [5]. For the main rotor impulsive noise may originate from shock waves forming at high forward speeds or blade-vortex interaction at near hover or descent conditions (Fig. 2). Broadband noise may be a result of blade self-noise, turbulence ingestion or blade-wake interaction, and although present under all flight conditions is more of concern during cruise flight. Tail rotor noise may contribute substantially in the form of main rotor - tail rotor interaction noise with the tail rotor being operated in the downwash of the main rotor.

As systematic research at full-scale is often hindered by elaborate testing procedures, limited variation of governing parameters and combined noise emission of multiple sources, the potential of aeroacoustic testing with scaled helicopter models in wind tunnels has been recognized early in the last decade and has since then grown considerably in scope and depth.

Noise research testing at DNW using rotor models started in 1982 at the initiative of the US Aeroflightdynamics Directorate AFDD using a 1/7th scale rotor model of the AH-1/OLS (Fig. 3) in the aeroacoustic open jet configuration [6, 7, 8, 9]. This test served as a trendsetter demonstrating the ability to get good correlation data with full-scale in-flight data [6, 7] but also illustrated certain shortcomings [8, 9] which are now mainly attributed to insufficient dynamical scaling of rotor blades. Since then new series of tests have been initiated and conducted by both NASA and AFDD in co-operation with DFVLR and NLR respectively. This paper discusses several testing aspects, dimensions and characteristics of the open jet configurations and applied test set-ups. Moreover information is given on measuring techniques like a traversing microphone array for mapping noise directivities and a directional array for selecting noise of rotary sources. A collection of data samples has been added to illustrate the aero-acoustic testing capabilities of the DNW open jet configuration.

2. Helicopter Noise Scaling and Testing Aspects

A prerequisite for helicopter model rotor noise testing is that the scaling parameters are well understood and properly applied. As this subject has been treated already extensively by several authors (see for example References 6, 7 and 8), it suffices to mention here only the governing scaling parameters and discuss their implications.

From the definition of a non-dimensional acoustic pressure coefficient at a measurement point it follows that in order to obtain similarity with full-scale conditions a geometrically scaled model rotor with scale γ needs to be operated at essentially the same rotational tip Mach number M_T and advance ratio μ under similar blade loading conditions, usually expressed in terms of the blade pressure and thrust coefficients C_P and C_T (Fig. 4). This implies similarity in the aerodynamic flow field and scaling of rotor thrust along the blade at each azimuth angle, which in fact requires full Reynolds number analogy and duplication of the blade dynamical characteristics. The process of scaling further requires duplication of the non-dimensional time which implies that all lengths are scaled by γ and frequencies are inversely proportional with γ.

In practice the application of these principles may create some problems that require a trade-off between some of the scaling parameters. Combination of equal Reynolds and Mach numbers is virtually impossible under almost comparable atmospheric conditions at model-scale and flight. With the Mach number being the dominant parameter in the contributing terms to the acoustic pressure coefficient it is clear that a compromise in Reynolds number is unavoidable and that model sizes should be selected to give basically comparable flow fields and thus noise levels. As can be seen in Figure 5 showing the effect of blade section Reynolds number on overall self-noise levels for untripped boundary layer blades, additional noise is produced over turbulent boundary layer trailing edge noise below $Re_c = .7x10^6$ with the start of transition to laminar boundary layer vortex shedding noise dominance [10].

If the assumption is made that most of the generated noise is created over the outer 30% of the radius the above-mentioned Reynolds number leads for a rotor in hover with a tip Mach number $M_T = .64$ to a minimum chord length of about .07 m. At forward flight and high advance ratios, say $\mu = .35$, the minimum chord length should be increased then to .14 m to fulfil the Reynolds number requirement also at the retreating side. As transition is not a mere function of Reynolds number alone but also depends on flow conditions and airfoil shape it usually suffices to use a chord length of at least .10 m.

Duplication of the blade dynamical characteristics and depending on the type of rotor also the rotor head chararacteristics require similar distributions of mass and stiffness. However, as blade behaviour is also a function of the exciting forces proper balancing of aerodynamic, mass and elastic forces may lead to an increase of the chord length at scale [11], which results in a slightly higher blade solidity.

The above-mentioned considerations make clear that simple geometric scaling as often applied in conventional airframe noise testing is not sufficient and that ample consideration must be given to the aerodynamic performance and aeroelastic behaviour of the model rotor. Under these precautions the test parameters can be defined as follows.

For similarity in flow field conditions:

Tip hover Mach number	M_H
Advance ratio	μ

For similarity in loading conditions:

Tip path plane angle of attack	α_{TPP}
Thrust coefficient	C_T

3. Open Jet Configuration Dimensions and Characteristics

The DNW open jet configuration may be characterized by the size and quality of the "potential" core, the noise floor, and the degree of anechoicness of the surrounding testing hall. The first may be determined from flow quality calibrations as velocity uniformity, angularity and turbulence using generally accepted deviations from the mean velocity. Stationary data as obtained by means of a 5-hole sperical pressure probe and nonstationary data from an X-wire probe may be correlated on the basis of rms values of the latter to define the open jet boundaries. Typical values are shown in Figure 6, illustrating the available core size for aeroacoustic rotor studies. It is further remarked that the open jet turbulence level is dominated by the shear layer generated fluctuations contrary to the closed jet (Fig. 7). The shear layer induced fluctuations are particularly noticeable between 1 and 10 Hz with a peak Strouhal number of .49 based on the equivalent contraction exit diameter. This also explains the similarity between u and v components in the horizontal plane and u and w components in the vertical plane when approaching the shear layer (Fig. 8). The turbulence from upstream appears in the spectrum only for frequencies above 10 Hz but is irrelevant for the rms value of u since the level is about 40 dB down. Based on the analyses of Reference 15 it may be concluded that for the quoted in-flow turbulence levels and spectral distributions no significant rotor in-flow turbulence noise is eminent within the defined jet constraints.

The second characterization, i.e. the background noise floor, is less easier to define. Each experimental assessment of background noise is liable to some contamination by the self-generated noise contribution of the test set-up itself. In fact one could argue that only the noise floor in the presence of the test set-up is relevant and in practice this has led to a procedure whereby the noise floor is established for a base-line configuration like a clean rotor rig without blades or in case of an airframe noise test, a clean support, with just the in-flow microphones being present. In the initial 1980 aeroacoustic calibration tests of DNW [16] the noise floor was set by the presence of a non-active calibrated noise source provided by The Boeing Noise Technology Laboratory. This rather large, voluminous "cigar" provided with several cavities housing 4 horns and a speaker created self-noise levels, especially near field in-flow, which do not represent the real noise floor. Hence, in order to find a more representative noise floor, in 1985 two in-flow test set-ups were examined independent of each other. The first consists of an in-flow traverse carrying a dual microphone support system (Fig. 9) as used by TBC during a jet-airframe interaction noise test [17], the second an almost similar arrangement in the presence of a clean streamlined sting as used by NLR during a propeller noise test. The corresponding data are shown in Figure 10 as 1/3 octave band sound pressure level (1/3 OBSPL - dB) for velocities of 40, 60 and 80 m/s respectively. The newly obtained data indicate 5 to 10 dB lower levels at 80 to 40 m/s respectively than in the 1981 calibration. Corresponding narrow band data are given in Figure 11. When compared with estimated microphone self-noise the data even suggest that between 500 and 5000 Hz the levels are influenced by noise shed from supports and traverse and that consequently the absolute in-flow levels are those set by the microphone.

Whatever the conclusion the in-flow noise levels obtained clearly demonstrate that a fair deal of modelled helicopter rotor noise can be measured by means of suitable in-flow techniques. Only for that part of the spectrum that is dominated by broadband type noise emissions other out-of-flow techniques are required to avoid contamination of the open jet noise floor by microphone traverse and supports. Relevant out-of-flow noise levels are shown in Figure 12.

The third characterization, the anechoicness of the open jet environment, has been investigated twice. The first time in 1980 using three different noise sources, i.e. a low frequency speaker, a dodecahedron speaker assembly, and an air ball for the very high frequencies [12]. The second time in 1984 part of the calibration, especially for lower frequencies, was repeated using a full-scale 2 m diameter propeller rotating at approximately 2400 rpm as noise source [18]. The calibration involves the determination of the deviations of the emitted noise relative to the spherical decay of a point source of equal strength located at the centre of the propeller (Fig. 13). Samples of the decay patterns are shown in Figure 14 for low and high speed wind conditions at 1/3 OB center frequencies of 160 Hz and 315 Hz, corresponding to the second and fourth harmonic, respectively.

The results demonstrate that even in a well and extensively treated hall with wedges with a height up to 90 cm standing wave patterns are unavoidable.

Still if the standing wave maximum/minimum level differences are compared to pure tone calibrations (Fig. 15) it is clear that even with large size models realistic noise measurement data can be obtained with an accuracy of $\pm$ 1 dB down to about 125 Hz without corrections or special measuring techniques.

4. Model Rig Features and Treatment

An essential condition for the execution of aeroacoustic tests with model rotors is that the drive system is sufficiently small to avoid excessive shielding or reflection, and still, to avoid contamination of the emitted rotor noise. Unfortunately, most existing rigs were never designed with the objective in mind to perform aeroacoustic tests so that the above-mentioned requirements have often to be treated on an ad-hoc basis. Another important aspect is that the rigs contain at least a balance for the measurement of stationary and instationary rotor forces and moments and preferably a slipring set or telemetry equipment for the transmission of pressure transducer signals and/or strain gauge signals from the blades to a ground based receiver station.

For the execution of rotor tests DNW is usually supported by the Flight Mechanics Institute of DFVLR. Alternatively users like the Aeroflightdynamics Directorate bring their own rotor test stands which are accordingly integrated with DNW support systems.

DFVLR-FM has now the availability of two main rotor test stands (Table 1). The eldest system, named ROTEST (Fig. 16) was used in an aeroacoustic experiment in 1986. The newest system, named MWM is less bulky, more powerful and has better measuring possibilities and will come available in 1987. For the execution of the 1986 experiment ROTEST was modified to reduce its overall size and to allow for support by the DNW sting support mechanism (Fig. 17). The test stand consists essentially of three main elements, i.e. the hydraulic drive system, the rotor balance, and the rotor control system [11]. Technical data of the set-up are given in Table 2. The whole stand is housed inside a reinforced, sound insulating 4 mm thick glass fibre shell (Fig. 18). The latter is required as noise measurements performed in the DFVLR Anechoic Chamber in Braunschweig showed that the harmonic noise components of the drive system (fundamental frequency 120 Hz) would exceed the DNW out-of-flow background noise in the frequency domain up to 3 kHz by 20 dB and more. As a consequence the fairing was provided on the inside with a 3.5 mm thick heavy layer of sound damming material covered in turn by a 30 mm thick layer of open cell foam for sound absorption to give about 30 dB transmission loss in all directions. In addition the outer side of the glass fibre shell is lined with 50 mm open cell foam to minimize rotor sound reflections of the fairing. The transmission noise tests showed an overall sound pressure loss of more than 30 dB for azimuthal angles from 0° to 360° for a completely closed fairing with white noise and 27 dB with simulated hydraulic drive noise. A typical spectrum is shown in Figure 19 showing a fall-off at about 20 Hz, well below the second harmonic (240 Hz) of the rotor drive noise [19].

The tests made further clear that the spacing around the rotor hub should be kept to an absolute minimum. Verification measurements during the actual test proved that the desired background noise levels were met indeed.

Since 1986 DFVLR-EA/TA has the availability of a tail rotor test stand which can be placed on a three orthogonal axis traverse system (Fig. 20) for position variations relative to a main rotor. The rotor has collective pitch control and an electrical drive system. Rotor forces and moments are measured by means of a 6-component balance. A slipring set is provided for transmission of blade pressures. The tail rotor test stand was first tested at DNW in 1986 [20].

Given the favourable experience with the DFVLR rotor test stand ROTEST on the DNW sting support system future acoustic measurements can even be more representative as the new DFVLR-FM test stand MWM is sufficiently compact to be housed inside a representative helicopter fuselage model (Fig. 21). In combination with a properly housed tail rotor test stand this would enable in principle complete system verifications including main rotor, tail rotor and airframe contributions.

5. Test Set-Up Applications

Helicopter model noise testing at DNW has shown over the past five years a number of applications using different set-ups for different purposes. The first tests in 1982, performed by AFDD and DFVLR made use of the rotor test stand of AFDD supported by a DNW-owned floor based pedestal. Major objectives were to investigate scalability and parametric variation of rotor noise by comparison with full-scale flight test data of the AH-1/OLS Cobra helicopter.

In the framework of Joint Research Agreements between the US Army, NASA and major US contractors a series of wind tunnel tests was started for which a contract was signed with NLR in 1985. These tests aim at a verification of aeroacoustic performance of a number of rotor systems over a period of four years from 1985 to 1988. This program is known as AATMR (Aerodynamic and Acoustic Testing of Model Rotors) and will presumably have a follow-up with tests of more advanced rotor systems in the period from 1989 to 1990 (Table 3). Figure 22 shows the test set-up with the 1/5th scale model (Fig. 23) of the Boeing Vertol Model 360 rotor [21]. In this set-up the modified rotor test stand of AFDD has been adapted for support by the DNW sting support mechanism thus providing a large range in rotor shaft angle of attack. The stand has been attached directly to the torpedo head to give a large upstream in-flow directivity range. Acoustic data are obtained by a series of in-flow microphones attached to a large ground based traverse system. Test stand and microphone supports are suitably lined to minimize acoustic reflections.

Independent of the above mentioned activities the NASA Aeroacoustics Branch initiated a series of aeroacoustic tests in co-operation with the DFVLR Aeroacoustics Department in order to acquire a comprehensive data base to improve the present knowledge of blade vortex interaction (BVI) noise and to aid and verify broadband (BB) noise prediction development. The tests were conducted under contract with DNW in the framework of the $(NR)^2$ program in 1986 and consisted of two parts, i.e a BVI [22] and a BB [23] part. For these tests the DFVLR ROTEST stand was mounted to the outer end of the DNW sting support system carrying a 40% scale model of the Bo 105. After a thorough dynamic checkout the test program comprised rotor speeds of basically 525 and 1050 rpm, tunnel velocities from 0 to 62 m/s giving an advance ratio range up to .35 and an angle of attack range varying from -20° (tilt forward) to +10° (tilt aft). Rotor thrust coefficients varied from almost 0 to .0066. Typically rotor positioning accuracies including displacement corrections due to wind and thrust loading are in the order of ± 2 mm, while shaft and flapping angle measurements accuracy is ± .1°.

For the BVI part use was made of a microphone array traverse system consisting of a horizontal wing with its span located normal to the flow direction placed on a ground based traverse system with a stroke of about 7 m (maximum 11.3 m). The wing and support struts protruding through the shear layer are covered with a 25 mm thick, open-cell foam airfoil section. The supporting structure is covered with a 100 mm thick open-cell foam lining except the base which is typically covered with standard 800 mm high wedges. The microphone wing carried 9 in-flow microphones giving an in-flow overhead directivity range from about 10° to 135° in the vertical plane depending on the selected rotor height, of course (Fig. 24). Overall microphone positioning accuracy including wind deflections is ± 3 mm. A typical example of a directivity contour plot is given in Figure 25 which makes clear that the microphone wing traverse is a powerful tool in establishing the BVI noise directivity pattern.

For the BB part the microphone wing traverse system was removed from the test set-up. Instead explicitly out-of-flow microphones in the 90° plane perpendicular to the flow direction were used, including a NASA-developed [24] 12 microphone overhead directional array system (Fig. 26) to study noise source distributions over the rotor disk. Analysis of the test data lead to the revelation of blade wake interaction noise as an important broadband noise source for the mid frequency range and trailing edge bluntness as an overestimated contributor (Fig. 27).

In addition to the main rotor experiment with the Bo 105 40% scale rotor DFVLR-EA/TA organized a pilot experiment with an equally large scaled tail rotor (Fig. 28) at comparable main rotor conditions during take-off, landing and cruise [25]. Major objectives were to understand and document tail rotor noise single and in combination with the main rotor, and verification of the usefulness of the combined test set-up in simulating fly-over measurements for certification purposes. A first analysis of the data has shown that the tail rotor contributions are considerable both during low speed horizontal flight and take-off and cannot be neglected in the overall sound pressure level.

In all of the above-mentioned tests good acoustic data quality is essential. Consequently a lot of effort is spent on realizing sufficiently low background noise, good repeatability and reflection free data. These efforts are typically test set-up bound [22] and must consequently be part of each individual test program.

Figure 29 shows an example of a set-up for reflection calibration as used during the NASA/DFVLR experiment. Small explosive charges were mounted to a dummy rotor and ignited to create impulsive noise sources in the test section. The amplitude and time delay of the recorded microphone signals are accordingly used to quantify the reflections and to initiate appropriate measures.

6. Outlook

The described tests make clear that as well for system evaluation as fundamental research the DNW aeroacoustic open jet configuration provides in its present status a reasonably ideal environment for rotorcraft noise testing at a representative scale. Prerequisites for successful testing are the availability of geometrically and dynamically scaled models, and a low self-noise, sufficiently powerful test stand such as those available at AFDD and DFVLR. Testing techniques both in-flow and out-offlow are available to support model rotor noise testing in near and far field conditions and correction techniques for checking reflections and shear layer transmission are available or under evaluation.

When the acoustic capabilities of the DNW were presented to the European Rotorcraft Forum five years ago it could not be foreseen that the present status would show such an impressive list of projects as off today. The question therefore what the next five years may bring and what that will require seems appropriate. A natural development completely in the line of the ICAO noise standard for new helicopters and closely linked to the present status of noise testing is to use the facility for aeroacoustic tests of a certification nature, that is using complete helicopter representations at scale to produce EPNL figures. With the availability of compact test stands like the MWM and complementary tail rotor rigs this possibility seems even nearby, provided validation of acoustic far field conditions is reached [22] and suitable shear layer transmission corrections come available if out-of-flow measurements are unavoidable, e.g. for side-line noise. Also reliable wall constraint corrections are required to accurately predict the simulated flight conditions.

A slightly different trend may be derived from the rebirth of tilt rotor aircraft and the development of high speed helicopters. Apart from special demands to rotor test stands the relatively large velocity range from hover to forward flight for the first category and the high cruise speeds for the second category may show an increasing demand for higher test section velocities.

In all of the above-mentioned problems DNW in co-operation with DFVLR and NLR is actively searching for answers and solutions. The following activities are planned:

- Validation of helicopter model testing with emphasis on Reynolds number scalability and wall constraint;

- Validation of noise certification testing using a scaled MR-TR model;

- Augmentation of the maximum wind speed range of the open jet configuration to about 95 m/s;

- Analysis of shear layer transmission effects using large scale rotary sources.

7. References

1. Environmental Protection, Volume I Aircraft Noise, Annex 16 to the Convention on International Civil Aviation, First Edition - November 1981, ICAO.

2. Marze, H.J., Helicopter External Noise, ICAO Standards and Operational Regulations, Paper No. 9.4, 8th European Rotorcraft Forum, September 1982, Aix-en-Provence, France.

3. Raney, J.P., Hoad, D.R., Creating Competitive Rotorcraft Noise Technology, Aerospace America, pp 60 - 63, February 1984.

4. LHX and V-22 Osprey Benefit from Long-Term Research Programs, Aviation Week & Space Technology, pp 50 - 53, January 1987.

5. Brooks, T.F., Schlinker, R.H., Progress in Rotor Broadband Noise Research, Vertica, Volume 7, No. 4, 1983, pp 287 - 307.

6. Splettstösser, W.R., Schultz, K.J., Schmitz, F.H., Boxwell, D.A., Model Rotor High-Speed Impulsive Noise: Parametric Variations and Full-Scale Comparisons, 39th AHS Annual National Forum, May 1983, St. Louis, Missouri.

7. Boxwell, D.A., Schmitz, F.H., Splettstösser, W.R., Schultz, K.J., Model Helicopter Rotor High-Speed Impulsive Noise: Measured Acoustics and Blade Pressures, Paper No. 17, 9th European Rotorcraft Forum, September 1983, Stresa, Italy.

8. Splettstösser, W.R., Schultz, K.J., Boxwell, D.A., Schmitz, F.H., Helicopter Model Rotor-Blade Vortex Interaction Impulsive Noise: Scalability and Parametric Variations, Paper No. 18, 10th European Rotorcraft Forum, August 1984, The Haque, NL.

9. Boxwell, D.A., Schmitz, F.H., Splettstösser, W.R., Schultz, K.J., A Comparison of the Acoustic and Aerodynamic Measurements of a Model Rotor Tested in Two Anechoic Wind Tunnels, Paper No. 38, 12th European Rotorcraft Forum, September 1986, Garmisch-Partenkirchen, Germany.

10. Brooks, T.F., Marcolini, M.A., Airfoil Self-Noise Effect of Scale, AIAA 8th Aeroacoustics Conference, Paper AIAA 83-0785, April 1983, Atlanta, Georgia.

11. Langer, H.J., DFVLR-Rotorcraft Construction and Engineering, NASA TM-77740, August 1984.

12. Van Ditshuizen, J.C.A., et.al, Acoustic Capabilities of the German-Dutch Wind Tunnel DNW, AIAA 21st Aerospace Sciences Meeting, Paper AIAA 83-0146, January 1983, Reno, Nevada.

13. Michel, U., Froebel, E., Definition, Sources and Lowest

Possible Levels of Wind Tunnel Turbulence, AGARD CP 348, Paper 11, 53rd TDP Symposium, Çesme, Turkey.

14. Boxwell, D.A., A Comparison of the Acoustic and Aerodynamic Measurements of a Model Rotor Tested in Two Anechoic Wind Tunnels, 12th European Rotorcraft Forum, Paper 38, September 1986, Garmisch-Partenkirchen, Germany.

15. Paterson, R.W., Amiet, R.K., Noise of a Model Helicopter Rotor Due to Ingestion of Turbulence, NASA CR 3213, November 1979.

16. Ross, R., van Nunen, J.W.G., Young, K.J., Allen, R.M., van Ditshuizen, J.C.A., Aeroacoustic Calibration of DNW Open Jet, DNW TR 82.03 (also Boeing Document D6-51501), July 1982.

17. Glover, B.M., Shivashankara, B.N., Aeroacoustic Testing in Wind Tunnels, AIAA 10th Aeroacoustic Conference, Paper 86-1886, July 1986, Seattle, Washington.

18. Dobrzynski, W., Anechoic Quality of the DNW Test Hall with Reference to Full-Scale Propeller Noise Measurements, DFVLR IB 12986/4, March 1986.

19. Splettstösser, W.R., Schultz, K.J., Transmission Loss Determination of the DFVLR Rotor Test Stand, Aeroacoustic Fairing, Annex 4, DNW TR 86.03.

20. Heller, H.H., Splettstösser, W.R., Dobrzynski, W.M., Schultz, K.J., Aeroacoustics at the German-Dutch Wind Tunnel, 15th ICAS Congress, Paper ICAS-86-16.4, 1986, London, Great Britain.

21. Dadone, L., Dawson, S., Ekquist, D., Model 360 Rotor Test at DNW - Review of Performance and Blade Load Data, 43rd AHS Annual Forum, May 1987, St. Louis, Missouri.

22. Martin, R.M., Splettstösser, W.R., Acoustic Results of the Blade-Vortex Interaction Acoustic Test of a 40 Percent Model Rotor in the DNW, AHS Specialists' Meeting, February 1987, Arlington, Texas.

23. Brooks, T.F., Marcolini, M.A., Main Rotor Broadband Noise Study in the DNW, AHS Specialists' Meeting, February 1987, Arlington, Texas.

24. Brooks, T.F., Marcolini, M,A., Pope, D.S., A Directional Array Approach for the Measurement of Rotor Noise Source Distributions with Controlled Spatial Resolutions, Journal of Sound and Vibrations, Volume II 2(1), pp 192 - 197, 1987.

25. Splettstösser, W.R., Schultz, K.J., Kurzbericht über das aeroakustische Haupt-/Heckrotor Pilotexperiment im DNW, 1986, DFVLR-Braunschweig, Germany.

TABLE 1:

COMPARISON OF NEW AND OLD ROTOR TEST STAND OF DFVLR-FM

SUBJECT	ROTEST (1972)	MWM (1987)
Rotor - design - diameter (m) - rpm - drive (kW) - head	 Mach no. & dynamic scaling ≤ 4 1050 100 not scaled, cont. PCM encod.	 Mach no. & dynamic scaling ≤ 4 1050 160 scaled, dep. on rotor design
Support	Vertical floor column or rear strut (1986) SSM-DNW (range alpha: 60 degrees)	Bellow strut (1987) SSM-DNW (range alpha: 90 degrees)
Data Acquisition and Reduction System	PCM: 32-channel on rotating system 32-channel on fixed system	PCM: 96-channel on fixed system Slipring set: to be defined
Test Objectives - rotor perform. - blade aerodyn. - rotor aeroelast. - MR-fuselage int. - MR/TR interfer. - aeroacoustics	 good, except for rotor head good, no pressure measurem. good, limited strain measur. limited, bulky rig design limited, extra support (1986) good, except for rotor head, fuselage and TR support	 good good, incl. pressure measur. good, extended strain meas. good, compact design good, optional good, TR-optional
General Application	Research, limited Project support	Research and industrial Project support

TABLE 2:

TECHNICAL DATA OF THE DFVLR ROTOR TEST STAND AND THE BO 105 MAIN ROTOR MODEL

1. MAIN ROTOR	SI-UNITS
Rotor diameter	4 m
Blade profile	NACA 23012
Number of blades	4
Blade solidity	7.73 %
Blade tip speed	216 m/s
Flapping frequency ratio	1.12
Lagging frequency ratio	0.71
Rotor thrust at load factor 1	3600 N
2. CONTROL SYSTEM	**SI-UNITS**
Blade setting angle range	-4 deg to +14 deg

3. DRIVE SYSTEM	SI-UNITS
Shaft power	100 kW
Rotor drive moment	900 Nm at 1050 rpm
Power consumption	3 x 380 V/300 A
4. BALANCE LOAD RANGE	**SI-UNITS Static/Dynamic**
Axial force	1000 N/?
Side force	2000 N/?
Thrust force	7000 N/ 1500 N
Rolling moment	700 Nm/?
Pitching moment	700 Nm/?
Yawing moment	n.a.

TABLE 3 AATMR PROGRAM

TECHNICAL PLAN

RESEARCH ENTRIES - PHASE I

360 MODEL ROTOR	BOEING VERTOL	JULY 86
HARP MODEL ROTOR	MCDONNELL DOUGLAS	SEPT 1987
UH-60 MODEL ROTOR	SIKORSKY	MAY 88
TILT ROTOR MODEL	BELL	NOV 88

ADVANCED ROTOR ENTRIES - PHASE II

MCDONNELL DOUGLAS / BELL	1989
SIKORSKY / BOEING VERTOL	1990

US ARMY AVIATION SYSTEMS COMMAND
AVIATION R&T ACTIVITY

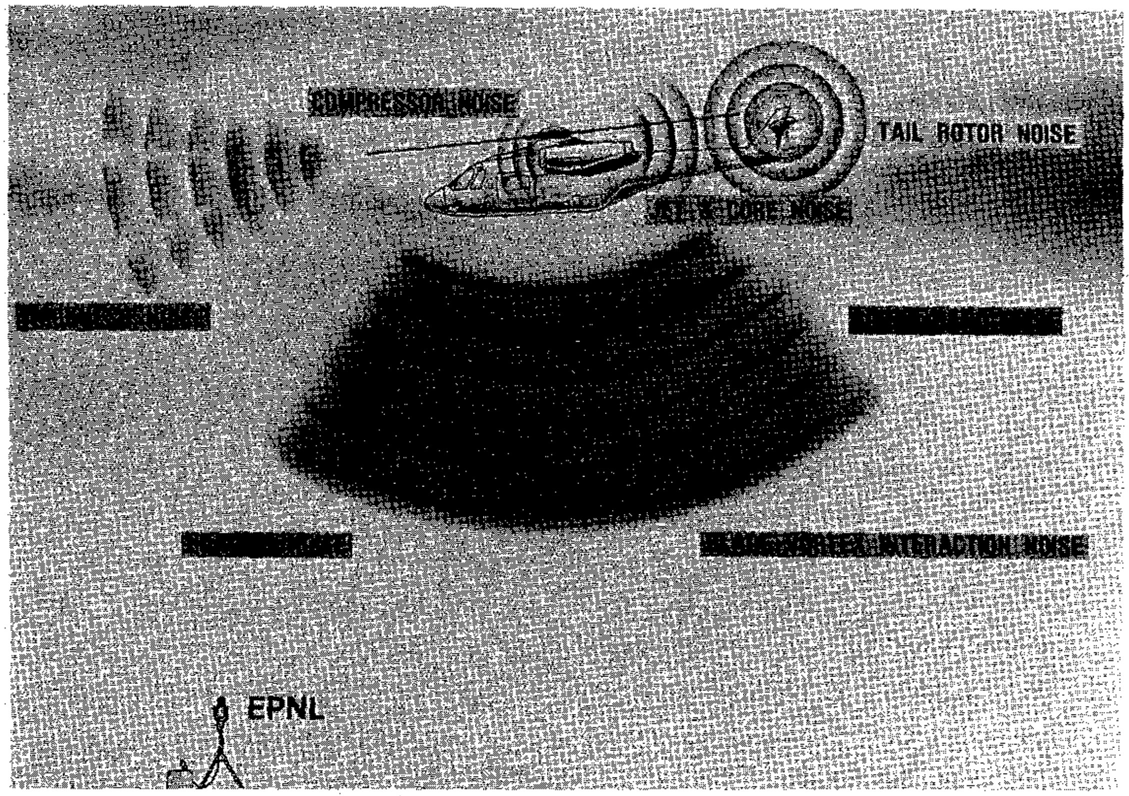


Figure 1 Helicopter Noise Modelling. Courtesy NASA

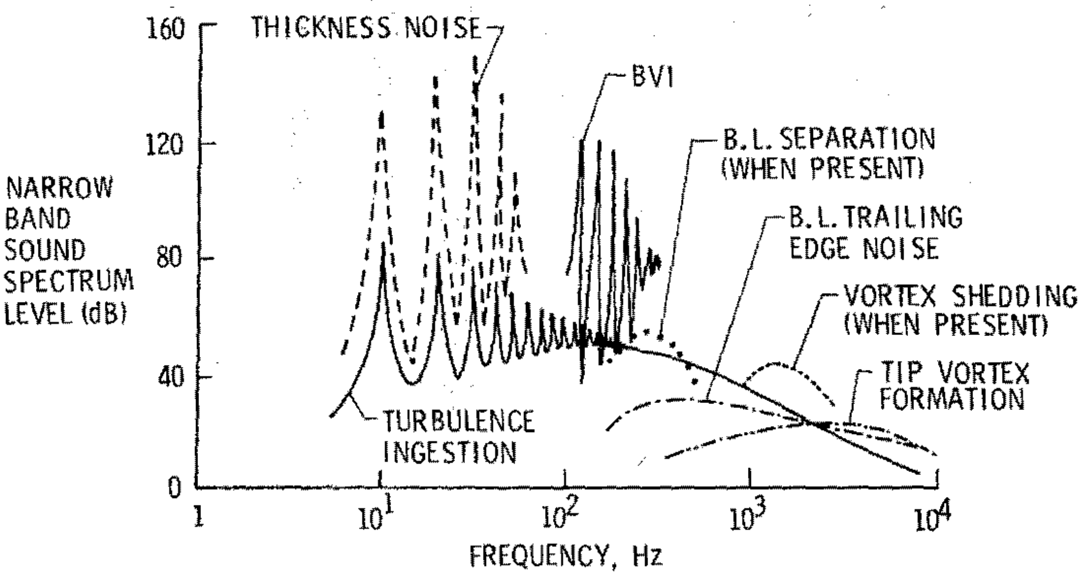


Figure 2 Noise Frequency Diagram. Courtesy NASA

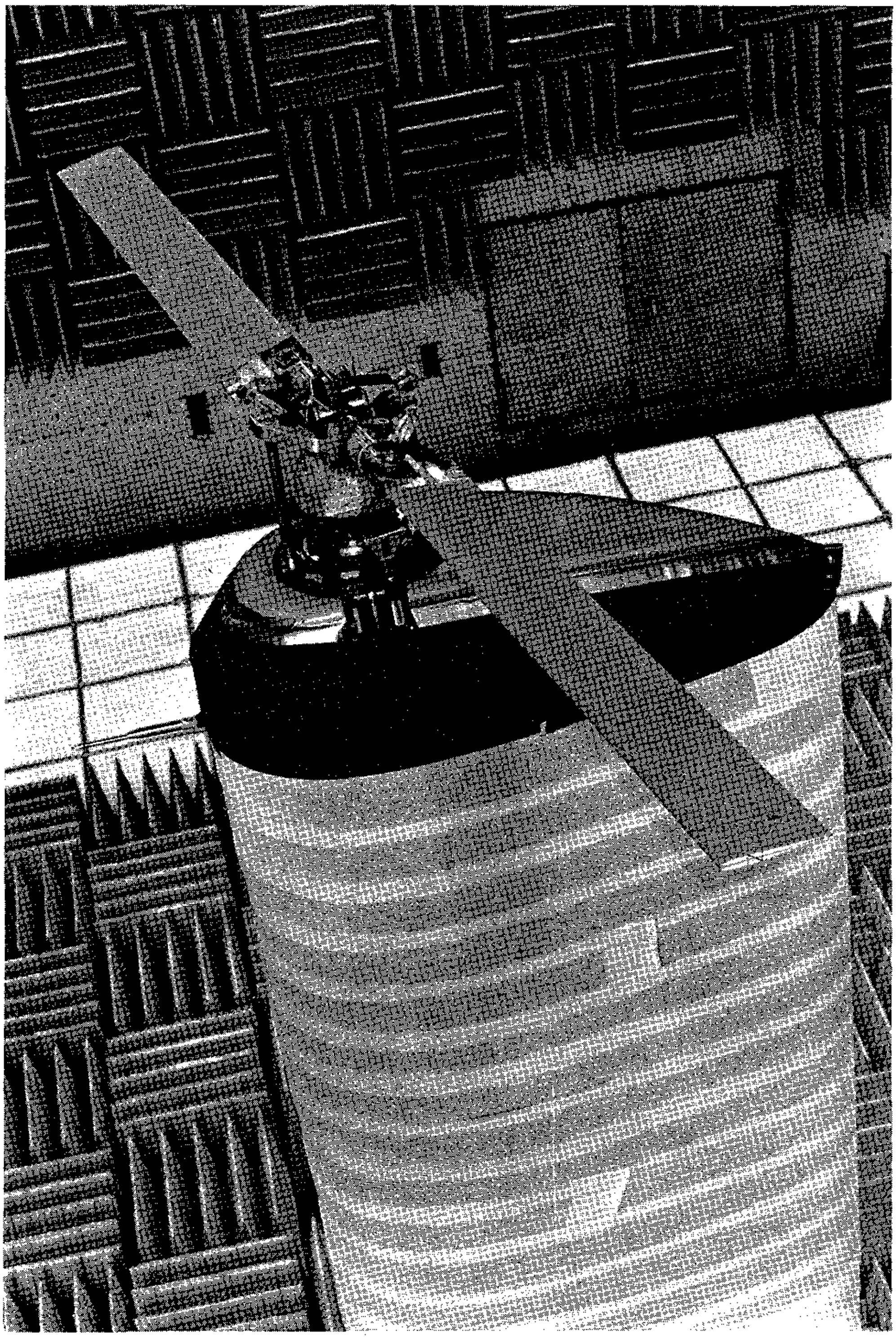


Figure 3 1/7th Scale Model of AH-1/OLS [6]

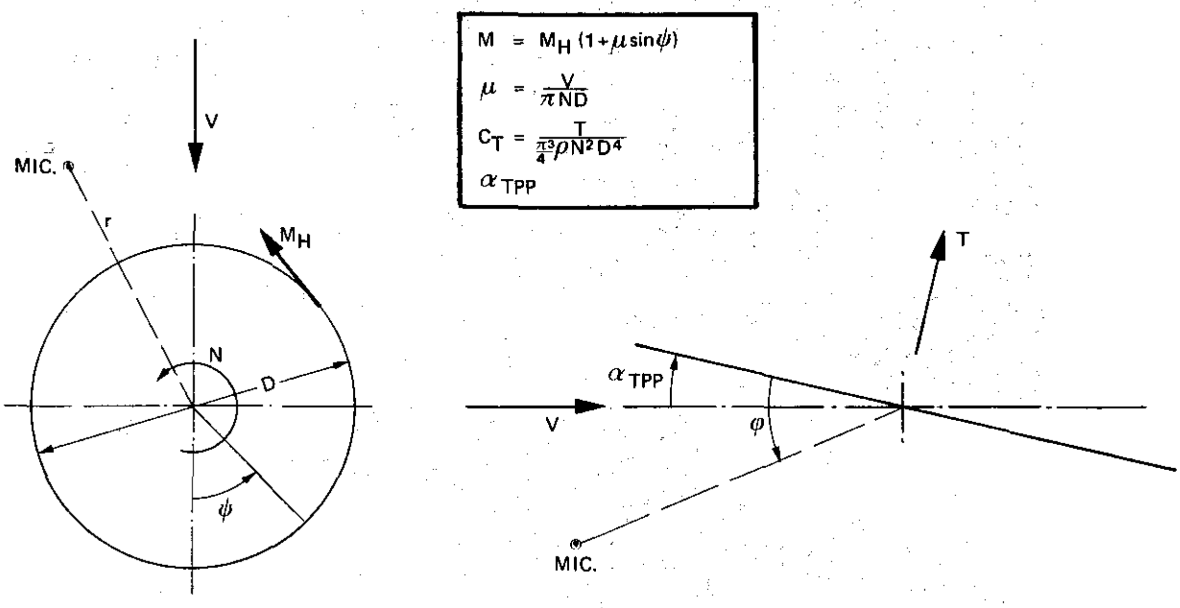


Figure 4 Rotor Scaling Parameters

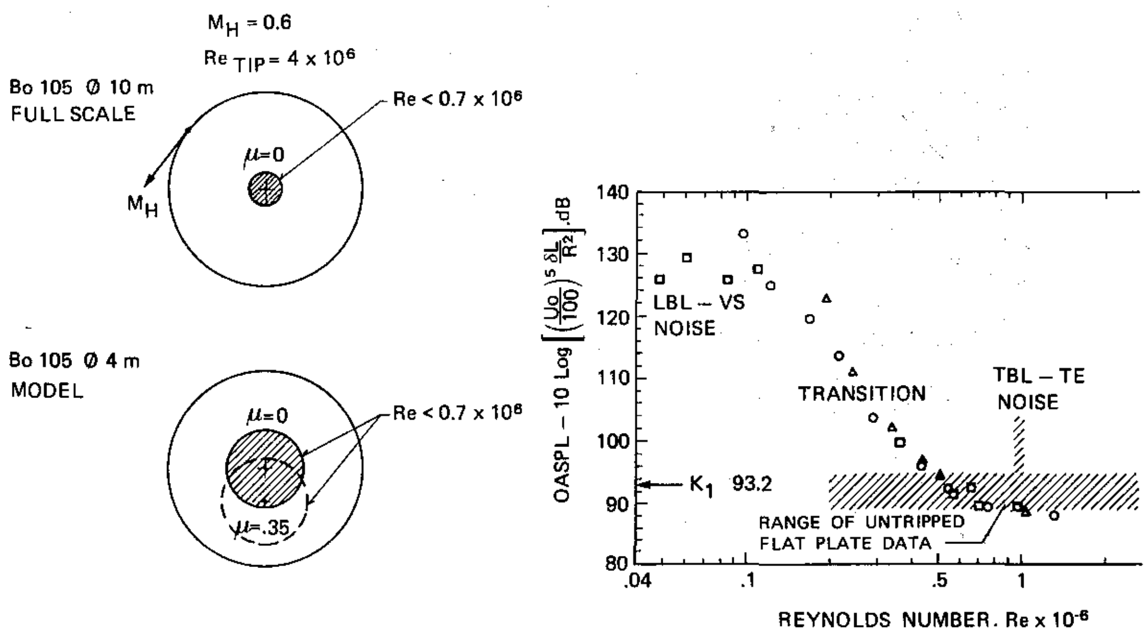


Figure 5 Effect of Blade Chord Reynolds Number on OASPL [5]

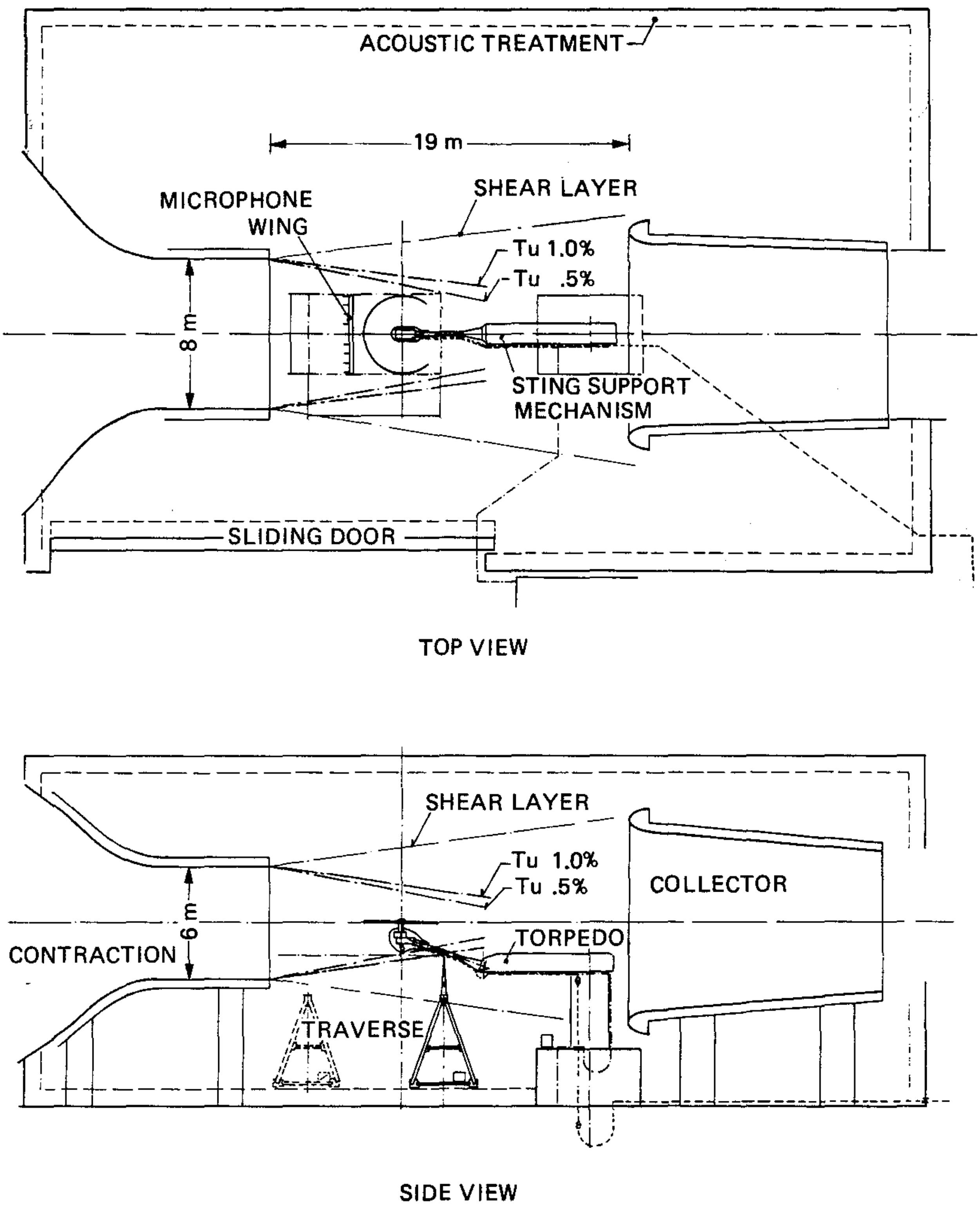


Figure 6 DNW Open Jet Configuration

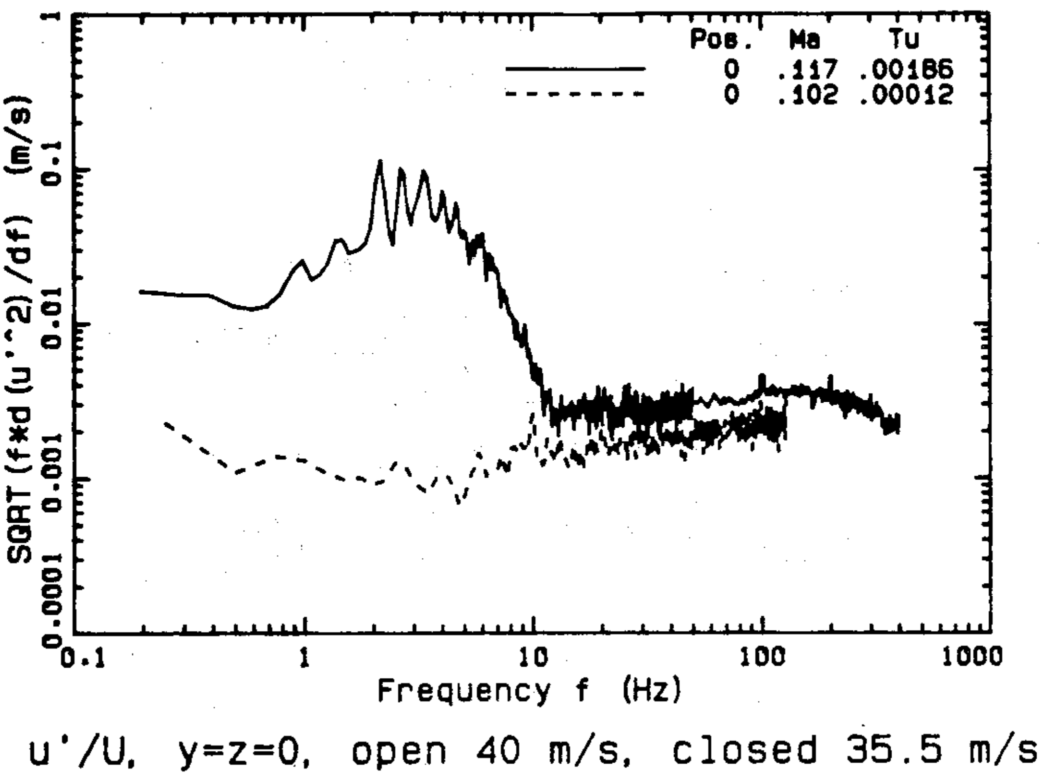


Figure 7 Comparison of Longitudinal Turbulence Power Spectral Density in Open and Closed Jet Test Section

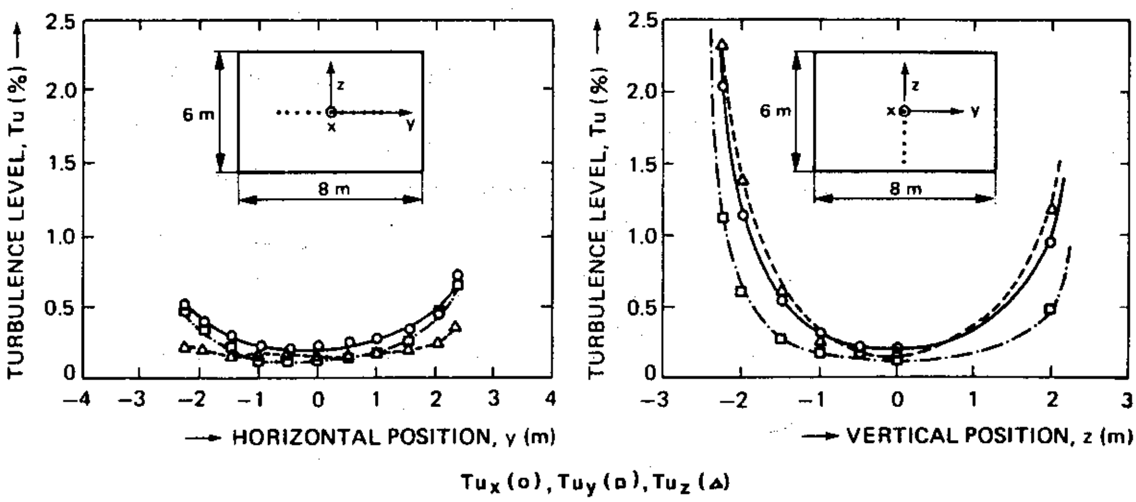


Figure 8 Turbulence Intensity Spatial Distribution in Open Jet Test Section

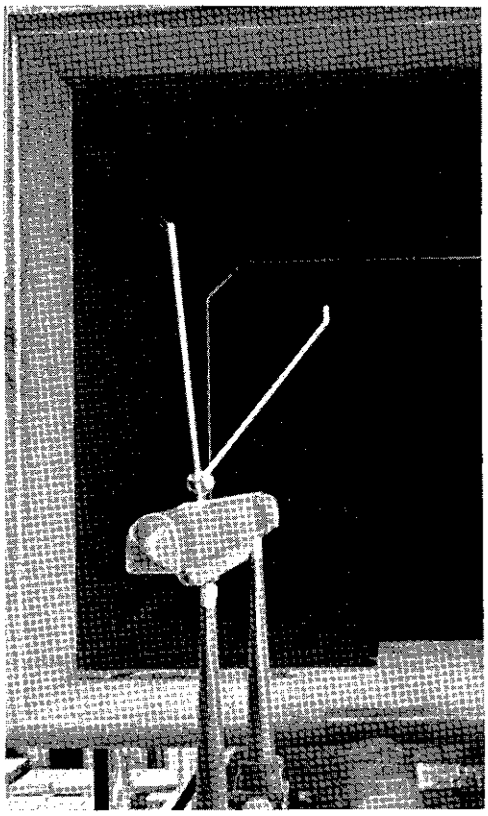


Figure 9 In-flow Microphone Set-up. Courtesy TBC

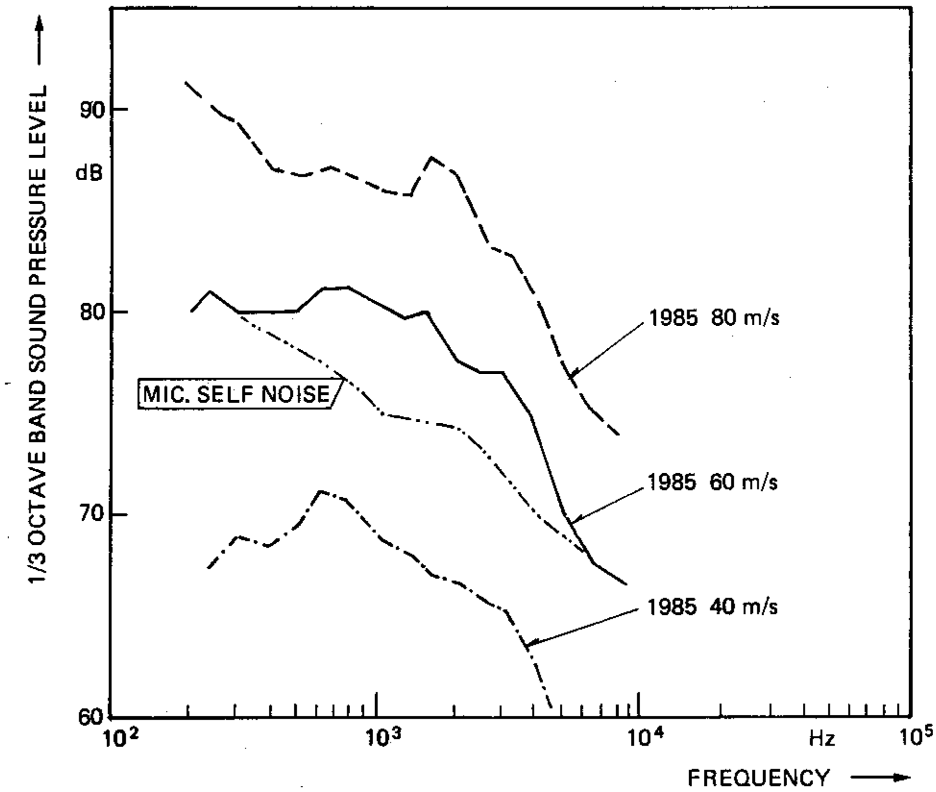


Figure 10 In-flow Background Noise Spectra (1/3 OBSPL)

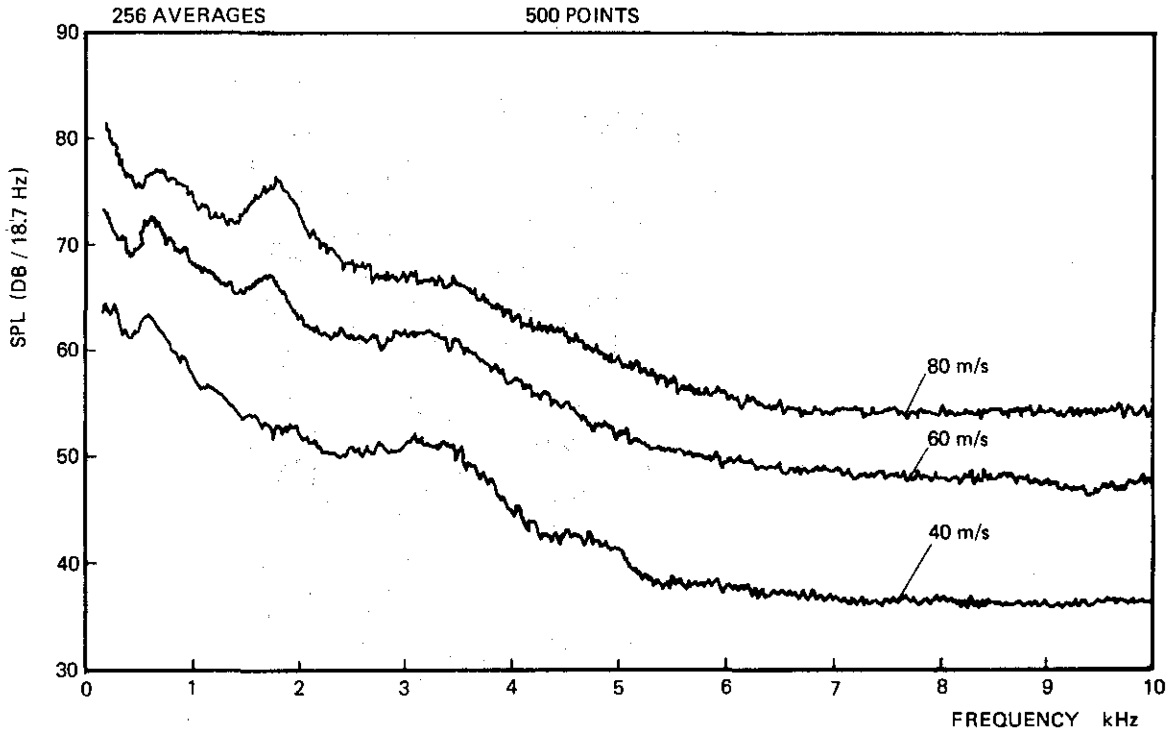


Figure 11 In-flow Background Noise Spectra (Narrow Band)

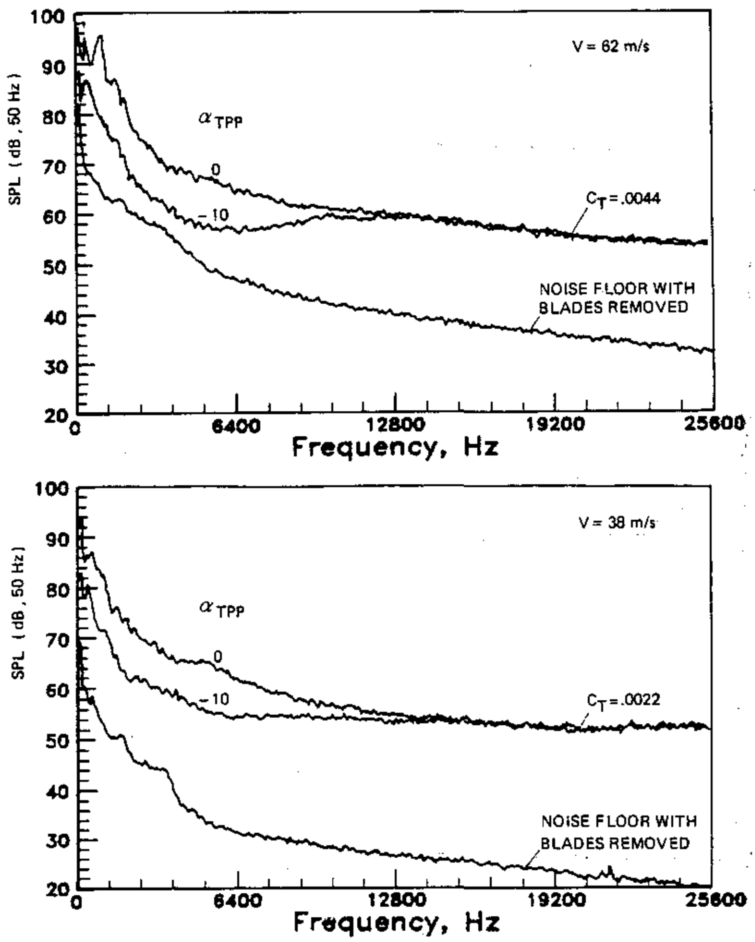


Figure 12 Out-of-flow Background Noise Spectra at 7.14 m Overhead Position with Model at Sting Compared to Noise Spectra of 40% Bo 105 MR

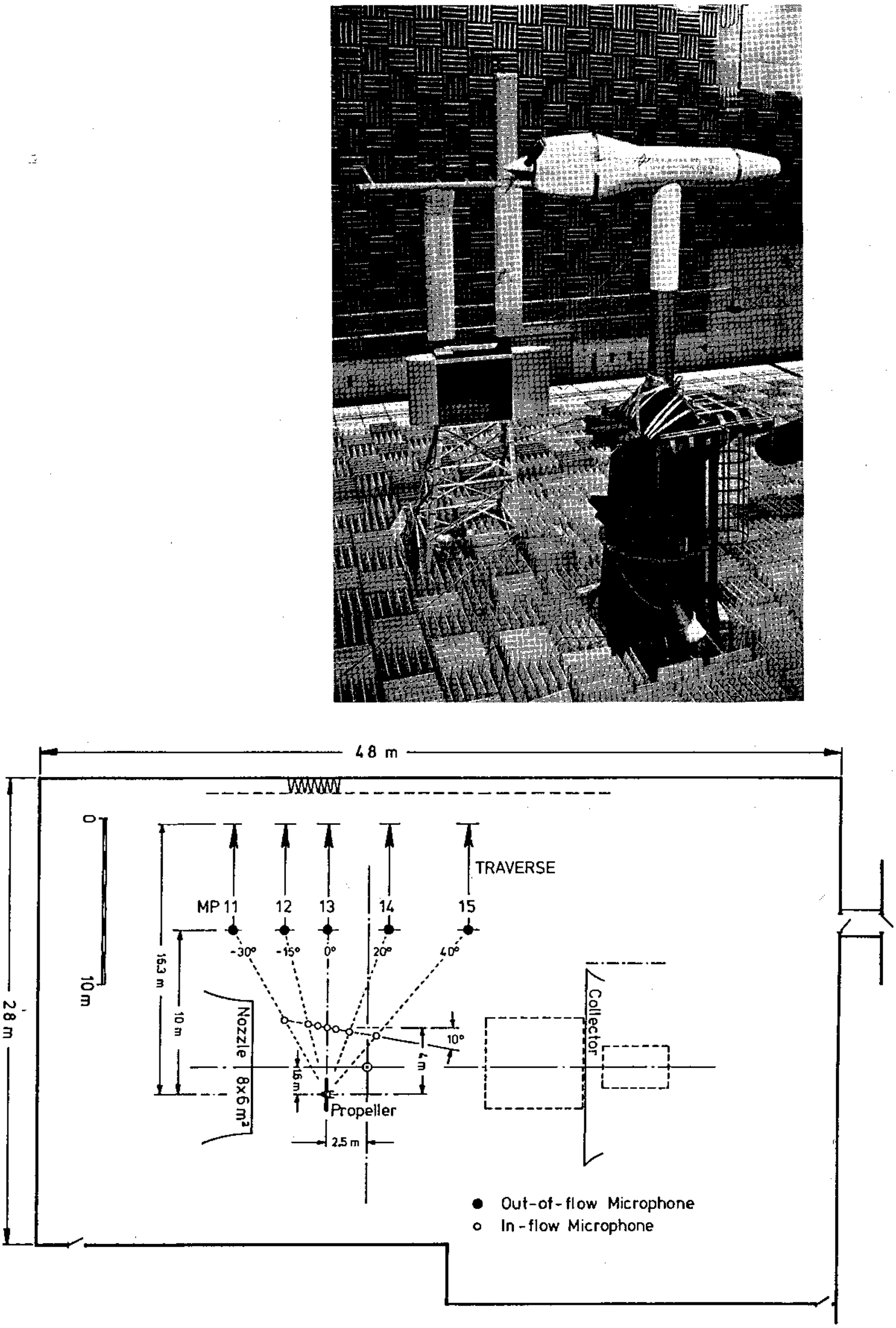


Figure 13 Full-Scale Propeller (Ø 2 m) Test Set-up for Anechoicness Calibration. Courtesy DFVLR

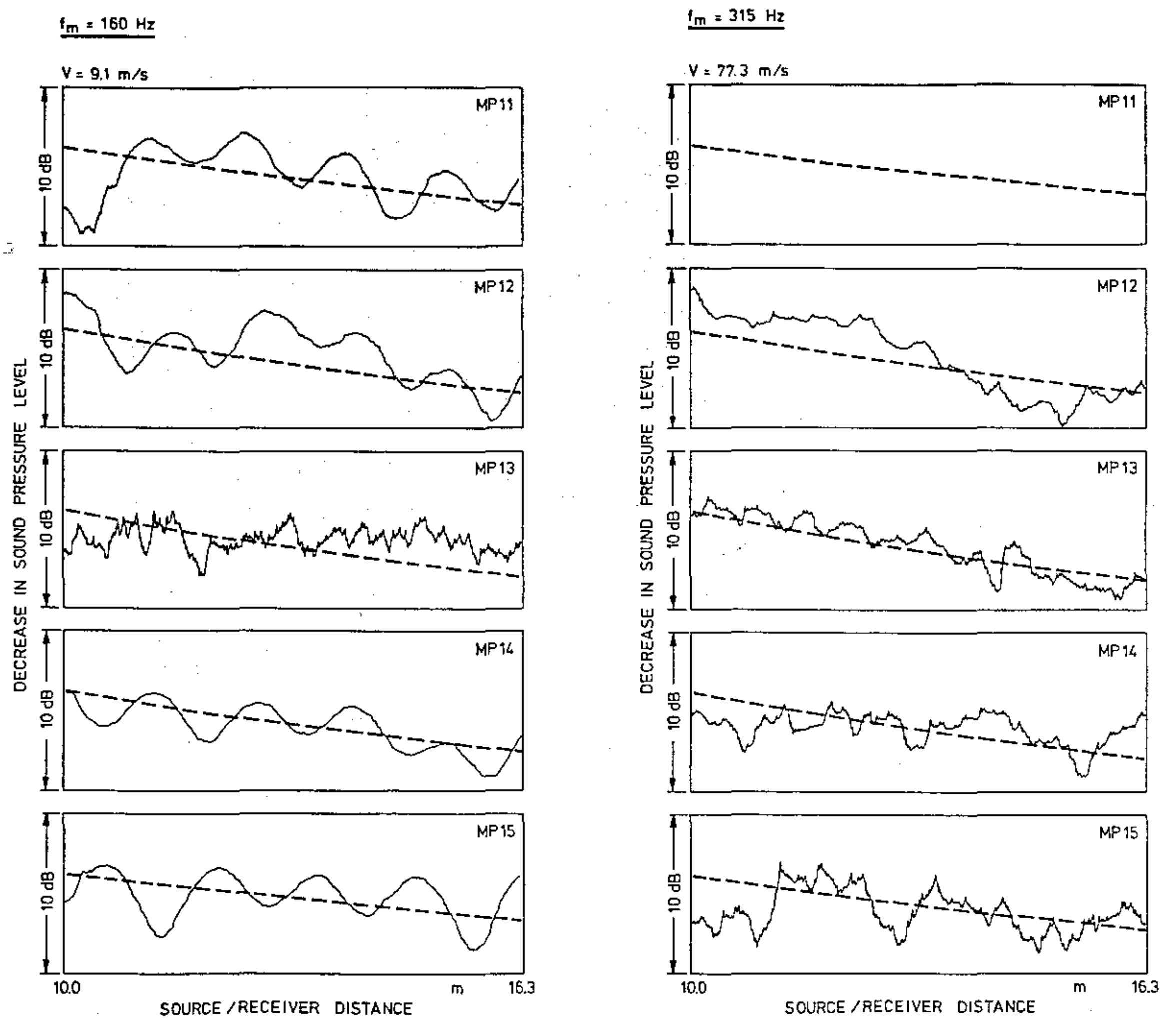


Figure 14 Spherical Decay of Low Frequency Noise [18]

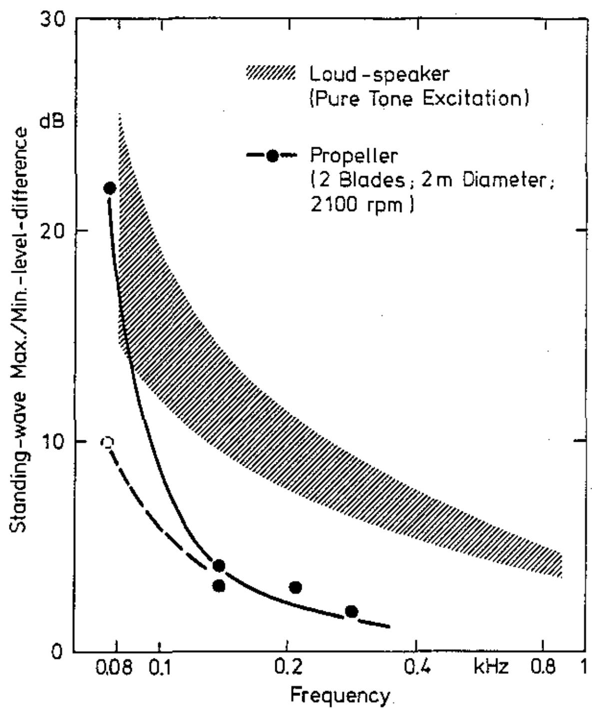


Figure 15 Anechoic Quality of DNW Testing Hall [18]

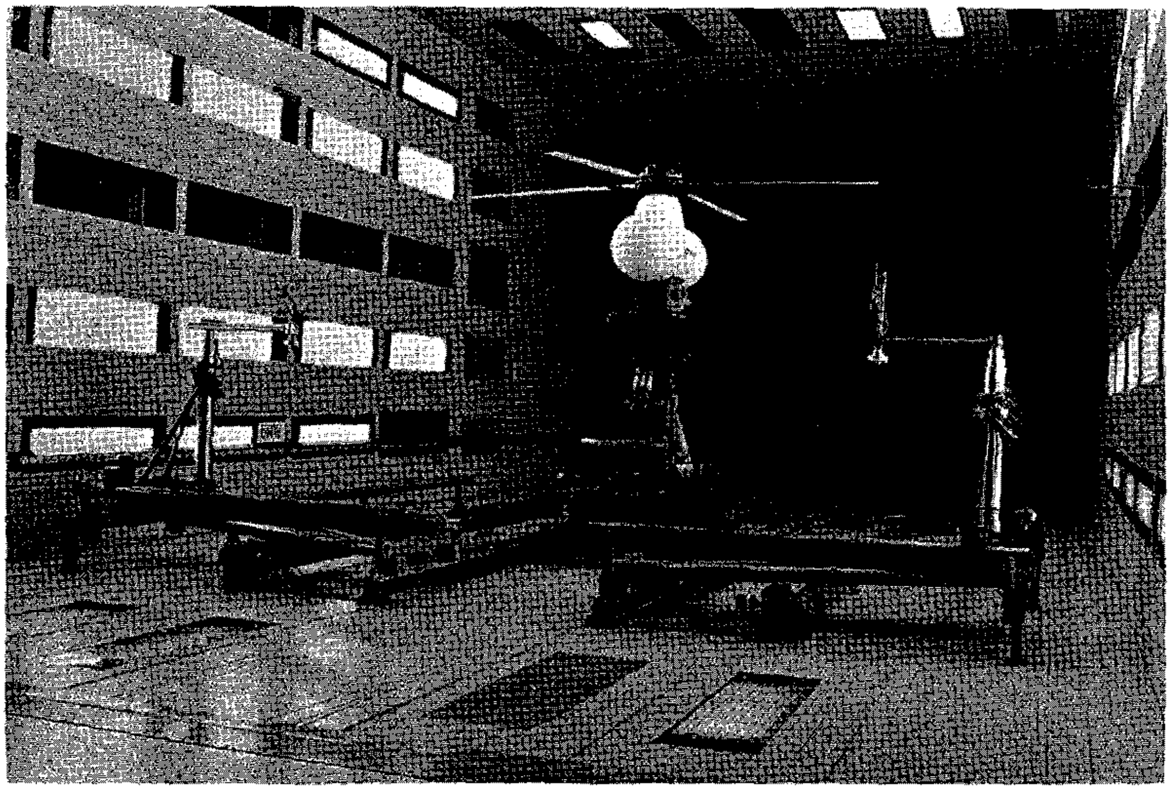


Figure 16 Rotor Test Stand (ROTEST) DFVLR-FM. Courtesy DFVLR

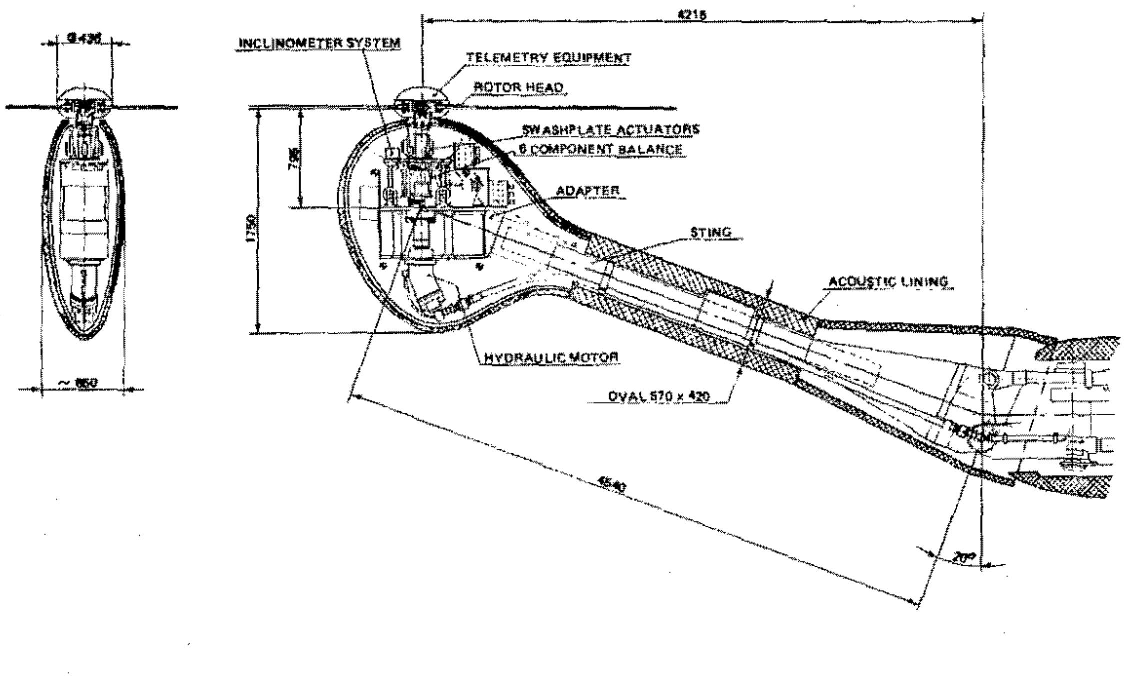


Figure 17 Rotor Test Stand. Sting Support Assembly

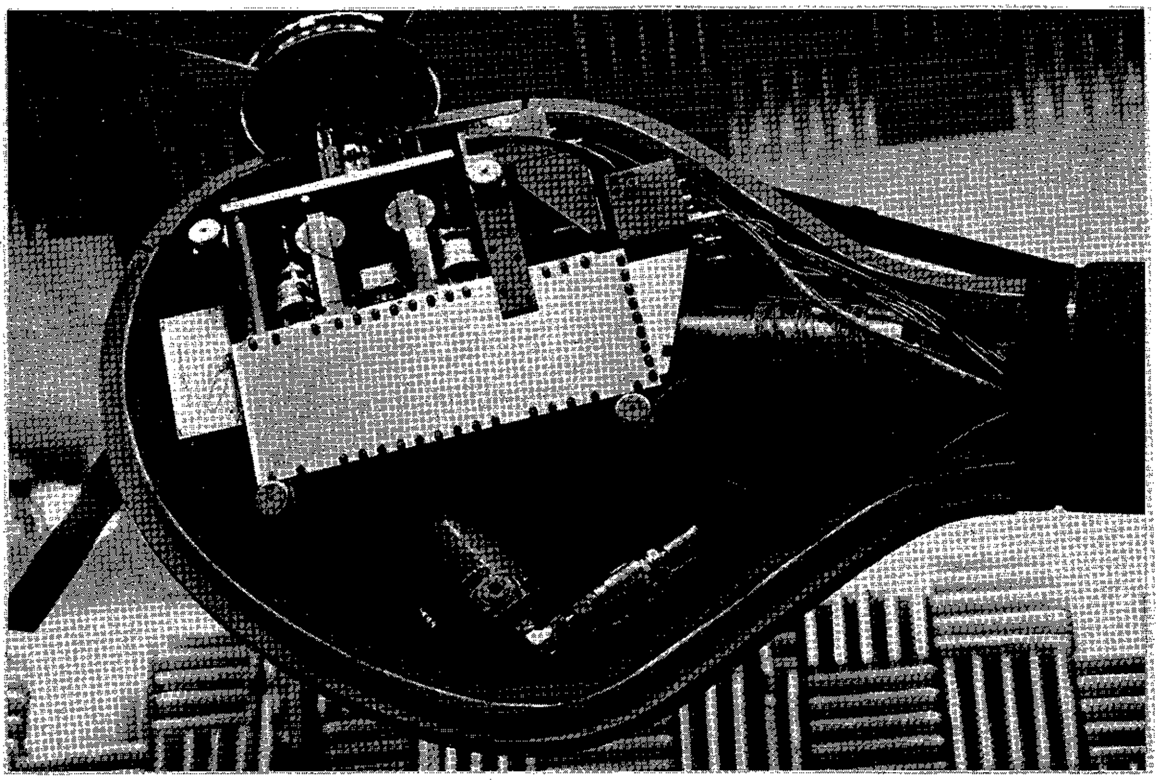


Figure 18 Inside View of ROTEST and Acoustic Fairing

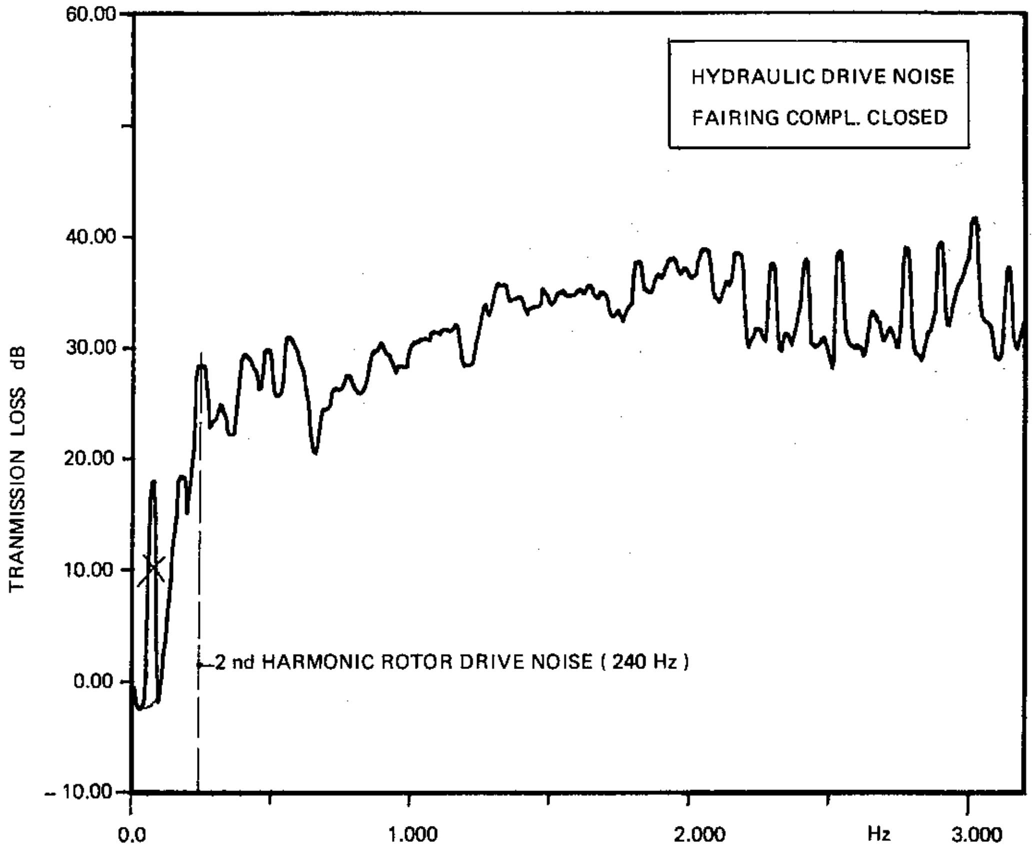


Figure 19 Transmission Loss Spectrum of Aeroacoustic Test Stand Fairing [19]

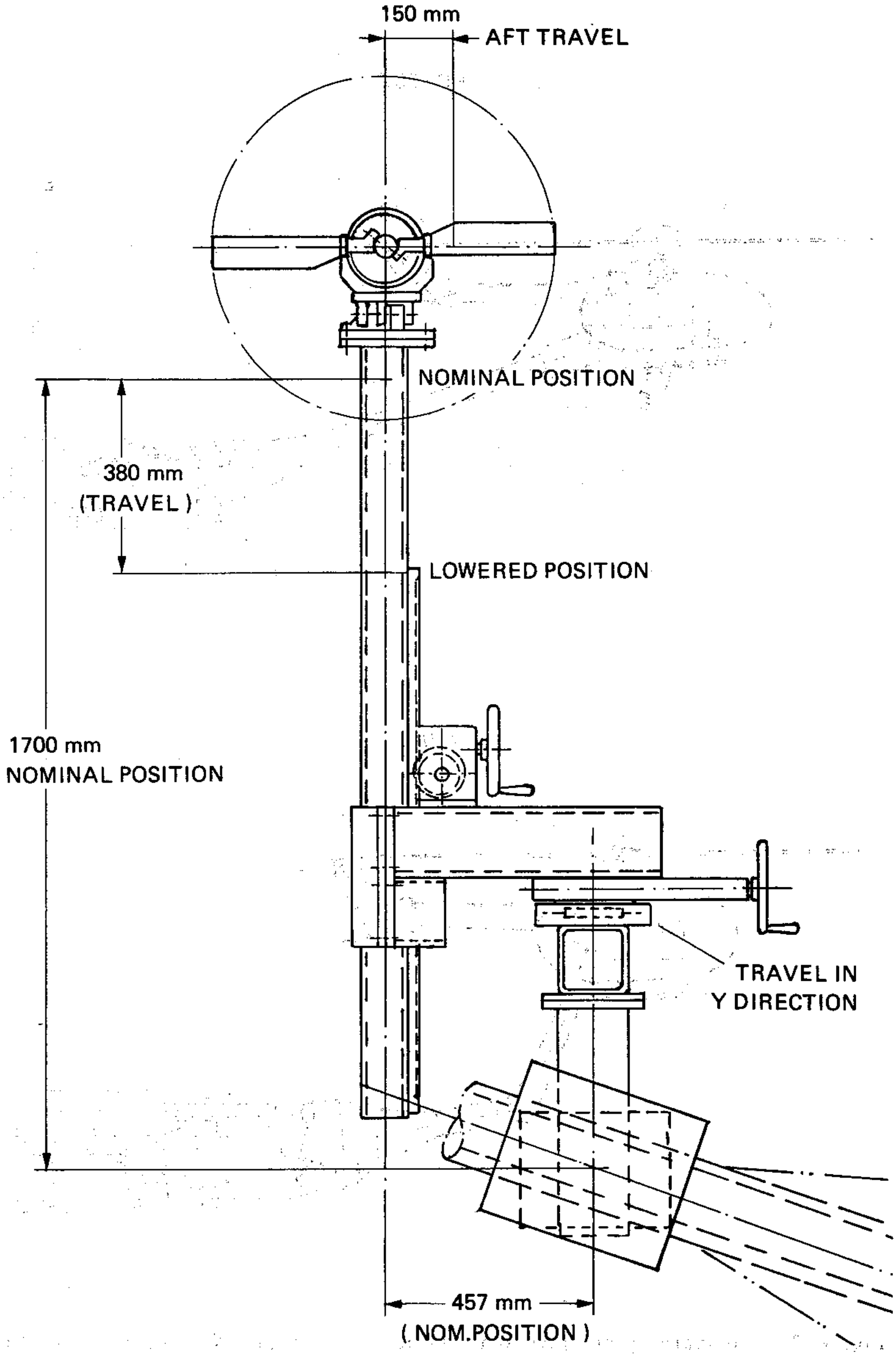
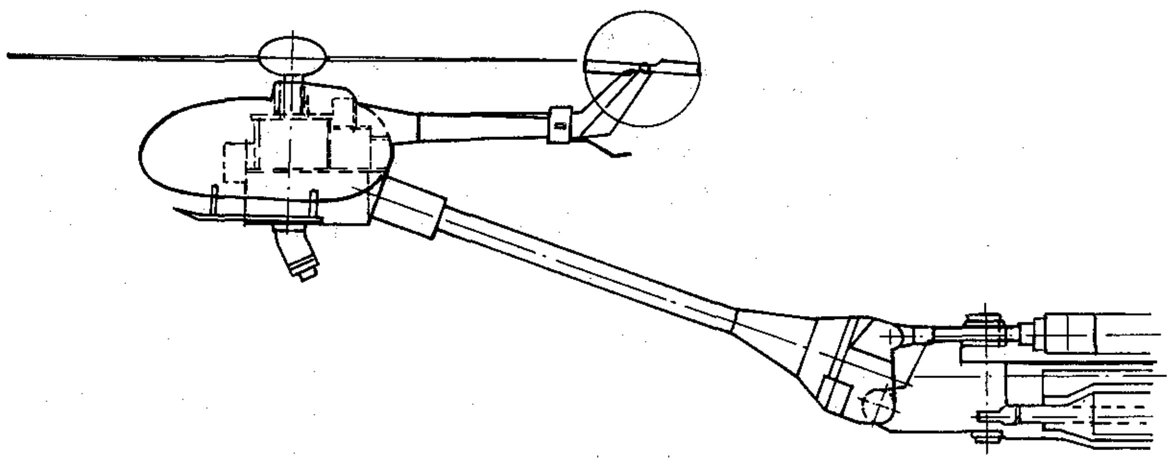


Figure 20 Tail Rotor Test Stand (Side View) DFVLR-EA/TA.
Courtesy DFVLR

ROTEST



MWM

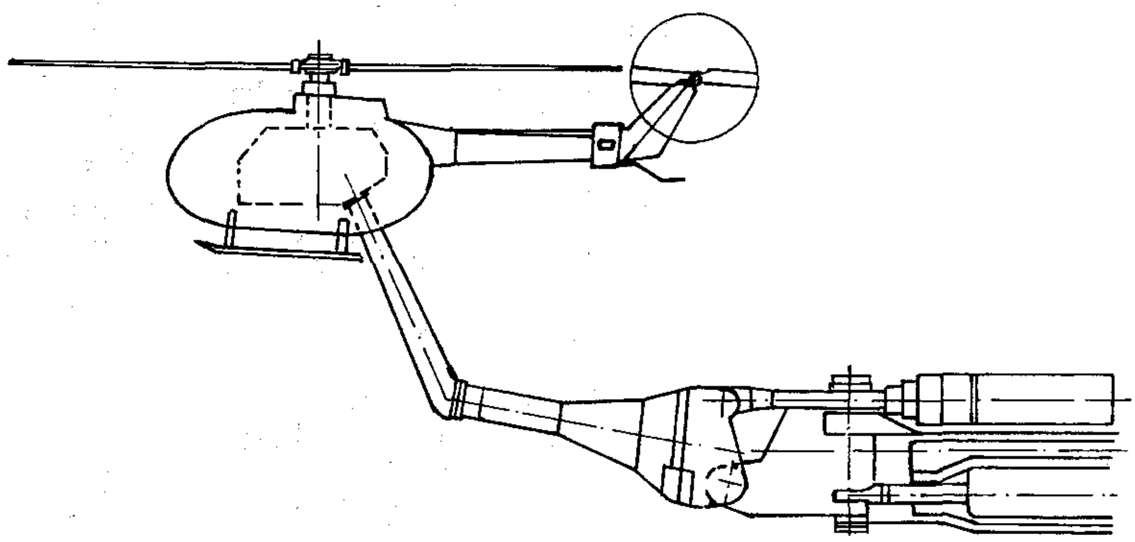


Figure 21 Comparison of New and Old Rotor Test Stands. Courtesy DFVLR

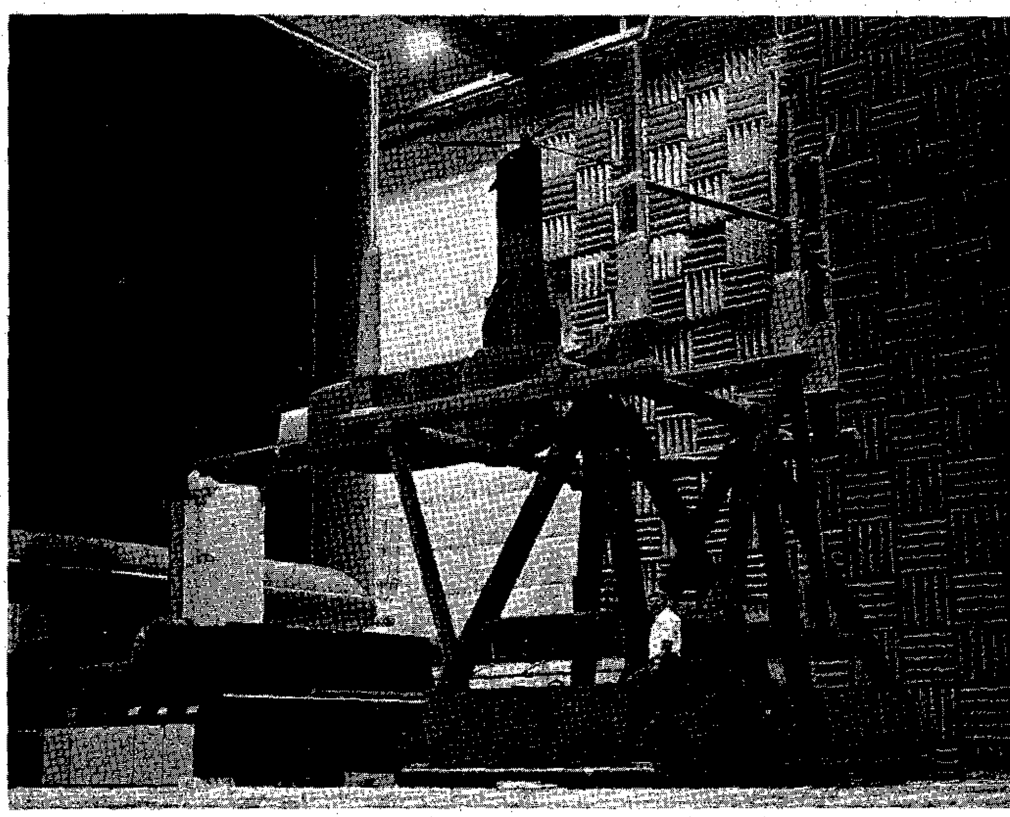


Figure 22 Test Set-up AFDD with Boeing Vertol Rotor. Courtesy AFDD

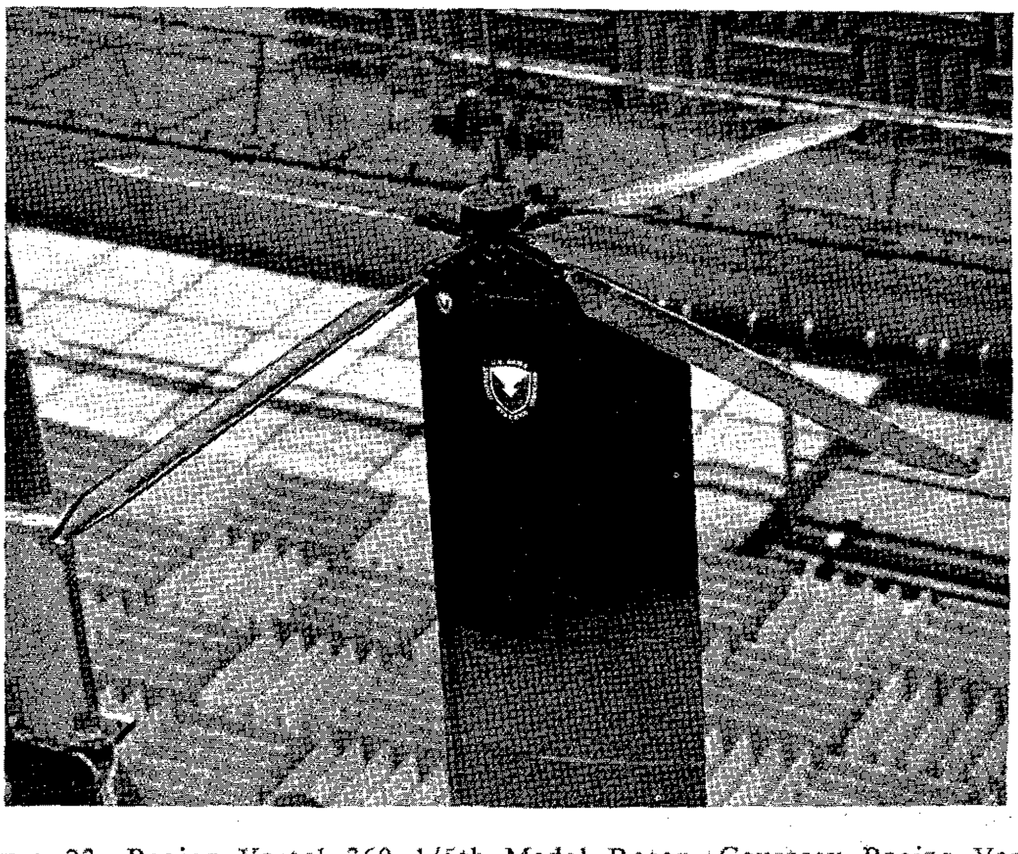


Figure 23 Boeing Vertol 360 1/5th Model Rotor. Courtesy Boeing Vertol

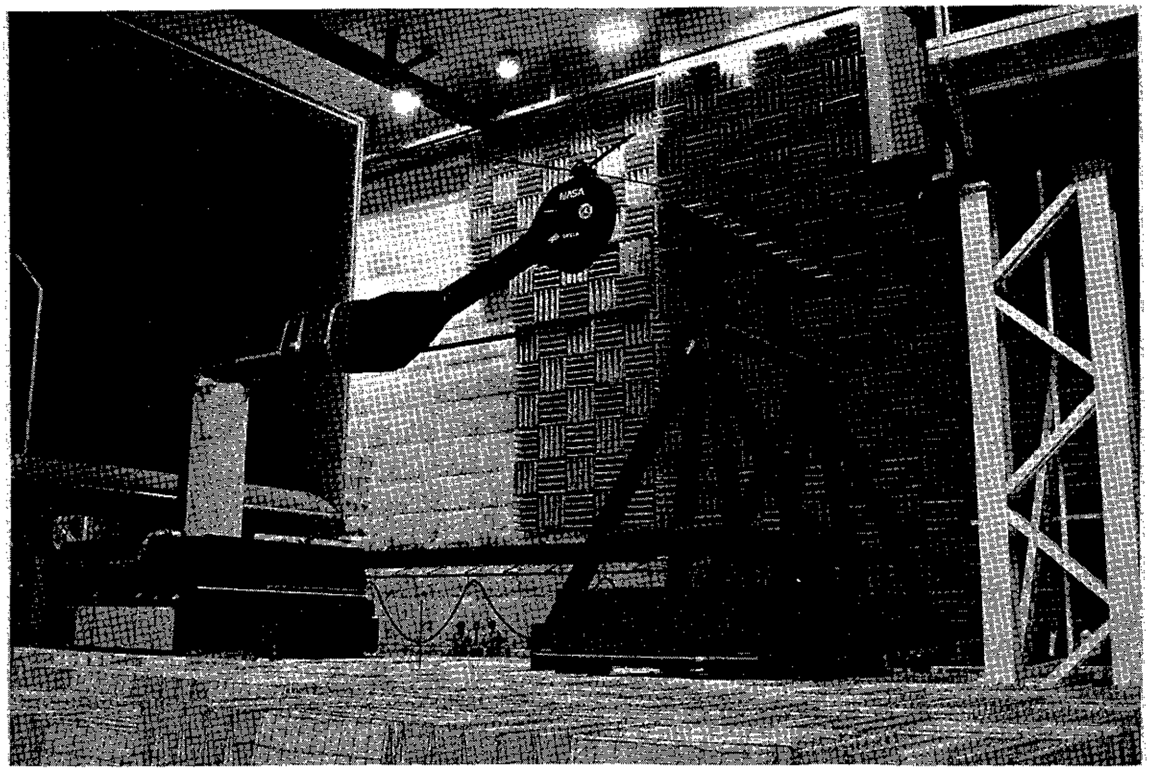


Figure 24 Test Set-up NASA/DFVLR BVI Experiment with Bo 105 Main Rotor [22]

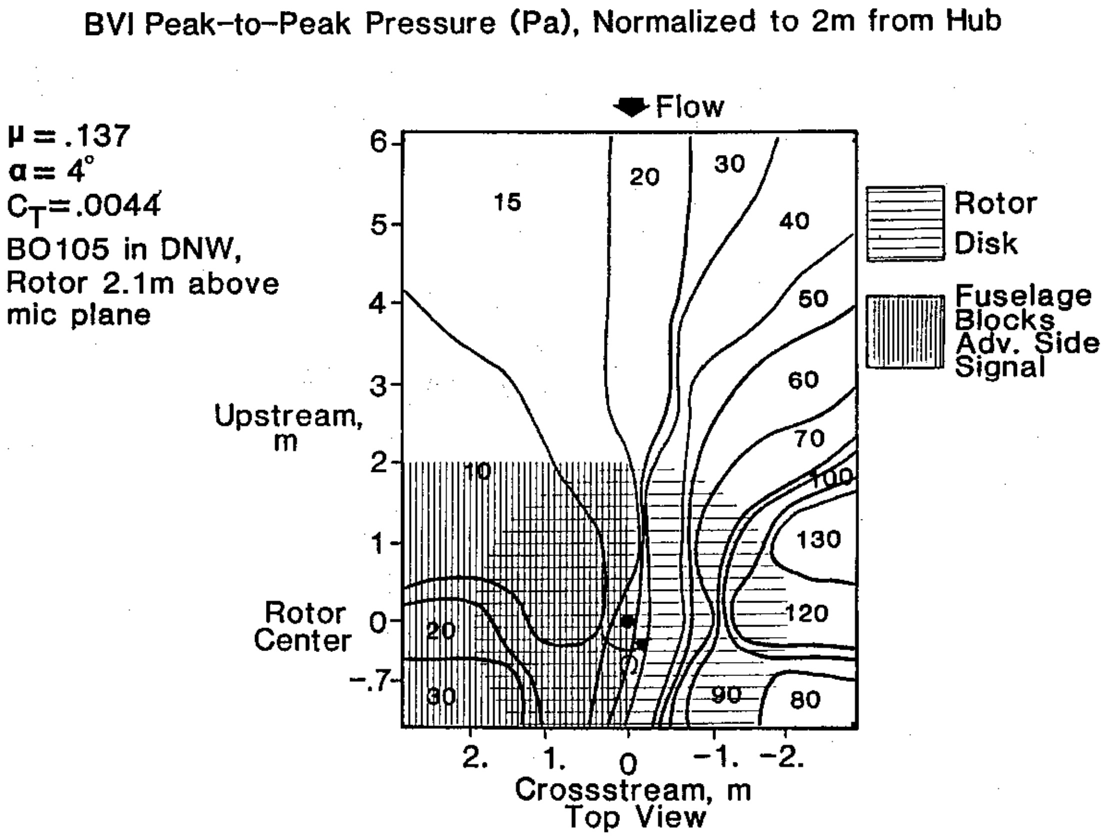


Figure 25 Main Rotor BVI Noise Directivity as Obtained with Microphone Wing Traverse. Courtesy NASA

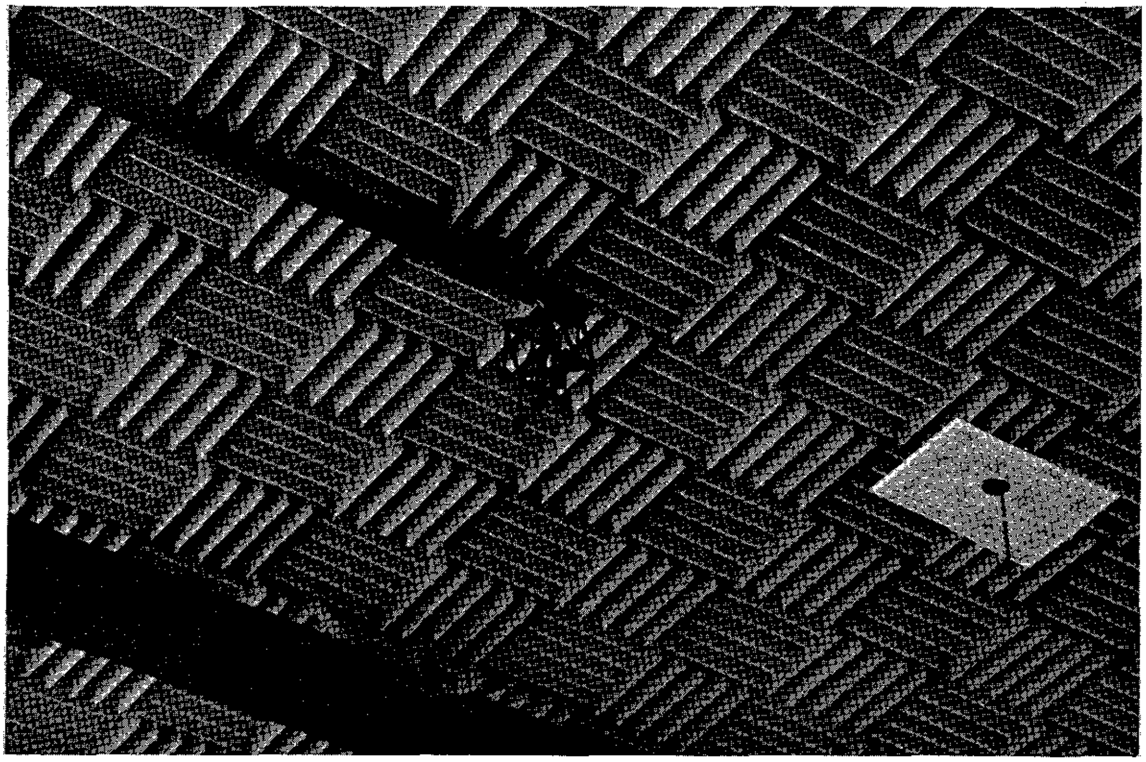


Figure 26 Directional Array Microphone System as Used in NASA BB Experiment [23]

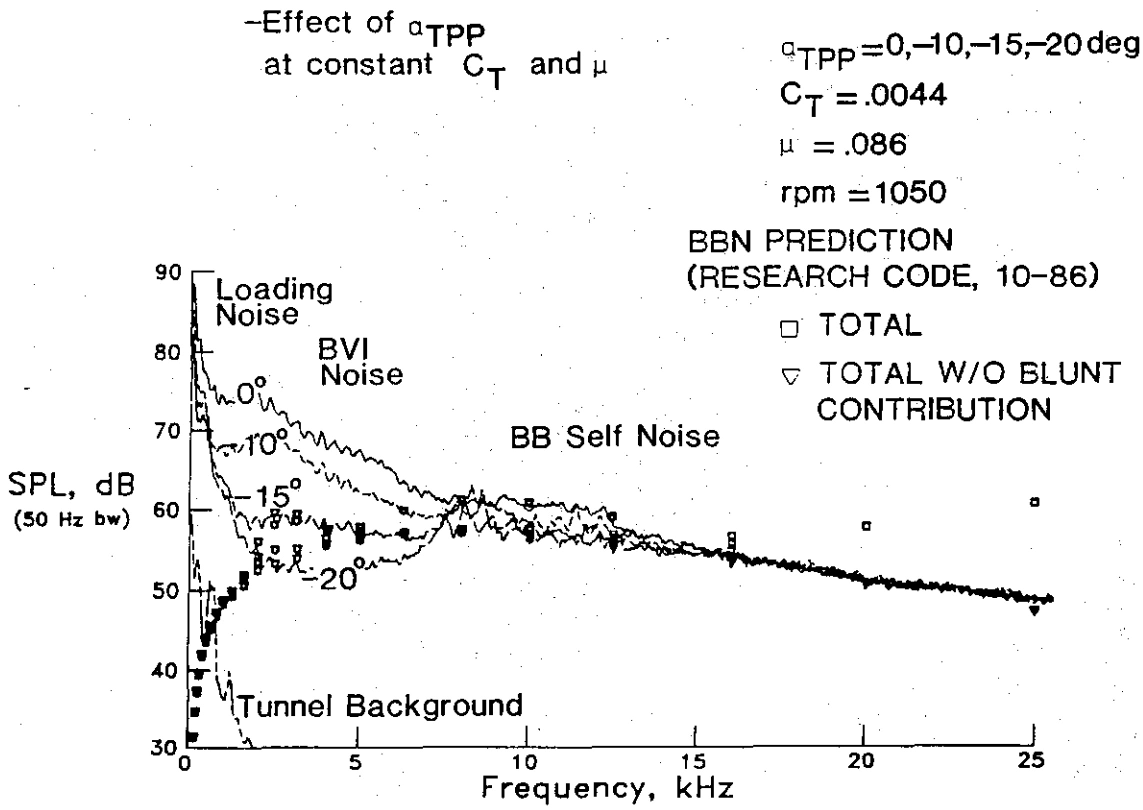


Figure 27 Main Rotor Noise Spectra in BB Noise Experiment. Courtesy NASA

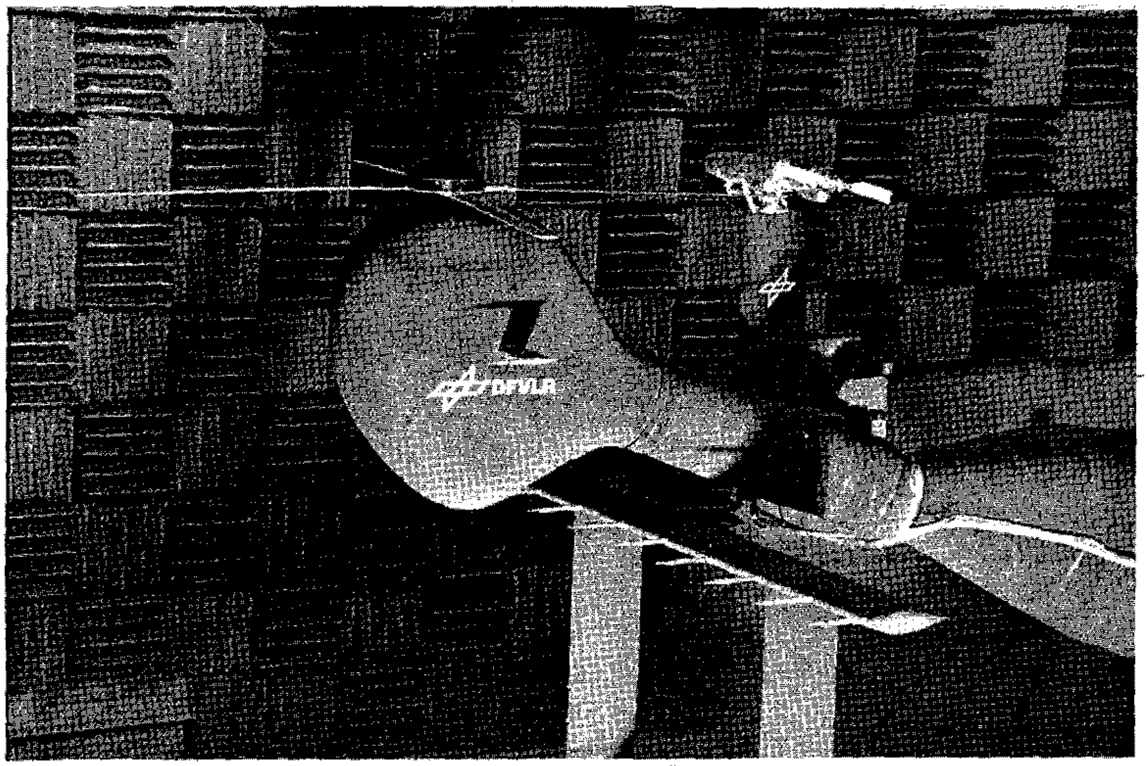


Figure 28 Test Set-up DFVLR Bo 105 MR-TR Experiment, Courtesy DFVLR

Figure 29 Test Set-up for Noise Reflection Calibration