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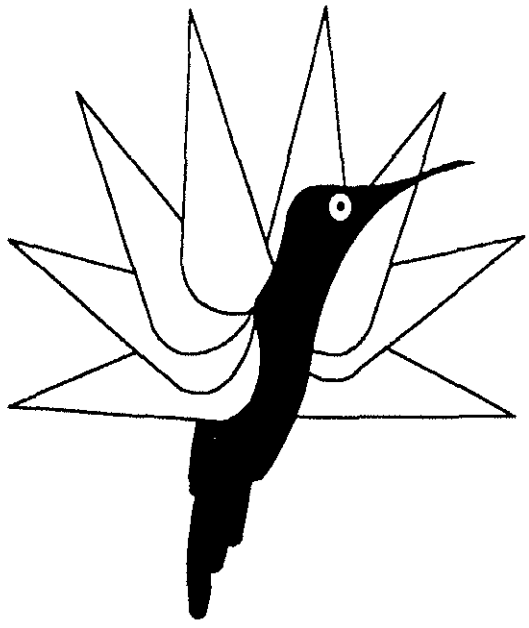

Rotorcraft Activities in the European Research Establishments (DLR, DRA, NLR, ONERA)

by

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Abstract

In the light of increasing European cooperation in the field of aeronautics, this paper focusses on the rotorcraft activities of the four major European research establishments, the German DLR, the British DRA, the Dutch NLR, and the French ONERA. These organizations have clearly defined rotorcraft programmes, they are active in European cooperation, and their activities are closely related to an industrial background in the respective country.

The paper starts with a short introduction of the research establishments and their activities. The rotorcraft programmes are discussed, including the organizational structure, the main subjects and facilities, and selected highlights and results of the research work.

The increasing European cooperation in the rotorcraft field is addressed, including the GARTEUR groups, the EU programmes, and other cooperative activities. The major relations between the research establishments and non-European countries are also presented.

1. Introduction

Depending where an interested observer is coming from, the national aeronautical research establishments in Europe may appear either to be a homogeneous group of very similar, if not identical, entities or on the other side each of these centers presents a markedly individual profile, distinct characteristics, and a pronounced competitive policy in relation to other establishments. All views are more or less correct and there are a number of indications supporting every possible opinion. For most Europeans this fact is not very surprising because they are experienced in the process of the European integration, and they know about the enormous variety of national aspects in all fields.

In order to introduce this paper a short excerpt of a brochure recently and jointly published by the 7 Aeronautical Research Establishments in Europe (CIRA, DLR, DRA, FFA, INTA, NLR, ONERA) may be helpful[1]). In the description of the status of the establishments the missions and characteristics are given as follows:

> *First, all research establishments serve the same purpose, i.e. to act as an important national focus for aeronautical research and technology acquisition. As essential elements of the national aviation research systems, the establishments' mission is threefold:*

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[1]) Kröll, W. (Ed.): Joint Position on the Future Role of the Aeronautical Research Establishments in Europe. German Aerospace Research Establishment, Cologne 1994

- *to carry out fundamental and applied research,*
- *to assist industry in technology development, and*
- *to advise and assist public authorities in pre-normative, regulatory, and programme policy matters.*

Conceived as intrinsically national entities, the research establishments were - and generally still are - expected to serve primarily domestic interests. Their origins in several cases go back to the beginnings of aviation, which made these institutions become constituent factors of the respective country's aeronautical culture.

Second, the research establishments' basically common mission is contrasted by a number of divergent characteristics. They are by no means single purpose, purely aeronautics related research organizations. The portfolios of some of the larger research establishments comprise considerable portions of space, energy, and other technologies. In some cases (DLR, DRA) aeronautics does not even represent the major area of involvement.

Although nearly all research establishments are also committed to military aeronautics, these involvements vary considerably in size and nature.Where defence work exceeds 50% of their aeronautical research budgets, the research establishments have strong ties to their Ministries of Defence (DRA, FFA, INTA, ONERA), and consequently are governmental organizations responsible to the respective MoD. By contrast, the other, "civilian" research establishments (CIRA, DLR NLR) are privately constituted, and can enjoy a much greater degree of freedom in their planning and decision making.

In addition, the 7 research establishments differ considerably in size, turnover, and scope of their involvement. Each research establishment is tuned to the specific national needs, and has "its" place in the respective country's R&D system.

As in the total field of aeronautics, European cooperation in the rotorcraft area is growing rapidly and continuously. This is highlighted by a number of joint European civil and military rotorcraft projects, like EH101, NH90, Tiger, EUROFAR, but also by dramatic changes in the helicopter industry up to a restructuring on a European level (e.g. EUROCOPTER).

In this changing environment the role of the research establishments in future will not be the same than in the past and therefore it seems to be timely to focus on the activities in the research organizations and to provide some of the necessary information for further discussions.

This paper concentrates on the rotorcraft activities in some of the European research establishments (DLR, DRA, NLR, ONERA) and intentionally excludes the others from consideration. The selection of these organizations is based on (1) the explicit and visible presentation of rotorcraft activities or programmes, (2) the active involvement in European cooperative programmes and organizations (e.g. GARTEUR), and (3) the industrial background in the respective country.

2. The Research Establishments

2.1 The German Aerospace Research Establishment (DLR)

Deutsche Forschungsanstalt für Luft- und Raumfahrt e. V.
DLR German Aerospace Research Establishment

Status:	**National Research Establishment for Aeronautics, Space and Energy Technology**
Budget:	**Total 318 MECUs** 30% Aeronautics 60% Space 10% Others
Funding:	**Institutional Funding (55%)** **Contracts (45%)**
Staff:	**Total 4200** **Research 2440** (Academics & Engineers)
Research Centers:	**Berlin, Braunschweig, Göttingen, Köln, München/Oberpfaffenhofen, Stuttgart**

The DLR is the largest research establishment in Germany dealing with engineering sciences. It was formed as DFVLR in 1969 by the merger of three predecessor organizations, one of them, the Aerodynamische Versuchsanstalt Göttingen, was founded in 1907.

The research tradition inherent in these three research and test establishments is being continued by the DLR as the national large-scale aerospace research establishment.

DLR's work focuses on the fields of aeronautics, astronautics and non-nuclear energy technology. The scientific-technical expertise of the DLR is located in the institutes of its five research departments: Flight Mechanics/Guidance and Control; Fluid Mechanics; Materials and Structures; Telecommunications Technology and Remote Sensing; and Energy. The expertise available is also used for the construction and operation of large-scale test and simulation facilities. A great deal of importance is also attached to the management of scientific-technical projects.

The medium and long-term perspectives in the sectors of aeronautics, astronautics and energy technology are developed and planned in the R&D programmes controlling the research work, the investment policy and the supporting services.

DLR's research and development work takes into account the objectives of the Federal Government's relevant research programmes, the medium and long term demands of industry, and the possibilities for cooperation with universities performing fundamental research.

2.2 The British Defence Research Agency (DRA)

Defence Research Agency

Status:	**Established as a Trading Fund owned by the UK Ministry of Defence for Research & Development Progams in Air, Land and Sea Systems**
Budget:	**Total 1125 MECUs** 15% Aeronautics 3% Space 82% Others
Funding:	**Contracts (100%)**
Staff:	**Total 11000** **Aerospace 3600** **Research Aerospace 2160** (Academics & Engineers)
Centers for Aerospace:	**Farnborough, Bedford, Boscombe Down**

The DRA results from the amalgamation of the major UK Ministry of Defence non-nuclear research establishments in the Air, Land, and Sea Systems Controllerates including the former Royal Signals and Radar Establishment, the Admiralty Research Establishment, the Royal Armament Research and Development Establishment, and last but not least the Royal Aerospace Establishment, which was founded in 1918.

Formed in 1991 DRA is evolving rapidly to rationalise so as to improve cost effectiveness and to this end it was established as a Trading Fund in 1993 owned by the Ministry of Defence. Further developments combine DRA with numerous additional establishments, institutes, R&D ranges and major test facilities forming an impressive organization currently organized in 11 Business Sectors ranging from Operational Studies & Command Information Systems to Weapons, and Fighting Vehicles.

The DRA R&D programme is currently organized into 3 categories, according to the timescale of application: Strategic Research for the long term, Applied Research for the medium term, and Project Support which includes research in support of Technical Demonstrator Programmes.

The Aircraft Sector provides research expertise across a range of key platform technologies, the majority of which apply to both military and civil aircraft. It has the benefit of and responsibility for some of the UK's most important facilities: the fleet of experimental aircraft, the wind tunnels, as well as complex simulators. These facilities provide indispensable support to the Sector in its major role to equip the official customers with the broad and detailed knowledge they require to maintain intelligent customer status.

2.3 The Dutch National Aerospace Laboratory (NLR)

Nationaal Lucht-en Ruimtevaartlaboratorium
National Aerospace Laboratory

Status:	**Private Foundation for Aerospace Research**
Budget:	**Total 71 MECUs** 90% Aeronautics 10% Space
Funding:	**Institutional Funding (30%)** **Contracts (70%)**
Staff:	**Total 920** **Research 700** (Academics & Engineers)
Research Centers:	**Amsterdam, Noordoostpolder**

The NLR is the central institute for aerospace research in the Netherlands. The Foundation NLR was established in 1937, to continue the research activities of the Netherlands Government Office "Rijksstudiedienst voor de Luchtvaart" (RSL) established in 1919. NLR's volume of activity has grown considerably since that time, but the mission has remained the same: providing scientific support and technical assistance to aerospace industries and organizations, civil and military aircraft operators, and government agencies all over the world.

NLR is a non-profit organization, and conducts a programme of basic research sponsored by the Dutch Government. In addition, contract research for Dutch and foreign customers is carried out representing the major part of the activities.

With sites in Amsterdam and Noordoostpolder, NLR operates several wind tunnels, laboratory aircraft and research flight simulators. It also has equipment for research in the areas of air traffic control structures and materials, space technology and remote sensing. NLR's extensive computer network includes a supercomputer, tools for software development and advanced software for computational fluid dynamics and for calculations of aircraft and spacecraft structures.

2.4 The French National Institute for Aerospace Research and Studies (ONERA)

ONERA Office National d'Etudes et de Research Aérospatiales
National Institute for Aerospace Research and Studie

Status:	**Public Establishment under Ministry of Defence Supervision for Aerospace Research**
Budget:	**Total 210 MECUs** 45% Aeronautics 18% Space 37% Others
Funding Sources:	**Subsidy of Ministry of Defence (30%)** **Contracts (70%)**
Staff:	**Total 2200** **Research 1250** (Academics & Engineers)
Research Plants:	**Chatillon, Chalais-Meudon, Palaiseau, Modane-Avrieux, Le Fauga Mauzac, Toulouse, Lille**

ONERA was founded in 1946 as a scientific and technical public establishment, managed according to industrial and commercial practice, having financial autonomy and placed under the authority of the Minister of Defence. Its mission was defined as to develop, orient and, in connection with services and organizations in charge of scientific and technical research, coordinate research in the field of aeronautics or, as modified later, in the field of aerospace.

The contribution of ONERA to technical progress in aerospace includes basic research supplementing that conducted in university laboratories, applied research preparing long- and medium-term projects and direct technical assistance to industry, either by making the testing potential of its centers available or by studying problems raised by projects under development or difficulties encountered on operational equipment. Thus, ONERA serves as a link between scientific research and industry, by transfers between scientific work and civil or military aerospace programs in the design and production stage.

ONERA's activity covers many fields, as the solution of the difficult and varied problems raised by aircraft and spacecraft design involves multiple disciplines and techniques which lie outside the traditional aerospace area (data processing, solid state physics, coherent optics); conversely, the results often find applications in areas more or less far removed from their initial purpose.

Main Areas of Aeronautical Activities

(Not for Comparative Use Between the Research Establishments)

*** high activities (> 15%) ** medium activities (5-15%) * low activities (< 5%)	DLR	DRA	NLR	ONERA
Aerodynamics	***	***	***	***
Flight Mechanics, Control and Stabilisation Systems	***	***	***	*
Navigation and Guidance (ATM)	**	***	**	*
Structures	**	**	**	**
Rotary Wing Aircraft	**	**	*	**
Propulsion	**	***	*	**
Materials	*	***	*	**
Flight Testing	*	**	**	

All four research establishments conduct work across a wide range of aeronautical science and technology. All are engaged intensively in the classic field of aerodynamics, but also in flight mechanics, control and stabilisation systems, navigation and guidance, structures, propulsion materials, and in Rotary Wing Aircraft. ONERA does not operate test aircraft by its own, but it has direct access to flight tests via the French test centers of CEV and industry.

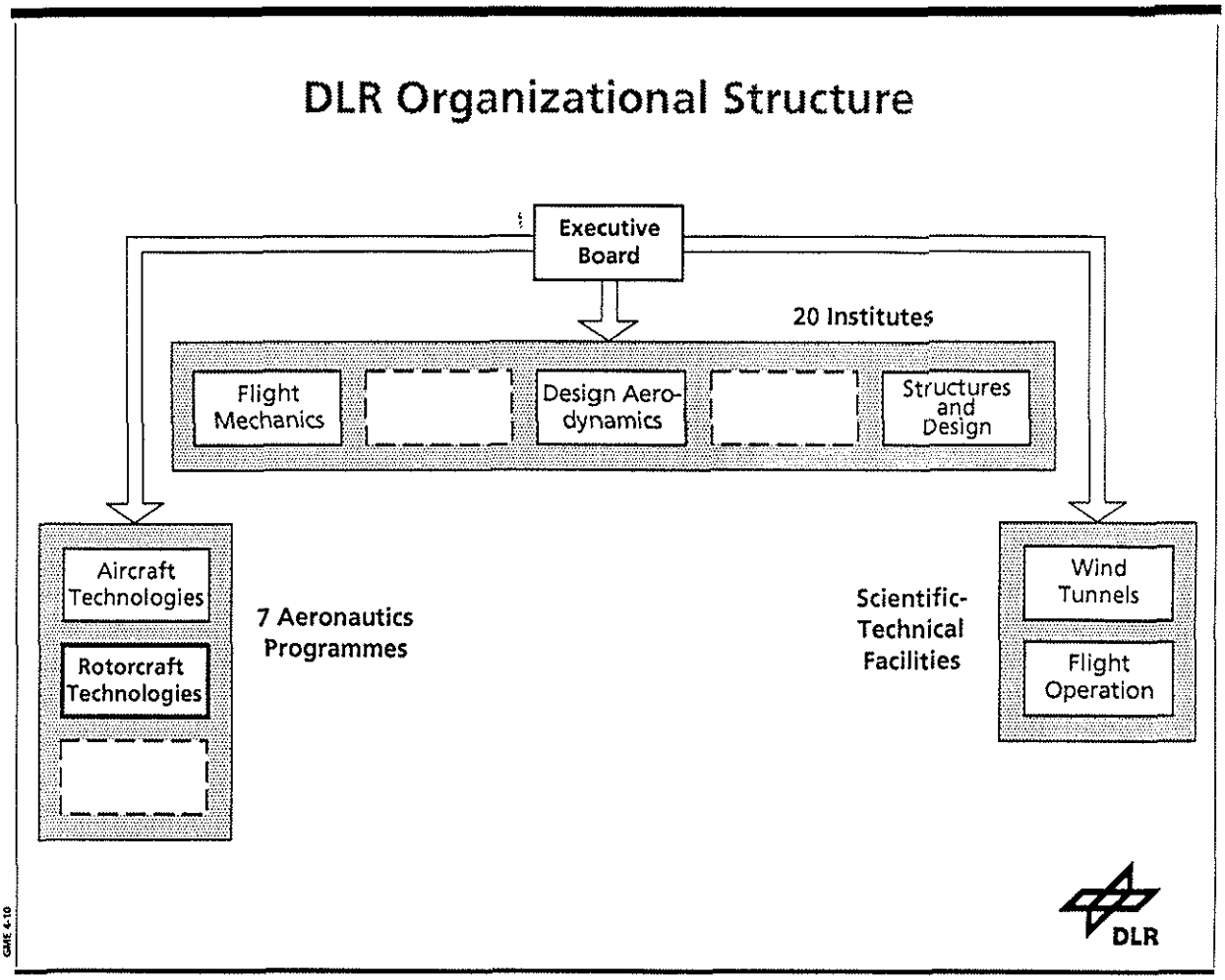
The activity overview, taken from [1]), does not allow a comparative assessment of the individual research establishments' strengths and specialities. Such an analysis requires an in-depth study and some information in the field of Rotary Wing Aircraft is given in this presentation. The table does, however, provide an additional insight into the emphasis the different organizations put on specific disciplines, which continue to be decisive for further significant advances in aircraft development. The overall scope of involvement depends heavily on the specific distribution of aeronautical R&D functions in each country. It should also be noted that much of the work carried out by those research establishments which receive funds from civilian and military sources has a dual-use potential.

[1]) Kröll, W. (Ed.): Joint Position on the Future Role of the Aeronautical Research Establishments in Europe. German Aerospace Research Establishment, Cologne, 1994

3. The Rotorcraft Programmes

3.1 DLR

Organizational Structure

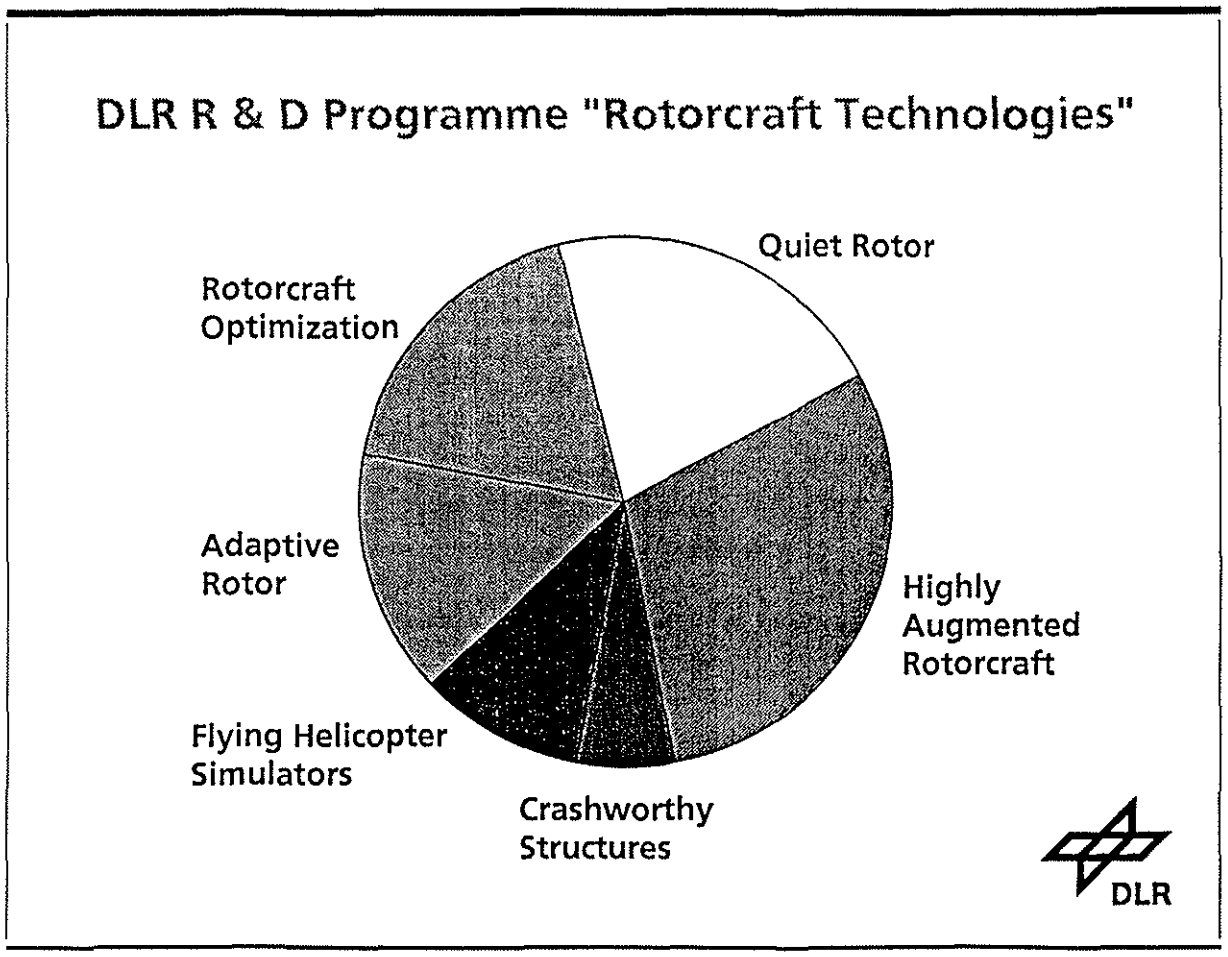


DLR's scientific-technical objectives are defined and described in detail in the program sector. In the field of aeronautics 7 programmes are presently established, one of these is the vehicle oriented programme Helicopter Technologies. The programme objectives are based on DLR's long-term policy and are discussed thoroughly with the partners in politics, science and industry. The research activities are planned on a mid-term basis and have to be updated in a yearly sequence as part and result of the controlling process. By this mechanism interdisciplinary tasks in the various programmes are defined and implemented, assigning research activities in different institutes, necessary support of the scientific technical facilities, and the other resources to the specific objectives.

The programme Helicopter Technologies defines six research tasks for the year 1995 including contributions of 7 institutes:

- Institute for Flight Mechanics, Braunschweig
- Institute for Flight Guidance, Braunschweig
- Institute for Design Aerodynamics, Braunschweig
- Institute for Fluid Mechanics, Göttingen
- Institute for Structural Mechanics, Braunschweig
- Institute for Aeroelasticity, Göttingen
- Institute for Structures and Design, Stuttgart.

In addition, support activities of the Scientific Technical Facilities like wind tunnels and flight operations are essential for the successful completion of the tasks and the overall programme.



The interdisciplinary mid term research tasks include the following subjects:

- Highly Augmented Rotorcraft
  - validation and improvement of flight dynamic models
  - control system and handling qualities research
- Quiet Rotor
  - numerical and experimental simulation of aeroacoustic phenomena
  - exploration and utilization of noise reduction potentials
- Rotorcraft Optimization
  - improvement of wind tunnel test techniques and facilities
  - application of active rotor control
- Adaptive Rotor
  - exploration and application of adaptive structures for rotor control and optimization of rotor characteristics
- Flying Helicopter Simulators
  - development and application of fly-by-wire/light experimental helicopters for technology demonstration, in-flight simulation, and system integration
- Crashworthy Structures
  - energy absorbing helicopter airframe sub-structures
  - numerical crash simulation.

In addition to these research tasks activities for direct project support are accomplished, using the methods and facilities available.

DLR Main Facilities for Rotorcraft Research

- **Research Helicopters and Technology Demonstrators**
  - BO 105 Multipurpose Research Helicopter
  - BO 105 ATTHeS In-Flight Simulator
- **Wind Tunnel Test Facilities**
  - Modular Helicopter Test Rigs for DNW
  - German/Dutch Wind Tunnel DNW (Joint DLR/NLR Facility)
  - Laser Doppler Velocimeter
  - Acoustic Measurement Equipment for DNW
- **Drop Tower for Crash Tests**

For experimental rotorcraft investigations DLR operates among others the following facilities:

- Research Helicopters
  - BO 105 multipurpose research helicopter with extensive rotor and airframe instrumentation
  - ATTHeS In-Flight Simulator based on the fly-by-wire/light BO 105, equipped with a model following control system and extensive instrumentation.

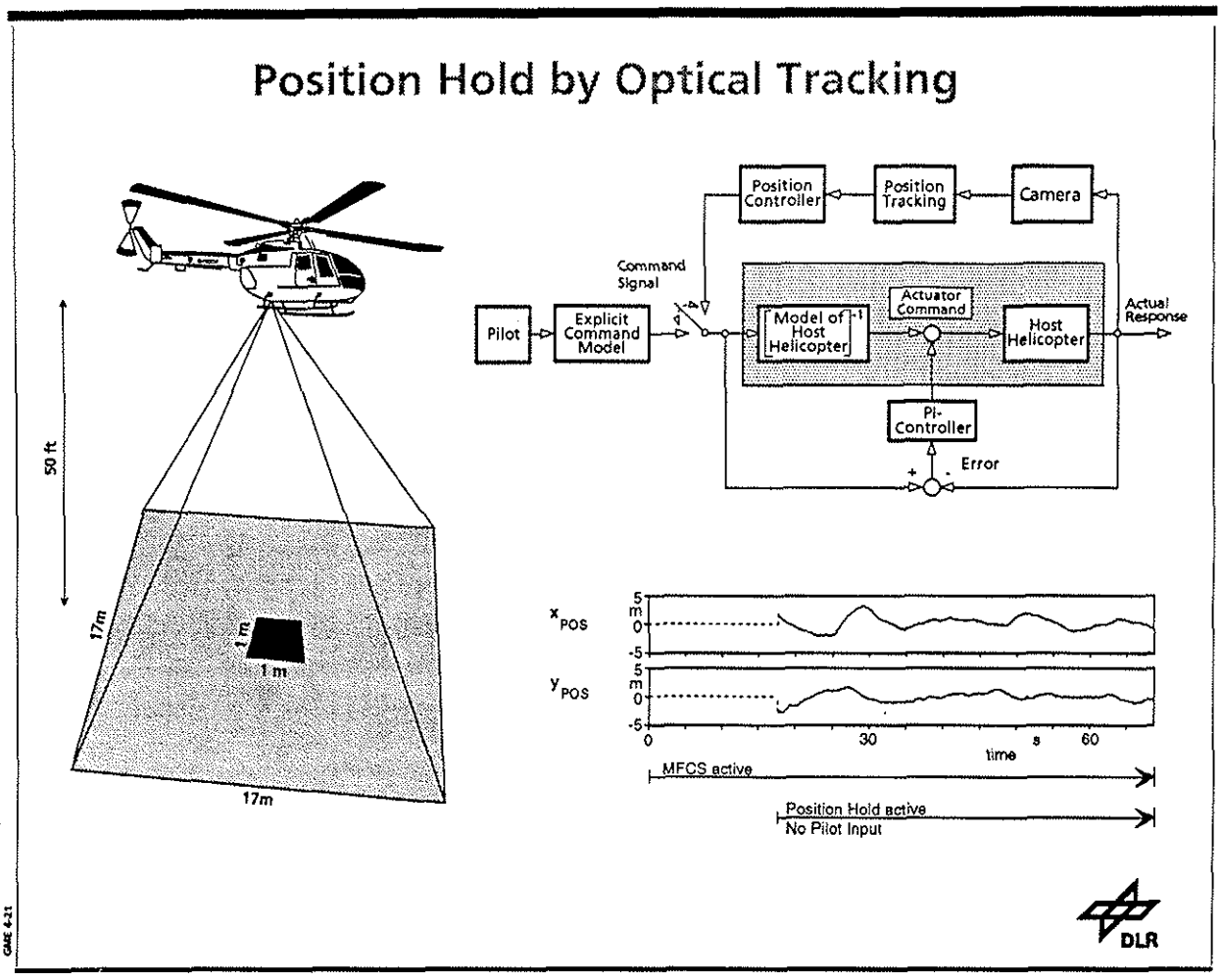
- Wind Tunnel Test Rigs
  - Rotor Test Stands for DNW for tests using Mach scaled rotors up to 4.2 m diameter including HHC, extensive instrumentation including rotor pressure sensors
  - Modular Helicopter Test Rig for configurational tests in DNW.

- Wind Tunnels
  - German/Dutch Wind Tunnel DNW (Joint DLR/NLR facility) with different interchangeable test sections (8m x 6m open anechoic or closed, 9.5m x 9.5m closed)

- Additional Facilities
  - Laser Doppler Velocimeter
  - Acoustic measurement equipment for DNW
  - Drop tower for crash tests
  - Super computers.

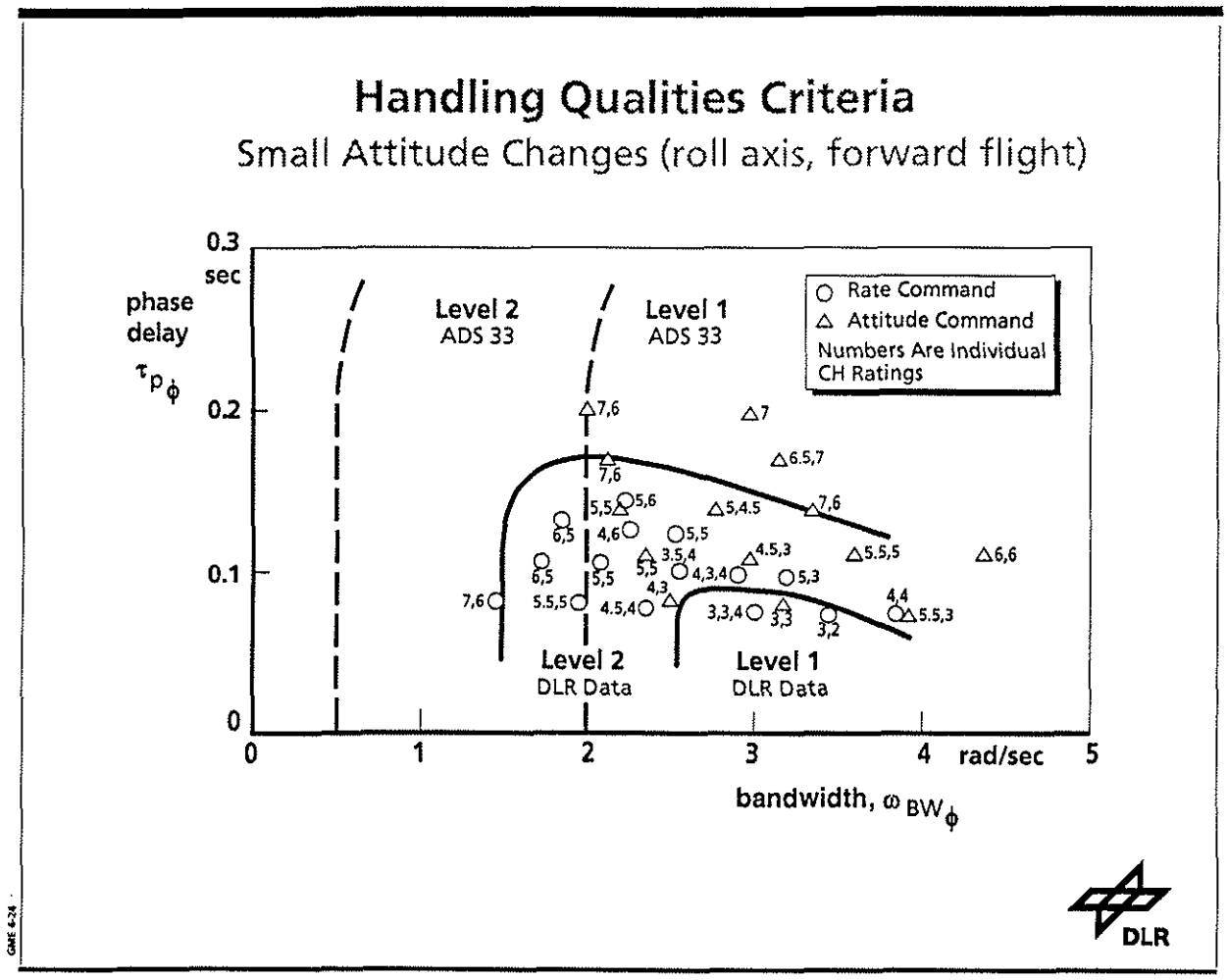
These facilities are used in research tasks as well as for project support.

Position Hold by Optical Tracking



The design of control systems for helicopters in hover and low speed is a basic requirement for the extension of mission profiles with new mission demands. A special task for various applications is the position hold under wind and gust conditions above a ground fixed or moving target, like a shipboard reference, or a small vessel or lifeboat in rescue missions. For the solution of this problem a controller concept was developed and the feasibility was proofed and successfully demonstrated in flight tests.

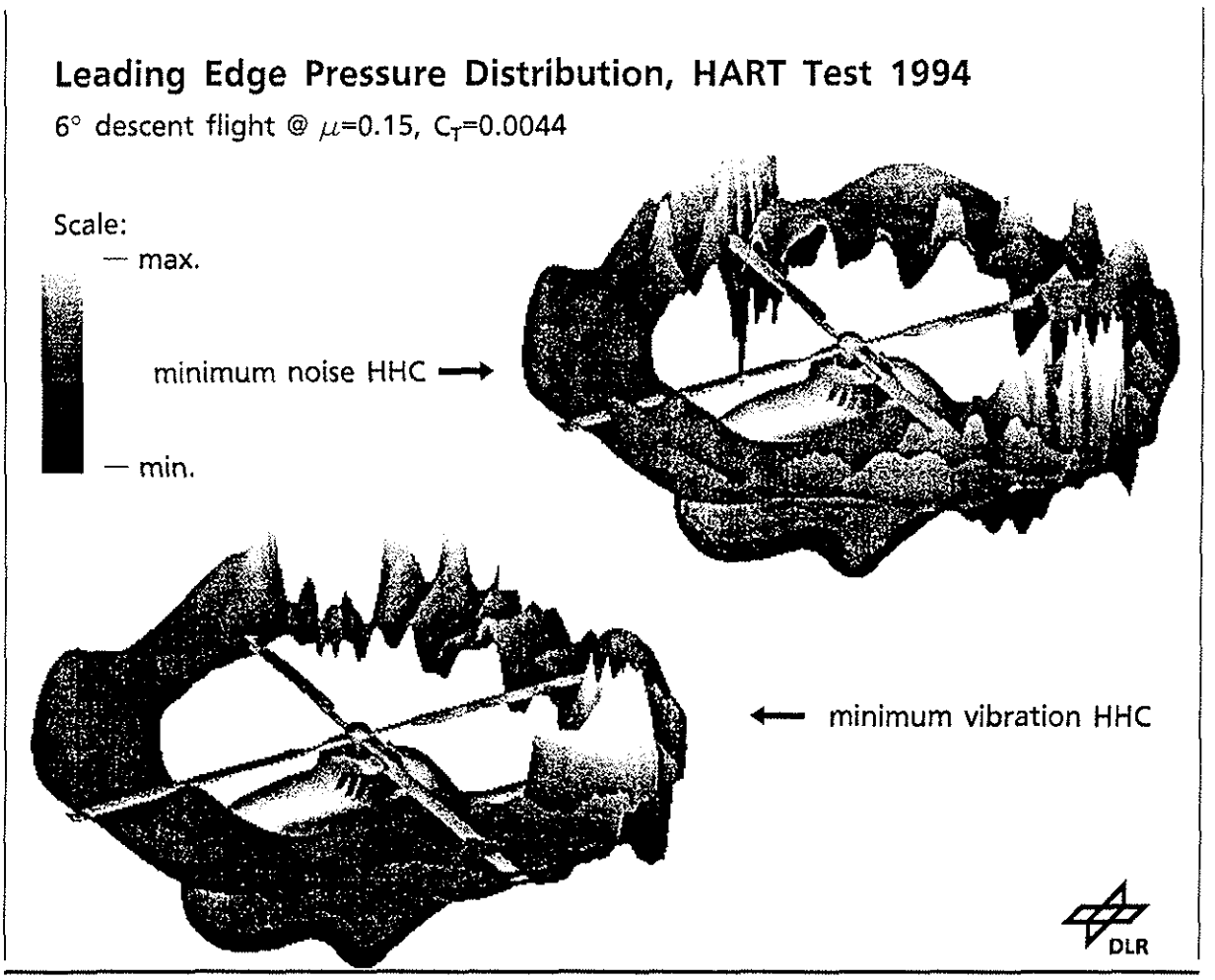
The helicopter in-flight simulator ATTHeS (**A**dvanced **T**echnologies **T**esting **H**elicopter **S**ystem) of the DLR has been equipped with an innovative measurement system for the hover position above a target. A video camera in combination with a highly parallel computer system for processing the optical information was used as an integrated sensor system for the measurement of the relative position of the aircraft to a target. Based on the existing well-proven model following flight control laws (MFCS) of ATTHeS for the forward flight condition, which are implemented for handling qualities investigations, these control laws were modified and adapted to fulfil the special requirements of the position hold task, including altitude hold and heading hold capabilities. The integrated system of the optical position sensor and the control computer enables the helicopter to hover automatically above a defined target in constant altitude and with constant heading. Flight tests above a moving car under wind and gust conditions demonstrated the future potential of the overall system to be used under operational conditions.



The introduction of Active Control Technology in rotorcraft created the urgent need for new handling qualities requirements. In response to this, a new helicopter handling qualities specification was developed under the leadership of the US Army and published as Aeronautical Design Standard 33 (ADS 33). Since its introduction, research has been conducted to expand the handling qualities data on which ADS 33 is based.

From the beginning DLR contributed to this research. A standard BO 105 was used to evaluate the applicability and repeatability of the current criteria in forward flight. As a result of this study, some data gaps were recognized and the criteria that need further verification were identified. The in-flight simulator ATTHeS was used for an investigation of the effects of *bandwidth* and *phase delay* on helicopter handling qualities in a high gain slalom tracking task. The results indicate a need to more tightly constrain the phase delay for the roll axis than in the current ADS 33 requirements.

Another programme in cooperation with US Army AFDD investigated the pitch-roll coupling criteria and resulted in a proposal for a new frequency domain criterion that offers more comprehensive coverage of all types of pitch-roll coupling.

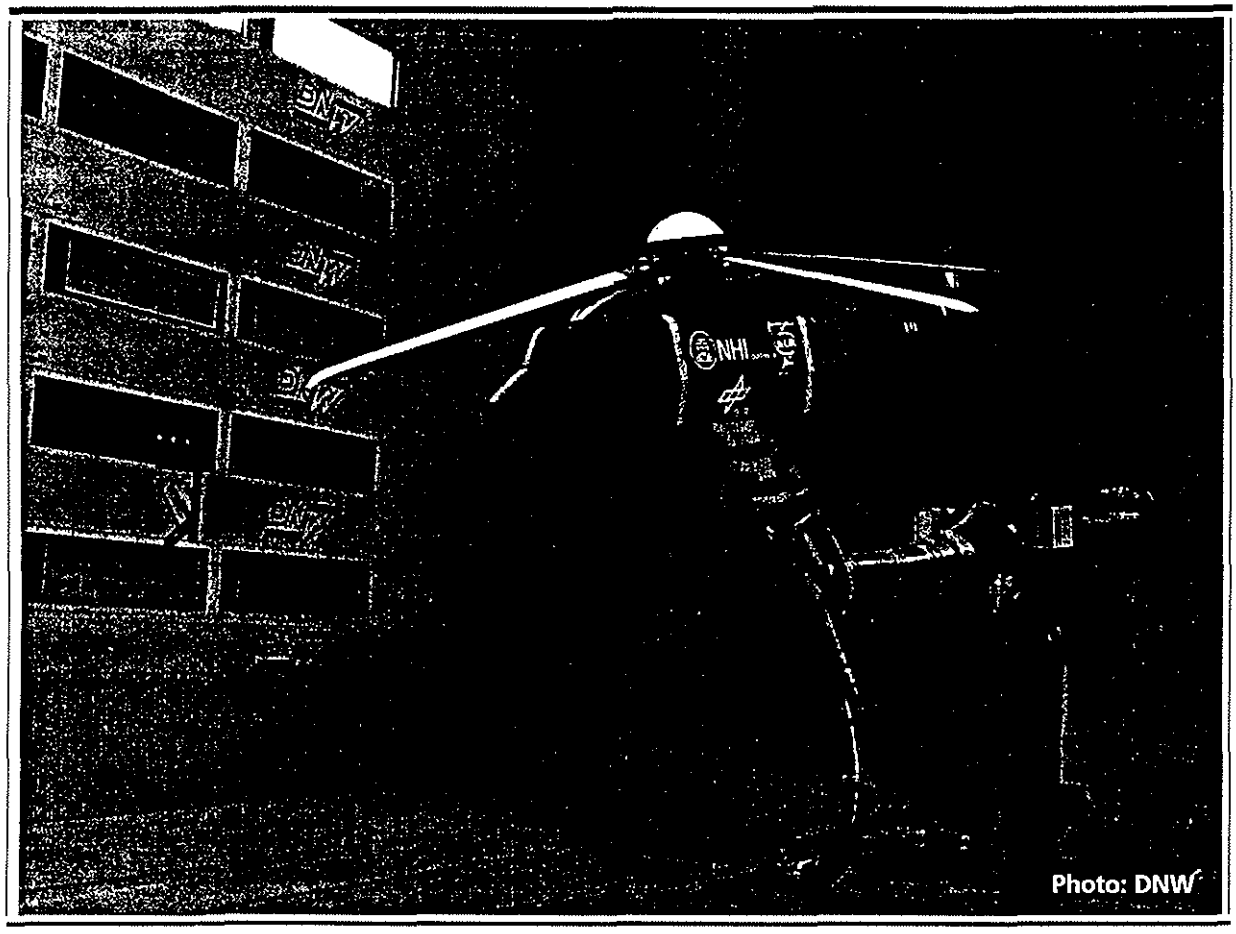


In a major cooperative programme within existing US/German and US/French Memoranda of Understanding, the German DLR, the French ONERA, the American NASA Langley, and the US Army Aeroflightdynamics Directorate (AFDD) conducted a comprehensive test with a 40% geometrically and dynamically scaled model of the BO 105 main rotor in the 8 m by 6 m anechoic open test section of the DNW.

The objective of the programme was to improve the basic understanding and the analytical modelling of the effects of the HHC technique on rotor noise and vibration reduction. Comprehensive acoustic, aerodynamic, dynamic, loads, and rotor wake data were obtained with the pressure-instrumented rotor blade.

This international cooperative project carries the acronym HART, HHC Aeroacoustic Rotor Test.

The responsibility of DLR was for the test rig including the instrumented rotor and the HHC-system, for acoustic, rotor and blade pressure instrumentation, data acquisition and on-line analysis, and for the LDV-system on the advancing side of the rotor. The effort was undertaken by four DLR institutes integrated in the international test team which was headed by DLR.

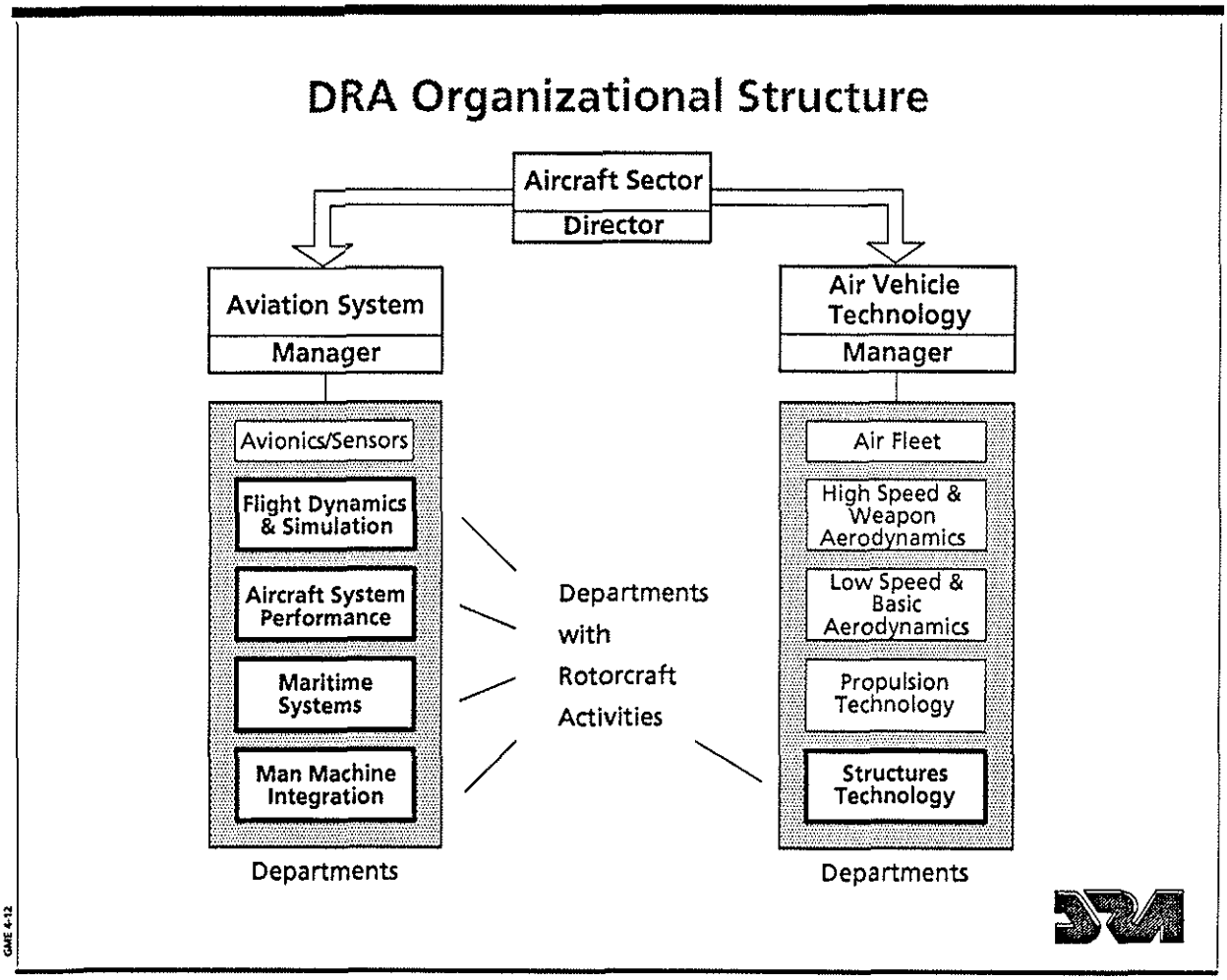


The systematic and intensive utilization of wind tunnel test technique in helicopter projects will substantially reduce development risk and time. For this purpose dedicated test facilities have to be available that allow flexibel adaption to the specific problem under investigation. Moreover, procedures for the preparation, the conduction and the analysis of wind tunnel tests have to be developed in order to produce high quality and reliable data in a short time. With DNW's capabilities in mind, DLR together with ECD built-up a modular test rig for configurational helicopter tests using Mach scaled rotors up to 4.2 m diameter. The measurement system, control system, quick-look system, and the data acquisition and analysis system are designed for ambitious and extensive test programmes. In order to reduce the wind tunnel occupation time a preparation facility was built-up in Braunschweig allowing the model integration, the system check and the calibration of the total measurement system without wasting wind tunnel test time in the DNW.

The test facilities are continously improved and have been used during more than 10 years in a great number of research programmes and for project support. Recently a first NH 90 test programme was completed, using DLR's modular test rig, a model rotor provided by EUROCOPTER, and the fuselage model provided by NLR.

3.2 DRA

Organizational Structure



The helicopter platform activities of DRA are mainly within one of the 11 Business Sectors, the Aircraft Sector, and there largely within the Departments Structures Technology, Flight Dynamics & Simulation, Man-Machine Interface, and Propulsion Technology. Minor activities are within the Aircraft System Performance and the Maritime Systems Departments.

In the Applied Research Programme the Tri-Service Helicopter Package is the main focus for helicopter research and is organized to meet a number of research objectives of which those most closely related to platform technology are:

- Mobility and Agility: To investigate techniques that could improve the mobility and agility of helicopters in all roles. This area includes research on helicopter specific topics of propulsion systems including the need to extract high power bandwidth response from small and lightweight engines, and the need to operate in more hostile climatic environments. Much of the work is collaborative with Rolls-Royce. Rotor technology and flight control are also included.
- Sortie Generation: To improve sortie generation, maintainability and reduce the life cycle costs of helicopters. This area includes research on materials and environmental degradation, prediction and control of vibration, electro-magnetic hardening and modular avionic system development.
- Day/night operations: To improve the capability to operate in poor weather conditions and at night with very high availability.

The Strategic Research Programme is organised on a broad technology base including research directly and indirectly applicable to the helicopter.

DRA Main Helicopter Research Topics

- Rotor Technology
- Structural Dynamics
- Structural Acoustics
- Flight Dynamics & Simulation
- Man-Machine Interface
- Materials Technology
- Propulsion Technology

The programmes relevant to the main helicopter platform technologies include the following subjects.:

- Rotor Technology
  - British Experimental Rotor Programme: BERP3 blade design
  - Coupled Rotor Fuselage Model (CRFM) for rotor loads prediction
  - Mach scale rotor testing techniques for large wind tunnels
  - rotor icing research.
- Structural Dynamics
  - improvement of structural models and optimisation methods
  - shake testing techniques: multi-shaker, in-flight excitation
  - airframe response minimisation by passive optimisation and Active Control of Structural Response (ACSR).
- Structural Acoustics
  - Noise Path Identification Technique: understanding of the main transmission modes and identify alleviation strategies.
- Flight Dynamics & Simulation
  - flying qualities of ACT-helicopters including carefree handling systems and rotor state feedback control concepts
  - flying qualities in ship operations for extending operating limits and improving safety margins
  - enhancing the fidelity of ground-based simulators for research and training.
- Man-Machine Interface
  - development of integrated cockpit night vision systems
  - development and integration of Visually Coupled Systems (VCS).

DRA Main Facilities for Helicopter Platform Research

- 6 Experimental Helicopters (2 Lynx, 3 Sea Kings, 1 Wessex)
- Advanced Flight Simulator (large motion system)
- 5m Pressurized Low Speed Wind Tunnel
- 24 ft Low Speed Wind Tunnel
- Mach Scale Model Rotor Test Rig (3m rotor diameter)
- Hover Test Facility
- Helicopter Operational Visual Engagement Real-Time Simulator (HOVERS)
- Structural Dynamics Test Facility

The experimental aircraft of DRA include 6 helicopters: 2 WHL Lynx, 3 WHL/Sikorsky Sea Kings and 1 WHL Wessex.

For helicopter research the major wind tunnels include the 5 m pressurized low speed wind tunnel, the 24 ft low speed tunnel and numerous other facilities for small scale and component testing. Test capabilities include a facility for testing Mach scale model rotors up to 3 m diameter in hover and forward flight up to a maximum speed of about 200 kts.

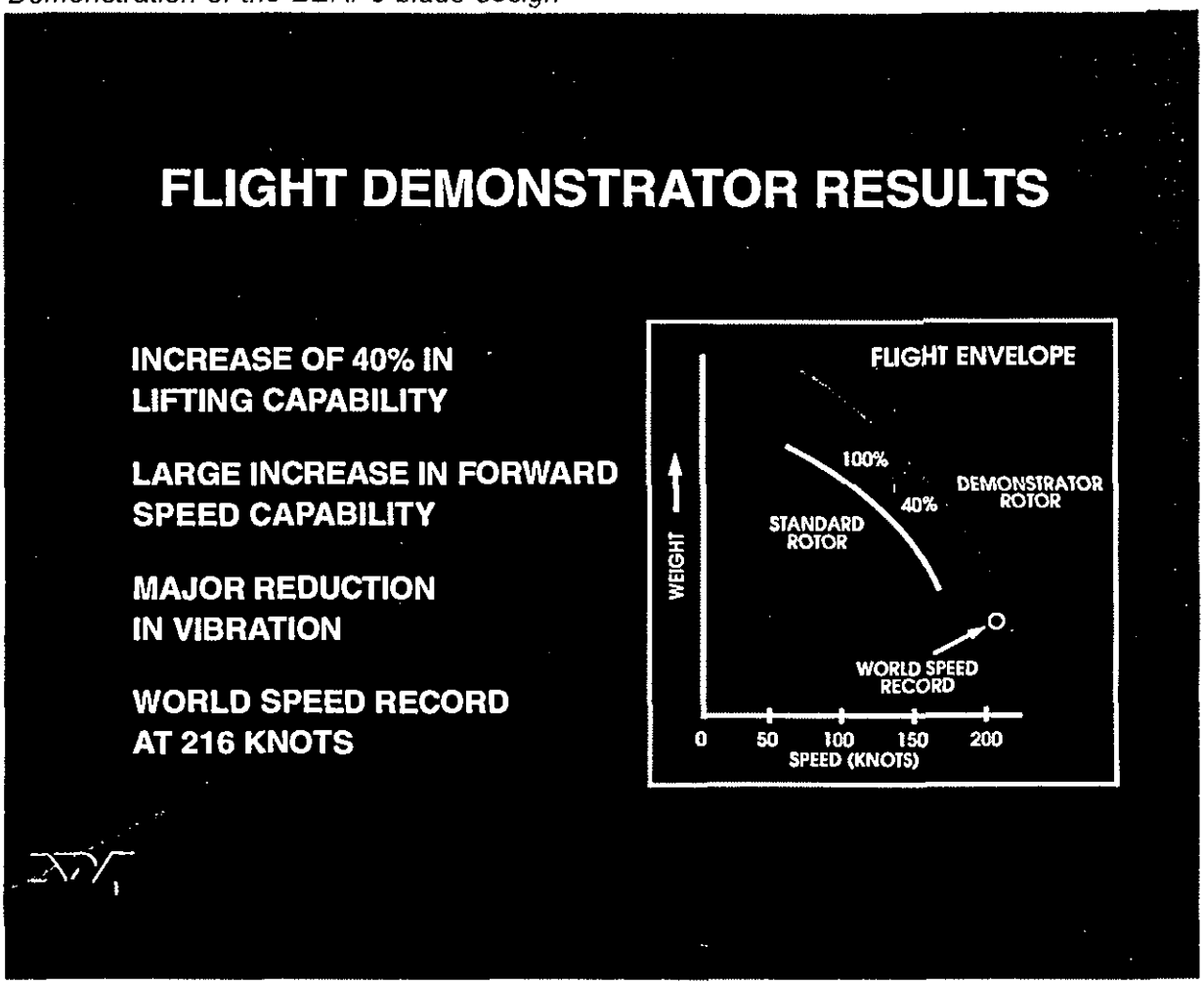
A range of fixed and moving base flight simulation facilities are available for helicopter research, from the Advanced Flight Simulator with a large motion system, through combat simulators to fixed base tactical mission simulators.

Full scale engine test cells, facilities for the simulation of individual engine stages, a large anechoic chamber (Noise Test Facility) for engine noise experiments are part of a comprehensive range of simulation and test facilities for all aspects of helicopter research.

Various super computers, the structural dynamic test facility, the electro-magnetic compatibility and hazard test facility, the GPS simulator and other facilities are also used for rotorcraft activities.

Representative Results/Accomplishments

Demonstration of the BERP3 blade design

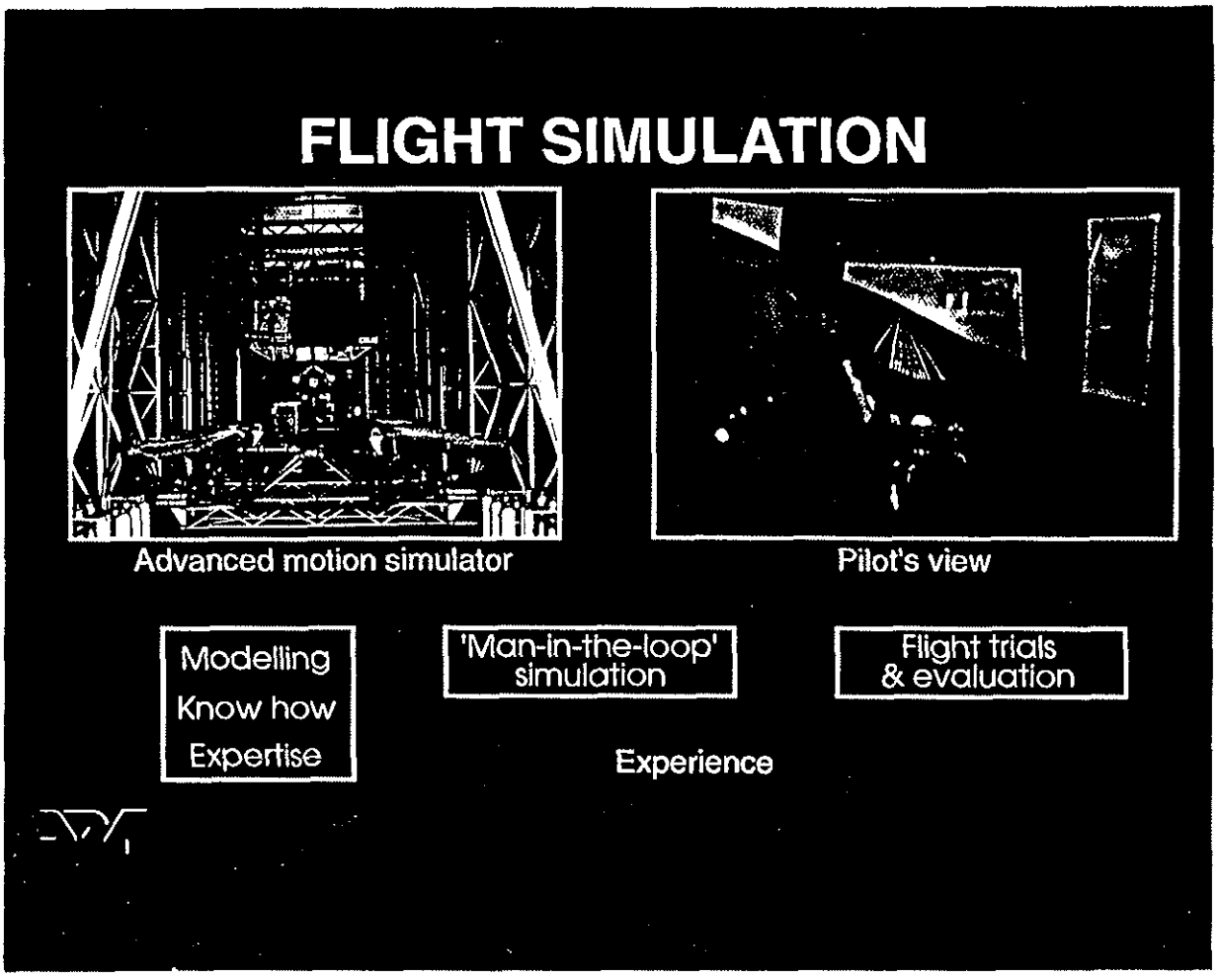


The British Experimental Rotor Programme involved close collaboration between the DRA and WHL and led to the highly successful demonstration of the BERP3 blade design, which exploits the ability conferred by composites for fully three dimensional design employing distributed aerofoil sections and a large swept tip. The demonstrator blade, flown on a LYNX helicopter by WHL, proved a 40% increase in lift compared with the standard blade and established a World Speed Record for helicopters at 400 km/h. This blade is now the production standard for LYNX and has been adopted as a retrofit for in-service LYNX helicopters worldwide. BERP3 technology is also incorporated into the EH101 main rotor design.

Current research programmes are pursuing the basic approach established by the BERP3. Advanced aerofoil design using state of the art CFD methods backed by unsteady aerofoil testing in the Aircraft Research Association aerofoil tunnel, is combined with development and validation of rotor loads prediction methods and the development of CFD for the prediction of pressure, particularly in the tip region and to interface with acoustic models.

The development of CFD methods for application in routine design studies to rotor flows lags those for application to fixed wing aircraft because of the added complexity and the DRA therefore currently concentrates on small perturbation theory and full potential methods and their coupling with the comprehensive rotor analysis to provide hybrid prediction methods.

The development of methods for the accurate prediction of acoustic signature and the development of techniques and rotor designs for signature reduction or manipulation are studied experimentally and theoretically for both civil and military applications. The modelling of the various noise sources associated with the helicopter is a core activity and other work is directed to the development of the Kirchoff approach for incorporating compressibility effects into the acoustic calculation.

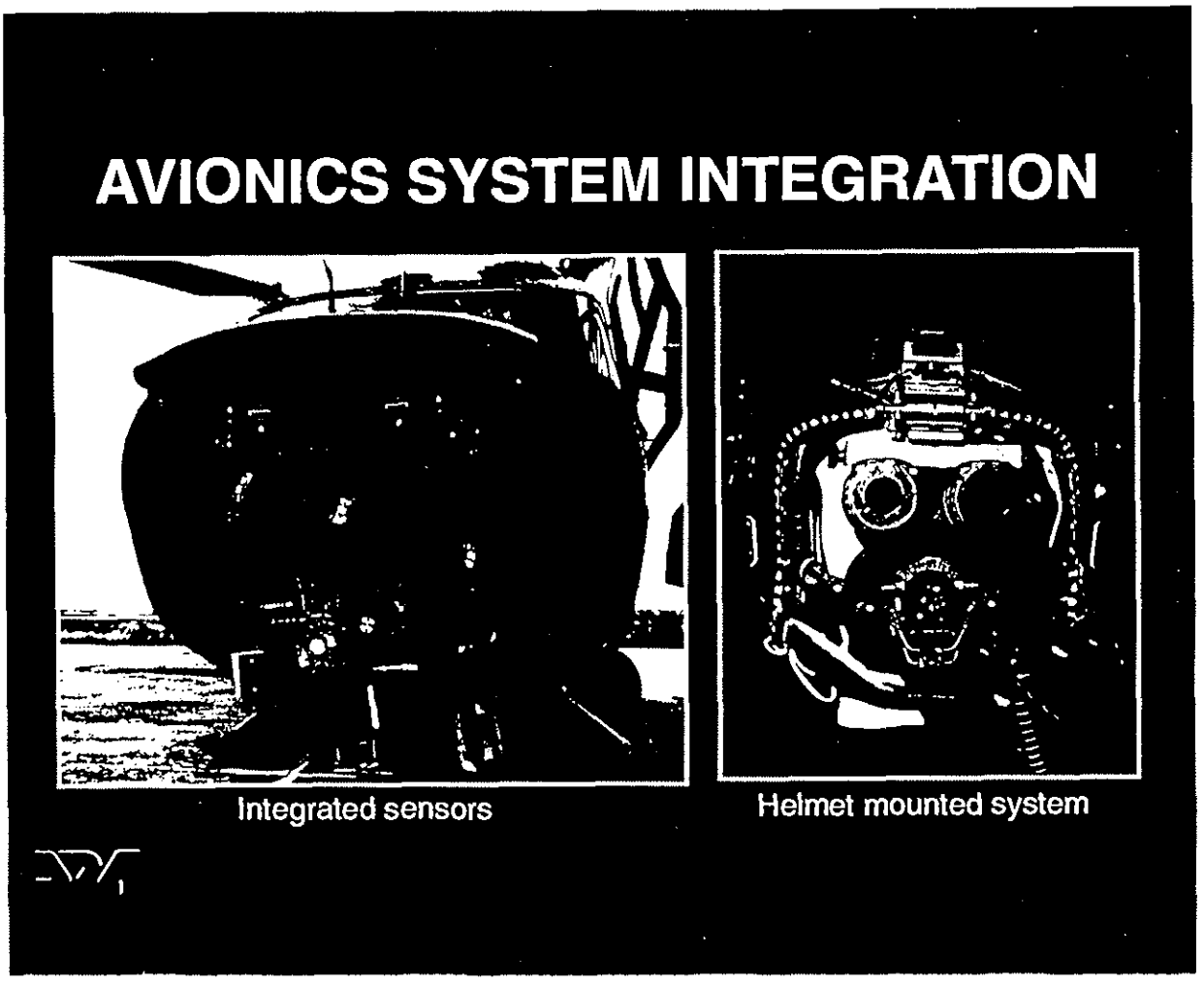


DRA's Advanced Flight Simulator at Bedford is an essential facility for all aspects of man-in-the-loop helicopter & V/STOL simulations.

In flight control research emphasis is on enhancing agility by improving the precision and ease of flight path control, thus making more of the inherent capability of the helicopter available to the pilot through advances such as ACT and carefree handling systems and the introduction of novel control concepts such as rotor feedback.

Correlation of pilot workload with task performance and flying qualities for rotorcraft mission tasks have been central themes of DRA's research programme. The aim is to establish a database of response and control activity for high workload tasks, and develop metrics for pilot workload for comparison with pilot assessments.

Significant emphasis is now being placed on the study of flying qualities in ship operations as a route to extending operating limits and improving safety margins in the harsh environment of the helicopter/ship interface. Enhancement of the fidelity of ground based simulators both for research and also as training aids is an important related objective. Improvements in ship airwake turbulence models, and models for the prediction of helicopter response characteristics, are utilised in the development of operating strategies hover/landing visual aids for all weather operations and analysis of their subsequent validation in flight trials. Earlier DRA programmes contributed to the establishment of the US ADS33C standard for handling qualities requirements for military rotorcraft, which treats operation in degraded visual environments through the concept of the usable cue environment. Current work is seeking to quantify the interaction between sensor/display combinations and the aircraft handling qualities particularly in operations in poor weather and at night and to consider the extension of ADS33C to provide a better match to high workload maritime tasks such as helicopter/ship operations.

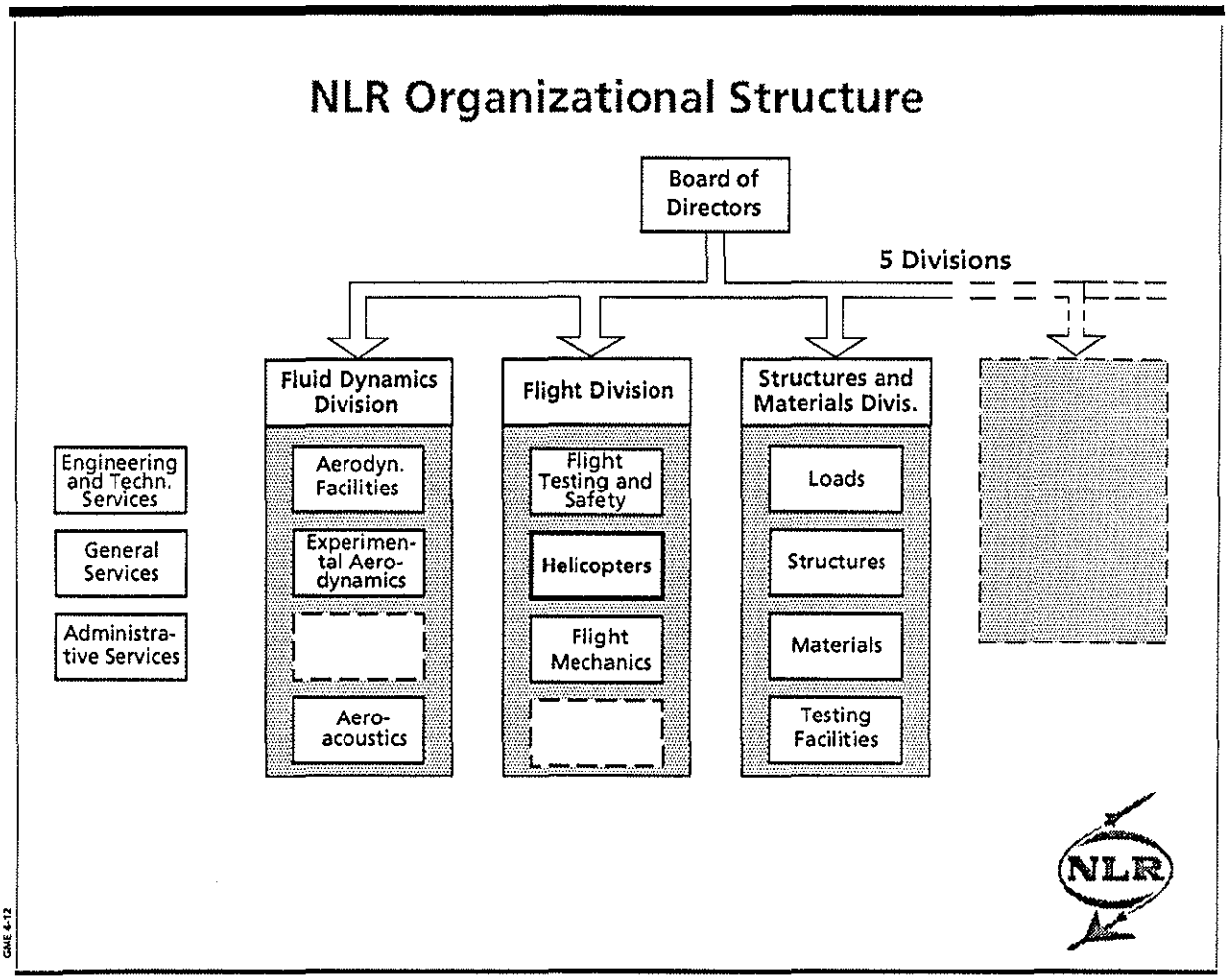


In the area of man-machine interface DRA covers the development of integrated cockpit and night vision systems to provide high levels of aircrew situation awareness by operating "head up, eyes out" with minimum crew workload. A key area is concerned with the development and integration of Visually Coupled Systems (VCS) comprising a head position sensor, high resolution thermal imager, and a high quality helmet mounted display, and the determination of the effectiveness of such systems in various mission phases. VCS research embraces simulation and flight research into fundamental visual/motor relationships, helmet mounted display technology and appropriate symbology, image generation, head tracking systems, the integration with navigation systems and flight control, and quantifying the resulting benefits in aircrew workload.

Related research programmes address the pilot interface more generically to study display technology, situation awareness, workload assessment and reduction, lightweight helmet displays, and novel modes such as direct voice control. Aircrew workload generally is addressed through research on mission planning aids utilising knowledge based systems, and the integration of tactical decision aids.

3.3 NLR

Organizational Structure



NLR's activities are organized in five major research divisions: Fluid Dynamics, Flight, Structures and Materials, Space, and Informatics. These research divisions are supported by the Engineering & Technical Services, General Services, and Administrative Services. Multidisciplinary project teams are formed if required in order to meet the customers needs concerning quality, planning, security, and costing of the investigations.

The Flight Division is subdivided in 9 Departments: Flight Testing and Safety, Helicopters, Flight Simulation, Flight Mechanics, Operations Research, Aircraft Instrumentation, Air Traffic Management, Man-Machine Integration, and Transport and Environmental Studies. Originally integrated in the Flight Testing and Helicopter Department a new Helicopter Department was formed recently, showing the growing interest of NLR in Helicopter research and development activities.

Although the main rotorcraft work is located in the Helicopter Department, other departments and other divisions contribute to the programmes and support these vehicle oriented tasks with their experience and know how in the respective disciplines.

NLR Main Rotorcraft Research

- Helicopter and Systems Evaluation
- Performance, Stability and Control Analysis
- Helicopter and System Flight Tests
- Helicopter-Ship Qualification
- Helicopter Simulation Development
- Support to Industry in NH 90 Design and Development

In order to meet the national/international, civil and military customers future needs NLR is active in the following research areas:

- Mathematical Modelling
  - flight performance and flight dynamics codes
  - manoeuvre criteria evaluation program
- Rotorcraft Identification
  - six-degree of freedom models, higher order models
- Simulation
- Helicopter-Ship Operations
- Helicopter Aerodynamics
  - airfoil design/optimization codes
  - 3-D rotor codes, based on propeller/wind turbine programs
  - fuselage aerodynamics, 3-D potential and boundary layer flows
- Aero-Elastics and Vibrations, Rotor Dynamics
- Aeroacoustics
  - external/internal acoustics
- Tilt Rotor Concept Analysis
- Structures/Materials/Crashworthiness
- Avionics

The outcome of these research activities form the basis to assist helicopter manufacturers and operators and to contribute to certification and operation procedures.

NLR Main Facilities for Rotorcraft Research

- **Wind Tunnels**
  - Pilot tunnel for steady and unsteady airfoil tests
  - Transonic Wind Tunnel HST for airfoils and blade tip configuration tests
  - Low Speed Tunnel LST (3mx 2.25m) for fuselage and component tests
  - German/Dutch Wind Tunnel DNW (Joint NLR/DLR Facility) with different test sections for rotor and helicopter testing
- **Helicopter Flight Test Data Acquisition System HEDAS**
- **National Simulation Facility NSF**
  - Pilot-in-the-loop flight simulation using complex real-time helicopter models

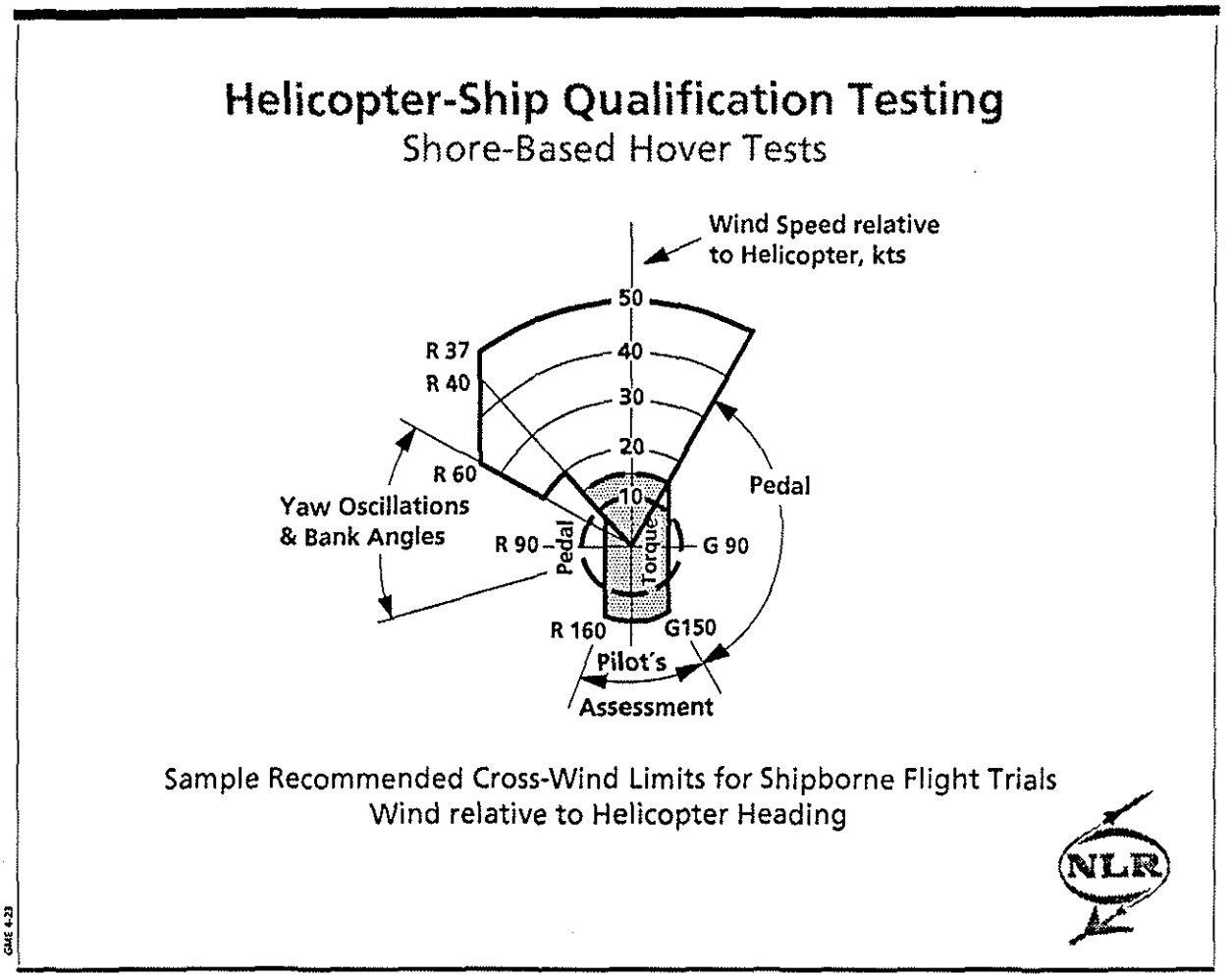
NLR's facilities being applied for helicopter activities include

- different wind tunnels with broad coverage of speed and Re-number ranges,

- a new measurement system for use on board helicopters during helicopter/ship qualification testing, the helicopter flight test data acquisition system HEDAS, and

- the newly developed flexibel and versatile National Simulation Facility NSF as an extension to NLR's existing flight simulators. The basic NSF is planned to be completed by end of 1994. Developments in following phases include making possible low-level flight simulation, mission rehearsal and helicopter simulation.

These facilities are or will be used in research tasks as well as for project support.



Helicopter operations are restricted by limitations specified in the flight manual. Apart from engineering limitations (weight, centre of gravity, airspeed, power, etc.), flight manuals give a few operational limitations such as for flight in icing conditions and for landings on slopes.

Operations on board ships, however, require special procedures which give additional limitations. These limitations are not supplied by the helicopter manufacturer, since they depend to a large extent on the ship involved and its environment.

In the past 25 years the NLR has gained a great deal of experience in the determination of limitations for helicopter operations from ships. NLR has carried out test programmes for a variety of helicopter-ship combinations, under contract of Dutch and foreign customers.

In close cooperation with customers, test programmes are carried out to determine the limitations that ensure safety during operations. These test programmes consist of the following parts:

- wind tunnel tests on a scale model of the ship;
- full-scale measurements of airflow on board the ship;
- measurements of ship motions at sea;
- shore-based tests of helicopter performance at low speed;
- ship-based helicopter flight tests.

Operational limitations are derived from the test programmes for:

- take-off and landing procedure;
- deck handling.

The results of the qualification testing are presented in comprehensive graphs showing the operational limitations and ensuring an optimal operational availability for the helicopters on board ships.

The increasing complexity of modern helicopters requires an increasing effort of the operators during the operational life. A considerable effort may already be necessary in the pre-operational stage, when various helicopter types are evaluated in order to determine a particular type and its equipment, which best fulfills a particular operational requirement.

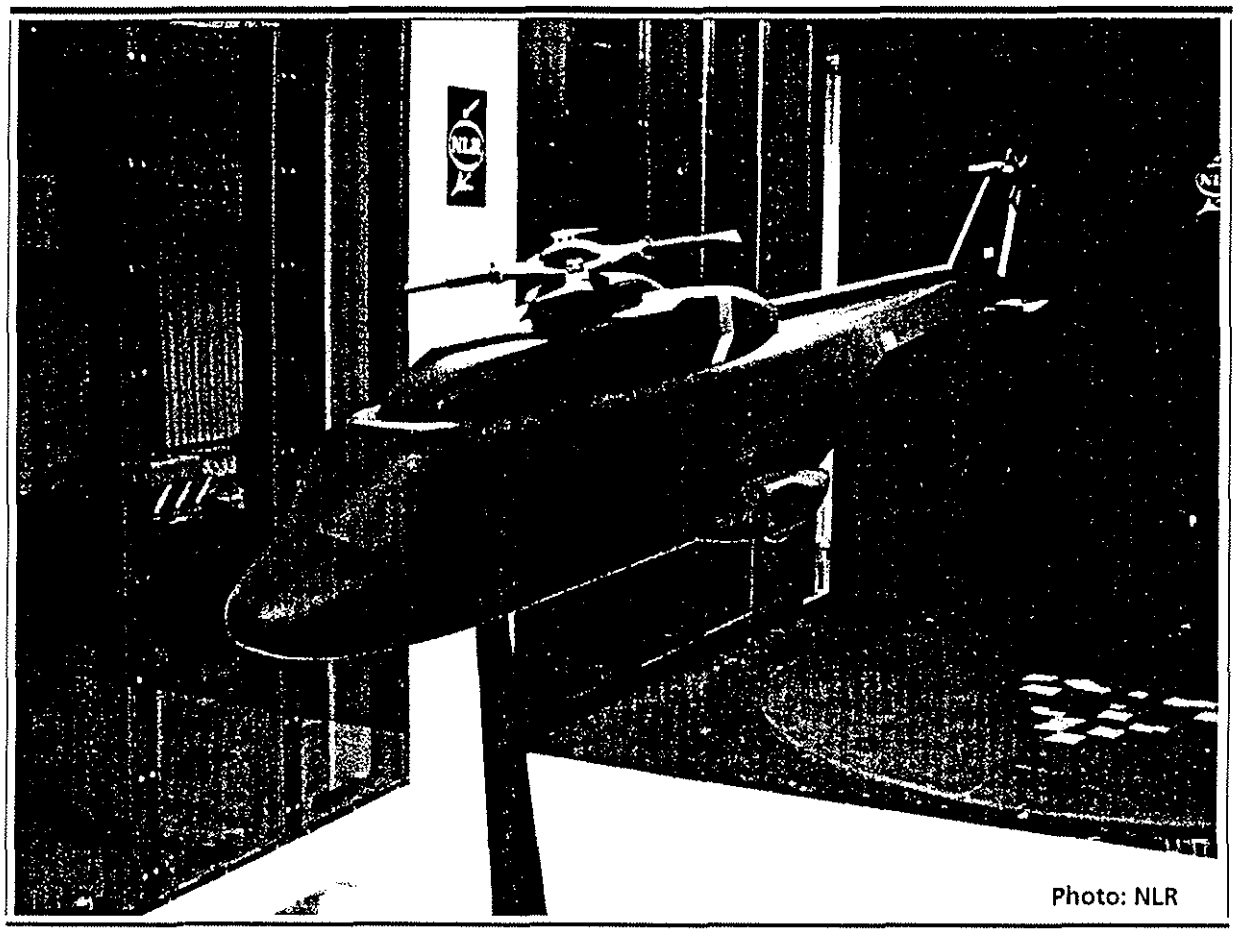
An example for NLR's activities in this area based on the expertise in helicopter technology is the support given to the Royal Netherlands Navy in connection with the introduction of the Westland Lynx helicopter:

- participation in the relevant evaluation working group;
- execution of performance calculations in connection with the desired missions;
- analysis of basic design, and of the results of strength and fatigue tests on rotor and undercarriage.

The use of the Lynx under various weather conditions from ships with small flight decks requires the establishment of additional operational limitations to ensure an acceptable safety level. The efforts of NLR in a number of test programs on various classes of ships have been:

- organization of test program;
- design, installation, operation of all required test equipment;
- data gathering and analysis;
- determination of the operational limitations.

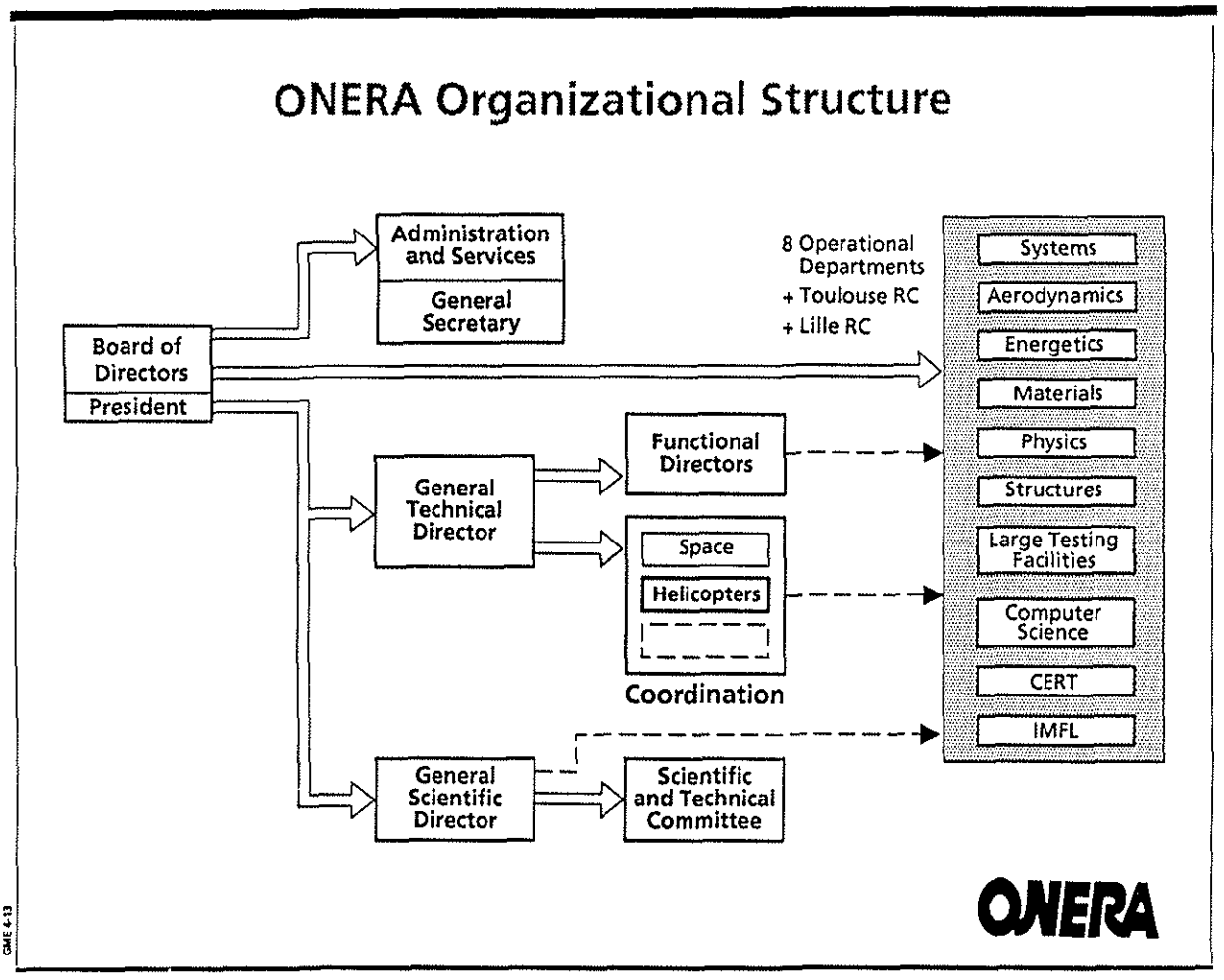
Fuselage Model of NH90 in the Low Speed Wind Tunnel LST



Together with Fokker and DAF Special Products, NLR has taken a share in the design and development phase of the NH90 programme, for a NATO helicopter for the nineties. A wind tunnel test was conducted in the LST using a 1:10 scale fuselage model designed and manufactured by NLR. Supporting activities were carried out for the Programme Office NH90.

3.4 ONERA

Organizational Structure

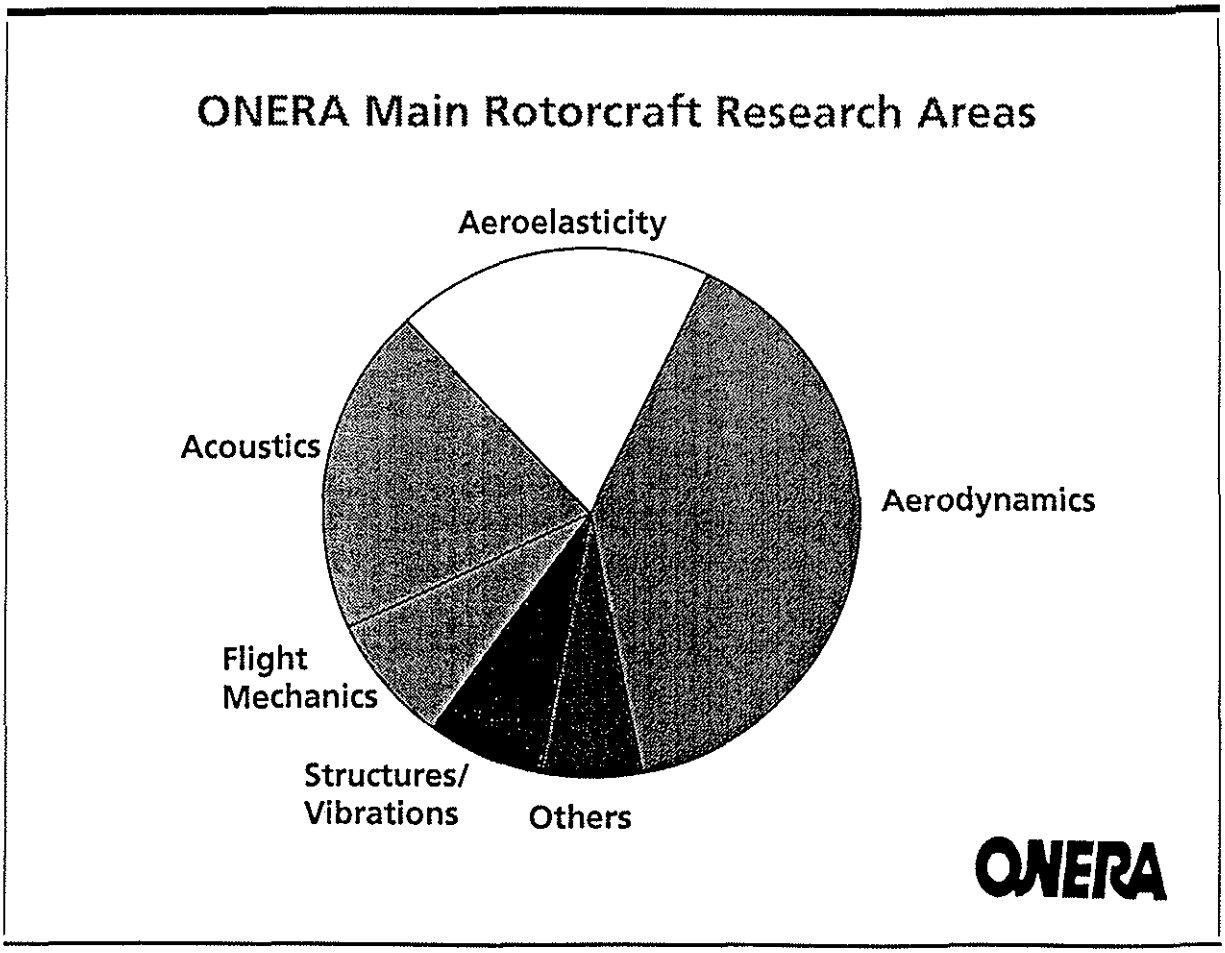


The scientific-technical expertise of ONERA is located in the 8 Operational Departments and the Toulouse and Lille Research Centers. The Operational Departments are mainly organized by disciplines: Systems, Aerodynamics, Energetics, Materials, Physics, Structures, Large Testing Facilities, and Computer Science. The Toulouse Research Center CERT and the Lille Research Center IMFL are by itself interdisciplinary organizations covering a broad field of aerospace activities.

The President directs the scientific and technical activity at ONERA, supervises the execution of the programmes, and prepares the budgets. He is assisted by a General Secretary, a General Scientific Director, and a General Technical Director.

The General Scientific Director is responsible for preparing the long term scientific policy of ONERA. The General Technical Director coordinates the activities of the Operational Departments. He is assisted by different Functional Directors and by a team of high-level engineers to coordinate the activities with respect to specific applications, like Space, Turbomachines, and Helicopters.

This organizational structure allows to assign the research activities in the different departments, the necessary support of the scientific technical facilities and the other resources to the specific applications, programmes, and contracts.



The actual rotorcraft research studies at ONERA include the following main subjects:

- Basic Tool Improvement, Validation and Development Studies
  - free wake code for low speed configurations
  - hovering rotor code
  - power prediction from CFD codes
  - dynamic stall on rotors
  - separated flows and drag prediction for fuselage
  - aerodynamic code for the complete aircraft
  - comprehensive aeroelastic codes
  - BVI and impulsive quadrupolar noise codes
  - comprehensive handling qualities code.
- Experimental Studies in Wind Tunnels and in Flight.
- Applied Research and Development Programmes
  - aerodynamic and vibratory rotor performance improvements (ORPHEE Programme)
  - aeroacoustic rotor optimization (ERATO Programme)
  - active control technology and methodology for rotors
  - helicopter vibration prediction and minimization
  - participation in designing future quiet helicopters, in smart helicopters realization, and in stealthy helicopter studies.

In addition to these research tasks activities for direct project support are accomplished, using the methods and facilities available.

ONERA Main Facilities for Rotorcraft Research

- Wind Tunnels (S1 MA, S2 Ch, CEPRA 19, etc.)
- Test Rigs (rotor and helicopter rigs for different wind tunnels)
- Super Computers
- Laser Doppler Velocimeters

External Facilities:

- CEV Ground-Based Flight Simulator
- CEV Dauphin 6075 Helicopter for Multipurpose Research (Mid 1994 +)
- ECF Demonstrator Aircraft

ONERA

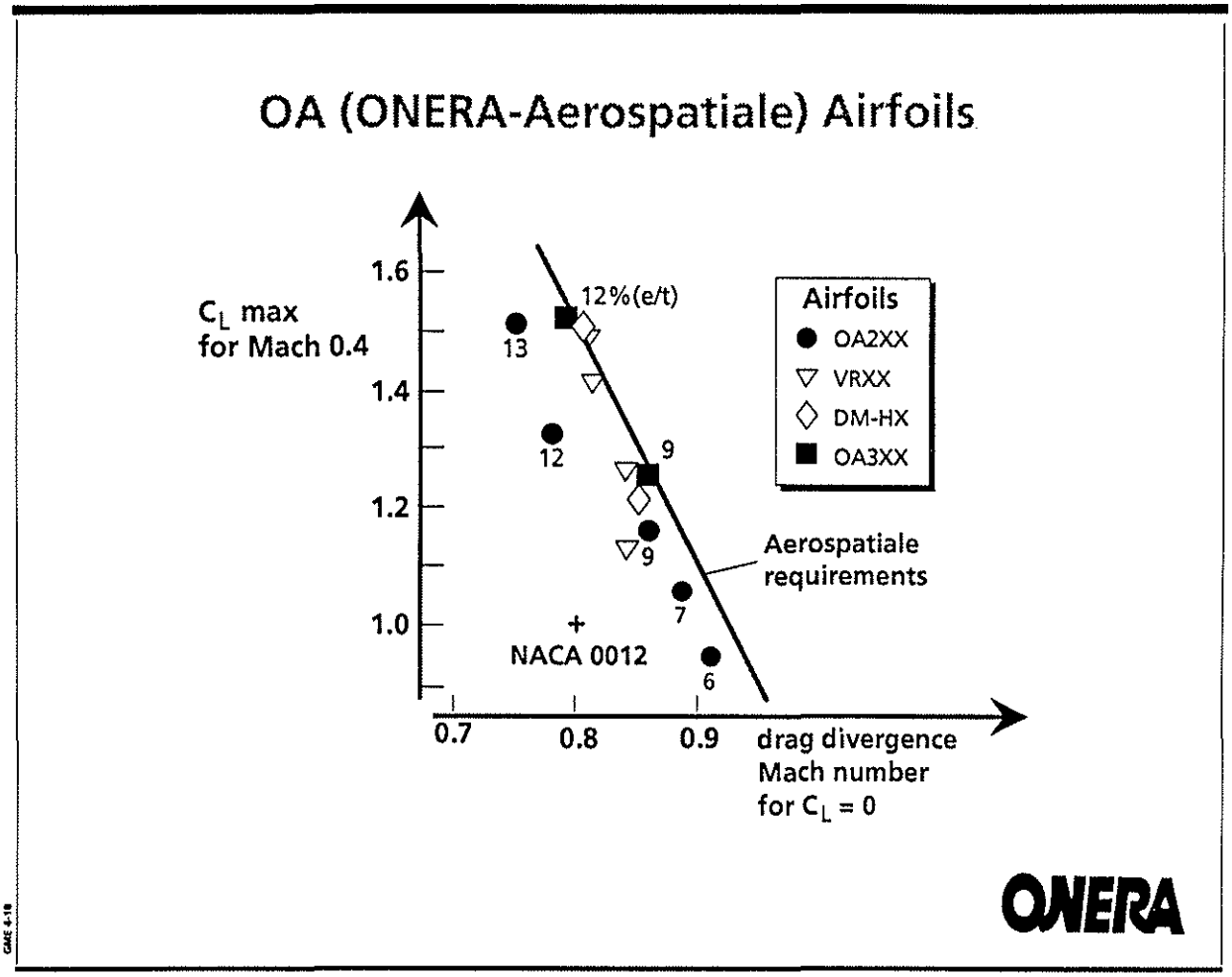
Corresponding to the big effort ONERA has concentrated in the aerodynamic field wind tunnels and the respective helicopter, rotor and component test rigs play a major role in ONERA's experimental studies. In addition, the flightmechanical research requires access to corresponding facilities which has been ensured via cooperative programmes with other organizations, like the French test center CEV, the national helicopter industry ECF, and international cooperation partners like DLR.

In particular the following facilities are utilized for rotorcraft research:

- S1 Modane Wind Tunnel (Ma $\leq$ 1, 8 m diameter test section)
- S2 Chalais Wind Tunnel
- CEPRA 19 Anechoic Wind Tunnel
- Wind Tunnels for Component Tests (airfoils, fuselage, etc.)
- Rotor Test Rig for S1 MA Wind Tunnel
- Rotor Test Rig for S2 Ch Wind Tunnel
- Rotor Test Rig for CEPRA 19 Wind Tunnel
- Powered Dauphin Helicopter Model for S2 Ch Wind Tunnel
- Hover Test Rig for Stability Research
- Super Computers
- Laser Doppler Velocimeters
- CEV Ground-Based Flight Simulator
- CEV Dauphin 6075 Multipurpose Research Helicopter
- ECF Demonstrator Aircraft.

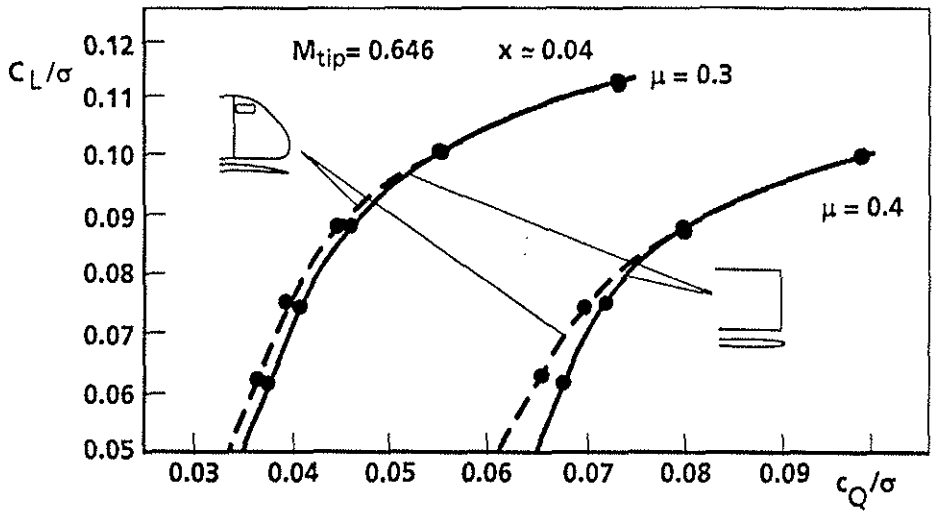
These facilities are used in research task as well as for project support.

Helicopter Airfoils



Based on requirements of Aerospatiale (now Eurocopter France) ONERA designed several airfoil families for helicopters. The OA2 airfoils, representing a big step beyond the standard airfoils, are used on the French Ecureuil and Dauphin helicopters. The OA3 airfoils have been defined by using an automatic optimization code and will be used for the NH90 helicopter. New airfoils (OA4) have just been defined for future optimized rotors in the framework of the ORPHEE Programme. This research programme in cooperation with ECF, and to some extend with ECD and DLR, is devoted to performance and vibrations optimization for helicopter main rotors.

Forward Flight Performance on Model Rotor
(MODANE wind tunnel test)

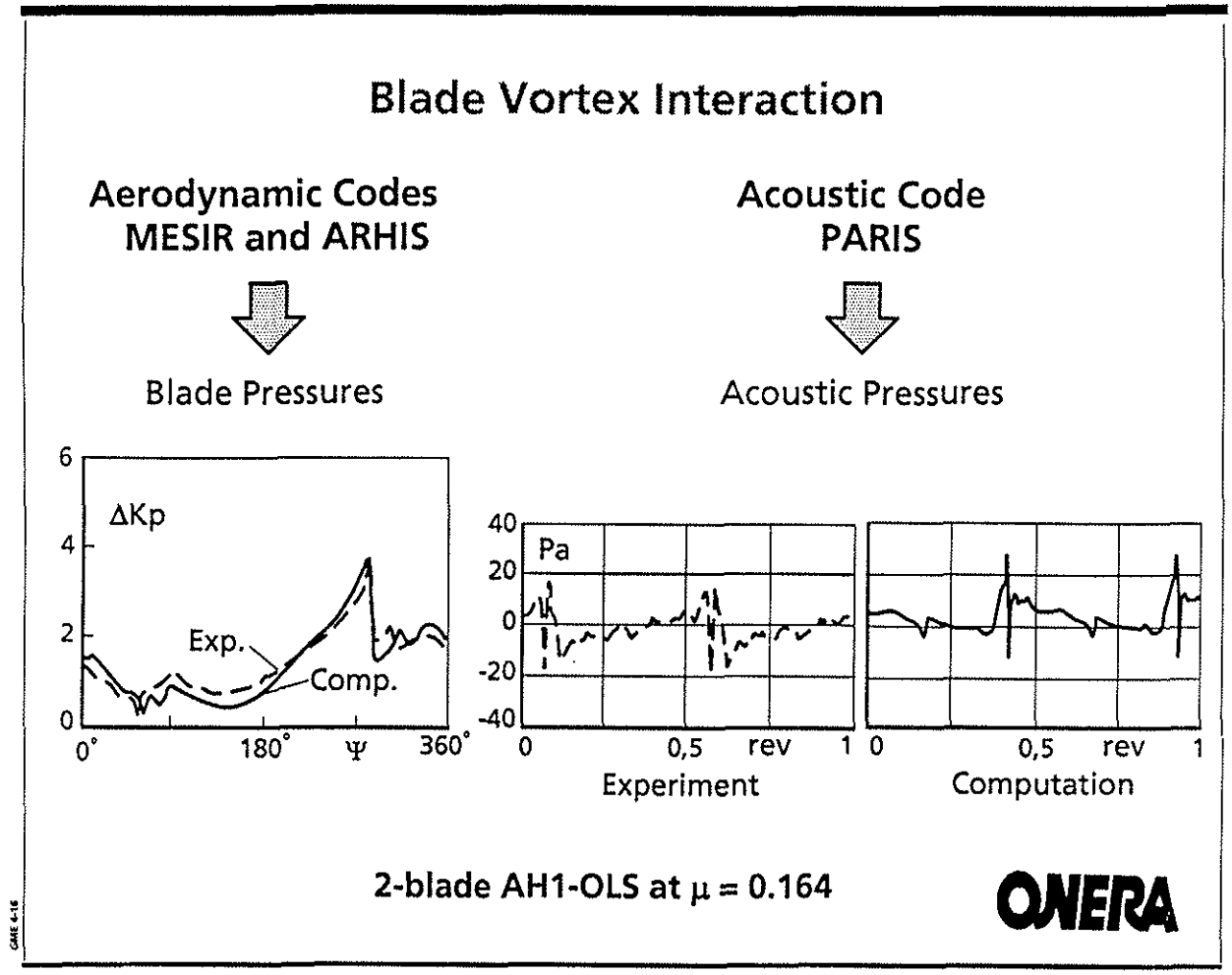


ONERA

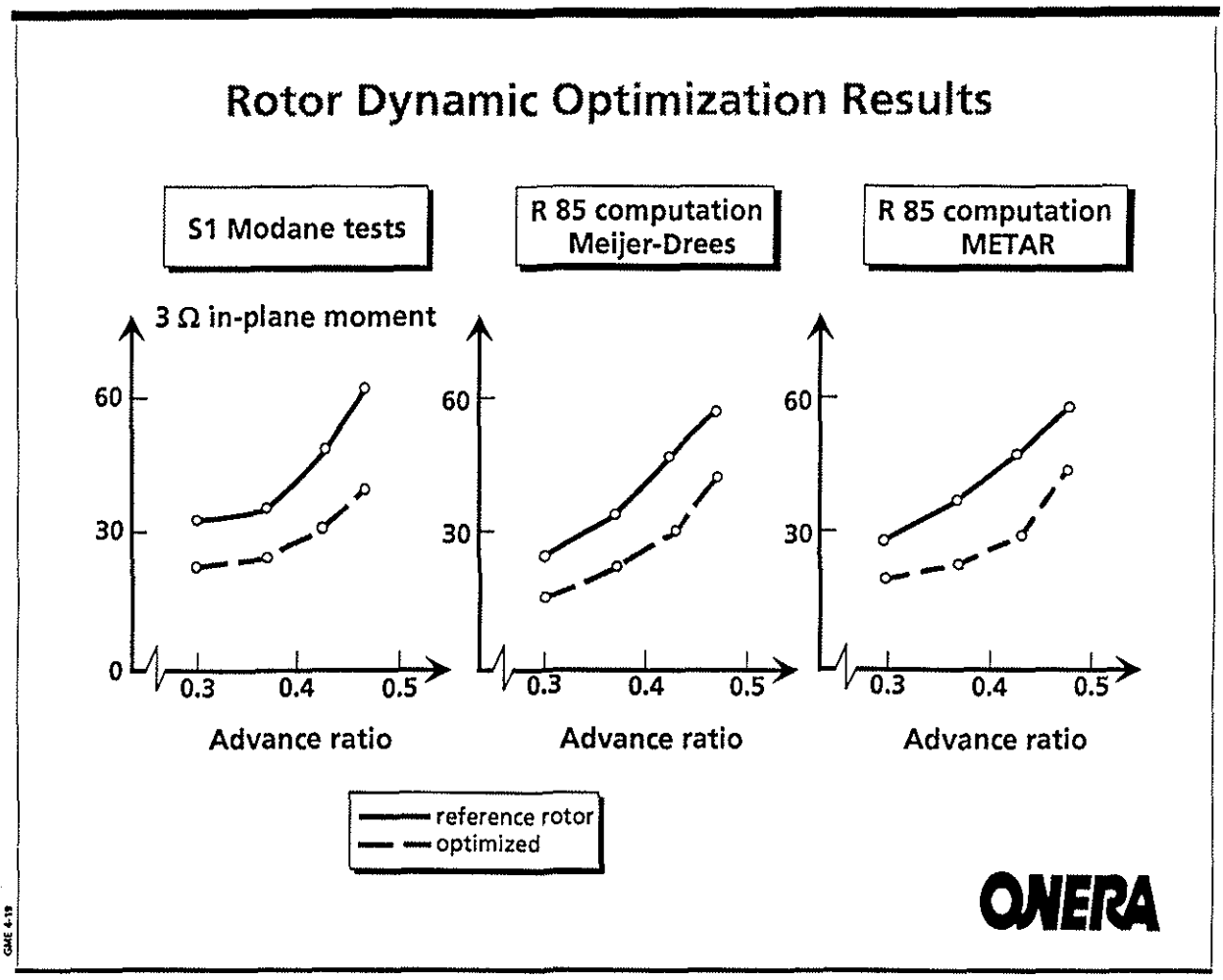
GME 4-17

In order to increase the main rotor performance ONERA designed new parabolic and anhedral blade tip shapes. The model rotor measurements performed in the S1 Modane Wind Tunnel confirmed the performance improvement obtained in flight on the Super Puma Mk2 helicopter. The new type of blade tips have been defined by using ONERA's Transonic Small Perturbation (TSP) code. The blade tips are used for the Tiger helicopter, for the ECF high speed demonstrator DGV 200, and will be used for the NH90 main rotor blades.

These results demonstrate the main effort ONERA places in the field of aerodynamic research with particular emphasis on the industrial application.

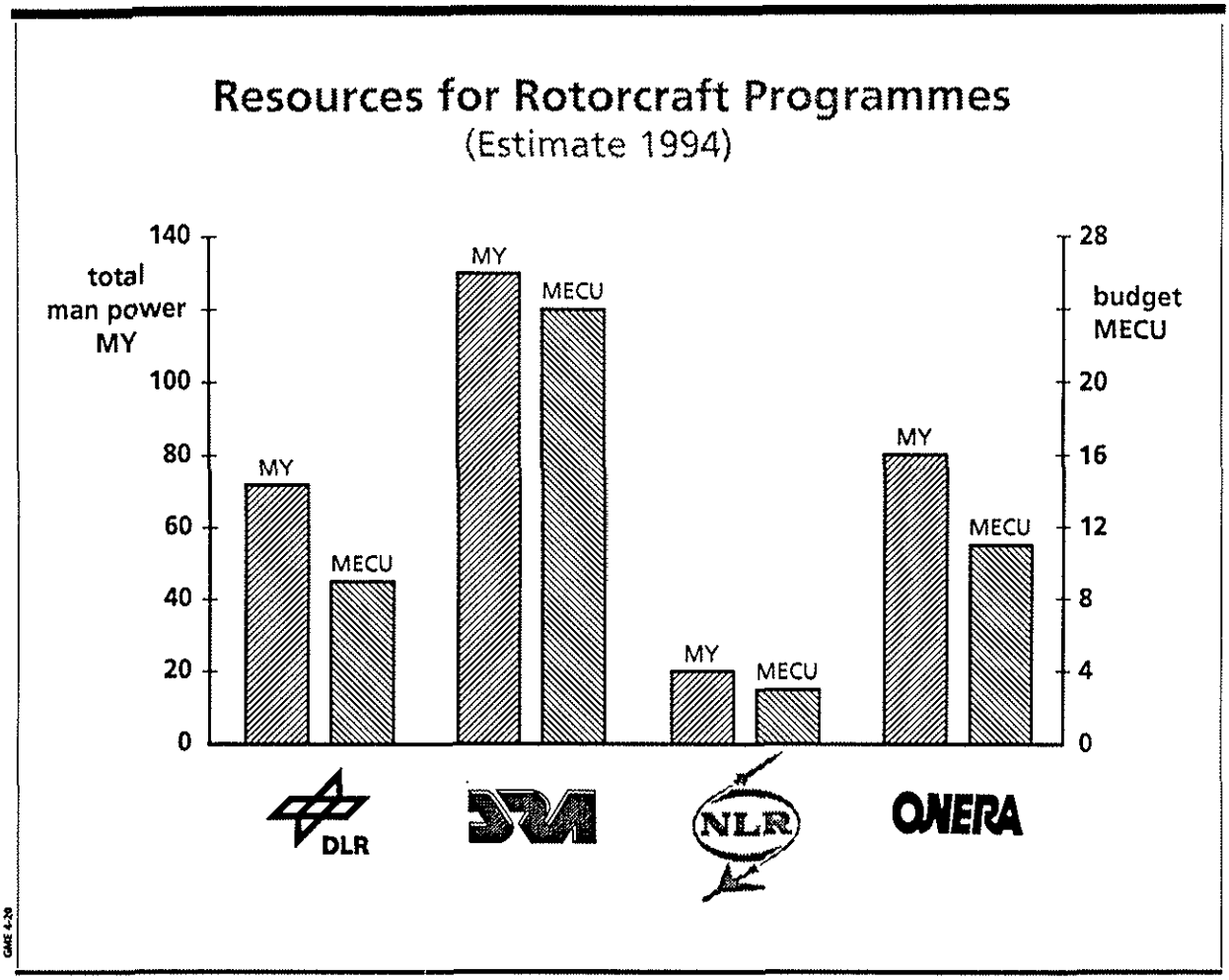


In the field of rotor noise prediction ONERA is active in code development. The comparison of calculated blade pressures and acoustic pressures with experimental data collected at DNW for a simulated helicopter descent flight including BVI phenomena shows good agreement. The codes developed by ONERA include a free wake lifting line code (MESIR), a special code for blade pressure prediction in case of close blade vortex interaction (ARHIS), and an acoustic code based on the Ffowcs Williams and Hawkings equation (PARIS). These prediction codes are continuously improved and validated by experimental data and subsequently used for designing efficient rotors in the respective programmes.



ONERA designed a low vibration rotor by optimizing the internal structure of the rotor blade. For the design ONERA used the R 85 aeroelastic rotor code of ECF with different rotor wake representations (Meijer-Drees, METAR prescribed wake) and coupled with the optimization code CONMIN. The results obtained for the 3Ω in-plane unsteady moments are very promising as shown by the comparison of respective tests in the S1 Modane Wind Tunnel. The calculations for the reference and the optimized rotor using the different versions of the R 85 code show the same trends and improvements.

The development of aeroelastic codes for designing efficient rotors has high priority at ONERA. These codes are used in the ORPHEE Programme, a joint ONERA/ECF/ECD/DLR programme for rotor optimization.



Reviewing the organizational structure, the main activities, the facilities and also the representative results of the individual research establishments, the difficulties in estimating the actual resources spent for the rotorcraft programmes in the different countries become obvious. The structure of some establishments does not allow to specifically segregate the helicopter activities.

The inclusion of the cost of flying, of wind tunnels, and other large facilities is not clear in each case as well as the consideration of external contracts and extramural research. Nevertheless, the numbers with respect to the total man power and the 1994 budget are the best guess of responsible managers deeply involved in the respective rotorcraft programmes.

As can be seen, the rotorcraft activities of ONERA and DLR are similar in size as their mission and the position in the respective country's system resemble strongly, although other characteristics differ substantially, and the fields of main emphasis are quite different. The rotorcraft activities of DRA exceed the others by far, corresponding to the estimation of the resources. This may reflect the deep involvement of DRA in system and function related military research and development programmes, which in the other countries are assigned to specifically dedicated government organizations. The rotorcraft activities of the Dutch NLR are relatively small but growing in parallel to the increasing helicopter operations and the industrial development share in this country.

1 ECU = 2.0 DM = 2.3 HFL = 7.0 FF 0 0.7 UKL (= 1.25 US$)

4. Cooperative Rotorcraft Research in Europe

4.1 GARTEUR [1)]

GARTEUR

Group for Aeronautical Research and Technology in Europe

- Member Countries: France, Germany, Netherlands, Sweden, United Kingdom
- Mission: Collaborative research activities in basic aeronautics
- Incorporation of Governments and Industry, civil and military research
- Presently 200 specialists involved, appr. 50 man years/year
- Activities in Aerodynamics, Flight Mechanics, Helicopters, Structures & Materials, Propulsion Technology

GARTEUR

The Group for Aeronautical Research and Technology in Europe (GARTEUR) is the major European research organization in the field of aeronautics.

- includes European countries with major aeronautical research capabilities and government funded programmes;
- was established as an independent organization under the provisions of a Memorandum of Understanding between the Governments of France, Germany, The Netherlands, Sweden, and the United Kingdom (member countries);
- has a flexible approach towards participation by organizations of non-member countries and international organizations.
- concentrates existing resources of the member countries in an efficient manner and recommends how to close technology gaps;
- focuses on collaborative research topics with regard to the needs of the European aeronautical industry;
- stimulates and executes joint research activities in the areas of aerodynamics, flight mechanics, helicopters, structures and materials and propulsion technology.
- includes participants from research organizations, aerospace companies and government authorities;
- operates efficiently within a developed administrative framework geared to international collaboration;
- adopts the principle of an overall balance of resource contributions and benefits between the participating countries;
- performs joint research work within specifically established research groups.

[1)] GARTEUR Guide 1993, Published by the GARTEUR Council

GARTEUR Helicopters
Action Groups

- Comparison with Experiment of Analytical Drag Prediction for a Helicopter Fuselage*
- Analysis of the Operational Requirements and Missions for Advanced Rotorcraft*
- Mathematical Modelling of Helicopters for Handling Qualities and Performance*
- Helicopter Fuselage/Rotor Interaction Aerodynamics*
- Advanced Rotorcraft Evaluation*
- Mathematical Modelling for the Prediction of Helicopter Flying Qualities
- Helicopter Performance Modelling
- Helicopter Vibration Prediction and Methodology
- Low Speed Wake Interaction Modelling**
- Dynamic Stall of Helicopter Rotors, Prediction and Accounting for Blade Torsion Effects**

*completed **in preparation

GARTEUR

Unlike the different discipline-oriented GARTEUR research topics the helicopter activities are concentrated on vehicle-oriented research. Therefore, a close cooperation is needed between the European helicopter industry and the research establishments as reflected in the respective Group of Responsables and in the Action Groups.

With respect to the development of advanced rotorcraft the Action Groups are currently concerned with subjects related to the mathematical modelling for the prediction of flying qualities, performance, and vibrations. This includes the generation of common European procedures and codes in particular for the verification, validation, and improvement of individual and specialized programs in the participating organizations.

Topics under consideration refer to low speed wake interaction, dynamic rotor stall, helicopter internal and external noise, tilt-rotor aeroelastic stability and oscillatory airloads, anti-torque systems for yaw control, and helicopter operational safety aspects.

The total man power involved in helicopter research tasks is presently about 8 man years per year. The participating organizations include DLR, DRA, NLR, ONERA, ECD, ECF, WHL.

Cooperative Programmes of the European Union

Helicopter Related R & D Projects

- **Exploratory Phase (1990-91):** Total Budget 9,3 MECU (RE 20%)
  - Helicopter Rotor/Fuselage Interactional Aerodynamics(Agusta, 13 Partners)
  - CFD Design Methods for Rotorcraft Blades (ECD, 5 Partners)
  - Rotorcraft Exterior Noise Research HELINOISE (ECD, 10 Partners)
  - Helicopter Health and Usage Monitoring Research (WHL, 5 Partners)
- **Intermediate Phase (1992-94):** Total Budget 12 MECU (RE 20%)
  - Reduction of Helicopter Internal Noise RHINO (Agusta, 12 Partners)
  - Rotorcraft Aerodynamics and Aeroacoustics HELISHAPE (ECD, 16 Partners)
  - Crashworthiness (British Aerospace, 18 Partners)
- **Main Programme (1995-98):** Under Preparation

The European Union (EU) is supporting aeronautics research in areas of new and rapidly developing advanced technologies, which will be essential for achieving a competitive technological advantage in the medium and longer terms.

The overall objective of the research is to strengthen the scientific and technological base of the European Aeronautical Industries to facilitate the future design and manufacture of civil aircraft products that compete in the global market whilst improving levels of environmental protection and sustaining or improving overall air transport safety in the face of the projected growth in traffic and aircraft size.

The helicopter related research and technology demonstration projects are jointly accomplished by industry, research establishments and universities and include rotor/fuselage interactional aerodynamics, CFD rotor blade design methods, health and usage monitoring research, crashworthiness, and as a main priority, exterior and interior noise research. These activities have been respectively are performed in the exploratory and the intermediate phases of the EU R&TD Programme [2]).

For the main programme a more concentrated, long-term, and adequately funded aeronautical research action is expected in the time frame 1995-98. This programme is presently under negotiation and preparation.

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[2]) D. Knörzer: Die Luftfahrtforschung der Europäischen Gemeinschaft. Presentation Sept. 1993, Braunschweig

Other European Cooperative R & D Programmes

- **DLR/NLR Bilateral Cooperation**
  - Wind Tunnel Interference (1994+) (+DNW)
  - Crash Tests (1994+)
- **DRA/ONERA/WHL/ECF Anglo-French Aeronautical Research Programme (AFARP6)**
  - Rotor Aerodynamics
  - Rotor Loads and Instabilities
  - Icing Studies
- **ECD/ECF/WHL/DLR/ONERA/DRA Euro ACT Programme (1992-94+)**
  - Handling Qualities for FbW-Helicopters
  - Control Law Development
  - Pilot Inceptors

DLR NLR ONERA

Beside the activities under the auspices of GARTEUR and EU other cooperative helicopter research and development programmes are being accomplished with the active participation of the research establishments.

Bilateral collaborative agreements include the Anglo-French Aeronautical Research Programme AFARP, which for the helicopter area (AFARP6) involves collaborative activities between DRA/WHL and ONERA/ECF mainly on the topics of rotor aerodynamics, rotor loads prediction, rotor dynamics, and aeroelastic stability. One example of AFARP6 work is the flight testing on the DRA research PUMA of rotor blades with large swept tips as part of the BERP programme.

NLR and DLR recently agreed on a bilateral cooperation in wind tunnel interference (participation of DNW) and in helicopter component crash test.

The European helicopter manufacturers ECD, ECF and WHL together with the respective research establishments DLR, ONERA and DRA are collaborating in the EuroACT programme, including research and development work in the areas of handling qualities for fly-by-wire helicopters, control law development, and pilot inceptors. Phase 1 of this programme will be completed in 1994, a follow-on phase 2 is under discussion.

French/German Bilateral Cooperative R & TD Programmes

- **ONERA/DLR Cooperation in Rotorcraft Research**
  - Aero-Acoustic Rotor Optimization (1992-96) (+ECD/ECF)
  - Helicopter Handling Qualities in Hover and Low Speed (1992-95)
  - Composite Structural Helicopter Crashworthiness (1995+)
  - Rotorcraft CFD Code Development (1995+)
- **DLR/ECD/ECF Memorandum of Agreement**
  - Development and Operation of an Active Control Technology Demonstrator and Flying Helicopter Simulator (ACT/FHS) (1994+)
- **ECD/ECF/ONERA/DLR Rotor Optimization Programme (ORPHEE/HLR)** (1991-96)

DLR ONERA

In parallel to the merger of the French and German helicopter manufacturers, forming now the EUROCOPTER company, ONERA and DLR agreed to increase the cooperation in the rotorcraft research area using their complementary capabilities in order to avoid future duplication of work and facilities, and to achieve synergy effects. This cooperation is considered to be an element of the partnership of the European Aeronautical Research Establishments and therefore, it is open to other partners, in general. It is acknowledged that the aim of being jointly more efficient will lead to some interdependence, at least in a mid term time frame. Technical areas for cooperation have been defined and the joint activities are in progress.

In this context, the joint programmes of ONERA and DLR with the French/German company EUROCOPTER will be coordinated too, in order to provide the best capabilities available for supporting the actual helicopter development projects. Agreements between industry and research establishments on new research and technology development programmes, and on the development and operation of future large scale facilities will demonstrate the new quality of cooperation.

Main Cooperations with Non-EU Countries

- France/US MoU "Helicopter Aeromechanics" (1971+)
  Partners: ONERA, US Army AFDD, Institute of Fluid Mechanics Marseille, ECF
- Germany/US MoU "Helicopter Aeromechanics (1973+)
  Partners: DLR, US Army AFDD & VSD, NASA Ames & Langley, (ZFL, ECD)
- UK/US/Canada/ (Australia and New Zealand added) "Tripartite Technical Coordination Programme (TTCP)
  Partners: DRA, US Army, NASA, NRC, ARL
- DLR/NASA Langley Letter Agreements "Helicopter Aeroacoustics Research", "Rotor Higher Harmonic Control Acoustic Tests"
- Netherlands NLR/US MoA "Model Aerodynamic and Aeroacoustic Testing of Rotors"
- UK MoD (DRA)/NASA Joint Aeronautical Programme
- AGARD Working Groups

In general, the research establishments are participants in collaborative programmes both in Europe and elsewhere, which are to the mutual advantage of the partners and to their main customers. Outside Europe the main collaborative activities centring on research partnerships with sister organizations in the US. This cooperation has generally been confined to areas of basic research because of competitive interests, and technology transfer restrictions on both sides. There are, however, examples of closer interaction in well defined tasks, and of complementary utilization of unique research facilities (e.g. DNW, NASA 40 x 80 ft Wind Tunnel, research helicopters).

The main Europe/US far ranging long-term research programmes include[1])

- France/US MoU on Helicopter Aeromechanics.
  This effort involves rotor aerodynamics, aeroacoustics, aeroelasticity, and rotor/fuselage interactions.
- Germany/US MoU on Helicopter Aeromechanics (Helicopter Flight Control).
  The complementary efforts include stability and control analysis, handling qualities research, rotor acoustics, composite structural crashworthiness, rotor data correlation, individual blade control, and dynamic stall and vortex shedding.
- UK/US/Canada/Australia/New Zealand TTCP.
  Key technical areas include rotor loads prediction and aeroelastic stability, flight dynamics and simulation, with particular emphasis on the helicopter/ship dynamic interface, and man-machine integration.

[1]) A. Gessow: European Research in Rotorcraft Technologies. Prepared for US Army Research Office, Dec. 1993.

6. Summary and Outlook

The review of the rotorcraft activities in the four national research establishments DLR, DRA, NLR, and ONERA demonstrates a substantial magnitude and quality of basic and applied research work. The total resources sum up to a yearly man power of approximately 300 man years and a budget of about 45 MECU.

Although public funding constraints, and governmental research policies have caused growing financial pressure on the research establishments the magnitude of helicopter research remained more or less constant over the last years. The reason for this is due to the ever increasing new technological challenges arising from modern helicopter developments. The scientific technical contributions and results of the individual establishments are impressive and also recognized outside Europe. Nevertheless, the past national oriented, often competing structures in industry and research organizations resulted in historical barriers for inter-European cooperation. These includes the well known potential disadvantage of parallel work with undercritical man power and investment resources.

The ongoing and future cooperative and joint development programmes, the beginnings of a restructuring of the European aeronautical industry, the emergence of a coordinated research effort of the European Union, and the numerous cooperative initiatives in Europe are going to change the future role of the national research establishments. To remain attractive and indispensable partners, the national research establishments need to actively and decidedly embark on a converging course, and to reshape their activities for Europe's common benefit.

At this point it has to be mentioned that there are additional potential partners for coordinated rotorcraft research in Europe. Within the EU the Italian research establishment CIRA (Annex) (Centro Italiano Ricerche Aerospaziali), formed in 1984, is going to organize rotorcraft activitiesreelated to the industrial partner AGUSTA. Also, in eastern Europe, in Russia and Poland, additional government supported institutes and helicopter centers exist which played an important role in the past.

Although this paper is centred on the European scenery it should be stated that the research establishments are definitely committed to maintaining the well established relationships with their American counterparts. Whilst a sound measure of competition between Europe and the US will continue to limit applied technology oriented cooperation, the pre-competitive cooperative research, the complementary use of unique test facilities, and exchange of scientific personnel will, also play in the future an indispensable role within the research establishments.

Acknowledgement

This is not a scientific and technical paper and the main contribution of the author is more or less to collect and to arrange the information provided by others. In this case the author owes much to the managing engineers responsible for rotorcraft/helicopter research activities in the respective organizations, which are also the author's colleagues at the GARTEUR Helicopter Group of Responsables,

- Mr. Alan F. Jones of DRA in Farnborough,
- Mr. Loek T. Renirie of NLR in Amsterdam, and
- Mr. Jean Jaques Philippe of ONERA in Chatillon.

However, the views expressed by this author stay in his own responsibilities.

The annex was provided by Dr. Piergiovanni Renzoni of CIRA in Capua.

Annex: Rotorcraft Activities at CIRA

CIRA (Centro Italiano Ricerche Aerospaziali) S.C.p.A. is the main establishment for aerospace research in Italy and as such it aims to excell in a number of aerospace disciplines. Since its founding in July 1984 a large number of initiatives have been launched in the rotorcraft sector with contributions in

- aeroacoustics
- aerodynamics
- flight mechanics and control
- structures and materials
- vibrations and acoustics.

A brief overview of CIRA's rotorcraft activities is given below.

Since 1989 the Aeroacoustics Branch has been developing methodologies for the calculation of noise from open rotors. Based on the Ffowcs Williams-Hawkings equation, several codes have been developed in the attempt to improve the representation of the relevant noise generating mechanisms of propellers and helicopter rotor blades. In the specific area of helicopter aeroacoustics, CIRA has taken part in the European research project **HELINOISE**, in the frame of the Brite/EuRam programme, and is currently participating in the follow on, the IMT project **HELISHAPE** (1993-1996). The main involvement of CIRA in the above projects is in the development of a code for the prediction of noise from helicopter rotor blades at high tip speed. The validation of codes is performed through comparison of numerical results with experimental data from test campaigns conducted within both projects.

Research in rotorcraft aerodynamics is ongoing since 1989 and addresses both transonic and interactional phenomena. Over these years a large effort has gone into developing and validating a boundary element method (Morino's Panel Method) for rotor flow fields and a code is under development for the free-wake modelling of multi-rotor/fuselage configurations. The validation of the method has benefitted greatly from CIRA's participation in the European research projects **DACRO** and **SCIA** (1990-1991), within the Brite/EuRam programme, which saw the participation of leading European experts in the field. Work on this method is continuing in the follow-own IMT project **HELISHAPE** (1993-1996). In this same project CIRA is participating in the development of a common European conservative full potential code for modelling the transonic flow on helicopter blade tips in high speed forward flight, bringing to this effort its experience with nonconservative full potential codes. Recently, internal projects have been launched on viscous-inviscid interaction methodologies.

The theoretical/numerical expertise in aeroacoustics and aerodynamics will be supported by experimental capabilities starting from 1998 when the Low Speed Wind Tunnel (**LSWT**) will become operational. This state-of-the-art facility will permit aerodynamic testing of model rotorcrafts in a 7.1m×5.5m slotted test section at a maximum speed of 85 m/s. The open jet test section (7.1m×5.5m with a maximum speed of 70 m/s) will be used both for aerodynamic and aeroacoustic testing of rotorcraft models.

The increased use of active control of forces and vibrations (Active Control Technology - ACT) for civil and military rotorcraft has led to a rethinking in rotorcraft design in terms of control systems. The Flight Mechanics and Control department is involved in two main research programmes. The first of these, developed in conjunction with Agusta and the University of Naples, partially supported by the Consiglio Nazionale delle Ricerche (CNR), concerns the possibility of significant improvements in the handling qualities of the next generation of rotorcraft by an ACT approach. In order to carry out these feasibility studies, a robust Stability Augmentation System design which provides some kind of fault-tolerance against incidents like sensor failure, has been developed. Moreover, a new robust stability analysis tool to check the stability of the augmented rotorcraft under bounded parameter changes has been developed

in order to perform a robust analysis of the flight control system with respect to different flight conditions. By using the robust control system design and analysis tools, the handling qualities and robustness properties have been verified with reference to the Agusta A-109 helicopter in the hover condition. The objective of the second research programme, supported by Agusta and developed in conjunction with the Universities of Napoli, Roma, Bologna, and Milano, concerns the design of a generalized numerical helicopter able to simulate the aerodynamic and mechanic phenomenology. The role of CIRA in this project is the development of a simulation code of a generic helicopter control system. This project, named **DREAM** (Dynamic Rotorcraft Evaluation by Advanced Modelling), has started on September 1994.

Rotorcraft related activities in the field of structures and materials:

- **Development of damage tolerant primary dynamic structures**
  - **DESIR** project (just completed): NDE monitoring of damages/defect propagation in helicopter primary dynamic structures under dynamic testing (in cooperation with Agusta)
  - Development of a model for the prediction of the residual strength of damaged composite materials (quasi-isotropic laminates with impact damages)
  - Development of on field applicable NDE methods (in cooperation with Agusta, Westland, ECD, and RISO).
- **Crash behaviour of helicopter structures**
  Two complete structures are already available for crash tests (vertical impact) with foreseen execution Oct. '94 - Feb. '95. Moreover, CIRA is going to build the **LISA** facility, a "full size" crash test bed (any impact angle within 8° and 90°, any attitude, impact speed up to 20 m/s) that will be closely linked to the development (and testing) of crashworthy rotorcraft structures.

The Vibrations and Acoustics department is involved in several rotorcraft related activities. It is currently participating in the European research project **RHINO** (Reduction of Helicopter Interior Noise), in which it is mainly concentrating on the study of Active Control methods involving the use of shakers and piezo electric patches bonded to aircraft structures, and in development of advanced SEA methods for structural-acoustics analysis at high modal densities. A second important activity is the realisation of the mobile laboratory **EVA** (Evaluation of Vibration and Acoustics) which will have operational modules responding to various test specifications mounted aboard a transportable container and a "camper" type vehicle respectively. A module for Ground Vibration Testing of aircraft (including helicopters) and a module for External Noise Testing and Certification of aircraft as per ICAO annex 16 and FAR 36 (Chapter 8 and Appendix H respectively for helicopters) will be operational by the end of 1995. Furthermore, the **EVA** mobile laboratory will be equipped with an Internal Noise and Vibration Test module for aircraft and helicopters, for both in-flight and on-ground operations with particular emphasis on passenger comfort requirements and "flutter" certification.

A brief overview of CIRA's activities has been given, showing the level of expertise reached in several disciplines. The theoretical/numerical expertise will be supported by a number of test facilities that will become operational in the near future.