NLR TP 97288

First results from operating the Dutch national simulation facility NSF

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DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF. NLR TP 97288 U		SECURITY CLASS. Unclassified

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
First results from operating the Dutch national simulation facility NSF.

PRESENTED AT
the 1997 International Training Equipment Conference (ITEC), 22-25 April 1997, at Lausanne Switzerland.

AUTHORS H.A.J.M. Offerman	DATE 961205	pp ref 9 2

DESCRIPTORS

Cockpit simulators	Man-computer interface
Configuration management	Mission planning
Cues	Motion simulators
F-16 aircraft	Research facilities
Flight simulators	Speach recognition
JAS-39 aircraft	User requirements

ABSTRACT
The NLR National Simulation Facility (NSF)is one of the few high quality **research** full mission flight simulators intended to support both aircraft industry and operators for investigations with the full operational envelope of an aircraft. The NSF has been and is used in a number of simulator experiments where a high degree of simulator fidelity is required in combination with the need for easy reconfiguring for a specific aircraft type or conditions where the aircraft will be operated in. Three simulator experiments performed in 1996 are described showing the various possibilities; a handling qualities experiment for the SAAB JAS-30 Gripen, a Speech recognition study with the F-16 MLU and a simulator requirements study with an Aermacchi MB/339C. Also, some lessons learned during the development of the NSF and the subsequent operational period, will be presented.

217-02

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DUTCH NATIONAL SIMULATION FACILITY NSF

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The NLR National Simulation Facility (NSF) is one of the few high quality **research** full mission flight simulators intended to support both aircraft industry and operators for investigations with the full operational envelope of an aircraft. The NSF has been and is used in a number of simulator experiments where a high degree of simulator fidelity is required in combination with the need for easy reconfiguring for a specific aircraft type or conditions where the aircraft will be operated in. Three simulator experiments performed in 1996 are described showing the various possibilities; a handling qualities experiment for the SAAB JAS-39 Gripen, a Speech recognition study with the F-16 MLU and a simulator requirements study with an Aermacchi MB-339C. Also, some lessons learned during the development of the NSF and the subsequent operational period, will be presented.

INTRODUCTION

The NLR National Simulation Facility (NSF) is one of the few high quality **research** full mission flight simulators intended to support both aircraft industry and operators for investigations with the full operational envelope of an aircraft. The word research must be emphasised here because this takes an entirely different approach of looking at simulator requirements compared to the average training simulator. This does not imply that a comparable training simulator would be less complex, but it takes another mindset to develop a research simulator.

The NSF has already been described in full detail in previous papers. In the following section a short description is given to set the scene, but this will only be superficial. For more detailed information the interested reader is referred to earlier publications (Offerman 1995/1, 199512). Also, information on the NLR facilities can be found on the NLR Internet homepage (http://www.nlr.nl)

The NSF, which was developed during 19924995 is a reconfigurable (primarily military oriented) simulator for fast jets or helicopters. Currently it is configured for the Lockheed Martin F-16 MLU (a Block 50 comparable derivative from the F-16 A/B). One of the most important reasons to implement this aircraft type was the role of NLR in the F-16 MLU industrial co-development phase. Also the continuation of RNLAF support due to the modification of existing F-16 A/B's to the MLU version by the Royal Netherlands Air Force (RNLAF) and their commissioning during 1998 and following years is important.

While traditionally NLR's simulation facilities were used for handling quality and procedural investigations without extensive avionics and weapon simulations, the NSF is a full mission simulator. A full F-16 MLU avionics and weapon suite, including Electronic Warfare systems, operated within an interactive target and threat environment can be handled by the simulator. This ability increased the simulation support role of

NLR to the RNLAF considerably; already in the beginning of 1996 a combined MoD/RNLAF project used the NSF to investigate the operational benefit of speech recognition in the F-16 MLU aircraft.

While being a research simulator, the utmost is done to support an arbitrary customer to perform his specific research or (system) development. This necessitates a modular and flexible architecture of the entire simulator; both hardware and software components must be designed and implemented in such a way that they easily can be 'replaced' by functional comparable modules. For the EUCLID CEPA-11 programme, in which the NSF plays an important role, the flexibility in modifying system parameters and changing cockpit and aircraft characteristics was crucial.

Managing this flexibility aspect of the simulator is however, one of the most difficult parts in the NSF operation. Configuration management and scrupulous interface control must be of the highest standard to allow this flexibility to be operable. Anyone who has been in the process of software development knows the pitfalls of modifying software modules in one place and seeing the (mostly unintentional) disastrous results in the other.

In the next chapters the three most important simulator experiments performed with the NSF during the last year are described. However, no quantitative or in-depth results of the described simulation experiments are (and can be) presented in this paper. For more details of these projects it is recommended to await the separately to be held presentations.

ABBREVIATIONS

ASR	Automatic Speech Recognition
CEPA	Common European Priority Area
EUCLID	European Co-operation for the Long Term in Defence
HOTAS	Hands On Throttle And Stick
MFD	Multi Function Display
MLU	Mid Life Update
NLR	National Aerospace Laboratory
NSF	NLR National Simulation Facility
RNLAF	Royal Netherlands Air Force
RTP	Research & Technology Project
SGI	Silicon Graphics Inc.

DESCRIPTION OF THE NSF

The NSF as is showed in figure 1 is a moving base flight simulator. It features a large number of different cueing systems necessary to support various research programmes; our aim is to support R&D programmes like:

- evaluation of training concepts
- prototyping of cockpit and avionics concepts
- evaluation of operational procedures and tactics
- research into aircraft handling qualities
- evaluation of weapon system and weapon platform concepts
- determination of pilot workload
- human factors research

Next to these more 'common' research items, our second important aim is to support the RNLAF in some training niches;

- F-16 MLU familiarisation and
- mission rehearsal.

To support the above mentioned subjects we were forced to design a radical new simulator concept based on the twenty odd years experience gathered operating the civil based NLR Research Flight Simulator. Taking the best concepts from this simulator and innovating them according to the latest computer and information technology, we were able to develop this updated NSF within four years.
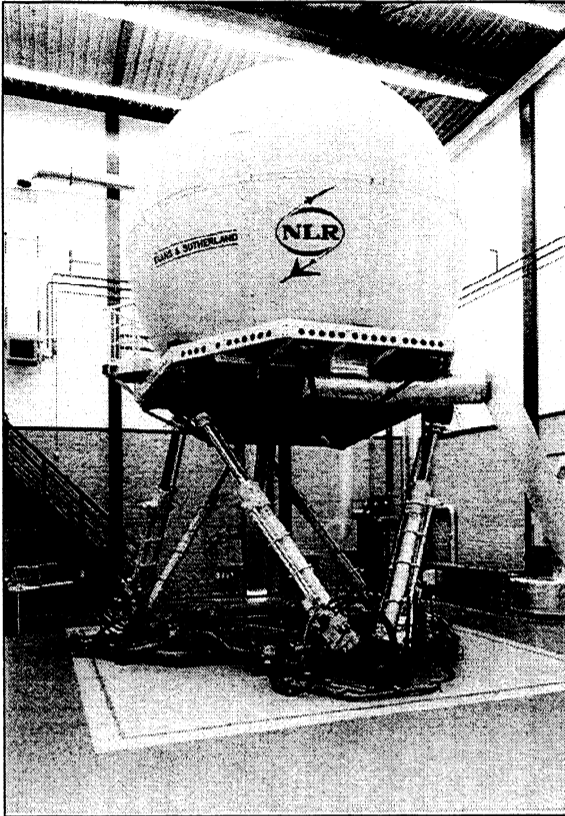
Figure 1: The NSF with motion in neutral

Its main components are:
- A SGI Challenge host computer running the real-time simulation program.
- All hardware components are linked to this host with a SCRAMNet fibre-optic high-speed reflective memory databus interface system. The data-handling intensive components have a separate front-end interface computer; from a specific memory partition on the interface network, data is 'unpacked', calibrated or reconfigured and send to the actual hardware. For instance, the F-16 cockpit is linked via the CHeSS Cockpit Interface node to the host computer with a single fibre-optic wire. The Cockpit Interface Node 'unpacks' received engineering data values as Angle-of-Attack in degrees or Calibrated Airspeed in knots and converts the data to an equivalent voltage unit which in its turn is sent to an Digital /Analogue or Synchro converter which is connected to the actual cockpit instrument.
- The Hydraudyne six degrees of freedom (synergistic) motion platform is one of the most prominent visible parts of the simulator. This

motion system provides the crucial motion stimuli to the human inner ear sensors (semi circular canals and otoliths) and is important whenever manned simulations are performed where the flying task is emphasised. For aircraft handling qualities experiments these platform motion induced stimuli become an integrated part of the pilot's control loop, and cannot be substituted by other means.
- For completing the force cueing environment a combination of a specially developed Sogitec G-seat (equipped with both inflatable cushions and moveable seat and back panels), anti-G-suit, strap belt tension and a helmet loader can be used. While the motion platform gives the onset accelerations and large total body stimuli, the G-cueing system provides high-frequency and pressure stimuli to the body.
- The visual system consists of an Evans & Sutherland three channel ESIG-3000 GT image generator in combination with a servo-controlled head-tracked area-of-interest dome projection display. The pilot has an unrestricted, almost 360 degrees, field-of-regard (see figure 3). To allow for rapid visual and sensor database development and modification a database generation system completes the system.
- For generation of the target and threat environment the CAE software package ITEMS is used. Up to 50 real time players can be active at any given time.
- A two channel Fokker Control Systems control loading system can be used for 'conventional' pilot controls, such as a high-roll stick and rudder pedals.
- A Lockheed Martin F- 16 MLU cockpit with fully functional and MMI identical instruments, panels, switches and displays. The avionics suite is driven by software which was developed at Lockheed Martin's (General Dynamics in those days) Flight Simulation laboratory to support the MLU development.
- The hardware components are completed with a digital Sound system and an extensive Control desk which is comparable to an Instructor/Operator Station.

FIRST SIMULATOR EXPERIMENTS ON THE NSF

In the following section the three most important simulator experiments of 1996 will be reviewed.

Speech Recognition in the F-16 MLU cockpit

In 199 1 a contract was awarded to NLR and the Human Factors Research institute (TNO-TM) to investigate the feasibility and operational benefit of using Automatic Speech Recognition (ASR) in the F-16 MLU cockpit.

The project evolved gradually from a paper study to a PC demonstrator using a dedicated speech recognition board and interfacing with the simulator through advanced software routines which handled the complex MLU avionics architecture. The speech recognition and mode processing software could cope with over 200 voice commands, from quite simple assignments like "DISPLAY SMIS" to the more complex "SWITCHING VOLKEL TOWER". The first example command would activate the Stores Management Set page on one of the Multi Function Displays, which alternately could also manually be activated by pushing a mere bezel switch. The latter example command replaces multiple manual entries on the Integrated Control Panel's keyboard; it commands a switch from the active UHF frequency to the frequency of the ATC tower of Volkel Air Force Base.

The project required both possibilities of (standard) manual input as well as voice activated mode switching within the avionics modules. Also, several interactive ASR applications were implemented, ranging from checklist executions to management of the Electronic Warfare (sub)systems. The availability of the avionics software (functional) code instead of manipulating real hardware boxes proved to be much more flexible and easy to adapt. The 'Voice' project had strict requirements for direct access to all avionics functions and for continuous synchronisation between avionics and speech recognition states. The digital sound system created extra help for the pilot during busy periods, such as reading the Fence checklist before target ingress whereby the next item on the list was activated if the pilot answered with "CHECK". Also the sound system acknowledged certain stick switch or voice commands, such as "JAMMING FIGHTERS" when the corresponding EW mode was activated.

A large part of the projects' preparation took place in our F- 16 mock-up; the mock-up uses the same simulation software as the NSF uses, only the final MMI is different. The most obvious difference is the cockpit interior, however the mock-up handles nearly all the important cockpit MFD bezel functions and panels through its use of touch screens.
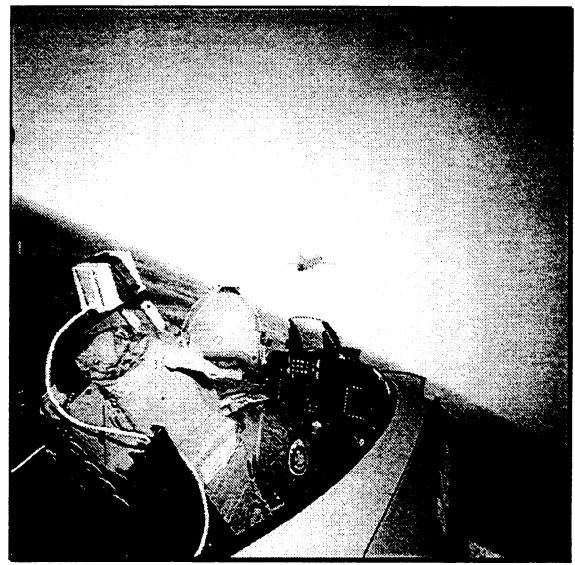

Figure 2: NSF cockpit with projected out-the window visual

The "Voice" project was the first one to use the NSF to its fullest extent in full mission scenario's and because of the operational value, the ITEMS interactive environment simulation package had to be used to its fullest extent. Bogeys, 'sleeping' SAM sites etc. were programmed to be activated on various predetermined sets of events or conditions.
The difficult part of the project was the test and shake-down phase; the interaction of visual sighting, avionics systems behaviour and interactive threat and target generation could not be tested without actually flying the scenario's. Thus an extra test dimension on top of the speech recognition test was created which complicated things considerably.
Murphy's Law then showed its face: already stabilised software, interface systems and data communication programs showed inexplicable

failures. Obviously, configuration control had slipped for a period of time which is difficult to maintain whenever time pressure becomes too big. We had to halt the "Voice" testing and concentrate on stabilising the problems encountered. This took several weeks, but after rigorous debugging, problem solving and testing almost all problems had disappeared.

The project was finally conducted with F-16 test pilots from the RNLAF, some 6 pilots flew different scenario's. First result from this project seems to indicate the usefulness of some speech recognition applications. However, in general the speech recognition rates achievable in semi-operational environment were still too low. Furthermore, it appeared that a possible future introduction of ASR has to compete with the pilots' affinity with using the HOTAS switches. Good ASR potential however, is seen for the crew support voice interactive functions.

During the experiment the platform motion system was used during some missions to demonstrate the added effects to the pilots and to obtain feedback (the G-cueing system was not yet installed). The motion set-up in these kind of experiments is quite difficult because of the large variation in flight speeds and manoeuvring rate's, The wash-out parameters driving the motion control laws must be such that no false cues (like actuator buffer stops) are generated at any time. In these cases a compromise is reached: only the combination of high speed with maximum g's gives full platform excursion. In normal flight conditions the motion is heavily attenuated and produces only high-frequency cues (onset acceleration during manoeuvring and turbulence).

SAAB Military Aircraft JAS-39 Gripen handling qualities investigations

Having witnessed two unfortunate incidents with their prototype aircraft due to pilot aircraft coupling, SAAB Military Aircraft had reason to investigate their JAS-39 Gripen flight control laws with respect to certain unfavourable conditions. Most of the flight control law development had taken place at SAAB's fixed base JAS-39 simulator, which could unfortunately not prevent at that time the incidents from happening.

In 1995 SAAB contracted NLR to perform a simulator study to investigate the use of platform motion on the pilot's stick activity for a number of flight conditions, most of them related to increased wind and turbulence levels.

The study was performed with a fast-jet fighter aerodynamic model, a modified fighter flight control law model (generating a Gripen-like response for the low speed regime) and the JAS-39 ministick mounted in the F-16 cockpit (were normally the centre instrument pedestal is situated). The study was performed with approaches for landing for several atmospheric conditions with and without the platform motion system active. Results showed unambiguously the positive effect of using platform motion on the pilot's stick activity; with the non-moving base the results were similar to those found on the fixed base simulator at SAAB, for the moving base situation the results were comparable to actual flight test results under comparable conditions.

The result from this 'demonstration' program was reason for SAAB to contract NLR for a detailed simulator investigation to study the various flight control law schemes and conditions. At the time of writing this paper the investigation was about to begin and scheduled for the end of October 1996. For this simulator experiment SAAB provided simulation models for the Gripen aerodynamics, flight control system, hydraulics, servo actuators, sensors, engine and the undercarriage (all in FORTRAN), on the basis of detailed interface specifications provided by NLR. Some parts of the NSF's simulation programme Software Development System were provided to SAAB for early testing at their premises. This illustrates the amount of flexibility in software coding necessary to support an investigation like this.

The update rate of the actual Gripen Flight Control Computer required the simulated flight control system and accompanying actuators to run at a simulation update rate of 120 Hz (or 8.3 milliseconds), which even for a four processor (200 MHz R-4400) SGI-Challenge is quite a challenge. Both the single-seat and the two-seater versions of the Gripen were flown in a two week period.

Also for this experiment the actual Gripen ministick was mounted in the cockpit. Special attention had been given at the on-line data analysis and quick-

look plot facilities, to allow SAAB engineers to respond to the actual session being flown.

Of course, the motion washout set-up required special attention. The platform performance was to be used to its fullest extend, which implied that the wash-out was optimised for the approach and landing speed regime. Flying in various turbulence conditions (from light to extremely severe) with various wind speeds provided the necessary input to the pilot's control behaviour.

The results from this experiment will probably be presented by a SAAB representative in due course.

EUCLID RTP 11.2 Work package 1: Environmental Cueing Systems for Simulators

The objective of the EUCLID CEPA-11 programme is to gain scientific and technological insight in the use of (military) simulators for training. NLR is involved in two Research and Technology Projects (RTPs), being RTP- 11.1 with the subject "human factors and training" and RTP- 11.2 with "simulation technology". While the simulation experiment part of RTP-11.1 is to take place in the beginning of 1997, the RTP- 11.2 experiment on the NSF will run in December 1996.

RTP-11.2 Work package 1 is carried out by the consortium members Thomson Training & Simulation (main contractor) together with DRA-Bedford for rotary wing and Aermacchi and NLR involved in the fixed-wing cueing evaluation.

The programme started in 1993 with detailed scientific paper studies, describing the various cueing effects on the human being, the expected effects on simulated task performance and the minimal required simulation and simulator fidelity to perform specific tasks.

Within the 'fixed-wing part' of the 11.2 programme it was decided to compare different training devices having different fidelity levels with one reference ruler; the Aermacchi MB-339C jet aircraft. In increasing fidelity level would be used:

- the engineering fixed-base simulator at Aermacchi;
- the moving-base NSF with the MB-339C flight dynamics and flight control characteristics, and;
- the actual MB-339C aircraft.

For a number of tasks, notably high-speed low-altitude navigation and attacks, pilots from the Italian Air Force, Aermacchi and RNLAF were equipped with physiological measurement equipment (Vitaport) and both subjective and objective data from the task was gathered from the flights with the aircraft in October 1995.

The Aermacchi MB-339C aircraft has conventional flight controls; a high-roll centre stick coupled to a non fly-by-wire flight control system. Compared to the 'normal' NSF configuration of the F-16 MLU, a cockpit modification was necessary to allow not only the centre stick to be installed but also the control loading system.

The F- 16 aerodynamic and flight control system models were replaced by MB-339C data delivered by Aermacchi, which was installed, interfaced, tested and fully operational within a few weeks.

At the moment of writing this paper last part of the experiment had yet to take place at NLR.

The experiment called for different motion cueing set-up's to be evaluated, being:

- a non-active motion platform and non-active g-cueing system (to compare to the Aermacchi fixed-base simulation part);
- an active g-cueing system only;
- an active motion platform only;
- both motion platform and g-cueing system active.
- visual field-of-regard of 90 deg and 180 deg

Pilots are to fly different ground attack manoeuvres with one of the above mentioned combinations. Directly after each run the pilot has to fill in a number of questionnaires (e.g. Cooper-Harper, NASA-TLX, Rating Scale Mental Effort) who's comments will be correlated with the measured aircraft parameters and pilot heart rate.

Because all results obtained in the EUCLID programme are company confidential, the actual experiment outcome is available from a participating country's MoD or from the industrial consortium.

LESSONS LEARNED

In this section some of the lessons learned during the final part of the NSF development and before and during some of the mentioned simulator experiments are presented.

- Take time to stabilise software; if you are not totally confident with it, do not trust it to work the way you envisioned it to work;
- Never trust software engineers who claim that they need 'no pre-integration test because: 'we didn't change things.. .., euh yes we did, but it has no impact on the rest of the program';
- Graphical User Interfaces maybe user friendly but can rather quickly become a nuisance;
- Fibre-optic data transport is the way to go;
- UNIX computers are real time capable, as long as you know what you're doing;
- Distributed computers tend to increase the number of single failure points in the system: also debugging can be quite difficult;
- The use of non-deterministic reacting threat and targets necessitate very thorough scenario testing. Causal effects can complicate a scenario to a degree that it becomes virtually impossible to test it.

Although many of these items must be known to a large part of the simulation community, the only way of gaining experience from large-scale difficulties is being confronted by them and to resolve them.

CONCLUSIONS

Since its inauguration in November 1995 the NLR National Simulation Facility (figure 3) has proved already in many simulator experiments with varying operational requirements the value of having available a high-fidelity research simulator with full mission capabilities.

The reconfigurability of this simulator is one of the main assets of the NSF. Next to this is the extent of the available cueing systems, ranging from the full field-of-regard head tracked dome visual system to the extensive and state-of-the-art force cueing systems.
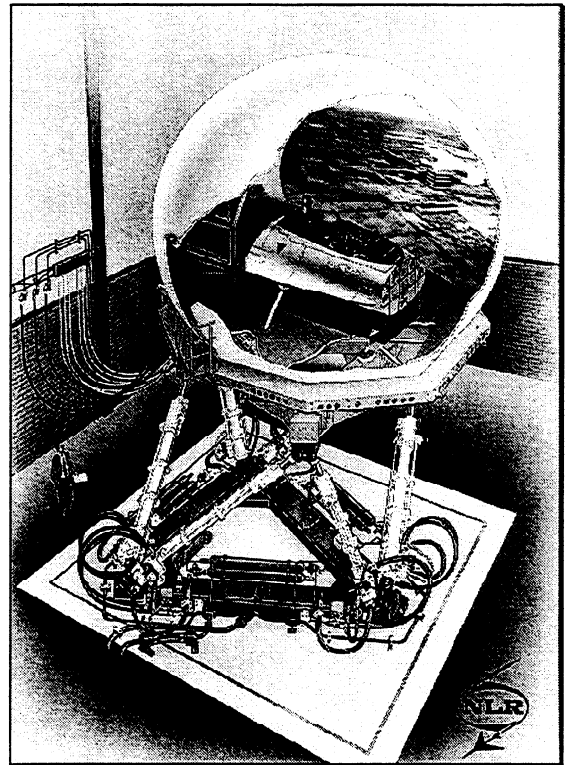

Figure 3: Cut-away drawing of the NSF

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