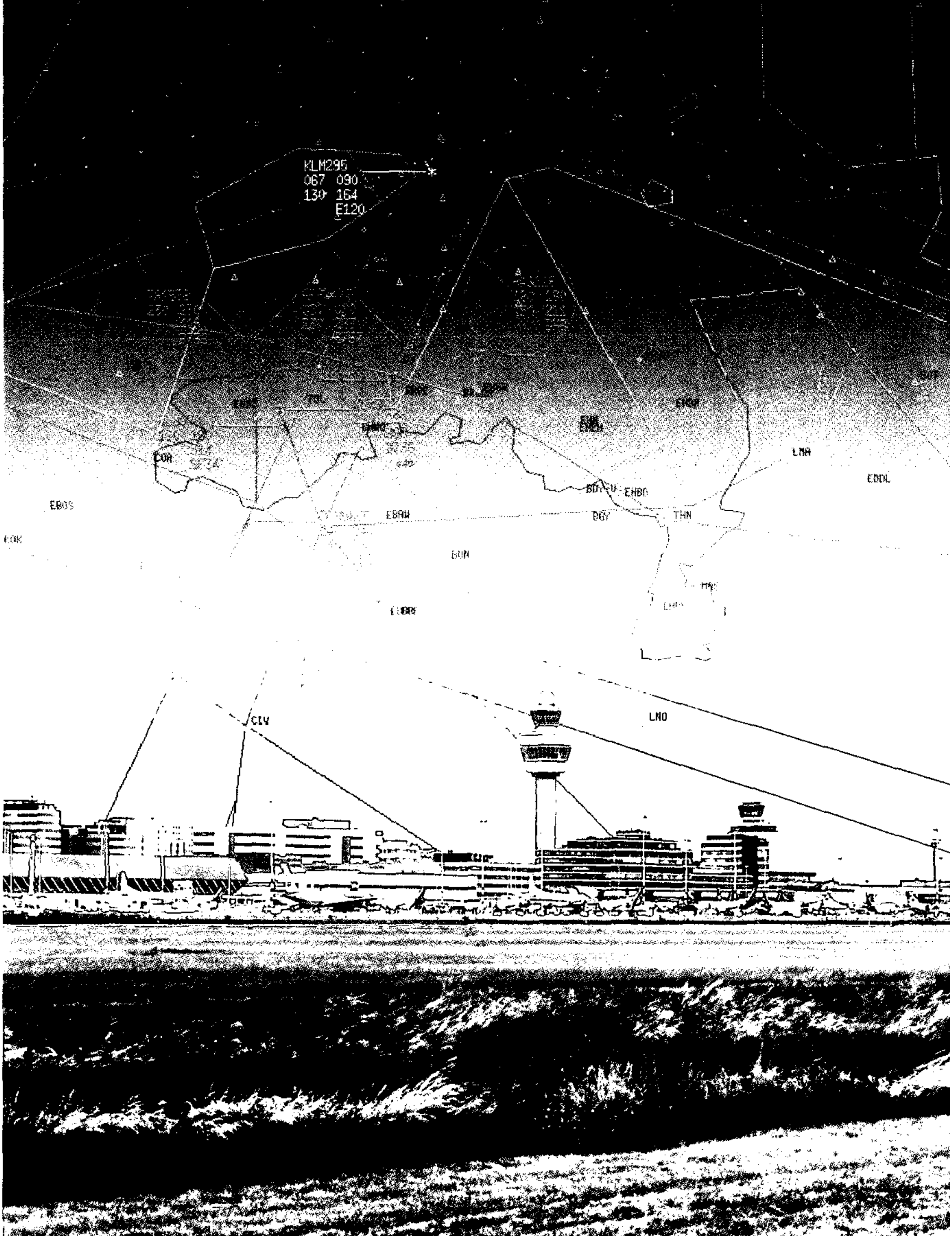
Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Annual Report 1996



Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Anthony Fokkerweg 2
1059 CM Amsterdam
P.O. Box 90502
1006 BM Amsterdam
The Netherlands
Telephone +31 20 5113113
Fax +31 20 5113210
Web site: http://www.nlr.nl

Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Annual Report 1996

The Board of the Foundation NLR

On 31 December 1996

	Appointed by:
J. van Houwelingen, *Chairman*	Ministers of Transport, of Defence, of Economic Affairs and of Education, Culture and Science
Ir. H.N. Wolleswinkel	Minister of Transport, for the Netherlands Department of Civil Aviation (RLD)
Drs. E.A. van Hoek	Minister of Defence
Gen.maj.ir. M.R.H. Wagevoort	Minister of Defence, for the Royal Netherlands Air Force (RNLAF)
Drs. P.G. Winters	Minister of Economic Affairs
Dr. P.A.J. Tindemans	Minister of Education, Culture and Science
Ir. H.N. Wolleswinkel *(acting)*	Netherlands Agency for Aerospace Programs (NIVR)
A. van Bochove	Air Traffic Control The Netherlands
–	Fokker Royal Netherlands Aircraft Factories
Ir. C. den Hartog	KLM Royal Dutch Airlines
Ir. R. Uijlenhoet	Amsterdam Airport Schiphol
Ir. E.I.L.D.G. Margherita	Netherlands Organization for Applied Scientific Research (TNO)
Prof.dr.ir. J.L. van Ingen	Delft University of Technology, Faculty of Aerospace Engineering
Mrs. prof.dr. A.J.M. Roobeek	Board of the Foundation NLR, upon nomination by the Works Council
Jhr.mr. J.W.E. Storm van 's Gravesande	Board of the Foundation NLR

The Board of Directors of NLR

On 31 December 1996

Dr.ir. B.M. Spee	General Director
Prof.ir. F.J. Abbink	Technical Director
J.A. Verberne R.A.	Financial Director

Table of Contents

1 Introduction

The year 1996 has been another difficult year for NLR due to the bankruptcy of Fokker in March 1996, resulting in a strongly reduced support by the Netherlands government for research and technology programmes related to aircraft development. For NLR this resulted in less contract work for the Netherlands aircraft industry and a significantly lower research budget from the Netherlands Agency for Aerospace Programs (NIVR).

Nevertheless, the total volume of contract work was maintained at the same level as in previous years. The decrease of research work for aircraft development was to a large extent compensated by a growth of research programmes in support of aircraft operations both on the civil and the military side. In addition, the volume of the contract work for foreign customers further increased.

The expectations that 1996 would be the year for the aircraft industry in Europe to take initiatives for the development of new civil transport aircraft did not materialize. This continued to have a negative effect on the requirement for support from the research institutes and particularly on the workload of the large test facilities of the institutes. Also on the military side there is a lack of activity with respect to new aircraft projects in Europe.

The need for support from the research institutes in the area of aircraft operations, on the other hand, is increasing rapidly. The continuously growing demand for air transport calls for an increase in capacity and efficiency of the transport system and stricter rules with respect to environmental and safety aspects. This is particularly true in the case of large and busy airports in highly populated areas such as in the Netherlands. The development of the technical means to solve the increasing capacity problems of the future air transport system requires large contributions from the research institutes.

An important impetus to the development of the technology for future aircraft and for the air transport system has been given by the European Union (EU) within the Fourth Framework programme. This programme is intended to increase co-operation within Europe and to enable the European industry to keep up its competitiveness against the industries in the US and the Far East. NLR has been very successful in obtaining a prominent position in many EU projects. Also, NLR participates in many research projects on Air Traffic Control and Air Traffic Management initiated by Eurocontrol.

An increasing percentage of NLR's activities is related to military programmes. There is a growing need for NLR support to the aircraft operations of the Royal Netherlands Air Force and Navy. In addition NLR participates in military aircraft development programmes (NH90, F-16 Mid Life Update) and in co-operative research programmes initiated by the WEAG, the Western European Armament Group. Also a growing share of NLR's research projects are related to space technology.

In 1996 NLR continued to give strong support to international co-operation, in particular to more intensive co-operation between the European research institutes, both within the framework of GARTEUR, the Group for Aeronautical Research and Technology in Europe, which includes the industry, and within the framework of AEREA, the Association of European Research Establishments in Aeronautics. Furthermore, preparations were made to further expand the co-operation with DLR, the Deutsche Forschungsanstalt für Luft- und Raumfahrt, by integrating the aeronautical high-speed wind tunnels of DLR and NLR into the foundation DNW (German-Dutch Wind Tunnel).

J. van Houwelingen,
Chairman

2 General Survey

2.1 Mission and Means

The National Aerospace Laboratory NLR is the central institute for aerospace research in the Netherlands. NLR provides 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 basic research and development programme sponsored by the Dutch Government.

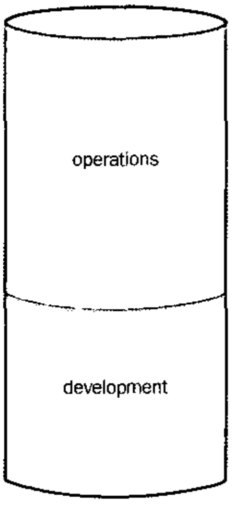
With sites in Amsterdam and in the Noordoostpolder, NLR operates several wind tunnels, laboratory aircraft, research flight simulators and an Air Traffic Control research simulator. NLR has available an extensive set of equipment for gathering, recording and processing flight test data. NLR also has facilities for research in the areas of structures and materials, space technology, remote sensing and environmental testing. NLR's extensive computer network includes a 32-GFlops NEC SX-4 supercomputer, tools for software development and advanced software for computational fluid dynamics and for calculations of aircraft and spacecraft structures.

NLR participates, on an equal base together with the Deutsche Forschungsanstalt für Luft- und Raumfahrt, in the German-Dutch Wind Tunnel, which operates the Large Low-speed Facility in the Noordoostpolder and two 3-m low-speed wind tunnels. Together with DLR, the Ministry of Defence of the UK and the Office National d'Etudes et de Recherches Aérospatiales of France, NLR also takes part in the European Transonic Wind Tunnel (ETW) in Cologne.

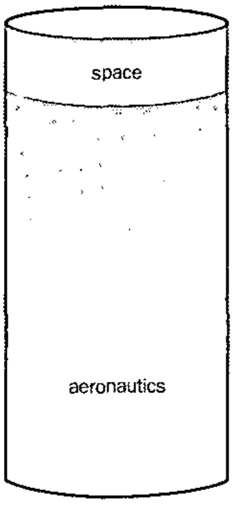
2.2 Activities in 1996

In 1996 NLR's turnover was 140 million guilders compared to 144 million in 1995. The income from contracts was 101 million guilders, the same as in 1995. In 1996 about 40% of the total of NLR's activities were related to the development and 60% to the operation of aircraft and spacecraft; 85% of NLR's activities were related to aeronautics and 15% to space. Civil and military research amounted to 65% and 35% respectively. About 30% of the work under contract was carried out for foreign customers.

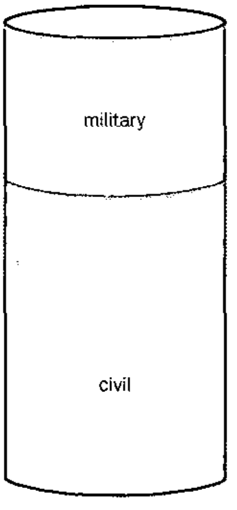
The total operating costs of NLR, amounting to 140 million guilders, included personnel costs of 93 million guilders.



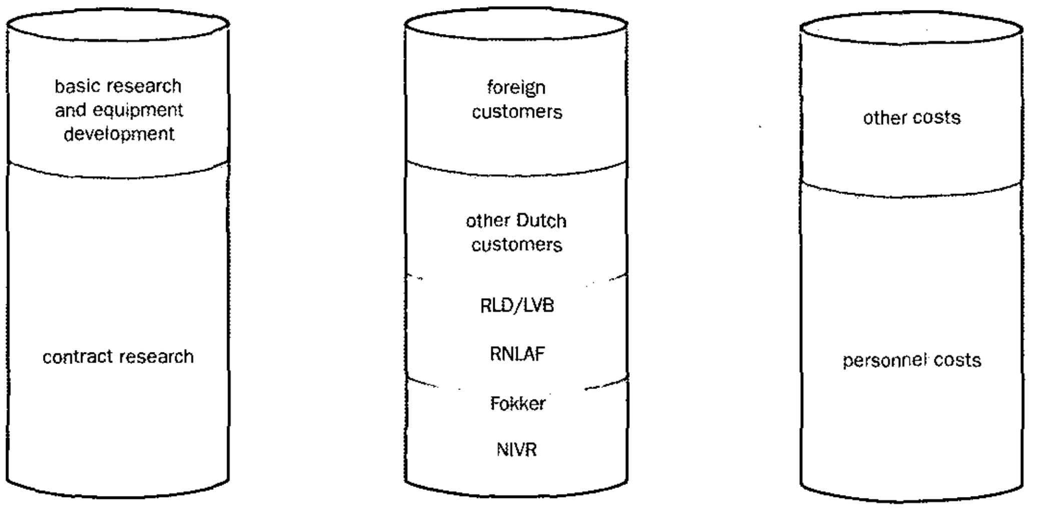
Division of the work into development and operations support



Division of the work into aeronautics and spaceflight support



Division of the work into civil and military support



Division of the work into contract research and the programme for basic research and equipment development

Distribution over customers of the contract research

Division of the costs

Services Provided under National Contracts

Activities under contract to Dutch customers amounted to 70 million guilders. These contracts included work for the Netherlands Agency for Aerospace Programs (NIVR) under its programmes for aeronautics and space research and technology, and for the development of aircraft and spacecraft. A number of research programmes were executed under contract to the Royal Netherlands Air Force, the Royal Netherlands Navy, the Netherlands Department of Civil Aviation (RLD), Air Traffic Control The Netherlands (LVB), Fokker Aircraft and Fokker Space. NLR also carried out work to support the Ministry of Defence, the German-Dutch Wind Tunnel (DNW), the European Transonic Wind Tunnel (ETW) and several other government services and private companies.

Contracts from Fokker concerned the development of the Fokker 60 and of the NH90 helicopter. A major part of the work for the RLD was related to studies on airworthiness and regulations, on present and future ATC systems and on safety and environmental aspects of aeronautics. Research on present and future ATC systems was also done under contract to the LVB, KLM Royal Dutch Airlines and Amsterdam Airport Schiphol.

Services Provided to Foreign Customers

Research carried out under contract to foreign customers amounted to 31 million guilders. Major customers were the European Space Agency, the Commission of the European Communities and Eurocontrol.

Research and Equipment

NLR spent 24 million guilders on its basic aerospace research programme supported by the government, aimed at preserving NLR's capability to support its customers in the future. Research aimed at the development and modernization of NLR's research facilities amounted to 19 million guilders, for the greater part used for the modernization of NLR's transonic wind tunnel HST and on the extension of NLR's research flight simulation facilities. A total of 17 million guilders was used for capital investments, of which the modernization of the HST and the purchase of a Flight Inspection System for the calibration of navigation and landing aids were the most important ones.

National and International Co-operation

A large part of NLR's basic research is carried out as NLR's own contributions to European research projects both on the civil (EU, Eurocontrol) and military (EUCLID, WEAG) sides. Another significant part is carried out in connection with co-operative programmes under the aegis of GARTEUR, the Group for Aeronautical Research and Technology in which Germany, France, the United Kingdom, the Netherlands, Spain and Sweden take part.

NLR and the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) jointly govern the German-Dutch Wind Tunnel (DNW), which operates the Large Low-speed Facility in the Noordoostpolder. Since 1995 the 3-m low speed wind tunnels of DLR and NLR, located in Braunschweig and in the Noordoostpolder, respectively, are incorporated in the foundation DNW. In 1996 preparations were made to include all aeronautical wind tunnels in the foundation DNW.

Although the European Transonic Wind Tunnel (ETW) located near Cologne, Germany is in full operation and performed in 1996 the first paid test for customers it was decided to extend the so-called initial operation period until mid-1999. This enables the participating countries, Germany, France, the United Kingdom and the Netherlands to distribute their financial support to ETW GmbH better over the coming years.

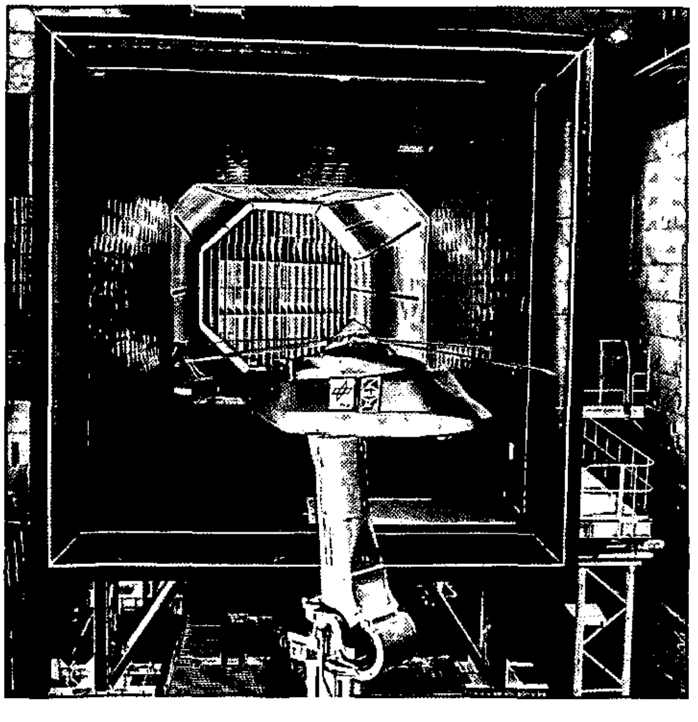
The seven aeronautical research establishments of the countries of the European Union continued their common activities under the agreement for co-operation within the Association of European Research Establishments in Aeronautics (AEREA). The association will execute joint research programmes and establish a joint approach towards the planning, use and management of large facilities.

In several projects NLR co-operates with research institutes and universities of the Netherlands. NLR and the Delft University of Technology (DUT) jointly operate a Cessna Citation II, which is used as a research aircraft. Several members of NLR's staff are part-time professors at the DUT's faculty of Aerospace Technology.

Collaborative activities of the research institutes Aero-Gas Dynamics and Vibration Laboratory (LAGG) of Serpong and NLR, together with Nusantara Aircraft Industries (IPTN) and the universities Delft University of Technology and Institut Teknologi Bandung were continued under an Aerospace Programme for Education, Research and Technology. The co-operation is co-ordinated by NLR and by the Agency for the Assessment and Application of Technology of Indonesia.

As in previous years, NLR has been very active in AGARD, NATO's Advisory Group for Aerospace Research and Development. NLR is represented in most of the AGARD Panels and participates in the activities of many Working Groups. AGARD will be integrated together with the Defence Research Group in one NATO research organization.

Co-operation with the US National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA) included research on air-ground integration for Air Traffic Control.



NH90 model in the open jet of the DNW Large Low-speed Facility

2.3 Organization and Personnel

The Board of the Foundation NLR consists of members appointed by the Netherlands government, the industry and other organizations having an interest in aerospace research. The meetings of the Board are normally attended by Prof.dr.ir. P.J. Zandbergen, Chairman of the Scientific Committee NLR/NIVR, and by the members of the Board of Directors. The Scientific Committee, consisting of experts from the aerospace community (industry, universities), advises the Board on the long term programme of basic research and on results of research carried out, described in NLR reports and in the annual report of NLR's basic research programme.

Since the bankruptcy of Fokker, the seat of Fokker in the Board has remained unoccupied. The seat of NIVR was occupied *ad interim* by Ir. H.N. Wolleswinkel. Ir. E.I.L.D.G. Margherita succeeded Ir. C.M.N. Belderbos as the member appointed by the Netherlands Organization for Applied Scientific Research (TNO).
Gen.maj. ir. M.R.H. Wagevoort succeeded Gen.Maj. drs. D. Altena as the member appointed by the Minister of Defence for the Royal Netherlands Air Force.

The laboratory was headed by the directors mentioned on page 3.
Drs. A. de Graaff was *Associate Director*.

On 31 December 1996 the Heads of Divisions and Services were:
Prof.ir. J.W. Slooff, *Fluid Dynamics Division*
Ir. J.T.M. van Doorn, *Flight Division*
Dr.ir. G. Bartelds, *Structures and Materials Division*
Ir. B.J.P. van der Peet, *Space Division*
Ir. W. Loeve, *Informatics Division*
Ir. H.A.T. Timmers, *Electronics and Instrumentation Division*
Ir. J. van Twisk, *Engineering and Technical Services*
Ir. W.F. Wessels, *General Services*
J.A. Verberne R.A., *Administrative Services*

As of 1 April 1996, Ir. J. van Twisk succeeded Ir. G. Brink, who retired, as head of the Engineering and Technical Services.

The senior staff further included Mr. E. Folkers, *Secretary* and Ing. F.J. Sterk, *Head Support Staff.*

As per 1 January 1996, two departments of the Informatics Division were divided. The Department of Numerical Mathematics and Applications programming was divided in the Department of Software Applications, headed by Ir. F.J. Heerema, and the Department of Data and Knowledge Systems, headed by Ir. J.C. Donker. The Computing Centre and Systems Programming Department was divided in the Department of Computing Services, headed by Ir. U. Posthuma de Boer, and the Department of Embedded Systems, headed by Drs. E. Kesseler. The Domestic Services and Guarding Departments of the General Services were merged in one department, headed by Mr. G. Lipsius.

The staff of the Low Speed Wind Tunnel joined the NLR staff detached to the German-Dutch Wind Tunnel.

The organization of the laboratory on 31 December 1996 is shown on page 12.

At the end of 1996 NLR employed a staff of 907 (compared with 944 at the end of 1995), of whom 393 (391) were university graduates. Of the total, 814 (840) were employed on a permanent basis, and 93 (104) had temporary appointments. About 60 per cent of the staff are posted in Amsterdam, 40 per cent in the Noordoostpolder.
A breakdown of the staff is given on page 13.

Organization Diagram

31 December 1996

Technical Director
Prof.ir. F.J. Abbink — DT

General Director
Dr.ir. B.M. Spee — D

Financial Director
J.A. Verberne R.A. — DF

Associate Director	Drs. A. de Graaff	DO
Support Staff	Ing. F.J. Sterk	DD
- *Public Relations*	Ms. J.F. van Esch	DPR
- Publications	Dr. B.J. Meijer	DPI
Co-ordinators:		
- Defence Projects	Ir.J.M.A. van den Heuvel	CPD
- Aircraft Development Projects	Ing. P. Kluit	CPO
- Spaceflight Projects	Drs. J.C. Venema	CPR
- Aircraft Operations Projects	Ir. J.A.J. van Engelen	CPG
- Basic Research and *Equipment Development*	*Ir. J.A.J. van Engelen*	CEW
- Quality Assurance NLR	H. Blokker	CKZ

Secretary		E. Folkers	DJ
- Legal	DJ		
- Filing	DB		
- Security	DB		
Personnel		Ms. W.J. van Druten	DZ
Co-ord. AGARD/Indonesia		Ir. L. Sombroek	DA
Company Welfare Work		Ms. M.C. Wielemaker	DM
		Ms. C. Diekema	DM

Fluid Dynamics
Prof.ir. J.W. Slooff — A

- **Aerodynamic Facilities** — Ir. F. Jaarsma, Ir. H.A. Dambrink — AF
- **Experimental Aerodynamics** — Ir. A. Elsenaar — AX
- **Theoretical Aerodynamics** — Dr. B. Oskam — AT
- **Unsteady Aerodynamics and Aeroelasticity** — Prof. ir. R.J. Zwaan — AE
- **Aeroacoustics** — *Dr. H.H. Brouwer* — AK

Flight
Ir. J.T.M. van Doorn — V

- **Flight Testing and Safety** — Ing. M.A. Piers — VV
- **Helicopters** — Ir. L.T. Renirie — VH
- **Flight Simulation** — Ir. W.G. Vermeulen — VS
- **Flight Mechanics** — Ir. W.P. de Boer — VM
- **Operations Research** — Ir. G.J. Alders — VO
- **Air Traffic Management** — *Ir. J. Brüggen* — VL
- **Man Machine Integration** — Drs. P.G.A.M. Jorna — VE
- **Transport and Environmental Studies** — Ir. G. Bekebrede — VT

Structures and Materials
Dr.ir. G. Bartelds — S

- **Loads** — Ir. J.B. de Jonge — SB
- **Structures** — Ir. H.H. Ottens — SC
- **Materials** — Ir. H.H. Ottens, acting — SM
- **Testing Facilities** — Ing. H.J.C. Hersbach — SL

Space
Ir. B.J.P. van der Peet — R

- **Remote Sensing** — Dr. G. van der Burg — RR
- **Systems** — Dr.ir. H.F.A. Roefs — RS
- **Laboratories and Thermal Control** — Ir. H.A. van Ingen Schenau — RL

Informatics
Ir. W. Loeve — I

- **Mathematical Models and Methods** — Dr. R.J.P. Groothuizen — IW
- **Software Applications** — Ir. F.J. Heerema — IA
- **Data and Knowledge Systems** — Ir. J.C. Donker — ID
- **Computing Services** — Ir. U. Posthuma de Boer — IC
- **Embedded Systems** — Drs. E. Kesseler — IS

Electronics and Instrumentation
Ir. H.A.T. Timmers — E

- **Avionics** — Ir. M.A.G. Peters — EA
- **Electronics** — Ing. H. Slot — EE
- **Instrumentation** — Ir. R. Krijn — EI

Engine ng and Techni l Services
Ir. J. van isk — T

- **Technic Projects** — Ir. C.C. C othoff — TP
- **Technic Design** — A. van d Berg — TO
- **Worksh s** — Ir. H.Th. . Lafleur — TW

General Services
Ir. W.F. Wessels — G

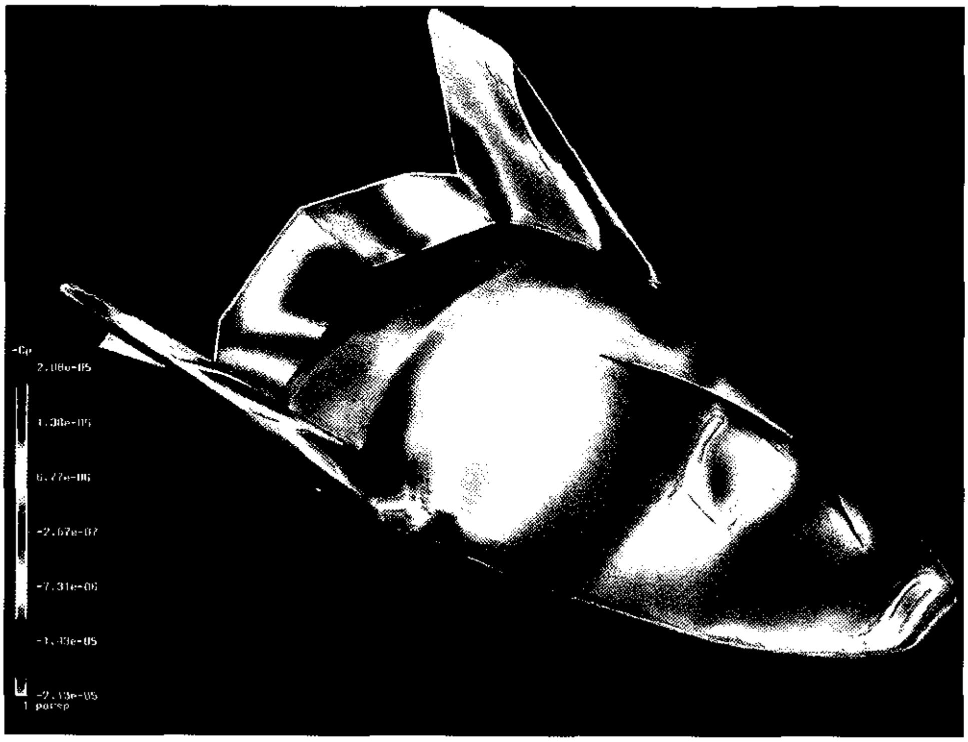
- **Buildings** — Ing. H. van der Roest — GG
- **Electrical Engineering** — A.M.G. Reijntjens — GE
- **Domestic Services and Guarding** — G. Lipsius — GZ
- **Library and *Information Services*** — Ir. W.F. Wessels — GB
- **Document Processing** — Ing. D.J. Rozema — GT

Administrative Services
J.A. Verberne R.A. — O

- **Administration** — Drs. B.P.E. Haeck — OA
- **Stores and Dispatch** — Drs. B.P.E. Haeck — OM
- **Purchasing** — J.F. Post — OI

Table 1 - The NLR staff (Cat. I: university graduates, Cat. II: advanced technical college graduates, Cat. III: others) at the end of 1996 (between brackets the numbers at the end of 1995)

		Cat. I		Cat. II		Cat. III		Total	
Board of Directors		3	(3)	–	(–)	–	(–)	3	(3)
- Support Staff		15	(16)	6	(5)	10	(10)	31	(31)
		18	(19)	6	(5)	10	(10)	34	(34)
Fluid Dynamics Division	A	2	(2)	2	(1)	2	(3)	6	(6)
- Aerodynamic Facilities	AF	9	(12)	21	(22)	20	(23)	50	(57)
- Experimental Aerodynamics	AX	13	(16)	7	(9)	–	(–)	20	(25)
- Aeroacoustics	AK	7	(7)	2	(3)	–	(–)	9	(10)
- Theoretical Aerodynamics	AT	18	(19)	–	(–)	–	(–)	18	(19)
- Unsteady Aerodynamics & Aeroelasticity	AE	6	(7)	3	(3)	–	(–)	9	(10)
- German-Dutch Wind Tunnel	AD	4	(4)	16	(15)	20	(20)	40	(39)
		59	(67)	51	(53)	42	(46)	152	(166)
Flight Division	V	4	(4)	1	(1)	1	(1)	6	(6)
- Flight Testing and Safety	VV	10	(8)	6	(6)	1	(1)	17	(15)
- Flight Simulation	VS	12	(12)	16	(14)	1	(2)	29	(28)
- Operations Research	VO	21	(21)	6	(6)	1	(2)	28	(29)
- Man Machine Integration	VE	19	(17)	1	(–)	2	(1)	22	(18)
- Helicopters	VH	14	(13)	1	(1)	1	(1)	16	(15)
- Air Traffic Management	VL	38	(31)	5	(3)	–	(1)	43	(35)
- Flight Mechanics	VM	10	(12)	–	(–)	1	(1)	11	(13)
- Transport and Environmental Studies	VT	9	(7)	5	(5)	–	(–)	14	(12)
		137	(125)	41	(36)	8	(10)	186	(171)
Structures and Materials Division	S	1	(1)	1	(1)	–	(–)	2	(2)
- Loads	SB	8	(8)	3	(5)	2	(2)	13	(15)
- Structures	SC	13	(13)	3	(3)	1	(1)	17	(17)
- Materials	SM	7	(7)	4	(4)	–	(–)	11	(11)
- Testing Facilities	SL	–	(–)	13	(13)	15	(19)	28	(32)
		29	(29)	24	(26)	18	(22)	71	(77)
Space Division	R	1	(2)	–	(–)	1	(1)	2	(3)
- Remote Sensing	RR	7	(7)	3	(4)	–	(–)	10	(11)
- Systems	RS	15	(15)	–	(–)	–	(–)	15	(15)
- Labatories and Thermal Control	RL	8	(8)	7	(7)	1	(1)	16	(16)
		31	(32)	10	(11)	2	(2)	43	(45)
Informatics Division	I	1	(1)	1	(1)	4	(4)	6	(6)
- Mathematical Models and Methods	IW	14	(15)	–	(–)	–	(–)	14	(15)
- Software Applications	IA	16	(33)	10	(23)	2	(2)	28	(58)
- Data and Knowledge Systems	ID	17		11		(–)		28	
- Computing Services	IC	14	(24)	12	(19)	9	(10)	35	(53)
- Embedded Systems	IS	13		8		(–)		21	
		75	(73)	42	(43)	15	(16)	132	(132)
Electronics and Instrumentation Division	E	1	(1)	1	(1)	1	(1)	3	(3)
- Avionics	EA	14	(12)	7	(7)	–	(–)	21	(19)
- Electronics	EE	5	(6)	18	(20)	4	(6)	27	(32)
- Instrumentation	EI	11	(13)	20	(32)	7	(8)	38	(53)
		31	(32)	46	(60)	12	(15)	89	(107)
Engineering and Technical Services	T	1	(1)	–	(–)	1	(1)	2	(2)
- Technical Projects	TP	5	(5)	4	(4)	1	(2)	10	(11)
- Technical Design	TO	1	(1)	11	(12)	1	(1)	13	(14)
- Workshops	TW	1	(1)	16	(15)	19	(21)	36	(37)
		8	(8)	31	(31)	22	(25)	61	(64)
General Services	G	1	(1)	2	(2)	–	(–)	3	(3)
- Buildings	GG	–	(–)	2	(2)	1	(1)	3	(3)
- Electrical Engineering	GE	–	(–)	4	(5)	5	(4)	9	(9)
- Domestic Services and Guarding	GZ	–	(–)	2	(2)	36	(39)	38	(41)
- Library and Information Services	GB	2	(2)	3	(3)	3	(4)	8	(9)
- Document Processing	GT	–	(–)	4	(5)	29	(31)	33	(36)
		3	(3)	17	(19)	74	(79)	94	(101)
Administrative Services	O	–	(–)	–	(–)	–	(–)	–	(–)
- Administration	OA	1	(2)	17	(17)	15	(16)	33	(35)
- Stores and Dispatch	OM	–	(–)	1	(1)	4	(4)	5	(5)
- Purchasing	OI	1	(1)	6	(6)	–	(–)	7	(7)
		2	(3)	24	(24)	19	(20)	45	(47)
Grand total		393	(391)	292	(308)	222	(245)	907	(944)



Navier-Stokes solution for flow around Crew Rescue Vehicle

3 Activities

3.1 Fluid Dynamics

Summary

Technology research and development activities in fluid dynamics were executed in the areas of experimental aerodynamics, Computational Fluid Dynamics, applied aerodynamics, aeroelasticity and aero-acoustics, both under contract and as part of NLR's basic research programme. Furthermore, work was done for the development and improvement of aerodynamic facilities and measurement techniques.

The total volume of contract research and development activities in fluid dynamics decreased dramatically relative to 1995. This decrease was entirely due to the bankruptcy of Fokker Aircraft. Wind tunnel occupation was low, both as a result of the current low level of activities in development programmes of the international aerospace industry and because the modernization of the power supply of the transonic and supersonic wind tunnels made these facilities inoperative from early September 1996.

NLR continued active participation in most of the Action Groups of GARTEUR (Group for Aeronautical Research and Technology in Europe) and in many projects of BRITE/EURAM (Basic Research in Industrial Technologies for Europe/European Research on Advanced Materials) in several areas of aerodynamics of steady and unsteady flows and in aeroacoustics.

In the area of *applied aerodynamics,* the activities aimed at supporting Fokker Aircraft in aerodynamic studies were largely terminated. This was partially compensated by an increase of activities in the area of aerodynamic analysis of military aircraft.

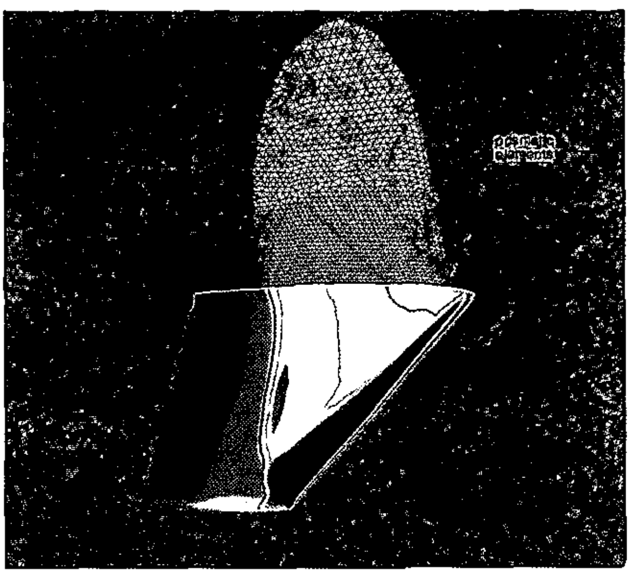
A significant part of the research and development activities in the field of *applied Computational Fluid Dynamics* remained concentrated on improving the readiness of a computer code system, ENFLOW, for solving the Reynolds-averaged Navier-Stokes equations using block-structured grids.

In the framework of the Western European Armament Group (WEAG), NLR continued the verification and validation of Reynolds-averaged Navier-Stokes methods for fighter type aircraft and initiated the development of time-accurate Computational Fluid Dynamics (CFD) methods.

The activities in *aero-thermodynamics* were redirected towards the application of CFD technology to the ESA/NASA Crew Rescue Vehicle, using solutions of the Reynolds-Averaged Navier-Stokes equations. Within the framework of the national AEOLUS (Advanced Earth to Orbit Launcher Upgrade Studies) programme, research on aerothermodynamics of the inlet of airbreathing spaceplanes was redirected towards control surfaces.

Activities in the area of *aero-elasticity* concentrated on the continued development of a system of codes (AESIM) for the computational aero-elastic simulation of transport type aircraft in transonic flow and on the continued research of Limit Cycle Oscillation (LCO) phenomena of fighter aircraft.

Propeller *acoustics* research continued to be aimed at the development, validation and improvement of computational methods for the noise from propellers, including diffraction and refraction of sound by the aircraft's fuselage.



Navier-Stokes solution of wing flow, computed in a DLR/NLR co-operation

Research in turbofan acoustics was directed at improved description of noise sources, duct acoustics and liner properties and included validation activities for rotor transmission models, 'rotor-alone-noise' of turbofan rotors with supersonic tip speeds, low-frequency noise research, bulk-absorbing liner materials and research on active impedance control.

In the area of *experimental facilities*, the main effort was the implementation of Phase II of the modernization of the High Speed Tunnel (HST), involving the replacement of the power plant and the drive motors, to be completed in 1997. Other activities included the continued development of a new generation of accurate wind tunnel balances for force measurements and the application of two new measurement techniques, Particle Image Velocimetry and Pressure Sensitive Paint.

Per 1 January 1996, the operation of the 3x2.25m" Low Speed Wind Tunnel (LST) of NLR was formally transferred to the Foundation German-Dutch Wind Tunnel (DNW) after a two-year trial period. Discussions between DLR and NLR were started to investigate possibilities for also including the transonic and supersonic wind tunnels HST and SST and a number of DLR facilities in the foundation DNW.

Applied/Configuration Aerodynamics

Aerodynamics of Wings of Transport Aircraft

The MATRICS-V full potential and boundary layer code has been developed to the point where it can be routinely applied for wing design analysis. To extend the capabilities of this code further, additional applications have been made for high-wing configurations in addition to the more usual wing-body configurations. The theoretical extraction of the various drag components has also been improved. Progress was made in wing optimization techniques using 'optimal control theory' for multi-point aerodynamic design. The program SYN87 was obtained from Princeton University and evaluated.

NLR is active in Multi-disciplinary Design Optimization (MDO) through participation in the MDO project of BRITE/EURAM. MDO addresses the need for more efficient approaches to designing complex engineering systems. Four NLR Departments, Theoretical Aerodynamics, Structures, Mathematical Models and Methods, and Flight Mechanics co-operate with other European partners in the project. The design problem selected is the wing optimization for a 650-seat Airbus A3XX type of passenger aircraft. The MATRICS-V code has been applied in a routine fashion in this project.

The contribution of NLR to the sub-task of the BRITE/EURAM Programme on 'Laminar Flow Technology' (ELFIN II) to evaluate various approaches to predict boundary layer stability was completed. A combined report with contributions from all partners is expected to appear early 1997.

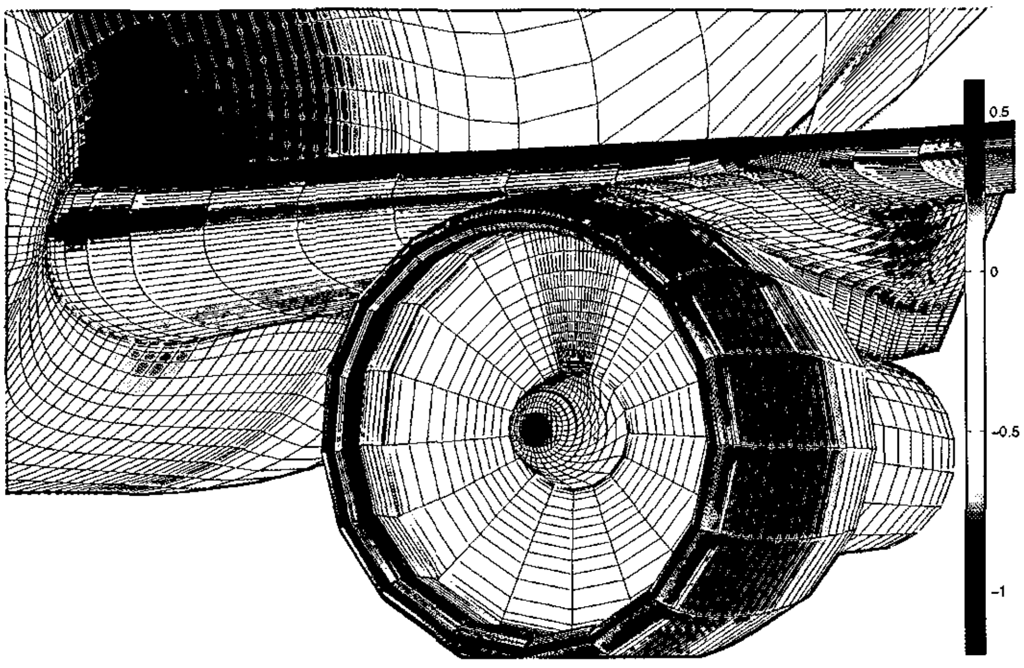
A new test entry in the Indonesian Low Speed Wind Tunnel of the high-lift wing model with variable sweep was postponed until 1997. NLR contributed to the instrumentation required.

The participation of NLR in the BRITE/EURAM project Euroshock was continued by compiling the numerical and theoretical data from all partners. In this project, which was completed at the beginning of 1996, NLR modified and applied its computer code ULTRAN-V to investigate means to control shock/boundary layer interaction.

On the subject of a European supersonic transport aircraft, NLR contributed to the BRITE/EURAM project Eurosup, both by delivering aerodynamic coefficients based on CFD and by making preparations for a future wind tunnel test at NLR.

Propulsion Airframe Interaction

NLR participates in the BRITE/EURAM programme Enifair on the integration of high-bypass-ratio turbofan engines with the wing. Calculations with the Navier-Stokes ENFLOW code for wing/body configurations with a very high and an ultra high bypass turbofan engine were started. Resulting computational grids were delivered to partners. A wind tunnel model of the same configuration as used in the Enifair programme, named ALVAST and made available



Computing propulsion-airframe interaction: Navier-Stokes flow solution

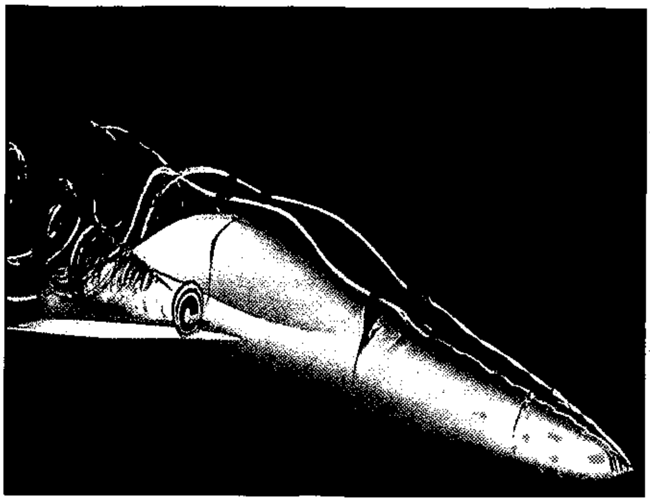
by DLR, was equipped with a conventional turbofan engine and tested in the Large Low Speed Facility of the DNW (DNW-LLF) to refine the measurement technique with turbine powered simulators. A half-wing of the same model with a through-flow nacelle was also tested in the DNW-LST, as part of the DLR/NLR co-operation. The objective of this test was to measure the flow field with a five-hole probe rake behind the wing to analyse the drag characteristics. The various drag components have been deduced from these measurements, and compared with the measured balance forces. These were also compared with balance results obtained in the DNW-NWB low speed tunnel. In a second entry in the DNW-LST the powered Counter Rotating Unducted Fan (CRUF) simulator was installed. The measurements involved overall balance measurements, five-hole pressure probe surveys by NLR and Particle Image Velocimetry (PIV) measurements by DLR of Göttingen. This enabled different techniques for flow field measurements to be compared, and exemplifies the co-operation between DLR and NLR further demonstrated by NLR contributing three papers at a Workshop organized by DLR on 'Aspects of Engine-Airframe Integration for Transport Aircraft'.

The analysis of propeller/slipstream interaction effects measured in the Indonesian Low Speed Wind Tunnel as part of a collaboration project of Indonesia and the Netherlands was completed.

The GARTEUR Propulsion Technology Action Group (PT) AG-02 almost completed the evaluation of calibration data obtained for three model engine configurations (including one powered engine simulator) in various European calibration facilities.
A study was made of the effect of small deviations in the thrust vector both on aircraft performance and on measurements of engine interference effects in the wind tunnel. The study confirmed the expectation that the direction of the thrust vector must be known accurately for properly 'accounting' the interference.

Aerodynamics of Combat Aircraft

NLR assisted the Royal Netherlands Air Force by computing aerodynamic forces and moments on components of F-16 configurations. The readiness of CFD technology for addressing operational aerodynamic problems was extended by generating a modular grid aiming to model the flow around a number of different F-16 configu-



Navier-Stokes solution for forebody

rations. The availability of this modular F-16 grid enables NLR to support the Royal Netherlands Air Force in a more timely fashion.

CFD technology development for military applications was continued as part of the WEAG TA-15 programme 'Computational Methods in Aerodynamics'. Phase VII of this programme was completed, and an MOU was signed covering Phases VIII through X. New CFD applications started in 1996 comprise Navier-Stokes computations of generic inlet geometries and delta wings with rounded leading-edges. A time-accurate simulation of a sharp-edged delta-wing with leading-edge separation, pitching around an average angle of incidence of 9 degrees with an amplitude of 6 degrees, was demonstrated and compared with a low-speed experiment also carried out in the framework of the WEAG TA-15 programme.

Helicopter Aerodynamics

The contribution of NLR to the BRITE/EURAM project Helishape was completed. In this project a common European computer code for helicopter rotor aerodynamics was developed, based on *unsteady full potential theory.*
NLR also participated in the development of a common rotor code based on Euler equations in the EROS project of BRITE/EURAM, where NLR focused on grid generation.

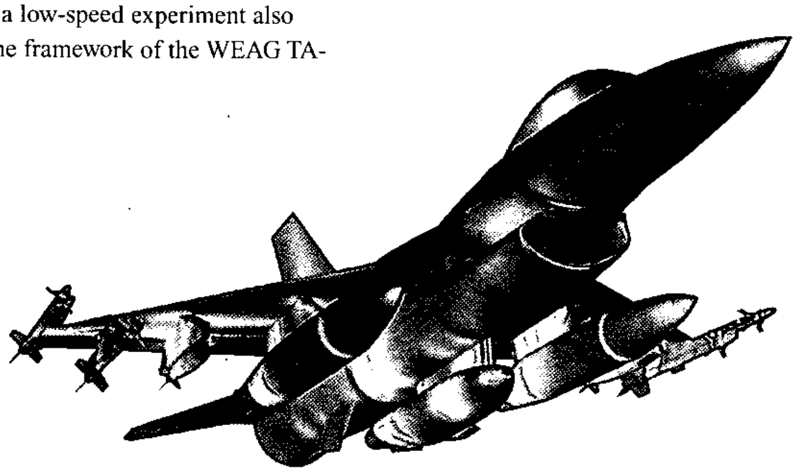
Contributions were made to wind tunnel tests in the DNW-LST and DNW-LLF for the NH90 development programme.

Vortex Wake Aerodynamics

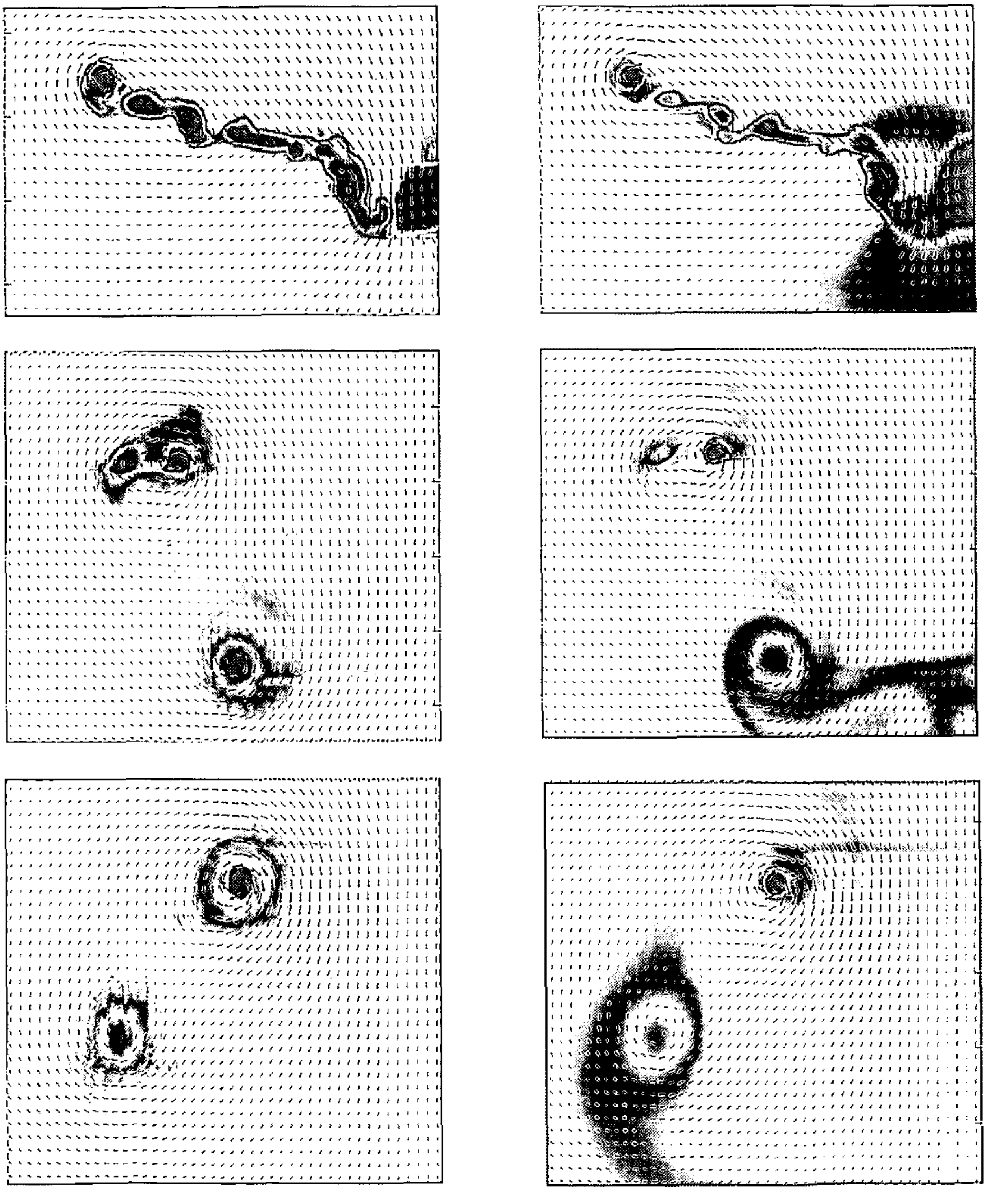
The effect of the spanwise lift distribution on wake vortex roll-up was studied for Boeing. The wake of an aircraft model was studied in detail, with emphasis on the engine-wing interference, in collaboration with DLR.

Hypersonic/Space Vehicle Aerothermodynamics

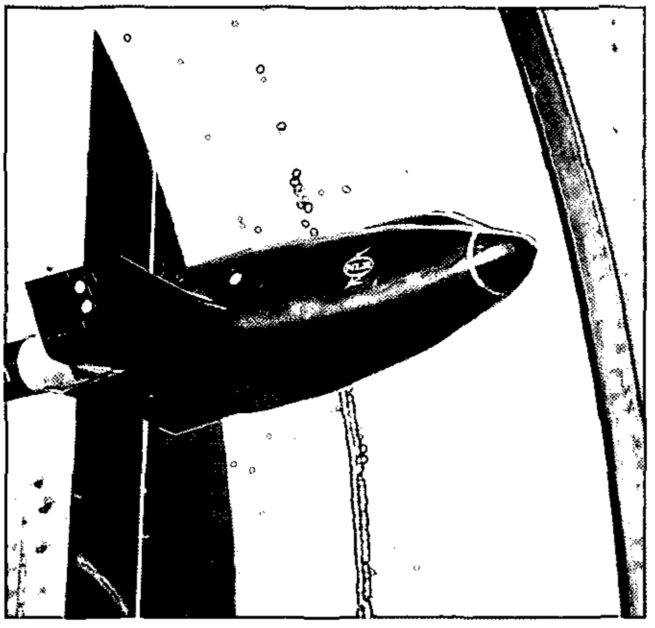
In the framework of ESA's Manned Space Transportation Programme, NLR has performed calculations on the chemically reacting, hypersonic flow around the Aerodynamic Reentry Demonstration (ARD) capsule, and wind tunnel tests including measurements to study the interaction of jets that are part of the Reaction Control System. The calculations were performed on the NEC SX-3 supercomputer in the



Euler solution for F-16 configuration



Flow properties in the wake of an aircraft wing, from top to bottom at 0.67, 2.0 and 4.7 span widths downstream of an aircraft model in a wind tunnel. Left-hand pictures: streamwise vorticity (colours) and cross-flow vectors (arrows), right-hand pictures: axial velocity (colours) and cross-flow vectors (arrows)



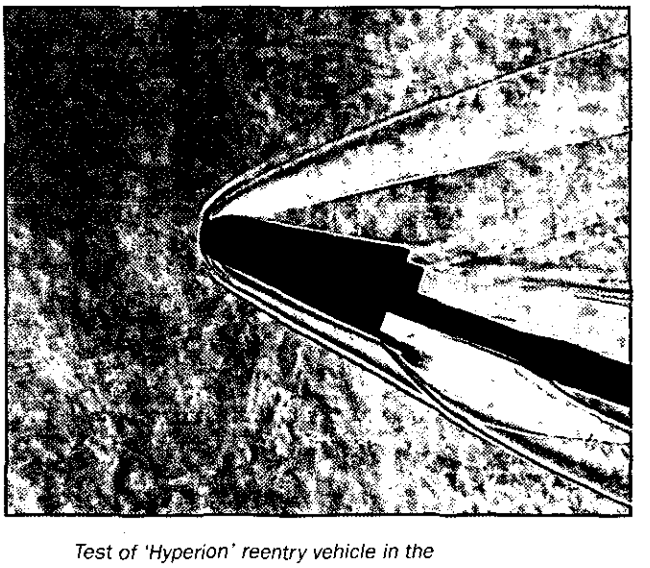
Model of a Crew Rescue Vehicle in the Supersonic Tunnel (SST)

first half of 1996, and on the NEC SX-4 in the second half of the year. Both a free-flight and a wind tunnel flow-field computation have been performed. The computations involved aerodynamic surface heating and aerodynamic force and moment coefficients to determine the trim angle of the ARD capsule. For the free flight condition, the CFD results agreed with the trim angle of the Apollo capsule. The wind tunnel condition, taking account of the non-equilibrium flow in the nozzle of the ONERA F4 hypersonic, high-enthalpy wind tunnel, turned out to be significantly more difficult to calculate, requiring further CFD analysis. The CFD results were entered into the Hypersonic Aerothermodynamic Engineering Data Base.

The activities in the aerothermodynamics of winged vehicles involved the completion of the conservation of HERMES space vehicle technologies. Co-ordinated space vehicle activities were initiated in the NASA X-CRV programme and the ESA CRV/CTV programme, where CRV stands for Crew Rescue Vehicle of the International Space Station and CTV stands for Crew Transfer Vehicle. NASA selected a CRV shape with a windward side identical to a former lifting body of the US Air Force/Martin Marietta X-24A research vehicle. ESA investigated the feasibility to derive an autonomous CTV from the CRV design. NLR carried out wind tunnel tests to verify the aerodynamic characteristics of an initial modification of the X-CRV shape, at transonic and supersonic speeds. Subsequently, NLR contributed to CFD activities to support further aerodynamic modifications of the aerodynamic shape.

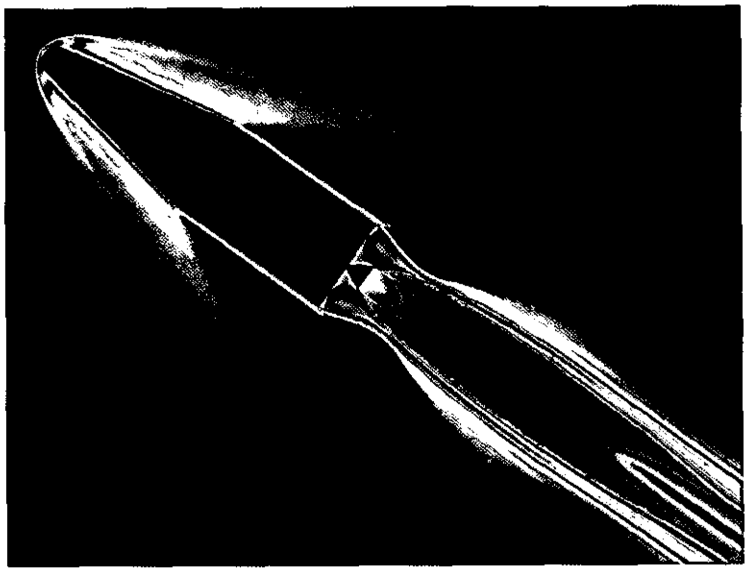
In the technology part of the Future European Space Transportation Investigations Programme (FESTIP) of ESA, NLR concentrates on CFD computations for base flows with plume interaction. The base flow investigations are carried out in a close collaboration with SAAB and the Aerospace Department of the Delft University of Technology. In the systems part of the FESTIP programme, NLR together with DASA contributed to the formulation of a technology development and verification plan for aerothermodynamics.

Activities in the national programme AEOLUS (Advanced Earth to Orbit Launcher Upgrade Studies) were reviewed with the AEOLUS partners and redirected towards space vehicle control surfaces. Furthermore, an experimental investigation was performed on the re-entry module 'Hyperion' in the Supersonic Wind Tunnel, to support Fokker Space.



Test of 'Hyperion' reentry vehicle in the Supersonic Tunnel (SST)

Computational Fluid Dynamics



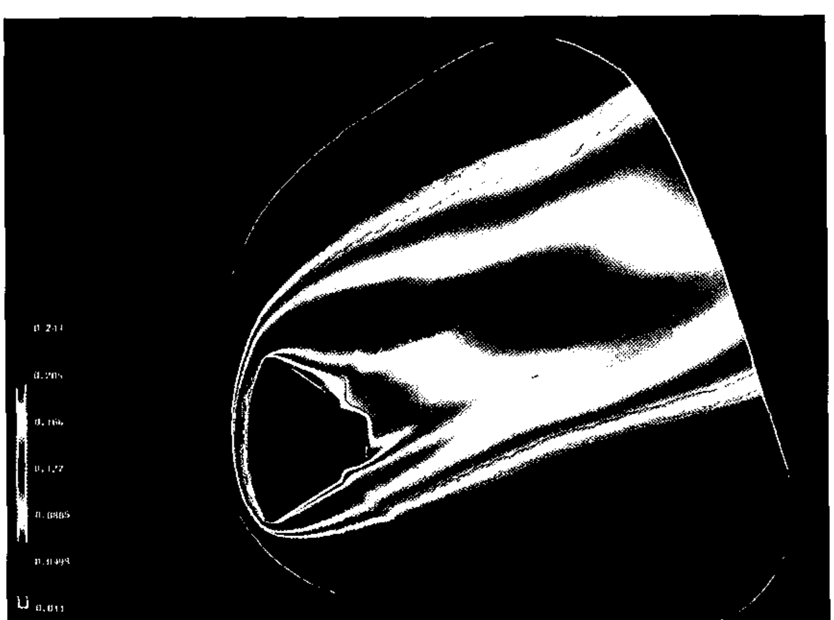
Navier-Stokes-computed baseflow for space transport

Reynolds-Averaged Navier-Stokes Methods

A significant part of the research and development activities in the field of computational fluid dynamics remained concentrated on improving the readiness of a computer code system for Reynolds-Averaged Navier-Stokes equations (ENFLOW). This work is carried out in close co-operation between the Fluid Dynamics and Informatics divisions of NLR and is funded partly by the Netherlands Agency for Aerospace Programs (NIVR), and partly by the Ministry of Defence.

The ENFLOW system is based on the use of multiblock grids, fully-conservative central-difference methods, and explicit time-integration methods accelerated by a multiblock/multigrid method. This system contains codes for:

- the preparation of geometric shapes of surfaces in 3D space for CFD work (ICEM CFD),
- the decomposition of 3D flow domains into blocks (ENDOMO),
- the construction of multiblock grids in 3D space (ENGRID),
- the execution of 3D flow calculations (ENSOLV),
- the multiblock grid adaption to flow solutions (ENADAP), and
- the graphical inspection and further processing of CFD results.



Oxygen mass fraction of Navier-Stoker solution around Reentry Capsule

Applications of ENFLOW in wing/body/pylon/nacelle design studies with Fokker had drawn attention to a number of aspects that need further improvement before wing/body/pylon/nacelle computations can be considered to be fully validated. One of the aspects of ENFLOW that have been improved is the representation of the jet engine inlet face. A stable solution algorithm for the jet-engine-inlet boundary condition of the Navier-Stokes equations has been achieved. For thoroughly testing this algorithm with flow computations, a multi-block grid was produced around the DLR TPS-441 jet engine, with a total of 2.17 million grid cells in the fine grid. Calculations on fine grids are necessary to resolve complex flow phenomena such as shocks and shear layers in the exhaust jets. The results of the engine computations match the results of the wind tunnel experiment reasonably well. Increasing the angle of attack leads to an increase of differences between the computational results and the experiment results. The computational time for aerodynamic analysis of propulsion/airframe integration problems was reduced substantially by making use of the SX-4 computer. A typical Reynolds-Averaged Navier-Stokes computation for a wing/body/nacelle/pylon configuration with about three million cells takes four hours to converge on a single processor of the NEC SX-4/16.

Other developments of the ENFLOW system were aimed at application aspects such as further reduction of turnaround times for generating and improving multiblock grids:

- the functionality of ENDOMO was widened by including specific options to manipulate topologies;
- the turnaround time for ENGRID was reduced by implementing a option allowing users to generate and tune high-resolution grids in block faces of multiblock grids on workstations, which is followed by generating the grid points internal to each block on the supercomputer;
- the work on multiblock grid adaption (ENADAP) was continued;
- the parallelization of ENSOLV on the NEC SX-4/16 was implemented on the level of the 'do-loop' internal to each block; this parallelization strategy could be realized without significant changes to the ENSOLV algorithm and without significant efforts in terms of manpower, but satisfies user requirements only in part.

The development of an unstructured-grid Reynolds-averaged Navier-Stokes solver for two-dimensional problems (FANS) such as multi-element airfoils was interrupted after an initial calculation for a high-lift airfoil configuration with a double slotted trailing edge flap.

To further validate Reynolds-averaged Navier-Stokes CFD methods NLR continued its participation in several GARTEUR Aerodynamics (AD) Action Groups:

- (AD) AG-20 for single element airfoils and grid adaptation,
- (AD) AG-24 for supersonic flow about slender configurations,
- (AD) AG-25 for maximum lift of multi-element airfoils,
- (AD) AG-26 for transonic wing/body computations, and
- (AD) AG-28 for a transonic wing/body code validation experiment.

Turbulence Research

The evaluation of the two-equation k-omega turbulence model was continued along the following three lines. First, a large number of similarity solutions of the k-omega turbulence model were generated for various forms of the k-omega differential equations, to investigate the sensitivity of the solutions. The resolution of discontinuities in the specific turbulent dissipate rate omega were found to depend strongly on the grid size.

The second line of turbulence research comprised the evaluation of the k-omega model against detailed experimental turbulence data measured on the GARTEUR wing in GARTEUR (AD) AG-07. A version of the k-omega model for low Reynolds numbers, implemented in a 3D boundary layer code, was tested against the experimental data and compared with computational results of a number of different turbulence models provided by other participants in GARTEUR (AD) AG-23.

The third line of turbulence research consisted of the implementation of the improved k-omega model in the ENSOLV flow solver. This activity, initiated in 1995, progressed to the demonstration of steady state solutions of the full Reynolds-Averaged Navier-Stokes equations for airfoils and wings. The results from ENSOLV confirmed earlier findings with respect to increased grid resolution requirements of the k-omega turbulence model.

Euler Methods

NLR is the lead partner in the BRITE/EURAM project FASTFLO. The other participants are DLR, DASA, Ingenieur Buro Kretzschmar, SAAB and FFA. The long-term objective of this co-operative research is to demonstrate a CFD system that will satisfy two basic requirements: low turnaround time for complicated geometries, and high accuracy of aerodynamic forces and moments. This co-operative research was started on the level of the Euler equations. Hybrid body-fitted grids, consisting of tetrahedral and prismatic elements, are employed to achieve improved automation.

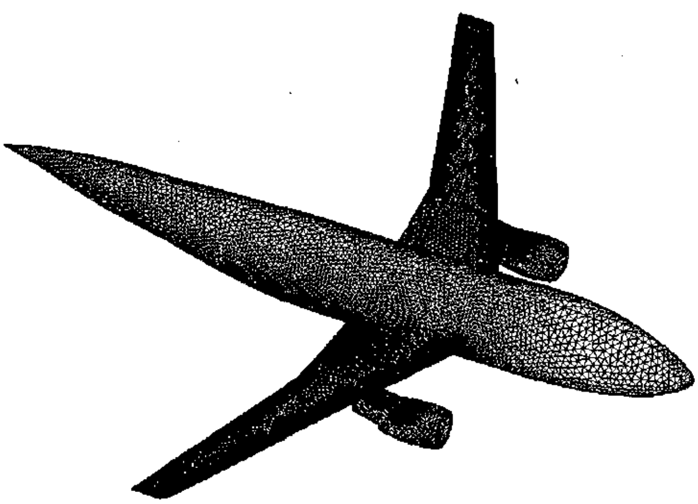
The development of a time-accurate Euler solver based on finite-elements (Hexadap) was continued. The method was verified for moving bodies such as rotating propellers and pitching wings. This method achieves accurate results for arbitrary motions by using discretization schemes that satisfy generalized conservation laws. The method was also successfully parallelized on the NEC SX-4 using 16 processors; the computational speed was a factor 18.5 higher than on a single SX-3 processor.

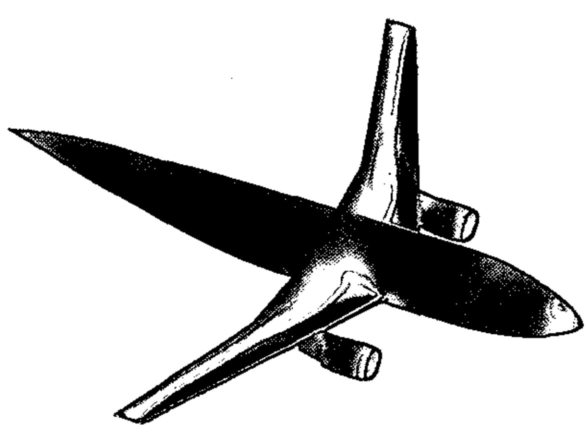
Radar Cross Section (RCS) Prediction Techniques

NLR started the second phase of an RCS Prediction Techniques project for the Ministry of Defence. This project aims at the development of RCS knowledge and prediction capabilities to support the Royal Netherlands Air Force and the Royal Netherlands Navy. One of the subjects that received attention was the interface between CAD geometry modelling and RCS prediction codes.

Aeroelasticity

NLR made descriptions of grid generation, methods and validation of the computer code for aeroelastic simulation of transport-type aircraft in transonic flow, AESIM. In this method the flow is modelled on the basis of an unsteady full-potential representation. Dynamic aircraft deformation is modelled using vibration modes imported from the MSC/NASTRAN programme. A demonstration of applications of this code including flow calculations for a fighter-type aircraft was made on a Euromech colloquium. In view of future fighter applications, the preparation for implementation of time-accurate Euler and Navier-Stokes solvers was started.





Surface triangulation grid and Euler solution of wing-body-pylon-nacelle configuration

The research programme on Limit Cycle Oscillations (LCO) of fighter-type configurations was continued with a flow visualization study in the High Speed Tunnel (HST). The unsteady flow about an oscillating simple-strake semi-span model was visualized by a 'vapour screen' technique, and by Particle Image Velocimetry (PIV). Attention was focused on shock-wave motion and on vortex development and motion, in order to relate the spatial information with data on surface pressure and overall forces and moments from previous experiments. The data will be used for further development and validation of LCO prediction methods.

The participation in the GARTEUR Structures and Materials Action Group (SM) AG-19 on ground vibration testing was continued by the preparation of a final report describing the results of vibration measurements on a standard structural model.

Aeroacoustics

The research on aeroacoustics was marked by the successful completion of three major BRITE/EURAM projects.

The measured data from the SNAAP project (Study of Noise and Aerodynamics of Advanced Propellers) were used for the validation of existing lift-surface codes for the aerodynamics and acoustics of single-rotating propellers. The computed performance data compare very well to measured data, up to the highest test Mach number of 0.78. The comparisons of computed and measured acoustic data also yielded a fair agreement, although the discrepancies for the so-called Low Speed Propeller, a rather classical design for a cruise speed of Mach 0.7, were found to be smaller than those for the High Speed Propeller, an advanced design with supersonic tip.
The computer code for the diffraction of sound by an aircraft fuselage of circular cross-section and the refraction by its boundary layer, was delivered to the partners. The European co-operation on propeller noise was continued in the project APIAN (Advanced Propulsion Integration Aerodynamics and Noise), in which the sound field of installed propellers is investigated. Some preliminary computations were carried out, to optimize the location of the instrumentation on a model fuselage.

In the area of fan noise, the FANPAC project (FAn Noise Prediction And Control) was completed with a test in the Rolls-Royce facility at Ansty. This test concerned novel liner concepts previously investigated in the NLR Flow Duct Facility. The acoustic data from the test, obtained with NLR's acquisition and processing system, constitute a valuable database for liner performance analysis and code validation. Furthermore, research was carried out on the capability of folded Helmholtz cavities to reduce low-frequency noise.

In the field of cabin noise, the BRAIN project (Basic Research on Aircraft Interior Noise) was concluded.

In the 'Dutch Green Aircraft' project, sponsored by the RLD and the Ministry of Housing, Physical Planning and the Environment, studies were carried out on potential future developments in engine noise reduction as a consequence of progressing technology and on the feasibility of the application of active acoustic linings to reduce environmental noise.

Under contract to the NIVR, investigations on the influence of wind and temperature gradients on the propagation of sound from an aircraft to the ground were started. A pilot computer program based on ray acoustics was developed.

Non-Aerospace Aerodynamics

In co-operation with the Energie Centrum Nederland (ECN) and Delft University of Technology, a method for the prediction of stall delay on wind turbine blades due to 3D effects was further improved. Results were presented on the European Rotorcraft Forum. In close connection with this co-operation, NLR contributed to the validation of two- and three-dimensional prediction methods for dynamic stall in the framework of the European Joule project 'Dynamic stall and 3D effects'.

A remarkable non-aerospace aeroelastic activity was the vibration test and analysis of the suspension cables of the Erasmus bridge, located in Rotterdam. The test on this new bridge was necessary in view of the occurrence of high-amplitude cable vibrations during moderate winds combined with rain.

Facilities and Equipment

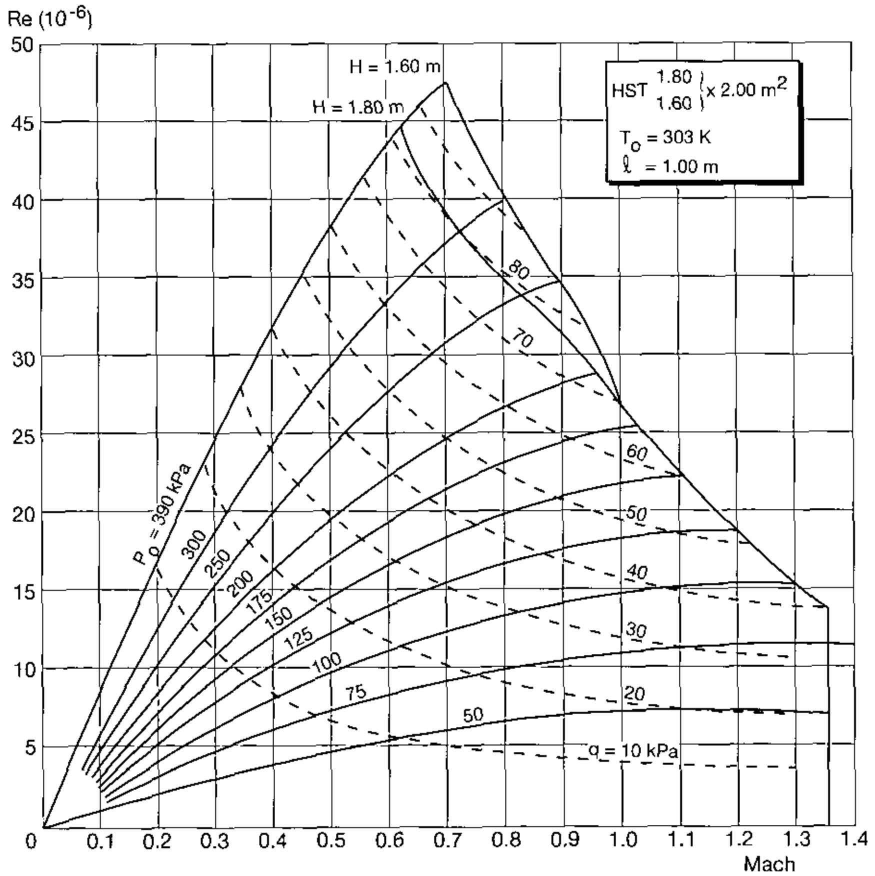
The Transonic Wind Tunnel HST

As in 1995, the majority of the work for the transonic wind tunnel was related to the second phase of the modernization, which concentrates on the replacement of the power and drive systems. Contracts were awarded for the associated civil works, new settling chamber screens, a honeycomb flow rectifier and for an upgrade of the fan housing. NLR has designed and has begun manufacturing a set of new fan blades. The work proceeded according to plan, and on 6 September 1996 the steam boiler power plant blew off steam for the last time, marking the start of actual work on site. By the end of the year, the site work had progressed so far that the HST was expected to become operational again in the Spring of 1997, driven by a new, more powerful electric motor with the public electricity grid for power source.

Measures were taken also to improve the productivity by decreasing pressurization times and by improvements of the pressure and Mach number controls. The temperature control will be improved by substantially shortening the response time of the cooling system.

The Supersonic Wind Tunnels SST and CSST

After the shutdown of the steam boiler power plant, the drives for the air compressors of the SST pressure vessel were replaced by electric drives. The air compressors and with them the supersonic tunnels will become operational again shortly before the commissioning of the HST.



Working envelopes of the upgraded High Speed Tunnel (HST), test section width: 2.0 m, height 1.60 m or 1.80 m

Propulsion and Acoustics Laboratory
The background noise of the Small Acoustic Tunnel was substantially reduced by adding an extra muffler in the duct just upstream of the nozzle. The turbulence level was reduced by placing anti-turbulence screens.

Instrumentation and Measurement Systems
By the replacement of the 14.7-Megawatt drive system by a new 19-Megawatt electric drive motor, the dynamic pressure range of the HST will increase by more than 50 per cent. In order to be able to use this extended range for force measurements on full-span models, a high-load internal balance was designed and its manufacturing was started. For the same reason, the equipment for the measurement of the tunnel reference pressures was replaced by a new dual-range Flow Reference System.

An optical surface pressure measurement system based on the use of Pressure Sensitive Paint (PSP) was developed and tested in the HST, using a paint developed by the Netherlands Organization for Applied Science (TNO). The results of the tests were analysed, and several problems relating to the accuracy of the technique were identified. By this investigation NLR contributed to the work of GARTEUR Action Group (AD) AG-21 with the objective of demonstrating the possibilities to apply accurate and productive PSP techniques.

Considerable progress was made with the development of a Particle Image Velocimetry (PIV) system, capable of measuring velocity vectors in two components in the plane of a laser sheet, primarily for use in the HST wind tunnel. After the purchase of laser, camera and data handling equipment, investigations into the seeding system were carried out in the HST. A seeding system has been specified.

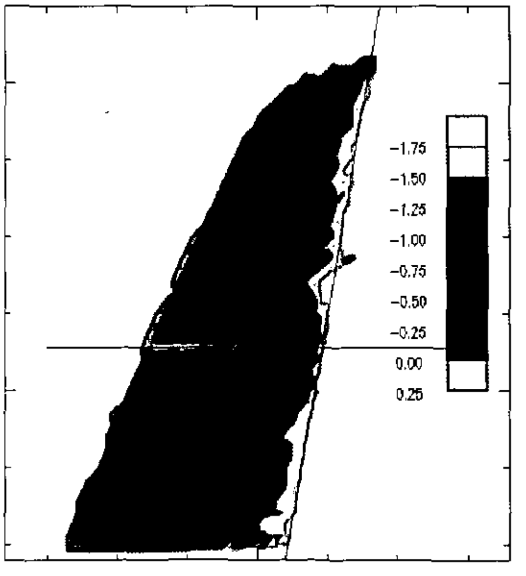
In parallel with these activities NLR participates in the BRITE/EURAM project EUROPIV, a co-operative action to study the applicability of Particle Image Velocimetry to problems of industrial interest.

A method to electronically compensate for the effect of model vibrations on the accuracy of gravity sensing inclinometers, used in wind tunnel models to measure model incidence, was tested and implemented in an inclinometer conditioning unit.

A new, high performance, hydraulic system for the excitation of models in unsteady (wind tunnel) testing was purchased and installed.

In co-operation with the DNW, a feasibility study was carried out on the application in the open jet test section of acoustic array techniques for locating acoustic sources. Advanced algorithms were developed and tested for the use of arrays with non-redundant microphone distances. The study showed that DNW's requirements for frequencies up to 40 kHz can be met.

At the aero-acoustics laboratory a test set-up was realised, and used, to investigate pressure waves generated by fast moving trains in tunnels.



A Pressure Sensitive Paint technique was tested in the HST

3.2 Flight

Summary

The total volume of contract activities related to flight operations increased by more than 30 per cent relative to 1995. In addition to growing support to the Royal Netherlands Air Force this increase was due to expanded participation in the Commission of the European Communities' Fourth Framework Programme, resulting in activities in the areas of air traffic management and human factors.

In the field of *flying qualities and flight control systems*, NLR in co-operation with foreign research institutes continued the study focused on the development of guidelines for handling qualities of modern civil transport aircraft.
NLR chairs a GARTEUR Action Group on the application of robust control techniques to realistic flight control design problems, and in which a prototype framework for computer aided control engineering for design process management is developed.
With the partners in the GARTEUR Action Group on windshear, NLR continued the execution of WINDSTREAM (Windshear Technology Research Advances Masterplan).

In the field of *air traffic management (ATM)*, NLR continued its participation in many Eurocontrol programmes and in the Commission of the European Communities' Fourth Framework Programme 'ECARDA', European Coherent Approach for the Research and Technology Development of ATM, as well as supporting the Netherlands aeronautical cluster. Activity areas were: ATM concepts; ATC; Communication, Navigation and Surveillance; Aeronautical Telecommunication Network; Avionics; Human Machine Interface; airport TM; and facilities and basic research.

Airport capacity assessments for Amsterdam Airport Schiphol (AAS) in the year 2015 were made under contract to KLM Royal Dutch Airlines and AAS.

Human factors issues were studied with respect to glass cockpit design (modification of flight and navigation displays); air traffic controller working positions and working methods, in collaboration with Eurocontrol, ATC The Netherlands (LVB), and NASA and FAA; airport ground movement efficiency and aircraft maintenance, both supported by the Commission of the European Communities (CEC); and airport hindrance.
NLR developed an integrated workload analysis tool set which allows data from many sources to be integrated and synchronized into one consistent database.

In the area of *military support*, NLR assisted the Royal Netherlands Air Force in several projects: in a national technology project on the application of voice in the cockpit, during flight tests with various military aircraft, in tests with several air defence systems, in the replacement of a tactical recce system and in the investigations of accidents with Air Force aircraft. On the international level, NLR participated in a project on training and simulation research.
SAAB Military Aircraft was supported in the evaluation in the National Simulation Facility (NSF) of a flight control system.

NLR participated in the activities of several GARTEUR Action Groups on *helicopters*.
NLR in co-operation with Fokker Aviation and SP Aerospace and Vehicle Systems continued its contribution in the Design and Development phase of the NH90 programme for a future NATO helicopter.
For the Royal Netherlands Navy a flight test programme was carried out on board of a new replenishment oiler ship, which constituted the final phase of the qualification of the Lynx helicopter for operations on board of this class of ships.

Within the scope of *policy analysis*, advice was provided concerning the formulation of a policy on the management of early morning flights at AAS.

In the field of *transport and environmental studies*, NLR realised a computer model for the assessment of aviation emissions. Noise exposure and third party risk calculations were carried out for several airfields. The models for the calculation of risks around airports with a traffic

mix of general aviation and propeller-driven commercial aircraft were accepted by a government committee. NLR started to develop models for performing risk analysis around military aircraft.

Aircraft operations with NLR's Metro II research aircraft concerned flights using the Caesar optical scanner; the Phased Array Universal SAR was used in flights with the Cessna Citation II. With the LVB a contract was signed under which NLR will perform flights for the inspection of the radio navigation aids in the Netherlands.

With regard to *facilities and equipment*, the NLR ATC Research Simulator (NARSIM) system was modernized by finalizing the NARSIM Client/Server project. The system is now flexible enough to allow easy integration of external software.

To enable a multitude of simulation experiments to be performed in several configurations, modifications were made to the NLR Research Flight Simulator (RFS), for instance by the implementation of new navigation and flight path displays. The displays were designed using the NLR Advanced Display Design and Evaluation System (NADDES).
The development of the National Simulation Facility (NSF) was continued with the installation and the acceptance of the g-cuing system. The generic mock-up was equipped with a point-of-gaze measurements system.

Flying Qualities and Flight Control Systems

Flying Qualities

In the framework of GARTEUR and under contract to the Netherlands Agency of Aerospace Programs (NIVR), work on the development of design guidelines for low speed lateral/directional handling qualities of civil transport aircraft equipped with advanced fly-by-wire flight control systems was continued.

Effects of Control Augmentation

Under contract to the Netherlands Department of Civil Aviation (RLD), an investigation was carried out to gain a better understanding of the effects of control augmentation systems on aircraft handling and pilot workload during approach and landing in adverse weather conditions. The results of this experiment, carried out using NLR's Research Flight Simulator, were analysed. A validation experiment was carried out using the MD11 training simulator at the Douglas Training Center in Long Beach, USA.

Robust Flight Control

NLR chairs a GARTEUR Action Group that conducts research into the efficiency and transparency of the flight control laws design cycle. A design challenge has been made in which two flight control benchmarks are considered. Designs have been proposed by twenty-one teams using thirteen different classical and modern control techniques. Under the supervision of DASA and British Aerospace, the designs have been evaluated by control engineers working throughout the European aeronautical industry.

NLR has developed a prototype framework for computer aided control engineering for design process management. The prototype offers facilities for design process definition and execution, including tool integration and a central data repository.

Advanced Continuous Descent Approaches

Current procedures for approach and landing are far from optimal from an environmental point of view. New, environmentally-friendly procedures are becoming feasible with the introduction of new approach, navigation and flight management systems, such as the Microwave Landing System, the Global Positioning System and modern Flight Management Systems. One promising procedure is the Advanced Continuous Descent Approach (ACDA), which allows the aircraft after passing the Initial Approach Fix to start a continuous, low power, descent to the runway threshold along a curved approach path with both lateral and vertical guidance. During the greater part of the approach the aircraft is kept in a clean configuration, while the engines are operating near flight idle.

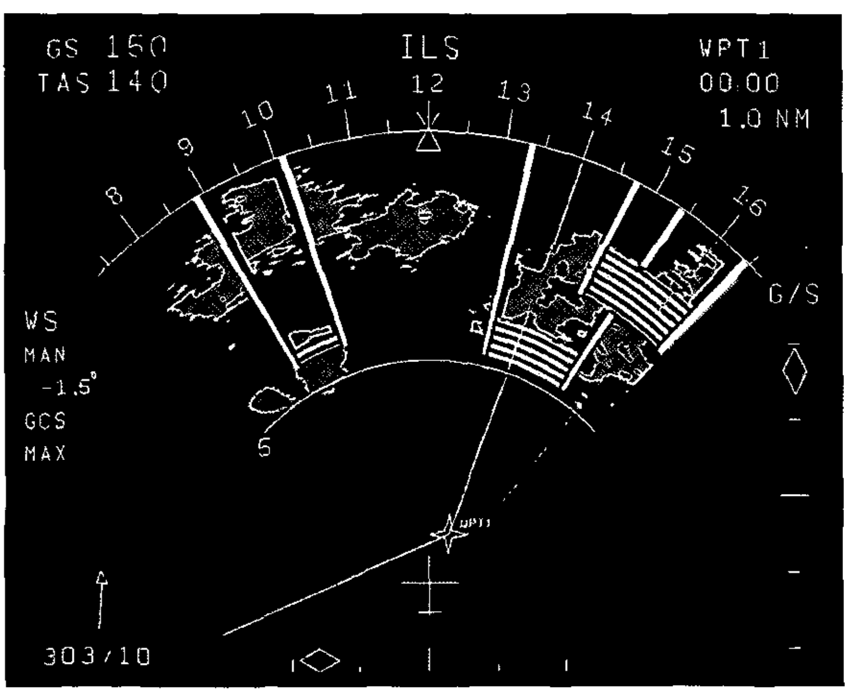
A preliminary study indicated that ACDA may lead to substantial noise reductions, whereas significant improvements in other environmental issues appear to be feasible as well. Based on these results, the NIVR awarded NLR a contract for a feasibility study.

NLR made preparations for a simulation investigation that will include the combined use of a flight simulator and an ATC simulator. In this investigation the expected environmental and economic benefits will be verified and the operational possibilities and limitations will be determined, from the viewpoints of both aircrew and air traffic controllers. Attention is also paid to provisions needed in avionics systems (such as adaptations in the FMS) and to the development of tools for supporting the air traffic controller in his metering and spacing task for handling a mix of conventional and ACDA traffic. A demonstration programme of ACDA approaches on the RFS and NARSIM has been prepared.

Windshear

NLR continued research into windshear under contracts to both the Netherlands Department of Civil Aviation (RLD) and the Netherlands Agency for Aerospace Programs (NIVR), and participated in GARTEUR Action Groups. Research was aimed at the development of new technologies related to windshear detection, guidance and avoidance systems, and to getting a better understanding of the impact of these technologies on flight operations (including procedures), flight safety, human factors and established cockpit alerting mechanisms.

The experiment of Phase II of the project WINDSTREAM (Windshear Technology Research Advances Masterplan) was successfully executed on the NLR Research Flight Simulator (RFS). In the experiment, an in-house developed airborne Doppler weather radar model provided with forward-looking windshear detection



Windshear icons shown on weather radar display in flight simulator test capability was used. Weather and ground clutter information were presented in real time. When a windshear was actually detected, the crew was alerted not only by aural cues but also by special windshear icons superimposed on the weather radar display. Multiple icons represented multiple shear cells.

The windshears were derived from actual accident cases obtained from the FAA. These cases are also used by the industry in the certification of new systems. Crews were assisted in the execution of their approach and landing tasks by a flight director including a windshear recovery guidance mode. Manual approaches were flown with assistance from an autothrottle system.

Verification of Flight Management Concepts
NLR was involved in a design study for a short to medium range commuter aircraft with seating capacity of 60 to 80 passengers, capable of operating in a future 4D Air Traffic Management (ATM) environment. The primary objective of this study was to identify the main requirements for the cockpit of a commuter aircraft in a future ATM environment. Apart from a number of Flight Control and Display Concepts, a 4D Flight Management System with datalink capability was developed for an experiment using the Research Flight Simulator (RFS) and the NLR ATC Research Simulator (NARSIM) combined.

Support of Computer-Aided Engineering Project
NLR continued supporting Fokker Aircraft's project Computer-Aided Engineering (CAE). Existing tools and models were developed and applied in design exercises.

The CAE subproject Engineering Design Simulation involved the development of a general tool for the simulation of the dynamics of all Fokker aircraft. The tool was used by Engineering Departments at Fokker. Feedback from these users led to additions and improvements, notably in the Graphical User Interface.

Assistance in the CAE subproject Structured Design of Aircraft Systems consisted of participation in a design exercise. Training was given in the processes and methods to be applied for requirements analysis and conceptual design. Interviews with Fokker specialists were held to determine requirements for a so-called Utility Management System.

The final contribution to the CAE subproject Interaction of Brake and Landing Gear was the documentation of a generic model library for the analysis, design and simulation of typical aircraft brake components.

Mathematical Models of Aircraft and Helicopters
In co-operation with the Faculty of Aerospace Engineering of the Delft University of Technology and the Technical University of Braunschweig, NLR continued to work on creating a simulation model of the Metro II research aircraft and a generic helicopter model, the latter in accordance with the specification from GARTEUR Action Group (HC) AG-09 in which NLR participates.

Flight Management System Training and Demonstration
For an Avionics System manufacturer, NLR is developing a PC-based Flight Management System training tool. Copied from the current development environment of the Research Flight Management System (RFMS) with some modifications to match the functionality of the manufacturer's system, this tool will enable the manufacturer to demonstrate his product to potential customers.

Air Traffic Management

National solutions in the field of Air Traffic Management must fit within European supranational guidelines and structures. NLR's participations in international programmes of Eurocontrol and of the Commission of the European Communities' Fourth Framework and in other programmes enable it to provide effective support to the Netherlands aeronautical cluster, in particular Amsterdam Airport Schiphol (AAS), KLM Royal Dutch Airlines, Air Traffic Control The Netherlands (LVB) and the Netherlands Department of Civil Aviation (RLD).

NLR is one of the leading organizations in PHARE-X, a consortium (NLR, National Air Traffic Services Ltd, Sofréavia, Deutsche Flugsicherung GmbH, DLR, Defence Evaluation and Research Agency) that has successfully been bidding for Fourth Framework tasks. NLR has been active in several areas, as detailed below.

Support to the LVB

In co-operation with the LVB (Air Traffic Control The Netherlands), NLR developed a pilot version of a runway usage advisory system, giving guidance to air traffic controllers in the optimum use of available runways, taking into account meteorological factors and environmental aspects.

The conflict detection functions realized by the manufacturer Raytheon for the new ATC system of the Netherlands, AAA, were evaluated against the requirements.

As part of the research into advantages of new developments to be used in an ATC environment, attention has been given to the modelling of aircraft equipped with 3D and 4D Flight Management Systems and a flight path conformance model.

For the SOCS Working Group (Steering group on the Optimization of the Capacity of Schiphol), consisting of experts of LVB, RLD, KLM and AAS, the possibilities and the techniques to be implemented for a Schiphol Advanced Surface Movements Guidance and Control System (A-SMGCS) were explored.

In co-operation with the RLD, the LVB Flight Track and Monitoring System has been upgraded.

In co-operation with LVB and Eurocontrol, the operational requirements and functional requirements of a Medium Term Conflict Detection Method for the European Air Traffic Control Harmonization and Integration Programme (EATCHIP) have been finalised.

On behalf of the LVB, NLR took part in activities of international ICAO Panels such as the SSR Improvement and Collision Avoidance Systems (SICAS) Panel, the Aeronautical Telecommunication Network Panel (ATNP), the Automatic Dependent Surveillance Panel (ADSP), the Review of the General Concept of Separation (RGCS) Panel and the All Weather Operations Group (AWOG), and in activities of Eurocontrol in the European Air Traffic Management System Concept Task Force (ECTF).

Support to the RLD

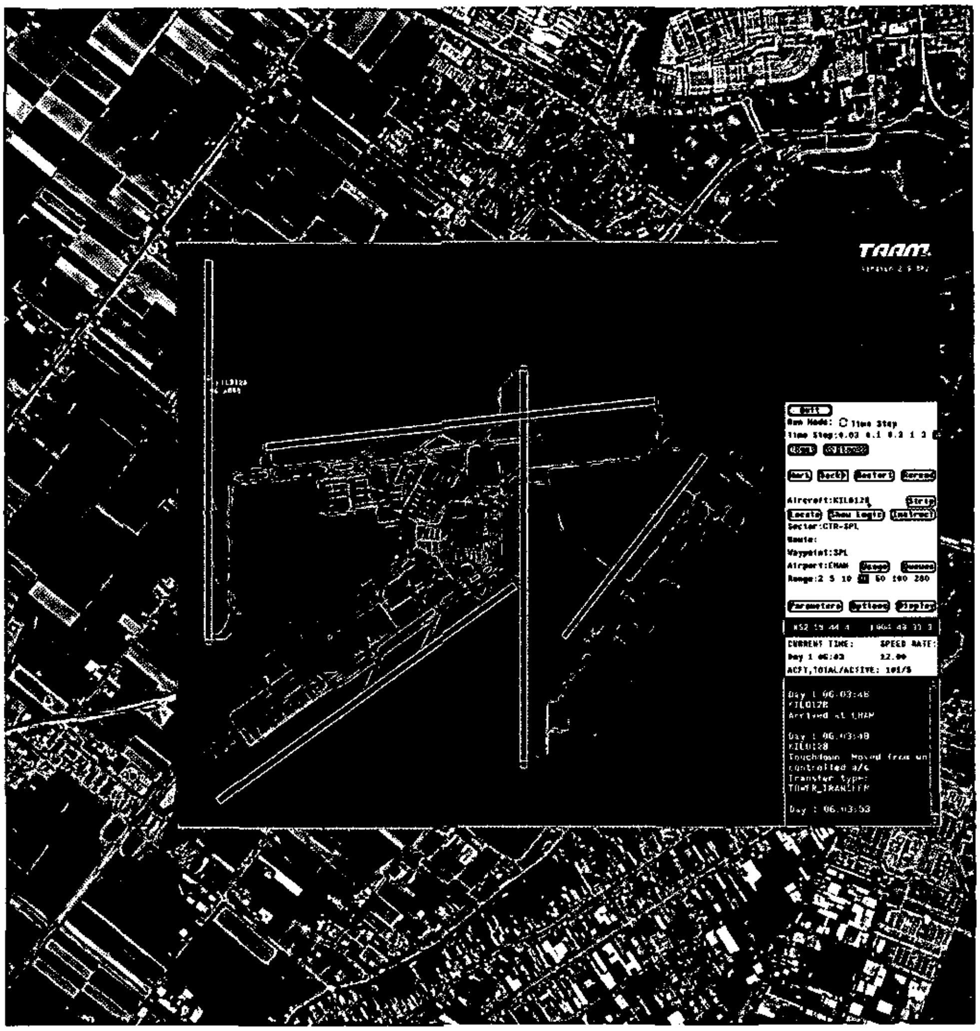
For the RLD (Netherlands Department of Civil Aviation), the Netherlands regulatory authority, consultancy services were provided in the field of data communication and ICAO Aeronautical Telecommunication Network Panel activities. A study was made into the navigation aspects of GNSS and the Required Navigation Performance. Some concluding work on the analysis of the safety of the Converging Runway Display Aid (CRDA) approaches was carried out.

A study was made of the hindrance impaired by unauthorized or unintended VHF transmissions. Some countermeasures were proposed.

Technical advice was provided to the RLD in the matter of ILS sustainability, in support of the discussion about the installation of the Microwave Landing System at Amsterdam Airport Schiphol.

Support to KLM and AAS

Two airport capacity studies for Amsterdam Airport Schiphol with a five-runway system in the year 2015 were conducted. One comprised a rough assessment of the situation in 2015, and the testing of several solutions to the observed bottlenecks in aircraft handling on the ground and in the air. The other study was conducted in the framework of the Schiphol Masterplan 2015 and consisted of a detailed study of the expected capacity. The views of KLM and AAS on the expected air traffic mix and the expected ATM development have been modelled and studied in fast time simulations.



Simulated airport operations at Amsterdam Airport Schiphol
Photography: KLM Aerocarto, Arnhem

Support to Eurocontrol

A major contribution was made to the Programme for Harmonized ATM Research in Eurocontrol (PHARE), especially in the following projects:

- Experimental Flight Management System (EFMS)
- Common Modular Simulation Environment (CMS)
- PHARE Aeronautical Telecommunication Network (PATN)
- Airborne Human Machine Interface (AHMI)
- Ground Human Machine Interface (GHMI)
- The Phare Advanced Tools (PAT)
- Validation
- PHARE Demonstration 3.

NLR has the lead in the AHMI and GHMI projects. The laboratory is one of the main sites of the PHARE Demonstration 3, a large scale, multi-site, multi-sector demonstration of an advanced Air Traffic Management concept developed by PHARE partners and intended to be operational in the period 2000–2015.

NLR provided a full staff member to the PHARE office at Eurocontrol, Brussels.

Several consultancy services were provided to Eurocontrol in the field of reduced vertical separation.

NLR also contributed to FACTOR/CT (Development of Functional Concepts from the EATMS Operational Requirements/Complementary Task), making an assessment of the requirements for a future European ATM system.
In the project called SIERA (SIM5+ (the new ATC simulator of Eurocontrol) Extension Requirements Analysis), NLR participates with Sofréavia and Thomson CSF.
NLR participates in the project TOSCA (Testing Operational Scenarios for Concepts in ATM) started at the end of the year. TOSCA is aimed at finding the impact of the introduction of a certain number of options in the European ATM system (EATMS) concept on the performance of the system.

Support to the European Union

The Commission of the European Communities is conducting an extensive Fourth Framework Programme: the 'European Coherent Approach for Research and Technological Development in Air Traffic Control' (ECARDA). This programme is supported by DG-7, DG-12 and DG-13, and concentrates on the development of a future European Air Traffic Management system. The programme also aims at stimulating research on ATM in Europe and at improving the European industrial position in ATM. NLR participates in several consortiums in many of these projects. The main objective of the participation of NLR is the realization of an advanced ATM infrastructure in the Netherlands in order to support the mainport function of Schiphol. The projects can be distinguished in various domains as described below.

ATM Concepts

Studies were carried out into advanced Air Traffic Management operational and functional concepts and procedures, including air space management aspects, operational scenarios, and safety and validation aspects. In several projects 'proof of concept' demonstrators will be developed, pre-operational systems that play important roles in the evaluation and validation of the operational feasibility of the new concepts.

Air Traffic Control

Studies were carried out aimed at providing support to air traffic controllers in order to increase the capacity of the air traffic control system and/or to decrease the controllers' workload. The studies concerned new controller workstations with advanced HMI, advanced ATM functionality (e.g. conflict detection tools, planning tools, problem solvers, arrival and departure managers) which exploit the new CNS (Communication, Navigation and Surveillance) technology (e.g. air-ground data communication, satellite-based navigation and enhanced surveillance).

Airport

Research carried out concerned all aspects related to aircraft movements on the airport surface such as improved surveillance and automated guidance and control in order to handle precise departure times, increased use of runway and taxi tracks, landing and approach aids which are less susceptible to multipath effects, optimal taxi routes and gate allocation, and automated assistance for the tower controller.

Avionics and CNS (Communication, Navigation and Surveillance)

Research on advanced flight management systems concerned: aircraft-based optimal flight routes, Automatic Dependent Surveillance, air-ground data communication, advanced primary flight and navigation displays, and Control and Display Units, monitoring and alert and warning systems and integration of relevant avionics with the ATC ground system.

Facilities and Fundamental Research

The research subjects can be distinguished in: ATC simulators, ATM software tools, tower research simulator, research flight simulator, fast time ATM simulator, safety prediction and analysis tools, capacity prediction and automated ATC environment.

Human Factors

Glass Cockpit Design for Airliners

Prototype navigation displays of the new on-screen interactive generation were evaluated for effectiveness of man-machine interaction. The displays assist the flight crew in strategic route negotiations with Air Traffic Control. Designed with the NLR Advanced Display Design and Evaluation System (NADDES), they were implemented in the Research Flight Simulator for crew evaluation under operationally realistic scenarios. The so-called 4D capability was used effectively by flight crews and the transmissions via the digital datalink proved to enable routes and constraints to be efficiently exchanged. Input devices such as tracker balls and touchpads were used without major difficulties. When combined with the interactive display design, these devices increased the level of crew participation in the air-ground negotiation process. The concept can be applied to several types of ATM, both strategical and tactical, and could also serve Free Flight.

Traditional PFDs (Primary Flight Displays) were modified to include information on time, heading and altitude constraints, by additional data on display elements of the 'tape' type. The 4D PFD was compared in a flight simulator experiment with a tunnel-in-the-sky design, intended to be used in an ATM scenario with strict time constraints. The results revealed a superior accuracy for the latter display, as it allows a pre-view on the trajectory. The improved accuracy with respect to the ground tracks resulted in accurate management of the noise footprints, relevant for environmental issues around airports. The work was supported by the NIVR and included collaboration with the University of Leiden.

The advent of Free Flight scenarios is imposing new requirements for the information displays in glass cockpits. Specifications for extended navigation displays with traffic information and different levels of displayed 'traffic intent' were drafted and incorporated in a research proposal that led to participation in a co-operative project of the US NASA and FAA with the RLD. Human factors issues in the design of windshear display elements and modified flight path vector displays for enhanced manual control functions were evaluated for effectiveness in flight simulator experiments with airline flight crews.

Awareness of system status and trends was investigated in a study supported by NIVR by means of alternative designs for engine displays and general systems. The human navigation capabilities could be improved, but more work is needed to address cockpit integration issues associated with using multiple systems in one cockpit. Training issues in the transition from one system to another were found to be of increasing importance.

Enhanced and synthetic vision research continued in a project of the Commission of the European Communities (CEC). Many essential Human Factors issues were identified that warranted intensive research because of the necessary trade-offs between required data and the problem of clutter. Stable and world conformal display elements, combined with consistent colour coding reduce the perception of clutter. Overall cockpit consistency and compatibility of data formats appeared essential for performance improvements.

The changing role of the FMS (Flight Management System) in future ATM systems was investigated in a study supported by the CEC. Specifications for additional capabilities of Command and Display Units were drafted and included in a design specification to be implemented for crew evaluation.

Controlled Flight Into Terrain

Under contract to the RLD, a study was initiated into the operational implications of terrain separation assurance displays. The objective of the study is to investigate the influences that terrain displays have on crew decision making and the overall effect on flight safety. A number of candidate display concepts and algorithms necessary for predictive terrain alerting have been developed. A part-task evaluation of these displays, with pilot-in-the-loop, has been conducted.

ATC/ATM Controller Human Machine Interface
In collaboration with Eurocontrol and the LVB, work on the design and specification of controller working positions for the next generation ATC/ATM was continued. The en-route interfacing with the terminal area was the subject of the PHARE PD/2 experiments. The results showed that some controller interactions, particularly initiatives, are counterproductive for attainable traffic capacity with advanced trajectory planning. Combined with earlier lessons learnt with the en-route PD/1 experiment, the results again indicated that new roles and tasks for tactical and planning controllers will evolve from the application of new technology and associated working methods. The computer-based training and familiarization package designed by NLR was crucial in the achievement of quality experimental data with (variable) human subjects, and facilitated the use of ATM-compatible working methods. Transition training issues were identified that warrant extensive research into controller retraining to facilitate the implementation of ATM.

Exploratory work on Free Flight ATM solutions was performed in collaboration with NASA and FAA and with support from the RLD. The impact of Free Flight on the role and required capabilities of air traffic controllers proved substantial, as the traditional 'building of the picture' will not be comparable with today's practices. New informational displays and tools were found to be required.

In collaboration with NASA and the Catholic University of Washington, alternative working methods for air traffic controllers were investigated using the 'adaptable' and 'adaptive' Human Machine Interface concepts. State-of-the-art assistance tools were implemented in an experimental Controller Working Position based on the CTAS concepts and tools. The vigilance and situational awareness (traffic awareness) in predefined working periods was improved by allowing flexible switching between levels of automation as a function of traffic load as well as regular switching between fully automatic and partly manual modes.

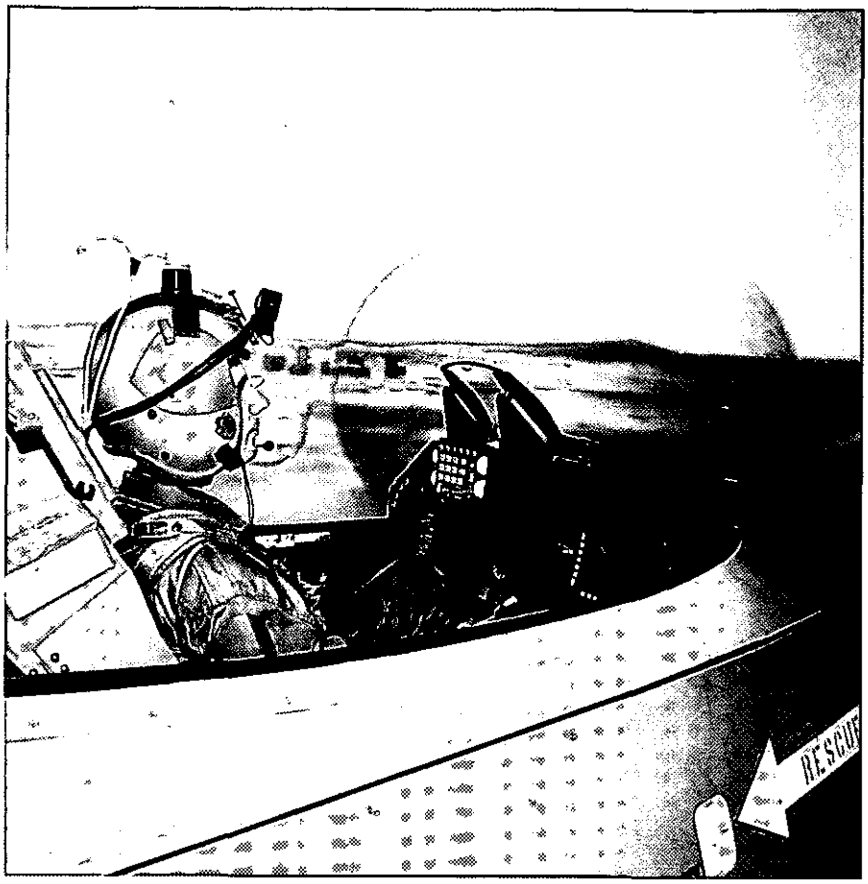
Human factors issues with respect to the design of controller equipment were studied in the context of a programme supported by the CEC. Human-machine interfaces were specified to be included in future field trials on ground movements at airports.

Military Crew Station Design
The F-16 mock-up was used for experiments on the visual scanning effectiveness of pilots working with head-down display formats that contain colour-coded multiple targets. Datalinks and expanded radar ranges allow a multitude of objects to be displayed. The workload implications and the processing of such information was analysed by means of highly accurate head-mounted 'point of gaze' measuring equipment. The results revealed inconsistencies in the AIFF (Advanced Identification Friend/Foe) software, which could be corrected in consultation with Lockheed Martin.

In collaboration with the UK Defence Evaluation and Research Agency (DERA) and the RNLAF, a research programme into advanced display and pilot support tools was defined. This programme, denoted as POWER (Pilot Oriented Workload Evaluation and Redistribution), will involve intensive collaboration between DERA, the TNO Human Factors Research Institute and NLR.

Under an F-16 Mid Life Update contract to Lockheed Martin, colour display formats were selected and implemented in the F-16 Mock-up for further evaluation.

The Royal Netherlands Navy (RNLN) was supported by analysing industry proposals for Nato Frigate Helicopter (NFH90) crew stations. Several modifications concerning cockpit lay out, overhead panels and pedestals were accepted by both officials and industry. Proposed designs for control panels of fuel systems, radio panels, auto flight controls etc. were reviewed for human factors. Modifications were proposed and discussed with industry.



Test in National Simulation Facility for military crew station design

Operator Performance and Workload Measurement

Research into the development of a practical 'toolbox' for the measurement of human machine interactions continued.

The use of 'event related' workload measurement techniques was tested with pilot responses to datalink uplink messages. The uplink was presented as either 'text' or synthetic speech. Event-related heart rate responses discriminated between these formats, indicating different ways of mental information processing, with the speech format favoured.

The use of brain potentials was evaluated by analysing Event Related Potentials correlated with changes in EFIS information. The complex laboratory technique could be replicated in the cockpit domain, but will need much additional work before serving as a standard technique.

The work was supported by NIVR and was performed in co-operation with Tilburg University.

NLR's Standardized Workload Evaluation and Assessment Techniques (SWEAT) toolbox for human machine interaction measurements was extended by including the software package HEART (Human factors Evaluation, Analysis and data Reduction Techniques). The first version allowed data from many sources to be integrated and synchronized into one consistent database. This database was used as input for several types of analysis such as spectral analysis of heart rate, point-of-gaze fixations etc. The application of point-of-gaze data was tested in several projects in cockpit and ATC environments. The software was used for initial test trials of a project on the cockpit application of point-of-gaze measurements for both crew members, supported by the CEC.

Training and Familiarization

Transition issues in the transfer from traditional to modern cockpits were identified in a project supported by the CEC. The work included the definition of cockpit design philosophies by manufacturers and the operational experiences of the airlines. The work was complicated by industry's hesitating to release information that could be considered as company confidential.

Under the PHARE GHMI programme, a computer-based training package was completed for the PD/2 experiments on en-route/extended Terminal Area interactions.

In support of the LVB, the application of computer-based training for skill acquisition of CRDA procedures (Converging Runway Display Aid) was investigated. The experiment was completed on PC platforms, and the results were favourable for both the methodology and the low-cost PC equipment.

Human Factors in Maintenance

Incidents and accidents in maintenance were reviewed in a project supported by the CEC. Visits to the participating airlines and maintenance companies, and interviews with maintenance personnel and managers were completed. Initial results indicate relatively high standards and high levels of interest of the staff concerned, but also high time pressure in maintenance, lack of detailed trend analysing tools, aircraft monitoring systems that allow indications of malfunctions to be cancelled by choice and gross inconsistencies between manuals and procedures from different aircraft manufacturers. Confidentiality proved essential, and fair competition will require an international approach to maintenance standards.

On a national level, the RLD was supported on maintenance issues by visiting a random sample of maintenance organizations (under assurance of confidentiality) to explore the status and nature of human factors issues in maintenance.

Human Factors Validation and Certification

Validation requirements for forthcoming ATM systems were investigated in a study supported by the CEC and the LVB. Requirements and procedures were drafted for discussions with national and international partners.

NLR participated in the steering committee of a project on 'Cockpit Certification requirements for Human factors in Cockpits' supported by Eureka. A work programme was completed and an international workshop was prepared.

NLR's CODEP (Cockpit Operability and Design Evaluation Procedure) methodology for the review of cockpits was extended with 'test cards' to assist in field reviews. The procedure was adapted for applications to fighter aircraft.

Human Factors of Airport Hindrance

The Ministry of Transport was supported with subject matter expertise to assist the scientific basis of the GES project (Gezondheids Evaluatie Schiphol) that addresses hindrance and possible health implications of exposure to high-density air traffic. NLR analysed and commented questionnaires and participated in the scientific committee.

Human Factors of Aircraft Incidents

NLR participated in the HUFAG (Human Factors Advisory Group) together with partners KLM, KLS, IFALPA, VNV, NLRGC and RLD with the aim to disseminate knowledge and expertise within the national aviation community. Meetings were organized and accident reports were analysed and commented, on request of agencies responsible for accident investigation.

Human Machine Interface Design Tools

Research into the operational value of 3D display information for cockpit and ATC was supported by extending the 3D capability of the NADDES tool (NLR Advanced Display Design and Evaluation System) used for initial prototyping of displays. The design of a fully rotatable 3D perspective ATC traffic display was completed and subjected to controller evaluations. The results identified the supervisor position as a candidate for application.

Military Support

Human Operator Training and Familiarization

Training and simulation research was carried out under two Research and Technology Projects (RTPs) of the European Co-operation for the Long Term in Defence (EUCLID): RTP 11.1 on 'Simulation based training system concepts' and RTP 11.2 on 'Simulation Techniques'.

In close co-operation with the Royal Netherlands Air Force and the other RTP 11.2 industrial consortium member Aermacchi (Italy), several pre-defined sorties were flown in the actual MB-339C jet trainer, the fixed base simulator at Aermacchi and NLR's National Simulation Facility (NSF) to compare the effect of motion cuing on pilot control behaviour, task execution and mental workload. To enable different motion stimuli to be applied to the pilot, the NSF was equipped with a g-cueing system. This system allows pressure and position stimuli to be applied to the pilot through inflation/deflation of the anti-g-suit and seat cushions, motion of the seat panels, restraining of the lap belt and pulling the helmet down under positive g's. Air-to-ground sorties were flown to assess the effectiveness and benefits of having platform motion, a wide field of view and g-cueing motion.

Training and simulation research for military applications were carried out under a EUCLID RTP 11.1 (European Co-operation for the Long term in Defence, Research and Technology Projects) project known as MASTER (Military Applications of Simulation Technology based on Empirical Results). Experiments on the feasibility of low-cost PC-based simulation for supporting the skill acquisition of advanced flight manoeuvres (aerobatics) were defined in collaboration with Wings over Holland. Training experiments on the role of stressors during the skill acquisition process were completed. The results indicate a higher performance level for the groups trained with the presence of environmental stressors. These stressors need to be functionally relevant for skill development, so that the addition of a random stress factor is counterproductive.

Application of Voice in the Cockpit

In a national Technology Project, NLR and the TNO Human Factors Research Institute are carrying out research into the possible use of voice recognition technology for control functions in military cockpits. A voice control implementation in an F-16 cockpit was evaluated using NLR's National Simulation Facility. The evaluation was carried out with both test pilots and operational pilots taking part. It provided insight in the performance of present-day voice recognition systems and in the performance required for such systems if they are to be used for control functions. It also provided insight in cockpit design requirements associated with the use of voice control.

Accident Investigations

NLR supported the Royal Netherlands Air Force (RNLAF) in the investigations of accidents with an RNLAF fighter aircraft and with a Belgian Air Force transport aircraft. NLR staff formed an integral part of the investigation teams, in particular to investigate possible technical and operational causes of the accident. NLR also supported the RNLAF in the investigation of a number of smaller incidents, mainly advising in technical matters.

Flight Test Support

NLR assisted the Royal Netherlands Air Force during flight tests with the F-16 and Hercules fixed-wing aircraft and Cougar helicopter, and with tests of several air defence systems. Plans for upgrades of existing instrumentation and for new instrumentation were prepared.

Tactical Recce System Replacement

NLR supported the RNLAF in the process of selecting new reconnaissance equipment to replace the present Orpheus recce system.
NLR also participated in an RNLAF project for the provision of an interim Medium Altitude Reconnaissance System (MARS) that supplies the required imagery (daylight, wet film cameras). NLR provided the Recce pod control electronics, the integration of the cameras from Recon Optical and the control equipment in the pod developed by Per Udsen. NLR also supported the RNLAF with the certification and the flight testing of the pod. The testing has been successfully completed.

Medium Altitude Reconnaissance System during integration and tests at NLR

Integration of New Stores and Equipment in Military Aircraft

Various customers were assisted in the integration of new stores and equipment in military aircraft. The assistance concerned the addition of selfprotection flare dispensers, podded navigation and sensor systems and weapons.

Certification of Military Aircraft Configurations

NLR provided services to various customers in the areas of store separation analysis, aeroelastic properties analysis, structural strength analysis and flying qualities analysis.

The Royal Netherlands Army received assistance in the certification of Remotely Piloted Vehicles.

V/SHORAD

NLR participates in the NATO feasibility study (Very) Short Range Air Defence Systems (V/SHORAD), as a sub-contractor to Fokker Space. NLR contributes in Command and Control and target sensor aspects.

Support of Military Operations

NLR supported the RNLAF with the analysis of threats, the own weapon system properties, performance, and self-protection countermeasures. NLR provided assistance in field trials, training analysis and instruction of pilots and other operational personnel.

Military Flight Support

Support has been provided to the RNLAF on the tactical and operational use of fighter aircraft and on the safety analysis of airshow flight demonstration programmes for the Lockheed Martin F-16 and Pilatus PC-7 aircraft.

Work on the construction of an aerodynamic model of the Pilatus PC-7 aircraft of the RNLAF was continued. This model is required to produce a supplement to the flight manual, that will contain data for operations with reduced propeller speed for noise reduction. The model has been verified with flight test data.

Simulator Component Usability

Under contract to the Royal Netherlands Navy, NLR started an investigation to assess the usability and the implications of continued use of the simulation host computer and the visual system of the Lynx Full Mission Flight Trainer, located at 'De Kooy' Naval Air Base at Den Helder.

Military Crew Station Design

Under an F-16 Mid Life Update contract with Lockheed-Martin, a cockpit lighting evaluation of the F-16 MLU was conducted in the National Simulation Facility (NSF). The objective of this evaluation was to assess the operational effectiveness of the F-16 MLU cockpit lighting at daytime conditions, and at night-time conditions with Night Vision Goggles (NVG). Three specific areas of interest were: cockpit lighting NVG compatibility, canopy reflections and outside visual acuity.

Flight Control System Evaluations

SAAB Military Aircraft conducted a full-scale evaluation of the Digital Flight Control System (DFCS) of both the single seat and the two-seater JAS-39 'Gripen' on the National Simulation Facility NSF. In operational conditions concerning approach and landing in turbulence, the DFCS parameters and various configurations were tested with SAAB test pilots in a modified F-16 cockpit, for the purpose equipped with the 'Gripen' centre stick. After the contract was awarded, the 'Gripen' simulation models were implemented and tested, the cockpit was modified and the actual evaluation took place. Saab carried out the evaluation at NLR's NSF for reasons of simulation fidelity; the combination of high-performance visual and platform motion cuing was crucial for extrapolating simulation results to the actual aircraft. This project was conducted within a period of four months.

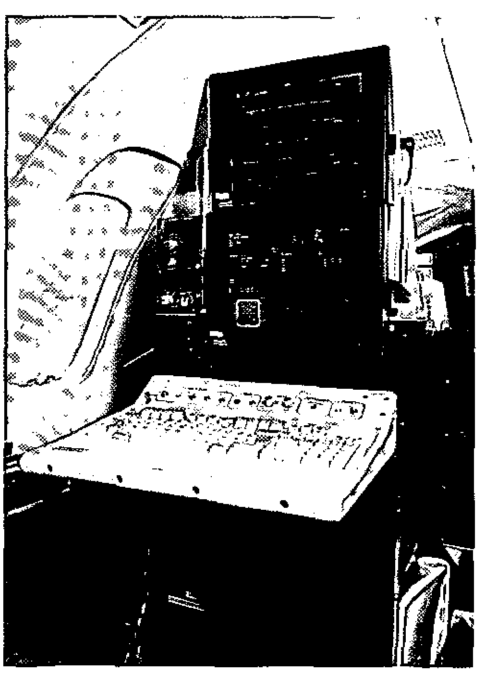
Aircraft Operations

Research Aircraft

Fairchild Metro II

As part of a study into the development of dunes in coastal waters, a number of flights with the CAESAR optical scanner have been made under contract to the Ministry of Transport.
A number of test flights have been made with various GPS phase tracking receivers as part of a continued investigation of NLR aimed at the development of a high precision navigation and positioning system.

A contract was signed with Air Traffic Control The Netherlands (LVB), for the flight inspection of the radio navigation aids in the Netherlands. NLR will perform the inspection flights in the time frame 1997 to 2004. The inspection flights will be made with the Metro II research aircraft.



Console of Flight Inspection System in NLR's Metro II research aircraft

In order to prepare the Metro II for this task, the aircraft was modified extensively. A dedicated Flight Inspection System (FIS) and many antennas were installed. The FIS was accepted by NLR from the manufacturer after an extensive test programme. Inspection flights began in the last two weeks of 1996.

Cessna Citation II

In a project for the Commission of the European Communities, equipment was installed for datalink communication via satellite for an Air Traffic Control application called Automatic Dependent Surveillance (ADS). A number of successful test and demonstration flights were made with this equipment in Europe.

A number of flights were made with the Phased Array Universal SAR (PHARUS) under contract to the Netherlands Remote Sensing Board (BCRS), to demonstrate and evaluate the capabilities of the radar. The Citation II, equipped with the PHARUS, also participated in an international test programme dedicated to the testing of modern digital sensors for air surveillance.

Helicopters

NLR participated in the activities of the GARTEUR Group of Responsables for Helicopters. Contributions were made to the GARTEUR Action Groups (HC) AG-09, 'Mathematical Modelling for the Prediction of Helicopter Flying Qualities', (HC) AG-07, 'Helicopter Performance Modelling', and (HC) AG-10, 'The Prediction of Dynamic Stall and Blade Torsion'.

In co-operation with Fokker Aviation and SP Aerospace and Vehicle Systems, NLR takes part in the Design and Development phase of the NH90 programme for a future NATO helicopter. Wind tunnel tests were conducted in the Low Speed Wind Tunnel using a fuselage model. In the DNW Large Low-speed Facility, a model was tested which consisted of a powered main rotor and a fuselage with simulated engine inlet and hot exhaust flow (see also Capita Selecta). NLR participated in the NH90 prototype flight testing. One employee was co-located at the flight test centre of Eurocopter France at Marignane, as a member of the international flight test team.

Support was given to the Netherlands Chinook Office at Boeing Helicopters, Philadelphia, USA, the manufacturer of the CH-47 Chinook helicopters for the RNLAF. Support was also provided for the procurement activities for training simulators for the Chinook and Cougar helicopters.

Projects, including flight testing, were executed for the qualification of a flares installation on BO 105 helicopters of the RNLAF and a chaff/flares installation on Lynx helicopters of the RNLN. For the RNLN a flight test programme was carried out on board of a new replenishment oiler ship, in the final phase of the qualification of the Lynx helicopter for operations on board of this class of ships.

The RNLN was supported in a re-adjustment of the Automatic Flight Control System of the Lynx helicopter, which was needed due to changes in the basic characteristics of the helicopter and of the radar altimeter.

For the Ministry of Defence, a theoretical study was conducted concerning the wind environment in the vicinity of hovering and slowly/low flying helicopters.

Transport and Environmental Studies

Policy Analysis

Under contract to the government, advice concerning the formation of a policy on the management of early morning flights at Amsterdam Airport Schiphol was given. Issue and stakeholder analyses were part of the study. Furthermore, research into an emerging strategy of general aviation noise reduction was performed. A conference was organized on the subject of regular checks of the noise exposure around general aviation airfields.

Air Pollution

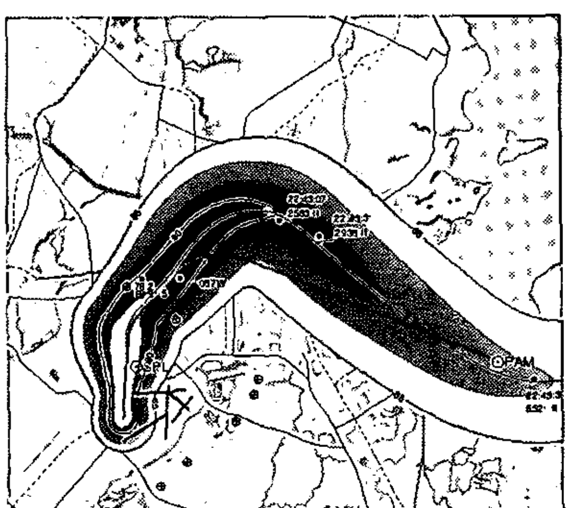
Under contract to the government, NLR contributed to international consultations on exhaust gas emissions of aircraft. In co-operation with Resource Analysis and MVA-Consultancy, NLR realised a computer model for the assessment of aviation emissions, named Aviation emissions and the Evaluation of Reduction Options (AERO).

Noise Exposure

Noise exposure was calculated for the actual situations at several airfields in the Netherlands. Calculations were also made for the establishment of the noise zone around Amsterdam Airport Schiphol. A preliminary study into the environmental consequences of additional airport infrastructure was performed. A study into the differences between several methodologies used in Europe for quantifying the noise exposure by aircraft was carried out. Most of the work on noise exposure was performed under contract to the government.

Monitoring of Environmental Aspects

Under contract to the Ministry of Housing, Physical Planning and the Environment, NLR has operated a noise monitoring system in the surroundings of Geilenkirchen Airbase. Under contract to the Ministry of Transport, Public Works and Water Management and under contract to LVB, NLR worked on the extension of functionality of the Flight track and Aircraft Noise Monitoring System FANOMOS. The extended FANOMOS will perform the following functions: track and noise monitoring, calculation of noise exposure and matching of information on noise, and recording of flight tracks, complaints and flight plans.



Information generated by the Flight Track and Aircraft Noise Monitoring System (FANOMOS)

Accident Investigations

NLR supported the Netherlands Bureau for Civil Accident and Incident Investigation in the investigation of an accident with a vintage airliner.

Third Party Risk Analysis for Airports

Models for the calculation of risks around airports with a traffic mix consisting mainly of general aviation aircraft and propeller driven commercial aircraft were developed in 1995. They were scrutinised by a government committee responsible for their acceptance. NLR provided assistance and refined the models. The models were accepted by the government committee and a test calculation was performed.

The expertise of NLR in the field of third party risk analysis led to invitations for holding lectures, resulting in national and international contacts.

NLR was awarded a contract by the Ministry of Defence for the development of models for performing risk analysis in the vicinity of military airbases.

Third party risk calculations were carried out for Amsterdam Airport Schiphol and Heathrow Airport, and for a study on an exercise location for helicopters of the Air Mobile Brigade.

Facilities and Equipment

NLR Air Traffic Control Research Simulator (NARSIM)

The 'NARSIM Client/Server' project, in which the architecture of the NARSIM system software has been converted to a client/server environment, has been finalised. The new architecture makes the system flexible and allows external software to be integrated easily. Maintenance costs have come down due to the object-oriented design.

The new NARSIM has already been used in several European projects making use of added capabilities such as the distribution of components of the simulator over different computers. Communication between the components is independent of the computer platform (HP, Sun, etc.) and the programming language being used (C, Ada or FORTRAN).

In the BRITE/EURAM project PATIO (Platform for ATM Tools Integration up to Pre-Operation), NLR is responsible for the development of the Air Traffic Generator system. This system will be based on the NARSIM air server and extended with PATIO related interfaces. The PATIO project, carried out under contract to the Commission of the European Communities, fills the need for the development of a European ATM validation platform.

The NARSIM platform is being prepared for the PHARE Demonstration 3 (PD/3), planned to include running an operational experiment in a 4D ATM environment, including datalink and negotiation features between pilot and air traffic controller.

Research Flight Simulator (RFS)

Modifications were made to the Research Flight Simulator (RFS) to enable a multitude of simulation experiments to be performed in several configurations. Three-dimensional (3D) perspective flight plan displays were designed and implemented using the NLR Advanced Display Design and Evaluation System (NADDES) and used for an enhanced 'Tunnel in the Sky' display concept. The Research Flight Management System was extensively modified to allow four-dimensional navigation capabilities to be included, with space and time constraints. Interactive en-route waypoint modification of the flight plan was made available through the combination of an interactive navigation display and the use of tracker balls. The navigation display included a profile mode to view the vertical consequences of the flight plan modifications. A dynamic weather radar model was developed for use in windshear experiments. The display showing the resulting weather picture and symbology was included in the standard navigation displays of the RFS.

The modification of the simulation software structure of the RFS, to harmonise the simulation software environments of the NSF and RFS is well under way. A large part of the aircraft models and hardware system drive laws have been ported to the new real-time simulation program and software development environment using a new Unix host computer system, to which a new Interface Node was linked.

National Simulation Facility (NSF)
The development of the National Simulation Facility (NSF) can be regarded as complete with the installation and acceptance of the g-cueing system. This system was essential for training task evaluation within the EUCLID programme. Also installed and accepted was a control loading system supplied by Fokker Control Systems, with a high-roll centre stick. Both have been installed in the F-16 cockpit.

Further enhancements have been made to the software development program to allow more flexible and customised programming. The Flight Simulator Interface System (FSIS) software has been extensively updated, to provide structured control of all computer systems linked into one simulation session.

Generic Mock-up
The mock-up was equipped with a point-of-gaze measurement system using an optical eye tracker for human factors experiments. The system was used for a number of simulation experiments where pilot reaction times and symbology assessment were measured.

Future Aircraft Systems Testbed (FAST)
The FAST project concerns the conversion of the Cessna Citation II research aircraft into a facility for airborne research and demonstrations. A strategy plan has been written, in which the required short term and long term investments are identified. The development of FAST will focus on operational issues, specifically in the fields of Air Traffic Management systems and concepts, Human Factors, and Advanced Avionic Systems.
Discussions were held with a vendor for the installation of an auto-throttle system. Activities were started to install an experimental third crew position in the aircraft.

3.3 Structures and Materials

Summary

The termination of transport aircraft development by Fokker Aircraft and the start-up of new projects under the Fourth Framework Programme for Research and Technology Development and Demonstration of the European Union were major factors affecting NLR's activities in the area of structures and materials. The first event gave rise to an accelerated wrap-up of aircraft technology projects under contract to the NIVR.

Usage monitoring continued as a prominent activity that is bound to increase in scope, as a larger variety of weapon systems is put into use, and as new technologies for measuring and for processing structural health and usage data are developed.

The existing expertise in the domain of aircraft loads was applied in studies of gust loads definition for aircraft with non-linear response characteristics and of variations in service load experience as observed in fatigue meter data. Also, a manual on aircraft loads is being compiled.

One of the products of earlier aircraft technology studies, a predictive model of noise transmission through fuselage walls, was successfully applied to the problem of a passenger cabin with special damping features installed in the interior trimming and insulation layers.

Another technology product, the design and optimization code PANOPT was provided with an option to optimize panels with regard to both undamaged and damaged conditions.

Considerable progress was made in the definition of the damage sensitivity of stiffened composite panel structures and in the development of global inspection procedures and repair methods.
A full-scale demonstration structure including stiffened panels and repairs was prepared for certification testing under mechanical and environmental conditions.

Proven capabilities in the area of materials characterization were applied to an evaluation of new aluminium alloys for applicability in damage tolerant airframe structures, including weldable construction concepts. Extremely efficient fibre metal laminates were evaluated at a structural level in full-scale fuselage panels. Of increasing importance is the performance of high temperature materials for aero-engines. Research included damage tolerance investigations and evaluations of protective coatings.

Aircraft Loads

Current aircraft designs often feature active control systems leading to non-linear aircraft response characteristics. The design criteria for continuous turbulence (Power Spectral Density, or PSD, design gust cases) contained in present Airworthiness Requirements are not directly applicable to non-linear aircraft. Under contract to the RLD, NLR is evaluating the practical implications of the Stochastic Simulation Method, whereby the design loads are obtained from response calculations in the time domain on turbulence patches with prescribed statistical properties.
NLR takes part in the so-called Gust Specialist Meeting which convenes twice a year under the aegis of the US Federal Aviation Administration to discuss aspects of flight in turbulence and the associated airworthiness rule-making.

Under contract to the RLD, NLR is preparing a Manual on Aircraft Loads, containing explanatory information on aircraft loads in general, with specific reference to the loading conditions specified in current Airworthiness Requirements. The first chapter, dealing with loads in pitching manoeuvres, has been completed.

Under contract to the US Federal Aviation Administration, through the RLD, NLR has carried out an analysis of aircraft c.g. acceleration data obtained with so-called Fatiguemeters installed in Fokker F27 and F28 aircraft. The analysis presented unique statistical information about the variation in service load experience between aircraft of the same type, but owned by different operators in different parts of the world.

NLR completed a study for NIVR concerning the consequences of proposed changes in the airworthiness requirements with regard to dynamic rudder manoeuvre load conditions. NLR concentrated on the formulation of a simplified model for the complex control system (including boosters, yaw damping etc.) that would still provide the correct design loads.

In-flight tail load measurements on a Fokker 100 aircraft operated by KLM Royal Dutch Airlines, carried out under contract to the NIVR, yielded a database of structural tail loads in combination with aircraft flight parameters. A detailed analysis has been carried out in which the fatigue load design assumptions with respect to tail loads were checked and verified with the measured load experience. Lateral and vertical gust statistics were derived from measured accelerations.
Also under contract to the NIVR, an investigation was started to evaluate various steady and unsteady aerodynamic methods to calculate lateral gust loads on aircraft. These methods include the AESIM package which is currently being developed by NLR.

The Fatigue Load Monitoring programme of F-16 aircraft of the Royal Netherlands Air Force (RNLAF) has been continued. Four aircraft within each squadron are equipped with a four-channel digital solid state recorder measuring wing root bending moments and three additional load quantities. From these measurements, average spectra per mission type and per squadron are calculated.
The RNLAF has procured new and more advanced equipment. In future, load measurements will be carried out in each aircraft of the fleet. Quantities measured include strains at five different structural locations, 'control points', and a number of engine usage parameters. The implementation of this new system in the fleet has started. The system will become fully operational in 1997.

NLR is carrying out Load and Usage Monitoring programmes for other fixed-wing aircraft and helicopters of the RNLAF and Royal Netherlands Navy, and for aircraft of foreign Armed Forces.

Dynamic Analysis of Structures

The development of a method for the prediction of noise transmission through a fuselage wall, under contract to the NIVR, was concluded. Several methods were used to model the dynamic behaviour of the exterior fuselage structure in combination with cabin panelling and the cavity in between. Modelling of structural details such as cabin panel connectors and glass wool insulation was continued in the European collaboration programme Basic Research in Aircraft Internal Noise (BRAIN). In this programme, a comparison with experiments demonstrated that the methods developed by NLR predict the structural response and the resulting noise accurately. The description of damping in the analysis method was improved and the investigation of methods to increase the damping by applying special adhesive layers was continued.

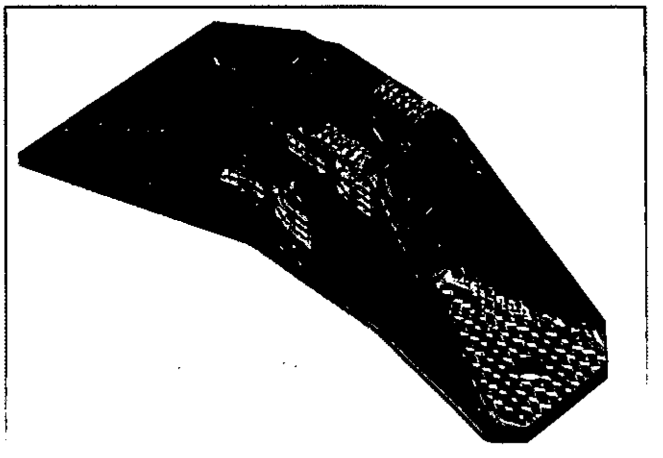
Strength and Stiffness of Structures

The comparative investigation of different approaches to multilevel optimization, carried out in a GARTEUR Exploratory Group allowed a selection of methods to be implemented in the preliminary design programme ADAS (Aircraft Design and Analysis System).

Under contract to the NIVR, an investigation of final panel failure and damage behaviour in an impact-damaged panel was continued. To be able to translate damage behaviour measured in small coupons to real structures, an intermediate level of so-called structure-relevant specimens is being further improved under a project in EUCLID (European Co-operation for the Long term In Defence).

The design and optimization code PANOPT (panel analysis and optimization) was extended to be able to optimize the panel design to meet the undamaged and damaged strength requirements. Tests on the first series of specimens showed results that promised obtaining comparable damage. Stitched laminates of composite sheet material, fabricated by the Resin Transfer Moulding (RTM) technique, were investigated for improved strength after impact.

In future, composites may replace complex metal parts made by forging or machining. In particular the RTM technique was studied for this application.
The development of composite parts of a helicopter undercarriage was started, in collaboration with SP Aerospace and Vehicle Systems. Tools to analyse the static strength and buckling behaviour of composite spars were developed. Analytical results for different access hole geometries in the web were verified experimentally.

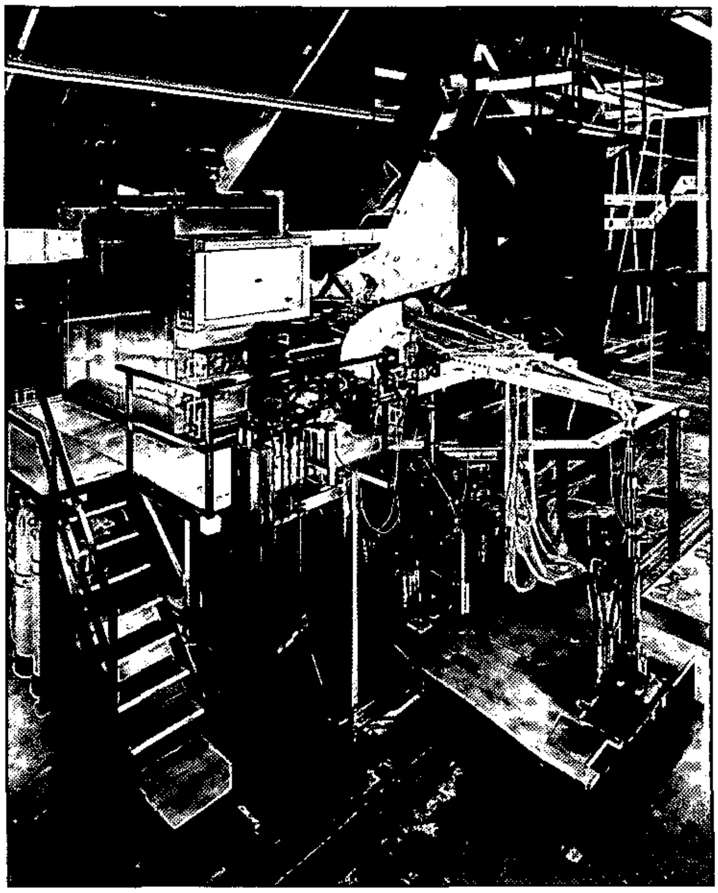


High precision low weight bracket for spacecraft structure produced by resin transfer moulding

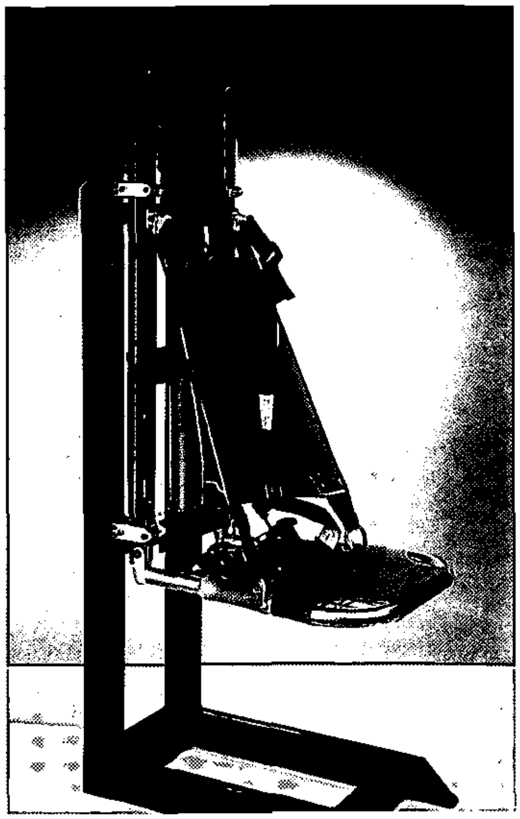
Tests on sub-components representative of composite stabilizer structures to establish a feasible validation and certification process for composite primary structures were finalized.

A test set-up for performing static and fatigue tests on the major part of a composite stabilizer was built. This set-up includes facilities to do tests in a hot/wet environment. Preliminary tests and tests to verify the stress/strain distribution were completed. The composite stabilizer has been sitting in a hot/wet environment for several months.

The improvement of the crashworthiness of civil transport aircraft is being studied in a research project CRASURV (Crash Survivability) of BRITE/EURAM (Basic Research in Industrial Technologies for Europe/European Research on



Assembly of a test set-up for damage tolerance and durability evaluation of a full-scale composite stabilizer under simulated mechanical and environmental loading



Crashworthy helicopter troop seat featuring support structure and energy absorber in advanced composites

Advanced Materials). A stretchable composite skin concept, the so-called tensor skin, is being developed for the improvement of the water impact behaviour of helicopters. This concept may also improve the bird impact resistance of leading edges of wings and stabilizers.

Damage Tolerance of Materials and Structures

The structural safety associated with the damage tolerance of lap joints in ageing aircraft continued to be studied in a programme under contract to the RLD, co-sponsored by the US Federal Aviation Administration (FAA).

The ageing aircraft problem was also studied in GARTEUR (SM) AG-18 'Assessment of Multi Site Damage (MSD) in highly loaded joints'. Research focused on the analysis and testing of the residual strength of stiffened panels. This activity is continued as BRITE/EURAM programme SMAAC (Structural Maintenance of Ageing Aircraft). A unique test set-up was applied to test curved, stiffened fuselage panels under biaxial loading and internal pressure.

The crack growth rate in metal structures is largely determined by plastic deformation near the crack tip. NLR has investigated this effect in detail. The investigation has led to models that can be applied in feasible engineering methods for crack growth prediction. These models have been validated using a large data base of test results for crack growth under different loading conditions.

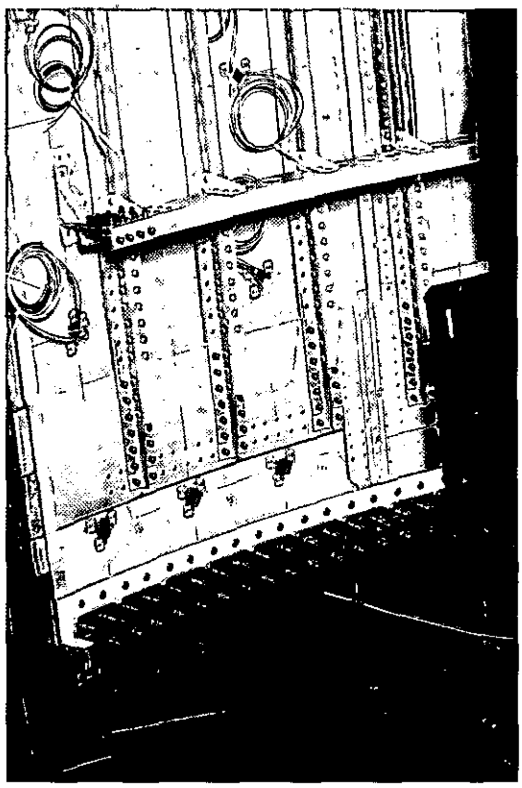
Advanced crack growth models are being implemented in the standard damage tolerance analysis program NASGRO. This activity is performed under contract to the European Space Agency (ESA) as part of a collaboration programme of ESA with the US National Aeronautics and Space Administration (NASA).

In a collaborative programme with the Portuguese Air Force, the severity of its aircraft usage was assessed using advanced load monitoring and damage tolerance analysis methods.

The evaluation of aluminium alloy/fibre laminates under NIVR funding was concluded. Two types of laminate have been developed, now both commercially available: ARALL, containing aramide fibres, and GLARE, containing glass fibres.

An NIVR programme on the fatigue and residual strength behaviour of riveted lap joints made from biaxially reinforced GLARE laminates was finalized.

Work in the framework of EUCLID in the Research and Technology Project 'Application Technology of Composites' has continued. Impact tests were done on specimens with four types of protective layers, which were found to have a large beneficial effect on the residual strength. The D-sight method of non-destructive inspection of impact damage was evaluated, and methods were developed for repairing lightly damaged skin/stiffener constructions.



Complex structural detail of fibre metal laminated fuselage structure being prepared for development fatigue testing

Materials Characterization

The damage tolerant aluminium sheet alloy C188 from Alcoa has been investigated. Comparison of basic material properties such as fracture toughness and fatigue crack growth properties of C188 with those of 2024-T3 showed that C188 can be considered as a potential replacement for 2024-T3 in damage tolerant applications. The investigation was continued with fatigue tests on riveted joints and residual strength tests on riveted joints after fatigue testing for a specific number of cycles. The results of the latter investigation did not show a superior fatigue or residual strength behaviour of C188 joints over 2024-T3 joints.

After a previous investigation of the weldable fuselage alloy 6013-T6 from Alcoa, a new weldable fuselage alloy 6056-T78, from Pechiney was investigated. The characterization concentrated on mechanical properties, damage tolerance properties and corrosion behaviour.

The programme of the GARTEUR Action Group (SM) AG-17 'Cadmium substitution in aircraft' sponsored by the NIVR was continued. It includes comparisons of rapid electrochemical test methods and standard corrosion testing, including outdoor exposure. The effect of coatings on fatigue crack initiation was also determined.

Engine Materials

An NIVR programme to develop modelling tools for calculating thermal-mechanical stresses in gas turbine blades and vanes was started. Heat transfer and temperature distributions were calculated and tests were carried out in cooled and uncooled tubes. In addition, corresponding temperature gradients and stress distributions were calculated and measured.
Another NIVR programme, for monitoring non-destructively the condition of service exposed turbine blades was also started. A replication

technique has been developed to measure the microstructural degradation from etched surfaces.

High Velocity Oxygen Fuel (HVOF) sprayed coatings are becoming an alternative for the more expensive plasma sprayed MCrAlY coatings on gas turbine components. Coatings sprayed by the two techniques were evaluated in the burner rig for adherence and for corrosion and oxidation resistance.

Work funded by the Ministry of Defence under the WEAG (Western European Armament Group) TA31 programme on Lifing Concepts for Aero-Engine components was completed with Corner Crack and Engineering Rim specimen fatigue crack growth tests on Inconel 718.

Failure Analysis

Several fractured components were examined which had previously been subject of a failure analysis by NLR. For two of the components, a nose landing gear piston and a flaperon root rib, prior service failures had already led to a recommended nondestructive inspection. The failure analysis data were used to evaluate the current Non Destructive Inspection (NDI) procedures. In the near future, the two components will be replaced by redesigned ones.

Several investigations were carried out on launcher attachment bolts. The first examination started following the loss of a launcher. Investigations revealed that this was caused by loss of preload and subsequent fatigue failure of the attachment bolts. Since the RNLAF suspected the deterioration of the bolt locking insert to be a contributing factor in the loss of preload, NLR determined bolt torque-preload relations under several conditions. It appeared that the effect of the locking insert was marginal compared to the effect of lubrication. An inventory of the launcher attachment bolts made by the RNLAF revealed five fracture bolts, of which two were in stock. Failure analysis showed that the fractures could be related to a poorly controlled manufacturing process. The fractured bolts all contained the same supplier code.

Facilities and Equipment

A test cell for mechanical tests at -110°C has been designed and manufactured to test materials used in space vehicles.

The control units for the static and dynamic test facilities were modernised, and new data acquisition systems were introduced.

A new data acquisition system was acquired for strain measurements at airfields.

For the fabrication of high-tech products out of fibre reinforced materials, new mould materials were introduced, a design of a stitching machine was completed and a sawing machine was modified and installed.

A new temperature measuring system, based on pyrometer systems, for high temperature corrosion tests has been made. A method based on a digital image analysis system has been developed for the measurement of stresses within test specimens during thermal shocks (200°C – 1600°C).

Images of electron microscopes and light microscopes were digitized and stored in digital format.

The equipment for non-destructive testing was extended in order to carry out a training programme for personnel of Fokker Special Products.

An Oracle data acquisition programme has been installed for the flight load monitoring programmes. The Royal Netherlands Air Force will use the same system and software.

3.4 Space

Summary

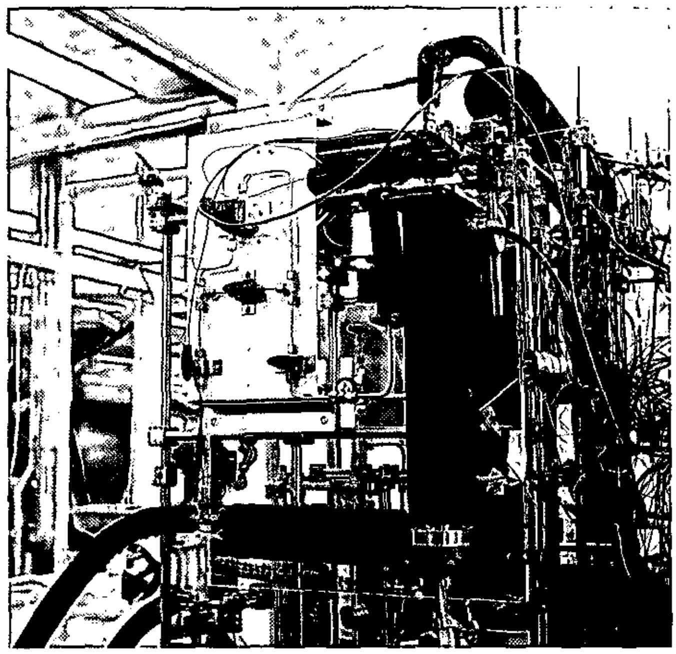
Research and technology development activities for space applications were executed in the areas of two-phase flow, testing and simulation, structures, payloads, utilization, robotics and remote sensing, both under contract and under NLR's basic research programme. The total volume of contract activities increased by 50% relative to 1995, mainly due to the activities for international customers, especially the European Space Agency (ESA). Major activities were the development of the Test and Verification Equipment for ESA and the development of the Attitude and Orbit Control System (AOCS) test equipment for the X-ray Multi-Mirror mission satellite under contract to Matra Marconi Space (MMS). The realization of the minisatellite Sloshsat Flevo and the development of the Mission and Training Equipment for the European Robotic Arm were approved. Preparations were made for the development of the AOCS test equipment for the Integral satellite and for the second flight of the Two-Phase experiment in a Space Shuttle. A new version of the earth observation meta-information system Neonet on the Internet was made. NLR received an award from Eurimage for its activities as National Point of Contact for the distribution of remote sensing data.

Two-Phase Heat Transport

The second Two-Phase experiment, TPX II, will fly as a Get Away Special on a Space Shuttle, in late 1997. It will have novel components, an increased number of sensors, a parallel condenser configuration and extended experiment control software. TPX II is being developed under ESA's Technology Demonstration Programme 2 and Earth Observation Preparatory Programme, by NLR as main contractor, and SABCA of Belgium.

Under contract to ESA, NLR developed and tested a high-efficiency two-phase condenser, with Bradford Engineering (BE) and Daimler-Benz Aerospace Bremen as subcontractors. Test results were delivered to ESA.

NLR continued the study on the *spatialization* of liquid-flow meters, under contract to ESA. Two commercially available flow meters were selected, one for an ammonia two-phase heat transport system, the other for a water single-phase heat transport system. The two will be modified for use in space and tested. The study is performed in co-operation with Bradford Engineering and SABCA.



Test set up of low-pressure-drop two-phase condenser for temperature control in spacecraft

For ESA a study was performed on the thermal modelling of a diode-pumped laser head. The purpose of the study was to analyse the thermo-mechanical effects, to characterise the induced optical effects and to recommend improvements of the head design. The optical calculations were performed by the Laser Zentrum Hannover, Germany.

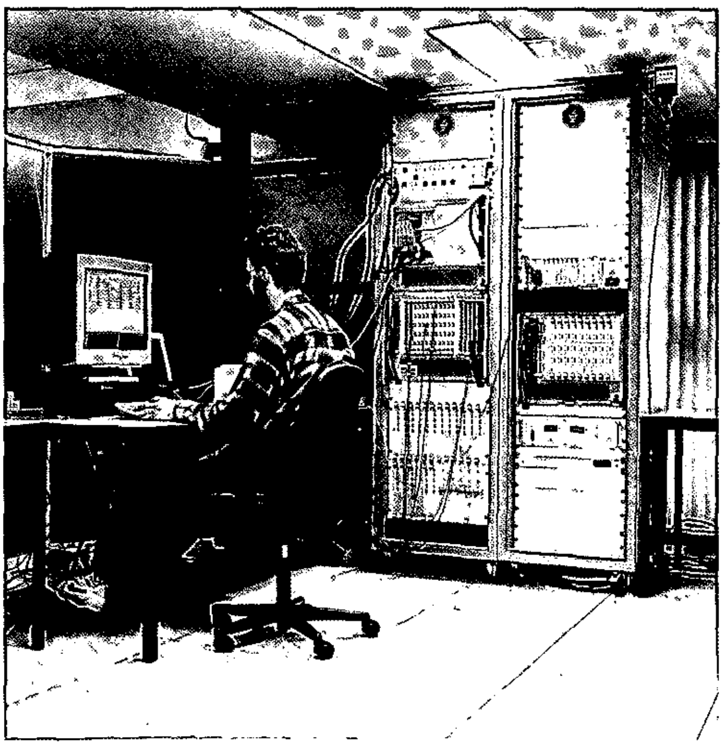
NLR is the only non-US participant in the co-operative Loop Heat Pipe Flight experiment, an American development derived from Russian loop heat pipe technology. The other participants are Dynatherm/Thermacore, Hughes, the Center for Space Power, the Naval Research laboratory, Wright Patterson AFB and Kirtland AFB. The experiment is manifested to fly as a hitchhiker payload on a Space Shuttle flight.

Testing and Simulation

The Test and Verification Equipment (TVE) was delivered to ESA. It will be used to support the integration and testing of the various components of Attitude and Orbit Control Systems (AOCS) and the verification of the functioning of the control loops during several stages of integration, both without and with hardware in the loop. The project was carried out in co-operation with Fokker Space and Adelsy of Switzerland, and was partly funded by the Netherlands Agency for Aerospace Programs (NIVR).

The development and production of the AOCS test equipment for the X-ray Multi-Mirror mission (XMM) was continued. This test equipment is based on the TVE. Two sets of equipment are being produced: one for attitude control system testing at Matra Marconi Space UK (MMS-UK) and one for spacecraft system testing at DASA in Germany.

Compared to the TVE, the test equipment for the AOCS of the XMM has extensions for the AOCS stimuli and monitoring, the simulation of the power distribution unit and the remote terminal unit. It also has electrical/optical support equipment for the stimulation of the Sun Acquisition Sensor (SAS) and the Star Tracker (STR). The SAS and STR are produced by the TNO Institute of Applied Physics and the Office Galileo of Italy, respectively.



Test equipment for the Attitude and Orbit Control System of the X-ray Multi-Mirror mission

The stimuli and monitoring equipment contains a number of VME modules, for the generation of analog stimuli signals and bi-level digital data and for the simulation of timing, monitoring and separation switching. A simulator equipped with protection circuitry powers the units of the attitude control testbed.

The test software and the XMM satellite dynamics software run on workstations, as does the PROSIM simulation tool. The software supports a number of vital functions, such as the routing of telemetry and command data, the AOCS simulation data and the stimuli and monitoring data. The XMM project is carried out under contract to MMS-UK.

NLR will build a similar test system for the Integral satellite. This system will be used for AOCS subsystem level tests at MMS-UK and AOCS spacecraft level tests at Alenia Spazio in Turin, Italy. XMM and Integral are both science projects of ESA's Cornerstone 2000 programme, and the service modules of the spacecraft are identical.

The European contribution to the International Space Station will include an Automated Transfer Vehicle (ATV), to be launched by an Ariane 5, that will provide logistic services and will be used to re-boost the station. For the development of critical components of the ATV technology, ESA executes an ATV Rendez-Vous Pre-development project (ARP). Key elements are the application of differential position determination using the Global Positioning System (GPS) and the development of a Rendez-Vous and Docking Sensor (RVS). The prime contractor, MMS of Toulouse, has defined a Kernel simulator for the development and verification of ATV technology. The basic component for this simulator is Eurosim. Fokker Space is prime subcontractor and supplies the basic hardware and software, NLR designs the interfaces and integrates the model software, whereas ICT Engineering of

Deventer, the Netherlands, participates in the development of the interfaces between the external hardware and the ARP Kernel Simulator.

Grating Element Support Structure

The flight model of the Grating Element Support Structure (GESS) was delivered to NASA. A mass model of the GESS was made and delivered to Space Research Organization Netherlands (SRON). This model is used for checking the physical properties and mounting interfaces.

Payloads

Sloshsat FLEVO (Facility for Liquid Experimentation and Verification in Orbit) is a mini-satellite to be launched from the Space Shuttle for the investigation of forces exerted upon a manoeuvring spacecraft by liquid in a partially filled tank. The project is executed under contract to ESA and NIVR, in co-operation with Fokker Space, the Belgium companies Verhaert and Newtec, and Rafael of Israel. The detailed system and subsystem design of Sloshsat FLEVO was pursued. Laboratory tests to support the design of the instrument package of the experiment container were completed, and the development of the Sloshsat Motion Simulator package in support of experiment design was continued. Discussions with ESA/NASA were held to ensure compliance with Space Shuttle safety requirements.

In a project for ESA and NIVR, carried out by a team with Stork Comprimo as prime contractor, NLR completed the conceptual design of a fluorescent detector unit, part of a miniature capillary electrophoresis instrument.
In another project for ESA and NIVR, carried out by a team with Bradford Engineering as prime contractor, NLR completed the conceptual design of a video microscope system that will be part of the Biological Glovebox.
In a similar project for ESA and NIVR, with Fokker Space as prime contractor, the development of a video stereo and a video research microscope, suitable for accommodation in both the Biological Glovebox and the Biological Workbench, was continued.

Utilization

Under contract to NIVR, scenarios including the use of high-speed data networks for remote operations in space, *telescience*, were developed, concentrating on remote visual access. The potential of the Internet for on-line information services for telescience was also explored.

Under contract to NIVR, the potential of multimedia systems on workstations for remote interactive operations was explored for typical missions, Sloshsat FLEVO and Moon exploration.

In a project for ESA, carried out by a team with Origin as prime contractor, NLR contributed to the development, implementation and demonstration of the Advanced Crew Terminal (ACT), a laptop computer enabling crew to monitor and control systems and payloads.

In a project for ESA and NIVR, in a team with Origin, TNO, Trinity College and IDIAP of Switzerland, NLR has introduced speech recognition and synthesis technology into the ACT. This speech-equipped ACT will be used in support of the Smart Gas Sensor experiment operations in the Euromir-extended mission.

In another project for ESA and NIVR, NLR investigated the feasibility of using the ACT for on-board data storage in Sloshsat FLEVO.

Under contract to LABEN of Italy, NLR started the characterization of measurement accuracies of a GPS-based attitude determination unit. A facility for the testing of GPS receivers in a dynamic environment was designed.

Under contract to NIVR, NLR investigated aspects of on-board integration of GPS and inertial attitude measurements, to support the modelling of satellite navigation applications. Furthermore, NLR participated in discussions on Dutch industrial participation in military satellite communication systems (Eumilsatcom) and contributed to the promotion of ANITA, the Associated Netherlands Industries for TACOMS Post-2000.

Space Robotics

Under contract to Fokker Space, NLR tested an ERA Camera and Lighting Unit (ERA-CLU) simulator integrated with proximity algorithm processing, in its optics laboratory. Under contract to ESA, in a team with Technospazio as prime contractor, NLR contributed to the integration and test of ERA-CLU image processing algorithms as a part of the study 'Validation of vision processing tools'.

Under contract to Fokker Space, NLR contributed to the architectural design and the validation and verification plan of the ROBCAD path planner, according to ERA simulation facility standards.

Under contract to ESA and NIVR, the development and demonstration of automation and robotics in experiment facilities inside and outside spacecraft was continued. The Columbus Automation and Robotics testbed (CAT) at the European Space Research and Technology Centre (ESTEC) was provided with a typical payload model and a mock-up of an external payload platform in the ARCADE-project (ARMADE in CAT demonstrator), performed in co-operation with Fokker Space, Stork Product Engineering and ICT. In conjunction with this development, work on the user interface and control software of the model incubator in NLR's Robotics Laboratory was continued.

For ESA and Fokker Space, NLR with subcontractors Spacebel and Trasys started the development of the Mission Preparation and Training Equipment (MPTE), part of the ground equipment of the European Robotic Arm (ERA). System requirements were determined and purchase orders for major parts of the MPTE basic system were placed.

In conjunction with the MPTE development and under contract to NIVR, NLR reviewed the feasibility of computer-based training for robotics and payload operations in space. NLR started the integration in its robotics laboratory of a large-screen visualization system to support astronaut training activities.

Under contract to NIVR, NLR, together with TNO and Fokker Space, started preliminary specifications of lander and rover manipulator operations for a prototype LEDA (Lunar European Demonstration Approach) systems simulator.

Remote Sensing

The prototype Neonet meta-information system, which became available on the Internet at the beginning of 1996, was operated throughout the year. Apart from general earth observation information, specific information was provided on topics related to water quality and atmospheric chemistry research. In late 1996, an upgraded version with improved functionality was made available. New functions were added, facilitating the search for earth observation data and information. Many organizations and institutes were added as Service Provider to the system.

The Neonet activities are carried out by NLR in co-operation with the Royal Netherlands Meteorological Institute (KNMI) and the Survey Department of Rijkswaterstaat under contract to the Netherlands Remote Sensing Board (BCRS) and the Space Research Organization Netherlands (SRON).

A tool for electronic generation and distribution of remote sensing products NeoPAS (Neonet Provider Access) was demonstrated successfully. By means of NeoPAS, customers using the World Wide Web (WWW) on the Internet can not only order, but also initiate the generation of products, without first acquiring intermediate products. NLR developed an improved version, NeoPAS$^+$, which facilitates near-real-time product data transfer between providers and customers using the WWW or otherwise. In NeoPAS$^+$ a mixture of different languages is used (Java, Javascript, Perl) to provide the functions required at the client and server sides of the WWW application. NeoPAS is a joint effort of NLR, Origin and ICT Engineering, and is partly funded by NIVR.

The development of a Meteorological Datafusion WorkStation (MDWS) was continued. The software of the Armada concept (Adaptive Reconfigurable Multiplatform Architecture for

Data-driven Applications) was extended by routines to store and retrieve imagery data and to monitor non-native Armada programs. Armada is a joint effort of NLR and ICT, partly funded by NIVR.

Under contract to ESA, a study on the development of a quasi-lossless data compressor was started. In this study, the application of the wavelet transform for the compression of hyper spectral data is investigated. An extensive literature study was conducted. A reference implementation of the wavelet transform, based on the so-called 'lifting scheme', will be required. The software will be integrated with the existing software at ESTEC's image processing laboratory.

For the Commission of the European Communities (CEC), NLR participates in a consortium to analyse the constraints and opportunities for cost-effective utilization of earth observation in developing countries. Under contract to BCRS and NIVR, a PC-based ground station for the reception of ERS-SAR data is being developed. NLR is responsible for the interface to the hardware and for the demonstration of the SAR software. The station will be field tested in collaboration with Indonesian users.

Under contract to NIVR, preparatory studies were performed for a possible future satellite for Forest Assessment and Monitoring of the Environment (FAME). The concept of a P-band SAR was studied. In collaboration with Fokker Space and the TNO Physics and Electronics Laboratory, a number of critical items were defined. NLR focused on the applicability of current and future payloads for forest monitoring, on-board data reduction and orbit analysis. Results were presented.

Remote sensing image showing dredgings storage and water flow phenomena in Ketelmeer, the Netherlands (Image by SPOT satellite, 10 m resolution)

The work on Research and Technology Project 9.1 'Technology concepts and harmonisation', of the Common European Priority Area 9: Advanced technologies for surveillance satellites of the European Co-operation for the Long Term In Defence (EUCLID), was completed. In this study NLR acted as national representative.

Together with TNO-FEL, NLR participated in the Defence project 'Geographic Remote Sensing'. Within this project the value of remote sensing data for topographic applications is evaluated using two sets of data on test areas in the Netherlands and near Freiburg in Germany.

As before, NLR acted as National Point of Contact (NPOC) for the distribution of Landsat, ERS-1 and NOAA remote sensing data for Eurimage and for the distribution of SPOT data on behalf of SPOT-Image within the Netherlands.

Facilities and Equipment

The two-phase ammonia loop was upgraded and installed in a climate chamber of circa 10 m^3. The loop is capable of operating under different environmental temperatures and has an increased heat transport capability. Loop control and data acquisition software have been improved.

In the Robotics Laboratory, a high-resolution projector system with a large screen, based on the latest graphics technology, was installed to support investigations into astronaut training (operating ERA), tele-operations and remote payload operations (telescience).
A PC-based system for the acquisition and processing of colour images was installed. Satellite network simulation software was purchased.

The Remote Sensing Data Processing system was provided with a CD-recorder to produce data output on CD-ROM and with a plotter capable of producing high resolution A4 colour graphs.

3.5 Informatics

Summary

Extensive research, development, and application of aerospace information systems carried out in 1996 show that Information Technology (IT) has become a core technology of NLR. Work was often done in multidisciplinary project teams with other specialists from NLR, customers, and partners in national and international consortia.

NLR developed IT products that comprised data, documents and software, integrated when necessary with appropriate hardware. Product development was based on the analysis of present and future user needs, assessment of requirements feasibility, and technology development. Research activities were often performed in national and international consortia, collaboration proving to be an effective means to support public and private organizations in the Netherlands.
Projects were controlled using procedures and working instructions that meet the ISO 9001/AQAP-110 standards. The maturity in applying this process control was demonstrated by the Informatics Division with the renewed certification by KEMA Registered Quality.

The use of NLR's computing facilities showed considerable growth. The creation of an ATM (Asynchronous Transfer Mode) backbone in the network that integrates both sites of NLR was started. A new supercomputer, an NEC SX-4 with 16 processors of 2 Gflops, has been installed.

Decision Support Systems for Airport Applications

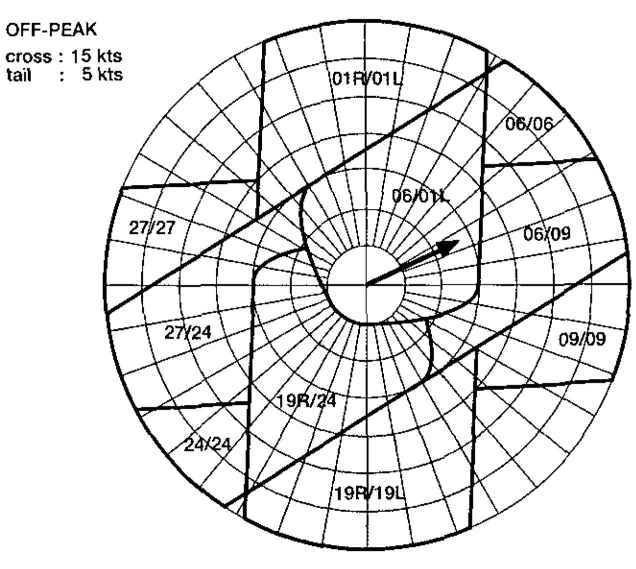
The activities to support to operators, regulatory authorities and policy makers were extended, they included airport environmental monitoring and decision support. The development of national information systems for noise abatement and environmental monitoring was continued. New international co-operative research and development efforts to reduce congestion both in airspace and at European airports were begun.

Monitoring

In the project 'Aviation Emission and Evaluation of Reduction Options' (AERO), models were developed to help predict the scope of environmental problems related to air traffic and to find suitable strategies to reduce the impact on the atmosphere. Among other things, the models take into account environmental benefits and economic impacts on airline industry.

In the area of environmental monitoring, the mid-life update of the Flight Track and Aircraft Noise Monitoring System (FANOMOS) system was completed. This system enables airports, aviation authorities and air traffic control organizations to reconstruct flight tracks from actual radar data. The new user interface features platform-independent graphical visualization of the deviations of actual aircraft tracks from those in the flight plans. Computations and actual measurements of noise levels enable noise loads to be established and used for monitoring purposes.

As a further noise abatement effort NLR has developed concepts and pilot systems to assist in the allocation of runways to aircraft, based on noise considerations, runway availability, and traffic and weather conditions. One pilot system provides information on the actual allocation of runways in comparison to preferential runway use. Using the system, ATC authorities can efficiently monitor and check compliance with regulations aimed at minimizing the noise around Amsterdam Airport Schiphol. Another pilot system provides advice on preferential runways to air traffic controllers. Decision factors which influence the actual allocation of runways to aircraft have been depicted in a wind rose model.



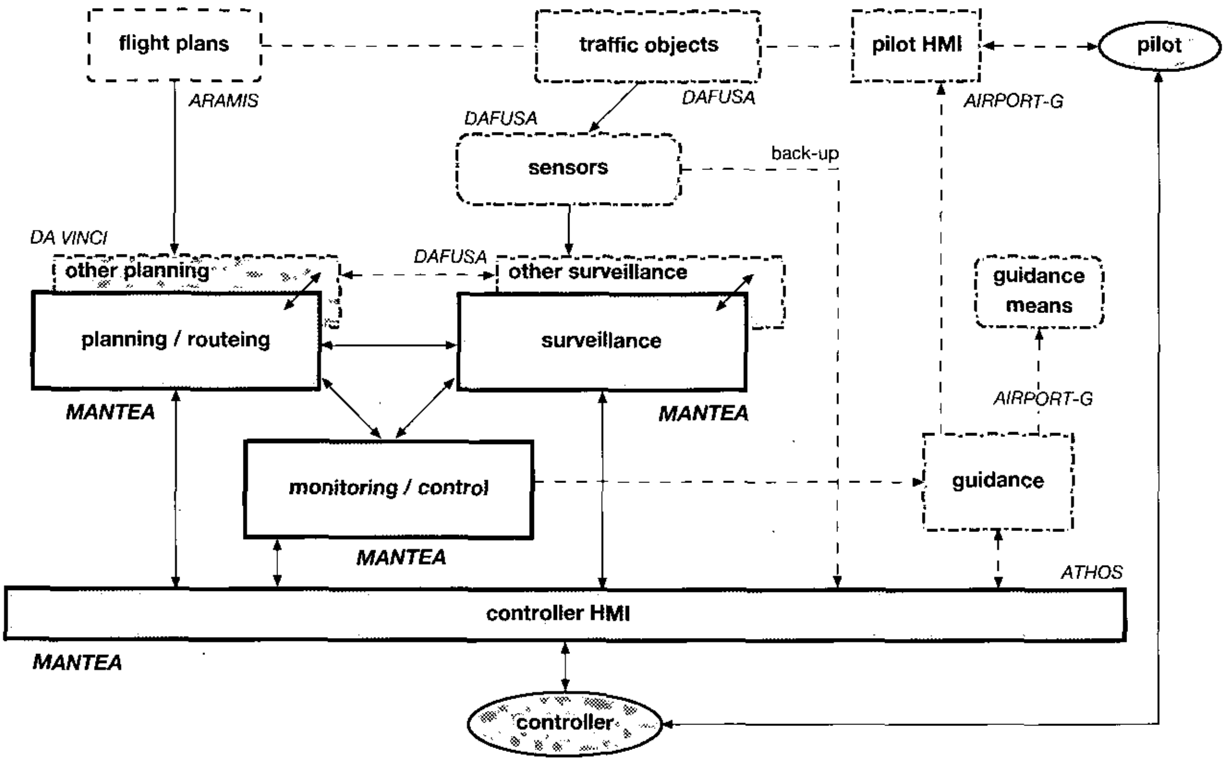
Graphical presentation of preferable runway combinations at Amsterdam Airport Schiphol

By registering deviations from the advice provided by the system and reasons for deviating from the controller's advice, the analysis task performed by ATC authorities using the first pilot system can be alleviated.

Planning

As part of the Telematics for Transport programme of the Commission of the European Communities (CEC), a project 'Management of Surface Traffic in European Airports' (MANTEA) was begun. The objective is to develop decision support tools dedicated to the improvement of surface traffic management at airports. NLR's contribution to this project is focused on assistance to tower controllers on tactical decisions in the process of traffic planning and monitoring under nominal and special situations (e.g. bad weather conditions). NLR has modelled the controller's decision making process, using task analysis. A distributed open architecture based on the Common Object Request Broker Architecture (CORBA) was designed to enable the controllers to use the decision support tools effectively. NLR also worked on the provision of aircraft movement plans to controllers, for guiding taxiing aircraft and preparing runway sequences.

Another decision support project which is being carried out as part of the Telematics for Transport programme is AIRPORT-G, which aims at supporting pilots on-board aircraft by a guidance function that enables them to follow a planned route at an airport. The guidance may be provided through MANTEA.



Management of Surface Traffic in European Airports (MANTEA) project and relation to other airport projects

Advanced Human Machine Interface Functions were designed and developed for airport surface management. A graphical user interface building package, specifically suited for air traffic control applications, was used. It enables multiple presentations to be shown of shared information, if necessary on different displays. Whenever one of the presentations of an information element is updated, the other presentations of the same element are automatically modified.

Planning for Air Traffic Flow Management

Coping with the expected growth of the air traffic in Western Europe requires the development of methods and techniques for Air Traffic Flow Management. Within the Fourth Framework programme ECARDA (European Coherent Approach for the Research and Technology Development of ATM) the project New Optimization Approaches for Air Traffic Flow Management (NOAA) has been carried out by a consortium led by Smith System Engineering. In this project, air traffic flow management (ATFM) problems were investigated in order to develop optimised and integrated ATFM techniques, and to recommend methods for the optimization of ATFM procedures. NLR was responsible for the review and the study of the applicability of optimization algorithms to the European ATFM environment. Direct optimization methods and heuristics have been evaluated with respect to requirements of this environment, and real-time re-routing models have been evaluated for dynamically changing environments.

Research on the applicability of mathematical techniques from operations research (OR) was initiated. These techniques have not often been applied in the field of ATM, whereas they have successfully been applied to other problems in the area of transport. Three important research items have been selected: real-time trajectory planning, slot allocation, and sequencing landing aircraft.

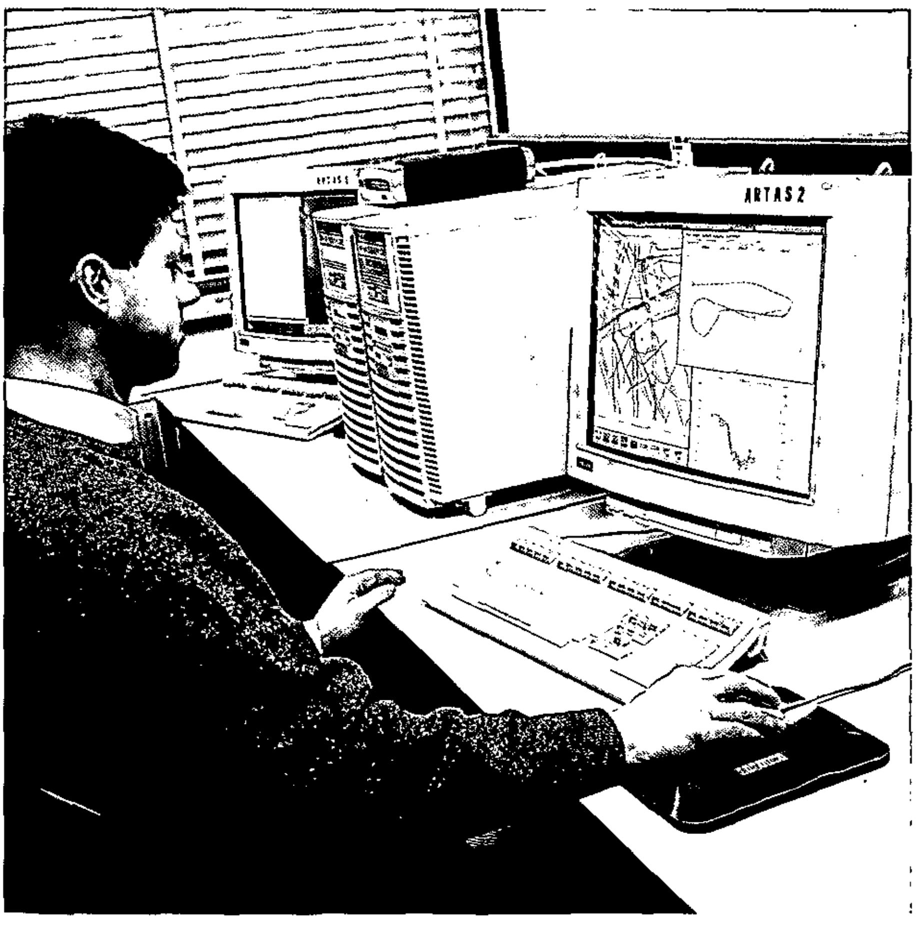
In trajectory planning the goal is to generate flight plans for aircraft. These plans have to satisfy constraints resulting from safety requirements, technical capabilities of aircraft, and fair treatment of airlines, and must minimize the inconvenience for aircraft, airlines and/or passengers. The inconvenience can be measured by, for instance, costs of delays, fuel costs, and route lengths. Research on this topic was started based on the current practice that aircraft can only fly along specified routes. Initially each aircraft is planned according to its shortest route under the assumption that it flies with its preferred speed. This initial plan may not satisfy all constraints, in particular those related to safety. By adjusting the speed of aircraft or by rerouting aircraft the solution can be adapted so as to satisfy all constraints. To determine the adaptations that yield the least inconvenience three local-search techniques are used: iterative improvement, simulated annealing, and genetic algorithms.

Slot allocation, the assigning of departure times to aircraft, should ensure that the sectors are not overloaded so as to minimise inconvenience. In co-operation with DLR, NLR was involved in developing an allocation method using column generation. Numerical experiments are very encouraging; they indicate both possibilities for real-time applications and good solutions.

Sequencing landing aircraft is the assigning of a runway and a landing time to each aircraft entering a certain area around the airport. The common practice is to sequence aircraft in their order of arrival at a certain point near the airport. In its basic formulation the problem of sequencing arriving aircraft is similar to the well-known travelling salesman problem with time windows and to machine scheduling problems with release dates and deadlines. Because this similarity has not yet been exploited much, the use and extensions of the OR techniques that have been successfully applied to these related problems are investigated.

Surveillance

In the area of surveillance, NLR continued the development and installation of radar data processing systems for Eurocontrol and national



ATC Radar Tracker and Server (ARTAS) development configuration aviation authorities. In addition, studies into the applicability of radar data processing systems for military applications were started.

ATC Radar Tracker and Server (ARTAS)

After the successful demonstration of the ATC Radar Tracker and Server (ARTAS) in August 1995, a contract for the second and third phases of the ARTAS project was awarded by Eurocontrol. The second phase consisted of the delivery of an ARTAS system at each of the four designated ARTAS evaluation sites: Schiphol and Beek in the Netherlands, Karlsruhe in Germany and Toulouse in France. The first system was delivered at Schiphol, followed by the other ones. The site acceptance test was held in Karlsruhe. NLR provided assistance at each of the four sites in the tuning and evaluation of the tracker. The formal qualification process of the tracker was continued at NLR using the NLR tracker testbed. This testbed integrates, amongst others, the Eurocontrol RASS-C radar evaluation tool set, the NLR MTRAQ tracker quality measurement software, real-time replay and track display software.

In parallel, work for ARTAS phase 3 was started. This consists of the extension of the ARTAS phase 1 tracker into a dual, hot-redundant tracker, operating in parallel on two different computers, such that the backup tracker can take over the services of the main tracker, without interruption of the tracking.

Quality Assessment Facility for Radar Tracking

Work under contract to Eurocontrol for the development of the Multi-radar TRAcker Quality assessment facility (MTRAQ) was completed. Eurocontrol took delivery of MTRAQ, which has been demonstrated to users as a part of Eurocontrol's Radar Analysis Support System (RASS).

Eurocontrol has been provided with a tool to measure the performance of existing and newly developed aircraft tracking systems, such as ARTAS, and to use the measurements to assess and tune the quality of the tracker under test, using a comprehensive Human Machine Interface.

MTRAQ provides means to classify the data for which the tracker performance is measured (e.g. aircraft category or radar plot quality). It enables measurements related to tracking accuracy (e.g. position or heading), track detection (e.g. track initiation delay) and tracker Mode-Of-Flight indication (i.e. indication of aircraft behaviour per flight mode) to be made using data which has been classified. Performance characteristics can be computed and presented on several abstraction levels, ranging from raw ground tracks to class-based statistics (e.g. convergence values of root-mean-squared groundspeed errors per class). The Human Machine Interface enables the user to navigate between abstraction levels for detailed analyses.

As a consequence of using MTRAQ, users have come up with additional requirements. These will be met by modifications to MTRAQ to be implemented by NLR under a contract extension with Eurocontrol.

Consultation, Command and Control

NLR has continued its support to the Royal Netherlands Air Force (RNLAF) and other national and foreign armed forces. The support in the use of existing information systems included upgrading and modernization activities. Applied research and technology development under the auspices of the Western European Union was continued.

Operations Management Information System

Under contract to the RNLAF, a feasibility study was carried out of the modernization of the Operational Management Information System (OMIS) in use at Volkel Air Force Base since 1983. A description of the technical feasibility, and a project plan for the design, realization and implementation of a prototype were made.

Mission Support Systems

The Mission Support System/Campal (MSS/C), developed for the European Participating Air Forces, has been converted to a commercial off-the-shelf (COTS) hardware platform for the Hellenic Air Force in the framework of a support programme funded by the Netherlands Ministry of Defence. This version of MSS/C, called MSS/Pandora (MSS/P), is approximately ten times faster than MSS/C, and has improved growth potential due to the use of commercially available hardware and operating system components. The major goal of the project was the transfer of knowledge of the use and design of automated mission preparation systems. The MSS/Pandora system has been delivered to the Hellenic Air Force.

Decision Support, Planning and Tasking

Under the EUCLID Research and Technology Programme, NLR has continued work in RTP 6.1 'Advanced Information Processing for a Command and Control workstation'. The goal of this programme, carried out by eighteen participants from seven countries, is to accelerate the application of Artificial Intelligence (AI) and advanced software engineering methods such as agent-based and object-oriented approaches in Command, Control, Communications and Intelligence (C^3I) systems.

NLR participates in the area of decision support, planning and tasking. NLR focuses on real-time execution and updating of plans, using AI methods and techniques. Anytime planning methods, which can generate a plan at any moment in time, were investigated. If more time is available, the quality of plans generated by these methods is better. An experiment was carried out to demonstrate the feasibility of such a method for time-constrained allocation of sorties to prioritized targets in a military scenario.

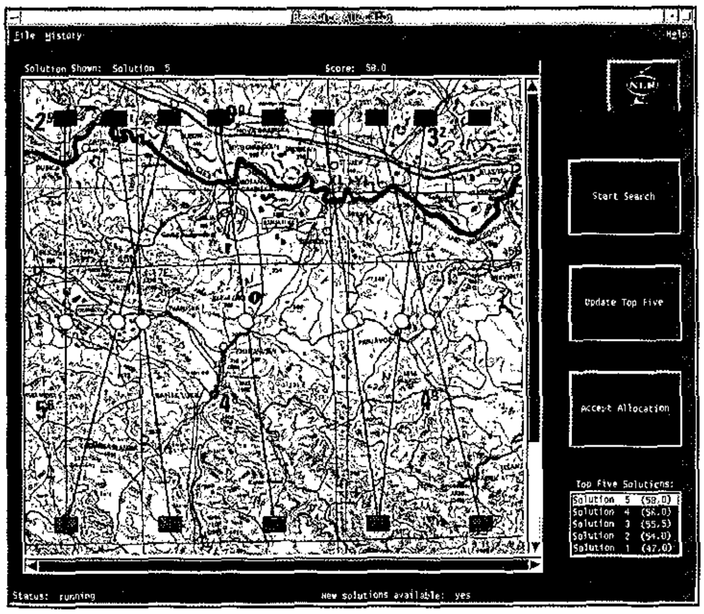
For the analysis, design and implementation, NLR has used an object-oriented analysis and design method.

In the area of on-board decision support, research results from the EUCLID RTP 6.5 Crew Assistant programme, successfully concluded in 1995, were used to establish co-operation with the UK Defence Evaluation and Research Agency (DERA). Weapons selection in air-to-air engagement has been chosen as the first application to demonstrate the feasibility of a Crew Assistant.

In the NATO project Very Short Air Range Defence Systems (VSHORAD), NLR continued contributing to the Battlefield Management and C^3I (BMC^3I) investigation. The feasibility of distributed artificial intelligence methods and database management for BMC^3I has been investigated.

Multi-Sensor Data Fusion

Under the military research and development programme of the Western European Armaments Group, NLR has continued its co-operation with Signaal and other parties in the Netherlands and in France to produce a near-real-time system for multi-sensor data fusion, using advanced information processing methods and techniques, including AI. This technology is applied to the observation of a military battlefield with several types of (simulated) sensors. The data generated



Time-constrained allocation of sorties to prioritized targets in a military scenario by the sensors are combined to provide more abstract data, which is used by an AI-based decision support module.

A world model was designed, using an object-oriented analysis and design method. This world model represents a military environment with entities including terrain, atmosphere, targets and civil transportation means, provided with their characteristics and behaviourial dependencies. The world model will be used by the AI-based reasoning component. A helicopter-borne data fusion system, which combines data from a radar Moving Target Indicator (MTI), and Electronic Support Measures (ESM), was designed. The design of a high-level data fusion system, enabling dynamic aspects of military objects and units to be established, was initiated.

Reliability, Availability, Maintainability, Safety and Certifiability

NLR has continued its support in the area of reliability, availability, maintainability, safety and certifiability to civil and military designers and operators of aircraft and space systems, and to aviation authorities.

Decision Support for Reliability and Maintainability

The RNLAF contracted NLR to investigate the applicability of knowledge-based systems for the improvement of fault detection, isolation and recovery of F-16 aircraft. The work is focused on line maintenance and the reduction of unnecessary removals of equipment from the aircraft.

Safety

For the Netherlands Department of Civil Aviation (RLD), accident location models were developed concerning light-weight aircraft around regional airports. These models can be used to calculate the probability that a crashing aircraft ends up in a specified area. With the location models, combined with accident ratio and consequence models, third party risk analyses can be made.

Using existing models for main airports, NLR made approximations of confidence intervals for individual risk contours around Heathrow Airport.

For the LVB, NLR worked on the development of a general model to determine tactical separation minima. Tactical separation is based on position information obtained through surveillance of the aircraft in the airspace. The traditional means of surveillance is radar, and a future means is expected to be Automatic Dependent Surveillance (ADS). The basic elements of tactical separation minima for radar-controlled and ADS-controlled environments are sufficiently similar to merit the derivation of a general model from which both a radar separation minimum and a tactical separation minimum in an ADS environment can be deduced.

For the RLD, NLR has undertaken a probability risk analysis of collisions between aircraft during independent parallel approaches. The study focused on the minimum required parallel runway spacing for which the collision risk may be judged adequately low. Issues which have been addressed are the identification of suitable risk measures and the adoption of a Target Level of Safety for the safety analysis of parallel runways both used for landing. Particular emphasis has been given to the intermediate approach and missed approach flight phases. A risk model has been developed and implemented for the determination of the collision risk. The model has been applied to a number of scenarios with varying parallel runway spacing and under various operational conditions. Measures to lower the collision risk were derived from the numerical results obtained. The results of this study are to be used by a working group of ICAO.

Safety and Certification

NLR continued an investigation into the relation between the software development process and the certifiability of systems containing software, carried out for the RLD. Topics were the use of structured analysis and design tools in both systems and software analysis and in design and development, and the use of formal methods for the specification of system and software functions.

Under contract to Fokker ELMO, certifiable embedded software is being developed for an application in an aircraft. Since some of the functions of this software are safety critical, parts of it have to conform to the highest level of the applicable RTCA standard for airborne software, DO 178 B (level A, anomalous software behaviour would cause a catastrophic failure for the aircraft). A procedure for the development of this class of certifiable software is being realised in parallel with the software itself. At the same time, experience is being gained on how to handle software of different criticality levels (levels A, B and D) which runs concurrently on the same processor. NLR is responsible for the entire software process, from requirements analysis up to and including verification and validation. NLR supports the airframe manufacturer in contacts with the certification authority for NLR's software.

Validation

Under the CEC's Fourth Framework programme, NLR and its Phare-X partners carry out the GENOVA (Generic Overall Validation of ATM) project. The aim of GENOVA is to define and specify a validation process for the overall ATM system, taking ATM complexity and evolutionary characteristics into account. Validation of an ATM system examines the extent to which the system meets the actor's needs. GENOVA extends and deepens the results of the VAPORETO (Validation Process for Overall Requirements in Air Traffic Operation) project, in which NLR also participated. High-level validation objectives have been specified, and inventoried validation methods and techniques have been assessed with respect to these objectives.

Process and Product Improvement

Continuous Acquisition and Life Cycle Support

For the Ministry of Defence, the use of life cycle costing and management methods and tools was investigated as part of the Continuous Acquisition and Life Cycle Support (CALS) initiative. A tool set which is suitable for all parts of the armed forces was identified.

Another project is the identification of possibilities to use electronic means for storage, exchange and presentation of information for life cycle support of the Patriot missile. Based on user needs, Fokker Services and NLR address topics including Interactive Electronic Technical Manuals, distribution of information via the World Wide Web, and security.

Both for CALS and for other purposes, NLR has made an overview of existing and emerging standards for information exchange, including text, static and dynamic graphics, video, and audio.

Optimization and Frameworks for Process and Product Improvement

NLR has continued working in the area of methods, techniques and tools for multi-disciplinary aerospace design. An international MDO project was started, as part of the Fourth Framework Programme of the European Union. In addition, international research and technology development was continued as part of GARTEUR activities.

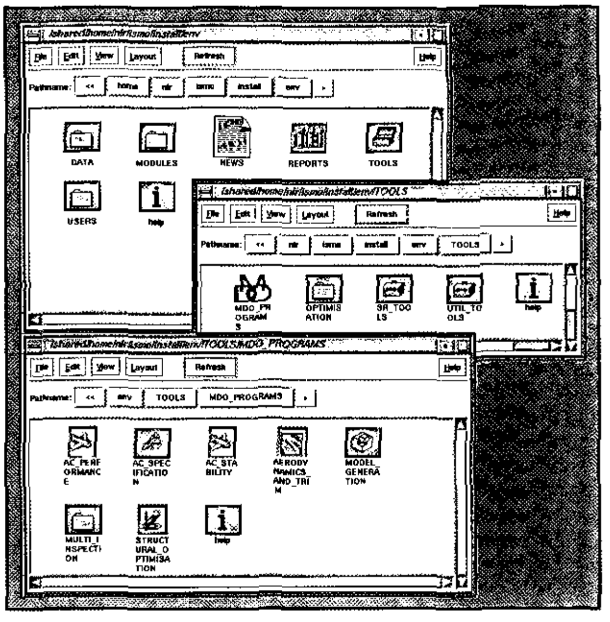
MDO Framework

In the MultiDisciplinary Design, Analysis and Optimization of Aerospace Vehicles (MDO) project, NLR is task leader in the area of information technology. An MDO framework has been specified as a reference for the evaluation of specific frameworks demonstrated by the MDO partners. These frameworks differ in basic approach:

- start from processes (as supported by the commercial package SiFrame),
- start from information,
- or start from combining processes and information (as supported by the software package SPINE (Software Platform for Integrated Access to a Network Environment) developed by NLR for NEC).

Two demonstrations, one based on SiFrame and one based on SPINE, have been prepared. The SPINE-based framework represented the MDO process as defined by NLR together with the disciplines involved in the analysis, design, and optimization activities.

The flow of information between these disciplines was captured in a so-called N2 diagram.



Graphical User Interface for Multidisciplinary Design, Analysis and Optimization (MDO)

Optimization in Flight Control

A GARTEUR Flight Mechanics, Systems and Integration Action Group (FM) AG-10 "Multivariable optimization techniques for experimental and conceptual design" was established, to develop a validated interface standard between mathematically formulated optimization problems on the one hand and existing numerical optimization routines on the other hand. NLR has made an inventory and a classification of optimization problems and methods in flight control design. In co-operation with the Delft University of Technology (DUT), a study on optimization problems, methods, and techniques for flight under windshear conditions has been carried out.

Middleware for Computer Networks

Under contract to NEC, NLR has continued the development of SPINE, a general tool for the development of working environments for specific application areas. Such working environments provide application users with one single virtual computer which gives transparent access to the computing, storage, and input/output resources available in a UNIX computer network. Transparent details include file transfer between computers, logging into remote systems, and data conversions.

SPINE is a coherent system including a graphical user shell, support for the definition and maintenance of working environments, and tools for manipulating and managing the information available in the forms of software, documents, and data in the network. The information management capabilities of SPINE have become valuable tools for the support of quality assurance procedures according to the ISO-9001 standard.

SPINE has been extended with a facility for exploiting World Wide Web functionality in the development of, possibly geographically distributed, multi-user working environments. A facility for defining and importing general reusable sets of tools (tool packs) has also been developed. One specific tool pack has been realized that supports development, analysis, debugging, and execution of Fortran software on the SX-4 supercomputer.

SPINE has been used in NLR projects and in several national and international projects, for the development of working environments for:

- Computational Fluid Dynamics: ISNaS, Matrics-V, NICE;
- Computer-Aided Software Engineering: ISEnS;
- Computer-Aided Control Engineering: ISMuS;
- Multi-Disciplinary design, analysis and optimization of aerospace vehicles: ISMO;
- Radar-data Processing: ISRaP.

Work Flow Management and Control Engineering

The facility for control engineering ISMuS has provided the framework for developments in the GARTEUR Action Group (FM) AG-08 towards a European environment for Computer-Aided Control Engineering. Additional requirements concerned tools for process management, including concurrent engineering. Selected commercially available tools (including the same SiFrame as considered in MDO) were integrated with tools already available in ISMuS to create a prototype environment for demonstrations to European aerospace industries. From the prototype development, requirements to SPINE have been derived that will be met in following versions so that process management support will become available to other projects using SPINE.

Software Engineering Process and Product Improvement

NLR has developed a facility for the development of software for the management of processes and products in information systems: ISEnS, a working environment for Software Engineering Based on SPINE. ISEnS supports the analysis of requirements and the design of software as well as version management and documentation. ISEnS uses SPINE to integrate two commercially available software applications and a version management package developed by NLR. Furthermore, tools have been incorporated for sending and receiving files and directories via electronic mail.

The ISEnS facility was applied in large-scale aerospace projects to achieve multi-partner, distributed software development environments incorporating both special purpose and commercial off-the-shelf components.

User access to ISEnS was enhanced and preparations were made to apply ISEnS as the default software development environment as part of the ISO 9001 Quality System of the Informatics Division.

Simulation, Training, Visualization and Virtual Environments

For a large variety of application areas, the visualization of existing or future situations may bring about cost and risk reductions, and enhance training and evaluation. Computer-based training options were developed for aircraft operators, air traffic controllers, and maintenance technicians.

Flow Simulation and Solvers

The NICE project, partially funded by the High Performance Computing and Networking (HPCN) Foundation of the Netherlands, was started. It aims at the development of flow simulation applications on HPCN platforms to increase the competitiveness of the Dutch industry. It is co-ordinated by NLR. All major Dutch technological and university research institutes active in the area of CFD participate in the project. A digital working environment for CFD, covering CFD applications, was made available at the sites of the partners. This environment, called HFS (HPCN centre for Flow Simulation) has been modeled to ISNaS, the NLR working environment for CFD. Several partners in the project (RuG, MARIN, CWI, TNO-TPD) have installed working environments at their sites using the SPINE support software that provides the basis for ISNaS. SPINE also provides easy access to external sites, in particular the NEC SX-4/16 at NLR. To support and enhance the use of the NEC SX-4, a development tool package has been developed for makefile generation, compilation, execution, analysis and optimization of software. This tool package and working environment have enabled the partners after a short time to use the NEC SX-4 efficiently. The HFS has already incited industries in the Netherlands to start using HPCN facilities.

Work was done on improving the flow solver ENSOLV of the ENFLOW system for numerical simulation based on the Reynolds-averaged Navier-Stokes equations of 3D viscous flow around complete aircraft configurations. The solver is being extended with a two-equation turbulence model, and the thin-layer approximation is being replaced by the complete Reynolds-averaged Navier-Stokes equations. Both extensions will make the flow solver better suitable for complex configurations. In the NICE project, ENSOLV has been parallelized on the NEC SX-4.

Also in the NICE project, the unstructured flow solver Hexadap has been parallelized on the NEC SX-4. The parallelization was based on do-loop parallelization. In less than two months the speed was increased by a factor of 11.5 on fourteen processors, and the flow solver reached a speed of 8.5 Gflop/s, demonstrating the capability and ease-of-use of the NEC SX-4. The parallelization experience is made re-usable through the SX-4 development tool package. Efficient parallelization of the adaptation algorithm of the unstructured flow solver Hexadap and high performance of the integration algorithm requires partitioning of the unstructured adaptive mesh. An algorithm has been developed which produces balanced partitions in a short time.

In the AIDA project, part of the CEC's third Framework programme, the NLR solvers Soleqs and Hexadap have been used for the development of a 64-processor shared-memory parallel computer. Test cases were supplied to evaluate the functionality and limits of compiler and operating system.

A study was made of the requirements of the structure of computational fluid dynamics software to ensure timeliness, testability and adaptability. Based on this study, work instructions were made to be used in the development of numerical simulation software by co-operating mathematicians and software engineers.

Simulation Facility for Sloshing Liquids

ISMuS, the NLR working environment for computer-aided control engineering, has been extended with the EuroSim Mk0.1 simulation support tool, creating an environment suited to the simulation of sloshing liquids.

Vehicle Simulation

A consortium of Dutch industries, technological institutes and a university was granted partial funding for the project 'Simultaan' by the Dutch HPCN foundation. In Simultaan, existing knowledge and products will be combined with tools to be developed, to arrive at a permanent infrastructure in the Netherlands for real-time simulation that involves complex high performance computing and networking. NLR is responsible for the development of a vehicle simulation model and for the simulation scheduling tool.

In co-operation with the Eindhoven University of Technology, dynamical models of roving vehicles have been studied. A general multibody dynamics model was selected, which included the description of the holonomic and non-holonomic constraints related to terrain interaction. The model was applied to derive the dynamics equations for a Mars roving vehicle of the Russian Marshokhod type.

Automatic Debiting Systems

The Ministry of Transport is planning to introduce automatic tolling stations on the roads leading to major cities. Such tolling stations, or Automatic Debiting Systems (ADS), consist of a gantry equipped with microwave communication equipment, video cameras and other optical sensors, and linking computers. Transponders in passing cars exchange messages with the ADS, and the toll fees are paid electronically. Video cameras are used to register the license plates of the vehicles for which the transaction fails, so that a bill can be sent to the owner. The Ministry of Transport has formulated strict requirements to the performance of the ADS systems. For example, only about one in a million cars may be registered incorrectly. A number of international consortia have offered proposals for an ADS. Since the requirements are hard to test in practice (for instance by installing a test ADS along a road and driving test cars through the system), computer simulations are essential. Therefore, a simulation facility is being built by the University of Amsterdam in co-operation with the Dutch software house CMG. NLR has been contracted by the Ministry to support the ADS consortia in the development of simulation models for their particular ADS systems. In this work NLR utilizes experience obtained in sensor modelling and simulator development for aeronautics and spaceflight.

Synthetic Environments

To enable designers and operators of aerospace systems to visualise and manipulate graphical representations of aerospace systems and components, the use of the Virtual Reality Modelling Language (VRML) is investigated. With VRML, three-dimensional graphical scenes, including synthetic environments, can be represented and manipulated.

Training

Computer-based training modules were designed and developed to familiarize air traffic controllers with advanced tools developed in the PHARE programme. For the RLD, a demonstration system for more efficient and cost-effective familiarization training was developed using low-cost commercial off-the-shelf hardware and authoring software.

NLR received a contract for the Mission Preparation and Training Equipment (MPTE) for the European Robot Arm (ERA). System requirements were composed as a basis for system design and development. The design of MPTE is based on re-use of existing components, most notably the Columbus Ground Station software and Eurosim, a development of Fokker Space, Origin, ACE, and NLR. NLR is responsible for the Demonstration Model, for the System Test Plan, and for the independent System Test.

Robotics Simulation and Control

NLR continued its participation in the development of the European Robot Arm (ERA) by Fokker Space. The participation concerned the ERA Simulation Facility (ESF) and the ERA Exception Handling system at Fokker Space. The ESF will have both non-real-time and real-time simulation capabilities. NLR focused on the specification and design of the simulated ERA motion control software and of the communication software. The simulated motion control software is the major software component of ESF versions that will be used as the design simulator to check and tune the proposed ERA control concept. The communication software is the major software component of the ESF versions that will be used for ERA Control Computer (ECC) verification, with ECC software and hardware in the loop.

The Exception Handling, or Failure Detection Isolation and Recovery (FDIR) system has been specified in detail. A preliminary plan for the verification of the requirements related to Exception Handling was generated.

Funded by the Netherlands Agency for Aerospace Programs (NIVR), a pilot study on observer-based and identification-based FDIR schemes for a robotic joint was performed. FDIR demonstrations to be conducted within the NLR robot laboratory were specified.

In close co-operation with Groningen University, investigations have been made into the representation of dynamical systems subject to inequality constraints, ubiquitous in aerospace applications, including robotic manipulators and flight control systems. Based on previously executed studies in the field of space-borne manipulators, a test plan has been made to study the interaction of controlled contact of a robotic manipulator with environment constraints. Real-world tests will be compared with tests executed with NLR's simulation program TRaCE (Trajectory and Constraint Evaluation).

Thermal Control

A study was performed on the benefits of an enhanced controller for the Smart Thermal Interface Plate developed for Cells In Space. Simulation results showed both a substantial decrease in the energy consumption and a better control accuracy.

Computing Facilities

The hardware facilities of NLR's computer network include a UNIX-based supercomputer, several other UNIX servers and a non-UNIX mainframe. A communication network based on the TCP/IP protocols connects these facilities with workstations, X-terminals, PCs and other terminal equipment at NLR. Wind tunnels, simulators and other experimental facilities are also connected to the network, which is linked to national and international networks. The number of stations connected to NLR's network increased from 963 to 1310.

The computer networks of the two sites of NLR are connected by a 34 Mbps ATM (Asynchronous Transfer Mode) link. In both sites a segmented network provides the users with a high communication capability.
A start was made with the creation of an ATM backbone. The supercomputer was directly connected to it. The design of a growth path to an infrastructure with improved data communication was also started. This infrastructure will allow high-speed Ethernet and ATM connections from the work places to the NLR backbone.

The NEC SX-3 supercomputer, having two processors of 2.75 Gflops, was replaced by an NEC SX-4, with sixteen processors of 2 Gflops. A list of the world's 500 most powerful computer systems of November 1996 showed that the NEC SX-4 installed at NLR is by far the most powerful computer in the Netherlands. NLR continues to provide access to its computer system for other organizations.

The gateway between NLR and the outside world is becoming very important. Both the data flow from NLR and the use of the NLR facilities by others is increasing rapidly. The computer facilities provided the basis for 34-Mbps European pilot experiments. To maintain a good security level, a start was made with an upgrade of the network security measures. These include ISDN, high speed dial-back and implementation of a 'firewall' on the Internet interface.

The use of the computer facilities showed considerable growth. A file server provides storage for the UNIX systems in the network. The total size of the files stored on this server increased from 115 GB to 155 GB. The number of workstations using the fileserver for automatic backup is rapidly increasing as well. To accommodate the projected growth, a proposal for an upgrade of the file server facility was prepared. This upgrade, to be implemented in 1997, will provide a doubling of the server's capacity.

The support structure for personal computers at NLR includes central PC servers to provide an efficient and cost effective infrastructure.

NLR's computing centre is one of the four HPCN centres in the Netherlands that participate in ANKHER (*Associatie van Nederlandse HPC Kernen*), an Association founded in May 1996 and aiming at providing the Dutch scientific and industrial sectors access to top level High Performance hardware and software.

NLR participated in the Working Group on Supercomputing and Networking of AEREA. In this working group all seven European Aeronautics Research Establishments participated. A work plan was made concentrating on a setup of a virtual centre for document exchange and networking.

3.6 Electronics and Instrumentation

Summary

A variety of projects were carried out to support civil and military national and international aerospace customers. Basic research included tests in support of the improving of an aerodynamic model of the Metro II by accounting for dynamic fuel displacements.

NLR worked on fault-tolerant avionics and participated in the development of the safety-critical Flight Control & Display Module of a future avionics system. An evaluation of computational models for the prediction of ILS performance affected by multi-path reflections was concluded.

A research programme for the validation of engine exhaust emission models in flight was started.

Flight testing of Fokker aircraft continued after the bankruptcy of Fokker, notably for the Fokker 60 programme. Development work continued on the high-accuracy positioning system for flight testing, based on phase tracking differential GPS.

The Automatic Dependent Surveillance demonstration programme ADS-Europe, including flights with the Cessna Citation research aircraft was successfully concluded.

NLR started work in the project 'Generic Avionics Scalable Computing Architecture' of the CEC. In the EURICE project of the CEC, work on certification of aircraft under icing conditions was started.

Under contract to Eurocontrol, NLR started the modification of the Data Link Processing Units, for the evaluation of mode-S communication in automated Air Traffic Management Systems.

In the area of military aviation, NLR participated in the EUCLID programmes 'Space SAR Technology' and 'Modular Avionics Harmonization'.

NLR continued to participate in the F-16 Mid Life Update (MLU) programme by the detachment of several avionics engineers of NLR at Lockheed and by research and development activities at NLR. A predesign for a flight test instrumentation system was made for the F-16 MLU.

Participation in the development of the mission system of the NH90 helicopter was continued. The programme comprises the development of a part of the NH90 mission system which fuses data, in real-time, from individual mission sensors. The development of the cockpit Fuel Panel and the external Fuel Panel of the NH90 were continued. The development of a Remote Frequency Indicator for the NH90 and Tiger helicopters was started.

In the areas of spaceflight and remote sensing, a variety of equipment was developed and tested for various customers. NLR designed a fully space-qualified Mass Storage Device that provides non-volatile data storage for manned space flight. The design and realization of a prototype Temperature Data Collection Unit for the Large Solar Simulator at Noordwijk was started. The Stimuli and Monitoring Electronics of the test equipment for the attitude and control system of the X-ray Multi-mirror Mission satellite was developed, realized, tested and delivered.

Flight tests with the PHARUS system resulted in high-quality images of the Earth's surface. PHARUS (Phased Array Universal Synthetic Aperture Radar) meets requirements including absolute reflectivity measurements as a function of polarisation.

In the area of facilities and equipment the upgrading of the calibration laboratory for flight test data acquisition equipment continued. The instrumentation of the research aircraft was modified in preparation for future flight tests for the CEC.
A Flight Inspection System was installed in the Metro II.

The NLR Infrastructure for Computer Aided Engineering of Electronics (NICE) was updated by including new software.

An advanced physiological measurement system was acquired as well as a second head-/eye-tracker system, enabling two-men cockpit research to be carried out.

Avionics System Engineering

Integrated Modular Avionics

NLR successfully concluded its contribution to EUCLID programme 'Modular Avionics Harmonization Study' (CEPA 4, RTP 4.1), a collaborative study of six European nations in which a total of 27 companies participated, headed by DASA. The study was aimed to research the technologies for the development of future avionics systems architectures. NLR's contribution was in the field of interconnect systems (data buses and networks/architectures), digital signal processing, system development, and component and rack cooling. Candidate architectures for interconnect systems were identified, and the most promising architecture was modelled and simulated. A computer-based tool was used to model and simulate the avionics network. The architecture modelled was an optical switch matrix under control of a cell-switched network. The optical switch matrix offers the avionics system high-speed, point-to-point connections. The main purpose of the matrix is to connect sensors producing high data rates with the core avionics processing cluster.

The optical matrix supports data rates of up to 622 Mbps, with possible growth up to 2 Gbps.

A project was defined for the development of a tool which can be used to model and evaluate the performance of avionics architectures.

Under the Fourth Framework programme of the European Union, NLR participates in the project '*Generic Avionics Scalable Computing Architecture*' (GASCA), executed with several European partners led by Dassault Electronique of France. The objective of this project is to define and validate a scalable avionics computer architecture for future civil aircraft. An actual demonstrator will be built and validated. The architecture must support the future advanced communication, navigation and ATC requirements. Requirements were identified, and described, both from a functional and from a certification point of view. Discussions on certification were started with the European and Netherlands certification authorities.

The EUCLID programme 'Training simulation combining real and simulated systems' (CEPA 11, RTP 11.7) was started. In this project, led by DASA of Germany, a training system for NATO fighter pilots, in particular for Air-to-Air missions, will be defined and specified. The system will be embedded in the avionics suite of the aircraft, generating virtual targets on the pilots' displays simulating a hostile tactical environment. In the project, attention will be given among other things to the operational and functional requirements, visualization of the targets and the resulting system design. Detailed operational and Human Machine Interface (HMI) requirements were identified, described and reviewed. These requirements will form the basis for the system design.

Under contract to the Netherlands Department of Civil Aviation (RLD), NLR worked on an overview of methods for the implementation of fault-tolerant avionics in modern civil aircraft, and specifically focused on the fault tolerant mechanism of the Primary Flight Control System of the Boeing 777 as a pilot project. The fault tolerant mechanisms were modelled and simulated in the performance assessment tool SES/Workbench, which provided the required insight into the mechanisms.

NLR concluded an evaluation of computational models for the prediction of ILS performance affected by multi-path reflections from buildings and constructional activities, also under contract to the RLD.

F-16 Mid Life Update (MLU)
Within the framework of the co-development programme for the F-16 Mid Life Update (MLU), NLR engineers were detached at Lockheed Martin Tactical Aircraft System (LMTAS) in Texas, USA, under contract to LMTAS. The engineers were working on Avionics System Requirements and Verification Team of the LMTAS F-16 MLU design team, at the Systems Integration Laboratory, and on the Attack Radar Flight Test at Edwards Air Force base.

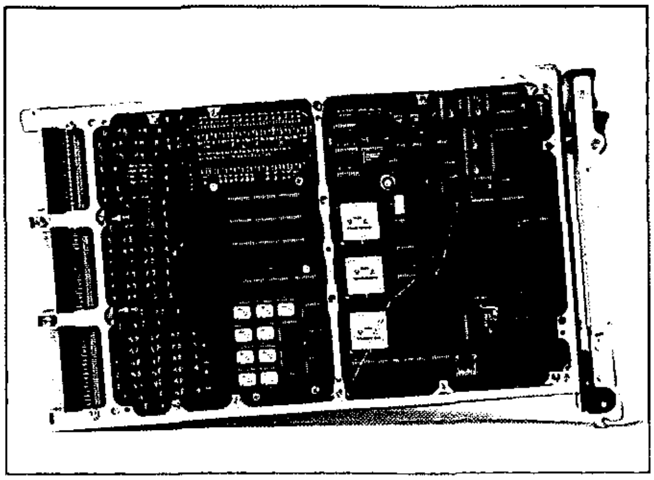
NH90 Mission System Development
NLR continued its development activities in the design of the Mission System for the NH90 NFH, the Nato Frigate Helicopter, and produced a detailed specification of NFH Mission System functions. NLR will develop a module that performs track-to-track associations of tracks from surface and subsurface vessels using information from the NFH mission sensors such as the radar, Forward Looking Infrared, Electronic Support Measures and sonar. This module will reside in the NFH mission system, with the objective of reducing the operator's work load. Association of tracks was previously done manually, but with this module the operator only has to confirm or reject suggestions by the module. Functional evaluations and simulations are part of the design approach.

Flight Control and Display Module
NLR is involved in the development of the Flight Control & Display Module (FCDM), a safety critical part of an avionics system that is being developed for the next generation civil helicopters and fixed-wing aircraft. NLR provides assistance with the hardware development and has complete responsibility for the development of the flight-critical software. The hardware development support consists of schematic entry

of the electronic circuit diagrams and the design of the printed circuit boards. Apart from software engineering, the software development includes verification, validation, and certification. Part of this software has to conform to the highest software level of the applicable RTCA (Radio Technical Committee for Aeronautics) standard for airborne software, DO-178B.

Synthetic Aperture Radar Technology

In the Phased Array Universal Synthetic Aperture Radar (PHARUS) project, a fully polarimetric airborne Synthetic Aperture Radar has been developed under contract to NIVR. This project is a co-operative effort of the Physics and Electronics Laboratory TNO, Delft University of Technology and NLR. Several flights were conducted with PHARUS on the Citation II research aircraft, which resulted in high-quality SAR images.



Flight Control & Display Module (FCDM) of an avionics system under development

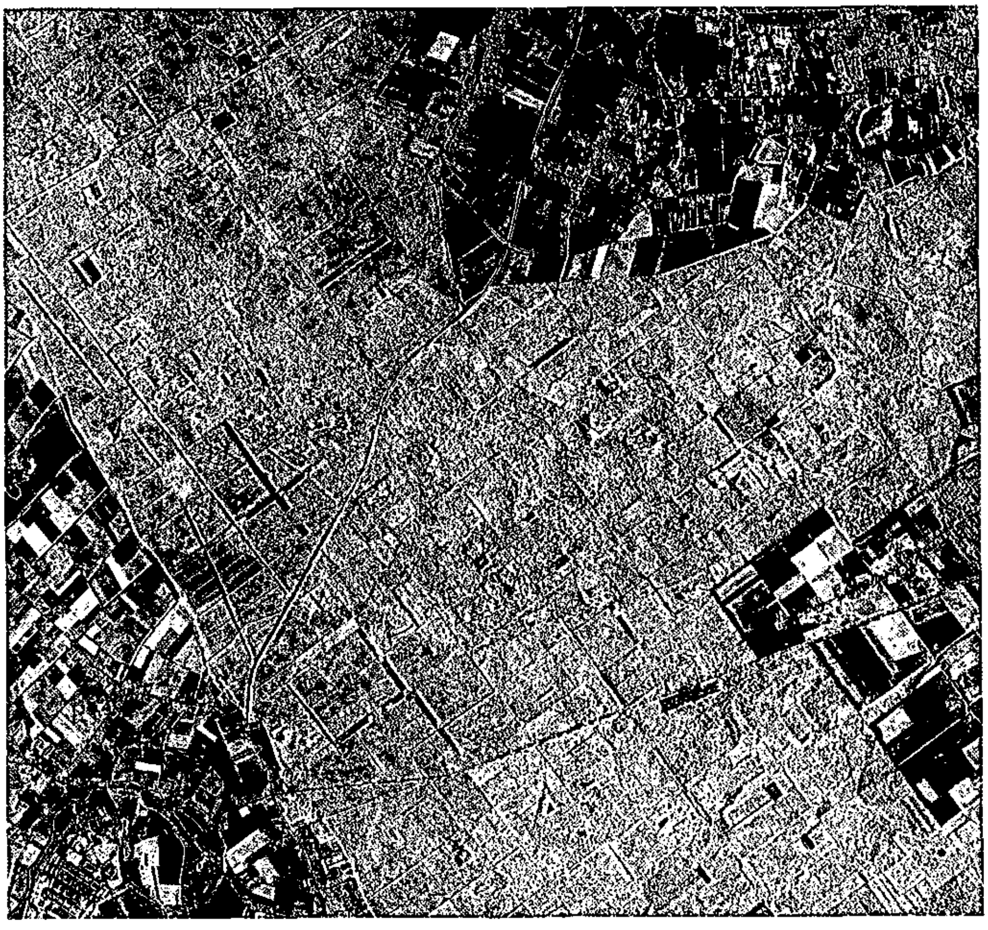


Image of a wooded area obtained by Phased Array Universal Synthetic Aperture Radar (PHARUS) on NLR aircraft shows open spaces and narrow paths (PHARUS data by TNO-FEL, NLR and DUT)

The EUCLID programme 'Space SAR technology' (CEPA 9, RTP 9.3) was started. It is led by Alenia of Italy. NLR participates in the areas of Electronic Counter Counter Measures (ECCM), digital control and thermal analysis and control. The goal of the programme is to define and develop new technologies to be used in military spaceborne SARs. The ECCM workpackage will define techniques which could counter signals from ground-based jammers which could inadvertently affect the SAR's performance. The digital control workpackage includes studies on the control of antenna elements. The digital control in a SAR also provides the phase and amplitude control of each of the individual transmit and receive elements. In addition housekeeping data have to be optimized for the large number (in excess of 1,000) of transmit/receive modules.

Mass Storage Device

For manned space applications NLR was involved in several activities under contract to ESTEC and NIVR regarding spaceborne mass memories. NLR designed a Mass Storage Device (MSD) for the Russian Module of the International Space Station (ISS) and the European Columbus Orbital Facility (COF). The space-qualified MSD will provide non-volatile data storage on state-of-the-art PCMCIA memory cards. Since in future higher density PCMCIA memory cards will become available which can replace the current drives, the growth potential of the solution chosen is evident.

The PCMCIA memory card will be housed in a sealed cartridge protecting the drive from vacuum conditions and allowing a convenient exchange mechanism to be used. In the design, precautions were taken to prevent the MSD from 'latching up', which could occur due to radiation. The MSD was designed, and an engineering model was built. This model was used to validate the MSD functionality. In addition, a qualification model was built, which was used to validate the performance of the MSD under operational conditions. A number of qualification tests (vibration, EMC and radiation) were carried out.

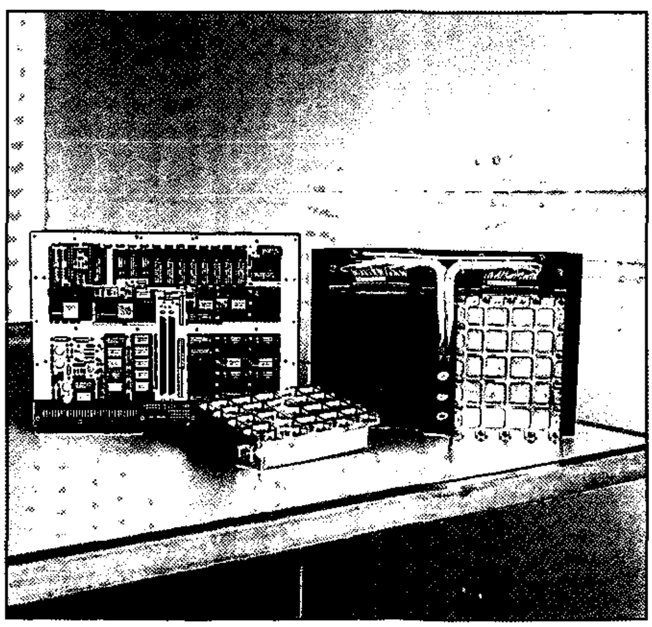
Electronics

Temperature Data Acquisition System

Under contract to the European Space Agency, NLR designs and manufactures a prototype Data Collection Unit (DCU). The DCU is part of a new Temperature Data Acquisition System (TEMPDAS), which will handle measurement signals generated by thermocouples placed on the test objects during thermal testing in the Large Space Simulator (LSS) at the European Space Research and Technology Centre at Noordwijk. Eventually TEMPDAS will consist of a maximum of five Data Collection Units (DCUs) located inside the LSS, and a Data Handling Unit (DHU) located outside the LSS. The Data Collecting Unit will be based on a VME-bus system. The DHU and DCUs will communicate via a MIL STD 1553 B bus.

Satellite Test Equipment

Under contract to ESA, the Stimuli and Monitoring electronics of the test equipment for the attitude control system of the X-ray Multi Mirror satellite was developed and realized. The Dutch company Van Rietschoten en Houwens was involved in the production of cabling and the Dutch company HYMEC was involved in the



Space-qualified Mass Storage Device (MSD) for the International Space Station production of the electronics, miniaturized in size. To obtain further miniaturization, both in size and in power consumption, NLR and HYMEC started a joint technology study, supported by NIVR.

NH90 Remote Frequency Indicator

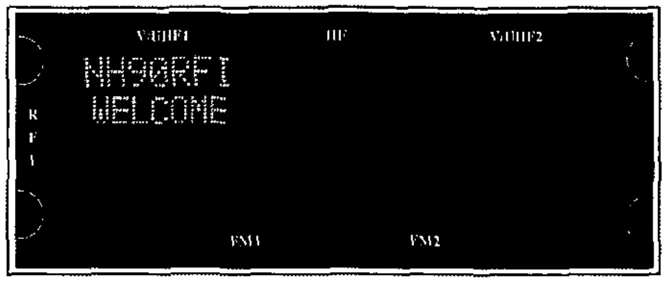
NLR supports Dutch industries in the design and development of avionics equipment for the NH90 helicopter. An international consortium led by BFGoodrich Aercor of Zevenaar has been selected by Eurocopter for the Design and Development of the Remote Frequency Indicator (RFI). Within this consortium NLR is responsible for programmatic and technical co-ordination of all development activities, and executes the analyses required to deliver qualified products to Eurocopter. The RFI is a five-field LED-based indicator. The displays are both Night Vision Goggle compatible and sunlight readable. Each helicopter will be equipped with two RFIs. Requirements on safety, reliability, maintainability and testability are important design drivers, for which NLR carries out much of the analysis. Embedded control software and test system software is being developed by NLR's Informatics Division. An ergonomic model was delivered to Eurocopter for Man Machine Interface evaluation. Since the RFI showed a promising performance, it has also been selected for the Tiger helicopter.

Data Link Processor Unit

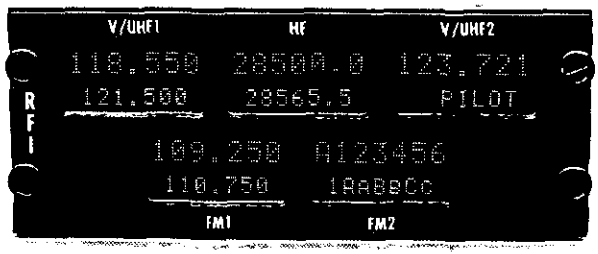
The Data Link Processor Units (DLPU) developed by NLR are applied in experiments for automated air traffic management. To reflect recent internationally established agreements on services and protocols, the units will be adapted. NLR started this work under contract to Eurocontrol, taking into account that the DLPU has to comply with civil airworthiness requirements as well.

Signal Conditioning, Wind Tunnel Instrumentation

From ESA/LABEN, NLR received a subcontract to develop and install the Safety System Sub-Assembly for the Automation System of the future Aerodynamic Plasma Wind Tunnel of CIRA (Centro Italiano Ricerche Aerospaziale), called Scirocco.



Modelling of Remote Frequency Indicator (RFI) by computer aided electronics design



Remote Frequency Indicator (RFI)

NLR has started the development of a new generation of Data Acquisition Interfaces, which will be used between NLR Conditioning Units and Data Acquisition and Reduction computers. A number of interfaces will be developed and manufactured. They will be installed in the data acquisition systems in use at wind tunnel facilities of NLR and of the German Dutch Wind Tunnel (DNW).

Instrumentation

Flight Testing and Flight Test Instrumentation of Fokker Aircraft

Owing to the bankruptcy of Fokker Aircraft, flight testing of Fokker aircraft decreased considerably. The Fokker 50, 70 and 100 flight tests were reduced to a minimum. The Fokker 60 flight test programme, however, continued at a high level. The Measurement, Recording and Data Processing system, managed, controlled and operated by a team of NLR personnel was used for all flight tests. These included an extensive take-off and landing performance measurement campaign in Granada, Spain. Data of more than five hundred measurement runs were processed at NLR. The resulting accurate flight paths were transferred to Fokker for final analysis.

For the factory acceptance of the Fokker 100, 70 and 50 aircraft that were produced in 1996, the Production Flight Test system (PFT) was used.

Since it was realized that, in spite of the Fokker bankruptcy, flight test instrumentation would remain to be required, a feasibility study into the capabilities of measurement, recording and processing systems (MRVS) was started. The study focuses on smaller, easy-to-install flight test instrumentation with limited on-board presentation and *in situ* data processing facilities.

Measurement and Analysis Techniques for In-Flight Research

Development work continued on the Position Reference System, a high-accuracy (0.15 m, 3-D) positioning system for flight test purposes, based on phase tracking differential GPS. A large amount of flight test data was acquired during the runway performance programme of the Fokker 60. A status was reached where the data can be successfully processed by a skilled operator, correcting for anomalies in the phase ambiguity resolving algorithm.

A research programme for in-flight validation of engine exhaust emission models was started. The work was aimed at the development of optical measurement methods for in-flight measurements of NO_x and CO concentrations. Initial experiments were carried out in a ground-based test set-up aft of the engine of the Cessna Citation II research aircraft.

Progress was made in the aerodynamic modelling of turboprop aircraft, notably NLR's Metro II research aircraft, by taking into consideration a number of additional influences, for example dynamic fuel displacements. New models for both the clean symmetrical and the asymmetrical case were deduced from flight test data. The accuracies of these new models were verified by proof-of-match simulations using measured flight control inputs against real flight test data.

As a different modelling technique the Multi-Input Multi-Output method was further developed by the of Delft University of Technology under a three-year contract to NLR. This contract was completed. The Advanced System Identification software package became operational and was made available to the NLR departments specialized in helicopter and aeroelastic research.

Support to the European Union

NLR participated as a partner of National Air Traffic Services (NATS) of the UK and Direction de la Navigation Aérienne (DNA) of France in the European Automatic Dependent Surveillance (ADS) project of the Commission of the European Communities. This pre-operational demonstration programme was successfully concluded. Using interim ICAO ADS and ATN standards, it was demonstrated that surveillance data could be transferred through satellite data links and ATN routers from aircraft outside radar coverage to Air Traffic Control Ground Stations (ATCGS). The Cessna Citation II research aircraft was used besides aircraft in airline service, to support trials for which those were not suited. Among these flights were high-energy manoeuvres to investigate the antenna coverage and flights to compare ADS and Secondary Surveillance Radar (SSR) data.

As part of the Fourth Framework programme, a consortium led by CIRA of Italy is carrying out the EURICE project, aimed at items related to aircraft flying under icing conditions, ranging from meteorological data to certification regulations. NLR contributed to the icing incident/accident data base, to the analysis of current regulations and to the preparation for instrumentation for flight trials to acquire atmospheric data under icing conditions.

NLR was involved in the Airborne Air Traffic Management System (AATMS), a Fourth Framework project covering the field of definition, development and demonstration of tools for the evaluation of new functions of future Flight Management Systems. In the consortium, led by DASA, NLR mainly worked on datalink facilities to be used between the NLR Air Traffic Management Research Simulator (NARSIM) and the Cessna Citation II research aircraft.

The Prototype Aeronautical Telecommunication Network (ProATN) project, led by Aerospatiale, concerns the development and demonstration of a prototype aeronautical telecommunication network meeting ICAO-specifications. NLR contributed to the definition of functional requirements and to the system architecture design.

The Global Navigation Satellite System (GNSS) project "Multimodal Approach for GNSS-1 in European Transport" (MAGNET-B) is being carried out by a consortium with Sextant as the prime contractor. The objective is the development of "GNSS-1 User Segments" with emphasis on accuracy, integrity and integration with data links. NLR will take part in application demonstrations with its research aircraft. NLR contributed to reports describing aeronautical applications of GNSS.

Military Flight Test Support

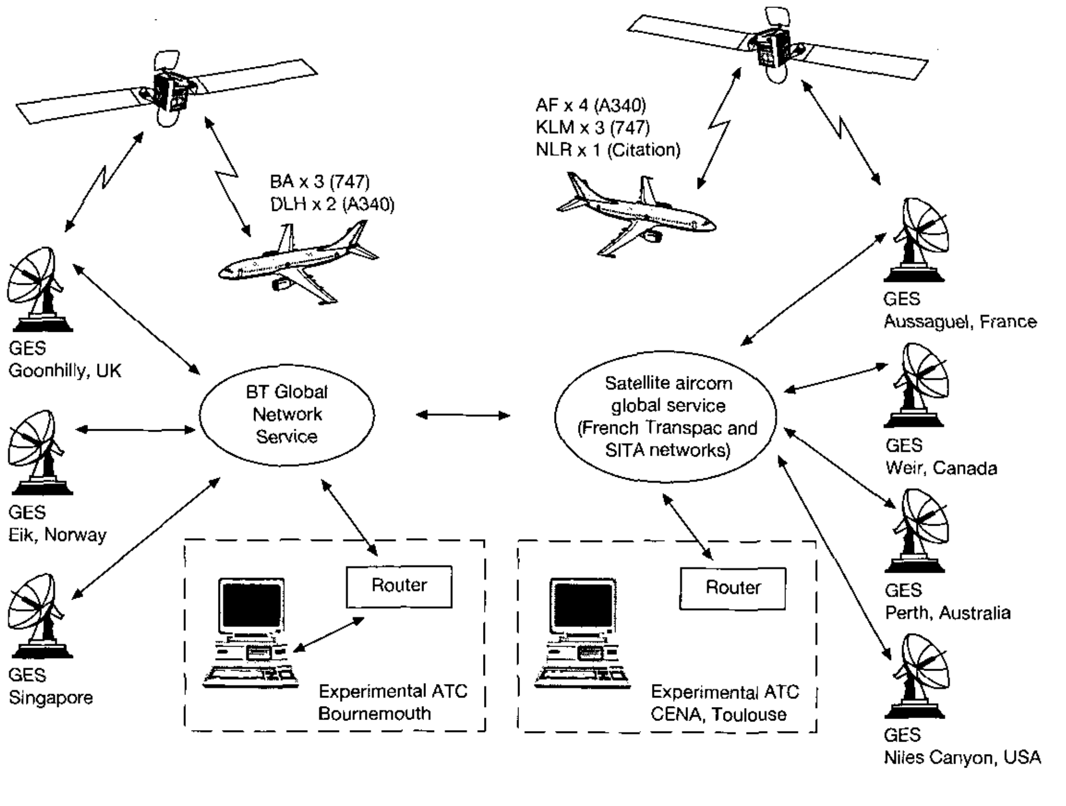
In preparation for future flight test programmes with F-16 Mid Life Update aircraft, a pre-design for a flight test instrumentation system was made.

For a foreign company an electronic interface unit was made available for a performance demonstration programme of a piece of military airborne equipment. NLR personnel supported the flight operations.

Support to Eurocontrol

Experimental Flight Management System

Within the framework of the 'Programme for Harmonized Air Traffic Management Research in Eurocontrol (PHARE)', NLR contributes, together with DERA, DLR and CENA, to the



Schematic diagram of the European Automatic Dependent Surveillance project development of an Experimental Flight Management System (EFMS). New software with increased functionality and improved stability was implemented in NLR's version of the EFMS. Work was done in preparation of a flight trials programme with emphasis on the 'Airborne Human Machine Interface', which will feature an experimental navigation display format.

Facilities and equipment

Environmental Testing, EMI/EMC and VST Laboratory

In both the EMC and Vibration and Shock Test (VST) laboratories, many tests were carried out on various equipment under contract to military and civil customers. Efforts to obtain accreditations for both the EMC laboratory and the VST laboratory from the Dutch Council of Accreditation were continued.

Avionics Design and Evaluation Facility

In order to be able to evaluate and design avionic systems in an efficient manner, an avionics design and evaluation facility was defined. During the realization phase, emphasis will be placed on the use of automatically generated software.

Computer Aided Engineering of Electronics

The NLR Infrastructure for Computer Aided Engineering of Electronics (NICE) was updated by installing a new version of the printed circuit board layout software tool. Preparations are made to implement a new set of CAE software tools based on Windows95. Existing software tools for reliability calculations such as MTBF (Mean Time Between Failures) calculations and FMECA (Failure Mode Effect and Criticality Analysis) prediction were expanded and improved. Existing workstations were replaced by more powerful ones.

Instrumentation for NLR's Research Aircraft

The Future Advanced Systems Testbed (FAST) project is aimed at extending the test instrumentation of NLR's research aircraft in preparation for upcoming flight test experiments for Air Traffic Management research in CEC and other projects. The development of a colour Liquid Crystal Display (LCD) Electronic Flight Instrument Display was started. It is designed to be software compatible with display formats used in ground-based research facilities such as the Research Flight Simulator. A 'Data 2' satellite communication system was commissioned and used in the ADS-Europe project, and a 'Data 3' system was acquired. A series of flight tests was carried out to evaluate new GPS-receivers for accurate flight path determination.

A Flight Inspection System was installed in NLR's Metro II aircraft, making it available for flight inspection of ICAO en-route navigation and landing aids in conformance with the ICAO recommended practices. After an extensive trials programme, the system was accepted for operational use.

Facilities for Acquisition and Processing of Measurement Data

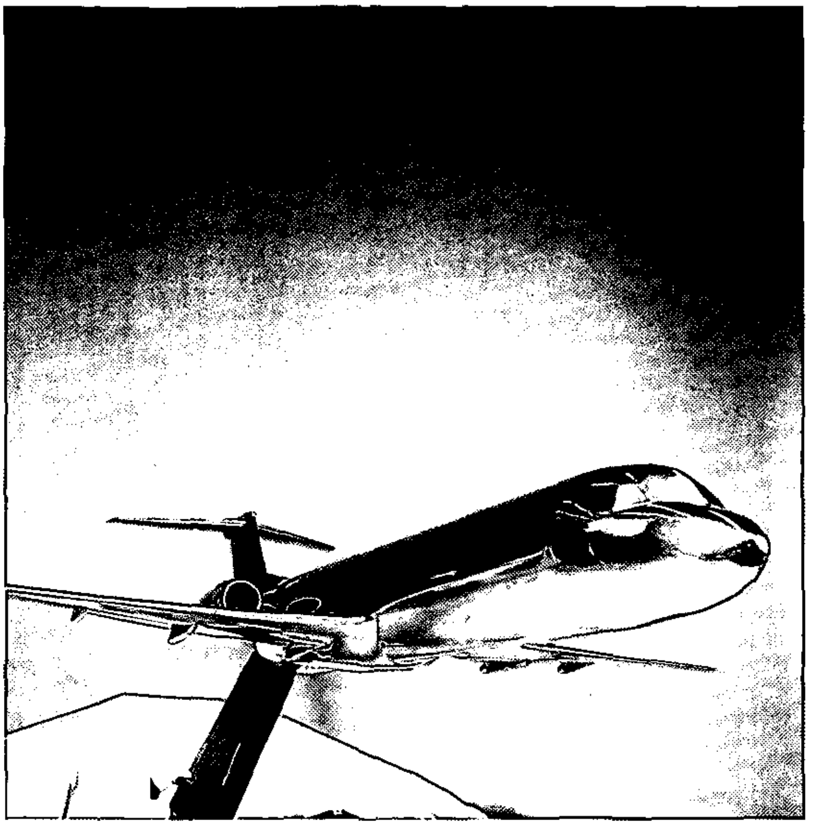
New transducers for in-flight vibration measurements were put into service. A fibre optic Attitude and Heading Reference System (AHARS) was evaluated. New data acquisition units were evaluated for use on board of the F-16 aircraft. The inventory of video equipment for flight test purposes was extended by adding recorders and cameras.

The data presentation facilities of the data processing station for flight test data were improved by adapting the processed data formats to a commercially available software package for data presentation.

The upgrading of the Calibration laboratory for flight test data acquisition equipment was continued. This laboratory was again successfully audited for its pressure calibration facility by the Dutch Council of Accreditation.

Measurement Equipment for Human Factors Research

For human factors research an advanced physiological measurement system was acquired as well as a second head/eye-tracker system, enabling two-men cockpit research to be carried out. Calibration procedures for this tracker system were developed for the application of the system in the magnetic environment of the Research Flight Simulator.



Wind tunnel model of Fokker 100 for cryogenic testing

3.7 Engineering and Technical Services

Wind Tunnel Models and Model Equipment
Various wind tunnel models and related equipment were designed and manufactured. Due to the bankruptcy of Fokker, no new models were made for programmes of the Netherlands Agency for Aerospace Programs (NIVR). However, the manufacturing of a model of the Fokker 100 for the cryogenic European Transonic Wind Tunnel (ETW) could be continued and was almost completed. All other models were made for foreign customers, or as part of NLR's contributions to international programmes.

The largest job was the design and manufacturing of a 1:4-scale main rotor model, part of the NH90 helicopter development programme. The strict requirements of the dynamic behaviour, including the simulation of five natural rotor blade frequencies, were met with the design. The scaled engine inlets and exhausts, which allowed gas flows of 600 deg C to pass, were incorporated in a partly heat-resistant fuselage (see also Capita Selecta). The existing 1:4 helicopter model for the German-Dutch Wind Tunnel's Low Speed Facility (DNW-LLF) was modified substantially.

Various models for aerospace and non-aerospace research and development (space capsules, space reentry vehicles, civil rockets, military missiles, ships and trains) were made for several customers.

Large wind turbine blades for acoustic testing were made and instrumented. For the simulation of power plants, various sets of propeller blades were realized of carbon composites.

Strain Gauge Balances and Model Instrumentation
The development of strain gauge balances and special purpose instrumentation was continued. The temperature sensitivity of sting balances has been investigated in detail, using finite element analysis methods, improving predictability and reliability.

Work was started on the development of various general purpose internal balances for use in the High Speed Wind Tunnel (HST) of NLR, and on two cryogenic gauged flexures for use in a twin sting model support for the European Transonic Wind Tunnel (ETW).
A platform balance for an Acoustic Wind tunnel was designed and built, and a rotating propeller balance was finished.

Various Structures
Besides models and balances, several structures of very different nature were designed and/or manufactured.

As part of the second phase of the modernization of the High Speed Wind Tunnel (HST), several installations were modified or redesigned and rebuilt. New fan blades for the HST were designed and manufactured of carbon composite materials to replace the existing steel blades.
A design was made for a smoke grid, to be installed permanently in the HST.
For the Supersonic Tunnel (SST) a quick acting alpha shifter was developed and built.

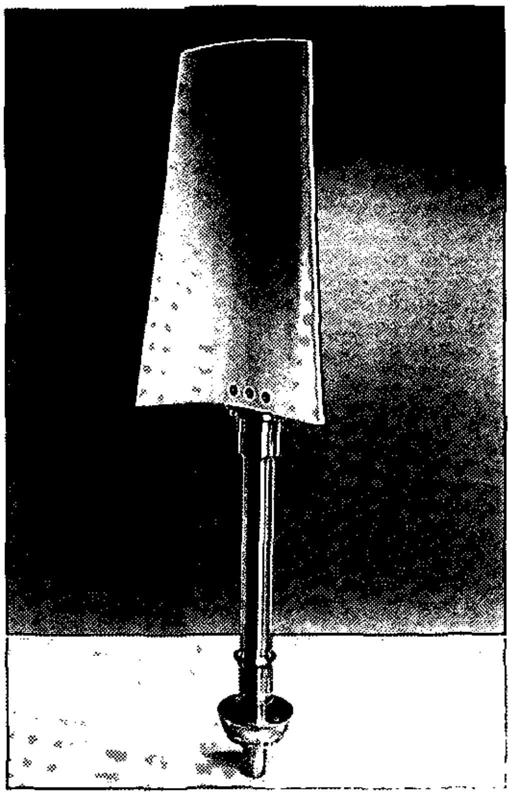
A twin sting model support system was designed for use in the cryogenic European Transonic Wind Tunnel (ETW).

A simulation facility was designed to investigate the air pressure/shock flow behaviour in long railway tunnels induced by high-speed trains.

Development of New Techniques
To ensure the capability of manufacturing highly specialized products, the development of new techniques has been given continued attention.
The use of carbon composites for large fan blades designed for prolonged use was investigated.

Expansion of the use of finite element methods in the design phase was investigated.

Improvements and extensions to the use of the Catia CAD/CAM system were realized. The acceptance of a new 5-axes high speed CNC milling machine was prepared, the training of personnel was started and the evaluation at the supplier was completed.



Fan blade for 20-MW wind tunnel drive

Five-axes high-speed milling machine

4 Internal and External Relations

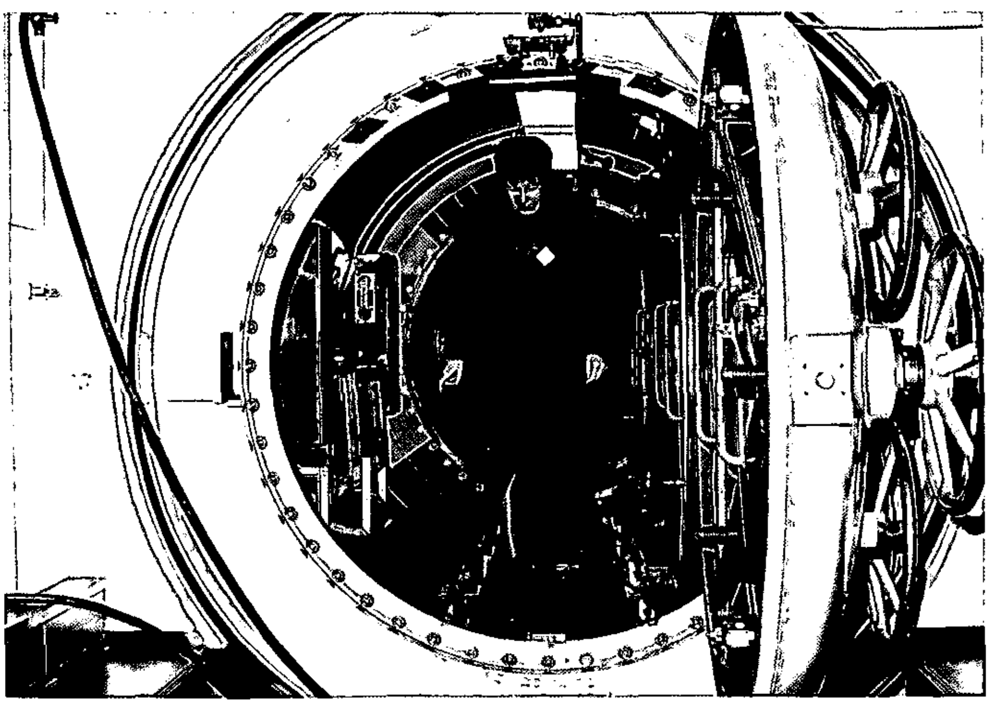
Many visitors showed interest in NLR's activities. NLR participated in several airshows and exhibitions and organized various events.

Visitors from the Netherlands

- Gen.-Maj. A.P.A. de Jong, Deputy Commander of the Royal Netherlands Air Force
- Dr. H.L. Jonkers, Advisor Director Science and Technology of the ministry of Education, Culture and Science
- Drs. D.W.A. Schut, of the Ministry of Transport, member of the EU Management Committee DG 7
- Mr. G. Dubbeld, Co-ordinator Brite/Euram programme within the EU Liaison
- Ir. Th. M. van Oostinjen, Director of the Maritime Research Institute Netherlands (MARIN)
- Mr. C.A. Ruitenbeek en Mr. J. Wilmes, of Fokker Aerostructures and Fokker Services, respectively, accompanied by Mr. H. van Leeuwen of NIVR
- Members of the Lower House Permanent Committee for Defence
- Staff members of HITT (Holland Institute of Traffic Technology)
- Lt.Kol. Theunissen and Mr. F. Huisman of the ministry of Economic Affairs
- Mr. A. Slingerland, Head of Division DG-7 E-2 of the European Commission
- Mr. R.M. Lutje Schipholt, Director of the TNO Prince Maurits Laboratory (PML)
- Gen.Maj.Ir. M.R.H. Wagevoort, member of the Board of the Foundation NLR
- Drs. J.C. Gmelich Meijling, State Secretary of Defence
- Mrs. A. Jorritsma-Lebbink, Minister of Transport
- Drs. E.A. van Hoek, Director Research and Development and Drs. D.J. Barth, Secretary General, of the Ministry of Defence.

Foreign Visitors

- Mr. Jim C. Schoene of McDonnell Douglas accompanied by Mr. P. Verschoor of the Netherlands Ministry of Economic Affairs
- Mr. D. Nischl, Director Engineering of Lockheed Martin Astronautics
- Members of the Royal Air Force Air Warfare Centre, Operational Doctrine and Training
- Col.Prof. B. Smólski of the Polish Ministry of Defence
- Col. Ronen, Defence Attache of Israel
- Rear Admiral G.E. Steidle, Director of the Joint Strike Fighter (JSF) Program
- Mr. Jun Sei Lee, Mr. Jong Chul Kim and Mr. Jong Bum Kim of the Korean Aerospace Research Institute (KARI)



Mrs. A. Jorritsma-Lebbink, Minister of Transport, was shown the upgraded HST test section

- Mr. M. Pirkl of DASA and Mr. U. Döhler and Mr. P. Hecker of DLR
- Members of the Chinese Academy of Space Technology
- Representatives of the Indonesian Air Force
- Prof.Dr.-Ing. A. Bachem, member of the Board of DLR
- Representatives of Texas Instruments.

Excursions

- The Netherlands Naval Air Service
- The Scientific Subcommittee 'Flying Qualities' of NIVR/NLR after their meeting in Amsterdam
- Technical personnel of the Netherlands Railways
- The study society 'Robot' of Twente University
- Students of Leeuwarden Northern College
- Students from the Haarlem College
- Members of the Technical Faculty for Informatics of the Technical College of Gelderland
- Members of Volonta, the Society of Students at Hollandse Signaal Apparaten (HSA)
- Delegates of the 'SETP 28th European Symposium', who visited DNW
- Students of the Fachhochschule Hamburg, Fachbereich Fahrzeugtechnik
- Members of 'Abacus' Mathematics Study Society from Twente University
- Members of the Royal Institute for Engineers (KIvI) Defence Technology
- Employees from DLR and DASA
- Staff of the Ministry of Transport, International Affairs and Communication
- Members of 'Niria' Society of engineers
- Officers of several Air Forces, who took part in international discussions on Air Mobile Operations 'Finabel Kilo'
- Members of the Aeronautical Study Society 'Sipke Wynia' of the Haarlem College
- Participants of a NATO Working party and staff of the NATOC[3] Agency (previously Shape Technical Centre)

Exhibitions

- NLR contributed tot the stand of the Netherlands Aerospace Group (NAG) at 'Asian Aerospace 1996' in Singapore.
- During a workshop for medium-sized and small companies (MKB), organized by MKB Nederland, NLR showed its activities by posters showing the most important facilities.

Demonstration at the Farnborough Airshow of MSS/ Pandora for Lt.Gen. B.A.C. Droste

- The International Training Equipment Conference (ITEC) was held in the Hague. In the stand of the Netherlands Industrial Simulator Platform (NISP), NLR showed a moving model of the National Simulation Facility (NSF) linked to a video with views from the cockpit.
- NLR presented simulation and spaceflight activities within the NAG stand during the 'Indonesian Airshow' in Jakarta. President Soeharto paid a visit to the stand after the official opening of the show. Furthermore, a delegation with Mrs. Jorritsma, Minister of Transport and a delegation with the State Secretary of Defence, Drs. J.C. Gmelich Meijling visited the stand.
- NLR participated in the exhibition during the Open Days of the Royal Netherlands Air Force at Twenthe Airbase.
- NLR contributed to the stand of the Netherlands Aerospace Group (NAG) at the Farnborough Airshow 1996 in the UK.
- The Netherlands Defence Manufacturers Association (NIID) organized a symposium in the Hague. During this event NLR showed its activities by means of pictures and a video film.
- NLR showed its spaceflight activities in the exhibition of 'Space '96' in Beijing, China.
- A two-day meeting, 'Decide' (organized by International Meeting Platforms) for Aerospace Industries and their potential clients was held for the first time in the Netherlands, at Soesterberg. NLR showed its activities on pictures and video.

Events

- Well-attended New Year Receptions for the NLR staff were held in both Amsterdam and Noordoostpolder.
- The Board members of the Confederation of European Aeronautical Societies (CEAS) met at NLR Amsterdam.
- The Garteur AG-20 meeting was held at NLR Noordoostpolder.
- Members of the Amsterdam Industrial Society (AIV) held their meeting at NLR, where alderman Drs. D.B. Stedig held a lecture.
- A three-day course on 'Wind Loads' was held at NLR Amsterdam, with contributions by the Fluid Dynamics Division.
- The Spring '96 meeting of the AGARD Technical Information Committee was held at NLR.
- The Informatics Division and RCI organized the European Member Management Symposium IX at NLR Noordoostpolder.
- Partners of the NLR Board members visited the sights of the Noordoostpolder. The members joined them on board of a boat for lunch during a round trip on 'De Wieden'.
- A meeting was held for the Preliminary Design Review of the NH90 Helicopter Project RFI (Remote Frequency Indicator).
- NLR hosted the kick-of meeting of the Aircraft Equipment Committee of the Approach and Landing Task Force of the Flight Safety Foundation.
- Meetings of the Association of European Research Establishments in Aeronautics (AEREA) were held in both Amsterdam and Noordoostpolder.
- At NLR Amsterdam and NLR Noordoostpolder, introductory meetings were held for new employees.
- NLR participated in a Transport Day organized by the Technological Institutes of the Netherlands (GTIs). Mrs. A. Jorritsma-Lebbink, Minister of Transport and other members of the Netherlands Government attended.

5 Scientific Committee NLR/NIVR

Advice Provided to NLR and NIVR

The Scientific Committee provided advice:

To the Board of the Foundation NLR, on:

- the results of the work NLR carried out under the Programme for basic research and development of facilities of NLR;
- the preliminary Work Plan for 1997;
- the Programme for basic research and development of facilities for 1998;

To the Boards of Directors of NLR and NIVR, on:

- the results of the work carried out by NLR in 1995 under the 'General Research Programme with a view to aircraft development in the near future' (ARP) of NIVR;
- the reports NLR submitted to the Committee to be considered for suitability as scientific publications.

Membership of the Scientific Committee

The composition of the Scientific Committee was not changed. The secretary, ir. P.G. Vermeulen, who left NIVR, was replaced by ir. G.J. Voerman. At the end of 1996 the Scientific Committee was composed as follows:

Prof.dr.ir. P.J. Zandbergen, *chairman*
Prof.ir. C.J. Hoogendoorn
Prof.dr. T. de Jong
Dr. R.J. van Duinen
Ir. F. Holwerda
Ir. G.J. Voerman, *secretary*

Membership of the Subcommittees

In the course of 1996, the following members of the subcommittees resigned for various reasons: Ir. N. Voogt (Subcommittee for Aerodynamics), Prof.dr. J.H. de Wit (Subcommittee for Structures and Materials), Drs. H. Walgemoed (Subcommittee for Structures and Materials) and KLTZE Ing. R.C.A. Patijn (Subcommittee for Electronics and Instrumentation).

New members are expected to be appointed in the near future.

At the end of 1996 the subcommittees were composed as follows:

Subcommittee for Aerodynamics

Prof.dr.ir. J.L. van Ingen, *chairman*
Prof.dr.ir. P.G. Bakker
Dr.ir. R. Coene
Prof.dr.ir. H.W.M. Hoeijmakers
Prof.dr.ir. F.T.M. Nieuwstadt
Prof.ir. E. Obert
Prof.ir. E. Torenbeek
Prof.dr.ir. P. Wesseling
Prof.dr.ir. L. van Wijngaarden
Ir. E.J. Bos, *secretary*

Subcommittee for Space Technology

Prof.ir. H. Wittenberg, *chairman*
Dr. B. Baud
Prof.dr.ir. J.A.M. Bleeker
Ir. P.Ph. van den Broek
Dr.ir. N.J.J. Bunnik
Prof.dr. W. de Graaff
Ir. P.L. van Leeuwen
Prof.dr.ir. L.P. Ligthart
Prof.ir. N.J. Mulder
Prof.ir. K.F. Wakker
Ir. D. de Hoop, *secretary*

Subcommittee for Structures and Materials

Prof.dr.ir. H. Tijdeman, *chairman*
Prof.dr. Joh. Arbocz
Prof.dr.ir. Th. de Jong
Lt.Kol. ir. J.W.E.N. Kaelen
Prof.dr. A. Rothwell
Prof.dr.ir. J. Schijve
Ir. L.H. van Veggel
Prof.dr.ir. S. van der Zwaag
Ir. F.J.M. Beuskens, *secretary*

Subcommittee for Applied Mathematics and Information Technology

Prof.dr.ir. P. Wesseling, *chairman*
Drs. P.J.W. ten Hagen
Prof.dr.ir. G.Y. Nieuwland
Prof.dr. J. Olsder
Prof.dr.ir. J. Schalkwijk
Prof.dr. C.R. Traas
Ir. H.M.P. Förster, *secretary*

Subcommittee for Aircraft Performance and Operations

Prof.ing. J.H.D. Blom, *chairman*
KTZSD ir. K. Bakker
Ir. H. Benedictus
Ir. W.G. de Boer
J. Hofstra
Ir. R.J.A.W. Hosman
Ir. H.J. Kamphuis
Maj. H.J. Koolstra
Ir. H.B. Langeraar
Prof.dr.ir. J.A. Mulder
Prof.ir. E. Obert
Lt.Kol.Vl. b.d. A.P. Okkerman
Ir. H. Tigchelaar
Ir. L.V.J. Boumans, *secretary*

Subcommittee for Electronics and Instrumentation

Prof.ir. D. Bosman, *chairman*
Ir. W. Brouwer
Ing. H. de Groot
Lt.Kol.Ing. H. Horlings
Ir. J.A. van Kaam
Kol.Ir. E.B.H. Oling
Ir. L.R. Opbroek
Prof.ir. G.L. Reijns
Dr. R.P. Slegtenhorst
Ir. A.P. Hoeke, *secretary*

Concluding Remarks

The concluding remarks in the Annual Report of the Scientific Committee are summarized below:

'The meetings of the Scientific Committee were dominated by the developments after the bankruptcy of Fokker Aircraft Company, and especially by the effects on the technical-scientific research in the area of aerospace as carried out by NLR, partly under contract to NIVR.
The Committee understands that after the termination of Fokker as a complete aircraft industry, a reorientation had to take place on the activities in a number of disciplines, with respect to the capacity to be deployed and the direction of the research. The shift in emphasis towards research in support of aircraft operations and the aeronautical infrastructure was expected. It is satisfying to note that this shift in emphasis already resulted in 1996 in a turnover at NLR, and a volume of research, at almost the same level as the year before.
The reorientation that took place concerned both the basic research programme and the research carried out under the NIVR's General Research Programme (ARP) and Aircraft Technology Programme (VTP).

The Committee noted with satisfaction that NLR wishes to maintain expertise in the various aeronautical disciplines, albeit that the allocation of the resources for basic research is being adjusted. NIVR continued to support the research in the areas of computational fluid dynamics, aeroelasticity and aeroacoustics and in the areas of flight mechanics, stability and control, but to a lesser degree. These disciplines are essential and basic elements for an 'aeronautical country' such as the Netherlands. The Committee fears that, due to the reduction of the volume of the research programmes in these disciplines, the full width of these areas can no longer be covered, whereas scientifically there are great challenges in these areas, such as the modelling of flows with vortices and the modelling of turbulence. The Committee is therefore concerned about maintaining the scientific status that NLR now enjoys internationally. The Committee noted that, perhaps for efficiency, NLR publishes most of the research results in its own report series rather than in professional journals. However, the reports examined by the Committee are of a high to very high quality.

From the transition NLR experienced in 1996, the contours of a new basis for the future are emerging. The further shaping of this basis will depend on the formulation of the policy with respect to the aeronautical cluster by the Netherlands government, as a result of the current strategic study.
NLR should approach the now fragmented Netherlands aircraft construction activities with concrete proposals and set a high standard, rather than act defensively. The approach should be taken in co-operation with NIVR. It is of great importance that several Government Departments, including the Department of Defence, explicitly underline the importance of NLR for their areas of responsibility.
The European co-operation in various programmes, in which NLR participates extensively, is also a stimulus.
The incorporation of the HST and SST wind tunnels in the German-Dutch Wind Tunnel (DNW) co-operation provides possibilities for wider European use.
The participation in European programmes – partly based on the Netherlands' contribution to European and international organizations – does require a national basis that must be maintained and extended. As examples of successful research in 1996, the Committee cites windshear research, aeroacoustic research and spaceflight research.

In the area of spaceflight, the Committee is of the opinion that the introduction of a new Ozone Monitoring Instrument for the new generation Metop satellites deserves full support. The award of an ESA contract for building a small satellite, Sloshsat, for the verification of fluid dynamics models, is a stimulus for NLR (and Fokker Space) to continue the spaceflight research in this area vigorously. The Committee suggests to increase the Netherlands' potential of obtaining scientific results from this satellite by acquiring an additional budget for data processing and analysis.

From the above it is clear that the Scientific Committee is of the opinion that there are sufficient activities, at Dutch and foreign aerospace companies, in European co-operative projects and at Government Departments, to maintain the research and development in aerospace at a high level, and to continue to request from the Netherlands government active support. This is of paramount importance to keep this sector at an adequate and competitive level.'

6 International Co-operation

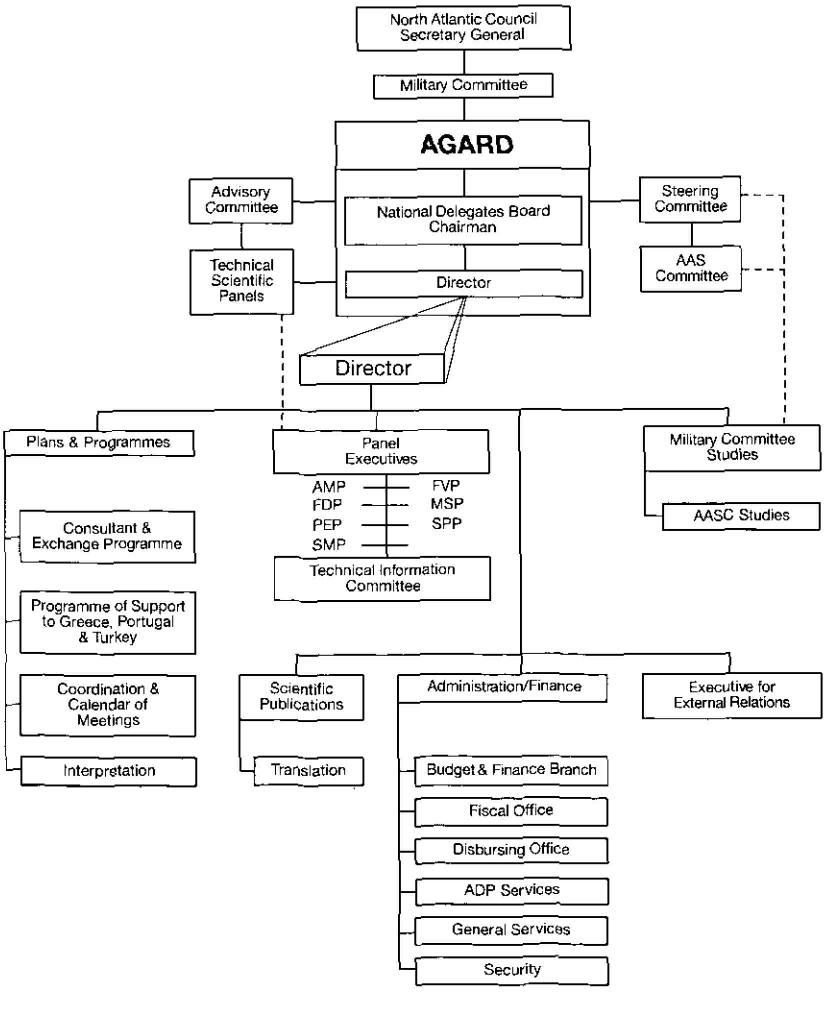
6.1 AGARD

Introduction

On 26 July 1996, the NATO Council established the *Research and Technology Organization (RTO)*. The mission of the RTO is to conduct and promote co-operative research and information exchange to support the development and effective use of national defence research and technology to meet the military needs of the alliance, to maintain technological lead and to provide advice to NATO decision makers.

Within the RTO the Research and Technology Board (RTB) constitutes the highest authority and is the policy body tasked by the CNAD/MC (Committee of National Armament Directors/Military Committee) to carry out the mission of the RTO. The Research and Technology Agency (RTA) is the management element tasked with providing support to the RTB and with executing those actions required to support the development, co-ordination and execution of the RTO's scientific and technical programme. Initially, the RTA will be composed of the AGARD staff, allocated in Paris, and a staff section located at NATO Headquarters, to facilitate the communication between NATO Headquarters and the RTA in Paris.

Ambassador Belanzino, the Deputy Secretary General, officially inaugurated the RTO on 21 November 1996. One of the consequences of the establishment of the RTO is that AGARD and DRG cease to exist as separate organizations. During the period in which the organization of the RTO and the procedures for the execution of the tasks are being developed, both organizations will carry out their 1997 programmes, in principle independently but making use of any opportunity to co-operate. This will be done on the responsibility of the RTO.



Organization diagram of the Advisory Group for Aerospace Research and Development

Mission

The mission of AGARD, NATO's Advisory Group for Aerospace Research and Development, has been to bring together the leading personalities of the NATO member nations in the fields of sciences and technology relating to aerospace for the following purposes:

- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;
- Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving co-operation among member nations in aerospace research and development;
- Exchanging scientific/technical information;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

Organization

Three levels can be identified in the AGARD organization:

- The National Delegates Board, the governing body, assisted by a Steering Committee and an Advisory Committee;
- The AGARD staff, the executive body;
- The Technical Panels and the Aerospace Applications Studies Committee, which together constitute the expert bodies of the Agency.

The mission of AGARD is carried out through a number of activities, including:

- Panel programmes of conferences, symposia and specialists' meetings, and meetings of sub-committees and working groups;
- Consultant and Exchange programmes embracing the provision of individual consultants to NATO member nations and the organization of Lecture Series and Special Courses;
- A programme of Military Committee studies, consisting of aerospace applications and technology studies initiated at the request of the NATO Military Committee;
- The publication of numerous reports;
- A programme of support to the Southern Flank nations (Greece, Portugal and Turkey).

Summary of Main Activities

Panel Meetings/Symposia

AGARD symposia are technical meetings concerned with subjects of relatively general interest within specific fields. In 1996, sixteen symposia have been organized, one of them in the Netherlands.

Lecture Series

AGARD organizes a number of Lecture Series each year. Each series is given for two days, usually in three nations. In 1996, four Lecture Series have been organized, one of them in the Netherlands.

Special and Short Courses

In these Courses, teams of experts present lectures in one, occasionally two or three nations on a specific topic. In 1996, eight Courses have been organized, one of them in the Netherlands.

Support Programmes

The following numbers of support programmes were active in 1996:

Greece	15
Portugal	14
Turkey	21

The Netherlands actively participated as a supporting nation in five programmes.

Consultants Programme

In 1996 a total of 98 consultants missions have been carried out.

Military Committee Studies Programme

The Steering Committee, with advice from the Aerospace Application Studies Committee recommended two topics from the Military Committee Memorandum as subjects for Aerospace Application studies (AAS), viz:

AAS-44 on “Improving battle damage assessment to support NATO operation” and AAS-45 on “Contribution of aerospace systems to the detection and neutralisation of land mines”.

The National Delegates Board adopted these recommended studies.

National Delegates Board Meetings

The National Delegates Board meets twice each year, in Spring and in Autumn. The 1996 Spring meeting was held in Paris. This meeting was combined with the Defence Research Group in a joint R&T session.
The Autumn meeting took place in Munich. During this session two Von Kármán Medals were awarded, namely to Prof.ir. J.W Slooff (NLR) and to Prof. G. Madelung (DASA). The Von Kármán Medal is awarded for outstanding contributions to aerospace science and technology and to enhancement of progress in scientific and technology co-operation among the NATO nations carried out in conjunction with AGARD activities.

Netherlands Delegation to AGARD

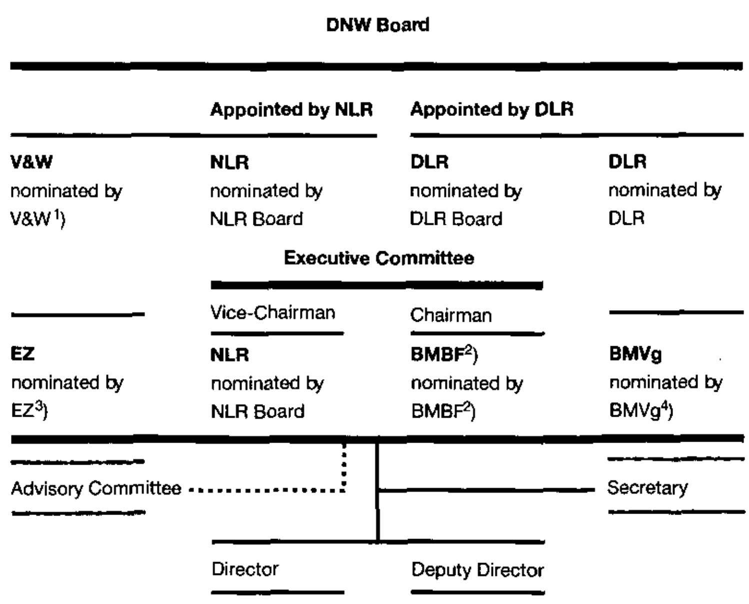
The Netherlands Delegation consists of:
- three National Delegates (two provided by NLR);
- one National Co-ordinator (provided by NLR);
- twenty-one Panel Members (fourteen provided by NLR).

6.2 The German-Dutch Wind Tunnel (DNW)

Since 1980, NLR operates – on an equal base together with the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) – the German-Dutch Wind Tunnel (DNW). This Large Low-speed Facility (DNW-LLF) is located on the Noordoostpolder site of NLR.

The Board of DNW

At the end of 1996 the Board of the Foundation DNW was composed as follows:
Min.Rat Dr. H. Diehl, *Chairman*
Ministry of Education, Science, Research and Technology of Germany (BMBF)
Dr.ir. B.M. Spee, *Vice-Chairman*
NLR
Dipl.-Ing. H. Max
DLR
Min.Rat R. Schreiber
Ministry of Defence of Germany (BMVg)
Dr.-Ing. H. Körner
DLR
J.A. Verberne R.A.
NLR
Ir. H.N. Wolleswinkel
Ministry of Transport of the Netherlands (RLD)
Secretary: Dipl.Kaufm. D. Smyrek



1) Ministry of Transport and Public Works (NL)
2) Ministry of Education, Science, Research and Technology (D)
3) Ministry of Economic Affairs (NL)
4) Ministry of Defence (D)

Organization diagram of the Foundation German-Dutch Wind Tunnel (DNW)

The Advisory Committee

At the end of 1996 the Advisory Committee, providing support to the Board and representing the aerospace industry and research establishments, consisted of:

Prof.Dr.-Ing. F. Thomas, *Chairman*
DLR
Dipl.-Ing. O. Friedrich
Dipl.-Ing. B. Haftmann
DB Aerospace Airbus
Prof.dr.ir. J.L. van Ingen
Delft University of Technology
Prof.ir. E. Obert
Dipl.-Ing. V. von Tein
Airbus Industrie
Dipl.-Ing. A. Rauen
DB Aerospace AG
Dipl.-Ing. D. Stempnewicz
Fairchild Dornier
Prof.ir. J.W. Slooff
NLR
Dipl.-Ing. K. Buchholz
DB Aerospace Airbus
Ir. F. Holwerda
Fokker Aircraft
Y. Richard
Eurocopter
Secretary: Dr.-Ing. G. Lehmann

The Board and the Advisory Committee had one joint meeting.

The Board of Directors

The Board of Directors of the DNW consisted of:
Director:
Prof.Dr.-Ing. H.U. Meier (DLR)
Deputy Director:
Until 1 September 1996: Ir. A. H. Runge (NLR)
From 1 September 1996: Ir. C.J.J. Joosen (NLR)

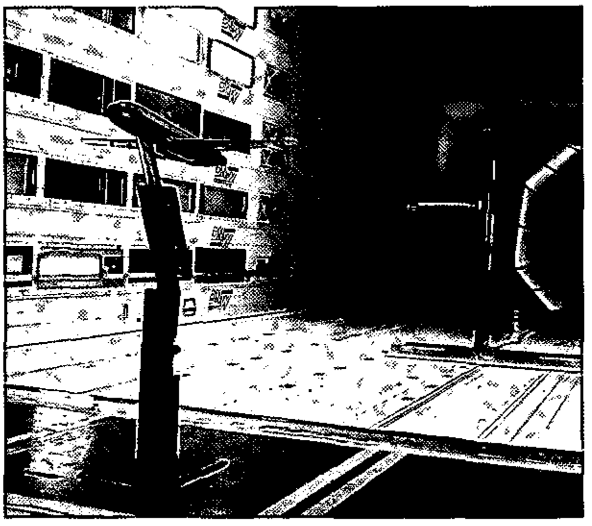
Integration of LST and NWB

On 1 January 1996, after a trial period of two years, two low-speed wind tunnels, the LST (Low Speed Wind Tunnel of NLR) located near the DNW-LLF and the NWB (Niedergeschwindigkeits Windkanal Braunschweig of DLR) located at Braunschweig, were integrated in the DNW organization.

DNW-LLF

The lack of new large aerospace projects resulted in a low occupancy of the DNW-LLF. The delay of some large aircraft research programmes also had a negative effect on the occupancy. On the other hand, the demand from the car and truck industry has remained stable. In total, however, even taking into account about 30 days for demonstration and calibration tests, the occupancy of the tunnel reached the lowest level of the past decade.

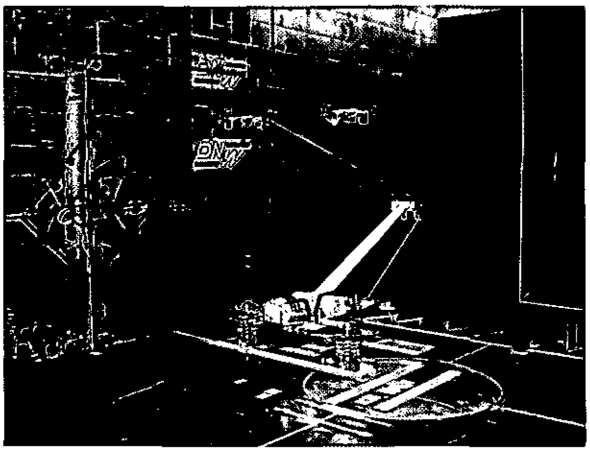
Some of the aerospace tests were unique. These included wake measurements for Daimler-Benz Aerospace Airbus on an A321 model and similar measurements for NLR/Boeing on a Fokker F-29 model. In both cases 3-D flow field measurements with a five-hole probe rake were performed in several planes at distances up to thirteen wing spans behind the model. Additional wake vortex measurements, obtained with the new DNW Particle Image Velocimetry (PIV) system behind the A321 model, showed excellent consistency with the five-hole probe rake measurements.



Wake measurements behind an aircraft model

An acoustic test was performed by DLR using a propeller test stand equipped with a remotely controlled piston engine driving a full-scale propeller. The results showed that radiated noise of a propeller can be reduced by appropriately positioning the propeller with respect to the crankshaft of the engine.

In order to examine possible measurement errors in engine simulation, the ALVAST aircraft model was tested by a joint DLR/NLR team. The immediate reason for this test were some inconsistent results in the past. The new test results showed the reliability of the measurement systems and procedures used. This means that the inconsistencies mentioned were not caused by DNW testing techniques.



Acoustic test with NLR microphone array on full-scale current collector of a high-speed train

One of the most complex projects in 1996 was the NH90 engine installation test. It was the first successful attempt to simulate the interaction of helicopter rotor aerodynamics with the engine intake and hot exhaust flow. Detailed measurements were taken with pressure and temperature probes and infrared cameras.

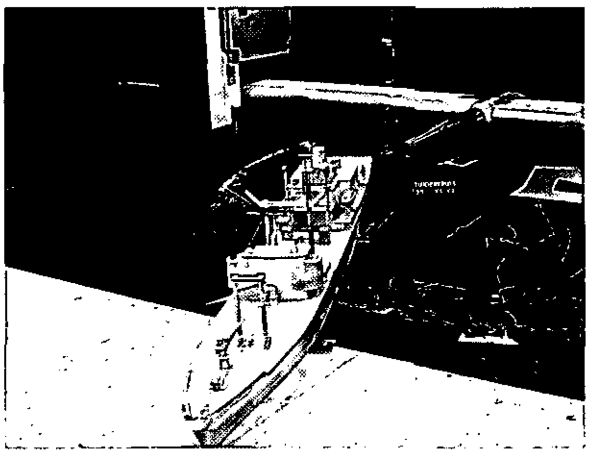
DNW has made an important step into a new market by conducting aeroacoustic tests with several testing techniques on full-scale current collectors for high-speed trains.

DNW-LST

Two major aircraft models were tested in the LST. One of them was a powered model of a propeller-driven commuter aircraft and the other the ALVAST half-span model equipped with an ultra high-bypass engine simulator (CRUF).

The test with the ALVAST model was part of a DLR/NLR research programme aimed at a better understanding of the interaction between the flow around the engine nacelle, the pylon and the wing. In addition to detailed flow field measurements with total pressure and five-hole probe rakes, the PIV system of the DLR was used to map the velocity field. The non-intrusive character of PIV allowed measurements to be taken at positions not accessible by probes.

A major part of the testing not related to aircraft development was concerned with vortex formation by wind around large buildings. Large buildings situated at or near airports may induce vortices that cause hazardous conditions during landing and take-off of aircraft. Results from detailed flow field measurements made in the LST were used as inputs for NLR's Research Flight Simulator. In this way the hazards could be assessed. An extensive investigation of the flow around wind turbine blades and studies related to helicopter flight operations on board of ships were carried out.



Scale model of the fast combat support ship HMS Zuiderkruis in the LST

DNW-NWB

In 1996 the DNW-NWB was well occupied with contract tests, most of them for the parent institute DLR. Main objectives were basic research at wing sections and new profiles as well as the effect of boundary layer suction at engine nacelles.

An important upgrade of the compressed air station was carried out with the objective to fulfil the requirements of modern TPS (Turbine Powered Simulation) testing with semi-span and full-span aircraft models.

6.3 The European Transonic Wind Tunnel (ETW)

On behalf of the Netherlands, NLR is a 7% shareholder in the European Transonic Wind Tunnel GmbH, established in 1988.

In 1996, various co-operative test programmes were executed. Besides, the first paid test was executed successfully. The agreement to extend the Initial Operation Period, allowing the available funds to be better distributed over the coming years, was prepared for signature.

ETW Supervisory Board

At the end of 1996, the membership of the Supervisory Board was as follows:

France

ICA X. Bouis, *Chairman*	(ONERA)
ICA Ph. Martelli	(DRET/SDEP)
ICA E. Lisack	(DPAC)

Germany

Dr. H. Diehl	(BMBF)
H. Max	(DLR)
Dr.-Ing. H. Körner	(DLR)

United Kingdom

Dr. G.T. Coleman	(DRA)
S.I. Charik	(DTI)
Dr. D.S. Woodward	(DRA)

The Netherlands

Ir. H.N. Wolleswinkel	(V&W)
Dr.ir. B.M. Spee	(NLR)

Managing Director Operation of ETW is Mr. T.B. Saunders. He is assisted by:

Dr. G. Hefer (G)
Manager Aerodynamics and Projects

Ir. J.C.A. van Ditshuizen (NL)
Marketing Manager

J.P. Hancy (F)
Manager Technical Operations

J.F. Moutte (F)
Administration Manager

6.4 GARTEUR

The Group for Aeronautical Research and Technology in Europe (GARTEUR) was formed in 1973 by representatives of the government departments responsible for aeronautical research in France, Germany and the United Kingdom. The Netherlands joined in 1977, Sweden in 1992 and Spain in 1996.

The aim of GARTEUR is, in the light of the needs of the European aeronautical industry, to strengthen collaboration in aeronautical research and technology between countries with major research and test capabilities and with government-funded programmes in this field.

The co-operation in GARTEUR is concentrated on pre-competitive aeronautical research. Potential research areas and subjects are identified by Groups of Responsables and investigated for collaboration feasibility by Exploratory Groups. If the subject is feasible, an Action Group is established in which parties (research establishments, industries or universities) from at least three GARTEUR countries participate.

GARTEUR provides no special funding for its activities. The participating parties provide for all costs of their part of the work.

Organization

The organizational diagram shows three levels: the Council/Executive Committee, the Groups of Responsables and the Action Groups. Via CARTE (Group for Collaboration on Aeronautical Research and Technology in Europe), Industrial Points of Contact in the Groups of Responsables and industry participation in Action Groups, GARTEUR has interfaces with the European Aerospace Industry.

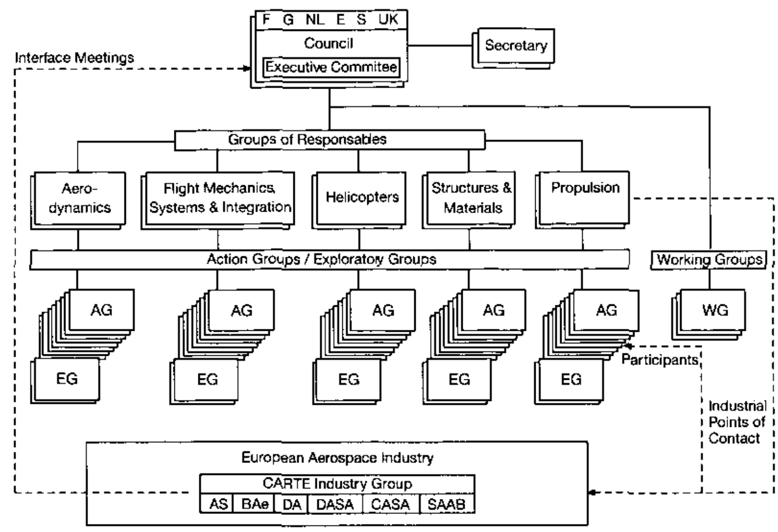
GARTEUR Council and Executive Committee

At the end of 1996 the GARTEUR Council was composed as follows.

France

IGA J. Deveaux	DRET/SDEP *
IGA J. Chéret	DRET/SDEP **)
IGA M. Scheller	ONERA
ICA E. Lisack	DGAC/DPAC
ICA J.L. Monlibert	DCAé/STPA

GARTEUR GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
FRANCE - GERMANY - THE NETHERLANDS - SPAIN - SWEDEN - UNITED KINGDOM



Organization diagram of the Group for Aeronautical Research and Technology in Europe

Germany

Dr. W. Döllinger	BMBF *)
Dr. H. Diehl	BMBF
Dr. R. Haupt	DLR **)
Prof.Dr. W. Kröll	DLR

United Kingdom

Dr. M.F. Steeden	DERA *)
S.I. Charik	DTI
Dr. G.T. Coleman	DERA **)
M.S. Markin	MOD

Spain

Dr. A. Gimenez	INTA *
G. Moreno Labata	INTA **)

Sweden

MGen L.B. Persson	FFA *)
A. Gustafsson	FFA **)
Ch. Heinegard	Nutek
BGen P. Lundberg	FMV

The Netherlands

J. van Houwelingen	NLR *)
Prof.ir. J.W. Slooff	NLR **)
Dr.ir. B.M. Spee	NLR

*) Head of Delegation
**) Member of the Executive Committee

From 1996, Sweden provides the chairman for the GARTEUR Council and the chairman for the Executive Committee as well as the Secretary. These positions will be held for a period of two years. The persons involved are:

MGen L.B. Persson
Council chairman

A. Gustafsson
Executive Committee chairman

K.A. Jonasson
Secretary

Strategy

The Council in its meeting on 23 October 1996 decided to organize a Task Force in order to prepare and propose a co-ordinated approach for European aeronautical research and technology development.

On 16 December 1996, this Task Force held its first meeting. Drs. A. de Graaff represents the Netherlands in the Task Force; Dr. G. Coleman (UK) was elected Chairman and Mr. A. Gustafsson (Sweden) Secretary.

NLR Participation

NLR participates in all five Groups of Responsables.

At the end of 1996, twenty Action Groups were active; NLR participates in eighteen of these Action Groups.

6.5 Co-operation with European Research Establishments in Aeronautics

DLR/NLR Partnership

Background

A formal partnership agreement between DLR and NLR is in force since 1994. This partnership is based on the good experience obtained with the co-operation within the German-Dutch Wind Tunnel (DNW). The aim of the partnership is to strengthen the ties between the two establishments in order to make more effective use of the extensive knowledge and facilities available.

In order to guide and control this task, a Joint Executive Board was set up, consisting of representatives of DLR and NLR. The chairmanship rotates annually.

DLR/NLR Executive Board at the End of 1996:

J. van Houwelingen (*chairman*)	NLR
Prof. W. Kröll (*vice-chairman*)	DLR
Dr.ir. B.M. Spee	NLR
Prof.Dr. A. Bachem	DLR

The Board was assisted by Dr.K.H. Kreuzberg (DLR) and Drs. A. de Graaff (NLR).

A Programme Committee, in which both DLR and NLR were represented, was active.

The Programme Committee at the End of 1996:

Dr.-Ing. H. Körner (*chairman*)	DLR
Prof.ir. F.J. Abbink	DLR
Dr. G. Bartelds	NLR
Prof.ir. J.W. Slooff	NLR

Facilities

The partners stimulate joint operation and use of existing research facilities. Furthermore, the partners exchange information on planned investments and where possible embark on joint or complementary investments. Potential facilities for co-operation are flight simulation equipment and wind tunnels. A working group provided a report on the proposal to incorporate all of NLR's and DLR's aeronautical wind tunnels in DNW. During a meeting of the joint Executive Board on 15 January 1997, a provisional agreement was reached. The incorporation is expected to become effective as of 1 July 1997.

Basic Research

The partners continued strengthening their collaborative efforts with respect to a number of basic research topics, such as aerodynamics (propulsion/airframe integration, computational fluid dynamics), structures, and simulation. The co-operation complements the co-operation within GARTEUR and often provides the nucleus for proposals for research projects under the Framework Programme of the European Union and the co-operation in the Western European Armament Group.

AEREA: Association of European Research Establishments in Aeronautics

Supported by the Commission of the European Communities (CEC), the seven European aeronautical research establishments have developed a joint view on future co-operation. The aim of this co-operation is to create the effective and efficient aeronautical technology base needed in Europe. On 11 October 1994 the research establishments formed an Association, in order to realize the first steps in a process which ultimately should lead to setting up a Union between regional centres. In the Union, strong organizational ties should exist resulting in integrated management of joint activities, pooling of facilities and the creation of interdepencies and specialisation.

The parties within the Association realize that the speed and outcome of this federative process will be highly dependant on the developments within the markets and the environment of the research establishments. Therefore, in 1994 the Association started a modest action plan comprising facilities, basic research, acquisition and personnel exchange. The following phase is planned for 1998.

Organization

The Heads of Establishment Board is the highest body within the Association. At the end of 1996 the Heads of Establishment Board consisted of:

Prof. W. Kröll, *Chairman*	(DLR)
Dr. M.F. Steeden	(DERA)
M. Scheller	(ONERA)
Prof. Dr. C. Golia	(CIRA)
J. van Houwelingen	(NLR)
B.Gen. H. Dellner	(FFA)
Dr. A. Giménez	(INTA)

The Heads of Establishment Board is assisted by a Strategy and Co-ordination Group, chaired by Dr. G. Russo (CIRA), and of which Drs. A. de Graaff is the secretary.

Facilities

The Associates have established a policy of co-ordinated use of and investment in large facilities. This should result in a rational utilization of existing and future facilities for common European needs. A Facilities Committee prepares this common policy. Prof. Slooff represents NLR in the Facilities Committee.

In the Subcommittee on Wind Tunnel Facilities, Prof. Slooff and Drs. De Graaff took part. This Subcommittee recommended actions to introduce measures to increase cost efficiency in the operation of wind tunnels by pooling resources including test rigs and equipment. Furthermore the topic of rationalization of the European wind tunnel capabilities was addressed. A working group on High Performance Computing Networks developed a proposal for a European supercomputing centre and proposals for standardisation of software to facilitate co-operation. Mr. Posthuma de Boer represented NLR in this group. A new activity aimed at combining capabilities of the workshops of the research establishments was started, with Mr. Van Twisk of NLR participating. Furthermore, Mr. Offerman of NLR joined a group aimed at pooling flight simulation facilities. AEREA also contributed to the establishment of an aeroacoustics network in Europe. Dr. Brouwer represented NLR in this activity.

Other ad hoc subcommittees have prepared overviews of existing simulator facilities, research aircraft, etc.

Research

A Programme Committee has to propose and manage strategic multidisciplinary programmes. Prof. Slooff represents NLR in this Committee. Several proposals were developed, which will be submitted for the last call for tenders of the BRITE / EURAM programme within the EU's Fourth Framework Programme. Topics concern SST and noise research. Furthermore, the Committee developed a programme for joint testing in the European Transonic Wind Tunnel and initiated projects on smart structures, emissions and joint development of measuring techniques.

Personnel Exchange

Personnel exchange will stimulate the creation of interdependence amongst the Associates and create the right European spirit amongst the establishments. The Board decided to take a pragmatic approach towards personnel exchange and to handle initiatives on a case-by-case basis.

Relations to the Commission of the European Communities

Since 1989, the aeronautical research establishments have worked together in the Aeronautical Research Group (ARG) to facilitate the communication with the Commission of the European Communities (CEC) and industry and the information exchange amongst the establishments on CEC-related issues. The ARG, chaired by Drs. A. de Graaff (NLR), is part of AEREA. Besides exchanging information and preparing project proposals for calls for tenders, the ARG prepared a note of the AEREA views on the next Framework Programme. A long term technology programme, prepared by ARG and the Programme Committee, was added. These documents were submitted by AEREA to the Commission at the end of 1996.

6.6 Co-operation with Indonesia

Introduction

From 1981 until 1991 a Technical Assistance Project (TTA-79) was active between Indonesia and the Netherlands. This project has been followed from 1992 by an interim programme for education, research and technology (APERT), originally scheduled for the period 1992–1995, later extended as APERT 95 for the period 1995–1997.

APERT 95

The main objective of the programme is the continuation, if possible extension of the long standing co-operation between Indonesia and the Netherlands. The participants on the Indonesian side are BPPT (Agency for the Assessment and Application of Technology), IPTN (Indonesian Aircraft Industry) and ITB (Institute Technology Bandung). The Netherlands' participants are NLR, the Delft University of Technology and URENCO/Aerospace (Fokker withdrew after its bankruptcy).

Organization

Within APERT 95 a governing group has been established, constituted as follows:

Indonesia

Prof.dr.ir. H. Djojodihardjo	(BPPT)
Dr. Said Jenie	(IPTN)
Prof.dr.ir. Sularso	(ITB)
Dr.ir. S. Kamil	

Project co-ordinator:
Ir. R. Mangkoesoebroto (IPTN)

The Netherlands

J. van Houwelingen	(NLR)
Dr.ir. B.M. Spee	(NLR)
Prof.ir. J.L.van Ingen	(DUT)

Project co-ordinator:
Ir. L. Sombroek (NLR)

On 2 July 1996 the governing group met for a plenary programme meeting in Jakarta.

Programme

APERT covers three areas, viz:

I Education. The main objective is to continue the co-operation between DUT and ITB.

II Laboratory Development. The main objective is to further improve the aerospace research capabilities and facilities in Indonesia.

III Joint Research. The main objectives are to increase the number of joint research subjects and to increase the number of participating institutes and industries.

The programme of APERT for the year 1997 has been drafted. Pending the agreement for that programme, the activities started in 1995 and 1996, are continued.

Other Activities

Apart from the Apert Programme, NLR has a co-operation agreement with IPTN on fatigue load monitoring of the CN235 aircraft under operational circumstances.

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Capita Selecta

Development and Testing in the DNW of a Powered NH90 Helicopter Model

NLR has carried out tests on a powered model of the NH Industries NH90 helicopter in the open-jet section of the German-Dutch Wind Tunnel. The model, equipped with a dynamically scaled 4.2-m diameter rotor and an engine simulation system, was developed by NLR. The tests provided data on engine-air intake and exhaust-gas characteristics and on the infrared signature during a range of flight conditions.

Introduction

The NH90 helicopter is being developed in a co-operative programme by four European nations: France, Germany, Italy and the Netherlands. During the Design & Development Phase of the NH90 programme, wind tunnel tests are carried out on scale models to determine the aerodynamic behaviour of the vehicle.

One of NLR's major contributions to the programme is the development of wind tunnel models and the execution of tests. Progress to date includes nine test campaigns performed with a 1:10-scale fuselage model, one test campaign with a 1:4-scale partial model with a powered tail rotor (both in the Low Speed Wind Tunnel now named DNW-LST at NLR Noordoostpolder) and two test campaigns with a 1:4-scale powered main rotor model in the Large Low Speed Facility of the German-Dutch Wind Tunnel (the original DNW at NLR Noordoostpolder now named DNW-LLF). The second test campaign in the DNW-LLF was successfully performed in December 1996 with a model completely designed and manufactured at NLR. It featured a powered main rotor system and a fuselage with engine air intake and hot exhaust gas simulation. While subsystems such as these have been tested in wind tunnels previously, their concurrent application to a large helicopter model has not been reported before.

The experiment has addressed engine air intake conditions, exhaust gas recirculation effects and infrared signatures in a wide range of test conditions. The main rotor system acted as a representative downwash generator, distorting engine intake and exhaust flow. To investigate the helicopter behaviour in flight, especially the longitudinal stability, stabilizer deflection tests were performed.

NH90, Helicopter of the Third Millennium

Studies conducted by NATO Industrial Advisory Group SG14 in the early 1980s are the conceptual origin of the NH90 programme. A Memorandum of Understanding for the full development was signed in December 1990 by France, Italy, Germany and the Netherlands. In February 1992, the four participating governments constituted an international programme office, the NATO Helicopter Management Agency (NAHEMA). The four companies sharing the Design and Development of the NH90 Programme (Agusta, Eurocopter Deutschland, Eurocopter France and Fokker Aerostructures) signed an Intercompany Agreement in March 1992 and established a joint venture, the company NHIndustries, to ensure international industrial programme management. The Dutch industrial participation is shared between Fokker Aerostructures, SP Aerospace and Vehicle Systems (formerly named DAF SP) and the National Aerospace Laboratory NLR.

The NH90 will be an integrated weapon system. Two versions are being developed, the Tactical Transport Helicopter (TTH) and the NATO Frigate Helicopter (NFH). The TTH is primarily intended for tactical transport of personnel (14-20 troops) and materiel (more than 2500 kg of cargo), heliborne operations and Search and Rescue. This version will be optimized for low acoustic, radar and infrared signatures and equipped with a night vision system including Tactical Forward Looking Infra Red, Night Vision Goggles, Helmet Mounted Sight & Display; an Obstacle Warning System; a defensive weapons suite; and passive and active measures against threats. The TTH is designed for high manoeuvrability in *Nap of the Earth* operations. Because of these features and systems integration, it will be capable of operating successfully by day and night and in adverse weather conditions in any environment.
The NATO Frigate Helicopter (NFH), the naval NH90 version, is primarily intended for autonomous Anti-Submarine Warfare and Anti Surface

Unit Warfare missions. It is designed to be capable of being used also in day and night operations, and for launch and recovery from small vessels in extremely adverse weather conditions, during severe ship motions. Equipped with a basic and mission avionics system, the NFH version will be capable of performing missions autonomously, with a crew of three.

Fig. 1 - Prototype of the NH90

The NH90, a twin engine helicopter in the 9-ton class, will be characterized by a wide use of composite materials, a high level of system integration and modularity, an advanced aerodynamic design, a low detectability, an optimized man-machine interface minimising the crew workload, a high level of safety and overall crashworthiness.

At the start of the Design and Development Phase, the estimated requirements of the four navies (of France, Italy, Germany, and the Netherlands), of the three armies (of France, Italy and Germany) and the German Air Force amounted to 726 aircraft; 544 in the Tactical Transport version (TTH) and 182 in the Naval version (NFH). The industrial shares in the design and development phase are proportional to the national requirements – Eurocopter France (ECF): 42.4%, Agusta: 26.9%, Eurocopter Deutschland (ECD): 24.0% and Fokker: 6.7%.

The first of five prototypes made its public debut on 15 February 1996 at Eurocopter France's facility in Marignane, France. Prototype 1, shown in Figure 1, successfully accumulated 75 flying hours in 1996. It has the basic airframe design, based on laboratory and wind tunnel tests and evaluations carried out to reduce development risks.

Project Organization and Progression

NLR contributes to the NH90 design and development as a partner in the Netherlands industrial share. To ensure that the Quality Assurance requirements of AQAP-110, the military equivalent of ISO 9001, are fulfilled, a dedicated NLR NH90 Quality Assurance Plan and a Wind Tunnel Project Plan have been drafted. The project plan contains a description of the activities to be performed, and of the specific procedures and references to general NLR quality assurance procedures to be applied. The project plan contains the requirements applicable to the work to be performed, work package descriptions, a global project planning, cost information and a description of the project organization.

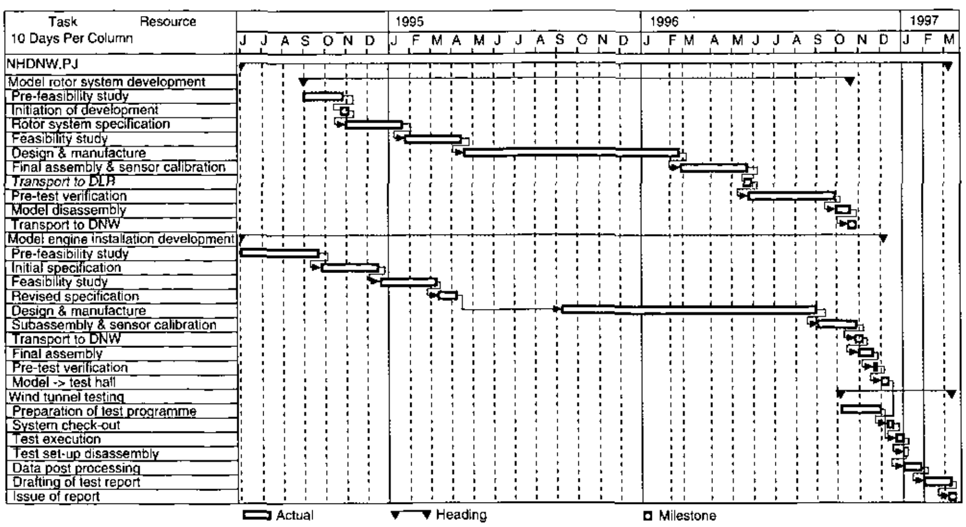


Fig. 2 - Project planning

The management of the NH90 wind tunnel project at NLR is the responsibility of the Helicopter Department (VH). The development of the model rotor system, model engine installation and execution of the wind tunnel test campaign were defined as dedicated sub-projects. Because of the multidisciplinary character of the work involved, a large number of NLR departments and personnel contributed to the project. Table 1 lists the major activities of the departments having a direct involvement.

Department	Activity
Aerodynamic Facilities (AF)	-sensor wiring -calibration of rotor sensors -control of IR camera
Unsteady Aerodynamics & Aeroelasticity (AE)	-shake testing
Experimental Aerodynamics (AX)	-test execution engineering -review of engine installation data
Theoretical Aerodynamics (AT)	-analysis of rotor functional test results
Helicopter Department (VH)	-project management -model design requirements -ground resonance analysis -rotor characteristics
Loads (SB)	-prediction of rotor blade natural frequencies
Structures (SC)	-test set-up FEM
Testing Facilities (SL)	-blade manufacture
Technical design (TO)	-model design
Technical Projects (TP)	-coordination of model development -blade design -strain gauge instrumentation
Workshops(TW)	-model manufacture -model instrumentation -model assembly
Laboratories and Thermal Control (RL)	-thermal radiation analysis
Electronics (EE)	-development of printed circuit boards -development of temperature sensor

Table 1 - Departments involved and their activities in the NH90 wind tunnel project

Approximately 80 NLR employees were involved in the main rotor system development, 45 in the engine installation development and 15 in the test preparation and execution.

Figure 3 indicates the number of employees grouped according to the time they spent in the three sub-projects main rotor development, engine installation development and wind tunnel testing. Figure 4 shows the relative contributions of the NLR divisions in the three sub-projects.

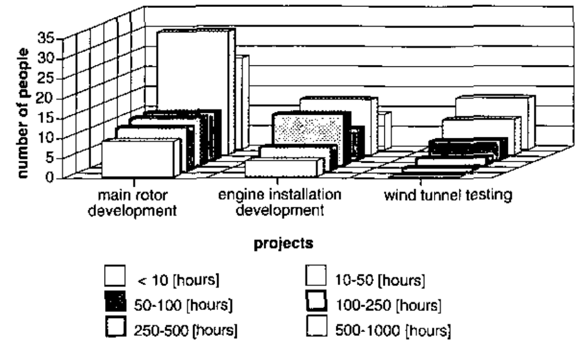


Fig. 3 - Involvement of NLR staff in the three major sub-projects

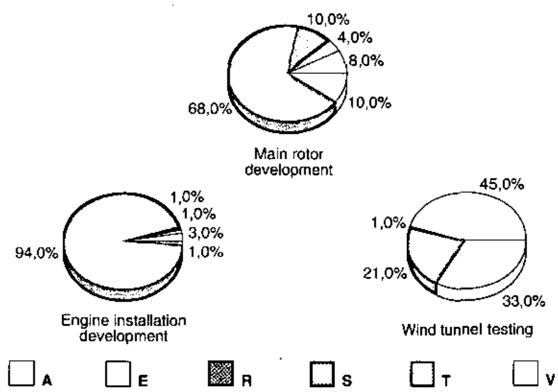


Fig. 4 - Relative contributions of the NLR divisions in the three sub-projects

In the NH90 wind tunnel test project, specific wind tunnel models are used in a series of test campaigns. NLR is responsible for the main part of the NH90 wind tunnel test activities. ECD provides a rotor drive system for testing in the DNW-LLF, and ECF is responsible for the test activities related to engine installation topics. Agusta leads the system engineering activity 'aerodynamics', to which all partners contribute, and which basically steers the wind tunnel test activities. In meetings held at regular intervals, representatives of the partner companies assess test requirements, initiate specific wind tunnel test campaigns and discuss results of previous test. Then, NLR transforms the test requirements into detailed wind tunnel model definitions and a preliminary test plan, which contains an overall description of the test campaign to be performed, including model and sensor definition, data acquisition and processing, data presentation and test matrix. When the test plan and model definition have been finalized, the preparation of the test campaign, which may include adaptation of model hardware or design and manufacture of new components, is started.

The first test programme carried out in the DNW-LLF concerned an experiment on a fuselage model of the NH90 helicopter equipped with a powered main rotor that was driven by the Modular Wind Tunnel Model (MWM), a rotor test rig of the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR). The blades of this rotor resembled the NH90 blades as to planform and sectional profiles, but their weight was about double the scaled value. The hub as a consequence was much more massive and voluminous than a geometrically scaled down NH90 hub. Since the emphasis of the first test in the DNW-LLF was on the assessment of the aerodynamic interaction with the downwash field of the main rotor, these differences were quite acceptable.

In November 1994, after a series of meetings and detailed analysis of the first NH90 DNW-LLF test results, the partners decided to launch the development of a geometrically and dynamically scaled NH90 model rotor system to represent the rotor system high speed behaviour accurately. To ensure representative rotor system wakes and related drag characteristics of the full-scale NH90 aircraft, the model rotor hub contour must follow the full-scale hub geometry closely.

The model design criteria, the requirements for the model sensors and the development approach were determined first. This information was laid down in a model design requirement document and an accompanying statement of work. This common activity was followed by issuing a Request For Proposal to potential model rotor suppliers, which included NLR. To demonstrate its capabilities in the area of model rotor blade development, new for NLR, a feasibility study was launched.

A review of the proposals received and of the results of the internal feasibility study led to the decision to launch the model rotor development at NLR. Preliminary rotor design loads provided by the NH90 partners were transposed to rotor component level, to be used as starting points for detailed stress analyses of the affected model components. Design requirements for elastomeric rotor bearings and lead-lag dampers were assessed for application by Lord S.A., which was granted a subcontract for the delivery of these very special components. A detailed design for the rotor system was made, and was reviewed by the NH90 partners. After the summer of 1995, the first model components were taken into production. As part of the model development, a dedicated blade angle measurement system had to be realized. The design driver for the blades of the rotor model was the matching of the natural frequencies. The blade development was characterized by an iterative approach. Calculated mass and stiffness distributions were converted to a blade core material lay-up. A sample blade was manufactured and its clamped-in natural frequencies were determined experimentally. The structural properties of the blade were adapted, and a second development loop was entered. This process was repeated until the blade characteristics complied with the requirements. Then the actual production of the blade set was carried out. The structural integrity of the blades was proved by a series of experimental verification tests, such as blade attachment pull test.

After the assembly of the model rotor system, including sensor wiring and routing, the sensors were calibrated in their intended use range. As part of the design substantiation, the susceptibility of the test set up to ground resonance was investigated too. For this purpose a mathematical ground resonance model was implemented.

In June 1996 the model rotor system was shipped to DLR Braunschweig, to check out the rotor system before testing in the DNW-LLF. The rotor was installed on the rotor drive system. Calibration data provided by NLR were checked and fed into the DLR's data acquisition and processing equipment. Hover tests were performed to verify the rotor behaviour.

In the first quarter of 1995, on request of ECF, preliminary studies were carried out by NLR to demonstrate the feasibility of an engine installation model development for integration in the DNW-LLF model. Based on the outcome of this study, ECF, responsible for engine installation tests, granted NLR an additional contract to develop engine installation model hardware. In September 1995 predesign activities were started, although there was some uncertainty about the final definition of the air intake lay-out to be applied on the wind tunnel model. NLR therefore scheduled the design activities such that potential intake modifications under study at ECF could be taken into account in a later stage. In order not to jeopardize progress on the model development, it was agreed to proceed with activities not affected by the potential intake modifications. Dedicated development work for the model support and exhaust gas burner system, including an angle-of-attack mechanism, was subcontracted to DNW. By the end of May 1996, the air intake configuration to be applied in the engine installation model was defined, and the remaining design activities were started. For the design of the complete engine installation set-up, the Computer Aided Design tool CATIA was used. ECF provided CATIA models of the actual engine installation that were used as the basis for the model design. Because of the complex nature of the test equipment and potential risks during operation, a structured approach was applied to identify hazardous failure modes, to reduce the risks to an acceptable level and to guarantee safe model operation during the execution of the wind tunnel test. This safety approach included the assessment, analysis and categorization of all significant functional failure conditions and their effects on the test set-up. This function-oriented analysis has been systematically applied to all subsystems. Issues such as structural integrity of mechanical parts, environmental conditions, human error by operators and fire have been considered. Each potential failure mode has been classified according to its severity. Next, the measures were defined to eliminate the hazards as far as practicable.

In the summer of 1996 the manufacturing of engine installation components was started, followed by sensor development, integration and calibration activities. Subassemblies were made for most of the model components. Final assembly work started mid-October 1996 at DNW, in parallel to the model support assembly. The model rotor and drive system MWM (Modular Wind Tunnel Model) in the meantime were shipped by DLR to NLR. The MWM and the engine air intake and exhaust subassemblies were mounted to the sting attachment, and placed on the model support. After successful completion of engine burner tests, heat insulation material was added to the hot model components.

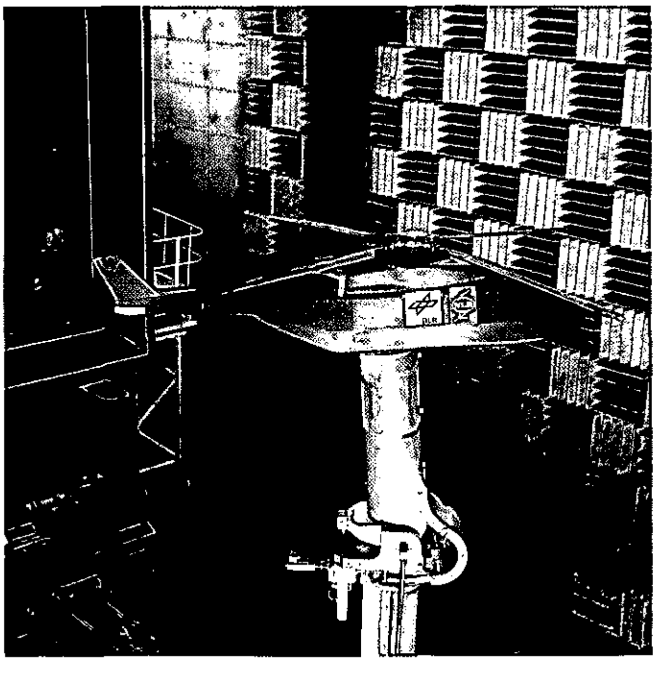


Fig. 5 - NH90 model mounted in DNW-LLF open-jet test section

In the first week of December the model test set-up was moved to the open test section of the DNW-LLF. The supply systems (hydraulic for the rotor drive, air suction for the intake, propane gas and air for the burner etc.) were connected. After a check-out of the model sensors and independent systems, the tracking of the rotor blades was verified by means of a stroboscopic light. Infrared camera systems of NLR and ECD were installed for the measurement of the exhaust gas temperatures. Wind tunnel production runs were performed during a period of ten days, following a detailed test programme established by NLR. During these tests, representatives of the partner companies were present for on-line analysis of test results and guiding of the test programme, based on results gathered. Data postprocessing and storage were performed by DNW (data related to the engine installation), DLR (data related to the rotor system) and NLR/ECD (infrared data). Final results were laid down in a test report written by NLR.

Description of the Model

The model test set-up consisted of three major subsystems:

- rotor test rig MWM of DLR, main rotor hub and blades;
- fuselage, horizontal tail surface and vertical fin;
- engine air intake and engine exhaust subsystems.

The hub utilizes spherical elastomeric bearings which allow the blades to pitch, lead-lag and flap. It accommodates the structural deflections due to the centrifugal force, while reacting to pitch control forces.
The bearings are composed of an inner structural member, an outer structural member, and a spherical elastomer/shim package made of alternating layers of metal shims and layers of elastomeric materials.
The inner member attaches to the rotor hub, the outer member to the sleeve. The outer member transmits loads and moments to the elastomeric/shim package. The elastomeric/shim package accommodates the cocking motions (due to flap and lead-lag) and the torsional motions (due to pitch change) in shear of the elastomer, while supporting the centrifugal force and lift loads in compression. The inner member transmits the resulting loads and moments to the rotor hub.
The spring rates of the bearing are based primarily on the stiffness and deflection of the elastomeric layers. The elastomeric material provides inherent damping due to hysteresis and allows minimal visual, on-condition inspection during the service life.

Elastomeric inter-blade dampers, located between two sleeves, have been included in the hub design. The dampers are equipped with ball bearings at both ends, to provide a rotation capability. The dampers provide lead-lag damping to the rotor system, which is necessary to control the rotor system resonance.

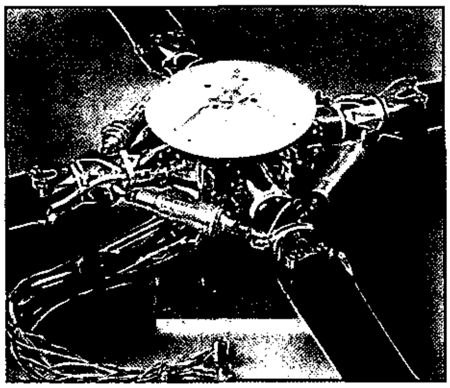


Fig. 6 - Main rotor hub of the model

Mechanical stops have been included in the design to limit damper compression deflection.

The elastomeric dampers have two functioning elastomeric elements. The first element provides a spring force, with very little damping effect. The second element provides damping. The amount of hysteresis damping in the elastomeric part is a physical property of the basic polymer and the compounding ingredients.

The sleeve attaches the rotor blade to the rotor hub. It also provides attachments for the pitch lever and flapping stops that limit the blade angles. The upper flap stop consists of a bronze stop block fitted into the inboard end of the sleeve. The lower stop is a ring mounted on top of the scissor attachment that support the blades (via fixed stops installed on the sleeve) when in rest.

The rotor torque is transmitted to the rotor drive system MWM via the rotor mast, by bushings. Rotor hub and mast can be separated at the flange. Rotor lift and moment are transmitted to the shaft by the flange bolts. The mast is hollow to allow for internal routing of the instrumentation cables.

The rotor blades are constructed of a D-spar wrapped with sixteen layers of uni-directional graphite epoxy material and a foam trailing edge core covered with two layers of aramid epoxy fabric material. Between the carbon fibres and the reinforced plastic skins is an adhesive film. Airfoils of the OA Series are applied, with linear transition between the various airfoil sections. The blade tip shape is parabolic with anhedral. The blades have a cavity at the blade tip for balancing, tungsten leading edge balance weights and a brass trailing edge trim tab. The blade root is composed of carbon fibre fabric reinforcements, with an incremental number of layers towards the blade attachment area. A more elaborate description of the blade development is given below.

Rotor control is supplied by a typical swashplate configuration, driven by three actuators of the MWM. The interface between sleeves and swashplate consists of a set of pitch links. Two pitch links are instrumented with piezo-electric transducers. All four pitch links have been made identical in shape and mass by adding dummy transducers to the two uninstrumented pitch links. The pitch links are interfaced both to the sleeve, by the pitch horn, and to the rotating star of the swash plate by means of off-the-shelf rod ends. The pitch link length can be adjusted to set the blade incidence during tracking of the rotor system. The swash plate allows the collective and cyclic pitch motion to be transferred from the fixed axes to the rotating axes. The fixed and rotating stars transmit the loads from the servo controls to the pitch links. Collective pitch movements can be applied by sliding the central swashplate spherical joint, while cyclic pitch is given through a swash plate tilt by means of the spherical joint.
A scissor assembly interfaces the rotor mast and *rotating star of the swash plate system.*

The rotor blades are equipped with 'safety-of-flight' strain gauge bridges in the blade root area. Two opposite blades are equipped with additional strain gauge bridges for the measurement of flapwise, chordwise and torsional bendings at four positions along the blades. The strain gauge *bridges are installed on the D-spar core of the* rotor blades. Strain gauge instrumentation wires run along the upper face of the D-spar core. This provides clean blade aerodynamics and long gauge lives.

A novel flexure system has been developed, and installed in the blade sleeve, to measure the blade pitch, flap and lead-lag angles. The electronic component used to measure blade pitch is a resolver. Strain gauges are used to measure blade flapping and lead-lag. Two sets of instrumentation are located at opposite blades. This provides a redundant backup system as well as ensuring rotational balance. The elastomeric bearings and dampers are equipped with thermo-couples to monitor heating during rotor operation.

Instrumentation wiring is plugged onto a dedicated printed circuit board (PCB), which is mounted inside the rotor beanie. This PCB is the front-end of the DLR data acquisition system (PCM unit). It provides:
- voltage excitation for the blade strain gauges,
- current excitation for the bearing and damper temperature sensors,
- rotor excitation for the blade pitch resolvers,
- resolver-to-digital conversion followed by digital-to-analog conversion.

The PCB is powered by an external ± 15 Volt DC power supply. All signals leads are coupled to the PCB by microminiature D connectors.

The rotor is driven by the rotor test rig MWM, operated by a crew of the Flight Mechanics Department of the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR). The MWM drives the rotor system with a hydraulic motor, which is connected to the drive shaft through an intermediate gearbox. Setting of the rotor blades is controlled via a swashplate through which *both the collective and the cyclic pitch of the* blades can be set. Loads generated by the rotating rotor are measured by means of a built-in balance system, composed of six strain gauge load transducers. Remote control of both the speed of the rotor and the settings of the swashplate enable the required model load conditions to be achieved.

A light-weight, but stiff glass fibre fuselage was mounted to the MWM structure. It consists of a nose section (with partly retracted nose wheel and closed wheel bay cavity), a centre section (cabin), engine cowlings and a tail section. Because the sense of rotation of the main rotor is reversed as compared to the actual NH90 main rotor, the aft part of the tail boom and the vertical fin are mirrored images of the actual fuselage. For the same reason the tail rotor gearbox fairing, the simplified tail rotor hub and the horizontal stabilizer were mirror imaged with respect to the fuselage longitudinal plane.

The fuselage is built up as a modular structure to facilitate its handling, both during testing in the wind tunnel and during transport. The fuselage was equipped with 76 thermocouples to measure the temperature of the circulating air.

The engine installation model hardware has been integrated in the fuselage hull. It contains engine air intake and exhaust modules with both external and internal geometries to scale, capable of simulating representative engine intake and exhaust gas flow conditions (for both the left and right hand side engines), and a wind tunnel model support system which allows tests to be carried out under a wide range of lateral wind conditions. The model hardware is equipped with instrumentation to monitor and record test parameters.
The air intake subsystem consists of the intake opening recess (intake plate), a caisson air intake, a bellmouth with a screen and the engine duct. The compressor entry has an adapted cross section area to obtain the scaled mass flow capability. The exhaust subsystem consists of a plenum settling chamber connected to the hot air supply pipe, a perforated stainless steel plate located between the nozzle and settling chamber, which reduces the pressure from 6.5 to 1 bar, and a stainless steel nozzle.
Thermocouples were applied in the air intake, providing a very rapid response and accurate absolute temperature data. They were calibrated in combination with the data acquisition system used during actual testing, which enhanced the absolute temperature recording capacity. The PT100 thermocouples were calibrated in a bath filled with special calibration fluid between -10°C and +100°C. A highly accurate certified PT100 sensor was used as a reference. A dedicated calibration curve was determined for each thermocouple.
Data on flow direction and velocity inside the engine air intake was obtained using six five-hole probes. To achieve the required accuracy in flow angle and speed, these probes were calibrated at speeds ranging from 100 to 140 m/s. This calibration was performed at the required wind speed in the pilot tunnel PLST which has the same geometry, on scale 1:10, as the DNW-LLF.

The model was mounted on the so-called DNW-LLF common support system, which allows for a wide range of crosswind conditions (270°) and a limited angle of attack range (±10°). The model support basically consisted of the DNW-LLF open jet common support housing structure, a vertical mast, an angle of attack hinge joint and a vertical sting. The MWM mounting adaptor interfaced the support system to the MWM rotor drive system. The vacuum duct connected the intakes to a vacuum pump located in the test hall. Pressurized air was supplied by an air supply system, transferred through flexible hoses to the air heating system located above the hinge joint. The central component of the air heating system is the burner can, in which propane gas is burned to heat the pressurized air to 500°C. The fuel controller is located inside the common support housing. All supply pipes, including MWM hydraulic lines and measuring cables are routed along the vertical strut and covered with a cylindrical fairing between the fuselage model and the hinge joint.

Specific Development Activities

The development of the 1:3.881-scale model has included activities specific to helicopter models:

- development of the model rotor blades, of which the mass and stiffness distributions closely match those of the full-scale blade;
- development of the blade angle measurement system, which is integrated in the sleeve and insensitive to any blade translation introduced by the elasticity of the blade bearing;
- analysis of ground resonance of the test set-up.

These activities are described below.

Rotor Blade Design, Manufacture and Verification

To simulate the aerodynamic and dynamic behaviour of the NH90 rotor blades accurately in the wind tunnel, NLR developed geometrically and dynamically scaled copies of the full-scale blades. These model blades have lower natural frequencies scaled to the full-scale blades. As a consequence, the model rotor blades have been made with highly specific stiffness and mass distributions in all directions. The most important blade characteristics to be scaled are the flap and chordwise bending stiffnesses, the torsional stiffness, the mass, the mass moment of inertia, the location of the centre of gravity and the location of the shear centre.

Like the full-scale blades, the model rotor blades are made of composites. Composites such as carbon fibre reinforced plastics are especially suited for this purpose. With respect to metal and other isotropic materials they provide an additional degree of freedom in design applications. Composite blades are built up of a large number of layers. By changing the fibre direction of the layers, the stiffness in different directions can be changed without the need to change the material density, and thus the blade mass, or the blade geometry.

To achieve the correct rotor blade characteristics, the design has been supported by extensive calculations. During the iterative design process use is made of the CAD/CAM system CATIA. The dynamic behaviour has been analysed with the finite element program B-2000. With this program it is also possible to calculate the influence of the centrifugal force on the rotating natural frequencies. The stretching effect of the centrifugal force will increase certain stiffnesses and will thus result in a natural frequency that increases with increasing rotor speed.

Each blade consists of a carbon fibre reinforced nose part (D-spar) with a temperature resistant foam core, an aramid fibre reinforced trailing edge with a foam core, a tungsten bar in the leading edge and carbon reinforcements at the blade root.

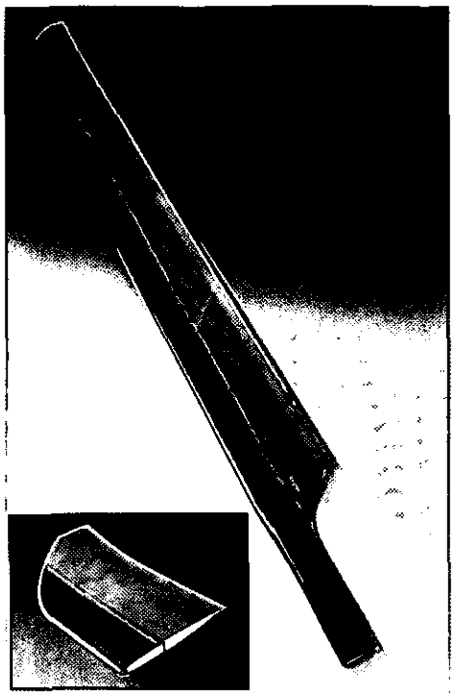


Fig. 7 - Model blade and blade tip

Prior to the blade spar manufacturing, the foam cores were numerically machined. The composite structures of the blades are manufactured in two stages. In the first stage the D-shaped nose part is manufactured, while in the second stage the rear part of the blade is made and connected to the nose part at the same time. The blades are manufactured in a mould. The resin is cured in an autoclave at a temperature of 125°C. During manufacture, detailed weight bookkeeping is applied to control the blade mass, the mass moment of inertia and the location of the centre of gravity. The rotor blades are made according to precise working instructions to ensure a constant high quality.

In total eight rotor blades have been manufactured: three preproduction/test blades, four production blades and one spare blade.

The model rotor blades have been extensively tested. The three preproduction/test blades have been used to measure and tune the natural frequencies. One test blade has been used for static pull, bending and torsion overload tests. Another test blade was cut into pieces to measure the mass of the different blade sections and the location of the centre of gravity.

The first four natural frequencies of all blades have been measured. The geometries of all production blades have been verified on a 3D co-ordinate measuring machine.

The strain gauge bridges, instrumentation for blade load measurement, were attached to the inside D-spar skin, providing an undisturbed load carrying structure and allowing the blade surfaces to be smooth. The strain gauge bridges were calibrated. For monitoring purposes during rotor operation, the inner lower surfaces of the blades, which are exposed to the hot engine exhaust gases, are covered with temperature sensitive paint that indicated rotor surface temperatures between 100°C and 140°C.

Novel Blade Angle Measurement System

A special measuring system has been developed to measure rotor blade angles with respect to the hub at the blade sleeve. The accuracy of the system was aimed at ± 0.1°, so that possible errors due to centrifugal effects and sleeve translation during rotation (due to the elastomeric properties of the bearing) had to be minimized. The system furthermore must not be sensitive to temperature changes introduced by the energy-dissipating elastomeric bearings. Moreover, the system must not change the external geometry of the hub, which would affect the flow. Two blades would have to be equipped with a measuring system.

The only available space for such a mechanism was inside the hollow blade sleeve. A feasibility study made clear that no commercially available system for measuring the three blade angles (pitch, lead-lag and flap) would fit in the available space. Only the pitch angle could be measured with a commercial resolver; for the two other angles a new system had to be developed. A system that converts exerted angles into the bending deformation of special measuring flexures was investigated. An experimental prototype was built to determine the accuracy of such a system (especially with respect to the material hysteresis of the very thin metal flexures) and to investigate some practical instrumentation problems related to the operating environment. The prototype results were sufficiently promising to start the detailed design of the actual system.

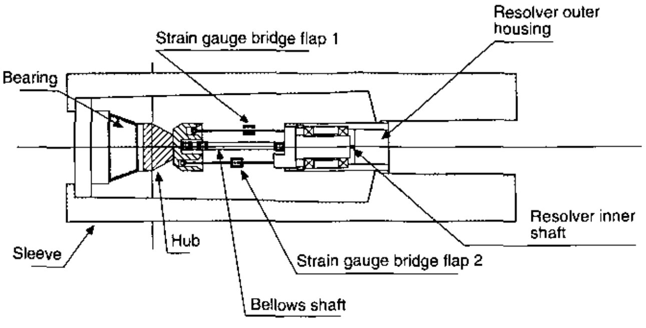


Fig. 8 - Schematic of the blade angle measurement system (lead-lag measuring flexures not drawn)

The setup of the system is shown schematically in Figure 8. Besides the resolver, the measuring system consists of four measuring flexures; two flexures for measuring the flap angle, and two for measuring the lead-lag angle. A strain gauge bridge was fixed on each flexure. The system is attached to the inner side of the sleeve. The resolver for the pitch measurement is placed most outwards; between the resolver and the measuring flexures for flap and lead-lag a bearing construction is mounted that keeps the inward part of the measuring device on zero pitch angle. The inner end of the flexures can freely slide in a part with grooves that is attached to the hub. In this way the pitch resolver follows the sleeve over all angles and the measuring flexures only over flap and lead-lag angles. Translation of the sleeve will also deform the measuring flexures. However, by making combinations of the strain gauge bridge signals from the flexures, a flap signal and a lead-lag signal were obtained that are insensitive to translation of the sleeve. The combined signals only respond to angular displacement of the sleeve. By the construction, the pitch signal is also insensitive to translations.

The strain gauge bridges are fully compensated for temperature changes. To cope with the dynamic environment, special attention was paid to the fixation of all wires. The locations of the gauges were optimized with the help of finite element calculations; the gauges were positioned at the locations which have the lowest deformation due to centrifugal inertia loads.

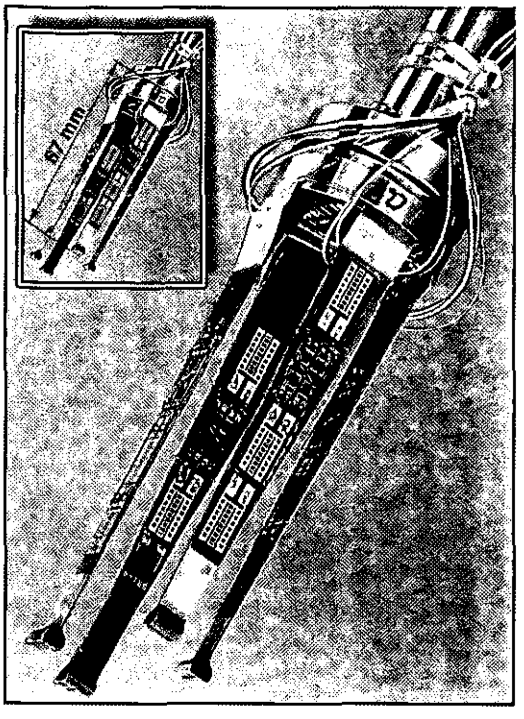


Fig. 9 - Instrumented blade measurement flexures

The measuring system has been manufactured by means of wire cutting; especially the highly vulnerable thin flexures required attention during manufacture and during gauging.

Special equipment was developed for the calibration of the system. The three measuring signals were not completely decoupled, so the system was calibrated as a three-component system, where each angle was a function of all three measuring signals, two from the measuring flexures and one from the resolver. Finally achieved accuracies were ± 0.25° for the flap angle and ± 0.10° for the lead-lag and pitch angles. The higher flap angle inaccuracy was caused by an unexpected larger material hysteresis for the flapping flexure set.

System susceptibility to sinusoidal excitation at the rotor frequency and its harmonics was verified by means of a vibration test, where the system, installed in the sleeve and attached to the hub, was exited in flap and lead-lag direction. Measurement signals were analysed and found to be not influenced by the dynamic excitation.

Ground Resonance Analysis

Ground resonance of a helicopter with a running rotor may occur as a self-excited mechanical vibration that involves a coupling between the lead-lag motion of the rotor blades and the motion of the helicopter fuselage on its landing gear. Exponential growth of the oscillation may make it almost impossible to 'arrest'. The oscillation may reach destructive proportions very rapidly without warning, in a way similar to flutter on fixed-wing aircraft.

Like actual helicopters, wind tunnel support assemblies to which a rotor model is mounted are susceptible to ground resonance. Therefore the support and the rotor blade lead-lag dampers should incorporate sufficient damping. Before actual testing in the DNW-LLF, the stability of the support assembly in conjunction with the NH90 model had to be demonstrated.

In order to be able to predict ground resonance behaviour, NLR implemented a mathematical ground resonance model. The model is based on theory developed by Coleman and contains the elastomeric damper behaviour of the NH90 helicopter rotor, which differs significantly from conventional viscous damper behaviour.

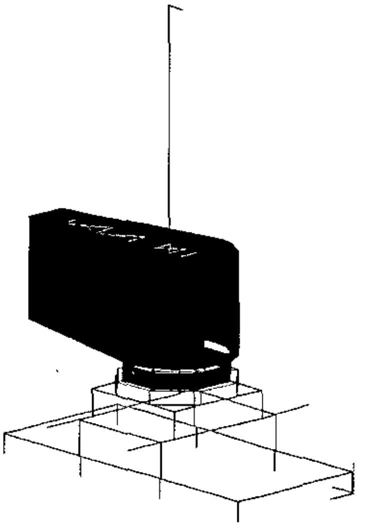


Fig. 10 - Finite element model of support assembly

NLR developed a finite element model of the support assembly (see Fig. 10). Natural frequency predictions from this model were used to perform a preliminary ground resonance analysis.

Sample results from the ground resonance analysis are presented as the real and imaginary parts of the roots in a so-called Coleman diagram (Fig. 11). The upper part shows the frequencies (imaginary parts) of the support and the rotor as functions of the rotor angular speed. The rotor speed is critical when the lead-lag rotor mode frequency coincides with one of the support assembly lateral or longitudinal frequencies. At these points the total damping should be sufficient, implying that the real part should be negative for all rotor speeds. The real parts of the roots are shown in the lower part of Figure 11.

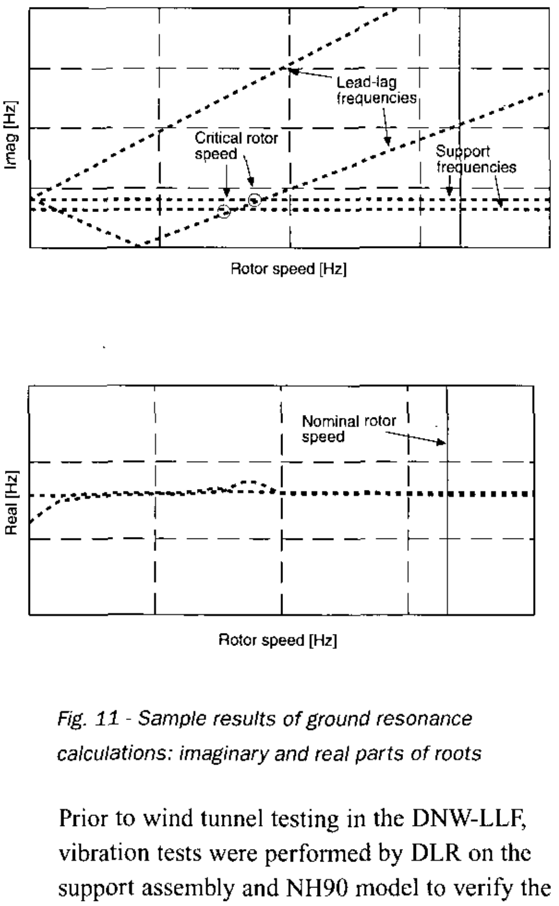


Fig. 11 - Sample results of ground resonance calculations: imaginary and real parts of roots

Prior to wind tunnel testing in the DNW-LLF, vibration tests were performed by DLR on the support assembly and NH90 model to verify the data (natural frequencies and damping) of the actual configuration and to validate the finite element predictions. These data were used by NLR for the final ground resonance analysis.

The tools for ground resonance analysis NLR developed enabled it to show that the support assembly in conjunction with the NH90 model was not susceptible to ground resonance, which was confirmed during actual testing.

Functional Tests and Preparations

After the completion of the model rotor system and engine installation development, an elaborate test preparation period, focusing on the two major model subassemblies preceded the actual wind tunnel test campaign. Dedicated rotor system functional tests were performed by the Flight Mechanics Institute of DLR at Braunschweig, Germany. During these tests, the rotor system was prepared for testing in the DNW-LLF. The performance of the rotor system was assessed, and the calibrations of the instrumentation were integrated in the DLR data acquisition system.

Engine installation functional tests were performed at DNW.

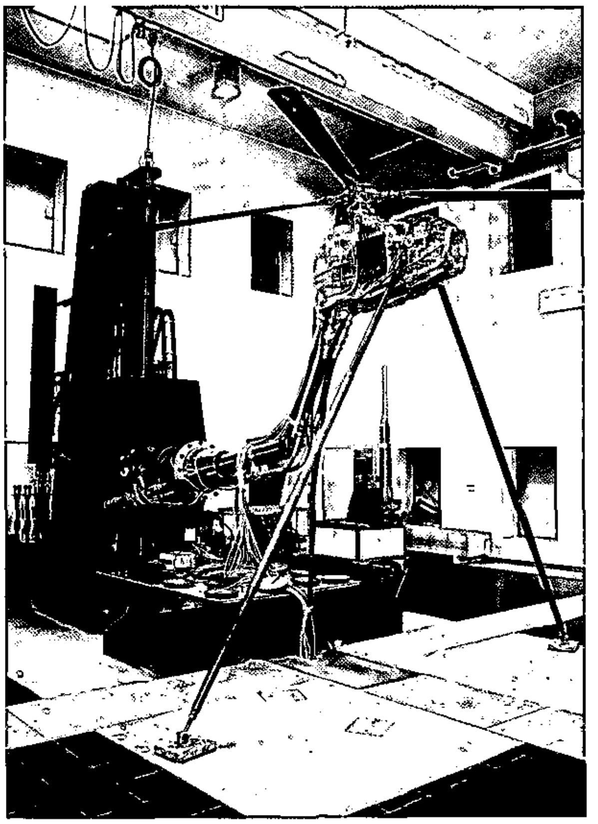


Fig. 12 - The model rotor system set up for testing at DLR Braunschweig

Rotor System Functional Testing

Before shipment of the rotor to Braunschweig, work ranging from completing the relevant documentation to wiring of the model sensors was carried out. Special attention was paid to effective routing and fastening of the sensor wires. A large number of wires from the blade strain gauges and blade angle measurement system had to cross the elastomeric bearings, and be subjected to large angular displacement during operation. Furthermore the violent operating environment (strong vibrations, circulating air and high centrifugal loads) had to be taken into consideration.

Documentation was extensive, to allow easy and safe operation by DLR. The documents that went along with the model included an elaborate description of all rotor system components, instrumentation, printed circuit board details and wiring pin allocation, a complete set of model design drawings, a model log book and an operating manual. The operating manual, laid out as a flight manual, contained a short description of the system, predicted rotor performance characteristics, operating limitations and procedures and maintenance instructions. Operating limitations were deduced from the model stress report and rotor kinematics.

After arrival at Braunschweig, the rotor was fitted to the rotor drive system MWM (Modular Wind tunnel Model) which was mounted to a dummy sting. Model sensor wiring was plugged in the DLR data acquisition system and all data streams were checked. Sensor calibration results provided by NLR were implemented in the data processing software, which now also included the influence of the DLR measuring system. A number of calibration activities were repeated for redundancy purposes. These calibrations were limited to sensor 'on-axis' excitation, without any cross coupling effects, to allow sensor read-out in case of failure of one of the other sensors. To verify controlled running down of the rotor system after a potential complete loss of the blade angle information, the kinematic characteristics of the control system were determined. Blade angles were measured for a large variety of actuator settings and stored in the control matrix. This was done experimentally, since control system kinematics are non-linear and difficult to be predicted accurately. Relevant model rotor operating limitations were implemented in the on-line monitoring system.

When these data acquisition activities were finalized, the test set-up was equipped with a number of accelerometers to perform rotor rotating balancing. On 17 September, the first test with running rotor (without rotor blades) up to the design rpm of 1000 was performed. High model manufacturing accuracy and special attention paid to model symmetry made balancing superfluous. Rotor vibrations caused by weight unbalance stayed well below the boundary value of 0.1 g. The next day the rotor blades were mounted and the rotor system was operational for the first time. The rotor thrust level was increased (at nominal rpm and no wind) up to 50%. Blade tracking was checked by a strobe light, and appeared acceptable for the time being. It was decided to postpone blade track refinement to actual testing in the DNW-LLF. Two provisions were built into the model to track individual blades: small blade chord extensions, so-called tabs, capable of being bent to change local lift characteristics and adaptable pitch link length to change the individual blade collective pitch. Rotor testing was resumed by correlating lateral and longitudinal control inputs to rotor bending moment read-outs of both the shaft gauges and rotor balance. The rotor operation time accumulated during these functional tests was almost five hours.

After completion of the functional tests early November, the rotor drive system and rotor hub were shipped to DNW to be integrated with the engine installation hardware and fuselage hull.

Engine Installation and Test Set-up Preparation

The air suction system was laid out to provide the mass flow required for the simulation of the air intake flow. In a early stage of the development phase, the required capacity of the air suction system was predicted by calculations of the expected pressure losses in the intake and air suction pipes. As soon as the model air intake was manufactured, a function test was performed to validate these calculations, using the piping that would be used in the actual tests. The capacity of the air suction system proved to be sufficient. During this test the instrumentation, including five-hole pressure probes in the air intake, was checked also. A so-called zero measurement run was performed for this instrumentation, to be used as a reference for the actual tests. This test set-up allows the flow speed and direction, which are influenced by the shape of the engine bellmouth only, to be measured, with all disturbing effects of the NH90 air intake eliminated. Deviations from the 'clean' measurement can be regarded typical for the NH90 configuration.

Prior to wind tunnel testing, the model was completely pre-assembled in a model preparation hall of the DNW-LLF, to check the interfaces between the parts supplied by DLR, DNW and NLR. The pre-assembly started with mounting the sting on a dummy support. After mounting the DLR rotor drive system on this sting, the engine simulation hardware was mounted, and the burner system was connected to the sting.

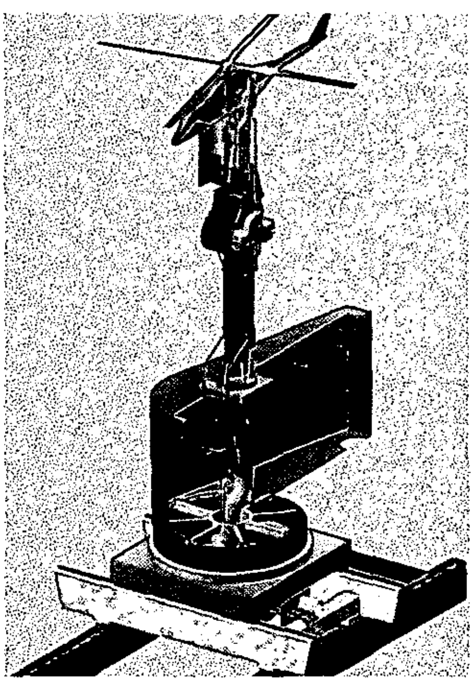


Fig. 13 - Schematic CAD/CAM model to aid assembly of the test set up

Because of the limited space available, the routing of pipes and cables had been prepared using 3D design tools including CATIA and Unigraphics. After all pipes and cables – for oil supply, return and cooling for the hydraulic drive unit, insulated hot air supply pipes, air suction pipes, measurement cables for the rotor, engine and fuselage instrumentation, reference pressure tube, fire extinguishers cables and cables for a CCD camera inside the model – were connected, the fuselage hull position with respect to the rotor hub, the engine air intakes and exhausts was checked.

After this complete pre-assembly, the fuselage hull was removed again to avoid damage to the instrumentation installed in the skin. The sting with the model was lifted from the dummy support and mounted on top of the alpha mechanism which on its turn was connected to the common support of the wind tunnel. In parallel with the model pre-assembly, all cabling and piping was already mounted on the common support. As soon as the sting with the model was placed on top of the alpha mechanism, the cabling could be connected to interfaces underneath the model.

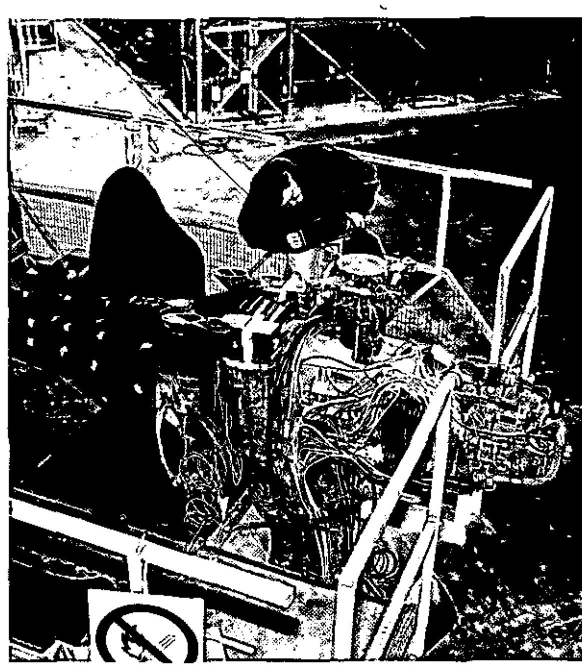


Fig. 14 - Model in DNW-LLF parking hall, fuselage and rotor blades removed

The engine exhaust flow was heated by a propane burner mounted alongside the model sting, just below the fuselage bottom. The original burner system has been developed by Boeing. DNW has adapted this system to the test set-up for the NH90 model. The system was pre-tested separately in the DNW-LLF parking hall, in the presence of a specialist from Boeing before the actual test. The burner was connected to the pipes supplying the hot air to the exhausts. The fuselage hull was not installed, to ease inspection of the burner, hot air piping and exhausts. Also the fire risk was minimized in this way. The insulated hot air pipes and the rotor drive system were equipped with thermocouples to determine the efficiency of the insulation.

First, the gas pressure and air mass flow optimal for ignition were determined and set. The gas mixture was ignited with a spark plug. The required temperature and mass flow could be established by increasing the gas pressure and air mass flow. Increasing the gas pressure had to be performed very carefully to prevent the propane from liquifying in the supply line between the evaporizer and the burner. This would lead to a sharp rise in the exhaust temperature causing fatal damage to the model. A dedicated computer program was used to monitor the propane and burner conditions. All critical parameters were displayed on-line. If the combination of the gas pressure and temperature were such that the gas state became to close to liquid, the propane supply was closed automatically. Pre-test showed that the required temperature and mass flow level could be obtained. The temperatures on the outside of the insulation stayed well below the maximum allowable temperatures.

Test Execution in DNW-LLF

In December 1996, the NH90 rotor model test was performed in the open jet test section of the Large Low Speed Facility of the German-Dutch Wind Tunnel (DNW-LLF). In this configuration, the LLF achieves wind speeds up to about 80 m/s. The test was a major collaborative effort of NLR, NH90 partner representatives (guiding the test programme), DNW and DLR. NLR was responsible for overall test co-ordination. The DNW team was responsible for the operation of the wind tunnel, the model support system and the burner control, and for the acquisition of the sensor data related to the engine installation. The rotor system was operated by 8-10 DLR personnel, who also took care of the rotor system data acquisition. Each day a short meeting was held to summarize progress to date, initiate actions and discuss activities for the present day. The availability from early in the morning to late at night and the willingness of all people involved was crucial to the completion of the test within the time frame scheduled.

The test set-up was transferred from the parking hall to the test section of the DNW-LLF, and supply systems (hydraulic, air suction and supply, propane gas) were connected. A stroboscope system was installed to be used for blade tracking. All instrumentation signals were checked and fire extinguishers were connected (two firemen of NLR were on site when the burner was being operated). Functional checks of all major systems, such as the rotor, air suction, exhaust gas burner were first done separately and finally collectively. The scanners of the infrared system were installed on special mounting platforms in the testing hall. Rotor blade tracking was checked using a stroboscope. As soon as all systems were operational, the first measurement production runs were made. Rotor system hover and low speed tests were performed.

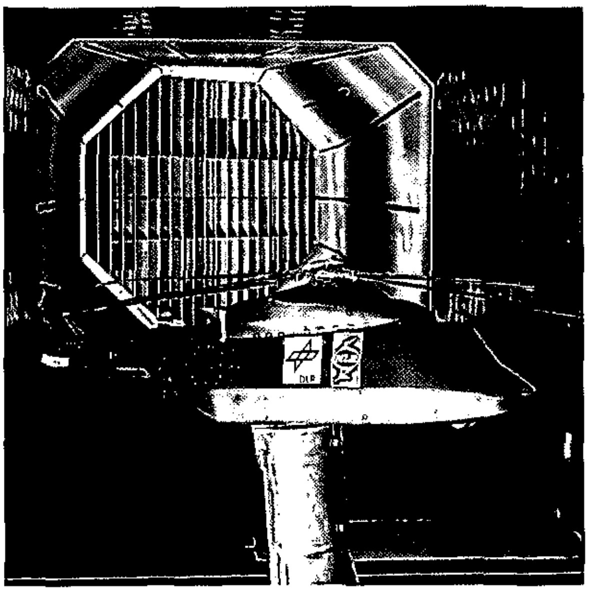


Fig. 15 - Complete model in the open jet test section of the DNW-LLF

Prior to run-up of all systems, the Agema infrared cameras of ECD and NLR were placed at the correct positions in the testing hall, since their view angles could not be controlled remotely. The desired sector of the model was framed.

For all test conditions, first the rotor system was engaged. The rotor speed was increased gradually. As soon as the requested blade tip Mach number was reached, the thrust was increased to a moderate level at zero (cyclic) blade flapping. Next, the burner system was engaged by spark plug ignition at the proper propane gas pressure and temperature and exhaust mass flow. Gradually the exhaust gas mass flow and temperature were brought to the required levels. In parallel, the air intake mass flow was set. As soon as the burner was on condition, the model angle of attack, sideslip and tunnel wind speed were in this order set to the specific values. Finally, the rotor thrust was set to the predefined thrust coefficient and the cyclic pitch was adjusted to achieve the required longitudinal and lateral flapping level. As soon as a test condition was settled completely, data acquisition started by recording the parameters related to the engine installation, pressures and temperatures. In parallel infrared recordings were made. Then, a data point number was assigned by DNW, and passed to the DLR crew who performed rotor system data acquisition. The average testing time needed for one test condition was six minutes. The above procedure was repeated for all test conditions of the test programme.

The NH90 wind tunnel test project has demonstrated NLR's ability to conduct a challenging multidisciplinary project by mobilizing the required expertise and equipment from its wealth of resources.

During testing the most important parameters were displayed on-line for monitoring purposes and test programme guidance. It allowed the tests to be executed efficiently and with a high productivity. A sample result of the infrared measurements is shown in Figure 16 below.

Fig. 16 - Sample of infrared measurements

Appendices

Appendices

1 Publications

In 1996, NLR produced a total of 794 reports, including unpublished reports on contract research and on calibrations and tests of equipment. The reports listed below were released for publication.

TP 94069 U

Jump linear model based aircraft trajectory reconstruction

Presented at the 1994 SPIE Conference on Signal and Data Processing of Small Targets, Orlando, 5–8 April 1994.

Neven, W.H.L.; Blom, H.A.P.; Kraker P.C. de

TP 94178 U

Optimization of target pressure distributions

Presented at an AGARD Special Course at the Von Kármán Institute, Rhode-Saint-Genèse, Belgium, 14–18 May 1990.

Egmond, J.A. van; Slooff, J.W.

TP 94360 U

Multimedia tele-education PC-based real-time narrowband applications

Algra, T.

TP 94552 U

Mission Support System Computer aided mission preparation at airbase level (MSS/C)

Presented for the Netherlands Association of Aeronautical Engineers (NVvL), 28 April 1994.

Moel, R.P. de

TP 94558 U

An analysis of controlled flight into terrain (CFIT) accidents of commercial operators 1988 through 1994

Published in "Flight Safety Digest" of the Flight Safety Foundation.

Khatwa, R.; Roelen, A.L.C.

TP 94565 U

Evolutionary computation in air traffic control planning

Presented at "The Sixth International Conference on Genetic Algorithms", University of Pittsburgh, Pennsylvania, 15–20 July 1995.

Hendriks, C.; Kemenade, K. van.; Kok, J.

TP 94600 U

Avionica voor de luchtvaart van morgen – Marktpotentieel voor de Nederlandse industrie

(in Dutch) Presented at the symposium "Avionica voor de luchtvaart van morgen, marktpotentieel voor de Nederlandse industrie", Delft, 24 November 1994.

Abbink, F.J.

TP 95035 U

Numerical and Experimental activities in Fluid/Spacecraft interactive dynamics

Presented at the 45th Congress of the International Astronautical Federation (IAF), Jerusalem, Israel, 9–14 October 1994.

Roefs, H.F.A.; Prins, J.J.M; Guelman, M.

TP 95114 U

The need for supercomputers in aerospace research and industry

Presented at HPCN Europe 1995, Milan, Italy, 2–5 May 1995.

Vogels, M.E.S; Ven, H. van der; Hameetman, G.J.

TP 95122 U

Elliptic surface grid generation on minimal and parametrized surface

Spekreijse, S.; Nijhuis, G.; Boerstoel, J.

TP 95126 U

A method to apply structure relevant impact damage to small structure relevant specimens for damage tolerance studies

Presented at the Tenth International Conference on Composite Materials, Whistler near Vancouver, British Columbia, Canada, 14–18 August 1995.

Ubels, L.C.; Wiggenraad, J.F.M.

TP 95151 U

Wind tunnel flutter testing on shingles in the transonic and supersonic speed regime

Presented at the 80th meeting of the AGARD SMP Panel, Rotterdam, 8–10 May 1995.

Persoon, A.J.

TP 95190 U

Vibro-Acoustic analysis of double wall structures

Presented at the first Joint CEAS/AIAA Aeroacoustic Conference, München, Germany, 12–15 June 1995.

Grooteman, F.P.; Boer, A. de; Schippers, H.

TP 95191 U

TPX for in-orbit demonstration of two-phase heat transport technology - evaluation of flight and post-flight experiment results

Presented (as SAE 951510) in the Two-Phase Technology Session of the 25th International Conference on Environmental Systems, San Diego, CA, USA, 10–14 July 1995.

Delil, A.A.M.

TP 95197 U

Full mission simulation in a research environment

Presented at the Royal Aeronautical Society conference on "Flight Simulation Technology, Capabilities and Benefits", London, 17–18 May 1995.

Offerman, H.A.J.M.

TP 95202 U

Embedding adaptive JLQG into LQ martingale control with a completely observable stochastic control matrix

Published in IEEE Transactions on Automatic Control, March 1996.

Everdij, M.H.C.; Blom, H.A.P.

TP 95209 U

Coupling of boundary and finite elements in aeroacoustic calculations

Presented at the 11th GAMM-Seminar Kiel on Numerical Treatment of Coupled Systems, Kiel, Germany, 20–22 January 1995.

Schippers, H.; Wensing, J.A.

TP 95223 U

Nieuwe rekenrooster-generatiemethoden voor industriële stromingsberekeningen

(in Dutch) Voordracht voor het Nederlands Mathematisch Congres 1995 van het Wiskundig Genootschap, Sectie Industriële Wiskunde, Groningen, 20–21 april 1995.

Boerstoel, J.W.

TP 95226 U

Computation of the flow about an F-16-like configuration for several flow conditions

Presented as AIAA Paper 95-1786 at the AIAA 13th Applied Aerodynamics Conference, San Diego, USA, 19–22 June 1995.

Berg, J.I. van de; Sytsma, H.A.; Schippers, H.

TP 95227 U

Transputer based static data acquisition systems at DNW

Presented at the 16th International Congress on Instrumentation in Aerospace Simulation Facilities, Wright-Patterson Air Force Base, Dayton, Ohio, USA, 18–21 July 1995.

Slot, H.; Joosen, C.J.J. (DNW)

TP 95235 U

Anisotropic grid refinement using an unstructured discontinuous Galerkin method for the three-dimensional Euler equations of gas dynamics

Presented as Paper AIAA-95-1657 at the 12th AIAA Computational Fluid Dynamics Conference, San Diego, CA, USA, 19–22 June 1995

Vegt, J.J.W. van der

TP 95239 U

Laser anemometry for in-flight flow investigations

Presented at ICIASF '95, International Congres on Instrumentation in Aerospace Simulation Facilities, Wright-Patterson Air Force Base, Dayton, Ohio, USA, 18–21 July 1995.

Jentink, H.W.; Beversdorff, M.; Foerster, W.

TP 95245 U

Parametric identification of transonic unsteady flow characteristics for predicting flutter of fighter aircraft with external stores

Presented at the FDP Symposium on "Aerodynamics of Store Integration and Separation", Ankara, Turkey, 24–27 April 1995.

Meijer, J.J.; Cunningham, A.M.

TP 95269 U

Flight testing of a wing deflection measurement method

Presented at the AIAA Atmospheric Flight Mechanics Conference, Baltimore, 7–10 August 1995.

Kannemans, H.

TP 95286 U

An avionics system approach for future civil aviation

Presented at the ERA Technology 1994 Avionics Conference and Exhibition "Systems integration - is the sky the limit?", Heathrow, UK, 30 November – 1 December 1994.

Abbink, F.J.

TP 95308 U

Outline and applications of a semi-empirical method for predicting transonic limit cycle oscillation characteristics of fighter aircraft

Presented at the International Forum on Aeroelasticity and Structural Dynamics 1995, Manchester, United Kingdom, 26–28 June 1995.

Meijer, J.J.; Cunningham, A.M.

TP 95314 U

The contact problem for linear continuous-time dynamical systems: a system theoretical approach

Submitted for publication in "IEEE Transactions on Automatic Control".

Dam, A.A. ten; Dwarshuis, E.; Willems, J.C.

TP 95341 U

The SLOSHAT Motion Simulator (SMS) and its Simplifications

Presented at the Symposium "Making it Real", Confederation of European Aerospace Societies (CEAS), Delft, The Netherlands, 30 October – 1 November 1995.

Vreeburg, J.P.B.

TP 95342 U

Application of genetic algorithms to the design of airfoil pressure distributions

Kuiper, H.; Wees, A.J. van der; Hendriks, C.F.W; Labrujère, Th.E.

TP 95362 U

Concepts for optical diagnostics instrumentation in facilities for micro-g fluid science

Presented at the IXth Eurpean Symposium on Gravity Dependent Phenomena in Physical Sciences, Berlin, Germany, 2 May 1995.

Kramer, A.J.; Assem, D. van den

TP 95372 U

Damage assessment and preservation of an Egyptian silver vase (300 - 200 B.C.)

Joint publication of the National Aerospace Laboratory NLR and the Allard Pierson Archaeological Museum of the University of Amsterdam.

Wanhill, R.J.H.; Leenheer, R.; Steijaart, J.P.; Koens, H.

TP 95382 U

From R&D in parallel CFD to a tool for computer aided engineering

Invited paper published in: S. Taylor, A. Ecer, J. Peraux, N. Satofuka (eds), Proceedings of parallel CFD '95, Pasadena, CA, USA, Elsevier Science B.V., 26-29 June 1995.

Loeve, W.

TP 95389 U

A model for performance of a block-structured Navier-Stokes solver on a cluster of workstations

Presented at the Parallel CFD '95 Conference, Pasadena, CA, USA, 26-28 June 1995.

Vogels, M.E.S.

TP 95401 U

Using HTML as basis for information sharing in heterogeneous computing environments

Presented at the SGML '95 conference, Boston, 7 December 1995.

Kuiper, H.; Ven, H. van der

TP 95402 U

Adaption of 3rd single-block structured grids around wings

Also to appear in a common ECARP publication in the Vieweg series 'Notes on Numerical Fluid Mechanics'.

Hagmeijer, R.; Kok, J.C.; Oskam, B.

TP 95414 U

The flow reference system - An air data system for windtunnels

Presented at the International Congres on Instrumentation in Aerospace Simulation Facilities, Wright-Patterson Air Force Base, Dayton, Ohio, USA, 18–21 July 1995.

Fuykschot, H.; Juanarena, D.B.; Klaser, H.N.

TP 95426 U

Flat-Floor facilities in support of configurable space structures development

Presented at the 46th Congress of the International Astronautical Federation (IAF), Oslo, Norway (Section "Space Structures - Dynamics and Microdynamics"), 2–6 October 1995.

Pronk, Z.; Woerkom, P.Th.L.M. van

TP 95442 U

ADAS structures module evalution report

Arendsen, P.; Dalen, F. van; Bil, G.; Rothwell, A.

TP 95444 U

Remote payload operations supported by automation and robotics ground-based simulation with hardware-in-the-loop

Presented at the CEAS Symposium on Simulation Technologies, Delft, October 1995.

Haas, J. de; Pronk, Z.; Schoonmade, M.

TP 95455 U

A historical review of two helicopters designed in the Netherlands

Presented at the 21st European Rotorcraft Forum, St. Petersburg, Russia, 30 August – 1 September 1995.

Vodegel, H.J.G.C.; Jessurun, K.P.

TP 95457 U

Recent experiences in modelling the NLR Metro II research aircraft

Presented at the CEAS symposium on simulation technology "Making it Real", Delft, The Netherlands, 30 October – 1 November 1995.

Kannemans, H.

TP 95461 U

MSS/C map topics

Presented at the EPAF meeting on minimum requirements, August 1994.

Moel, R.P. de

TP 95502 U

Explicit multi-time stepping methods for convection-dominated flow problems

Submitted to the Journal "Computational Methods in Applied Mechanics and Engineering".

Ven, H. van der; Maurits, N.M.; Veldman, A.E.P.

TP 95514 U

Hexahedron based grid adaption for future large eddy simulation

Presented at the AGARD symposium "Progress and Challenges in CFD Methods and Algorithms", Seville, 2–5 October 1995.

Vegt, J.J.W. van der; Ven, H. van der

TP 95519 U

Initial results of a piloted simulator investigation of modern windshear detection systems

Presented at ICAS 94 Congress/AIAA Aircraft System Conference, Anaheim, 18–23 September 1994.

Haverdings, H.; Rouwhorst, W.F.J.A.

TP 95520 U

The use of flat-floor facilities in simulation and testing

Presented at the CEAS Symposium on Simulation Technology "Making it Real", Delft, The Netherlands, 30 October – 1 November 1995

Pronk, Z.; Woerkom, P.Th.L.M. van

TP 95523 U

Presentation and analysis of results on an unsteady transonic wind tunnel on a semi-span delta wing model, oscillating in pitch

Presented at the International Forum on Aeroelasticity and Structural Dynamics 1995, Manchester, United Kingdom, 26–28 June 1995

Geurts, E.G.M.

TP 95534 U

A correction technique for gravity sensing inclinometers – Phase I: theoretical analysis

Presented at the 83rd semi-annual meeting of the Supersonic Tunnel Association at the Naval Surface Warfare Center,
MD, USA, 2–4 April 1995.
Fuykschot, P.H.

TP 95539 U

Robotic manipulators in space: a dynamics and control perpective

Survey Paper presented at the 46th Congress of the International Astronautical Federation, Oslo, Norway, 2–6 October 1995.
Woerkom, P.Th.L.M. van; Misra, A.K.

TP 95653 U

Altitude estimation for low-cost spacecraft equipped with GPS

Presented at the CEAS Symposium on Simulation Technology,
30 October – 1 November 1995.
Zwartbol, T.; Chu, Q.P.; Woerkom, P.Th.L.M. van

TP 95690 U

Evaluation of elastomechanical and aerodynamic data transfer methods for non-planar configurations in computational aeroelastic analysis

Presented at the International Forum on Aeroelasticity and Structural Dynamics 1995, Manchester, United Kingdom, 26–28 June 1995.
Hounjet, M.H.L.; Meijer, J.J.

TP 96003 U

Vibration compensation of gravity sensing inclinometers in windtunnel models

Presented at the 42nd International Instrumentation Symposium organized by the Instrument Society of America,
San Diego, CA, USA, 5–9 May 1996.
Fuykschot, P.H.

TP 96019 U

Het ontwikkelen van bedrijfszekere Avionica

(in Dutch) Contribution to Themadag "Kwaliteit in de tijd, het ontwikkelen van bedrijfszekere elektronica", georganiseerd door het Centrum voor Micro-Elektronica, Ede, 30 november 1995.
Aartman, L.J.

TP 96021 U

Application of distributed artificial intelligence in complex modular critical applications

Zuidgeest, R.G.

TP 96028 U

Possibilities and limitations of VHBR and UHBR Turbofan Fan Simulations in engine/airframe integration windtunnel experiments

Presented at the Workshop on Aspects of Airframe Engine Integration for Transport Aircraft, Braunschweig, Germany,
6–7 March 1996.
Wolf, W.B. de

TP 96036 U

Development of a fully automated CFD system for three-dimensional flow simulations based on hybrid prismatic-tetrahedral grids

Presented at the 5th International Conference on Numerical Grid Generation in Computational Fluid Dynamics and related fields, Starkville, Mississippi, April 1996.
Burg, J.W. van der; Maseland, J.E.J.; Oskam, B.

TP 96038 U

Variability of fatigue crack growth properties for 2024-T3 aluminium alloy

Oldersma, A.; Wanhill, R.J.H.

TP 96047 U

Failure and cracking of Inconel 718 supply manifold support rods - service-related

Wanhill, R.J.H.; Boogers, J.A.M.; Huisman, H.N.; Ottens, H.H.

TP 96057 U

Surface layers for protection of carbon composite materials
Presented at the SAMPE Europe Conference & Exhibition, Basel, 28–30 May 1996.
Hart, W.G.J. 't; Ubels, L.C.

TP 96079 U

Implementation of cause-based pilot model for dynamic analysis of approach-to-landing procedure – Application of human reliability to civil aviation
Presented at the International Conference on Probabilistic Safety and Management, Crete, Greece, 24–28 June 1996.
Bos, J.F.T.; Hooijer, J.S.; Macwan, A.

TP 96117 U

Theory of sound propagation in a flow duct lined with annular segments of porous material
Sijtsma, P.

TP 96118 U

Remote sensing based vegetation mapping projects – the Netherlands working group ROBOS perspective
Discussion paper for the Workshop on Remote Sensing Support for the Global Forest Resource Assessment FRA 2000, USA Forest Service Headquarters, Washington DC, USA, 12–14 March 1996.
Looyen, W.J.

TP 96121 U

Experimental investigation on the influence of liner non-uniformities on prevailing modes
Rademaker, E.R.; Sarin, S.L.; Perente, C.A.

TP 96122 U

Experimental validation of a lifting surface theory for rotor-stator interaction noise generation
Presented at the 2nd AIAA/CEAS Aeroacoustics Conference, State College, Pennsylvania, USA, 6–8 May 1996.
Sijtsma, P.; Rademaker, E.R.; Schulten, J.B.H.M.

TP 96135 U

Vane sweep effects on rotor/stator interaction noise
Presented as AIAA Paper 96-1694 at the 2nd AIAA/CEAS Aeroacoustics Conference, State College, Pennsylvania, USA, 6–8 May 1996.
Schulten, J.B.H.M.

TP 96153 U

Gem Cyclic life control: A smarter maintenance item within the Royal Netherlands Navy
Presented at the American Helicopter Society 52nd Annual Forum, Washington, D.C., 4–6 June 1996.
Leenaarts, M.L.W. (RNN); Have, A.A. ten

TP 96167 U

Product assurance for the development of the SAX AOCS application software
Presented at the "ESA 1996 Product Assurance Symposium and Software Product Assurance Workshop", Noordwijk, 19–21 March 1996.
Dekker, G.J.; Kesseler, E.

TP 96221 U

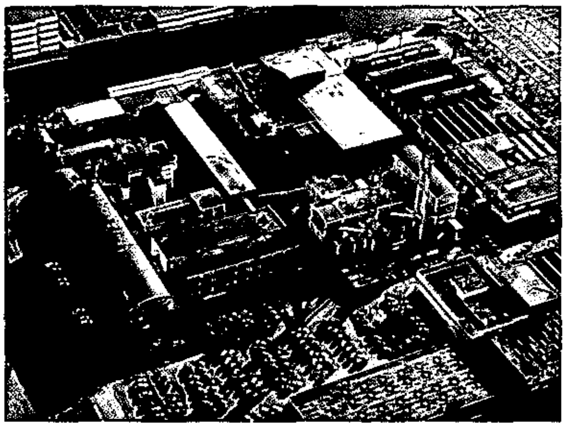
An evaluation of approach and landing factors influencing airport safety
Presented at the Flight Safety Foundation's European Aviation Safety Seminar (EASS): Challenges and Solutions, Amsterdam, The Netherlands, 27–29 February 1996.
Khatwa, R.; Roelen, A.L.C.; Karwal, A.K.; Enders, J.H.; Dodd, R.; Tarrel, R.

2 Abbreviations

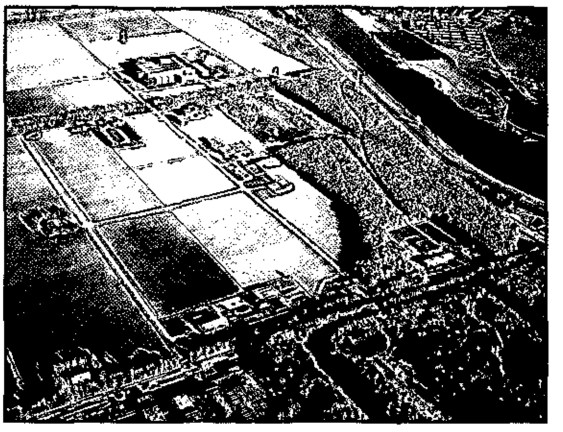
AEREA	Association of European Research Establishments in Aeronautics
AGARD	Advisory Group for Aerospace Research and Development (NATO)
AIAA	American Institute of Aeronautics and Astronautics
APERT	Aerospace Programme for Education, Research and Technology
ARALL	ARamide Aluminium Laminate
ATC	Air Traffic Control
BCRS	Beleidscommissie Remote Sensing (Netherlands Remote Sensing Board)
BMBF	Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (Federal Ministry for Education, Science, Research and Technology)
BMVg	Bundesministerium für Verteidigung (Federal Ministry for Defence)
BRITE	Basic Research in Industrial Technologies for Europe
CAE	Computer-Aided Engineering
CAESAR	CCD Airborne Experimental Scanner for Applications in Remote Sensing
CARTE	Collaboration on Aeronautical Research and Technology in Europe
CEC	Commission of the European Communities
CIRA	Centro Italiano Ricerche Aerospaziale
DLR	Deutsche Forschungsanstalt für Luft- und Raumfart
DNW	Duits-Nederlandse Windtunnel (German-Dutch Wind Tunnel)
DRA	Defence Research Agency
EC	European Communities
EFIS	Electronic Flight Instrument System
EMI	Electro-Magnetic Interference
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESOC	European Space Operations Centre
ESPRIT	European Strategic Programme for Research and Development in Information Technology
ESTEC	European Space Research and Technology Centre
ETW	European Transonic Wind Tunnel
EUCLID	European Co-operation for the Long term In Defence
EURAM	European Research on Advanced Materials
Eurocontrol	European Organization for the Safety of Air Navigation
EZ	Ministerie van Economische Zaken (Ministry of Economic Affairs)
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization
FEL	Fysisch Elektronisch Laboratorium (TNO) (Physics-Electronics Laboratory)
FFA	Flygtekniska Försöksanstalten (Aeronautical Research Institute of Sweden)
FSS	Fokker Space & Systems
GARTEUR	Group for Aeronautical Research and Technology in Europe
GPS	Global Positioning System
HSA	Hollandse Signaalapparaten B.V.
HST	Hoge-Snelheids Tunnel (High Speed Wind Tunnel)

ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronic Engineers
IEPG	Independent European Programme Group
ILST	Indonesische Lage-Snelheids Tunnel (Indonesian Low Speed Tunnel)
INTA	Instituto Nacional de Técnica Aerospacial (Aerospace Research Institute of Spain)
IPTN	Nusantara Aircraft Industries (Bandung)
ISARD	Integrated Support for Aeronautical Research and Development
ITB	Institut Teknologi Bandung (Indonesië) (Technological Institute of Bandung, Indonesia)
JAR	Joint Airworthiness Regulations
KLM	Koninklijke Luchtvaart Maatschappij N.V. (KLM Royal Dutch Airlines)
KLu	Koninklijke luchtmacht (Royal Netherlands Air Force)
KM	Koninklijke marine (Royal Netherlands Navy)
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
KNVvL	Koninklijke Nederlandse Vereniging voor Luchtvaart (Royal Netherlands Aeronautical Association)
LAGG	Aero-Gas Dynamics and Vibration Laboratory
LST	Lage-Snelheids Tunnel (Low Speed Wind Tunnel)
LVB	Luchtverkeersbeveiligingsorganisatie (ATC The Netherlands)
MBB	Messerschmitt-Bölkow-Blohm
MLS	Microwave Landing System
MRVS	Meet-, Registratie- en Verwerkingssysteem (Measurement, Recording and Data Processing System)
NAG	Netherlands Aerospace Group
NASA	National Aeronautics and Space Administration (USA)
NATO	North Atlantic Treaty Organization
NAVSTAR	Navigation System with Time and Ranging
NIVR	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart (Netherlands Agency for Aerospace Programs)
NKO	Nederlandse Kalibratie Organisatie (Netherlands Calibration Organization)
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR)
NLRGC	Nationaal Lucht- en Ruimtevaartgeneeskundig Centrum (National Aerospace Medical Centre)
NPOC	National Point of Contact
NSM	Niet-Stationaire Meetmethode (Non-Stationary Measurement Method)
NSF	Nationale Simulatie Faciliteit (National Simulation Facility)
ONERA	Office National d'Etudes et de Recherches Aérospatiales (Aerospace Research Institute of France)
PHARUS	Phased Array Universal Synthetic Aperture Radar
RESEDA	Remote-Sensing Dataverwerkingssysteem (Remote Sensing Data Processing System)
RLD	Rijksluchtvaartdienst (Netherlands Department of Civil Aviation)
RLNAF	Royal Netherlands Air Force
RTCA	Radio Technical Commission for Aeronautics
SICAS	SSR Improvement and Collision Avoidance System
SPOT	Système Probatoire Observation Terrestre
SSR	Secondary Surveillance Radar
SST	Supersone Snelheids Tunnel (Supersonic Wind Tunnel)

TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research)
TPD	Technisch Physische Dienst TNO-TU
TPS	Turbine-Powered Simulation
TTA	Technological/Technical Assistance
V&W	Ministerie van Verkeer en Waterstaat (Ministry of Transport and Public Works)
VKI	Von Kármán Institute of Fluid Dynamics
WEAG	Western European Armament Group
WL	Waterloopkundig Laboratorium (Delft Hydraulics)



NLR Amsterdam



NLR Noordoostpolder

photography: KLM Luchtfotografie

NLR Amsterdam

Anthony Fokkerweg 2
1059 CM Amsterdam
P.O. Box 90502
1006 BM Amsterdam
The Netherlands
Telephone: +31 20 5113113
Fax: +31 20 5113210

NLR Noordoostpolder

Voorsterweg 31
8316 PR Marknesse
P.O. Box 153
8300 AD Emmeloord
The Netherlands
Telephone: +31 527 248444
Fax: +31 527 248210