Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Annual Report 2002

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Board of the Foundation NLR

	Appointed by:
J. van Houwelingen, *Chairman*	Ministers of Transport, of Defence, of Economic Affairs and of Education, Culture and Science
Drs. A. de Ruiter	Minister of Transport, for the Directorate-General of Civil Aviation
Drs. E.A. van Hoek	Minister of Defence
Gen.-Maj. P.M.A. Vorderman	Minister of Defence for the Royal Netherlands Air Force
Drs. A.A.H. Teunissen	Minister of Economic Affairs
Drs. J.W.A. van Enst	Minister of Education, Culture and Science
B.A.C. Droste	Netherlands Agency for Aerospace Programmes (NIVR)
G.H. Kroese	ATC the Netherlands (LVNL)
Ir. C.A.M. de Koning	Stork N.V.
Drs.ing. P. Hartman	KLM Royal Dutch Airlines
Ms.ir. M.E. van Lier Lels	Amsterdam Airport Schiphol
Ir. E.I.L.D.G. Margherita	Netherlands Organisation for Applied Scientific Research (TNO)
Prof.dr.ir. Th. de Jong	Delft University of Technology, Faculty of Aerospace Engineering
Jhr.mr. J.W.E. Storm van 's Gravesande	Board of the Foundation NLR
Ms.prof.dr.ir. M.P.C. Weijnen	Board of the Foundation NLR, upon nomination by the Works Council

Chairman of the Scientific Committee NLR/NIVR

Prof.dr.ir. P.J. Zandbergen

Board of Directors of NLR

Ir. F. Holwerda	General Director
Ir. F.J. Abbink	Technical Director
Drs. L.W. Esselman R.A.	Financial Director

General Secretary

E. Folkers

Composition as on 31 December 2002

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1 Preface

The year 2002 has been more difficult for NLR than preceding years. Because of the bad situation in aviation business, still as a consequence of the '9-11' disaster, and because of delays in the decision processes of projects of various customers, NLR's turnover was lower than expected, and because cost reductions could not compensate for this, the year ended with an overall loss.

Through the decline in the economy in general, like many other Dutch companies, NLR faced a major financial problem with its pension fund. Only through a co-operative attitude from its personnel, accepting changes in the pension scheme, and a special financial contribution from the government, this could be solved.

In 2002 the Netherlands government signed a Memorandum of Understanding with the United States government, becoming a Level 2 partner in the SDD phase of the Joint Strike Fighter programme. NLR's direct contribution to this programme was materialised in this same year through contracts with Lockheed Martin Aero for wind tunnel tests in the DNW Large Low-speed Facility as well as for two projects concerning the Prognostic Health Management system. Together with several partners (industry, TNO, TU Delft) NLR has demonstrated the viability and potential of many new technologies, and several contract opportunities in these areas are being or will be pursued.

NLR's main customers in the area of aircraft operations, the Royal Netherlands Air Force and the Royal Netherlands Navy, although confronted with major budget constraints, continued to require NLR's assistance and support.

As in previous years, NLR was actively involved in international technology programmes. Especially in the Fifth Framework Programme of the European Union NLR's participation was substantial, and the – all time high – total contract value was only possible through a significant extra 'matching subsidy' from the Ministry of Economic Affairs. NLR further continued to participate in international co-operations such as GARTEUR and NATO's RTO, and in initiatives of the Association of European Research Establishments in Aeronautics to establish a structured co-operation agreement between its members and Airbus.

In October 2002, NLR and DLR expressed their intention to integrate their Air Traffic Management activities by signing a Memorandum of Understanding. In Beijing NLR signed a Memorandum of Understanding with the Chinese Aeronautical Establishment (CAE) for co-operation in research and technology development on a project-by-project basis. Nationally, NLR's long standing relationship in many different areas with the TU Delft was renewed with a Letter of Intent signed by both parties as a first step to more specifically formalise their mutual interests.

The year 2002 was the last one of NLR's strategic planning period 1998 – 2002; five years in which NLR far more than before had to face market competition to maintain its strong position in all areas of the aeronautics and space domain. On the one hand NLR's home market was reduced significantly since the bankruptcy of Fokker Aircraft, while – on the other hand – internationally there is no level playing field (or fair competition) in the field of R&D infrastructure due to quite different national funding structures of competitor institutions. This, together with the economic decline, facing not only the Netherlands but also other European and non-European countries, prompted the Board to initiate a project to reassess the position and organisation of NLR in view of its changing environment. This project, started at the end of 2002, is targeted to have a 'new' NLR, ready for the future and dedicated to claim a strong position in an integrated European aeronautics and space research and development infrastructure, by the end of 2004!

J. van Houwelingen,
Chairman

2 General Survey

2.1 Activities in 2002

In 2002 NLR's turnover amounted to € 76 million. The revenues from contracts totalled € 56.4 million. About 60 per cent of NLR's activities were related to the development and 40 per cent to the operation of aircraft and spacecraft. Due to an all-time low in ESA contracts, only 7.5 per cent of the activities were related to space. Due to the JSF programme, military research increased to 45 per cent, compared to 31 per cent in 2001. About 39 per cent of the work under contract was carried out for international customers.

Services Provided under National Contracts

Activities under contract to customers from the Netherlands amounted to € 34.5 million. These contracts included work on aeronautics and space research and technology for the Netherlands Agency for Aerospace Programmes (NIVR). In addition, a number of research programmes were executed under contract to the Royal Netherlands Air Force (RNLAF), the Royal Netherlands Navy (RNLN), the Netherlands Civil Aviation Executive Agency (IVW-DL), Air Traffic Control the Netherlands (LVNL), Stork Aerospace and Dutch Space. NLR also carried out contract work to support the Netherlands Ministry of Defence, the Netherlands Ministry of Transport's Aviation Policy Department (DGL), the German-Dutch Wind Tunnels (DNW) and several other businesses such as Amsterdam Airport Schiphol, Sulzer and Urenco Aerospace.

Services Provided to International Customers

Research carried out under contract to international customers amounted to €22 million, compared to € 17.8 million in 2001. Major customers were EUROCONTROL, Lockheed Martin Aero and the European Union (EU). Work was also done for industries in Europe and for the European Space Agency (ESA).

Research and Equipment

NLR spent € 14.7 million on its basic aerospace research programme supported by the government, aimed at preserving NLR's capability to support the Netherlands aerospace sector in the future. Research aimed at the development of NLR's research facilities amounted to € 4.9 million. A total of € 3.4 million was used for capital investments, of which investments in the ICT infrastructure and in the DNW wind tunnels were the most important ones.

National and International Co-operation

A large part of NLR's basic research programme has been carried out as contributions to European research projects both in civil and in military programmes, such as the EU Fifth Framework and EUCLID / WEAO (European Co-operation for the Long Term in Defence / West European Armament Organisation) programmes. Another significant part has been carried out in co-operative programmes under the aegis of GARTEUR, the Group for Aeronautical Research and Technology in Europe, in which Germany, France, the United Kingdom, the Netherlands, Spain, Sweden and Italy take part.

Internationally, NLR was active in many Working Groups of the NATO Research and Technology Organisation (RTO).

In several projects NLR co-operated with research institutes, mainly the Netherlands Organisation for Applied Scientific Research (TNO), and universities of the Netherlands. NLR and the Delft University of Technology (TU Delft) jointly operate a Cessna Citation II, which is used as a research aircraft. In October 2002 also a 'Letter of Intent' to further increase co-operation between the TU Delft and NLR was signed. Two members of NLR's staff were employed as part-time lecturers at the TU Delft. Another member was active as a part-time professor at the Cranfield Institute of Technology, UK.

Quality Assurance

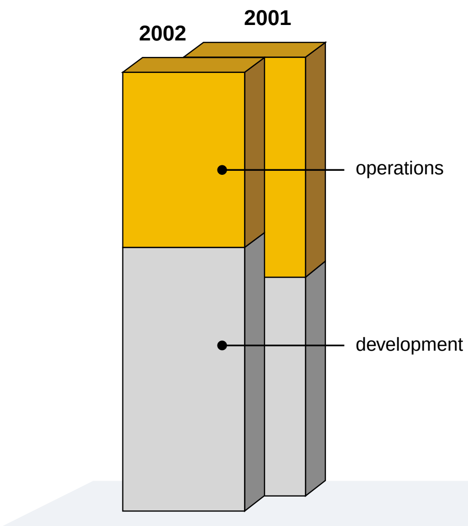
NLR has been holding ISO 9001: 2000 / AQAP-110 quality assurance certificates for its whole organisation including all staff functions. In addition, NLR maintained accreditations for EMC (Electromagnetic Compatibility) testing and for the calibration of forces, pressures and electronic quantities.

Outlook for the Coming Years

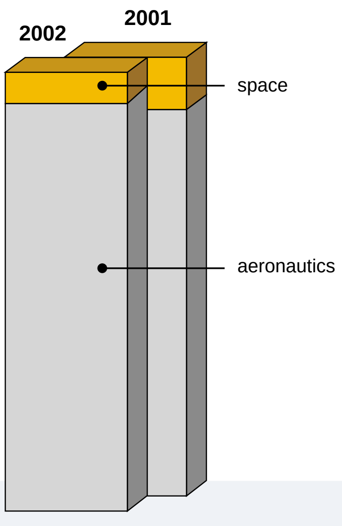
Challenging projects such as the Airbus A380 and the JSF-SDD Phase will determine NLR's contract work during the next few years to a large extent. In NLR's research programme, increased capacity of the air transport system and improved safety will be important topics. The research programme will be attuned to European research programmes such as the aeronautics parts of the Sixth Framework Programme of the EU.

Important new facilities, such as the Tower Research Simulator and a new, civil cockpit for the Research Flight Simulator will give new momentum to NLR's basic and contract research.

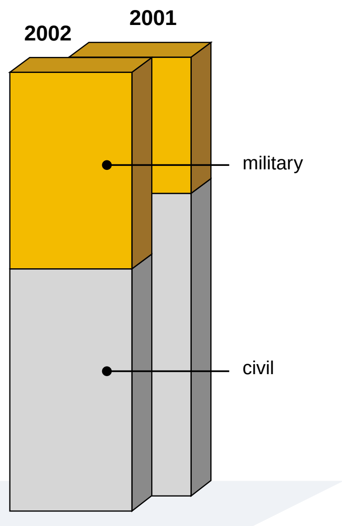
The coming years will see a further tuning of NLR's activities to those of European partner institutes. This will include integration of the ATC/ATM activities of DLR and NLR. NLR will continue to be a strong promoter of a European knowledge infrastructure in aerospace. Especially the new structure of the Sixth European Framework Programme with its 'Networks of Excellence' also opens new opportunities in this area.



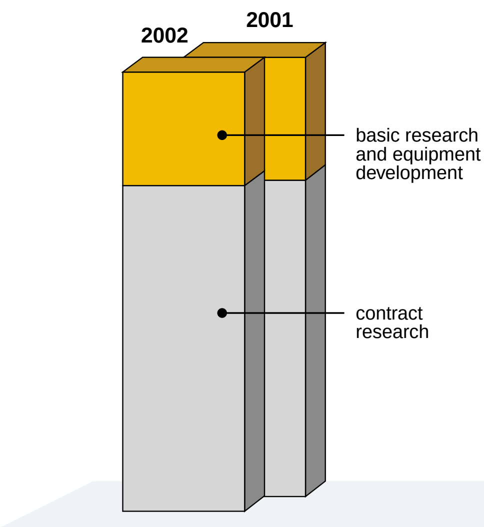
Division of the work into development and operations support



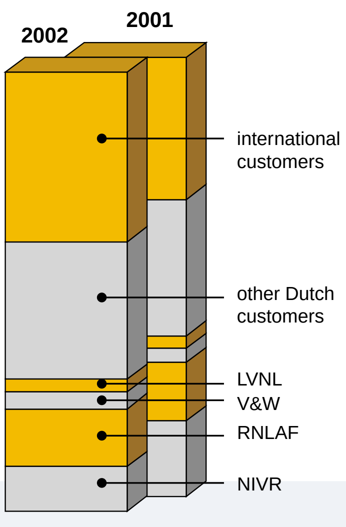
Division of the work into aeronautics and spaceflight support



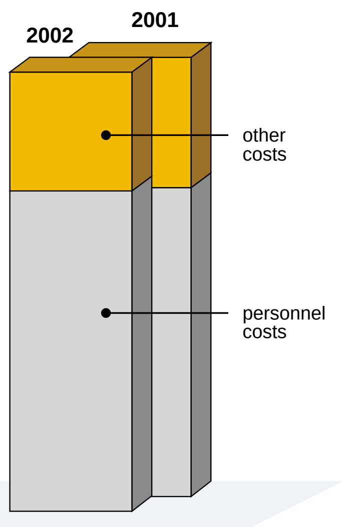
Division of the work into civil and military support



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

2.2 Organisation and Personnel

The Board of the Foundation NLR consists of members appointed by the Netherlands government, the industry and other organisations having an interest in aerospace research. The meetings of the Board are 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.

Two new members were appointed in the Board of the Foundation. The Minister of Transport appointed Drs. A. de Ruiter, who succeeded Ir. J.P.J.M. Remmen. Stork N.V. appointed Ir. C.A.M. de Koning, who succeeded Dr.Ir. A.W. Veenman.

The laboratory was headed by a Board of Directors. At the end of 2002 the Board consisted of Ir. F. Holwerda, General Director, Ir. F.J. Abbink, Technical Director and Drs. L.W. Esselman R.A., Financial Director. Mr. E. Folkers was General Secretary.

Drs. A. de Graaff was Associate Director, charged with strategy affairs and co-ordination of European integration projects. The Board of Directors was further assisted by Ir. J.C.A. van Ditshuizen, Head Marketing and Communication.

Dr.ir. B.M. Spee Prize awarded

The Board of the Foundation decided to award the Dr.ir. B.M. Spee Prize 2002 for exceptional scientific contributions to Dr. R.J.H. Wanhill, author of numerous reports and publications on aerospace materials and fracture mechanics.

Mr. J. van Houwelingen, Chairman, congratulates Mr. and Mrs. Wanhill

Ir. H.A.J.M. Offerman succeeded Ir. J. Brüggen, who left NLR, as head of the Air Transport Division. Ir. M.A.G. Peters succeeded Ir. H.A.T. Timmers, who retired, as head of the Avionics Division.

On 31 December 2002 the Heads of Divisions and Services were:

Dr. B. Oskam
Fluid Dynamics Division
Prof.drs. P.G.A.M. Jorna
Flight Division
Ir. H.A.J.M. Offerman
Air Transport Division
Ir. H.H. Ottens
Structures and Materials Division
Ir. B.J.P. van der Peet
Space Division
Ir. F.J. Heerema
Information and Communication Technology Division
Ir. M.A.G. Peters
Avionics Division
Ir. J. van Twisk
Engineering and Technical Services
Mr. W.C.P. van der Maas
General Services
Drs. L.W. Esselman R.A.
Administrative Services

The Engineering and Technical Services were reorganised by dissolving the Production Control Department.

In the Flight Division, the Man Machine Integration Department was renamed Human Factors Department. A new Department, Training Development and Concept Validation, was created by combining the existing Flight Simulation Department with the Training Group of the Human Factors Department.

The organisation of the laboratory on 31 December 2002 is shown on page 12.

A breakdown of the staff is given on page 13.

Organisation Diagram

31 December 2002

Technical Director
Ir. F.J. Abbink **DT**

General Director
Ir. F. Holwerda **D**

Financial Director
Drs. L.W. Esselman R.A. **DF**

General Secretary
E. Folkers **DA**

Associate Director	Drs. A. de Graaff	**DO**
Marketing and Communication	Ir. J.C.A. van Ditshuizen	**DM**
- *Public Relations*		DPR
- *Publications*	Dr. B.J. Meijer	DPI
- *Communication Specialist*	Ms.Drs. D.A. Nagelhout	DCS
Co-ordinators:		
- *Defence Projects*	Ir. W. Brouwer	CPD
- *Aircraft Development Projects*	Ing. P. Kluit	CPO
- *Spaceflight Projects*	Drs. J.C. Venema	CPR
- *Air Transport and Aircraft Operations Projects*	Ir. T.H.M. Hagenberg	CLV
- *Basic Research and Facilities Development*	Ir. F.J. Sonnenschein	CEW
Quality Management NLR	Ir. A.L.C. van Dorp	QM

Legal	Ms. M.Y. Spaargaren	**DJ**
Filing and Security	E. Folkers	**DB**
Personnel	Ms. W.J. van Druten	**DP**
- *Co-ordinator Occupational Health and Safety, and Environmental*	Drs. H. van Bremen	AMC
Company Welfare Work	Ms. J.H. van Dijk-Bol	DW
	Ms. C. Diekema-Schipaanboord	DW

Fluid Dynamics
Dr. B. Oskam **A**

- **Aerodynamic Engineering and Vibration Research** – Ing. J.A. van Egmond **AE**
- **Computational Fluid Dynamics and Aeroelastics** – Ir. K.M.J. de Cock **AT**
- **Aeroacoustics** – Dr. H.H. Brouwer **AK**

Flight
Prof.drs. P.G.A.M. Jorna **V**

- **Helicopters** – Ir. L.T. Renirie **VH**
- **Training Development and Concept Validation** – Prof.drs. P.G.A.M. Jorna *a.i.* **VT**
- **Flight Mechanics** – Ir. W.P. de Boer **VM**
- **Operations Research** – Ir. G.J. Alders **VO**
- **Human Factors** – Dr. B.G. Hilburn **VE**

Air Transport
Ir. H.A.J.M. Offerman **L**

- **Flight Testing and Safety** – Ing. M.A. Piers **LV**
- **Airports** – Ir. A.D.J. Rutten **LA**
- **Air Traffic Management** – Dr. R.J.P. Groothuizen *a.i.* **LL**
- **Transport and Environmental Studies** – Ms. Dr.ir. M.E.S. Vogels **LT**

Structures and Materials
Ir. H.H. Ottens **S**

- **Loads and Fatigue** – Ir. H.J. ten Hoeve **SB**
- **Structures Technology** – Dr.ir. J.F.M. Wiggenraad **SC**
- **Laboratory Facilities** – Ing. H.J.C. Hersbach **SL**

Space
Ir. B.J.P. van der Peet **R**

- **Remote Sensing** – Ir. B. Moll *a.i.* **RR**
- **Systems** – Dr.ir. H.F.A. Roefs **RS**
- **Laboratories and Thermal Control** – Ir. M.P.A.M. Brouwer **RL**

Information and Communication Technology
Ir. F.J. Heerema **I**

- **Mathematical Models and Methods** – Dr. A.A. ten Dam *a.i.* **IW**
- **Software Applications** – Ir. I.A. Woodrow **IA**
- **Data and Knowledge Systems** – Ir. J.C. Donker **ID**
- **Information and Communication Services** – Ir. U. Posthuma de Boer **IC**
- **Embedded Systems** – Drs. E. Kesseler **IS**

Avionics
Ir. M.A.G. Peters **E**

- **Avionics Systems** – Ir. M.A.G. Peters *a.i.* **EA**
- **Electronics** – Ing. H. Slot **EE**
- **Instrumentation** – Ir. R. Krijn **EI**

Engineering and Technical Services
Ir. J. van Twisk **T**

- **Technical Design** – Ir. J.H. Halm **TO**
- **Technical Projects** – Ir. H.B. Vos **TP**
- **Production Workshop** – Ing. W.A.M. Schrijver **TW**
- **Service Workshop** – F. Hofman **TS**

General Services
W.C.P. van der Maas **G**

- **Electrical Engineering** – A.M.G. Reijntjens **GE**
- **General Facilities** – Ms. J.L. Leeuwen, R. Raterink **GF**
- **Buildings** – Ing. P.T. Postma **GG**
- **Library and Information Services** – R. Lammers **GB**
- **Document Processing** – Ing. D.J. Rozema **GT**

Administrative Services
Drs. L.W. Esselman R.A. **O**

- **Financial Administration** – N.C. van der Mey **OA**
- **Financial Planning and Control** – M.W.H. Puijk **OC**
- **Purchasing** – G.S. Wijdeveld **OI**

Breakdown of the staff at the end of 2002

(Cat. I: university graduates, Cat. II: advanced technical college graduates, Cat. III: others; between brackets the numbers at the end of 2001)

		Cat. I		Cat. II		Cat. III		Total	
Board of Directors		3	(3)	–	(–)	–	(–)	3	(3)
– Support Staff		18	(18)	10	(11)	9	(12)	37	(41)
		21	(21)	10	(11)	9	(12)	40	(44)
Fluid Dynamics Division	**A**	4	(3)	1	(2)	1	(1)	6	(6)
– Aerodynamic Engineering and Vibration Research	AE	10	(9)	1	(1)	–	(–)	11	(10)
– Aeroacoustics	AK	6	(7)	5	(4)	1	(2)	12	(13)
– Computational Fluid Dynamics and Aeroelastics	AT	17	(17)	–	(–)	–	(–)	17	(17)
		37	(36)	7	(7)	2	(3)	46	(46)
Flight Division	**V**	3	(2)	–	(–)	1	(1)	4	(3)
– Human Factors	VE	17	(21)	3	(3)	–	(–)	20	(24)
– Helicopters	VH	17	(16)	1	(1)	1	(1)	19	(18)
– Flight Mechanics	VM	10	(12)	–	(–)	1	(1)	11	(13)
– Operations Research	VO	22	(22)	5	(5)	2	(2)	29	(29)
– Flight Simulation	VS	–	(10)	–	(13)	–	(–)	–	(23)
– Training Development and Concept Validation	VT	10	(–)	11	(–)	–	(–)	21	(–)
		79	(83)	20	(22)	5	(5)	104	(110)
Air Transport Division	**L**	2	(2)	1	(–)	–	(–)	3	(2)
– Airports	LA	10	(10)	4	(4)	1	(1)	15	(15)
– Air Traffic Management	LL	27	(27)	3	(4)	–	(1)	30	(32)
– Transport and Environmental Studies	LT	7	(8)	6	(7)	1	(1)	14	(16)
– Flight Testing and Safety	LV	14	(14)	8	(7)	1	(2)	23	(23)
		60	(61)	22	(22)	3	(5)	85	(88)
Structures and Materials Division	**S**	1	(1)	3	(3)	1	(1)	5	(5)
– Loads and Fatigue	SB	21	(22)	4	(5)	1	(1)	26	(28)
– Structures Technology	SC	15	(16)	5	(5)	–	(–)	20	(21)
– Laboratory Facilities	SL	2	(2)	33	(30)	13	(16)	48	(48)
		39	(41)	45	(43)	15	(18)	99	(102)
Space Division	**R**	1	(1)	2	(2)	–	(–)	3	(3)
– Laboratories and Thermal Control	RL	11	(11)	5	(5)	–	(–)	16	(16)
– Remote Sensing	RR	10	(9)	3	(3)	–	(–)	13	(12)
– Systems	RS	14	(12)	–	(–)	–	(–)	14	(12)
		36	(33)	10	(10)	–	(–)	46	(43)
Information and Communication Technology Division	**I**	2	(2)	1	(-)	3	(4)	6	(6)
– Software Applications	IA	16	(16)	6	(6)	1	(1)	23	(23)
– Information and Communication Services	IC	15	(15)	19	(14)	9	(8)	43	(37)
– Data and Knowledge Systems	ID	19	(20)	10	(10)	–	(–)	29	(30)
– Embedded Systems	IS	10	(10)	7	(7)	–	(–)	17	(17)
– Mathematical Models and Methods	IW	15	(18)	–	(–)	–	(–)	15	(18)
		77	(81)	43	(37)	13	(13)	133	(131)
Avionics Division	**E**	3	(2)	1	(–)	1	(1)	5	(3)
– Avionics Systems	EA	11	(13)	8	(7)	–	(–)	19	(20)
– Electronics	EE	7	(7)	19	(22)	4	(5)	30	(34)
– Instrumentation	EI	9	(8)	18	(19)	4	(5)	31	(32)
		30	(30)	46	(48)	9	(11)	85	(89)
Engineering and Technical Services	**T**	3	(3)	–	(–)	1	(1)	4	(4)
– Technical Design	TO	1	(1)	10	(7)	1	(1)	12	(9)
– Technical Projects	TP	2	(2)	5	(5)	–	(–)	7	(7)
– Service Workshop	TS	–	(–)	2	(3)	3	(4)	5	(7)
– Production Control	TV	–	(–)	–	(6)	–	(1)	–	(7)
– Production Workshop	TW	–	(–)	10	(8)	11	(10)	21	(18)
		6	(6)	27	(29)	16	(17)	49	(52)
General Services	**G**	1	(1)	–	(1)	–	(–)	1	(2)
– Library and Information Services	GB	–	(–)	4	(4)	3	(3)	7	(7)
– Electrical Engineering	GE	–	(–)	5	(5)	5	(5)	10	(10)
– General Facilities	GF	–	(–)	3	(2)	33	(39)	36	(41)
– Buildings	GG	–	(–)	3	(3)	2	(2)	5	(5)
– Document Processing	GT	–	(–)	6	(6)	26	(27)	32	(33)
		1	(1)	21	(21)	69	(76)	91	(98)
Administrative Services	**O**								
– Financial Administration	OA	1	(1)	17	(15)	9	(12)	27	(28)
– Financial Planning and Control	OC	1	(1)	1	(1)	–	(–)	2	(2)
– Purchasing	OI	2	(2)	4	(5)	1	(1)	7	(8)
		4	(4)	22	(21)	10	(13)	36	(38)
German-Dutch Wind Tunnels	WA/WN	13	(12)	42	(46)	17	(18)	72	(76)
Grand total		403	(409)	315	(317)	168	(191)	886	(917)

3 Research Activities

3.1 Fluid Dynamics

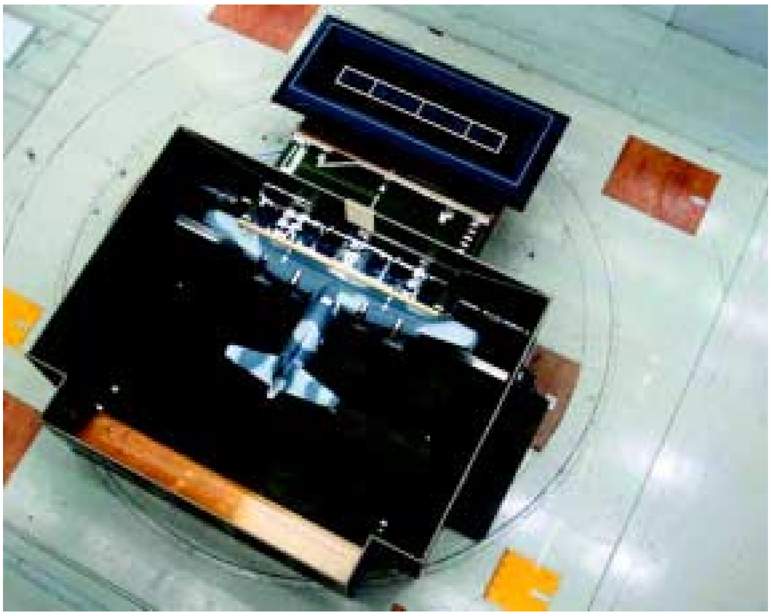
Research and development activities in fluid dynamics have been carried out in the areas of aerodynamic engineering and vibration research, aeroacoustics, computational fluid dynamics and computational aeroelasticity. Investigations and developments in applied aerodynamics and applied aeroacoustics were primarily related to aircraft operations near airports and safety. Applied aeroacoustics work was done also to support aircraft and engine manufacturers. Other principal areas of investigation were applied aerodynamics and aeroelasticity of military vehicles and civil transport aircraft. In space applications, the work concentrated on experimental aerodynamics related to base flows of space launchers. The volume of contract research and development activities in fluid dynamics was larger than in 2001 due to a high-volume contract covering low speed testing of the Short Take Off/Vertical Landing (STOVL) version of the X-35 aircraft in the German-Dutch Wind Tunnels Large Low-speed Facility (DNW-LLF).

STOVL X-35 jet flow field greatly increases the effective model size requiring a wind tunnel cross section as large as the DNW-LLF

Ground Run-up Enclosure

To comply with noise regulations the Royal Netherlands Air Force (RNLAF) is planning to build a Ground Run-up Enclosure (GRE) for its transport aircraft stationed at Eindhoven Airport. The GRE will be used for ground tests of C-130 Hercules, Fokker 50 and Gulfstream IV aircraft. The facility must be useable up to a maximum wind speed of 21 knots independent of the wind direction. This 21 knots requirement includes the tailwinds that are generally not acceptable in ground tests because they cause large propeller thrust and propeller torque fluctuations. For all wind speeds a very strict upper limit of torque-fluctuations of 2% is to be satisfied for the calibration of certain aircraft systems.

Because facilities capable of meeting these strict requirements do not exist, NLR was requested by the RNLAF to design one, in co-operation with Burns & McDonnell, a renowned U.S. engineering firm of airport facilities. TNO TPD performed the acoustic design of the facility. The aerodynamic design was developed in the Low-Speed Tunnel DNW-LST, with the emphasis put on fulfilling the requirements for the most critical tailwind condition. In the DNW-LST, experience had been obtained in engine/propeller simulation. Moreover, it is a cost-efficient wind tunnel offering the right environment for analysing the complex flow that occurs inside these types of facilities. The tested model, of scale of 1:13.5, represented one half of the GRE, which allowed it



Wind tunnel set-up with full Ground Run-up Enclosure model and C-130 Hercules aircraft model

to be tested in the 3m x 2.25m test section. The final step was to test the geometry developed for all wind directions, for which a full model of the GRE was built. Using model parts from the half-model tests reduced costs. The full-model test was performed in the 9.5m x 9.5m test section of the DNW-LLF. Atmospheric boundary layer simulation, enabling the wind velocity profile and atmospheric turbulence to be simulated, was developed especially for this test. The model had outside dimensions of about 5 m and was mounted on a turntable.

In order to measure thrust and torque fluctuations, the two port propellers were equipped with rotating shaft balances capable of measuring all forces acting on the propeller directly at the propeller axis. This is important because mass-inertia effects have to be minimised. It was shown that strict requirements could be met for all wind directions with only limited modifications to the baseline concept developed in the DNW-LST. Fluctuation levels remained below 1% even for the most critical tailwind direction. Differential pressures were measured at more than 100 locations on the model, and the dynamic behaviour of the pressure was determined at some of these locations. From the measurements, input data were derived for the final structural design of the facility. In all, the available aerodynamic expertise and facilities of NLR combined with the experience of Burns and McDonnell have led to a unique design complying with the requirements posed by the RNLAF.

Aerodynamics of Civil Transport Aircraft, GARTEUR Co-operation

The GARTEUR Aerodynamics Action Group 28 is a co-operation of Airbus UK, DLR (Deutsches Zentrum für Luft- und Raumfahrt), EADS Airbus France, EADS Airbus Germany, ETW (European Transonic Windtunnel), FOI (Swedish Defence Research Agency), NLR and ONERA (Office Nationale d'Etudes et de Recherches Aérospatiales). The research institutes DLR, FOI and NLR completed the construction of a full-span transport aircraft model (AS-28), which was designed by DLR.

One of the main objectives of the GARTEUR (AD) AG-28 transonic wing/body code validation experiment is to provide high quality experimental data in terms of pressures and boundary layer surveys on a half-span model of the AS-28 wing in the S1 wind tunnel of ONERA. The other objective is to provide accurate forces and selected pressure measurements of the AS-28 full-span model in the transonic DNW-HST and ETW wind tunnels. The measurements in the DNW-HST are performed as part of the second objective of this GARTEUR activity. The Mach number ranged from Ma = 0.60 to Ma = 0.85 and the lift

GARTEUR (AD) AG-28 aircraft model in DNW-HST wind tunnel

coefficient ranged from zero to buffet onset (about 0.65) at each Mach number. The DNW-HST test is to provide absolute forces/moments and pressure distributions for a 1:38-scale full-span model. The test data are therefore corrected for wall interference by a measured boundary conditions approach, and corrected for sting interference by tunnel calibrations.

Aeroacoustics

Air Vehicle Operations-related Acoustics

One of the key missions of NLR is to develop noise computation procedures for aircraft operations, and to apply these computational procedures to predict noise levels to support the government of the Netherlands, as well as private enterprises such as airports and aircraft operators. To improve the modelling of aircraft noise sources, NLR has invested in the knowledge of advanced measurement procedures using arrays of microphones both in wind tunnel testing and at airports.

In the framework of this government-funded research NLR has realised a capability to generate bright and colourful images of aircraft noise. These images are generated by special post-processing procedures of the acoustic array data. NLR has carried out measurements at Amsterdam Airport Schiphol on a large number of landing aircraft, using microphones arranged in acoustic arrays, under contract to the Madrid Boeing Research and Technology Centre. This application of NLR technology will allow the aircraft manufacturer to design quieter aircraft. KLM Royal Dutch Airlines has been contracted to supply NLR's customer with data from the aircraft flight recorders. Amsterdam Airport Schiphol

Noise sources on aircraft landing on Amsterdam Airport Schiphol made available air traffic data and the Royal Netherlands Meteorological Institute (KNMI) provided weather data.

These most recent array measurements were aimed at the quantification and visualisation of noise contributions from various aircraft sources. Noise sources include not only engines, but also details of high-lift devices (edges of flaps and slats), landing gear components and other less well-known sources. The noise measurement equipment consisted of three microphone arrays located at about 750 m from the threshold of runway 06, the *Kaagbaan*. The main array consisted of more than 200 microphones flush mounted in a square, horizontal platform. Two smaller additional square platforms were similarly equipped with an array of microphones, bringing the total number of microphones used to well above three hundred. The analysis of the acoustic array data shows that the measurement procedures have worked in accordance with expectations, and a multitude of colourful images is in the making. These results will allow the customer to see aircraft noise at Amsterdam Airport Schiphol, and will enable NLR to look for further improvements to its knowledge base with respect to aircraft noise mechanisms.

Turbofan Engine Source Noise and Duct Acoustics

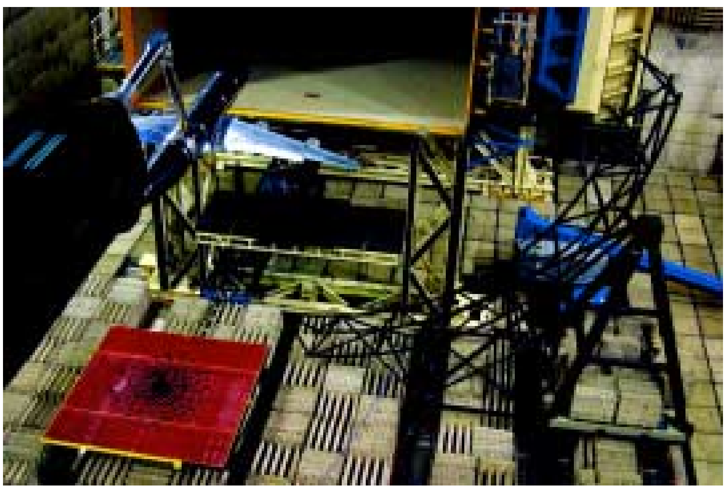
The validation of noise reducing technology concepts is carried out on a large scale in the 'Technology Platform' SILENCE(R) (Significantly Lower Community Exposure to Aircraft Noise). NLR is involved in most of the work packages concerning turbofan engine source noise and duct acoustics. Preparatory work was carried out for acoustic testing in a model engine at a facility of Rolls-Royce. Several circular microphone arrays were designed for acoustic mode detection.

Research on acoustic liner technology was continued along two lines. First, a facility was designed and built for the testing of liner samples under hot stream conditions. This unique facility allows insertion loss and impedance to be measured at flow temperatures up to 550 °C, at a Mach number of 0.35. A large number of liner samples, provided by industrial partners, have been tested successfully. Second, the possibilities of 'blown' liners were explored. These are liners with air flowing through the structure. As this is also a method used to de-ice nacelles, such liners are also called 'anti-icing' liners. Measurements on these liners in NLR's Flow Duct Facility showed that the airflow can be used to adapt the acoustic characteristics of the liners, and thus adapt their performance to various flight/engine conditions.

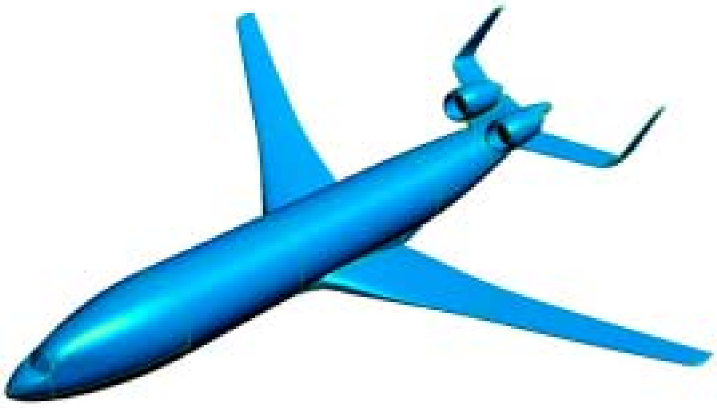
Airframe Noise

In the framework of SILENCE(R) contributions were made to two wind tunnel test campaigns in the DNW-LLF. NLR carried out acoustic array measurements on an Airbus A340 model with low-noise high-lift devices, in both the open and closed test sections of the DNW-LLF.

The tests in the open test section were aimed at validation of several noise-reducing concepts applied to high lift devices. The recently improved array technology proved to be a valuable tool for the analysis of the results. For example, an unexpected noise source was revealed that was related to specific parts of the aircraft model. These parts were not representative for the full-scale geometry. New post-processing software allowed accurate estimates of the absolute source



Investigation of the airframe noise signature of a 1:10-scale model of the Airbus A340 in the open-jet test section of the German-Dutch Wind Tunnels DNW-LLF



Low-noise aircraft configuration with exhaust jets shielded by tail surfaces

levels to be made for several parts of the wing, with and without noise-reducing devices.
A selection of devices was tested again in the closed test section of the DNW-LLF, enabling the aerodynamic aspects to be assessed. Some of the devices turned out to be unacceptable from an aerodynamic point of view.

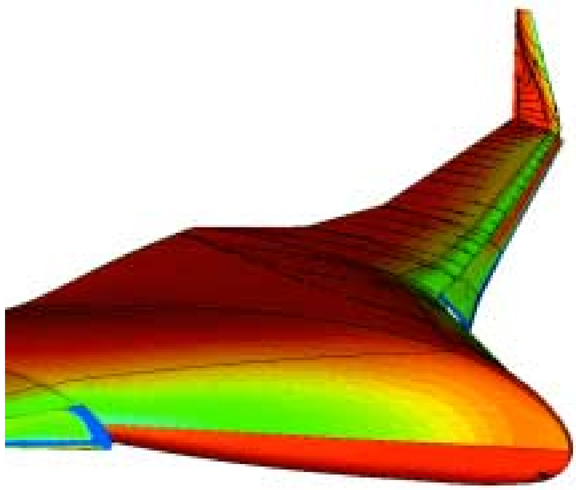
Low Noise Aircraft Configurations
One of the technologies to reduce noise is to shield engines by parts of the airframe, for instance the fuselage and two vertical tails.
A study of this potential noise reduction technology, the European Union project ROSAS, has been initiated, with an analysis of the aerodynamic and acoustic implications of aft-located engines.

Computational Fluid Dynamics

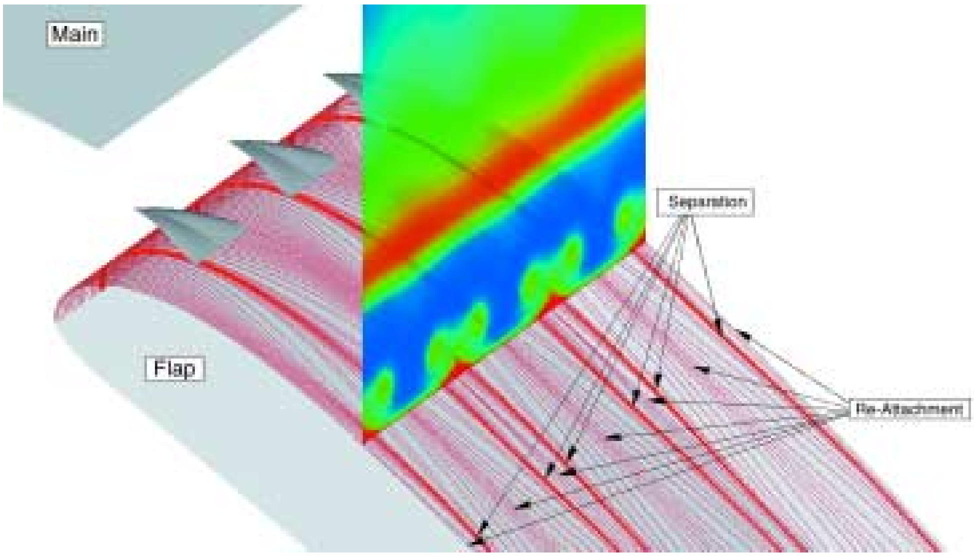
NLR continued research on Large Eddy Simulation (LES) in co-operation with DLR, to provide input for noise source modelling around large separated areas. A new approach to a hybrid Navier-Stokes - LES modelling, based on a dynamic switch between the Navier-Stokes and Large Eddy Simulation areas in the simulation, has been investigated. A hybrid turbulence model has been implemented and benchmarked for cylinder flow, relevant for simulating the unsteady vortex shedding from the leg of a landing gear.

In the search for improvements in structural efficiency combined with aerodynamic efficiency, the flying wing configuration still has attention of the industry. This configuration features performance gains over conventional configurations due to a reduction in wetted surface in combination with wing bending moment relief due to spanwise payload distribution. The inherent strong interdependencies of disciplines for such a configuration study calls for a multi-disciplinary approach. NLR contributed to the development of a Computational Design Engine (CDE) incorporating multi-disciplinary design and optimisation for a blended wing body configuration. This CDE for aircraft optimisation was implemented at sites across Europe. One part of the CDE, provided by NLR, is the implementation of high speed and low speed aerodynamic and aeroelastic assessment using NLR's Computational Fluid Dynamics system ENFLOW. Other disciplines involved are stability and control, structures, and innovative loading and accommodation. Follow-on research led by Airbus, focussing on a very efficient large aircraft passenger transport, was started.

Increasing the Competitiveness of Industry
NLR has conducted research on innovative high lift concepts for civil transport aircraft, considering cost-effective flow control solutions that provide low-speed performance of a 200-250 seat aircraft favourable in aerodynamic and noise characteristics. NLR conducted research on flap designs with substantially shorter chords than in conventional High-Lift systems, with as benefits an



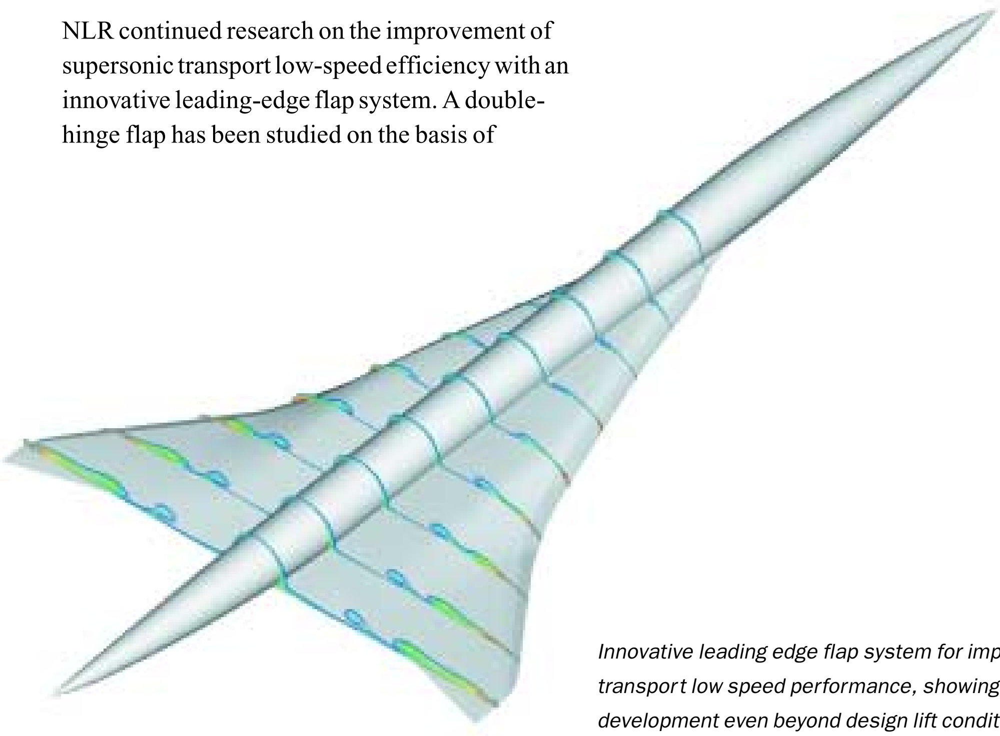
Assessment of low speed characteristics of a fuel-efficient blended wing body configuration



Innovative High Lift concept, using flow control through an array of delta wings to provide cost-effective low speed performance

increased freedom of the structural design of the wing, for lower weight or increased space for fuel storage. Short flaps have the drawback of unstable flow reversion in the wing wake, especially in the landing configuration. To overcome this drawback NLR investigated the idea of placing an array of delta wings in the gap between wing and flap. The effectiveness of the counter rotating vortices induced by the delta wings in re-energising the wake flow of the main wing has been demonstrated.

NLR continued research on the improvement of supersonic transport low-speed efficiency with an innovative leading-edge flap system. A double-hinge flap has been studied on the basis of simulations for a sequence of three different flap settings, showing a major and continuous reduction of separated flow, thereby significantly reducing drag at design lift. The third flap setting defined by NLR fulfils the lift-to-drag target and has been selected for experimental verification on a large wind tunnel model. The predicted lift-to-drag performance has been confirmed in wind tunnel tests.



Innovative leading edge flap system for improved supersonic civil transport low speed performance, showing only moderate vortical flow development even beyond design lift conditions

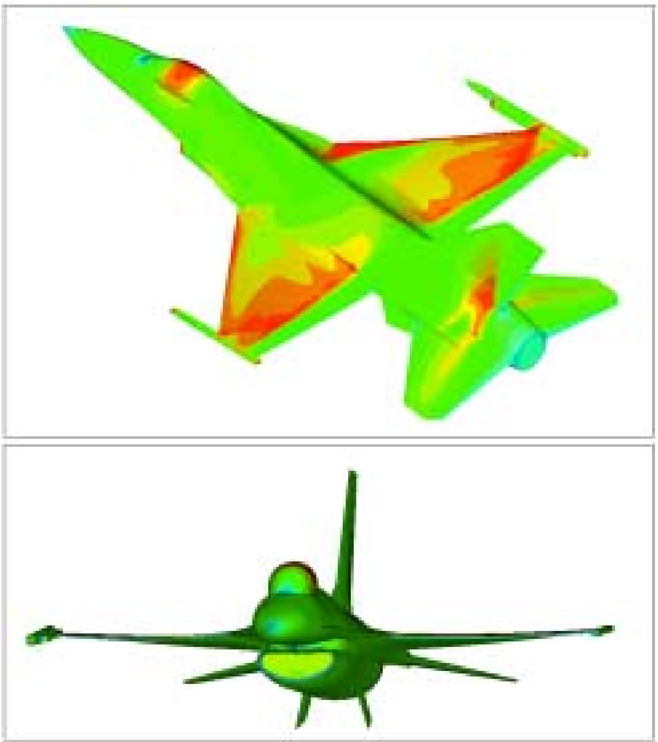
Increasing the Effectiveness and Efficiency of Military Aircraft

NLR continued its support to the certification and qualification of RNLAF F-16 configurations, and contributed to research on F-16 outer wing loads in the framework of life-cycle assessment. A study to ensure linear aero-elastic flutter certification with NASTRAN has been conducted, and a study to investigate aero-elastic effects of ageing aircraft was started.

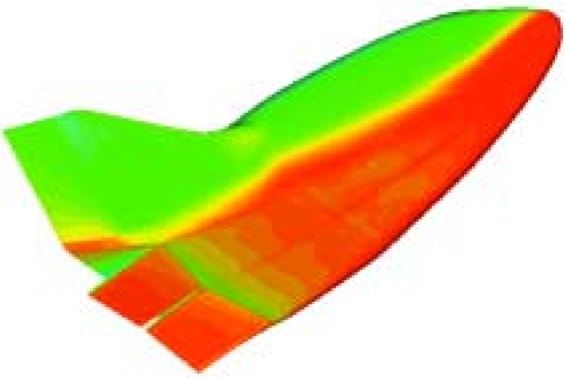
The effect of F-16 wing tip configurations on the static deformation of the F-16 A/B wing has been investigated using aeroelastic simulation technology developed in a previous National Technology Project (NTP). The aerodynamic and inertial loads obtained on the basis of the outcome of the NTP have been used as input for a detailed analysis of internal stresses in relation to the fatigue life of F-16 structural parts, using a detailed F-16 finite-element stress model.

The investigation has led to guidelines for the selection of F-16 training configurations that have minimum effect on lifetime consumption. Further it has been learned that for extreme limit load conditions and corresponding non-linear flow physics, the determination of the final wing deformation calls for a time-accurate approach. As part of the ongoing investigation towards the understanding and modelling of non-linear aeroelastic phenomena, such as transonic dip and limit cycle oscillation (LCO), various time accurate viscous flow simulations using the ENFLOW system have been conducted. For an F-16 heavy store configuration, experimentally observed limit cycle oscillations have been reproduced in Reynolds-averaged Navier-Stokes simulations at NLR for the first time.

The simulation technology used to compute the static deformation of the F-16 outer wing under limit load conditions and to compute limit cycle oscillations is relying to a considerable extent on the achievements of project called 'Joint Programme 12.15' within the THALES framework.



Study on the effect of F-16 wing tip configurations on the static deformation



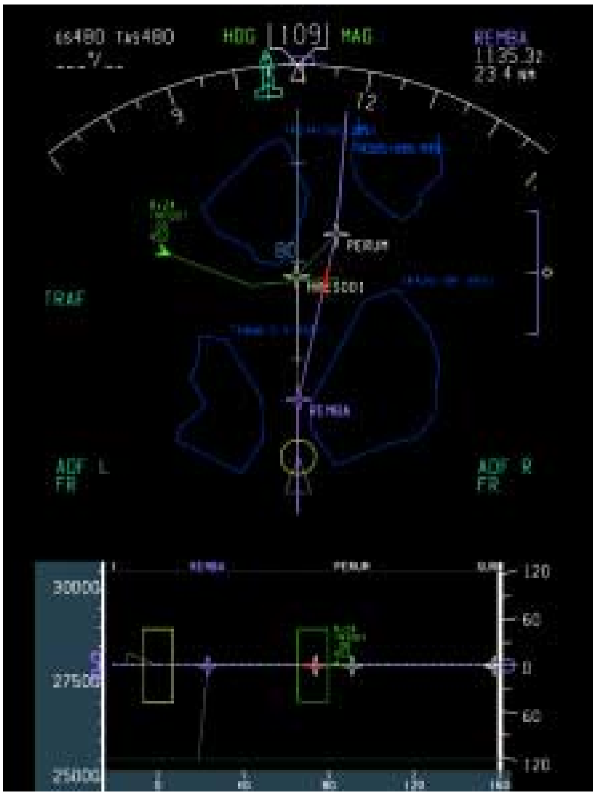
Predicted surface temperature on the X-38 Crew Rescue Vehicle, accounting for hypersonic flow conditions and real gas effects

Participation in Space Programmes

NLR concluded its participation in the X-38 crew rescue vehicle programme by performing aerothermodynamic simulations of the re-entry phase. These simulations have been used to complete the aerothermodynamic database of the X-38, for different flap settings, high angle of attack and Mach number, zero and non-zero sideslip, and real gas effects.

3.2 Flight

NLR performs research in support of innovative, safe and efficient airborne operations with all types of aircraft and aircraft systems, in the military and civil domains. The continuing increase in the societal need for civil air transport will necessitate the use of advanced aircraft systems for navigation and separation of aircraft, in order to allow more aircraft to operate in the same airspace. Such future aircraft systems are modelled, simulated and tested in realistic flight simulators under expected operational circumstances in order to assess and predict the operational utility and cost effectiveness of national and international applications. Potential risks, such as human performance issues, handling qualities problems and imperfect or even flawed operating procedures are identified.
Self-protection and weapon system effectiveness are crucial for safe and sustainable peace keeping operations in various areas of the world. NLR therefore analyses threats and investigates applicable technologies and procedures that can contribute to effectiveness, cost reduction and adequate survival rates.



Display used by the flight crew in INTENT validation trials

Problems are not solved by technology alone. Any new technology has to be accepted and implemented, its users have to be trained, and operating procedures adapted. In response to these requirements, NLR has created a new department, Training Development and Concept Validation, that focuses on both the validation of potential technologies and the implementation requirements associated with training and retraining of staff or new selection requirements. By the use of objective experiments and data gathering techniques, the department will provide independent information for national and international government policy development and industrial decision making.

Some examples of specific activities and projects are mentioned below.

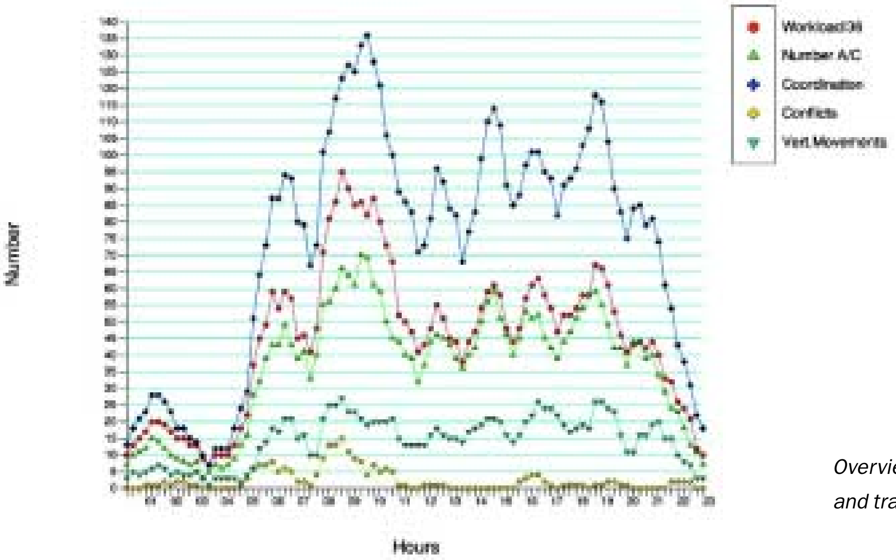
Procurement and Assessment

In the area of aircraft procurement and assessment, work focused on the potential application of advanced technologies in fighters and helicopters, such as crew assistant intelligent agents, helmet-mounted display systems and aircraft self-protection measures. Work on the application of Uninhabited Aerial Vehicles (UAVs) was continued intensively in collaboration with Netherlands industry.

Systems and Operational Concept Design

In the area of aircraft systems and operational concept design, proposals for studies and experiments as input for the so-called ACARE programme were completed. ACARE, the Advisory Council for Aeronautical Research in Europe, drafts the strategic research agendas needed to ascertain sound and safe air travel in 2020 and beyond.

The utility of data transmission systems that continuously broadcast the intentions of aircraft flying in civil airspace was investigated in the EU project INTENT on the transition towards global air and ground collaboration in traffic separation assurance. These intentions, such as destination, flight trajectory and flight path changes, can be used by Air Traffic Control and/or other aircraft for improving the use of the available airspace and the planning of arrivals at airports. Experiments carried out to validate the concept will lead to



Overview of relation between controller activities and traffic loads

specifications and requirements for the development of airborne avionics and operational procedures. NLR uses a unique combination of its Research Flight Simulator (RFS) and ATC Research Simulator (NARSIM) for the objective measurement of benefits of more direct routing and less time spent airborne on punctuality, fuel use and environmental load.
Results indicate that the intent information has no effect on airspace capacity when applied in a conventional ATC scenario. However, when the information is used to allow flight crew to assure aircraft separation, as in the Free Flight operational concept, more traffic can be handled.

Mediterranean Free Flight

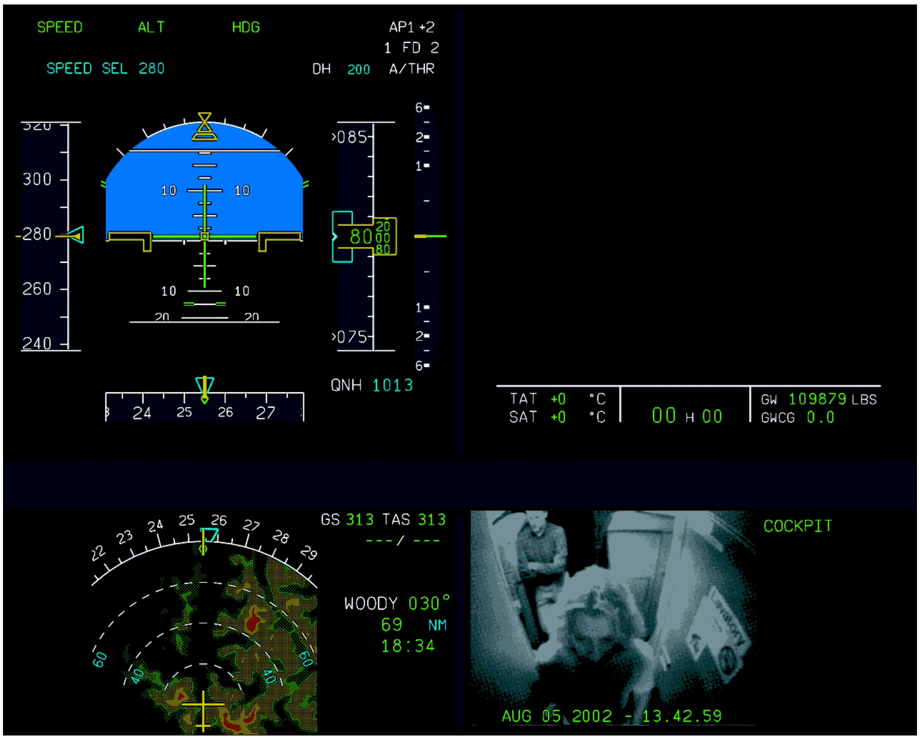
In the European Union (EU) project Mediterranean Free Flight, possible implementations of the Free Flight operational concept were defined and tested in the context of TEN-T (Trans European Transport Networks). The test area was located in the Mediterranean area. NLR contributed by defining the operational ATM concept, simulating possible implementations, identifying human factors issues and performing flight tests and safety assessments. Because Air Traffic Controllers would have to deal with the transition from managed air space to Free Flight Airspace, studies into specific activities required for performing the controller's task were initiated.

New Screen

In the EU project New Screen, NLR addresses the concept of a three-display (as opposed to the current day six-display) cockpit from the point of view of certification and technology requirements. Recent advances in flat panel (especially LCD) technology have made it feasible to design very large displays that show more information, and in a more flexible way, than in current practice. Key criteria in the development of such screens include safety, dispatchability, and reconfigurability, all touching on the aircraft and crew's ability to continue safely in the event of a display failure. The work has included: adaptation of the Human Machine Interface (HMI) and symbology to the new format; simulation of possible failure modes; implementation of the design in the RFS; and evaluation of the HMI by pilots and other experts.

Support for the Military

In the military field, support for the industry aiming at participation in the design phase of the Joint Strike Fighter was continued as well as the final development of maritime helicopters. This NH90 programme gained great success by receiving orders for significant numbers of helicopters from Nordic among other countries. Military self-protection has become more important than ever, so the research and consultancy into issues associated with missile and laser threats, self-protection systems and flying techniques was continued.

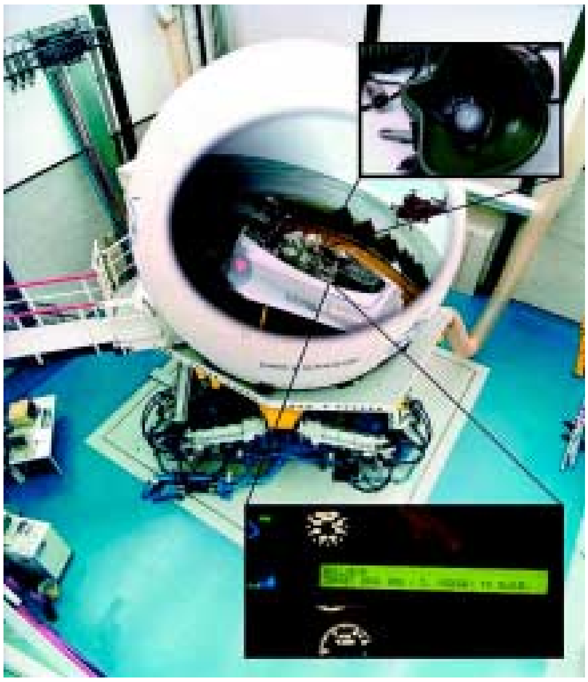


NewScreen display showing various data, including security camera image (lower right), and system parameters (upper right)

In the FalconEar project, NLR teamed with Philips Speech Processing to develop a fighter cockpit voice control application, as a candidate for inclusion in the Joint Strike Fighter. The voice control application was implemented and evaluated on the National Flight Simulator (NSF), NLR's F-16 Mid-Life Update simulator. Functions were developed to demonstrate voice applications across the various domains of fighter cockpit employment, and included emergency checklist control, interactive data retrieval procedures, and speaker-independent recognition in parts of the syntax, for facility name recognition to retrieve navigational aid and radio data. Simulator trials were used to conduct both system performance and human factors analysis of the voice control application. Analysis of pilot errors showed a strong training effect, with the average error rate decreasing from 27% to 13% over the course of training. Overall, pilots felt that commands were consistent, concise, natural, and easy to comprehend. Further, pilot ratings indicated that voice control did not negatively affect aircraft system awareness, overall situation awareness or task saturation.

Aircraft Simulation

In the area of aircraft simulation, work on the Research Flight Simulator (RFS) was continued with the completion of the re-configurable cockpit module. The development of NLR's context simulation concept, addressing detailed simulation



NLR's National Simulation Facility (NSF) as configured for voice control evaluations, showing the experimental microphone and message screen (insets) of combined operational and environmental factors influencing the realism of the human operators behaviour, continued with the testing of measurement techniques for objective assessment of human behaviour with future systems, a part of the safety assessments of future aircraft operations.

The simulation architecture largely defines the flexibility of simulators. In the JSA (Joint Simulation Architecture) project, simulation components that could serve as building blocks for simulators with potential re-use in more than one type of simulator were identified. Based on the principles of the High Level Architecture (HLA), a component-based simulation architecture for a training system has been proposed by Dutch Space, TNO Physics and Electronics Laboratory and NLR. The NLR Pilot Station has been restructured in accordance with the component-based architecture, and an experiment has been carried out to measure the performance with emphasis on latency issues.

The EUCLID RTP11.1 project addresses the issue of 'Realising the potential of networked simulation in Europe'. Setting up complex military exercises that involve networks of many different types of simulations will play a crucial role in future military strategy. The work aims at overcoming the obstacles that prevent synthetic environments (SEs) from being exploited in Europe by developing working processes and integrated prototype tool sets that will reduce the cost and time scale of creating and utilising SEs for training, mission rehearsal and simulation-based acquisition.

Training Development

In the area of training development the feasibility of an integrated European training system for fighter / bomber pilot training for the period 2010–2030 was investigated.
Twelve European Air Forces have assigned a consortium of industry and NLR to perform a state-of-the-art Training Needs Analysis using ADAPT-IT (Advanced Design Approach for Personalised Training - Interactive Tools). These tools identify the needs of various operational missions in terms of pilot skill competencies. Although most pilot tasks will be easier to perform than today, the mission context can be more demanding. All pilot competencies therefore need to be enhanced. A training syllabus will be outlined that is much more mission-oriented than the current training. This way, much of the squadron-based training may be transferable to the Euro Training. It is foreseen that, besides a modern training aircraft, embedded simulation and networked simulators will be required for future pilot training.

NLR co-ordinates the EU project ADAPT-IT (Advanced Design Approach for Personalised Training - Interactive Tools), which aims to assist training designers in meeting the stronger demands from organisations and society for more effective and efficient training for increasingly complex cognitive competencies. A prototype of a server-client tool based on the Four-Component Instructional Design methodology, which is dedicated to training for complex cognitive skills, has been completed. The training design method and tool has been successfully validated by training designers from EUROCONTROL and the Swedish ATC academy (SATSA), and from Piaggio Aerospace Industries, developing actual training in Air Traffic Control and aircraft maintenance, respectively.

A novel training for flight deck Situational Awareness and threat management techniques has been developed and delivered in the ESSAI (Enhanced Safety through Situation Awareness Integration in Training) project of the EU. Based on flight-crew surveys and incident and accident analysis, a practical, hands-on training solution was developed for these competencies. The training materials and techniques were experimentally evaluated with the help of sixteen two-person crews. The project resulted in a DVD-based multimedia flight crew training package. This training package has generated great interest among the airline community, and there are firm plans to disseminate it through several carriers.

Maintenance

In the area of maintenance, the EU project STAMP (Specialised Training for Aviation Maintenance Professionals) addressed the need for properly accredited training in order to ensure the competence of managers and trainers in handling human factors in aircraft maintenance organisations. The industry has recently mandated human factors training for certified engineers in JAR 66. Similarly, human factors instruction in continuation training is mandated in JAR 145. Engineers, trainers and managers are increasingly aware of the role of human factors in their areas of responsibility, but often feel inadequate to make effective changes. Training needs were assessed and described in terms of the desired competencies, including human factors. These training requirements will be used as a basis for a training course that should certify managers and trainers as human factors specialists. NLR participates in STAMP together with SAS of Sweden, Norway and Denmark, FLS Aerospace of Ireland, Trinity College Dublin of Ireland and Training and Technical Advice Centre Thomas Aristou of Cyprus.

Crew interaction and Situational Awareness

Crew interaction and Situational Awareness (or SA) of the flight deck crew are increasingly recognised as critical elements of aviation safety. NLR is actively involved in research to identify root causes of SA problems and objective means of assessing flight crew SA, and to develop countermeasures against deficiencies.

In the EU-funded project VINTHEC2 (Visual Interaction and Human Effectiveness in the Cockpit, Part 2), such objective physiological measures as eye point-of-gaze are being used in conjunction with cognitive modelling of the flight crew's tasks, in specifying a set of behavioural markers that can help assess team SA in operational flight settings. Dissemination plans call for the VINTHEC2 approach to be promulgated not only to the aviation community, but also to domains such as maritime bridge operations, and medical operating theatre procedures, which share some essential characteristics of the flight crew's task (team interaction, time criticality, complex systems, highly advanced automation, etc).

Human Factors in ATC

NLR has conducted show mode evaluations of Eurocontrol's new Medium Term Conflict Detection (MTCD) system as implemented at several sites around Europe. A variety of analysis techniques (e.g. paired observations, mental walkthroughs, anomaly analysis, and behavioural data logging) were used to explore controller roles, tasks and working methods under such a new system.

Human Factors in Certification

In the area of human factors aspects of aircraft certification, NLR participated in an FAA/JAA (Federal Aviation Administration/Joint Aviation Authorities) harmonisation working group that develops new rule-making based on human factors, for airworthiness. NLR provided a theoretical framework for analysing the deficiencies in the rule-making (Part 25) and formulating new rule-making.

3.3 Air Transport

For the global air transport business the year 2002 started with a significant decline of revenues after the September 11 tragedy compared to the year before. Owing to an economic downturn, this decline continued for the majority of the airlines and even deepened during the year. Despite this slump in the air transport sector, NLR has continued to increase its market share in the field of air transport research, development and operational support. In this field NLR assists air traffic service providers, airports, airlines, manufacturers, and European and national governmental agencies in their primary processes.

NLR has been active in such areas as Air Traffic Management, airport operations, safety studies, assessments and environmental impact studies of air transport, where necessary putting in its expertise, facilities and knowledge on various other domains for addressing air transport problems in multidisciplinary project teams.

Subjects of research and development have included the validation of air traffic control concepts (concerning area control, approach and tower) under simulated operational conditions. Within various projects of the European Union (EU), future operational benefits were demonstrated for advanced arrival and surface management systems. New aircraft/ground control datalink structures and implementation strategies were researched and tested with NLR's Air Traffic Control Research Simulator (NARSIM). By the design of efficient airport approach and departure procedures that provide more capacity within noise limits NLR is preparing for better use of the European Air Traffic Management system. The combination of strong assets: NARSIM, the Metro II and Citation II research aircraft and the Tower Research Simulator enables NLR to validate research results in a realistic environment.

NLR's expertise and knowledge of air transport was highly sought for by many national and international panels, committees and review boards. A major contribution was provided to the Advisory Council for Aeronautical Research in Europe (ACARE) in establishing what changes to the air transport system should be brought forward to reach the goals of the Vision 2020 paper. In addition, NLR contributed in the European Transportation Safety Council, the European Joint Safety Strategic Initiative, and many other bodies.

Close co-operation was pursued with and contracts continued to be carried out for EUROCONTROL, the U.S. Federal Aviation Authority and NASA.

Within the Netherlands, minimising the environmental load of air transport (noise and gaseous emissions) remains high on the political and societal agenda. NLR researches various possibilities to reduce the noise impact and proposes new procedures and tools, for example for Amsterdam Airport Schiphol and its stakeholders.
For Frankfurt Airport NLR is involved in providing guidance in noise monitoring around the airport.

One of NLR's core activities is oriented at increasing the safety of the entire air transport system. Multifaceted as main characteristic, safety improvements must be sought on the basis of a profound understanding of the intricate elements of the system. Therefore, NLR has carried out research to better understand how the air transport system can be unravelled, and to translate this understanding by means of models, mathematical analysis and tools. NLR has performed a multitude of analyses for customers world-wide. NLR provides tools and policy support to the Aeronautical Directorate of the Ministry of Transport and Air Traffic Control the Netherlands (LVNL). With its Air Safety Database NLR evaluates new or changed procedures, operations and infrastructure concepts of airports, etc. This database is used in particular in the provision of detailed background material for third party risk analysis and in qualitative risk assessments for LVNL while reviewing new and changed procedures at Amsterdam Airport Schiphol. NLR has been involved in many quantitative safety assessments with the LVNL in its newly developed and successful methodology for evaluating changes in the air traffic management system. The TOPAZ facility, in which NLR simulates the complex human behaviours of Air Traffic Controllers and pilots, plays a crucial role in these evaluations.

In the aftermath of an unfortunate mid-air collision of two aircraft over Switzerland, NLR won a prestigious contract of the Swiss Ministry of Environment, Transport and Energy to assess the Swiss Safety Management system for air transport operations.

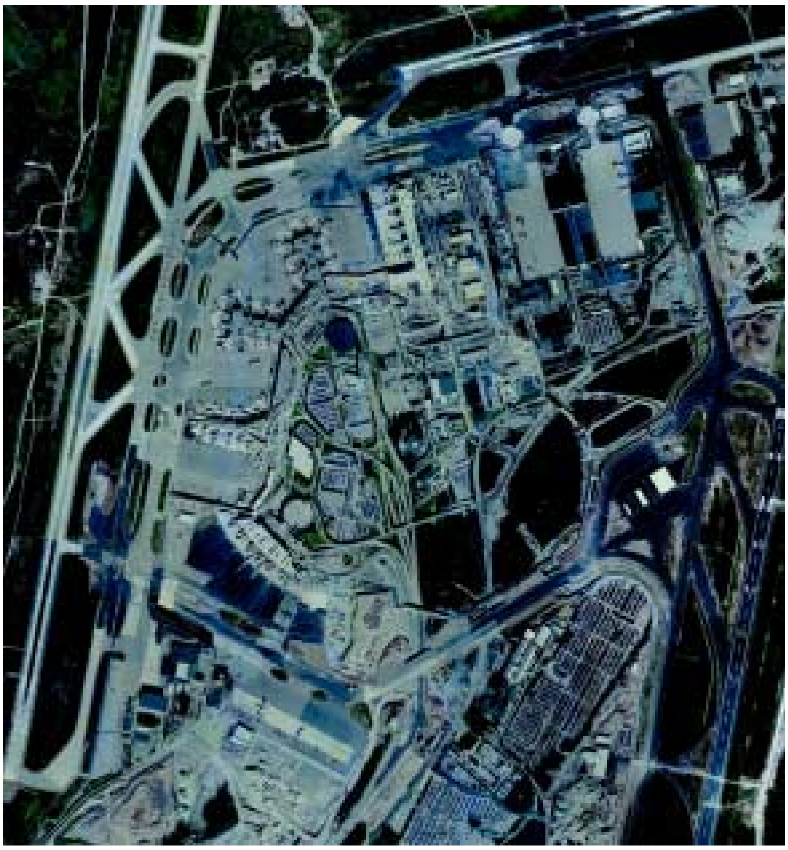
In the sections below some examples are given of projects conducted.

Third Party Risk Analysis

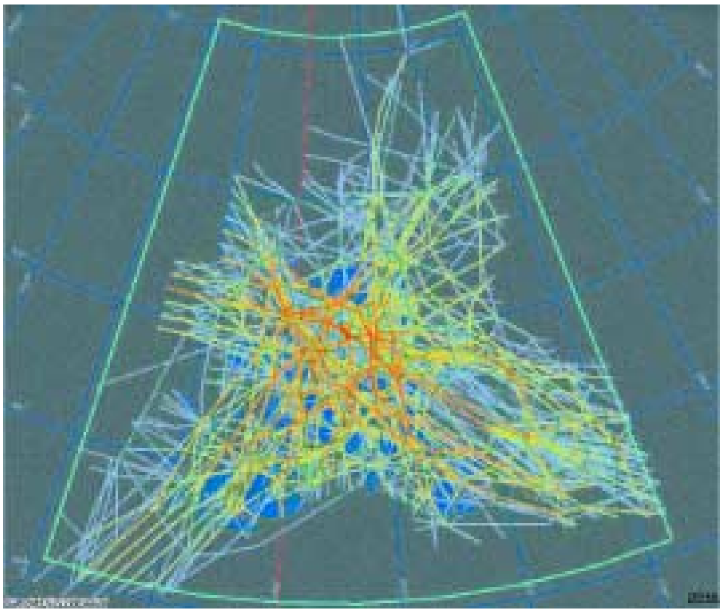
Arlanda, the airport of Stockholm, Sweden, has provided an economic boost to its vicinity, as is the case with many airports. As a consequence, the area around Arlanda has started to develop and prosper. Also, the airport itself is flourishing: Arlanda is currently the largest airport in the Nordic countries, with 64 airlines carrying well over 18 million passengers annually. A third runway has been constructed to cater for future growth and environmental compatibility. Eventually, these developments have led to tension between the airport and its surroundings, as is common to many airports. A recent addition to discussions at Arlanda has been the issue of third party risk, the risk of possible aircraft accidents to the population living and working around the airport. The Swedish authorities have contracted NLR to conduct a third party risk analysis for Arlanda. The results are to be used in the Environmental Impact Statement for the third runway and for land-use planning around Arlanda. In particular, decision making with regard to a large new building project near the airport will require an evaluation of the risks involved. The analysis concerned the calculation of risk contours, societal risk curves and supporting advice regarding risk management policy and risk perception issues. The calculations, carried out for current and future air traffic scenarios, were completed. NLR was selected by the Swedish authorities because of the extensive experience of NLR in the area of third party risk around Amsterdam Airport Schiphol and other airports in Europe.

Borderless European Air Traffic Management System: ONESKY

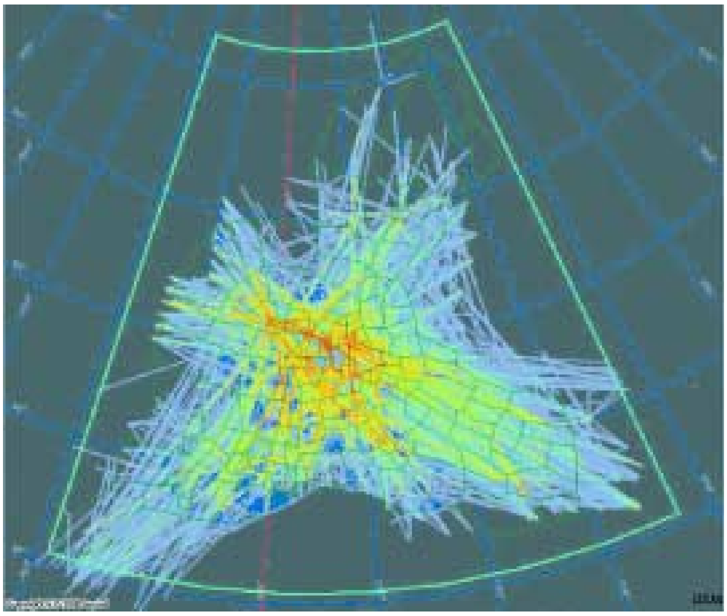
ONESKY is a project in support of the goal of the European Commission's Single European Sky initiative. NLR leads a European consortium of



Aerial view of Arlanda Airport, Sweden air traffic service providers and aeronautical research establishments that is tasked by the European Commission to propose new structures for the European airspace system. The objective of ONESKY is to design a European airspace structure that is able to support an efficient traffic flow based on traffic demand and needs, rather than on existing national structures and frontiers. An important factor is the division of the airspace between military and civil users owing to geopolitical realities.



Baseline (conventional routing) traffic density in area under study



Clean sheet design traffic density in area under study

The ONESKY work programme was conducted using fast-time simulations by a number of ATM Research Centres within Europe. NLR used its Total Airspace and Airport Modeller (TAAM) to verify various proposals on feasibility. Operational expertise was assured by the participation of various civil air traffic service providers, military air traffic service providers and an airport operator.

In ONESKY two lines of action were followed. By identifying those areas within the current European airspace which contribute most to the overall delays, and rearranging the airspace structure of these areas, irrespective of national boundaries and military airspace, improvements of the entire system could be achieved. In the second line of action, a 'clean sheet' approach was taken to design the European airspace system. As a basis it used a new airspace design strategy that was developed in the TOSCA II programme and included direct routing of aircraft above FL285 and a structured route system beneath FL285, without reference to national borders.

A reduction in the number of national (political) and physical air traffic control sector boundaries would lead to a decrease in the number of conflicts and an increase in the capacity of sectors involved. This would allow the total number of sectors to be reduced and the traffic to be increased by 30 to 35 per cent, compared to present standards.

Simulation results obtained in ONESKY. The figures left show, within the clean sheet design, the difference in traffic density between the baseline design (with conventional routing) and the clean sheet design, including direct routing and flexible use of military airspace. Projected on Europe are the upper airspace routes for air traffic, showing in yellow the busiest routes in the number of aircraft and in red the congested airways. In green the air traffic control sectors are depicted.

NLR's Tower Research Simulator (TRS)

Improving the Airport Ground Efficiency

Since airports are becoming bottlenecks within the ATM system, their capacity has to be increased to match the demand for air traffic. At the same time the safety of airport operations must be improved or at least remain on current levels, while the severity of environmental constraints placed on airports is increasing. At many places, capacity gains by extensions of existing infrastructure such as addition runways are impossible. Other measures to increase airport capacity are being explored. The introduction of Advanced Surface Movement Guidance and Control Systems (A-SMGCS) leads to higher efficiency in the management of airport traffic. In the project Benefit Testing of an A-SMGCS (BETA), NLR has been involved in testing new concepts and procedures with an operational A-SMGCS on two medium-sized European airports (Hamburg and Prague). A large European consortium has proved the feasibility of new concepts for the air traffic controllers in the airport tower. Features such as labelled surveillance data shown on electronic airport maps, planned action time lines from the Departure Manager and the system's flexibility to change with user demands, have led to positive reactions from the tower controllers involved. NLR achieved various targets of the BETA project. The A-SMGCS Operational Concept Definition and the A-SMGCS human machine interfacing definition were made, and the valuable pre-operational training for the controllers to work with the new system was provided employing the NLR Tower Research Simulator before the actual real-life try-outs.

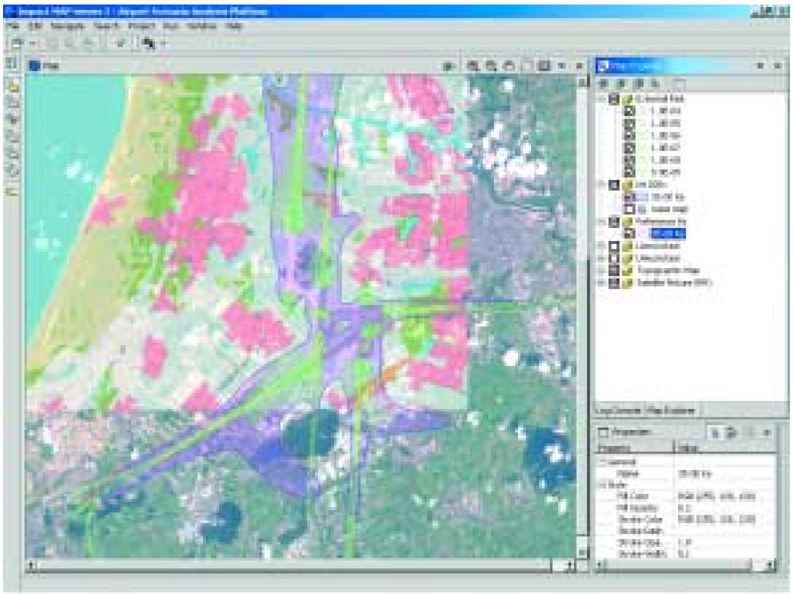
NLR's Airport Scenario Analysis Package

The development of the Airport Scenario Analysis Package (ASAP, see also Chapter 3.6) has been continued. This software package system contains customised applications that support the development of airport policy and procedures in addition to the monitoring of such daily operational aspects as:

- effects on the environment from noise and air pollution, and accident risk
- capacity of runways, taxiways, and gates
- economic parameters, including benefit/cost analysis
- logistics concerning air traffic, baggage handling, and fuel distribution.

ASAP has been conceived and built with the wishes and concerns of airports and regulatory authorities in mind, anticipating the research requirements of airport policy planning and operation. It builds on available models for noise calculation, baggage handling, and runway capacity. It uses these models in a clear and consistent way, providing the user with a unified interface for all calculations. The calculation results can be analysed to find an optimal combination.

The increasing densities of buildings around airports and of aircraft operations have caused a growing need for tools for studying and managing various aspects of an airport's operation. It is becoming increasingly difficult to find an optimised and non-conflicting combination of previously independently treated issues such as noise budgets, safety, and capacity. Support is needed in this domain to model these aspects in ways that lead to practical solutions both for policy development and for mitigating current violation of established quotas. Such a support system must provide policy makers with a complete overview of the information they need for making both short and long term decisions. It must give access to detailed problem analysis, and a way to compose and evaluate various solutions. ASAP now provides a comprehensive support system, an integrated facility that addresses the needs of airports, regulatory authorities, air traffic controllers, airlines, consultants, and industries.



Presentation by the Airport Scenario Analysis Package (ASAP) of information from various sources: satellite picture, GIS map info, and noise load and third party risk contours

3.4 Structures and Materials

Research and development activities in structures and materials were executed in the areas of loads and fatigue, structures technology, and the extension and improvement of laboratory facilities. Investigations and developments in these areas were primarily aimed at issues and themes that reflect the global industrial drive for improved affordability.

Projects under the Fifth Framework Programme of the European Union were continued or finalised.
The technology readiness demonstration programme, NVJSF, aimed at Dutch industry participation in the US Joint Strike Fighter (JSF) programme, was largely finalised in 2001. Projects on engine development were continued, to be finalised in 2003.
NLR participated in the development and certification of the fibre metal laminate GLARE that was chosen for the Airbus A380 fuselage structure. The major part of the work was completed. NLR participated in the continuing full scale test, a barrel test, on a large fuselage section with GLARE panels.

The activities mentioned, together with other contract research in the area of structures and materials, entailed approximately the same amount of work compared to the previous year. Contract research included work for the Royal Netherlands Air Force (RNLAF), the Royal Netherlands Navy (RNLN), the Netherlands Agency for Aerospace Programmes (NIVR), the Civil Aviation Executive Agency (IVW-DL) and aerospace and aeroengine industries mainly from the Netherlands.

Loads and Fatigue

Aircraft Loads and Certification

The one-dimensional modelling of atmospheric turbulence for gust loads analysis prescribed in the current airworthiness requirements may not be adequate for future very large aircraft. More realistic modelling that takes account of spanwise variation of gust velocities may be required for the development of large aircraft such as the Airbus A380. Various investigations have therefore been carried out to judge the effects of two-dimensional modelling of vertical turbulence on gust loads on large aircraft. In a continuation of research on this subject in the early nineties, work was carried out under contract to Airbus Deutschland.

Together with SP Aerospace and Vehicle Systems, NLR has investigated semi-active damping control to improve the performance of aircraft landing gear. In addition it was investigated whether the use of damage tolerance principles instead of safe life principles would be beneficial for design and certification of landing gear components.

To support the Dutch industry, under contract to the NIVR, a basic research project on the prediction of loads on helicopter components was continued.

Load and Usage Monitoring

The fatigue load monitoring programme for Lockheed Martin F-16 aircraft of the Royal Netherlands Air Force (RNLAF) has been continued. A similar load Monitoring program has been started for the F-16 aircraft of the Royal Belgian Air Force (BAF).

Apart from the F-16 aircraft structure, the engine also is monitored. NLR has developed models to predict the engine life consumption using monitored flight data and engine data.
A project to analyse the fault reports made during flight was started.

A load and usage monitoring system for Westland Lynx helicopters has been developed and installed. The system monitors structure and engine parameters.

Load measuring systems are installed in two Lockheed C-130 Hercules aircraft for the RNLAF. Design data and measured operational data were exchanged with Lockheed Martin.

Load monitoring in Lockheed P3 Orion aircraft for the Royal Netherlands Navy was continued.
A load monitoring system is installed in the Lockheed P3 Orion aircraft of the Spanish Armed Forces. Test flights have been carried out to prove that the system is working properly.

On behalf of the Royal Netherlands Navy, NLR participates in the Service Life Assessment Programme (SLAP) and Service Life Extension Programme (SLEP) for Lockheed Orion aircraft.

Calibration measurements on an RNLAF Lynx helicopter

SLAP/SLEP is a collaborative programme between the US Navy, the Canadian Forces, the Australian Forces and the Royal Netherlands Navy. As part of this programme, a full-scale fatigue test on an Orion aircraft will be performed in the USA. NLR is responsible for the comparison of the flight load spectra of the four participants in terms of fatigue life and damage tolerance behaviour.

Gas Turbines

Methods to analyse the life of gas turbine components under service loading were being developed. Models to calculate the creep and fatigue life of single crystal blades were developed.

For the engine to be used on the JSF, technology maturation programmes have been defined in co-operation with the industry. The programmes deal with advanced Thermal Barrier Coating systems and advanced sealing concepts. Coatings and seals are designed, manufactured and tested.

To improve the efficiency of gas turbines, new materials are being developed and evaluated. NLR was involved in a European programme on the characterisation and evaluation of TiAl and single crystal materials.

Statistical methods have been evaluated for their applicabilities to risk assessments of cracked structures. Efficient methods were implemented and used to predict the probability of failure of F-16 engine components.

Several NLR departments collaborated with the RNLAF for load monitoring of the Chinook helicopter. Test flights were carried out in order to show that the sensors were mounted such that the significant loads are measured

The applicability of statistical methods in the design of aircraft structures in relation with the regulations was studied in the EU project Advanced Design Concepts and Maintenance by Integrated Risk Evaluation for Aerostructures (ADMIRE). NLR participates in this project along with all major European aircraft manufacturers.

Space

To support the Dutch industry in the design of spacecraft components, the response of a stiffened component to an extreme thermal loading was analysed using a non-linear Finite Element model. A brazing procedure to join these materials for the production of honeycomb panels was improved.

Structures Technology

Research and development have been carried out under contracts from the Netherlands Agency for Aerospace Programmes (NIVR), the Netherlands Ministry of Defence, the Royal Netherlands Air Force (RNLAF), the industry, the European Union (EU), the Civil Aviation Authority Netherlands, the European Space Agency (ESA) and within the framework of the Programme of Basic Research.

Materials

Metallic, composite and hybrid materials have been evaluated and characterised with respect to their mechanical or corrosion properties, including the effect that various surface and heat treatments may have on these properties. For the NIVR, the potential of high strength steel alloys has been evaluated for use in landing gears by SP Aerospace and Vehicle Systems. The feasibility of using a more environmentally friendly anodising process was investigated, to be used by Fokker in relation to adhesive bonding or painting of aluminium components, for the NIVR. Several NIVR projects were carried out to support the development of GLARE in co-operation with Fokker Aerostructures, Fibre Metal Laminates Centre of Competence (FMLC), and Delft University of Technology. The damage tolerance behaviour of a friction stir welded stiffened panel was evaluated, to explore the potential of this fabrication method for Fokker and Dutch Space.

Environmentally friendly, chromate-free paint systems have been evaluated with respect to the more severe regulations that will be imposed in the near future, for the RNLAF. A study was performed to investigate the occurrence of Lüder lines as the result of the metal sheet forming process, as used by Fokker, under the Basic Research Programme. The characteristics of fracture surfaces of composite materials were studied in GARTEUR Action Group (SM) AG-20. An NIVR project focused on models for corrosion protection was being carried out.

Composites Technology

The development of fabrication technology for composite aircraft structures is a multidisciplinary activity, combining the selection and evaluation of materials and process parameters, the performance of design optimisation and analysis computations, and the experimental validation of components and prototypes.

Composite landing gear component

In co-operation with SP Aerospace and Vehicle Systems and Eurocarbon, a composite landing gear component made by the Resin Transfer Moulding (RTM) technique was being developed, for the Ministry of Defence. The Department of Applied Mechanics and Composites of Twente University has been contracted to develop the capabilities for automation of the RTM process. A method to monitor the process parameters of the RTM process was developed for the Ministry of Defence. Within EU-project TANGO (Technology Application to the Near-Term Business Goals and Objectives of the Aerospace Industry), NLR developed the technology to fabricate the fuselage frames for a full-scale composite fuselage 'barrel' section. Within EU-projects FALCOM (Failure Prediction in Advanced Low-Cost Composites), and DART (Development of an Advanced Rotor for Tilt-Rotor), process technology has been developed for RTM. For the NIVR, a low cost fabrication concept for the cone cap of the Ariane V was developed for Dutch Space. NLR participated in a trade-off study of Fokker, to evaluate fabrication concepts for doors of the JSF. Also for Fokker, a thermoplastic matrix material was tested for higher service temperatures.

Structural Design

Design methods were being developed for the aerospace industry, and explicit structural designs were validated, either experimentally or numerically. For the NIVR, design methods were being developed for composite bead-stiffened ribs and for stiffened shear panels, to be used by Fokker. To support the development of GLARE, for the NIVR, several design methods were being developed, and buckling of GLARE panels was evaluated by testing stiffened panels loaded in shear. Failure criteria for bolted joints were being developed in the EU project BOJCAS (Bolted Joints in Composite Aircraft Structures).

Numerical optimisation is a key element of the structural design development at NLR. New applications and developments were pioneered with the versatile in-house code B2000/B2OPT. An EU project named MOB (Multidisciplinary Optimisation of a Blended Wing Body) was being carried out, in which B2000 is used to size the structure for the EU. A programme to develop a computer-assisted structural design environment has been carried out for the NIVR. For Urenco Aerospace, projects to develop the technology for a composite helicopter drive shaft, and for the JSF lift fan drive shaft were being carried out, under contacts from the Ministry of Defence and industry.

Structural Mechanics/Numerical Analysis

The ability to model the structural response by computational methods is of great importance to speed up the design process, to reduce the technical risk of a selected solution, and to reduce the extent of time-consuming and costly experimental programmes. In GARTEUR Action Group (SM) AG-25, the effects of plasticity, mode-jumping and skin-stiffener separation on buckling and post-buckling behaviour were addressed.

Participants of the International Symposium on Composites Manufacturing, ISCM 2002, NLR hosted to mark the opening of its newly extended composites laboratory

Testing of a composite drive shaft

Active damping of vibrating structures was the subject of in EUCLID programme VIBRANT (Vibration Reduction by Active Control Technology), where the use of COTS (Commercial Off The Shelf) technology is being pursued. Within the framework of EU project CAST (Crashworthiness of Helicopters on Water, Design of Structures using Advanced Simulation Tools), a fuselage bottom skin panel concept was developed, aimed to resist the water pressure upon a forced landing. Within the EU programme CRAHVI (Crashworthiness of Aircraft for High Velocity Impact), design methodology was being developed for bird strike on composite leading edges of horizontal stabilisers. For the Civil Aviation Authority Netherlands, a computer code was being developed to model the collision of an aircraft with approach light structures near runways. Expertise of NLR in the areas of fatigue and damage tolerance has been applied in contracts from ESA. Within the framework of GARTEUR Action Group (SM) AG-26, NLR participated in the development of life prediction methods based on equivalent initial flaw size distributions.

Certification and Qualification Tests

Certification tests on material and design concepts for the J-nose of the Airbus A380 and A340-500/600 were performed under contract to Fokker Aerostructures.

A large-scale programme on materials to be used in the JSF was finalised.

To demonstrate the validity of structural concepts and materials, such as GLARE, tests on a barrel are performed by EADS Deutschland in Hamburg, Germany. This 'megaliner barrel' is a full-scale part of the fuselage. NLR gives on-site support to the barrel test activities in close co-operation with Fokker Aerostructures that has designed and manufactured the GLARE fuselage panels.
The certification programme on the GLARE material was continued, and a certification programme on the main landing gear lugs of the A340-500/600 aircraft was performed.

A material qualification programme was performed for dual pack canisters of Fokker Special Products.

A test set-up has been built under contract to Urenco in order to carry out torsion tests on the fan shaft of the JSF manufactured by Urenco. Further tests on the drive shaft of the Tigre helicopter produced by Urenco were carried out.

General Support

Under contract to Stork PWV B.V. a number of mock-ups were built and validated for various configurations of an armoured vehicle for the Royal Netherlands Army.
Intrusion resistance tests were carried out on modified door configurations for the F-28 MK100 and MK70 flight deck door, under contract to Fokker Services.

3.5 Space

In the year 2002 the implementation of an updated Netherlands space policy was started. The focussing on application-driven activities and priority areas in industrial activities has resulted in a new approach for Netherlands' technological and user support programmes. To improve its capability to fulfil the needs of the market, NLR has, after intensive consultation with its customers, evaluated its core activities in Space. This resulted in two main areas, a technological area focussed on industrial needs with the goal to improve industrial competitiveness and an application-oriented area focussed on user needs with the goal to make optimal use of the space infrastructure. The technological area includes activities related to satellite subsystems and launchers. The application-oriented area includes remote sensing applications, satellite navigation and space station utilisation.

Satellite Subsystems

Thermal Control

In the area of thermal control the activities have been focussed on the application of two-phase flow technology for efficient thermal transport and cooling.

In the AMS (Alpha Magnetic Spectrometer) consortium NLR is responsible for the thermal control system of the main detector, the silicon tracker. A cryogenic magnet that must not receive any heat from inside surrounds the tracker located in the vacuum case. Moreover, severe temperature gradient requirements and mechanical constraints of the tracker design require the dissipated power to be removed by means of an active two-phase loop. The detailed design of a mechanically pumped carbon dioxide two-phase loop was completed.

In the area of cooling devices, NLR has designed and built prototypes of new passive cooling and radiator devices such as the Flat Swinging Heat Pipe, a cooling concept for high-density electronics, and the variable emission radiator.

Small Satellites

NLR is the main contractor of Sloshsat FLEVO, a mini satellite for the study of liquid dynamics and liquid management problems in space. The behaviour of water in an instrumented tank in the satellite will be monitored to help understand how sloshing affects the attitude and orbit control of space vehicles. Sloshsat FLEVO is to be launched from the Space Shuttle and operated for two weeks from the ground via the Space Shuttle communication channels. It has been fully integrated and tested and put into storage, awaiting a launch opportunity.

Based on experience gained in the Sloshsat development, NLR together with Dutch Space has started preparations for the development of ConeXpress, a GEO satellite platform for telecommunication payloads.

Test and Verification Systems

In preparation of coming science and earth observation missions such as Herschl/Planck and ADM/Aeolus, NLR has been developing a next generation of Test and Verification Equipment for spacecraft avionics systems such as the spacecraft Attitude and Orbit Control Subsystem (AOCS). The contract for the AOCS subsystem of the Herschl/Planck has been awarded to Dutch Space. NLR supports Dutch Space in the development of the test and verification equipment. Furthermore, a Dutch test and verification equipment cluster consisting of Dutch Space, ATOS Origin, Satellite Service and CHESS has been established, led by NLR. This cluster has worked on the harmonisation and improvement of the capabilities of the members in this area, to establish a stronger international competitive position.

Satellite Navigation

In the area of satellite navigation NLR has focussed its activities on Galileo verification and validation. An overview of these activities is given in the Capita Selecta. On the spacecraft side NLR worked on the Galileo dependability and safety under contract to ESA/Alenia Spazio, and on the Galileo system verification, methods and tools for ESA/Astrium D. On the application side NLR participated in the Gallant project on advanced driver assistance systems.

In order to ensure a strong Dutch position for the realisation of the Netherlands verification and validation priority area in the European Galileo project, NLR with Dutch Space and TNO has set up a national consortium, named Valileo.

ESA astronaut Thomas Reiter at the Cosmonaut training position of the ERA External Man Machine Interface

Space Station Utilisation

Mission Preparation and Training Equipment

The Mission Preparation and Training Equipment (MPTE) for the European Robot Arm (ERA) is developed to provide Russia with means to prepare, train and support ERA operations on the International Space Station. Preparation and mission support will take place at the Mission Control Centre and Rocket and Space Corporation Energia, near Moscow. Cosmonauts will be trained for both external and internal control of ERA at the Gagarin Cosmonaut Training Centre in Star City. ESA will use its version of MPTE for instructor training and support tasks such as software maintenance.

The MPTE system installed at ESTEC has been successfully integrated and tested. Russian instructors, ESA astronauts, ESA experts and ERA experts participated in an MPTE 'dry run' training of instructors.

European Drawer Rack Facility Responsible Centre (EDR-FRC)

The EDR-FRC will be part of the European Decentralised Operations Ground Segment of International Space station (ISS), in which many User Support and Operations Centres co-operate. NLR represents the Dutch Utilisation Centre (DUC) and works together with the Belgian co-partner SAS on the development of the EDR-FRC.

As a member of the European Utilisation and Payload Operation Working Group, NLR has contributed to the definition phase of the EDR-FRC implementation. Furthermore, NLR provided System Integration and Management Support to the EDR-FRC pilot development at ESTEC; in particular specification and development for the EDR Payload Integration and Operations Reference Facility.

Remote Sensing Applications

NLR participates in the EUCLID RTP 9.8 project focussing on the development and demonstration of local reception and processing of satellite remote sensing data for military use. Components for the reception, raw data processing information extraction and distribution have been developed and demonstrated. The project has been successfully completed in 2002. A demonstration was held at the EU Satellite Centre at Torrejon d'Ardoz, Spain.

In the area of remote sensing applications NLR participated in the EU projects CROMA (Crop Reflectance Operational Models for Agriculture) and PRESENSE (Pipeline Remote Sensing for Safety and the Environment). CROMA is focussed on the improvement of modelling crop reflectance behaviour required in various agricultural applications and is also used for to study the instrument characteristics for future hyperspectral instruments. In the PRESENSE project a concept

Group of MPTE instructors and trainees and prototype for a European pipeline monitoring system is developed in co-operation with European Gas Companies (Gasunie for the Netherlands) to ensure the safety of their pipeline networks in a secure and efficient way.

NLR has started work on the development of a Geospatial Data Service Centre (GDSC) as a part of a national geoinformation infrastructure within the Geomatics Business Park. This has involved the preliminary design of a future GDI (Geospatial Data Infrastructure). The possible benefits and efficiency of a GDSC based on the GDI concept from Prof.dr. R. Groot of the International Institute for Geo-Information Science and Earth Observation and candidate product chains were quantified. An inventory of product chains was drawn up in co-operation with project partners Infram and Synoptics.

A representative of the Ministry of Defence and a member of the NLR staff demonstrating remote sensing at the EU Satellite Centre at Torrejon d'Ardoz, Spain

NLR and EU staff members in front of the EU Satellite Centre at Torrejon d'Ardoz, Spain

3.6 Information and Communication Technology

Activities in the area of Information and Communication Technology (ICT) were dedicated to the development, production and life cycle support of information systems for a variety of applications, aimed at national and European aerospace and air transport objectives.

In the area of Air Traffic Management, NLR has continued support to Eurocontrol and the industry in the maintenance and enhancement of the multi-radar tracker of the ATM suRveillance Tracker And Server system ARTAS. Under contract to SgyGuide of Switzerland, NLR provided assistance in tuning an ARTAS tracker.
The airport surveillance tools of Air Traffic Control the Netherlands (LVNL) have been extended and fine-tuned for Amsterdam Airport Schiphol. The airport surveillance at Schiphol can be monitored and analysed on the basis of tracks from ARTAS and plots from the ADSE radars.

Aviation security procedures are founded on international and national guidelines and recommendations. The aviation community has recently been undertaking substantial efforts to reconsider and improve the security situation. As a member of the Security of Aircraft in the Future European Environment (SAFEE) Core Team of a European consortium, NLR is well positioned to help European security improvements to be introduced in the Netherlands.

The new air transport law of the Netherlands has triggered new questions on environmental effects (noise, emission and external safety) of air transport. To allow timely in-depth analyses of these effects, customers demand results of calculations within very short time frames and in varying levels of detail. A flexible collection of software components has therefore been developed. These components have been incorporated in a set that allows them to be easily put together to produce applications tailored to customer demands. The acrchitecture of this set, called ASAP (Airport Scenario Analysis Package – see also Chapter 3.3), provides a basis for airport environmental support applications of the next generation, and enables NLR and its customers to answer questions in various circumstances in a cost-effective and efficient way.

Joint Strike Fighter

After the JSF Concept Demonstration Phase between 1998 and 2001, in which the Dutch Prognostics and Health Management (PHM) Consortium (DPC) demonstrated several novel multi-disciplinary PHM solutions to Lockheed and the JSF Program Office, the Consortium was awarded a six-year contract by Lockheed Martin to provide PHM technology for its F-35 Joint Strike Fighter (JSF) programme. The Consortium (DPC) is comprised of Perot Systems, NLR, TNO TPD, and Sun Electric Systems.

PHM is vital to achieve affordability, supportability and survivability goals of modern military aircraft. As part of the contract awarded by Lockheed Martin, DPC is detailing requirements and designing an Intelligent Help Environment (IHE). This IHE is a suite of methods, techniques and tools to assist maintenance personnel in troubleshooting via an Intelligent Help Desk (IHD). The IHE will be provided to users in the Customer Support Centre and to Maintenance Engineering and Fleet management. DPC builds upon NLR's long-standing experience in the combination of aerospace ICT with health and monitoring experience gained in structures, engine performance, electronics, and subsystems. The main ICT technologies provided by NLR for the Intelligent Help Environment are business requirements analysis, distributed software architectures, diagnostic and prognostic reasoners, case-based and model-based reasoners, data mining and visualisation and human-computer interaction.

NLR's new NEC TX7 computer

Demand for the capacity of NLR's vector-parallel NEC SX-5 supercomputer has been growing. However, an increasing number of projects require scalar processing capacity, if possible in a multiprocessor configuration. Therefore, an NEC TX7 computer, based on the latest 64-bit Intel® processor, the Itanium® 2, has been purchased. The configuration at NLR consists of 16 processors, 32 GB main memory and 288 Gbyte local disk capacity. Clusters of four processors can be combined to obtain separate functional computer systems. The system provides the capacity required for throughput and for research on parallel numerical simulations.

The development of critical (e.g. safety critical) aerospace software has relied heavily on process measures combined with extensive verification and testing. Now, formal IT methods offer the opportunity to apply mathematical-precise techniques in the development process to guarantee certain properties of software. Examples of such methods are refinement verification methods and model checkers or theorem provers. Refinement verification methods guarantee that safety properties are ensured. Model checkers or theorem provers guarantee that progress properties are achieved. NLR and CWI (*Centrum voor Wiskunde en Informatica*) have concluded a joint technology survey of formal IT methods, funded by the Netherlands Ministry of Defence. Formal methods of both types were applied on a sample from recent operational system developments at NLR, showing that they can be applied beneficially in critical system development.

To enhance visual inspection in Computational Fluid Dynamics (CFD) computations, a web-enabled visualisation tool based on Java3D has been developed, capable of showing subtle model imperfections in surface-grid quality by special lighting of the object model.

Under contract to NEC, the SPINEware middleware tool for Enterprise Application Integration has been upgraded to allow 'secure http' to be used in inter-institute working environments, improved workflow functionality with respect to hierarchy and improved support for web-based access to computing resources.

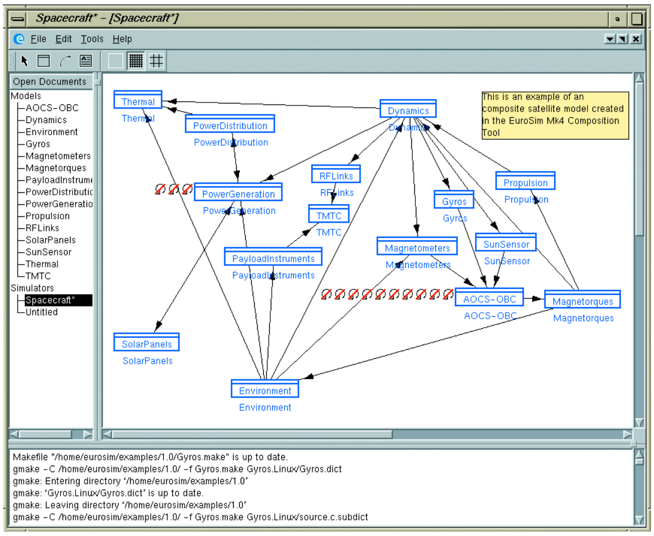
Optimisation of Aircraft Systems

In several EU projects NLR contributes to the optimisation of aircraft systems. By being actively involved in the development of European aircraft, NLR supports the position of the Netherlands aerospace cluster on the European market for aeronautic system development.

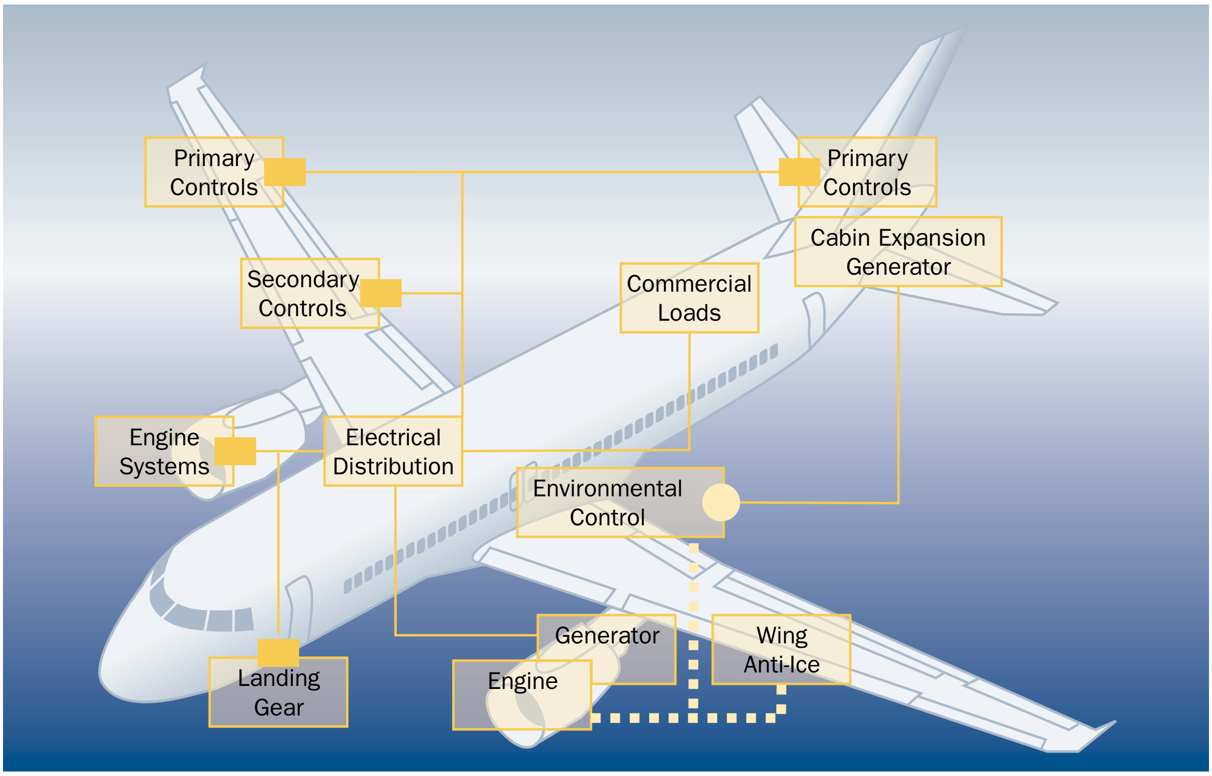
In the ASICA project the EuroSim Model Repository and the SPINEware workflows are used in an integrated application specific web-based working environment

In the EU project Air Management Simulation for Aircraft Cabin (ASICA), NLR has worked on three main topics. The development cycle of Environmental Control Systems (ECS) has been reduced through the creation of a distributed simulation framework for collaborative development. Methods to solve numerical aspects of the simulation of interacting systems have been demonstrated, and it has been shown that aircraft fuel consumption and passenger and crew comfort (temperature, pressure, air velocity) can be improved through alternative ECS controllers. In ASICA the EuroSim Model & Simulator Repository (MSR) is used as a knowledge management system for simulation models. SPINEware and the MSR are fully integrated, offering a single user view from model development to simulation.

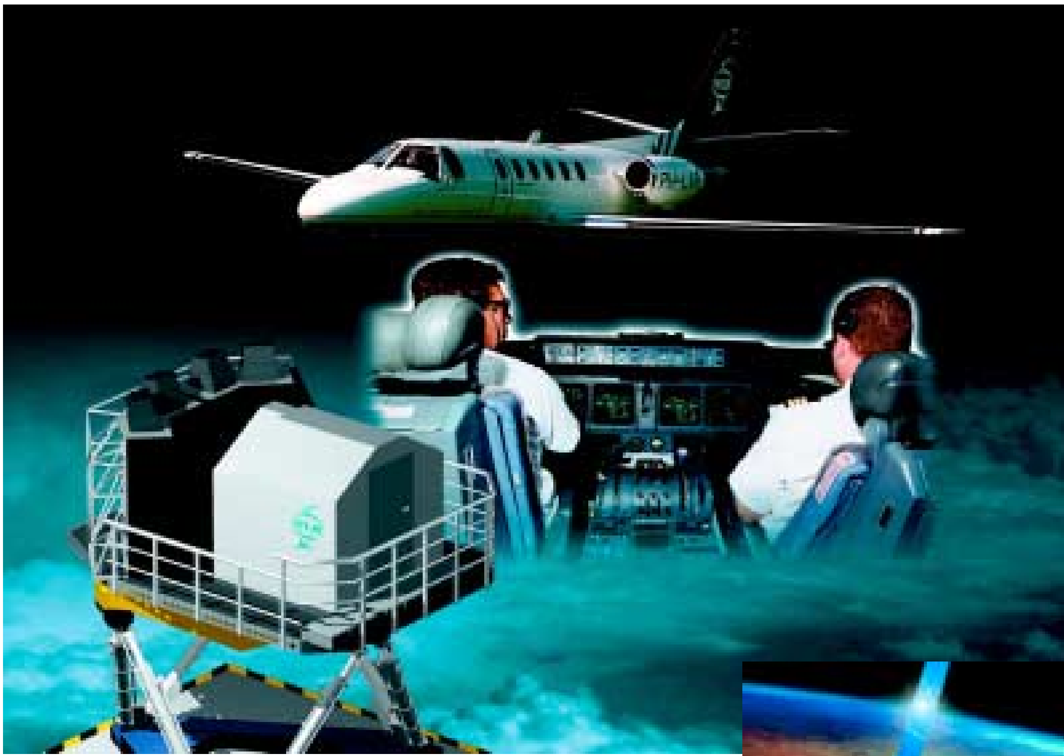
NLR has contributed in the EU project Friendly Aircraft Cabin Environment (FACE), which aims to improve the cabin environment with respect to air quality and noise. For hat purpose, simulations are carried out to evaluate the performance of the components separately and in combination. Work on an Integrated Technology Evaluation Platform (ITEP) was started, to provide a single facility for the integration of the various component models to support evaluation studies. The ITEP will be based on SPINEware and the MSR.



Graphical User Interface of Eurosim Model & Simulator Composition Tool



Power Optimised Aircraft: More Electric Aircraft Architecture



NLR software MOSAIC is used a wide variety of aerospace simulationapplications and projects involving aircraft, simulators and satellite use

In the EU project Power Optimised Aircraft (POA), NLR has contributed to the reduction of aircraft fuel consumption by the reduction of non-propulsive power through the replacement of mechanical, pneumatic, and hydraulic systems partly by electric equivalents. Work was started on the model interface definition to enable various partners' models of aircraft systems and components, which describe the steady-state behaviour, to be integrated into aircraft models for existing and novel aircraft-level architectures for non-propulsive power generation, distribution, and consumption. NLR also contributes to the Virtual Iron Bird modelling approach for steady state system simulation and optimisation.

In the EU project Multidisciplinary Design and Optimisation of Blended Wing Body (BWB) Aircraft Configurations (MOB), a distributed engineering environment called Computational Design Engine (CDE) is being developed. The CDE comprises design and analysis tools provided by members of the MOB consortium. Exchange of data and control of the tools at the different sites is achieved via secure connections over the internet. Design loops involving a complex sequence of design analyses of the BWB configuration have become operational. On top of the system level CDE, a more user-oriented environment has been built using the SPINEware middleware system.

System Simulation and Engineering

NLR has developed a EuroSim Model & Simulator Repository (MSR) and a EuroSim Model and Simulator Composition Tool (CT). Together, the MSR and the CT make up the EuroSim Simulator Development Environment. EuroSim developments are funded by the NIVR.

The MSR acts as a knowledge management system for models and simulators, and provides the means for multiple concurrent users to store, search for, and retrieve the information that is relevant to develop models and simulators in a coherent manner. Because of its generic nature and application-independent storage and retrieval functionality, the MSR can be used in any model development or simulation environment. Substantial reductions of development costs for simulation applications are obtained when models are re-used across project boundaries.

The Composition Tool (CT) is EuroSim's new platform for simulator integration. It allows models to be developed independent of the simulator in which they are used. This promotes model re-use, which can reduce simulator development time and cost. The CT has a user-friendly Graphical User Interface to construct simulators in an object-oriented fashion from multiple independent models and multiple instances of one original model.

The NLR software product MOSAIC (Model-Oriented Software Automatic Interface Converter) automatically transfers simulation models between various simulation environments. Under contract to EADS Launch Vehicles, MOSAIC has been further enhanced with so-called multiple model transfer and integration capabilities. In combination with the EuroSim MSR and CT, MOSAIC automates the entire workflow from MATLAB®/Simulink® model to a real-time EuroSim simulator. MOSAIC is also used to transport control algorithms made in Matlab to NLR's Cessna Citation II research aircraft.

Air Traffic Decision Support Systems

The EU project Optimisation Platform for Airports including Landside (OPAL) has provided a concept for a decision-support facility for airport stakeholders, and a first version of such a facility: the OPAL platform. The OPAL platform enables airport stakeholders to evaluate overall performance at airports. In the project, a validated, calibrated and evaluated OPAL platform was made by integrating existing airport modelling tools (located at geographically different sites) and by testing the platform for six major European airports: Amsterdam, Athens, Frankfurt, Madrid, Palma de Mallorca, and Toulouse. Its expertise in enterprise application integration has enabled NLR to establish the communication infrastructure of the OPAL platform, using SPINEware and secure communication. In addition, NLR was responsible for validating, calibrating and evaluating the OPAL platform for Amsterdam Airport Schiphol.

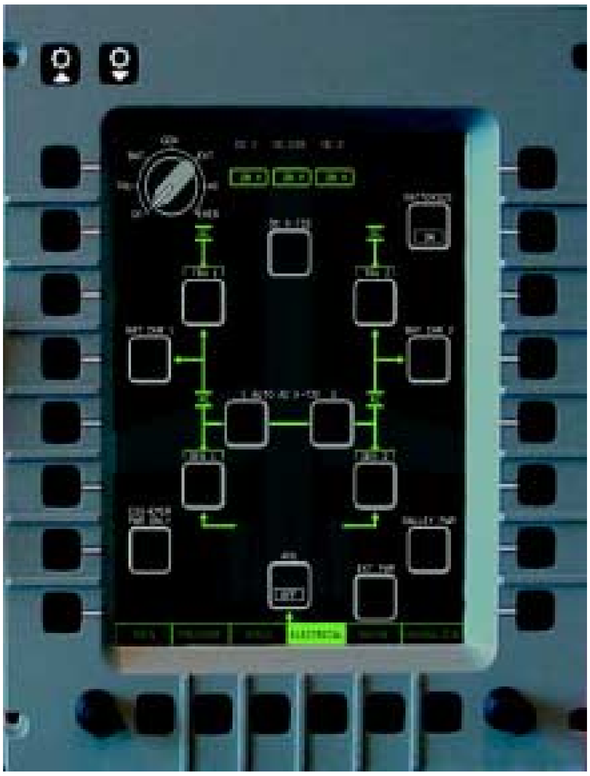
Airport Traffic Controllers require new tools to cope with increasing traffic, especially with bad weather conditions and environmental restrictions. In co-operation with national and international airports and industry, NLR is developing decision support tools for controllers. NLR assisted LVNL in the development and implementation of a runway incursion alert function. In the BETA (operational Benefit Evaluating and Testing an A-SMGCS) and Triple-I (Intelligence Instead of Infrastructure) projects, controllers have been provided with automatic systems for traffic planning for further anticipating traffic flows and early detection and solution of congestion. Such systems will lead to more efficient use of the infrastructure and will enable environmental constraints to be incorporated in an early stage.

3.7 Avionics

Avionics systems play an ever increasing role in both civil and military aircraft. Avionics systems provide for safe and timely execution of flight by means of, among other things, accurate navigation, reliable communication and, specifically for military aircraft, accurate target acquisition and identification.

The main areas of activities in avionics were research and technology development for avionics systems, the design and prototyping of aerospace electronics, and the design and operation of instrumentation for flight testing and wind tunnel testing. In addition, activities were carried out related to the use of aircraft were avionics systems are involved.

These activities require the development of an extensive infrastructure of partly computer-based tools for avionics systems performance assessment, virtual prototyping, systems design, electronics design, and computational electromagnetics. An extensive inventory of facilities for avionics flight-testing provides the means for conducting flight trials for customers operating aircraft in the Netherlands and abroad.



Prototype overhead panel

Cockpit Overhead Panels

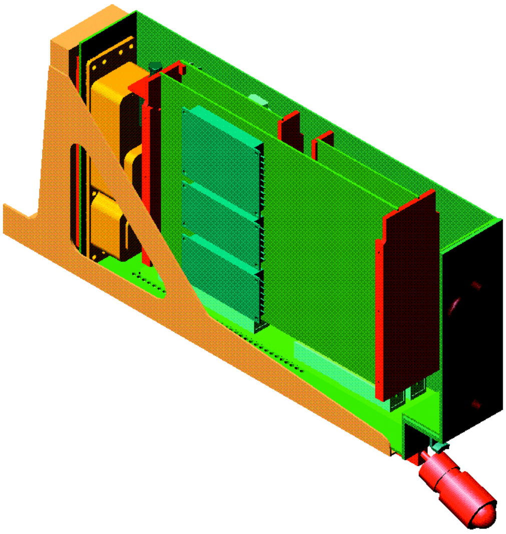
NLR participated in the EU Fifth Framework project COCOPAN (Cockpit Overhead Panels) on the development and evaluation of new concepts for overhead panels for large and regional aircraft. The project is executed in close co-operation with a Dutch industrial partner. It addresses issues such as safety, weight, operation and maintenance, and it includes the implementation of a new digital data bus architecture for the communication of the panels with aircraft utility systems. NLR leads the research activities on Human Machine Interfacing aspects.

Evaluations of several improved concepts have been performed in the NLR Human Factors simulation facility in co-operation with pilots from several countries. For the evaluation of the improved concepts, a prototype overhead panel has been developed using state of the art LCD and touch screen technology combined with NLR's rapid avionics and display prototyping software StateMate and NADDES II. In order to evaluate the panels in an operative cockpit environment they have been connected to an avionics simulation model that provided realistic behaviour of aircraft utility systems.

VICTORIA Project

A consortium of 33 European companies, all part of avionics / electronics supply chains, carries out the EU project 'Validation platform for integration of standardised components, technologies and tools in an open, modular and improved aircraft electronic system' (VICTORIA). NLR participates under contract to main contractor Thales Avionics. A Dutch industry also participates in the project.

Within the project NLR develops an Input/Output Module (IOM) which will be integrated in the so-called 'Energy Domain Experimental System'. The IOM provides a gateway function between the aircraft Ethernet bus and the other on-board legacy equipment. This equipment is connected via other avionics data buses or uses dedicated



Schematics of NLR input/output module developed in VICTORIA project

digital or analogue signals. The IOM contains Commercial Off The Shelf (COTS) hardware and software components. The internal architecture for the slim module is based on PowerPC and CompactPCI. The operating system software is ARINC653 compliant, providing a partitioned environment to the embedded applications.

NLR also prepares certification material for Integrated Modular Avionics building blocks in general and for the IOM in particular. A contribution to the preliminary certification plan, containing the concepts of hazards interface and configuration interface, was delivered. The process described in this plan provides a means to qualify and get certification credit for a stand-alone avionics computers as an individual building block of the avionics architecture. The contents of the 'certification data package' to get such an approval was defined.

Electronic Component Obsolescence Centre

Within various projects, research into strategies for managing the obsolescence risk for electronic components was continued. The so-called TACTRAC obsolescence management tool, which runs on a server at NLR, provided valuable data both for the benefit of avionics and space projects that were in progress within NLR and for the aerospace industry. Web-based access was provided to small and medium-sized enterprises (SMEs) in the Netherlands.

Expertise in this field was extended and updated through attendance at international conferences. Efforts were made to elevate the awareness of obsolescence risk in Dutch military organisations and industrial parties.

Under contract to the Royal Netherlands Navy (RNLN), current practices for obsolescence mitigation were evaluated. In co-operation with an RNLN working group, NLR made recommendations to achieve a sound obsolescence management structure, with the incorporation of pro-active methods.

A similar project was carried out for the Royal Netherlands Air Force (RNLAF). A survey among various RNLAF sections and divisions was made in order to list current practices and problem areas. Following the survey, recommendations were made for minimising the risk associated with obsolescence.

Facility Management System for Icing Wind Tunnel

NLR completed the design, development and realisation of a Facility Management System (FMS) for the Italian Icing Wind Tunnel (IWT). NLR has been working under contract to Turbo-Lufttechnik of Germany, responsible for the engineering of the total IWT facility. The FMS enables high level control of all major wind tunnel systems (i.e. the fan, cooling system and pressurisation system) to be exercised from one operator workstation.

Test team in the control room of the Icing Wind Tunnel

After development and extensive testing at NLR, the FMS had been delivered on site in 2001. After extensive test sessions, in which a total of nine complex subsystems were involved, the IWT received provisional acceptance. The FMS is an integrated Test Automation System, designed to support a high productivity test environment. The FMS supports all phases of wind tunnel operation, from test specification, through test execution to report generation. NLR has been responsible for the design, development, realisation and commissioning of the total FMS. NLR developed the FMS in close co-operation with ReACT Technologies Inc. of Canada.

NLR developed the applications specific to IWT, such as Man Machine Interfaces and Control, Data Acquisition and Report Generation applications, on top of the Test Automation System Kernel. The FMS is functionally partitioned into several distributed subsystems connected by a Local Area Network. All the subsystems are capable of operating both in a stand-alone mode and in an integrated mode coupled by the Local Area Network. Any subsystem is capable of distributing all kinds of data to all other subsystems. This structure makes the FMS a flexible, easily expandable system.

Particle Image Velocimetry (PIV)

For the EU's Fifth Framework project EUROPIV2, intended to demonstrate the 3-D stereoscopic capabilities of modern PIV technology in an industrial wind tunnel environment, earlier measurements performed in the DNW-LST low speed wind tunnel on a generic civil aircraft scale model were analysed. The model consisted of a fuselage and a wing, equipped with inboard and outboard flaps and slats; fins and engines were not mounted.

The objectives of the investigation of the trailing wake vortex flow field behind the model in high lift configuration (7° and 18° angle of attack) were:

- Absolute and independent verification of stereoscopic PIV measurement vs. the results of the proven 5-hole probe measurement technique.
- Error assessment of the stereoscopic PIV measurement in the wind tunnel environment.
- Assessment of the intrusive character of the 5-hole probe sensor by comparison with time-averaged stereoscopic PIV measurements of the flow field with and without a 5-hole probe rake.
- Investigation of the steady and unsteady characteristics and spatial evolution of the wake vortex field.

The measurements concentrated on the vortex emanating from a 5° deflected outboard flap and were taken at 1 and 2.4 wingspan behind the wing trailing edge. The 3-component velocity fields obtained by stereo-PIV and the results of the 5-hole probe were similar, but differences were found in the details. In the vortex dynamics an angle of preference of the vortex core vibrations showed up, oriented in the direction of the wing tip vortex. The stereo-PIV velocity fields measured with the probe inserted into the flow compared with the velocity fields without a probe inserted, showed a deflection of the mean vortex core position, caused by the horizontal strut, at which the 5-hole probe was mounted.

The measurements have demonstrated the complementary character of the stereoscopic PIV and the 5-hole probe measurement techniques. A 5-hole probe is applied best for quick investigations of large flow fields. Stereoscopic PIV on the other hand, having a limited field of view, but high spatial resolution and higher accuracy, can be used to zoom-in on areas of special interest and details of the flow field and for the investigation of unsteady flow characteristics.

NH90 Mission System

NLR participates in the design and development of the Mission System for the NH90 Frigate Helicopter (NFH). The Mission System supports the helicopter crew, in particular the tactical operator, with the tactical management of the mission. Tactical situation awareness is compiled from observations by the mission sensors (such as Radar, Forward Looking Infra-Red (FLIR), Electronic Support Measures and Sonar), from messages received via the data link containing observations by other participating units in the operational area, and by the operator himself. These observations of real-world objects are stored in the tactical database in data structures referred to as tracks. Tracks originating from different sources (sensors, data link, or operator) can refer to the same real-world object. Based on, among other things, observed position, course, and speed, the operator can decide that two tracks belong to the same real-world object, and establish a link (cross-reference) between them. To reduce the operator's workload, NLR develops a software module for the Mission System that performs track-to-track matching of tracks generated from surface and subsurface vessels. This relieves the operator from the task of comparing tracks in detail, and only in the case of doubt he has to confirm or reject suggestions made by the software.

A first version of the software, implementing part of the required functions, had been completed. Rigorous testing of this software has been carried out. Testing has taken place at various levels of integration, from low-level software procedures, to several subsystem integration rigs, up to a completely integrated Mission System (NFH Integration Rig). Approval for experimental flight tests with an NFH prototype was achieved. The development of the final version of the software, implementing all required functions, was also begun. A milestone was achieved in the qualification of the software module, by the successful completion of the Software Specification Review.

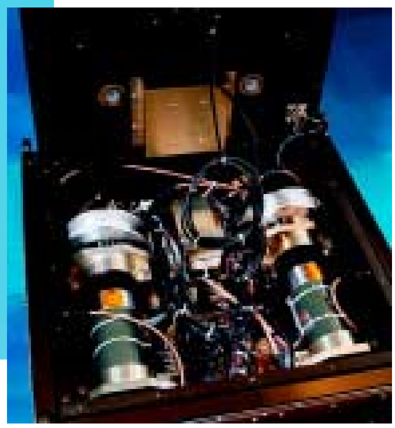
The NH90-NFH will come into service at the French, German, Italian and Netherlands Navy. Negotiations are underway with several other nations.

Avionics for the NH90 Helicopter

In co-operation with national and international partners, NLR takes part in the design and development of avionics equipment for use on the NH90 helicopter.

As a subcontractor of Schreiner Components, NLR is responsible for the hardware and software design and qualification of the Cockpit Fuel Panel and the External Fuel Panel of the NH90 Fuel Management System. NLR is responsible for system, electronics and software engineering. All prototype equipment has been subjected to severe

NH90 helicopter



Parafoil test flight and instrumentation (insert)

qualification testing, where the emphasis is on meeting the stringent EMI/EMC requirements. A series production cost reduction effort could be established by improving the design of the internal interconnections.

As a subcontractor of Schreiner Electronics, NLR is also involved in the design and development of the Remote Frequency Indicator (RFI) for the NH90 and the Tigre helicopter. The microcontroller-based RFI is a Line Replaceable Unit with five fields to display information for each radio installed on the helicopter. Data is exchanged with other equipment via multiple ARINC-429 links. An extensive qualification programme has been carried out under supervision of NLR to demonstrate compliance with all requirements. A final update of reliability and testability data has been performed, as well as a formal Maintainability/Testability Demonstration.

For qualification of this equipment NLR makes extensive use of specialised environmental test laboratories for testing on Electromagnetic Compatibility (including High Intensity Radiated Fields, HIRF), vibration and shock, altitude and temperature and salt spray. The RFI went into series production by the Netherlands industry.

The Nato Frigate Helicopter (NFH) version of the NH90 helicopter is equipped with a Nose Wheel Steering System. The hydraulically actuated Nose Wheel gives the pilot better control of the helicopter. NLR supports SP Aerospace and Vehicle Systems with the design of the controller for this Nose Wheel Steering System. A study has been performed, using virtual prototyping, to verify the requirements of the system. Special attention has been paid to safety aspects of the controller. The virtual prototype, modelled using the Statemate tool, will be extended and it will be the basis for the field programmable gate array, in which most of the functionality will be realised. A special test environment based on the NLR test facility ARTIS has been developed for functional testing.

Small Parafoil Autonomous Delivery System (SPADES)

Under contract to Dutch Space, NLR participates in a CODEMA programme for the Netherlands Ministry of Defence for the development of a small autonomously controlled parachute ('parafoil') demonstrator for the '*Korps Commando Troepen*' of the Royal Netherlands Army. This parafoil will be capable of delivering loads up to 200 kg from the Hercules C-130 transport aircraft within 200 m accuracy or better. NLR is responsible for the development of the instrumentation package, the computer system and the control laws.

The development of the system is divided into three phases. In the first phase, the deployment of the system was tested, in the second phase, the vehicle was guided to its aiming point using its steering mechanism manually controlled from a remote ground station. Analysis of data recorded during this phase permitted the aerodynamic model of the parafoil that was used in the control loops to be fine-tuned. In the final phase of the programme, the control loops were closed and the system autonomously guided itself using actual position, attitude, speed and wind estimates. Tests with two demonstrators were carried out at the Vliehors military range. Sixteen landings were performed of which eight in closed-loop configuration. All landings were safe and well within the specified distance from the target point. The onboard instrumentation package, data link and remote control station performed to their specifications.

F-16 MLU Flight Test Instrumentation

Work under contract to the RNLAF for the extension and maintaining of a flight test measurement system in the F-16B MLU 'Orange Jumper' aircraft was continued. NLR supported M3 Radar trials for Lockheed/Edwards AFB using the so-called 'Edwards compatibility' of the data recording system of the Orange Jumper. Throughout the year NLR supported several different flight test programmes from the home base of the aircraft at Leeuwarden AFB, the most extensive being the project for flight testing the PIDS 3 Pylon Integrated Dispenser System. For this programme the PIDS 3 pylon was fully instrumented and connected to the basic flight test instrumentation system. The work was carried out under contract to the RNLAF, under supervision of the F-16 System Programme Office of the EPAF countries and in close co-operation with Lockheed Martin and the USAF Seek Eagle Office.

Flight tests were made for the assessment of the vibration characteristics of the pylon and of its influence on the tail fins of the Mk 84 AIR bomb attached to the pylon. A total of six flights were carried out. The programme was executed in a period of no more than six months from contract award to final data analysis.

The functionality of the on-board instrumentation display system was upgraded. To this end a new, fully airborne qualified display processor unit, based on PC-104 technology, was realised. Display software, based on the use of commercially available packages was being developed.

NLR, RNLAF and Lockheed staff in front of the F-16 Orange Jumper

3.8 Engineering and Technical Services

The year 2002 was reasonably successful for the Engineering and Technical Services. Approximately 65 per cent of the work was related to wind tunnel testing, concerning both wind tunnel models and test equipment. The rest of the work was, as usual, very diverse in nature.

Models and Test Equipment

Work on various wind tunnel models was continued. Most important was the work performed on a low speed model for thrust reverser tests for Gulfstream in the DNW-LST, and the work on a half-span model of a new business jet for Dassault for tests in the F1 wind tunnel of ONERA. For the first model an existing Fokker 100 wind tunnel model was equipped with new engine nacelles and blown thrust reversers. A large number of different configurations were required and quick modifications were to be realised during the test campaign. Some of these could only be realised through rapid prototyping. Much experience was gained with metal printing, a rapid prototyping technique that results in metal products of reasonable strength.

The second model was a modification of a large (scale 1:5) half-span model that had been built initially for force and pressure measurements, but in a second test campaign was to be used also to define the forces on flap and slat hinges. For that purpose it was extensively modified, with three-component balances on all flap and slat brackets.

Work was done in various European Fifth Framework projects. For the TILTAERO project, the design of the rotor blades for a half-span model (scale 1: 2.5) of a tiltrotor aeroplane was started. These blades were to be scaled down to both statically and dynamically represent the actual dynamic behaviour of the full-scale rotor blades. Two of the four blades will be provided with some 90 Kulites to measure dynamic pressures. Similar work was started for the blades of the ADYN half-span model, the acoustic variant of TILTAERO. For the TILTAERO project, also a pre-design study for a full model was started.

Under contract to DLR, a set of leading edges was made for the EPISTLE model, a large study model of a supersonic transport aircraft, to be tested in the low speed wind tunnel F1 of ONERA.

For Air Technologies of France and Deutsche Airbus Bremen, various sets of propeller blades were made, of carbon fibre composite, for Airbus A400M models. NLR is the supplier of the model propeller blades for virtually all the wind tunnel models in this programme.

Two models for an Air Refuelling Boom System were made for CASA/Airbus Spain, for tests in the DNW-HST. A 2D-model of the boom with interchangeable cross-sections was made for investigations at the full scale Reynolds number, and a 3D-model with remotely controlled wings

Detail of EPISTLE leading edge instrumented for pressure measurements

Icing blade measuring device

was made for tests of the aerodynamic forces on the boom installation. Also for CASA/Airbus Spain, an adapter for an existing air intake model for the power plant installation of the A400M aircraft was made for tests in the DNW-HST. The adapter was instrumented with eight rakes to measure static and total pressures and temperatures in the inlet channel.
Various smaller modifications were made to existing models: the tail model of the NH90 helicopter, the wing of the full model of a future jet trainer of AerMacchi, and the canards of a guided missile of SAGEM.
For CIRA (*Centro Italiano Ricerche Aerospaziali*) a system for measuring the ice accretion on a calibrated blade in the newly commissioned Icing Wind Tunnel was developed.

Several non-aerospace models, such as models of ships, bridges, cranes, buildings, were produced for investigations in wind tunnels of DNW.
Of particular interest was the work for the Royal Netherlands Air Force on a model of a roofed enclosure for ground running its propeller transport aircraft. The enclosure will shield the engine/propeller noise from the surrounding community, whilst maintaining suitable airflow conditions for steady ground running of the engines at all wind conditions.

Strain Gauge Balances

Work on a large (170 mm diameter) six-component sting balance for the Large Low-speed Facility (DNW-LLF) was started, as was work on a new (36 mm diameter) six-component balance for the transonic DNW-HST, to be used for missile tests.
The first of four rotating six-component balances for one of the A400M models of Deutsche Airbus was finished and tested on a propeller test rig in the smaller Low Speed Wind Tunnel DNW-LST.
For the Maritime Research Institute of the Netherlands, MARIN, several multicomponent balances for measuring the drag on ship hulls and components in water tanks were instrumented.
Balances for gauged parts of various wind tunnel models, such as stores, flaps, ailerons and wheel doors, were supplied to customers including AerMacchi, Airbus UK and Dassault.

Support

Supporting activities for the various divisions of NLR resulted in very diverse work packages, both in nature and size.
A large RTM-mould was finished for the production of carbon composite frames for a fuselage hull section. Although large in dimensions, these moulds require a high degree of accuracy. The mechanical design was made of an installation that enables the performance of seals of gas turbine blades to be tested. The installation allows seal tests to be made at up to 820 °C, 24 bars absolute pressure, 7 bars pressure differential, and 27,500 rpm, a quite different challenge from the other products mentioned. A demonstrator was built to prove the suitability of the selected bearings and power source to drive the test installation.

Various housings and breadboards for electronic equipment were built. A box for studying the growth of germs in an environment without gravity, in space, was designed and produced.

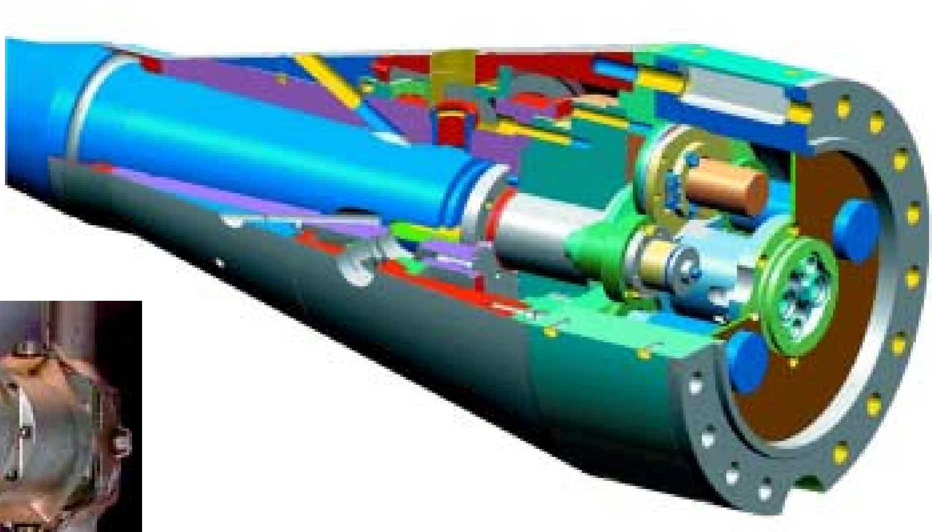
After the development in 2001 of an improved air bridge for supply air, called RALD (low reaction air supply system), a similar air bridge was developed for return air. This is particularly important for wind tunnel models where the exhaust air of the TPS (turbine powered simulator) motors has to be recaptured and returned through the model without affecting force measurements. This is the case for propeller-driven models.
Another development was that of a very compact Short Cone Roll Adapter (SCRA), to be mounted on the model support mechanism of the DNW-HST. The SCRA allows the model to be continuously rotated over 360 degrees under full aerodynamic load.

Also in support of DNW, a feasibility study was performed, as a joint project together with DLR, on a remote control system for traversing flaps for models that will be tested at low speed cryogenic conditions in the DNW-KKK and/or at high-speed ambient pressurised conditions in the DNW-HST.

Research

Research in the field of Layered Manufacturing Techniques (LMT) and other Rapid Prototyping techniques was continued. Particular attention was given to a new LMT technique called 3D-modelling, in development with the Fraunhofer Institute of Germany, allowing LMT-models to be made of metals instead of resins (like Stereo-lithography, Laser-sintering, Fused deposition modelling). These metal parts allow for significantly higher stress levels, comparable with those of aluminium alloys, do not need inserts for screws or bolts, and have stable structures, not deforming in time or by humidity. However, the achievable accuracies are still insufficient for most external parts of wind tunnel models.
Effort was spent into exploring the benefits of five-axis simultaneous milling. NLR has two modern milling machines that can be used for that. Machining times can be saved for certain products, be it at the expense of a bigger NC-programming effort.
The CADCAM systems of the Engineering and Technical Services also received attention. MasterCam level 3 was studied as an alternative for the CAM-side of CATIA, and the newly developed CATIA V5 software was studied.
Research on new balance techniques, materials and calculation software was continued. A study was started on the effects of various calibration methods and on the behaviour and the accuracy of the measured output of weighed control surfaces with a slender shape of wind tunnel models.

In the context of the European Co-operation on Cryogenic Models (E2CM), a co-operation between NLR, DLR and ONERA, a study to define common standards for materials, methods, formats, means and tools was started, aimed at effortless exchange of information, materials and products.



Short Cone Roll Adapter: CAD model and mounted device

4 Internal and External Relations

Many visitors were received at NLR Amsterdam, NLR Noordoostpolder and the German-Dutch Wind Tunnels (DNW). NLR participated in several air shows and exhibitions, and organised excursions and various events.

Visitors from the Netherlands

- Ir. W.H.J. Teeuwisse and Ms. ir. H.S. Boerigter of the Province of Flevoland
- Mr. M.M. van Rooij, President of Fokker Special Products
- Mr. F. Mertens, Inspector-General of Inspectie Verkeer en Waterstaat, accompanied by Mr. T. van Essen and Mr. M. Deul
- Drs. J.H. de Groene, director of Directie Markt & Innovatie of the Ministry of Economic Affairs, accompanied by Mr. drs. A.A.H. Teunissen, member of the NLR Board
- New members of the staff of Inspectie Verkeer en Waterstaat
- Members of the staff of the Netherlands Agency for Aerospace Programmes
- Students of Architecture of the Technical University Eindhoven
- Mr. R. Prins, of the Scientific Support Service of the Royal Netherlands Air Force
- Mr. E. Schwering, of the Tax Office, Unit large companies, Amsterdam, accompanied by Mr. E. Magnin, of Loyens & Loeff
- Kol. F. Groen (DM/MPF) and Kol. E. van Duren (DM/MPV) of the Royal Netherlands Air Force, accompanied by LtKol C. Dijkmans (DM/MXPS) and Mr. G. Kobus (DM/MPFTA)
- Cdre J.L.H. Eikelboom, Sous-chef Operational Policy and Requirements of the Royal Netherlands Air Force
- Ms. drs. M.H. Schultz van Haegen - Maas Geesteranus, State Secretary of Transport

Foreign Visitors

- Mr. J.M. Garot, Director, Mr. P. Andribet, Deputy Director, and Mr. Chr. Pusch, R&D Co-ordination Manager, of Eurocontrol Experimental Centre
- Dr. Bruce Fairlie, Councillor Defence Science of the Australian High Commission in London
- Members of the *Délégation Générale pour l'Armement* of the French Ministry of Defence and of the *Force Aérienne de France*
- Mr. Michael Clark, Counsellor Defence Research and Development of the Canadian High Commission
- Delegations of Autoflug GmbH and Schreiner Components
- Mr. M. de Gliniasty, Scientific Director, and Mr. H. Consigny, Director International Co-operation, of ONERA
- Members of a State of Arizona Trade Delegation
- Mr. Mather Mason, Research Leader, Crew Environments and Training of the Australian DSTO
- Mr. D.P. Mooney and Mr. T. Waggener of Boeing Commercial
- A delegation of AVIC1, of China
- Delegates of the Bank of America Investors, Connell and KPMG
- Dr. I. Chessel, Chief Defence Scientist, Australian Ministry of Defence, Dr. B. Fairlie, Counsellor Defence Science of the Australian High Commission in London and Mr. H.E.S. Page, Consul-General of Australia, accompanied by Drs. E.A. van Hoek, DWOO, Ir. N. Pos, National Co-ordinator WEAG/NATO, International co-operation, and Mr. F.W. Pieters, Logistic support, of the Netherlands Ministry of Defence

Excursions

- Two groups of students of Electrical Engineering of the Noordelijke Hogeschool Leeuwarden
- Members of the KLM Aeroclub
- Students of Business Administration of the Saxion Hogeschool of Enschede
- Students of Air Transport Economy and of System Logistics and Maintenance Management of the Erasmus University, Rotterdam
- Members of the Netherlands Royal Institute of Engineers (KIvI) Defence Technology Department
- Students of Electrical Engineering of the Technical University Eindhoven
- Participants of the ASME Turbo Expo 2002 held at Amsterdam RAI
- Directors of RIZA, the State Institute for Integral Water Management and Freshwater Disposal
- The mayor, aldermen and council members of the municipality of Steenwijkerland
- Directors Scientific Research and Development of the German and Netherlands Ministries of Defence, Mr. D. Elinger and Mr. J. Frank, of Germany; Ir. E.A. van Hoek, Ir. N. Pos and Mr. J.C.E. van den Brandhof (TNO), of the Netherlands
- Participants of a Measuring Behaviour Colloquium at the University of Amsterdam

– Participants of the semi-annual meeting of the Supersonic Tunnel Association International
– Members of the 7th Squadron RNLAF, Aircraft Training, Marine Vliegkamp De Kooy – Den Helder
– Staff members of the University of Amsterdam

Exhibitions
– Open Days of the Royal Netherlands Air Force, Gilze Rijen, 5–6 July
– Farnborough International Airshow, Farnborough, UK, 22–28 July
– 35th Anniversary of the Aeronautical Study Society 'Sipke Wynia', Lelystad, 31 July
– ICT Kenniscongres, The Hague, 5–6 September
– ICAS Congress, Toronto, Canada, 8–13 September
– AECMA Convention, Scheveningen, 4–5 October
– World Space Congress, IAF, Houston, USA, 10–19 October
– Promoplein, NIID, The Hague, 17 October
– Wetenschap en Techniek Week, Amsterdam, 18–20 October
– Bedrijvendag UT, Enschede, 22 October
– Het Instrument, Utrecht, 4–8 November

Events
– New Year Receptions for NLR staff at NLR Amsterdam and at NLR Noordoostpolder
– Internationaal Symposium on Composites Manufacturing for Aircraft Structures, NLR Noordoostpolder, 30–31 May
– Symposium 'Avionics for Future Air Operations', NLR Amsterdam, 12 June
– Final Presentation of EUCLID (WEAG) TA-15 Project 'Computational methods in Aerodynamics', Amsterdam, 20 June
– Meeting of Kwaliteitskring Noord-Holland, 20 June
– Handing over of a Visual System for the Tower Research Simulator by Mr. H. Koemeester of Siemens to Ir. F. Holwerda, NLR General Director, assisted by Mr. P.L.L. van Lieshout and Mr. T. van Birgelen of Siemens
– Final Presentation of the project Voice Control for the JSF, Amsterdam, 16 July
– Meeting of the Contact Group Numerical Fluid Dynamics of the J.M. Burgers Centre, NLR Amsterdam, 8 November
– Colloquium Satellite Navigation, NLR Amsterdam, 29 November

NLR demonstrated cockpit voice control at the Farnborough International Airshow

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 in 2001 under NLR's own Programme for basic research and development of facilities;
  - the Preliminary Work Plan for 2003;
  - NLR's own Programme for basic research and development of facilities for 2004;

- To the Boards of Directors of NLR and NIVR, on:
  - the reports NLR submitted to the Committee to be assessed for scientific value or for suitability as scientific publications;
  - proposals for new research in the framework of the NIVR Basic Research Programme.

Membership of the Scientific Committee

During the year one vacancy remained open. The Board of NLR has appointed Prof.dr.ir. G. Ooms as the successor of Prof.ir. C.J. Hoogendoorn. Professor Ooms assisted at the meetings of the Committee in 2002. The vacancy caused by the resignation of Ir. F. Holwerda has remained open, awaiting the results of the discussion on the relation of the NIVR to the Scientific Committee. NIVR has made known the intention for an appointment.

At the end of 2002 the Scientific Committee was composed as follows:

Prof.dr.ir. P.J. Zandbergen, *chairman*
Dr. R.J. van Duinen
Prof.dr. T. de Jong
Prof.dr.ir. G. Ooms
Vacancy
Ir. G.J. Voerman, *secretary*

Membership of the Subcommittees

Prof.dr.ir. M.G.H. Verhaegen took over the chair from ad interim chairman Prof.dr. G.L. Reijns in the Subcommittee for Avionics as of November 2002.
Prof.dr.ir. C.R. Traas resigned from the Subcommittee for Information and Communication Technology because of his superannuating; a successor is being sought.
Dr.ir. H.G. Visser has made known his wish to resign from the Subcommittee for Flying Qualities and Flight Operations / Air Transport because of the pressure of his work with the TU Delft. This matter is being discussed.
A need for a member with the Royal Netherlands Air Force as a background is felt in the Subcommittee for Aerodynamics
The Subcommittee for Space Technology has emphasised the wish to retain Dr. N.J.J. Bunnik as a member, in spite of his joining the NIVR

At the end of 2002 the subcommittees were composed as follows:

Subcommittee for Aerodynamics

Prof.dr.ir. J.L. van Ingen, *chairman*
Prof.dr.ir. P.G. Bakker
Ing. J. van Hengst
Dr.ir. A. Hirschberg
Prof.dr.ir. H.W.M. Hoeijmakers
Prof.dr.ir. F.T.M. Nieuwstadt
Prof.ir. E. Obert
Prof.ir. E. Torenbeek
Prof.dr. A.E.P. Veldman
Prof.dr.ir. P. Wesseling
Prof.dr.ir. L. van Wijngaarden
Ir. E.P. Louwaard (NIVR)

Subcommittee for Space Technology

Prof.Dipl.-Ing. H. Stoewer, *chairman*
Prof.dr.ir. J.A.M. Bleeker
Civ.Eng. N.E. Jensen
Ir. P.L. van Leeuwen
Prof.dr.ir. L.P. Ligthart
Dr. A.M. Selig
Prof.ir. K.F. Wakker
Prof.dr.ir. P.Th.L.M. van Woerkom
Ir. D. de Hoop (NIVR)

Subcommittee for Structures and Materials

Prof.dr.ir. H. Tijdeman, *chairman*
Ir. N. Fraterman
Prof.dr.ir. Th. de Jong
Ir. J.B. de Jonge
Kol. Ir. J.W.E.N. Kaelen
Ir. A.J.A. Mom
Ir. A.R. Offringa
Prof.dr. A. Rothwell
Ing. E. van Teeseling
Ir. L.H. van Veggel
Ir. J.J. Wijker
Prof.dr.ir. S. van der Zwaag
Ir. F.J.M. Beuskens (NIVR)

Subcommittee for Information and Communication Technology

Prof.dr.ir. P. Wesseling, *chairman*
Prof.dr.ir. J. Schalkwijk
Prof.dr.ir. J.L. Simons
Prof.dr.ir. H.J. Sips
Prof.dr. A.E.P. Veldman
Ir.R.C. Doeglas (NIVR)

Subcommittee for Flying Qualities and Flight Operations/Air Transport

Prof.ir. E. Obert, *chairman*
KTZSD b.d. ir. K. Bakker
Ir. W.G. de Boer
J. Hofstra
Dr.ir. R.J.A.W. Hosman
Ir. H.J. Kamphuis
Lt.Kol. H.J. Koolstra
Ir. P. Riemens
Ir. H. Tigchelaar
Dr.ir. H.G. Visser
Ir. G.C. Klein Lebbink (NIVR)

Subcommittee for Avionics

Prof.dr.ir. M.H.G. Verhaegen, *chairman*
Ir. W. Brouwer
Ing. H. de Groot
Lt.Kol. Ing. H. Horlings
Ir. S.O. van de Kuijt
Prof.dr.ir. L.P. Ligthart
Ir. P.J.G. Loos
Kol. ir. E.B.H. Oling
Ir. L.R. Opbroek
Prof.ir. G.L. Reijns
Dr. R.P. Slegtenhorst
Ir. A.P. Hoeke (NIVR)

Concluding Remarks of the Committee

In its meetings the Scientific Committee NLR-NIVR has always kept in mind the possibilities of furthering the knowledge in the Netherlands aerospace cluster. NLR is in the front ranks when it comes to the maintaining and expanding of knowledge in science and technology development. Wherever these activities could benefit the Netherlands manufacturing industry, the NIVR has always provided support wholeheartedly.

The Committee observes with disappointment the perils that now impel NLR to revise its activities and organisation; in 2002 however, the Committee has mainly considered the developments that occur in the environment of NLR and NIVR and that will appear to be of overriding importance for science and technology in the Netherlands in the long term. The directorial roles that European institutes and co-operations are assuming are becoming ever more evident, especially in the fields of technology development for aircraft construction and spaceflight, and also for air transport. International co-operations are increasingly set up also for the expansion of scientific methods. In the aerospace manufacturing industry, businesses are completely dependent on international programmes; the NIVR supports these according to its ability.

For NLR also a strengthened orientation on Europe is becoming ever more needed, the more so because the material involvement of the Netherlands government with NLR seems to be diminishing. In an increasingly globalising environment, the question then rises whether NLR should continue to define its mission primarily as supporting Netherlands institutes and companies. A widening of the task definition of NLR, aimed primarily internationally, and especially on Europe, requires the government's ability to support such a step on the basis of its own goals and considerations.

Like the viable survival of the manufacturing industry must be feared for in the absence of a clear sector policy of the government, for knowledge institutes a clearly expressed government view for the long term is indispensable. To give the initial impetus, a number of scenarios could be developed, given the plurality of fast changing environmental factors. The drawing up of a national Strategic Research Agenda may also constitute a valuable contribution to the development of a new government view on the sector.

6 International Co-operation

6.1 Military Research and Technology Organisations

NATO Research and Technology Organisation (RTO)

The NATO Council established the NATO Research and Technology Organisation (RTO), focus of NATO for Defence Research and Technology activities, in 1996. The RTO is headed by the R&T Board (RTB). The Netherlands voting member of the RTB was Drs. E.A. van Hoek of the Ministry of Defence.

The RTB is assisted by the R&T Agency, which is tasked with the day-to-day management of the RTO. The following Panels, with members from defence and research organisations, guided the R&T activities:

- Studies, Analysis and Simulation (SAS)
- Systems Concepts and Integration (SCI)
- Sensors and Electronics Technology (SET)
- Information Systems and Technology (IST)
- Applied Vehicle Technology (AVT)
- Human Factors and Medicine (HFM)
- NATO Modelling and Simulation Group (NMSG)

NLR Participation

R&T Board

The NLR member of the R&T Board (RTB) was Ir. F. Holwerda.

R&T Panels

NLR was represented in five panels:

SAS	Ir. F.J. Abbink
SCI	Prof.drs. P.G.A.M. Jorna
SET	Ir. H.A.T. Timmers, until 1 November; successor to be designated
IST	Ir. F.J. Heerema
AVT	Ir. H.H. Ottens

WEAO/WEAG R&T Organisation

Also in 1996, the Western European Armaments Organisation (WEAO) was established. The existing Western European Armaments Group (WEAG) tasked with establishing R&T programmes, known as European Co-operation for the Long term In Defence (EUCLID), was more or less absorbed in the WEAO. The WEAG is headed by the National Armaments Directors, with their Permanent Representatives in Brussels forming the Staff Group. The WEAG Research Cell (WRC) within the WEU structure became the initial executive body of the Western European Armament Organisation.

The WEAG has three panels: Equipment Programmes, Research and Technology, and Procedures and Economic Matters. Activities in Panel II, Reseach and Technology, mainly concern the EUCLID Programme, involving industry and research institutes. The following Common European Priority Areas (CEPAs) and Subgroup were active:

CEPA 1 –	Modern Radar Technology
CEPA 2 –	Micro Electronics
CEPA 3 –	Advanced Materials & Structures
CEPA 4 –	Modular Avionics
CEPA 6 –	Advanced Information Processing & Communications
CEPA 8 –	Opto-Electronic Devices
CEPA 9 –	Satellite Surveillance and Military Space Technology
CEPA 10 –	Underwater Technology and Naval Hydrodynamics
CEPA 11 –	Defence Modelling and Simulation Technologies
CEPA 13 –	Radiological, Chemical and Biological Defence
CEPA 14 –	Energetic Materials
CEPA 15 –	Missile, UAV and Robotic Technology
CEPA 16 –	Electrical Engineering

Sub Group on Test Facilities

The programmes and activities are co-ordinated by an R&T Management Committee (RTMC). The Netherlands members of Panel II and the RTMC were Drs. E.A. van Hoek and Ir. N. Pos, respectively, both of the Ministry of Defence.

NLR Participation

NLR contributed to various programmes within the CEPAs.

National Co-ordinator

National Co-ordinator of RTO and of EUCLID was Ir. N. Pos, of the Netherlands Ministry of Defence, assisted for NLR by Ir. D. Sjerp.

6.2 German-Dutch Wind Tunnels (DNW)

The main objective of the DNW, being a non-profit organisation under Dutch law, is to provide a wide spectrum of wind tunnel test and simulation capabilities to customers from industry, government and research.

In addition to the jointly developed Large Low-speed Facility (LLF), the largest low-speed wind tunnel in Europe, DNW operates all major aeronautical wind tunnels of NLR and DLR. The wind tunnels operated by DNW are grouped in three business units: 'Noordoostpolder' (NOP), 'Amsterdam' (ASD) and 'Göttingen und Köln' (GUK). In addition to the LLF, the two 3-m low-speed wind tunnels LST and NWB (the latter located in Braunschweig) as well as the Engine Calibration Facility (ECF) belong to Business Unit NOP. The main facilities in Amsterdam are the transonic wind tunnel HST and the supersonic wind tunnel SST. The transonic wind tunnel TWG and the cryogenic low-speed wind tunnel KKK are the major facilities of Business Unit GUK.

The Board of DNW

The Board of the Foundation DNW is formed by members appointed by NLR, DLR and the German and Dutch governments. At the end of 2002 the Board consisted of:

Ir. F. Holwerda, *Chairman*
NLR
Dr.-Ing. J. Szodruch, *Vice-Chairman*
DLR
B.A.C. Droste
Netherlands Agency for Aerospace Programmes (NIVR)
Drs. L.W. Esselman, R.A.
NLR
DirBWB K. Heyer
Ministry of Defence of Germany (BMVg)
Prof.Dr.-Ing. H. Körner
DLR
MinR. Dr. H.-M. Spilker
Ministry for Education and Research of Germany (BMBF)
Vacancy
Ministry of Transport of the Netherlands

Secretary: Ms. S. Pokörn, DNW

The Advisory Committee

The Advisory Committee, representing the aerospace industry and research establishments, advises the Board of DNW about long-term needs of the industry. In October 2002 the Advisory Committee consisted of:

Mr. J. Javelle, *Chairman*
Airbus France
Dipl.-Ing. A. Flaig
Airbus Deutschland GmbH
Prof. Dr.-Ing. S. Levedag
DLR
Prof.Dr.ir. J.L. van Ingen
Delft University of Technology
Dr.-Ing. E. Krämer
EADS Deutschland
Dr. B. Oskam
NLR
Mr. M. Polychroniadis
Eurocopter France

Secretary: Dr.-Ing. G. Lehmann
DNW

The Board of Directors

The Board of Directors of DNW consisted of:
Director: Dr.-Ing. G. Eitelberg (DLR)
Deputy Director: Ir. C.J.J. Joosen (NLR)

Business Unit NOP

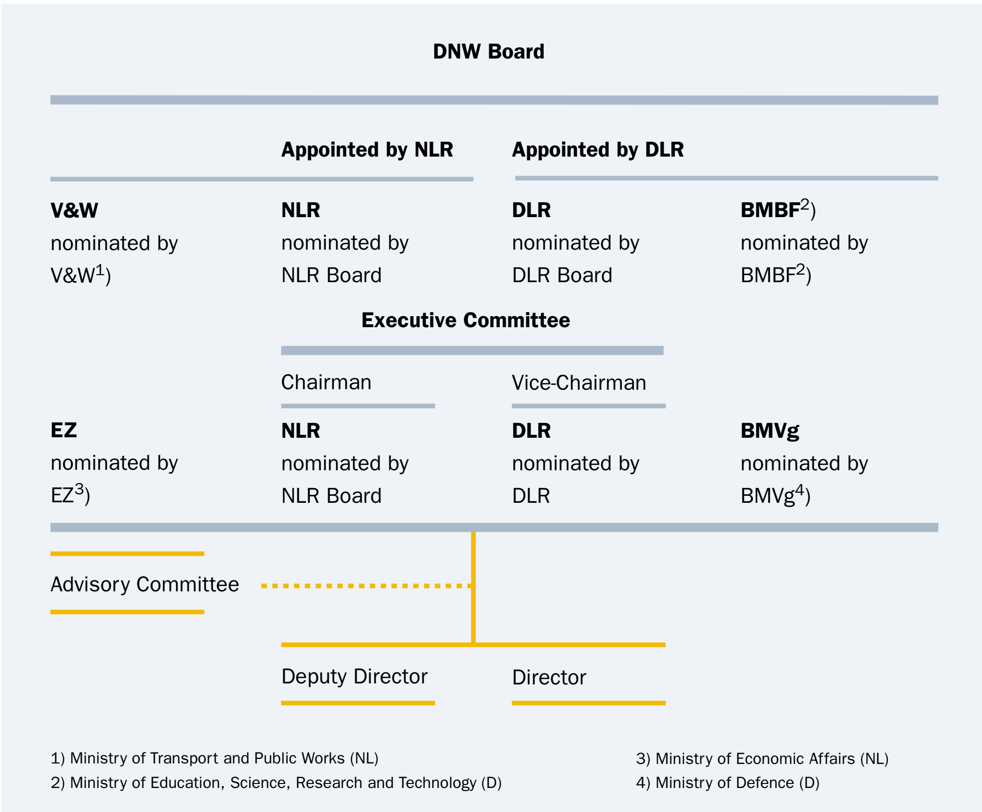
After a disappointing first quarter DNW-LLF, the main facility of Business Unit NOP, could nevertheless reach a good total occupation during the rest of the year. The aircraft segment represented about 80% of the occupation; the other 20% mainly consisted of car and truck tests. From the two smaller wind tunnels the LST had a good year due to a more than average occupation by aeronautical tests. The occupation of the NWB was negatively affected by the bankruptcy of Fairchild Dornier. Besides, the NWB was shut down in November for a three-month period to install a heat exchanger into the tunnel circuit. Some projects from the three low-speed wind tunnels are described below.

The major part of the LLF aircraft segment concerned fighter models. For Lockheed Martin two extensive test campaigns on Short Take-Off and Vertical Landing (STOVL) Jet Effects on a

12% scale model of the Joint Strike Fighter (JSF) were performed. The tests were very successful in terms of the productivity realised. These tests will be followed by other entries in the next few years. They are carried out under a contract between BAE Systems – partner of Lockheed Martin in the JSF programme – and NLR, within the framework of the JSF Systems Design and Development (SDD) phase.

Already in the earlier JSF Concept Demonstration Phase (CDP), the LLF was successfully used for STOVL testing on a 12% scale model, utilising the very accurate height positioning of the LLF sting mechanism. This wind tunnel is capable of providing a combination of specific test conditions needed for the STOVL configuration: a nearly constant flow at very low speeds (down to 15 knots) and a large amount of compressed air to simulate jet exhaust effects on lift fan, core engine and roll nozzles of the aeroplane. Furthermore, the dimensions of the largest test section of the LLF (9.5m x 9.5m cross-section), ensure that the wind tunnel wall effects on the model can be neglected.

An important civil project in the LLF was a European research project called Silencer. Two aeroacoustic test campaigns were carried out on a large aircraft model in high-lift landing configuration. The goal of the first campaign in the anechoic environment of the open jet test section was the aeroacoustic optimisation of newly developed devices on slats and flaps. The local influence of these devices on the airframe noise was measured with DNW's traversable out-of-flow microphone array producing online results. These results could be used to judge the quality of the measured data. The overall noise reduction was assessed with far-field microphones, which were mounted on a newly developed quarter-arch with a 7-m radius (see Figure 1). This traversable support is already scheduled for several other airframe noise tests. The goal of the second entry in the closed 8x6 m^2 test section was the aerodynamic verification of the optimised devices for the full-scale test, planned at the end of the Silencer project in 2004. Parallel to those measurements, DNW's wall-array was used to verify the acoustic performance of the new low noise high-lift devices online.



Schematic of the organisation of the Foundation DNW

Fig. 1 – Aeroacoustic measurement in the LLF

In view of future LLF campaigns with a model of the Airbus A400M, sting interference tests were done in the smaller LST. It was the first time that Airbus used the LST to prepare tests that are planned later in the LLF. The main objective of the LST tests was to find optimal sting support configurations for the LLF tests with a large-scale model, promising correctable sting interference effects on the measurement data. For this assessment the application of the classical wire suspension for aircraft models was essential. This suspension enables basic measurements to be made without dominant support interference effects on the fuselage rear end. Those measurements were compared with measurements after adding scaled supports simulating LLF testing.
Besides the force measurements on the model, Particle Image Velocimetry (PIV) measurements were performed in the flow around the model to determine position and strength of the fuselage rear end vortices. Measurements were made at three different planes, all perpendicular to the flow (see Figure 2).
The client was very satisfied with the results and expressed his intention to use the LST more often as preparatory test facility for the LLF.

Also in the NWB the A400M was subject of research. An extensive damping derivative test on a lightweight model supported by three struts was performed. The three-strut support was equipped with piezo elements on top of each strut, creating a six-component balance.

A full-span Ground Run-up Enclosure (GRE) model was tested for the Royal Netherlands Air Force in the LLF as a follow-up of a test with a semi-span model in the LST. The present model featured a full-span model of a Hercules C-130 aircraft with four air-driven four-bladed propeller engines. The port engines were equipped with rotating shaft balances. The Hercules model was placed inside the GRE construction and the complete set-up was mounted on the turntable of the 9.5m x 9.5m test section. Propeller thrust and torque fluctuations were measured for all wind directions. For the first time in its history, the DNW-LLF featured atmospheric boundary layer simulation.

In November 2001 a team of Dutch students of the Delft University of Technology and the University of Amsterdam had won the race for solar energy driven cars across the Australian continent from Darwin to Adelaide. With an average speed of 92 km/h over a distance of 3010 km the Dutch Solar Car successfully beat the competing cars, some of which were designed and supported by major car manufacturers.
The three-wheeled Solar Car had been designed and developed by students of different disciplines. The aerodynamic design was the task of students of Delft who used numerical methods as well as wind tunnel experiments with scaled models. Now it was important for the team to verify the realised aerodynamic quality of the full-scale car in the LLF. This verification was made in a half-day test by measuring the aerodynamic loads on the car with the external balance at different speeds up to 160 km/h, and by smoke visualisation of the flow around the vehicle (see Figure 3). Besides this, a stethoscope probe was used to detect the local boundary layer type. It was shown that the smooth installation of the solar panels in the curved contour of the car resulted in rather large areas with laminar flow. The results of the measurements proved that with the full-scale car the goal of an excellent aerodynamic design was reached. The excellent design, the experience gained and the success in the race encouraged a new team of students to further improve the car and to take part in the 2003 race across Australia.

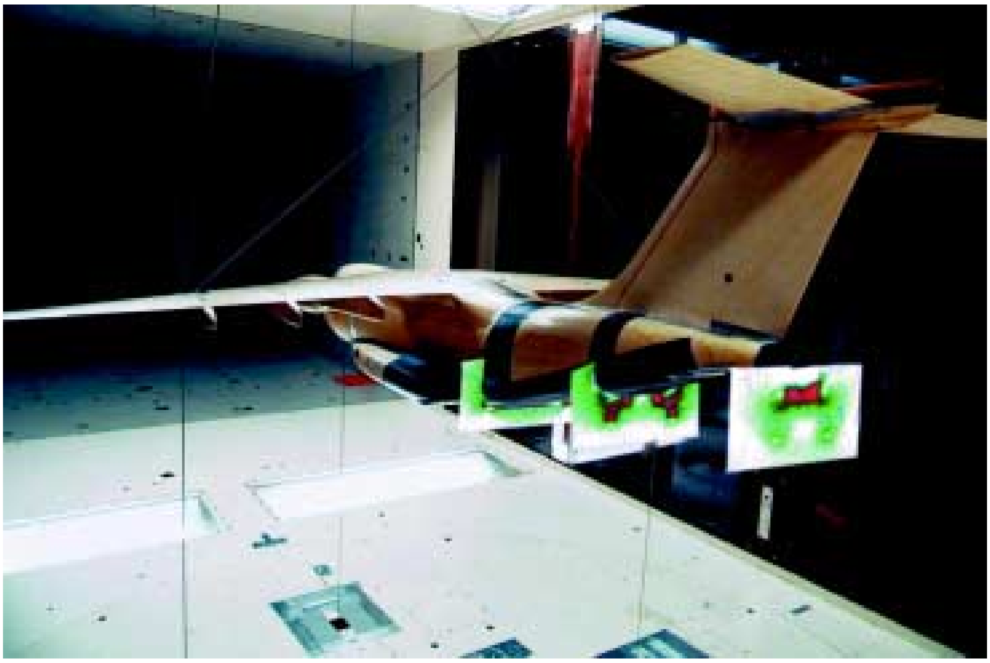


Fig. 2 – Particle Image Velocimetry measurements at three planes in the DNW-LST, for the A400M programme

Business Unit ASD

The occupation of the transonic wind tunnel HST of Business Unit ASD suffered an unexpected decline as in Spring one of the major customers, the manufacturer of regional aircraft Fairchild Dornier, filed for bankruptcy. As a consequence the total number of testing hours sold for the HST stayed below the level of the previous years. Although, in Europe, new projects (launch vehicles, missiles), requiring testing in the supersonic speed range were started, it was too early for the supersonic wind tunnel SST to benefit from this interest for supersonic testing.

For the HST the test volume related to civil aircraft was reduced to about 30% of all shifts sold, while military aircraft tests grew to a share of more than 50% of the total revenues. The remaining 20% of the revenues originated from missile and research-related testing.

Tested models of civil aircraft included a semi-span model equipped with a Turbofan Powered Simulator (TPS) for simulation of the full-scale engine. The objective of this type of test is to measure the interference between the engine inlet flow and the engine exhaust, and the flow around the wing. At low rpm the TPS 'simulates' a through-flow nacelle (TFN) and at higher rpm the TPS flow comes very close to the flow through the real engine. The difference in drag of the airframe between TFN and TPS running at high rpm (cruise power setting) is the so-called interference drag, which was determined with a precision of two drag counts. Compared to unpowered testing, where a precision of one drag count is common, two drag counts is an excellent achievement.

Besides semi-span models, full-span models were tested, including models of the IAI-designed Gulfstream G100™ and Gulfstream G150™ business jets. The main difference in layout between these two business jets is the cabin size.

Fig. 3 – Winning Dutch solar car in DNW-LLF

The G100 cabin is mid-sized, whereas the G150 has a wide cabin. The large degree of commonality between the two aircraft was also exploited in the wind tunnel models. In a single test campaign the complete database for both model configurations was built. It allowed the customer to make a direct comparison between the aerodynamic design improvements incorporated in the G150. Stringent time constraints set by the customer were a challenge for the wind tunnel team, but by going from the standard single-shift operation to a two-shift operation, the team completed the test well within the planned time frame.

For NLR as member of the GARTEUR Action Group (AD) AG-28 'Transonic Wing/Body Code Validation Experiment', a test on a full-span wing/body configuration of a civil aircraft model was executed. The model tested was mounted on a six-component balance for the measurement of forces and moments, and had over 200 pressure taps to measure local wing pressures. In addition five rows of pressure taps on the test section walls registered the pressure distribution in the test section in order to investigate wall interference effects. The test results will be compared with data from a semi-span model test in the S1 wind tunnel of ONERA and with data from a full-model test in the European Transonic Windtunnel (ETW).

For various military aircraft manufacturers, models of fighters and trainers were tested. Besides the standard force and moment measurements, the three-component Particle Image Velocimetry System was used to study the vortex flow over the wing of a fighter configuration. One of the trainer models was heavily instrumented, among other things with more than ten secondary balances in various control surfaces and stores. The large number of secondary balances constituted a challenge not only in instrumentation but also in data processing, as each balance has one or more dedicated calibrations. The DNW-HST data processing software proved its capability to handle data streams from complex models by presenting all the balance results together with the standard wind tunnel data on-line.

Another trainer model tested was the EADS Mako (see Figure 4). Besides force and moment measurements the Pressure Sensitive Paint method was applied. The PSP method gives detailed surface pressure information without the need for a large number of pressure taps.

Business Unit GUK

The occupation and productivity of the transonic wind tunnel TWG in Göttingen was on an average level. Again most tests were typically fundamental and applied research experiments conducted by DLR. These experiments are embedded in long-term interdisciplinary joint projects of different DLR Institutes. The most important projects for the TWG are addressed below.

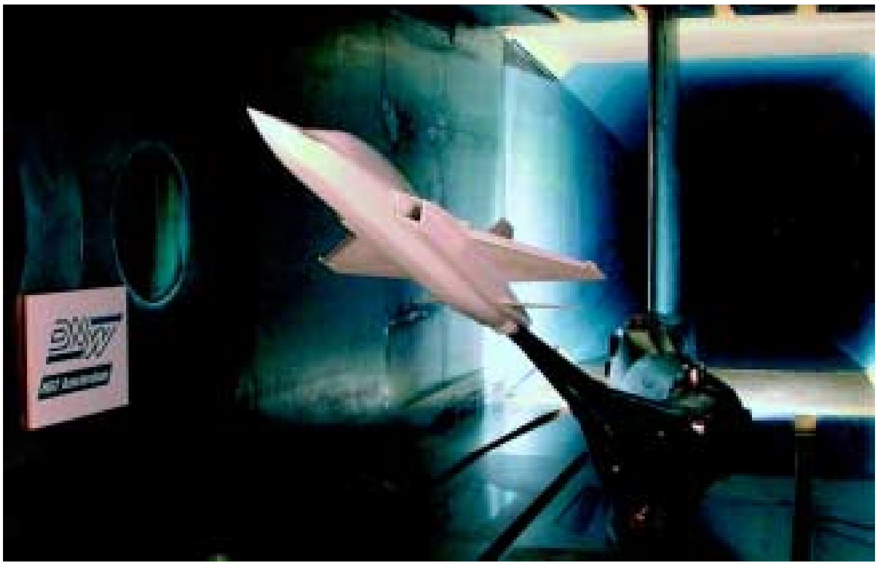


Fig. 4 – EADS Mako trainer model tested using Pressure Sensitive Paint in the DNW-HST

In the projects AeroSUM and its follow-up project SikMa, numerical code development for manoeuvring fighter configurations was complemented by validation experiments for a rolling delta wing with remotely controlled ailerons. Forced and free transient roll manoeuvres were examined with advanced unsteady force, pressure and optical field measurement techniques. SikMa started in 2002 in the TWG with experiments where emphasis shifted from manoeuvrable rigid configurations towards the coupling of structure and aerodynamics.

In the projects AeroStabil and its follow-up project HighPerFLEX, tests with forced and free oscillating aerofoils were continued, now with rigid and flexible half-wings, to reveal details of flutter and limit-cycle oscillation phenomena and to validate analysis and prediction codes. For these tests a new dynamic half-model test bed was integrated into the tunnel hardware. The expertise of the TWG staff with respect to such aeroelastic experiments is the basis to include further components like 'control surface dynamics' and 'wing with oscillating nacelle'.

Business Units ASD and GUK continued the joint realisation of a multiple-view PSP system for the TWG and the HST with support of DLR.

At the cryogenic low-speed wind tunnel in Cologne (KKK) the year was characterised by strong efforts to acquire tests in new market segments and to increase the attractiveness in established markets.

A feasibility test of a high-speed train model on the half-model balance demonstrated that the high standard of aeronautical wind tunnel testing can be transferred to ground vehicles. The usability of Particle Image Velocimetry (PIV) under cryogenic conditions was demonstrated.

The increasing size of modern wind rotors, especially of offshore plants, creates a rising demand of high Reynolds-number testing at low Mach numbers as can be realised in the KKK. Systematic tests with thick wind rotor aerofoils were carried out and combined with flow control experiments using advanced vortex generators and Gurney flaps.

In the high-pressure wind tunnel (HDG) in Göttingen successful efforts to extend the test spectrum have sharply increased the demand. Basic research boundary layer measurements with flat plates of different roughness were carried out to evaluate fabrication tolerances in turbomachinery. Systematic six-component balance measurements and flow visualisation tests were performed on current and generic high-speed train models. A major concern was the development and Reynolds-number dependency of rolling moments at side wind conditions. An airship model was tested at a total pressure of 100 bar and thus at the highest Reynolds number possible in DNW low-speed wind tunnels, although the scale was only 1:1000. The high Reynolds number is essential for a realistic estimate of the drag and the landing capability under wind conditions.

6.3 European Transonic Windtunnel (ETW)

On behalf of the Netherlands, NLR is a seven per cent shareholder in the European Transonic Windtunnel GmbH, established in 1988. The ETW provides Europe with a unique capability for transonic testing at realistic Reynolds numbers.

In 2002 a substantial number of paid tests was executed, including tests performed in relation with European programmes. The tests yielded good results and satisfied customers.

Supervisory Board

At the end of 2002, the membership of the Supervisory Board was as follows:

France

ICA X. Bouis, *Chairman*	ONERA
ICA H. Moraillon	DGAC/DPAC
ICA L. de Chanterac	DGA/DSP/ SREA/PEA

Germany

Dr. J. Szodruch	DLR
MinR. Dr. H.-M.Spilker	BMBF
Prof.Dr.-Ing. H. Körner	DLR

United Kingdom

Dr. R. Kingcombe	DTI
Dr. C.G. Burton	QinetiQ

The Netherlands

Vacancy	V&W
Ir. F. Holwerda	NLR

The Managing Director, Dr. W. Burgsmüller (G), was assisted by Dr. G. Hefer (G), Manager Projects.

6.4 Group for Aeronautical Research and Technology in Europe (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. In 2000 Italy joined GARTEUR as the seventh nation.

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 an Exploratory Group achieves an agreed proposal, an Action Group is established with participants (research establishments, industries or universities) from at least three GARTEUR countries.

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

Organisation

The organisation diagram shows three levels: the Council/Executive Committee, the Groups of Responsables and the Action Groups. Via the Industrial Management Group (IMG^3) associated with the *Association Européenne des Constructeurs de Matériel Aérospatial* (AECMA), Industrial Points of Contact in the Groups of Responsables and industry participation in Action Groups, GARTEUR has interfaces with the European aeronautical industry.

Council and Executive Committee

At the end of 2002 the GARTEUR Council was composed as follows.

France

IGA Ph. Ramette	DGA *)
Ms. Dr. D. Nouailhas	ONERA **)
ICA H. Moraillon	DGAC/DPAC
ICA L. de Chanterac	DGA

Germany

Dr.-Ing J. Bandel	BMWi *)
W. Riha	DLR **)
LB Dir. K. Heyer	BMVg
Dipl.-Ing. H. Hüners	DLR

United Kingdom

Dr. G.T. Coleman	DSTL *)
D.M. Way	DTI

Spain

A. Moratilla Ramos	OCT *)
P. Garcia Samitier	INTA **)
R. Herrero Arbizu	MdCyT
Dr. J.M. Carballal Prado	MdD

Sweden

Col. A.V. Johnson	FMV *)
L. Falk	FMV **)
Ms. C. Looström	FOI
Ms. Dr. E. Lindenzona	VINNOVA

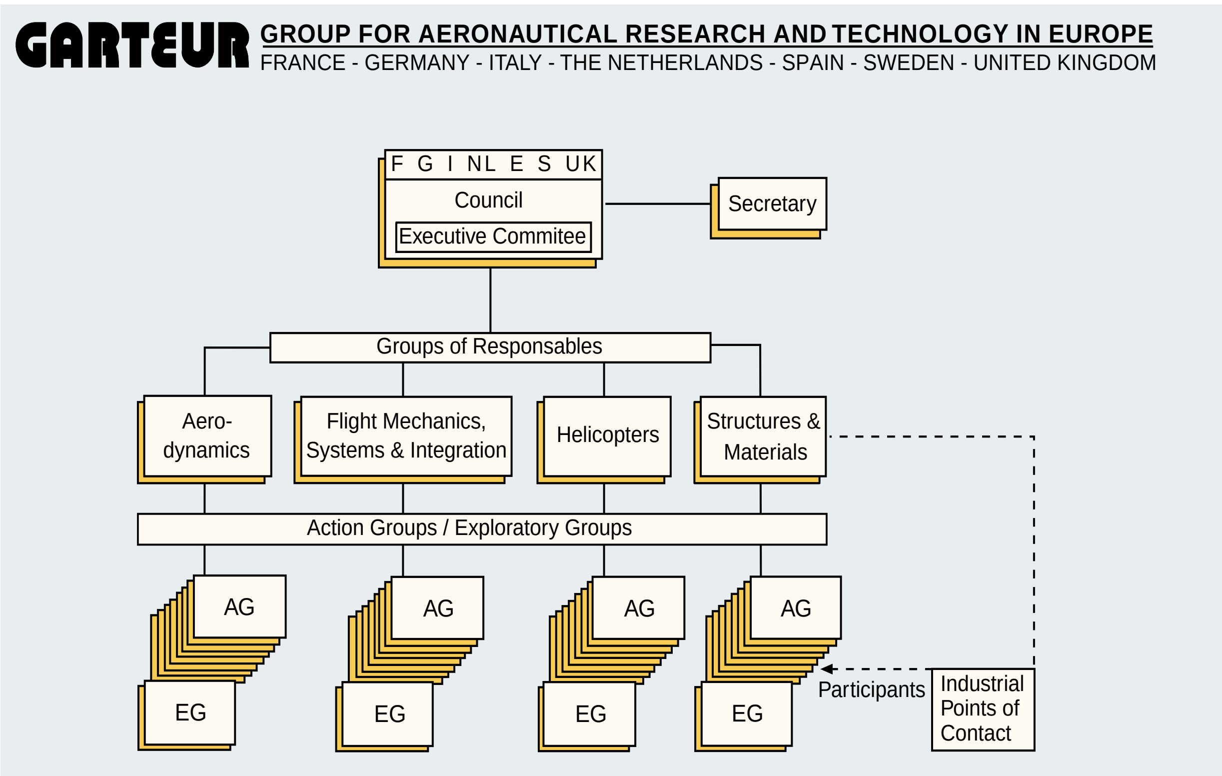
The Netherlands

Drs. E.A. van Hoek	MvD *)
Drs. A.A.H. Teunissen	MEZ
Ir. F.J. Abbink	NLR
Dr. B. Oskam	NLR **)

Italy

Prof. S. Vetrella	CIRA *)
A. Amendola	CIRA **)
M. Mazolla	MURST-SSPAR
Col. O. Spedicato	MDif

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



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

In 2002, Spain provided the chairman for the GARTEUR Council and the chairman for the Executive Committee as well as the Secretary. The persons involved were:

A. Moratilla Ramos	*Council chairman*
P. Garcia Samitier	*Executive Committee chairman*
F. Merida Martin	*Secretary*

The GARTEUR Council met in Paris, France and Berlin, Germany.

The Executive Committee had four meetings.

The NLR members of the Groups of Responsables (GoR) were:

Ir. A. Elsenaar	Aerodynamics GoR
Ir. W.P. de Boer	Flight Mechanics, Systems & Integration GoR
Ir. L.T. Renirie	Helicopters GoR
Ir. H.H. Ottens	Structures & Materials GoR

NLR Participation

NLR has participated in the activities of the GARTEUR Council, the Executive Committee and the Groups of Responsables. Table 1 shows the total numbers of Action Groups and the numbers of the Groups in which NLR has participated.

Table 1 – Numbers of Action Groups

Group of Responsables	Action Groups Total	NLR
Aerodynamics	12	11
Flight Mechanics, Systems & Integration	3	3
Helicopters	4	4
Structures & Materials	5	5
Total	24	23

6.5 Co-operation with European Research Establishments in Aeronautics

DLR/NLR Partnership

Background

A formal partnership agreement between the *Deutsches Zentrum für Luft- und Raumfahrt* (DLR) and the National Aerospace Laboratory NLR has been in force since 1994. The aim of the partnership is to strengthen the ties between the two establishments in order to make more effective use of knowledge and facilities available. A Joint Executive Board (JEB) and a DLR/NLR Board Working Group, consisting of representatives of DLR and NLR, guide and control this task. The NLR representatives, J. van Houwelingen and Ir. F. Holwerda, were assisted by Drs. A. de Graaff.

DLR and NLR continued their negotiations on the establishment of closer co-operation and eventually integration of the activities related to Air Traffic Management and Airport Traffic Management research, development, testing and evaluation.

Progress was made in the integration of the wind tunnels operated by DNW and those of ONERA in the future Aerodynamic Testing Alliance (ATA), to render better and more cost-effective services in the field of wind tunnel tests.

The DLR-NLR Programme Committee continued to stimulate and monitor bilateral precompetitive research. The NLR representatives were Ir. F.J. Abbink, Dr. B. Oskam and Ir. H.H. Ottens.

Bilateral co-operation covered:
– Low-speed Propulsion-Airframe Integration
– CFD for Complete Aircraft
– Development of B2000 Software

EREA: Association of European Research Establishments in Aeronautics

European aeronautical research establishments formed the association EREA in order to foster an effective and efficient European aeronautical technology base. EREA aims at ultimately creating a union between regional centres, where strong organisational ties result in integrated management of joint activities, pooling of facilities and the creation of interdepencies and centres of excellence.

In the General Assembly of EREA, NLR was represented by J. van Houwelingen, Ir. F. Holwerda and Drs. A. de Graaff, who was also treasurer and member of the Executive Secretariat.

Activities enabling closer co-operation on an EREA-wide basis were continued. These included the comparison of financial data and procedures, the EREA portfolio and capabilities and internal regulations. An EREA website and intranet were operational.

EREA also prepared a proposal for a network of excellence, sponsored by the European Union, aimed at lasting integration.

Relations to the European Union

European aeronautical research establishments work together in the Aeronautical Research Group (ARG) to facilitate communication and to promote joint interests with the European Commission and the European industry, as well as promoting information exchange amongst the establishments on EU-related issues. The ARG, chaired by Drs. De Graaff (of NLR), has been incorporated in EREA. Exchanging information and preparing project proposals are the main objectives of the ARG. The ARG has links to research organisations and universities outside EREA, outside the seven EU nations involved in EREA, and in Israel.

Together with the European Industry, the ARG prepared and updated versions of the ARTE21 (airborne systems related) and ARTECA21 (ATM related) documents. Both documents were used as the basis for the sixth Framework Programme, which was started at the end of 2002. Several national workshops were organised by NIVR and NLR to ensure that the Dutch research priorities are reflected in those documents.

Strategic Research Agenda

The European Commissioner for Research, Mr. P. Busquin, advocated a new approach for the European Union's research programme, amongst others by stimulating the integration and balancing of research activities of the Union with those on the national level and in private European organisations. A European Strategic Research Agenda (SRA) for civil aircraft and air transport research in Europe was established. The SRA identifies the major research issues in order to enable an environmentally friendly, safe, delay-free and low-cost air transport system to be in use by 2020. The SRA will facilitate to select research priority areas and to agree on priorities for European and national research efforts.

An Advisory Council for Aeronautical Research in Europe (ACARE) was responsible for the SRA. Mr. J. van Houwelingen was appointed as a member on behalf of EREA. ACARE has established six Working Teams and a support group to create the SRA. NLR participated in several of these.

NLR participation in Working Teams

WT-1: Quality and Affordability
Dr. B. Oskam
WT-2: Cleaner and Quieter air transport
Dr. H.H. Brouwer
WT-3: Safety
Prof. drs. P.G.A.M. Jorna
WT-4: Efficient air transport
Ir. H.A.J.M. Offerman and
Ir. J.C. Terlouw
WT-5: Research infrastructure
Ir. F.J. Abbink
WT-6: Supply chain and research co-ordination
Drs. A. de Graaff

Capita Selecta

Capita Selecta

1 Verification and Validation of the Galileo Satellite Navigation System

A civil, European, satellite navigation system, Galileo, is being developed. NLR is involved in the verification and validation process of Galileo, which will be capable of being used in air transport, among many other applications.

Introduction

Before the advent of satellite navigation it used to be difficult to ascertain one's precise position in space and time, and even more difficult to combine them. In a few years time this will be facilitated by the Galileo satellite navigation system, an initiative launched by the European Union and the European Space Agency. Galileo will be a civil system, in contrast to the military US Global Positioning System (GPS) and the Russian GLONASS system.

The Netherlands government expressed its satellite navigation policy in a letter to Parliament in 2001. The Netherlands aims at navigation services satisfying high quality requirements, ensuring safety, speed and controllability in all forms of mobility. It was pointed out that in addition to the safety aspects, Galileo could generate efficiency improvements for the various modes of transport, agriculture and meteorology. The government noted the strategically important role of NLR in verification and validation, enabling NLR to acquire detailed knowledge about Galileo, which would benefit Dutch industry in producing navigation-related products and services.

Satellite navigation is an advanced technology. It is based on satellites broadcasting signals that indicate the time extremely precisely. This enables individuals equipped with small low-cost receivers to determine their position on Earth to within a few metres. Similarly it enables the location of any moving or stationary object to be monitored.

Based on a constellation of thirty satellites and a few ground stations, Galileo will provide information concerning the positioning of users in many sectors. In particular in sectors such as transport, social services, law enforcement and customs services, public works, search and rescue systems, or leisure, Galileo will contribute to improved services and safety.

Galileo Programme

The Galileo Definition Phase was started in 2000. The following Galileo development and In Orbit Validation (IOV) phase will run until 2005. This phase covers the detailed definition and subsequent manufacture of the various system elements: satellites, ground components, user receivers. The IOV phase will require the placing into orbit of the first set of satellites and the creation of a minimal terrestrial infrastructure to control these satellites starting from 2004. It will allow the necessary optimisations to be made to the ground sector and the individual satellites, with a view to global deployment, and operational prototypes manufactured in parallel to be launched. During this phase it will also be possible to develop the receivers and elements for local augmentation further, and to verify the frequency allocation conditions imposed by the International Telecommunication Union.

Galileo components and users

The Full-Deployment phase will consist of gradually putting all the operational satellites into orbit starting in 2006, and of ensuring the full deployment of the ground infrastructure so as to be able to offer an operational service from 2008 onwards.

Role of NLR

Because NLR is the central institute for aerospace technology in the Netherlands, activities in the area of satellite navigation fit into NLR's mission by contributing to space applications and to the development of advanced navigation technology for the benefit of air transport and other transport modes. NLR participates in many international projects, often in collaboration with industries. NLR has available a great deal of knowledge and experience concerning GPS and the initiatives for Galileo and the European Geostationary Navigation Overlay System, EGNOS.

The activities of NLR in the area of satellite navigation encompass contributions to system design and analysis, design and realisation of specific measurement and evaluation equipment, simulation, operational validation of applications in aviation, and safety analysis. Specific project experience concerns applications of GPS, part development, tests and use of augmentation systems such as EGNOS, and the definition of Galileo.

In December 2002, the Netherlands State Secretary of Transport, Mrs. M. Schultz van Haegen - Maas Geesteranus, visited NLR Noordoostpolder and attended a presentation on recent Galileo developments. Mrs. Schultz van Haegen took part in a discussion on the relevance of Galileo for Europe and in particular for the Netherlands as one of the leading transport nations in Europe. Possible contributions and roles of the Netherlands government, institutes and industry were discussed.

Structure of Galileo

The principal component of Galileo is a global constellation of thirty satellites, distributed over three planes in Medium Earth Orbit. Within each plane, one satellite is an active spare, able to be moved to any of the other satellite positions within its plane, for the replacement of a failed satellite. The control of the satellite constellation, the synchronisation of the satellite atomic clocks, the processing of the integrity signal, and the handling of all data from internal and external elements is performed by two redundant Galileo Control Centres. Data transfer to and from the satellites is performed through a global network of Galileo Up-link Stations, each of which combines a Telemetry, Telecommand & Tracking Station and a Mission Up-link Station.

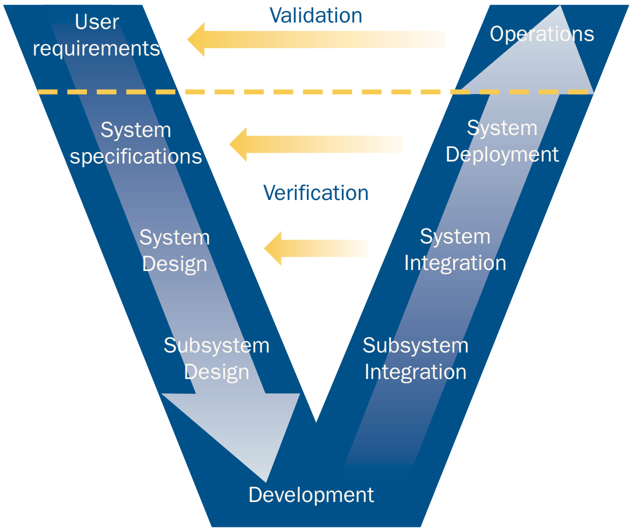
Galileo Sensor Stations distributed around the globe sense the quality of the satellite navigation signal (Signal In Space - SIS). The information of these stations is transmitted through a redundant Galileo Communications Network to the two Control Centres. The information on the SIS quality, also called integrity information, is the major differentiator of Galileo compared to other GNSS.

EGNOS as Precursor to Galileo

The European Geostationary Navigation Overlay Service, EGNOS, is Europe's first venture into satellite navigation. EGNOS is a joint project of the European Space Agency (ESA), the European Union (EU) and the European Organization for the Safety of Air Navigation, EUROCONTROL. It is Europe's contribution to the first stage of the Global Navigation Satellite System (GNSS) and is a precursor to Galileo. It will augment the two military satellite navigation systems now operating, the US GPS and Russian GLONASS systems, and make them suitable for safety critical applications such as flying aircraft or navigating ships through narrow channels.

Consisting of three geostationary satellites and a network of ground stations, EGNOS will achieve its aim by transmitting a signal containing information on the integrity and accuracy of the positioning signals transmitted by GPS and GLONASS. It will allow users in Europe and beyond to determine their position to within 3 m compared with about 15 m at present. EGNOS will become fully operational in 2004. In the meantime, a test signal, broadcast by two Inmarsat satellites, allows potential users to acquaint themselves with the facility and test its usefulness.

Prior to the operational implementation, the civil aviation community requires assurance with respect to the performance and safety of EGNOS-based operations. Together with the Spanish company GMV, under contract to EUROCONTROL, NLR developed a platform that can be used for two purposes: collection of data for the analysis of navigation system performance, and guidance for demonstration purposes and the analysis of total system performance. This so-called PREVAIL platform was installed on the NLR Cessna Citation II research aircraft for flight trials. During a number of flights, ferries between Amsterdam Airport Schiphol and Brétigny-sur-Orge and trials around Brétigny-sur-Orge, EGNOS Satellite Test-Bed (ESTB) navigation data was recorded.



The logic process that links the V&V activities to the overall design, development and deployment of the system

Verification and Validation of Galileo

Besides non-critical applications in the consumer market, Galileo is particularly intended for use in navigation, positioning and timing applications with requirements related to Safety of Life. This obviously requires proof that the system meets all performance requirements as well as a proof of safety. Verification and Validation (V&V) has to fulfill the major task of proving that the system and the services provided by the system are compliant with the system requirements and mission requirements, respectively.

NLR has participated in the GalileoSat Definition Study for ESA/Alenia Spazio focussing on the dependability and safety analysis of the GalileoSat System, the space segment and the ground Segment. It has gained considerable insight in the functionality, architecture and performance aspects of the Galileo System and associated service performance in terms of accuracy, availability, continuity and integrity.

It would be unwise to wait for the deployment of the full satellite constellation before starting validation. Rather, V&V activities are planned in advance, to minimise the risk of mission failure in terms of functionalty, performance, cost and time-to-market. The identification of such activities consists of analysing which are the key points to be assessed. Starting from the validation of the Galileo services as final goal, a ‘backwards’ analysis characterises the relevant phases to be considered. As the Galileo services are based on the signals broadcast from satellites, the analysis of the Signal In Space (SIS) is a primary need concerning the provision of the full navigation service directly. This leads to the identification of an initial single-satellite test-bed named Galileo System Testbed (GSTB) and the In Orbit Validation (IOV) phases as major V&V milestones during the Galileo development. During these phases as well as during the Full Deployment phase towards operational readiness, the validation requires activities such as static and dynamic measurement campaigns, simulations and analyses.

In the early phases of the system life cycle, verification activities prevail against validation activities in terms of procedures to be carried out and relevance of the results. The validation procedures take over more and more with the growth and the completion of the system. Because both activities run in parallel, co-ordination (methods, techniques, tools, results, etc.) between the two is of vital importance.

V&V methodology

Verification of the Galileo system has to provide evidence that each single unit (segment, subsystem, element, equipment, component) of the system and its interfaces are working properly, and also that the functions and operations that directly or indirectly support the provision of the Galileo services, perform properly, by one or more inter-operating system elements. The verification process evolves with the growth of the system, providing proof of correctness and suitability during the development of the system itself. Where low-level verifications may be performed directly by suppliers, the Galileo prime contractor supported by independent parties such as NLR can perform higher level system as well as space and ground segment verification activities.

NLR has been involved in the Galileo Definition Study project Phase B for ESA as a subcontractor of Galileo Industries for analysis of Galileo system dependability and safety and for the definition of methods, techniques and tools for Galileo system verification.

During In Orbit Verification (IOV) the focus is on the assessment of the Galileo system performance, on the testing of the functions of the system and on a preliminary assessment of the Galileo service. IOV consists of In Orbit Testing activities, as full mission validation is not feasible due to the low number of satellites in orbit at that time. During IOV it is possible to assess most of the parameters that are representative for the Galileo services that will be provided in 2008.

The features of the Galileo services are translated into the definition of the tests to be carried out to prove the fulfilment of the mission requirements. The validation procedures make use of an apportionment of analysis, simulations, and measurements including dynamic flight trials. Independent validation tests are preferred, as they assure that entities that carry out the validation are not involved in the design and development of the specified items under test.

V&V tools

The Galileo verification and validation process will require a collection of tools, specifically developed for the Galileo programme. A major advantage of such a tool set is that possible adaptation can be incorporated more easily, from managerial and technical viewpoints. Examples of tools are the Galileo System Simulation Facility (GSSF), the Galileo/GNSS-2 Signal Validation Facility (GSVF), the Galileo System Test Bed (GSTB) and the Test Receiver Support Facility (TRSF) incorporating GNSS antennas and receivers, data monitoring and analysis equipment and software.

A candidate for the TRSF is NLR's monitoring and analysis facility Celeste, named after the daughter of Galileo. NLR is setting up this facility, which incorporates antennas and receivers necessary to monitor and analyse the available satellite navigation systems GPS, GLONASS and EGNOS. Furthermore, Celeste contains GNSS post-processing and presentation software, developed in co-operation with other institutes such as EUROCONTROL and universities. In addition, it has simulation software for the analysis of existing and newly designed satellite navigation constellations and ground infrastructure. Celeste can be expanded into a major tool for static and dynamic verification and validation during IOV and beyond. It can also be used for the verification of performance on specific sites such as Amsterdam Airport Schiphol.

NLR has studied the specification of Galileo verification and validation tools in the Galileo Architecture Definition Study GALA for the European Commission. This study encompassed specification of tools for system analysis, system simulation at different levels of detail, as well as tools to support measurement campaigns including flight trials.

Valileo Consortium

By the time that the Netherlands government decided to support the development of Galileo, NLR took the initiative to introduce Dutch Space (then Fokker Space) and TNO-FEL to the

Galileo verification and validation activities. An informal Valileo Consortium was created under NLR leadership. Primary objectives of this teaming arrangement are:

- the extension of knowledge and expertise on Galileo verification and validation, and applications, in particular aviation and road transport;
- the joint preparation, execution and evaluation of verification and validation operations including trials and demonstrations;
- the introduction and supply of Galileo verification and validation tools;
- further development of the business case of Galileo - Verification and Validation activities.

In 2002, the consortium has jointly worked on a preparatory programme Valileo 2002, funded by NIVR, thus consolidating Dutch expertise in the Valileo team and preparing for participation in Galileo phase C/D. Joint participation in Galileo development in the European Union's Sixth Framework Programme is also anticipated.

The consortium has the ambition to establish itself as a Centre of Competence for Galileo Verification and Validation.

Dynamic component of Celeste monitoring facility

2 Flying Simulators for Effective Training

Embedded Training – a New Concept

NLR is at the forefront of the development of Embedded Training (ET) technology. ET is a form of pilot training in which simulated threats are fed into the various avionics systems of a combat aircraft in flight. This allows pilots to train against a virtual force, or a virtually augmented real force, with a mission debrief playback capability on ground. ET enables the operator to use the weapon system in situations it was designed for, whereas these situations are not available in everyday life. It provides capabilities to train fighter pilots more effectively, using the real aircraft in real flight in combination with an on-board simulated world.

An ET mission potentially provides the context of a real fighter mission, without the need for the actual presence of mission-critical air or ground objects, such as enemy aircraft, ground targets and friendly forces. While the aircraft capable of ET is manoeuvring through a reserved airspace sector (see Figure 1), the interaction with these objects is simulated with onboard equipment. Although the stress of real combat will probably never be accurately simulated, ET comes as close as possible.

Research by NLR in co-operation with Dutch Space has demonstrated that ET is a technologically viable concept. Now R&D needs to focus on the operational needs for ET capabilities. If the operational use and benefits can be demonstrated, it is worthwhile to equip the next generation training aircraft and fighters, such as the Joint Eurotrainer and the Joint Strike Fighter, with these capabilities.

Why Combine Real and Simulated Systems?

The ET system feeds additional players, such as targets and threats, into the Mission System of the aircraft. These data are treated by the aircraft as are real data, and will be displayed as such. The simulated players interact with the fighter pilot on the basis of his actions and their

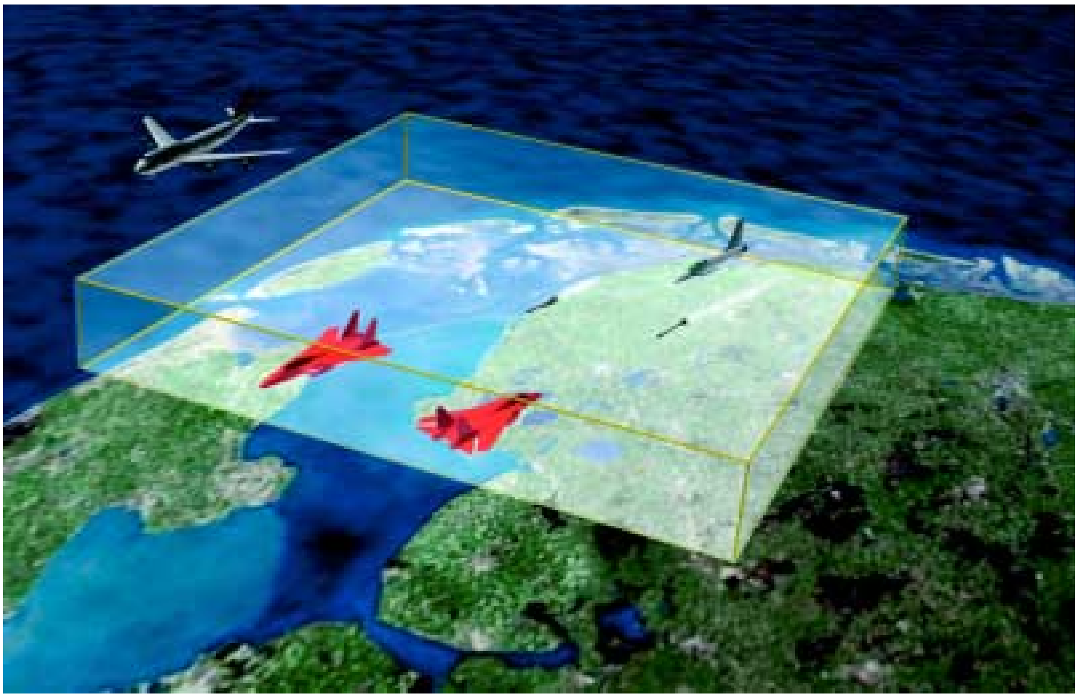


Fig. 1 – Airspace temporarily reserved for Embedded Training – Virtual adversaries and missiles are generated in simulation equipment onboard the own ship (on the right-hand side in the reserved airspace)

predefined role. As argued above, ET comes as close as possible to real combat missions. This is a strong argument for training. However, some more direct and quantifiable advantages can be argued for as well.

Fewer Red Air Flights Needed

In live combat training without ET, real aircraft act as the enemy. These so-called red air flights are costly and obviously have only restricted value for the instructors. With budgetary constraints on flight hours, ET as mere 'red air replacement' will be very cost effective.

Relatively Small Volume of Airspace Needed

Many of today's and future air-to-air engagements with enemy aircraft are Beyond Visual Range (BVR), which means that detection of the enemy target, identification, weapon delivery, and electronic warfare all take place at relatively long distances between the players. Airspace where such skills as electronic warfare and employment of medium range radar missiles can be trained is very limited. In live combat training of BVR engagements, training areas are needed with a size comparable to that of the Netherlands.

With ET, however, only small ranges are needed, simply because it allows virtual entities, including enemy aircraft, to fly outside the designated area as long as the real aircraft remains within the designated airspace. Because airspace for military training is scarce, particularly in Europe, ET will give significant logistic advantages.

Realistic Simulation of Ground Threats

In current tactical combat training, participation of realistic ground threats in the scenario, such as Surface-to-Air-Missiles is expensive, and sometimes technically not feasible. ET technology, however, has the potential of realistic simulation of ground threats. An existing example is the Patriot Air Defence Missile system where operators can be trained against simulated opponents when real opponents are not available or must be augmented with virtual opponents to enhance training effectiveness and efficiency.

Unrestricted Physical Experience

The current alternative of live tactical combat training is training in a full mission simulator. Although ground-based simulators have proven to be effective for training of many fighter skills, there are a number of perceptual sensations that can only partly be provided by these devices, such as sensations due to sustained accelerations (high g) and to unusual attitudes of the aircraft. Because fully realistic aircraft dynamics are present in ET, this form of training is to be preferred over ground-based simulation whenever the pilot has to combine various skills and knowledge in an integrated manner, such as tactics, leadership, perceptual skills, control skills and attention management.

Simulation of GCI/AWACS Anywhere

In combat and training, fighters often operate under control of Ground Control Intercept (GCI) or an Airborne Early Warning platform (AWACS). During training, however, these systems are not always available. ET is then capable of providing these control capabilities.

Security Benefits

Certain capabilities of fighter aircraft are not used during training for security or safety reasons. Specifically Low Observability (LO) or Stealth characteristics are not used to the full extent during training because of security aspects. ET allows training with the LO/Stealth characteristics by virtual systems, which increases pilot readiness for combat. The use of specific weapons such as lasers can be trained only in specific environments for safety reasons. ET allows these weapons to be deployed in a virtual environment.

Training During a Fighter Pilot's Career

Training the fighter pilot from screening to tactical combat training is a complex and costly undertaking. After being selected to become a military pilot, the student first receives about a hundred flight hours on a light propeller aircraft. In this 'screening stage' about 25 per cent of the students drop out. Hence more costly drop-out in further stages of training is prevented, and a group with relatively uniform capabilities is

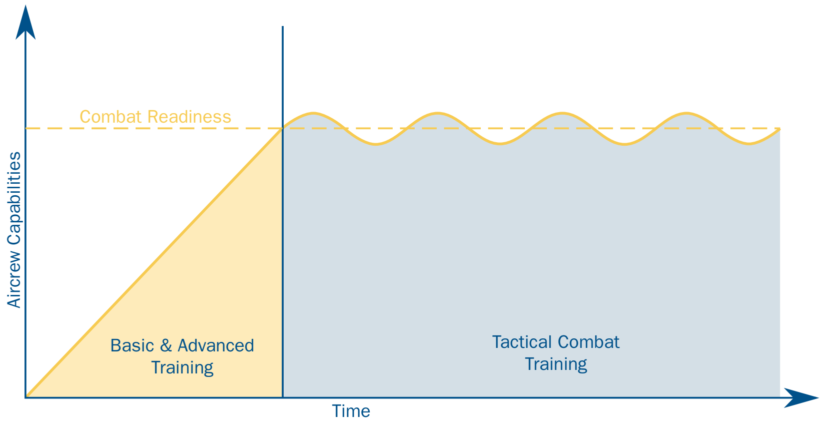


Fig. 2 – Aircrew capabilities during basic, advanced and combat training (schematically)

formed. The students selected to become fighter pilots subsequently receive 'basic flying training' (see Figure 2). This includes about 250 hours of jet training, and provides the student with the general knowledge, skills and attitudes of the military fighter pilot.

Basic training is followed by 'advanced flying training'. In this stage students learn basic fighter skills on a jet aircraft, including formation flying, fighter manoeuvres, tactical intercepts and weapon deliveries. Subsequently the student follows 'operational conversion training', which involves flight training with the specific operational aircraft type. On graduation the fighter pilots receive the classification 'limited combat ready', and are assigned to operational squadrons where their combat abilities are further developed through 'tactical combat training'.

Because fighter pilot training, from selection to combat readiness, is costly and complex, it must be carefully developed. The training development process as depicted in Figure 3 is representative for NLR's method to support the implementation of complex simulation technology into training.

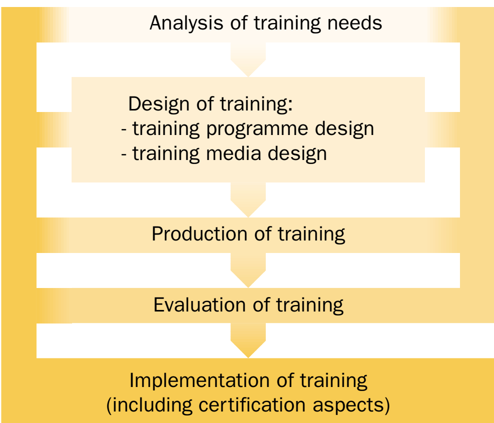


Fig. 3 – Training development process

The first step is the analysis of training needs. This results in a large set of so-called training objectives, statements that detail as precisely as possible the new knowledge, skills and attitudes to be acquired during the training. In the second step, a blueprint of the training programme is produced and suitable instruction methods and training media are defined.

After sufficient refinement, the actual training can be created, which may include developing equipment, resolving logistic and scheduling issues, defining performance measures, briefing, after-action review, etc. For it to become regular training, it needs to be evaluated against the objectives. Central in the evaluation is the notion of *transfer:* does the training actually provide the transfer of skills and knowledge to the next stage of training and eventually to the real mission?

Fighter Pilot Training, Today and Tomorrow

When aviation started, the aircraft was the only medium for flight training. In the late 1920s, simple devices for flight training on the ground were introduced. Gradually these simple devices evolved into the highly developed simulators and other ground training devices known today. These devices have now replaced about 30 per cent of the flight hours in basic, advanced and combat training.

In future, the share of the use of training devices for ground-based training is likely to increase further. It has been estimated by European industry (EADS, 1998) that ground-based tactical combat training will soon gain about 60 per cent of the overall tactical combat training hours, leaving only 40 percent of the training hours for actual flying. Major reasons for the increase in ground-based training are the limited availability and hence high cost of airspace, aircraft and training time. Improved computing power, computer graphics techniques and networking of simulators now allow ground-based training to be effective for the development of tactics and practice of war roles. Mission practice and rehearsal, using networked Full Mission Simulators and Pilot Stations will include training of air defence tasks against a variety of targets and threats.

Embedded training, live training in the aircraft combined with onboard simulation is a recent advancement in the training of fighter pilots. Gradual introduction and expansion of onboard simulation systems has been estimated to lead to a share of the use of ET of about 20 to 30 per cent in advanced and combat readiness training of military pilots. Joint exercises with other nations, using ET with on-board generated virtual air defence scenarios combined with networked full mission simulators (such as NLR's National Simulation Facility), are under development.

Combining Real and Simulated Systems

Basic Architecture

An ET system carried onboard an aircraft, consists of three main simulation modules (see Figure 4):

- First, the *simulation management module,* which performs many functions, such as starting and stopping training exercises and taking care that all players participating in the exercise have synchronised information;
- Second, the *own ship simulation module,* which stimulates the on-board sensors and simulates the own weapons and electronic warfare systems;
- Third, the *virtual world simulation, which* simulates the virtual players (Computer Generated Forces, CGFs) in the exercise - the virtual world simulation also comprising models for the terrain over which the exercise takes place and for atmospheric conditions.

To make the pilot believe that he/she is in a real mission, the three simulation modules maintain an intensive two-way communication with the aircraft's standard mission system. The mission system consists of modules that handle sensor data, weapon data, and electronic warfare data. Every time the pilot gives an input to one of the cockpit systems, the simulation needs to be updated and, as a result, new simulation data need to be fed into the mission system. To ensure a safe exercise a specific safety layer that safeguards both the aircraft mission system and the pilot has been developed.

The basic architecture described above is sufficient for the training of engagements in which one ET-carrying aircraft is involved and all other players are CGF. However, in more complex and realistic exercises, that is, beyond the one-versus-one/two engagements, an airborne datalink between ET-carrying aircraft and an air-to-ground datalink between aircraft and ground-based entities are needed to ensure that all players have matching sensor information.

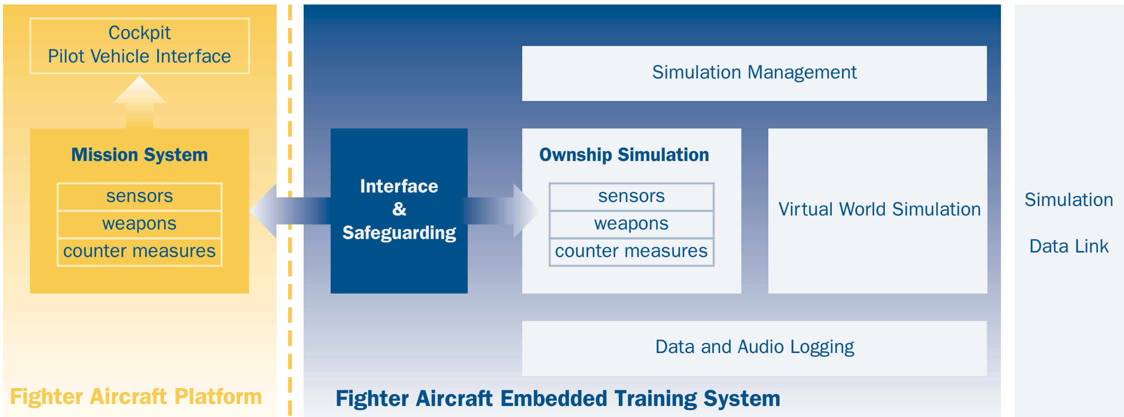


Fig. 4 – Basic architecture of an Embedded Training system

A scenario for the exercise needs to be prepared in advance on a dedicated ground station. After verification of the scenario, its digital representation can be loaded in the ET-carrying aircraft, either by physically inserting a credit-card-size memory card into the system or by datalink. The ground station can also be used for after-action review or debriefing purposes.

Simulation Management

During the exercise, the simulation management module must control all simulations as well as the overall course of the exercise. In addition, this module manages the recording of the exercise and performance measurement. Since complex exercises have many performance aspects, the assessment of pilot performance is a major challenge to fighter pilot training in general and to ET in particular. The performance aspects include use of weapons, sensors and countermeasures, selection of tactics, following the mission routes and selection/assignment of opponents. NLR is working on intelligent methods to keep track of and analyse the pilot's activities, to categorise pilot error and to determine kill ratios (the ratios of wins to losses or wins to total engagements).

Own Ship Simulation

The own ship simulation includes a complete dynamic model of the ET aircraft. Because weapon delivery must also be simulated, own ship simulation includes models for fire control; the weapons loaded, such as medium- and short-range missiles; on-board guns; flares and chaff; and the electronic warfare system. Another part of the own ship simulation is a realistic assessment of weapon effectiveness, including hit calculation and probability of kill. System displays onboard the own ship, such as the radar, the radar warning receiver and the air-to-air interrogator for target identification must interact as if real targets were present. These provisions enable Beyond Visual Range (BVR) engagements, in which opponents remain outside a range of 10 nautical miles (about 18 kilometres) of the own ship, to be fully exercised.

Virtual World Simulation

The virtual world includes the CGFs, their electronic signatures, weapons and dynamic behaviour, involving strategies, tactics, manoeuvres and counter measures. Moreover, the behaviour of the CGFs has to be in exact accordance with their individual roles (ground-based or airborne, friend or foe, fighter or fighter-bomber, etc.).

It is technically feasible to include BVR engagements in an exercise based on Embedded Training. However, Within Visual Range (WVR) engagements, that is, when opponents come closer to the own ship than 10 nautical miles, remain a major technical challenge. WVR engagements require that visual, but virtual, opponents can be superimposed on the outside world as seen through the pilot's eyes. Helmet Mounted Displays or other displays suitable for realistic visualisation of virtual opponents in the outside world as seen from the fighter cockpit do not yet exist. The development of a 'sufficient' visual display could make an interesting business case with spin-off to other domains.

NLR has identified certain safety issues that must be resolved before ET is practically operable. Potential safety risks are for example the inadvertently crossing of the boundaries of the reserved airspace by pilots immersed in ET or a virtual target flying through mountains and thereby putting the training pilot in danger. A similar safety risk occurs when, in the case of real problems, for example due to a system failure, a pilot error or low speed conditions, the simulated scenario must be halted and all pilots in flight must regain Situation Awareness of the real world immediately. NLR and Dutch Space have developed a specific safety layer that safeguards the aircraft mission system and the pilot from undesired simulation effects. When the feasibility of these solutions have been established, ET will be a cost-effective training medium, with a firm position at the high end of the gamut of training methods for fighter pilots.

Embedded Training in Perspective

Embedded Training (ET) technology has caught a lot of attention and will be more widely applied in the training aircraft and fighters of the future. The implementation of ET in aircraft is no trivial issue. In addition to identifying the required functionality for effective training, this functionality needs to be integrated at an early stage of the design and development process of new aircraft. The addition of ET to existing aircraft is obviously more costly. For training aircraft and fighters currently under development, such as the Eurotrainer and the JSF, it should be decided before the 'critical design review' to what extent ET functionality should be included.

NLR is at the forefront of the development of ET technology. The history of ET for fighter aircraft technology development at NLR dates back to the mid-1990s. In an early stage NLR and Dutch Space participated in a European long-term strategic defence programme to assess the feasibility of ET for fighter aircraft. The outcome of this study formed the basis for further development of an ET system. This system will be demonstrated on an advanced trainer aircraft, the AerMacchi MB 339. The demonstration of this system is scheduled for June 2003.

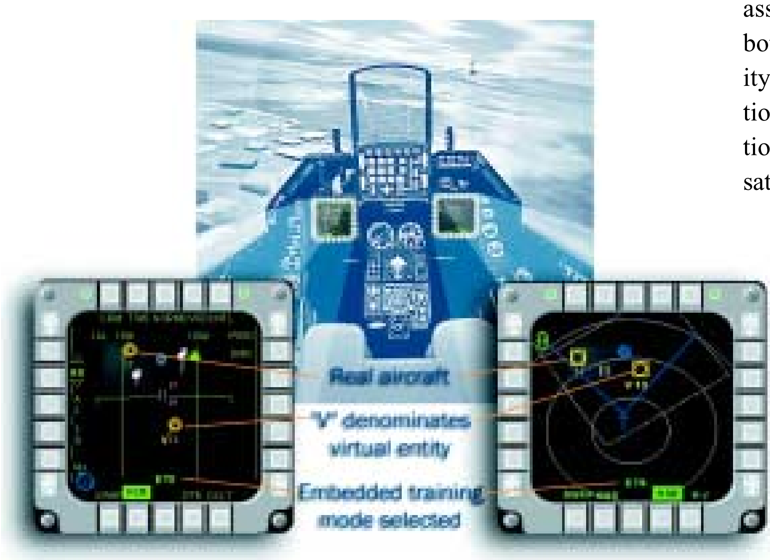


Fig. 5 – Multi Function Displays of the F-16 MLU that act as if real targets were present. Pictures are taken from an Embedded Training technology demonstration on the National Simulation Facility at NLR

In the meantime, in a Netherlands programme, NLR and Dutch Space have designed and implemented an Embedded Training module on the National Simulation Facility. The system has been demonstrated in August 2000 and proved the viability of Embedded Training for an F-16 MLU type aircraft. The demonstration also proved the concept of ET and identified the benefits for operational use (see Figure 5).

With these efforts, the Netherlands has gained a prominent position in the design and development of ET. NLR further invests and participates in national and international research programmes. The knowledge gained within these programmes now enables a 'Dutch concept' to be developed, which entails more efficient use of training equipment, personnel, training hours and air space. This will lead to savings in operational costs. The development of the Joint Strike Fighter and the Dutch interests in this programme offer a unique opportunity to commercialise the Dutch approach to ET.

It is anticipated that when ET is capable to simulate all players in a mission with a reasonable fidelity, such that the transfer of skills from an exercise to actual missions is positive, that readiness of fighter pilots can be achieved with significant cost savings. Now it needs to be demonstrated in real flight tests that safety risks associated with the unintentional presence of both real and simulated aircraft in close proximity to the training aircraft, unintentional violation of training sector boundaries and unintentional low speed conditions, can be dealt with satisfactorily.

3 Aeroelastic Behaviour of Military Aircraft: Development, Validation and Operation of a Numerical Simulation Method

Under contract to the Ministry of Defence, NLR has developed a numerical simulation method capable of analysing the aeroelastic behaviour of military aircraft such as the Lockheed Martin F-16 A/B fighter of the Royal Netherlands Air Force (RNLAF). This simulation method has been designed for the analysis of non-linear aeroelastic effects, which are insufficiently modelled using standard linear or semi-empirical prediction methods. The new method has been used for building up knowledge of the Limit Cycle Oscillation (LCO) phenomenon of the F-16, and for assessing the impact of specific F-16 A/B training configurations on its life time consumption. In the development, specialists from the Fluid Dynamics Division of NLR collaborated with colleagues from the ICT Division, the Structures and Materials Division, and the Flight Division.

Aeroelastic Simulation

Thanks to large efforts made in the aeronautical society internationally and throughout the years, aviation has reached a high safety standard. This is due to contributions from the numerous scientific and engineering disciplines involved in the design, production, operation and maintenance of aircraft. One particular discipline directly linked to safety in different phases of an aircraft life cycle is aeroelasticity, a discipline in aeronautical engineering located at the interface between aerodynamics and structural mechanics. It concerns the deformation and dynamics of elasto-mechanical bodies in an airflow. Aeroelastic simulation is used in combination with testing, to cover different aeroelastic aspects.

Safety Aspect: Flutter

A typical aeroelastic phenomenon relevant for safe military aircraft operation is a dangerous dynamical instability called flutter. In classical flutter, the amplitude of the structural response to disturbances, for example atmospheric turbulence, grows exponentially in time. Avoiding flutter is an important criterion in both design and operation of any aircraft. In design, the elasto-mechanical properties (mass and stiffness) of the wing structure should be chosen such that no unbounded exchange of energy between structural vibration modes and airflow takes place during flight. For military aircraft operations, involving many store configurations, changes of mass properties due to new or different stores need to be carefully assessed with respect to the danger of flutter instability. Many possible combinations of stores need to be checked for possible flutter occurrence within the mission profile of the aircraft. In order to limit this effort, one often uses the mass perturbation method, in which several representative store configurations are taken as fundamental and other configurations are considered as variations on these fundamental configurations. Flutter analysis of the fundamental configurations is mostly performed using cost-effective linear unsteady aerodynamic models. In transonic conditions however, the linear unsteady aerodynamic model is known to give a potentially dangerous, non-conservative prediction of the flutter boundary. Figure 1 shows a large difference between the predicted flutter boundary of a wing using a linear and a non-linear aerodynamic model. If the flutter boundary predicted by linear methods is too close to the operational envelope of the aircraft, non-linear aeroelastic analysis is required to mitigate the risk for flutter. Normally, theoretical flutter predictions are used to support flutter flight tests using an instrumented aircraft. Higher fidelity aeroelastic simulations allow the extent of such flutter flight test programmes to be reduced.

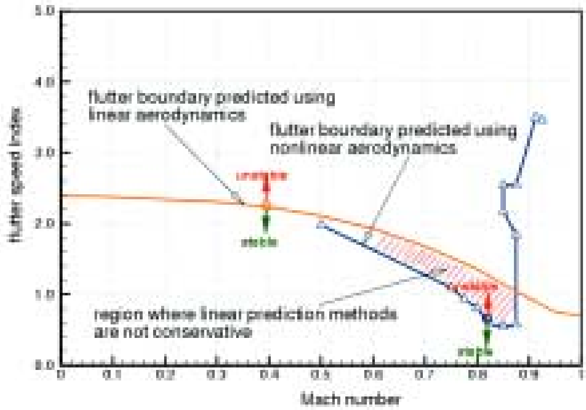


Fig. 1 – Flutter boundary of a 2D wing predicted using a linear and a non-linear aerodynamic model

Operational Aspect: Limit Cycle Oscillations

For current military aircraft (such as the F-5, F-16, F-18, F-111 and B-1) it has been reported that after the onset of specific dynamic aeroelastic instabilities, the amplitude stays at a limited level before real flutter starts. This phenomenon is usually called non-classical flutter or Limit Cycle Oscillations (LCO). In the case of LCO, vibration of the structure mainly leads to handling and flying quality limitations, limiting the operational use of the airframe for important store configurations. This is the case if acceleration levels exceed the acceleration levels as specified in Unified Abort Criteria, determined on grounds of pilot comfort, i.e.

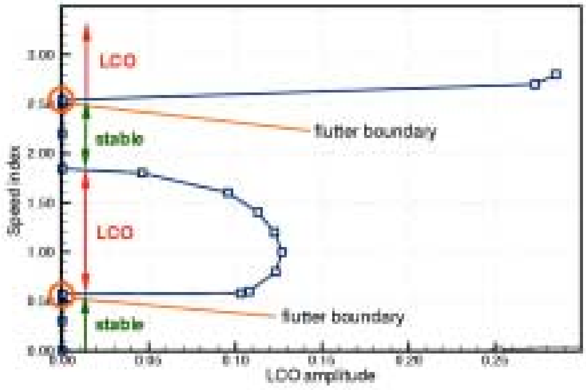


Fig. 2 – LCO amplitude as a function of speed index, for a 2D wing, illustrating a non simply connected flutter boundary in the case of LCO and domain of validity of analysis methods

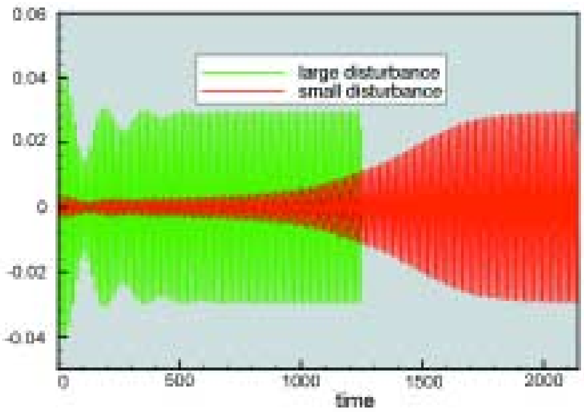


Fig. 3 – LCO amplitude of the first torsion mode, as a function of dimensionless time, for two different initial disturbances

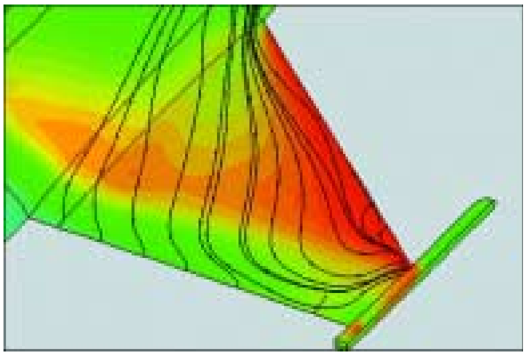


Fig. 4 – Aerodynamic non-linearity due to unsteady flow separation leading to LCO for a heavy store configuration

acceleration at the pilot seat. Due to the nonlinear physical phenomena involved, Limit Cycle Oscillations cannot be predicted on the basis of pure linear modelling. Non-linear structural or aerodynamic effects have to be introduced through aircraft-specific semi-empirical data, or through a fully nonlinear modelling. For the same wing as shown in Figure 1 and for a specific Mach number, the amplitude of the torsion mode is shown as a function of the speed index in Figure 2. Typical for nonlinear behaviour of a dynamical system, the amplitude of the Limit Cycle Oscillation is independent of the amplitude of the initial disturbance (see Figure 3). Initial disturbances are due to atmospheric turbulence. For a complete fighter aircraft in heavy store configuration and high manoeuvre loads, complex unsteady flow phenomena (see Figure 4) on the wing upper side cause the LCO.

Maintenance Aspect: Detailed Static Loads

Elastically deformed wings interact with the airflow through a change in local angle of attack, leading to a change in aerodynamic loads, and finally to a deformed state. An illustration is given in Figure 5, showing the computed pressure distribution on an elastically deformed model of the Fokker 100 aircraft at transonic flow conditions. In this computation a balanced free-flying condition is maintained through trimming the angle of attack and the horizontal tail plane. Knowing accurately the deformed shape and corresponding loads is important to construct a safe airframe capable of bearing all its expected loads. In Figure 6 the shear force versus wing span is shown for the Fokker 100 aircraft model of Figure 5, with an aerodynamic and an inertial contribution.

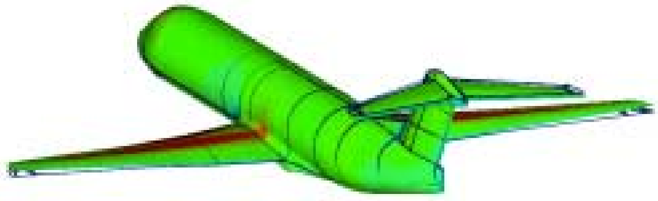


Fig. 5 – Pressure distribution on an elastically deformed model of the Fokker 100 in transonic flow

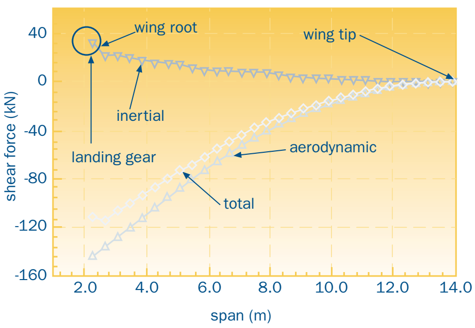


Fig. 6 – Shear force versus span, for an elastically deformed model of the Fokker 100 in transonic flow: shear force due to aerodynamic, inertial and total forces

For limit load conditions of an F-16 configuration with and without advanced wing tip missile, the static deformation of the outer wing has been computed (see Figure 7). The resulting aerodynamic and inertial loads have been used to determine the most favourable configurations with respect to fatigue life degradation. In this case, the detailed computed flight loads complement the interpretation of strain gauge readings on operational aircraft (FACE data). As such, they contribute to understanding the fatigue life degradation in the framework of the extensive loads monitoring and fatigue life research programme conducted by the Structures and Materials Division of NLR.

Prerequisites

Static or dynamic aeroelastic analyses require appropriate modelling of both the structure and the aerodynamics. For the structural part of the aeroelastic analysis, a Finite Element Model (FEM) of the structure is required. This aeroelastic model usually differs from FEM models used to compute internal stress in the construction. Firstly, since aeroelastic analysis concerns global stability of the aircraft, the aeroelastic FEM is only required to model global deformations accurately. This requirement is most easily achieved using a small number of degrees of freedom. Secondly, mass and stiffness properties should be accurate enough, such that the most important mode shapes of the modelled structure match the mode shapes of the actual structure. If a prototype or production aircraft is available, the mode shapes or dynamic behaviour of the actual structure can be determined in a Ground

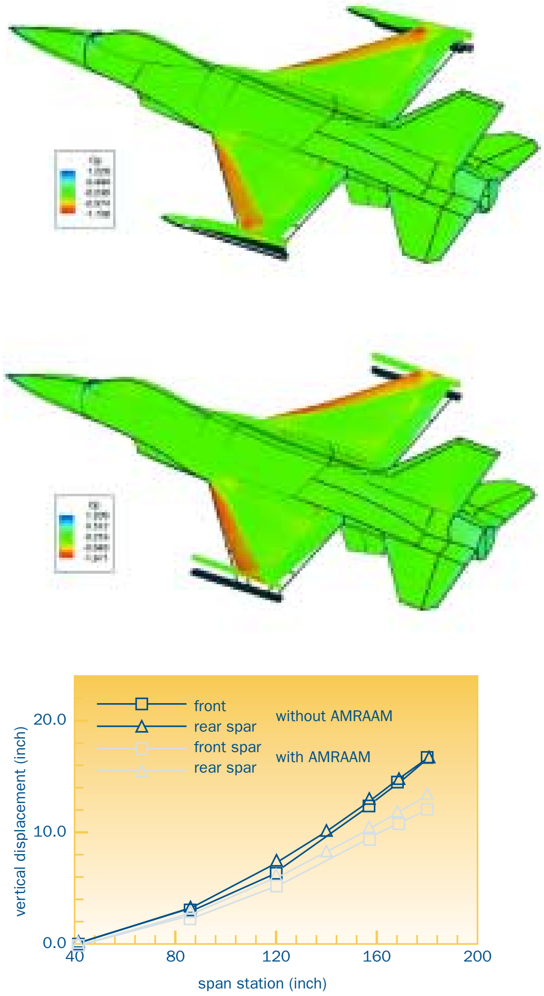


Fig. 7 – Static deformation of an F-16 configuration with and without advanced wing tip missile, for limit load conditions

Vibration Test. If the results of such a test are available, the aeroelastic FEM model can be updated on the basis of this experimental data. Figure 8 shows damping and frequency curves

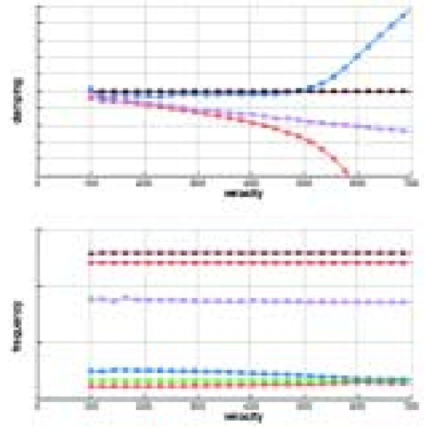


Fig. 8 – Damping / Frequency curves of two mode shapes of a rectangular wing computed using linear aerodynamics

for a rectangular wing as a function of the velocity, computed using flutter analysis tools based on linear aerodynamic modelling. For the aerodynamics part of the aeroelastic analysis, the levels of aerodynamic modelling depend on the physical processes involved and the uncertainty margins required. For the low subsonic or high supersonic flow regimes and small angles of attack, or where large uncertainty margins are allowed, linear aerodynamic modelling is sufficient for many applications. If transonic effects such as shocks, and/or viscous effects play a role, or for large angles of attack, more advanced aerodynamic modelling based on the Full Potential, Euler or Navier-Stokes equations is necessary.

Project Realisation

Parties Involved

Within a National Technology Project (NTP) the NLR Computational Fluid Dynamics and Aeroelastics Department designed and verified the aeroelastic simulation system, in close co-operation with the Mathematical Models and Methods Department. Validation of the aeroelastic simulation system has been conducted with assistance of the Aerodynamic Engineering and Vibration Research Department, providing advanced unsteady wind tunnel experimental data obtained in the DNW-HST transonic wind tunnel through a co-operative research programme between the US Air Force, Lockheed Martin Aeronautics and NLR. The Loads and Fatigue Department has been involved in providing FACE data from LCO flight tests, and in the development of applications of the new aeroelastic simulation system. The Operations Research Department has been involved in defining the qualification and certification framework, to which the new method adds an additional capability. The RNLAF actively participated in the project, especially by providing a user's perspective of the applications of the system and by acting as monitor of the project.

Planning

A work plan has been devised consisting of five work packages carried out in three years. Algorithm development as well as verification and validation activities have been anticipated. Several test cases involving various geometries and configurations have been selected based on the availability of experimental data.

System Design and Implementation

A new layout for the aeroelastic simulation system has been made (see Figure 9), using the NLR system ENFLOW as a starting point. Integration aspects of the non-linear compressible Computational Fluid Dynamics (CFD) flow solver and the Computational Structural Mechanics (CSM) solver using a linearised struc-

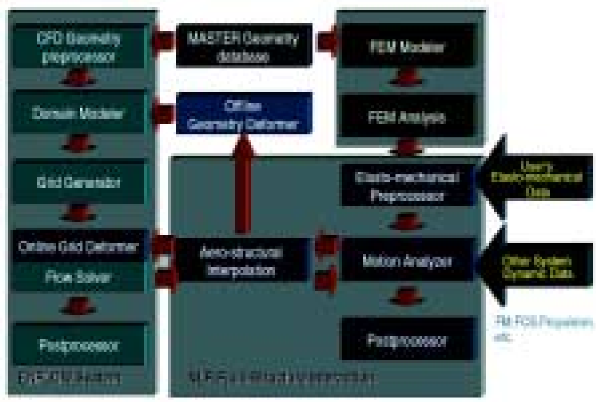


Fig. 9 – Design of a Numerical Simulation Method for the Aeroelastic Behaviour of Military Aircraft, based on the NLR ENFLOW system

tural dynamic model have been studied. A loosely coupled approach has been selected and implemented. The resulting new aeroelastic simulation system has been verified for standard aeroelastic test cases.

Validation

For validation, a unique database of unsteady transonic wind tunnel data has been used, obtained with a 1:9-scale semi-span wind tunnel model of an F-16 including the outboard wing oscillating in pitch. The tests had been conducted in the DNW-HST transonic wind tunnel facility. Based on this database, the effect on F-16 unsteady aerodynamic characteristics has been studied, accounting for:

- Variation in wing tip launcher / missiles configuration,
- Variation of flap setting,
- Variation of underwing stores.

Computed and experimental unsteady data have been compared, showing good agreement. Static aeroelastic analysis of a full-scale F-16 in flight has been conducted, with computed deformations comparing well with available flight test data.

Demonstration

A final demonstration of the applicability of the new Aeroelastic Simulation System to modelling LCO concerned a real fighter aircraft in air-to-ground configuration. An F-16 heavy store configuration known for its sensitivity to LCO during flight testing has been selected for final demonstration. From a geometrical point of view, the configuration (AIM-9J missiles at the tip and outboard underwing attachment, MK-84 bomb at the mid-underwing attachment and full 370-gallon fuel tank) needs aerodynamic simplification to make LCO simulations feasible. These aerodynamic simplifications have been made based on the assumption that the observed LCO is due to non-linear shock-induced flow separation on the upper outer part of the wing. Based on this assumption and on the validation effort made for assessing the unsteady aerodynamic effects due to underwing stores, these stores are deleted only from the aerodynamic modelling. The results of the simulation (for flight level FL 100, Mach number 0.9 and angle of attack 7 degrees) reproduce the dominant frequency of the LCO observed during flight testing, caused by unsteady shock-induced flow separations on the outer wing. The amplitude of the oscillation is overpredicted, which can be explained by the structural damping applied in the aeroelastic simulation being lower than found in Ground Vibration Testing.

Conclusions

A numerical simulation method capable of analysing the aeroelastic behaviour of military aircraft such as the RNLAF F-16 A/B fighter has been designed, implemented, verified and validated against available wind tunnel and flight data. The aeroelastic simulation method is now ready for application. It is capable of correcting non-conservative (potentially dangerous) flutter boundary predictions of linear methods in the transonic regions of the flight envelope. As a result, larger increments in flutter flight test programs are feasible, reducing their extent. Further, vibrations limiting the operational use of important store configurations can be investigated with the new aeroelastic simulation method. Unsteady non-linear aerodynamic data needed for this investigation can now be provided using a method based on first principles. By that, the main limitation of the semi-empirical LCO research used in the past has been lifted. Finally, detailed aerodynamic loads and resulting deformations can be determined to support the selection of favourable store configurations with respect to maintenance and life time consumption.

Appendices

Appendices

1 Publications

In 2002, NLR produced a total of 700 reports, including unpublished reports on contract research and on calibrations and tests of equipment. The reports listed below were released for publication.

NLR-TP-2000-355

Design guidelines for the prevention of skin-stiffener debonding in composite aircraft panels
Presented at the 15th Technical Conference of the American Society for Composites, College Station, Texas, USA, 24–27 September 2000
Rijn, J.C.F.N. van

NLR-TP-2000-671

Unit Testing at the NLR as applied in the MPTE project
Presented at the Zesde Nederlandse Testdag, Amsterdam, The Netherlands, 3 November 2000
Oerlemans, R.H.J.; Woodrow, I.A.

NLR-TP-2000-688

Electro-magnetic analysis of geometrically perturbed objects
Presented at the Millennium Conference on Antennas and Propagation, Davos, Switzerland, 9–14 April 2000
Schippers, H.; Bandinelli, M.; Bertoncini, F.; Sensani, S.

NLR-TP-2001-053

Human cognition modelling in ATM safety assessment
Presented at the 3rd USA/Europe Air Traffic Management R&D Seminar, Naples, Italy, 13–16 June 2000
Blom, H.A.P.; Daams, J.; Nijhuis, H.B.

NLR-TP-2001-351

Delegating configuration management responsibilities within the software development process
Presented at the DASIA Conference, Nice, France, 28 May – 1 June 2001
Guravage, M.A.

NLR-TP-2001-538

Tutorial on Single- and Two-Component Two-Phase Flow and Heat Transfer: Commonality and Difference
Presented in the Fundamentals of Two-Phase Flow and Heat Transfer Session of the Conference on Thermophysics in Microgravity, held during the Space Technology & Applications International Forum in Albuquerque, USA, 3–7 February 2002. The corresponding viewgraphs have been published in the Proceedings of the International Two-Phase Thermal Control Technology Workshop, El Segundo, USA, 7–8 June 2001
Delil, A.A.M.

NLR-TP-2001-545

Flight simulation fatigue crack growth guidelines
Presented at the Fatigue 2002 Conference, Stockholm, Sweden, 2–7 June 2002
Wanhill, R.J.H.

NLR-TP-2001-559

Slot Swapping Applications for Collaborative Decision Making
To be published in ATC Quarterly (2003)
Waal, P.R. de; Briel, M.H. van den; Akker, J.M. van den

NLR-TP-2001-569

Helicopter Ground Vortex, Comparison of Numerical Predictions with Wind Tunnel Measurements
Presented at the 27th European Rotorcraft Forum, Moscow, Russia, 11–14 September 2001
Boer, J.F.; Hermans, C.; Pengel, K.

NLR-TP-2001-604

Space-Time discontinuous Galerkin finite element method with dynamic grid motion for inviscid compressible flows – General formulation
Accepted, on 29 April 2002, for publication in the Journal of Computational Physics
Vegt, J.J.W. van der; Ven, H. van der

NLR-TP-2001-605

Space-Time discontinuous Galerkin finite element method with dynamic grid motion for inviscid compressible flows – Efficient flux quadrature

Accepted for publication in the journal Computer Methods in Applied Mechanics and Engineering, Elsevier Science

Ven, H. van der; Vegt, J.J.W. van der

NLR-TP-2001-608

In-service inspection of Glare fuselage structures

Presented at the 8th European Conference on Non-Destructive Testing, Barcelona, 17–21 June 2002

Heida, J.H.; Platenkamp, D.J.

NLR-TP-2001-611

On-Board Decision Support through the Integration of Advanced Information Processing and Human Factors Techniques – The POWER Project

Presented at the NATO SCI lecture series on 'Tactical Decision Aids and Situational Awareness' in Amsterdam (1–2 November 2001), Sofia (8–9 November 2001), Madrid (12–13 November 2001) and Patuxent River (MD) (19–20 November 2001), and at the NVvL (Nederlandse Vereniging voor Luchtvaarttechniek) Meeting, Amsterdam, 29 November 2001

Hesselink, H.H.; Zon, G.D.R.; Tempelman, F.; Beetstra, J.W.; Vollebregt, A.M.; Hannessen, D.P.

NLR-TP-2001-612

A Full Visual A-SMGCS Simulation Platform

Presented at the JISSA (International Conference on Airport Surveillance Sensors), Paris, 11–12 December 2001

Hesselink, H.H.; Maycroft, H.

NLR-TP-2001-624

Safety case in ATM is more than accident risk assessment alone

Published in Air Traffic Technology International 2000

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

NLR-TP-2001-625

Probabilistic Data Association Avoiding Track Coalescence

Published in IEEE Transactions on Automatic Control, February 2000

Blom, H.A.P.; Bloem, E.A.

NLR-TP-2001-627

Geometric and probabilistic approaches towards Conflict Prediction

Presented at the Third USA/Europe Air Traffic Management R&D Seminar, Naples, Italy, June 2000

Bakker, G.J.; Kremer, H.J.; Blom, H.A.P.

NLR-TP-2001-629

Modelling Human Reliability in Air Traffic Management

Presented at the Fifth Probabilistic Safety Assessment and Management Conference, Osaka, Japan, 27 November – 1 December 2000

Daams, J.; Blom, H.A.P.; Nijhuis, H.B.

NLR-TP-2001-632

Flap noise measurements in a closed wind tunnel with a phased array

Published as AIAA paper 2001-2170 in the Proceedings of the 7th AIAA-CEAS Aeroacoustics Conference, Maastricht, The Netherlands, 28–30 May 2001

Wal, H.M.M. van der; Sijtsma, P.

NLR-TP-2001-634

Probabilistic Approaches towards Conflict Prediction

Published in Air Transport Systems Engineering, Editors G.L. Donohue and A.G. Zellweger, by the American Institute of Aeronautics and Astronautics, Inc., July 2001

Bakker, G.J.; Kremer, H.J.; Blom, H.A.P.

NLR-TP-2001-636

Human Cognition Modelling in Air Traffic Management Safety Assessment

Published in: Air Transportation Systems Engineering, Editors G.L. Donohue and A.G. Zellweger, by the American Institute of Aeronautics and Astronautics, July 2001

Blom, H.A.P.; Daams, J; Nijhuis, H.B.

NLR-TP-2001-639

Evaluation of advanced conflict modelling in the Highly Interactive Problem Solver
Presented at the Fourth USA/Europe Air Traffic Management R&D Seminar, Santa Fe, 3–7 December 2001
Doorn, B.A. van; Bakker, G.J.; Meckiff, C.

NLR-TP-2001-642

Accident Risk Assessment for Advanced Air Traffic Management
Published in: Air Transportation Systems Engineering, Editors G.L. Donohue and A.G. Zellweger, by the American Institute of Aeronautics and Astronautics, Inc., July 2001
Blom, H.A.P.; Bakker, G.J.; Blanker, P.J.G.; Daams, J.; Everdij, M.H.C.; Klompstra, M.B.

NLR-TP-2001-647

Observations on literate program structure
Presented at EuroTeX 2001, Kerkrade, The Netherlands, 24 September 2001
Guravage, M.A.

NLR-TP-2002-003

Deploying network real-time simulation, putting the virtual enterprise to work – Some aerospace experience
Presented at The HICSS-35 Conference, Kona, HI, USA, 7–10 January 2002
Kesseler, E.

NLR-TP-2002-019

Development of generic composite box structures with prepeg preforms and RTM
Presented at the SAMPE Europe International Conference 2002, Paris, France, 9–11 April 2002
Vries, H.P.J. de

NLR-TP-2002-020

The development of a composite landing gear component for a fighter aircraft
Presented at the SAMPE Europe International Conference 2002, Paris, France, 9–11 April 2002
Thuis, H.G.S.J.

NLR-TP-2002-048

Thermal testing of low porosity microcracked thermal barrier coatings
Investigation carried out at Eindhoven University of Technology, Department of Mechanical Engineering, Eindhoven, The Netherlands, as part of the first author's PhD-research; submitted for publication in Surface and Coatings Technology
Koolloos, M.F.J.; Schouten, M.J.W.

NLR-TP-2002-052

Advanced Data Fusion for Airport Surveillance
Presented at the JISSA (International Conference on Airport Surveillance Sensors), Paris, 11–12 December 2001
Bloem, E.A.; Blom, H.A.P.; Schaik, F.J. van

NLR-TP-2002-057

Refined Flow Management – An operational concept for Gate-to-Gate 4D flight planning
Presented at the FAA-EUROCONTROL Workshop, 'The Impact of ATM/CNS Evolution on Avionics and Ground System Architectures', Toulouse, France, June 2002
Jonge, H.W.G. de

NLR-TP-2002-069

TERTS, a generic real-time gas turbine simulation environment
Presented at the ASME IGTI TurboExpo 2001, New Orleans, USA, 4–7 June 2001, and published as ASME-2001-GT-446
Visser, W.P.J.; Broomhead, M.J.; Vorst, J. van der

NLR-TP-2002-077

Wake vortex safety evaluation of single runway approaches under different weather and operational conditions
Presented at the Probabilistic Safety Assessment and Management (PSAM 6) Conference, San Juan, Puerto Rico, 23–28 June 2002
Baren, G.B. van; Speijker, L.J.P.; Bruin, A.C. de

NLR-TP-2002-091

Advanced Flight Data Analysis
Presented at the 14th European Aviation Safety Seminar, Budapest, Hungary, 11–13 March 2002
Es, G.W.H. van

NLR-TP-2002-105

A Simple, Robust and Fast Algorithm to Compute Deformations of Multi-Block Structured Grids

Published in the Proceedings of the 8th International Conference on Numerical Grid Generation in Computational Field Simulations, Honolulu, Hawaii, USA, 3–6 June 2002

Spekreijse, S.P.; Prananta, B.B.; Kok, J.C.

NLR-TP-2002-110

Increasing the survivability of helicopter accidents over water

Presented at the First European Workshop on Survivability at Air Base Cologne-Wahn, Germany, 26–28 February 2002

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

NLR-TP-2002-134

Pluriformity of the Air Traffic Management R&D Landscape

Presented at ATC Maastricht 2002, Maastricht, The Netherlands, 6 February 2002

Brüggen, J.

NLR-TP-2002-165

A comparison of the effect of DME and GPS on the aircraft position in the TMA

Presented at the 20th EUROCONTROL Terminal Airspace Applications Task Force (TARA) meeting at EUROCONTROL EHQ, Brussels, 16 January 2002

Gibbs, A.P.R.

NLR-TP-2002-184

Two-Phase Developments for the International Space Station ISS: AMS-2 TTCS, a Mechanically Pumped Two-Phase CO_2 Cooling Loop for the Alpha Magnetic Spectrometer Tracker Experiment; CIMEX-3, Versatile Two-Phase Loop for the Fluid Science Laboratory

Presented at the 12th International Heat Pipe Conference, Moscow, Russia, 19–23 May 2002

Delil, A.A.M.

NLR-TP-2002-193

Design and analysis of stiffened composite panels for damage resistance and tolerance

Presented at the 5th World Congress on Computational Mechanics, Vienna, Austria, 7–12 July 2002

Wiggenraad, J.F.M.

NLR-TP-2002-209

A virtual environment for transparent distributed computing in evolutionary search

Presented at the EUROGEN 2001, Athens, Greece, 19–21 September 2001

Vankan, W.J.; Maas, R.; Dam, M. ten

NLR-TP-2002-215

Integrating navigation and communication systems for innovative services

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Kesseler, E.; Grosmann, R.; Ehrmanntraut, R.

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NLR-TP-2002-218

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Schulten, J.B.H.M.

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Archaeological silver embrittlement: A metallurgical inquiry

Wanhill, R.J.H.

NLR-TP-2002-225

Collaborative flight planning in Europe – A contribution from NLR to identify operational concepts in ACARE

Contribution to the workgroup WP4-ST-1 of ACARE

Jonge, H.W.G. de; Terlouw, J.C.

NLR-TP-2002-226

Determination of absolute levels from phased array measurements using spatial source coherence

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Presented at the 32nd Conference on Environmental Systems, San Antonio, TX, USA, 14–18 July 2002

Delil, A.A.M.; Woering, A.A; Verlaat, B.

NLR-TP-2002-272

Thermal Modelling Issues Concerning the Mechanically Pumped Two-Phase CO_2 Cooling for the AMS-2 Tracker

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NLR-TP-2002-273

Miniature loop heat pipe with a flat evaporator – Thermal modelling, Experimental results

Presented at the 32th International Conference on Environmental Systems (San Antonio, Texas, 14–18 July 2002); and, as invited lecture, at the 12th International Heat Pipe Conference (Moscow - Kostrama - Moscow, 19–24 May 2002). The reported activities pertain to the final reporting of the INTAS-UKRAINE project 95-0196

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Presented at the TurbOMat: International Symposium on Thermal Barrier Coatings and Titanium Aluminides, Bonn, Germany, 17–19 June 2002

Koolloos, M.F.J.; Marijnissen, G.

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Presented at the 11th Workshop for Functional and (constraint) Logic Programming, Grado, Italy, 20–22 June 2002

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Vegt, J.J.W. van der; Ven, H. van der

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RNLAF/F-16 Loads and usage monitoring/ management program

Winkel, F.C. te; Spiekhout, D.J.

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NLR-TP-2002-320

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Presented at the CEAS Aerospace Aerodynamics Research Conference, Cambridge, UK, 10–12 June 2002

Ganzevles, F.L.A.; Bruin, A.C. de; Puffert-Meissner, W.

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Kooloos, M.F.J.; Arrel, D.J.; Henderson, M.B.; Gallet, S.

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Presented at the 15th International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Cairns, Australia, 17–20 June 2002

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Slooff, J.W.

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Vankan, W.J.; Maas, R.; Dam, M. ten

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Hofman, J.M.A.

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Presented at the FAA/Eurocontrol ATM 2001 Seminar, Santa Fe, New Mexico, 3 – 7 December 2001
Beers, C.S.; Huisman, H.

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Presented at the 33rd European Conference on Mathematical Psychology, Bremen, 23 August 2002
Roessingh, J.J.M.; Kappers, A.M.J.; Koenderink, J.J.

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NLR-TP-2002-470

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Lemmers, A.J.J.; Kuiper, P.J.; Verhage, F.R.

NLR-TP-2002-472

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Published: This report is an extended version of the paper 'A Farkas Lemma for Behavioral Inequalities' authored by A.A. ten Dam and J.W. Nieuwenhuis (University of Groningen) and submitted for inclusion in the book 'Open Problems in Mathematical Systems and Control Theory'
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NLR-TP-2002-484

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NLR-TP-2002-491

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NLR-TP-2002-496

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Muijden, J. van; Elsenaar, A.

NLR-TP-2002-506

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Wolf, W.B. de

NLR-TP-2002-524

Challenges for Distributed Exercise Management: The SmartFED Approach
Presented at the Modelling & Simulation Group Conference on Future Modelling and Simulation Challenges, Breda, The Netherlands, 12–14 November 2001
Keuning, M.F.R.; Sluis, E. van de; Dam, A.A. ten

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SmartFED Approach to Distributed Exercise Management
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NLR-TP-2002-588

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Presented at the NVvL & NLR Colloquium, Amsterdam, The Netherlands, 31 January 2002
Veerman, H.P.J.

NLR-TP-2002-589

A method to derive the usage of hydraulic actuators from flight data
Presented at the 23rd ICAS Congress, Toronto, Canada, 8–13 September 2002
Kannemans, H.; Jentink, H.W.

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An independent verification tool for multi-vendor Mode S airborne transponder conformance testing
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Aartman, L.J.; Heijningen, P.J. van; Brun, P.; Ziegler, F.

2 Abbreviations

AECMA	Association Européenne des Constructeurs de Matériel Aérospatial (The European Association of Aerospace Industries)
AIAA	American Institute of Aeronautics and Astronautics
ATC	Air Traffic Control
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry for Education and Research)
BMVg	Bundesministerium der Verteidigung (Federal Ministry of Defence)
CARTE	Collaboration on Aeronautical Research and Technology in Europe
CIRA	Centro Italiano Ricerche Aerospaziali
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
DNW	Duits-Nederlandse Windtunnels (German-Dutch Wind Tunnels)
DSTL	Defence Science and Technology Laboratory (UK)
EMI	Electro-Magnetic Interference
EREA	Association of European Research Establishments in Aeronautics
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
ETW	European Transonic Windtunnel
EU	European Union
EUCLID	European Co-operation for the Long term In Defence
EUROCONTROL	European Organisation for the Safety of Air Navigation
EZ	Ministerie van Economische Zaken (Ministry of Economic Affairs)
FAA	Federal Aviation Administration (USA)
FAO	Food and Agriculture Organisation (UN)
FEL	Fysisch Elektronisch Laboratorium (TNO) (Physics-Electronics Laboratory)
FOI	Swedish Defence Research Agency
GARTEUR	Group for Aeronautical Research and Technology in Europe
GPS	Global Positioning System
HMI	Human Machine Interface
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
INTA	Instituto Nacional de Técnica Aeroespacial (Aerospace Research Institute of Spain)
JAR	Joint Airworthiness Requirements
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)
LST	Lage-Snelheids Tunnel (Low Speed Wind Tunnel)
LVNL	Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)
NAG	Netherlands Aerospace Group
NASA	National Aeronautics and Space Administration (USA)
NATO	North Atlantic Treaty Organization
NIVR	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart (Netherlands Agency for Aerospace Programmes)
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory NLR)
NPOC	National Point of Contact
NSF	Nationale Simulatie Faciliteit (National Simulation Facility)
ONERA	Office National d'Etudes et de Recherches Aérospatiales (Aerospace Research Institute of France)
RNLAF	Royal Netherlands Air Force
RTCA	Requirements and Technical Concepts for Aeronautics (formerly: Radio Technical Commission for Aeronautics)
RTO	Research and Technology Organization (NATO)
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
TU Delft	Delft University of Technology
V&W	Ministerie van Verkeer en Waterstaat (Ministry of Transport and Public Works)
VKI	Von Kármán Institute of Fluid Dynamics
WEAO	Western European Armament Organization
WL	Waterloopkundig Laboratorium (Delft Hydraulics)

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