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THE RNLAf APPROACH TO CERTIFICATION OF THE AVIONICS CONTROL
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by

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THE RNLAf APPROACH TO CERTIFICATION OF THE AVIONICS CONTROL AND MANAGEMENT SYSTEM OF THE CH-47D CHINOOK

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Abstract

The Royal Netherlands Air Force procured 13 CH-47D Chinook Helicopters in June 1993. The helicopters are equipped with powerful (FADEC) engines, HUMS and a state of the art Avionics Control and Management System (ACMS).

At the time of procurement the ACMS was not fully developed. Therefore, the RNLAf was involved in both the final stage of the ACMS development to optimize to the Dutch specific requirements and the certification of the ACMS.

A combined RNLAf/NLR team was stationed at Boeing Defense and Space Group to fulfill the complex and sometimes conflicting tasks of development and qualification tests that should lead to the type certificate of the RNLAf CH-47D Chinook.

The purpose of this paper is to give an impression of the RNLAf approach to certification of the Avionics Control and Management System and about the experiences during the final development and certification of the RNLAf CH-47D ACMS.

Acronyms and Abbreviations

ACMS	Avionics Control and Management System
AVISP	Air Vehicle Integrated System Processor
BIT	Build in Test
CDU	Control Display Unit
CSCI	Computer Software Configuration Item
DTS	Data Transfer System
EFIS	Electronic Flight Instrument System
FAA	Federal Aviation Authorities
FADEC	Full Authority Digital Engine Control
FD	Flight Director
FQGS	Fuel Quantity Gaging System
MFD	Multi Function Display
MISP	Mission Integrated System Processor
NLR	National Aerospace Laboratory
NVG	Night Vision Goggles
ODA	Optical Display Assembly
RNLAf	Royal Netherlands Air Force
SRS	Software Requirement Specification
STP	Software Test Procedure
STR	Software Test Report
TCRD	Torque Cruise Guide RPM Display
VDD	Version Description Document
WCA	Warning Caution Advisory
WX	Weather Radar

Introduction

In June 1993 the Royal Netherlands Air Force procured 13 CH-47D Chinook Helicopters after an extensive evaluation. Part of this an evaluation of the avionic systems was performed (ref. 1). The prime task of the Chinook will be support of the 11th airmobile brigade.

The helicopters are equipped with:

- Powerful 55-L-714A FADEC engines.
- Health and Usage Monitoring System (HUMS).
- AFCS with modified control laws.
- Flight Director with three axis coupling.
- Cargo Hook Load Measuring System (HLMS).
- Avionics Control and Management System (ACMS).

The ACMS (a Honeywell / Boeing product) provides the pilots with air vehicle, mission and pilotage functions. When the RNLAF procured the CH-47D's the ACMS was not fully developed nor was it customized for the Dutch specific requirements. Since the RNLAF was the launching customer and the fact that the ACMS was not a certified system the RNLAF was actively involved in both the development and the certification of the ACMS and a number of other subsystems. A combined RNLAF/NLR team was stationed at Boeing Defense and Space Group in Philadelphia to fulfill the complex and sometimes conflicting tasks of development and qualification tests that should lead to the type certificate of the RNLAF CH-47D Chinook.

The purpose of this presentation is to give an impression about the experiences of the RNLAF during the final development and certification of the RNLAF CH-47D ACMS.

ACMS Description

The ACMS architecture (figure 1) is based around three integrated functional groups.

1. Air Vehicle Group. This group is responsible for all aircraft dependent systems. The conventional electro-mechanical displays and control panels were replaced by two Air Vehicle Integrated System Processors (AVISP's), two Air Vehicle Multi Function Displays (6 x 8 inch) and two full color Torque, Cruise and RPM Display (TCRD's).

2. Mission Group. This group is responsible for all mission and aircraft "independent" systems. There are two Mission Integrated System Processors (MISP's), two Mission Multi Function Displays (6 x 8 inch), two CDU's, Data Transfer System (DTS) and a Optical Display Assembly (ODA). Examples of this functionality are the navigation /communication suite, digital map and mission management.

3. Pilotage Group. This group consists of the flight instrument portion of the ACMS. The conventional flight instruments are replaced by a full color Night Vision Goggles (NVG) compatible Electronic Flight Instruments System (EFIS). NVG compatibility was accomplished by the use of advanced triple notch filters for the respective color display units.

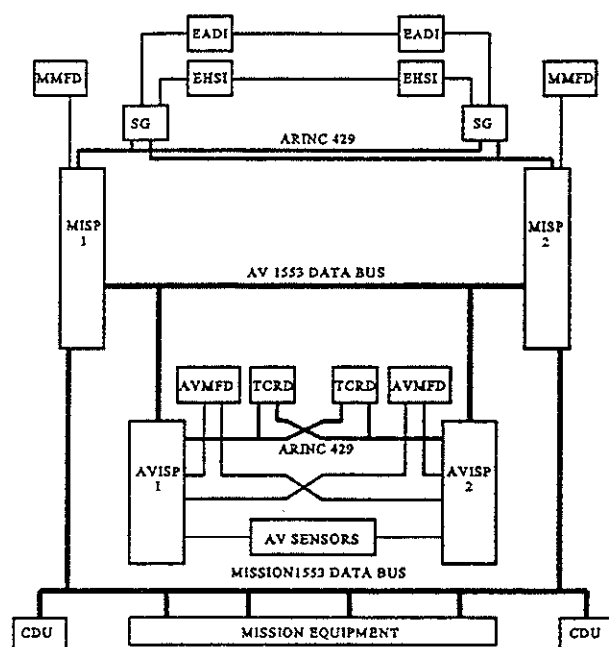


Figure 1: ACMS Architecture

The entire ACMS architecture (figure 1) is based around four Integrated System Processors which are communicating via two dual redundant MIL-STD 1553B data buses and special high- and low- speed ARINC 429 buses.

Earlier integrated cockpit programs showed that it is of utmost importance that the user interface with the system is as simple as possible. At all times it should be avoided to bring the operator in a so called CTRL ALT DEL stage because of the fact that he/she is "lost" in the system.

Therefore from the start of the program it was decided to maintain a two layer control matrix philosophy. This implies that independent of the displayed MFD page the operator needs only a maximum of two key strokes to accomplish a certain task.

The bottom bezel keys B1 through B4 of the Air Vehicle MFD give respectively access to the engine, aircraft, Warning Caution Advisory (WCA) and operators data manual (ODM) page. The pilot can access these pages independently from the page currently shown on his AV MFD. Some of these pages give access to other AV MFD pages as shown in figure 2.

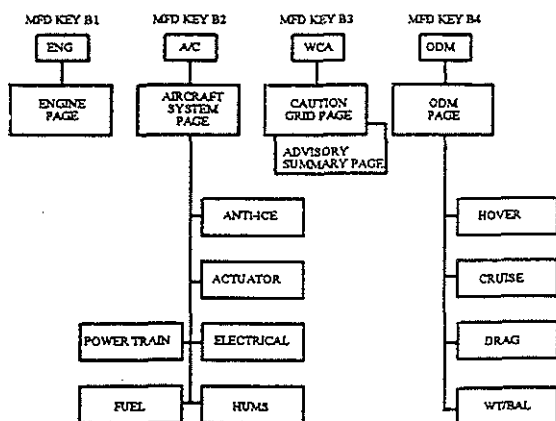


Figure 2: Page structure of the AV MFD

The bottom bezel keys B1 through B4 of the Mission MFD give respectively access to the equipment status, weather radar, map and mission management page. The pilot can access these pages independently from the page

currently shown on his Mission MFD. Some of these pages give access to other M MFD pages as shown in figure 3.

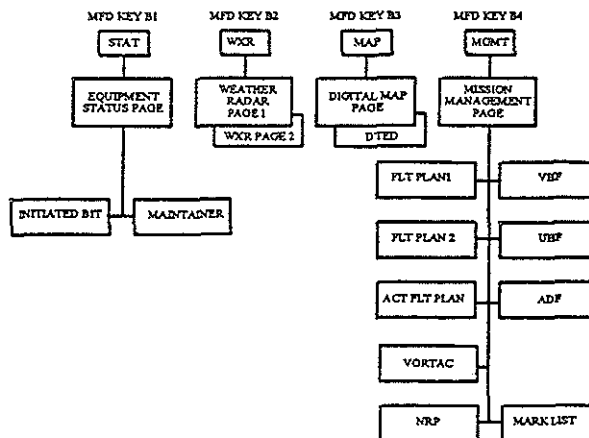


Figure 3: Page structure of the Mission MFD

Philosophy

A lesson learned from previous programs with advanced avionic systems with embedded software is that documentation of the software is of prime importance. Both for the development and the users life of the software its the only way to maintain configuration control and allow for software updates in a "cost controlled environment".

In earlier days software was qualified separately from the hardware. However, most of the modern avionics have embedded software. The combination of hardware and software is certified and not the hardware or software in isolation. Therefore the RNLAf followed a system approach.

To determine the safety aspects a hazard analysis of the ACMS was performed and properly documented. The data used was extracted from Failure Mode Effect and Criticality Analysis (FMECA) of the ACMS components. The potential hazards were all but one assessed and controlled. Operation with the Optical Display Assembly (ODA) will be assessed by the RNLAf during the operational and training evaluation (OT&E) program to be held in the fall of 1996.



The approach to certification of the Avionics Control and Management System of the CH-47D Chinook was divided in following area's:

- documentation of the hardware and software
- qualification testing of the hardware components
- CSCI testing of the components unique features
- system integration testing of the ACMS
- development and evaluation flight tests.

Documentation

The reason the RNLAF required complete ACMS documentation was four folded: the documentation was required for the software development, configuration control, certification purposes and the documentation is of prime importance to define future software and hardware modifications. Initially, the required software documents had to be written in a format as described in the applicable DOD standards. Due to several reasons the ACMS manufacturer, Honeywell Inc, and the RNLAF decided to follow a different approach. The software documentation tree in figure 4 shows the software documentation that was made available to the RNLAF. The software documentation necessary for quality assurance is not part of this tree.

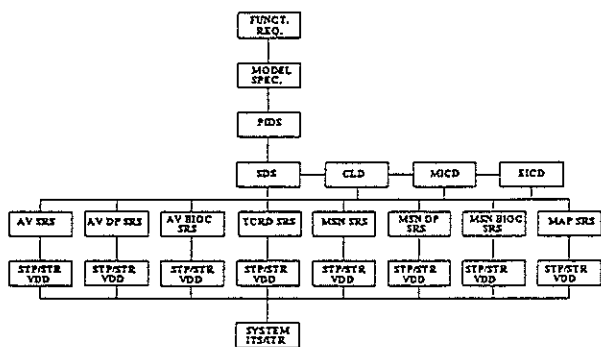


Figure 4: ACMS Software Tree

As the figure shows, all Computer Software Configuration Item (CSCI) documents refer to a System Design Specification (SDS), Control

Layer Document (CLD), Multiplex Interface Control Document (MICD) and Electrical Interface Control Document (EICD).

Four CSCI's are embedded in the Air Vehicle Group and four in the Mission Group. The functionality of each computer software configuration item is described in a software requirement specification (SRS). The SRS describes in detail the following:

- Software functional requirements and architecture
- Database interfaces
- Internal and external interfaces
- Analog and digital inputs and outputs

The configuration changes and modifications per CSCI are controlled with a Version Description Document (VDD). The VDD describes the software load procedure, the checksums, the modification per software change report (SCR) and the known problems. Software modifications were established without the use of software patches.

Qualification Testing

The ACMS is mostly build of the so called "commercial of the shelf" (COTS) components. The unique way these components are integrated made the ACMS such a powerful system. Using COTS components has especially an advantage during the qualification process. Part of the system hardware is qualified according to Military Standards, like the integrated system processors (ISP's). Other parts are qualified according to civil standards, like the Electronic Flight Instrumentation System (EFIS). The RNLAF supports as much as possible the trend to accept civil standards in military aircraft, mainly because of cost advantages, and the positive effect on the development time.

FAR section 29.1321 requires a permanent visibility of rotor RPM and torque. The rotor RPM and torque are displayed on the aircraft system page of the AV MFD. Other pages can be displayed as well on the AV MFD. Which



necessitates the development of a dedicated instrument, the Torque Cruise guide and RPM Display (TCRD). The TCRD is originally a commercial display for the Terminal Collision Avoidance System (TCAS), and manufactured under a technical standard order (TSO). Thus, the hardware was qualified. New graphics software was developed to present the rotor RPM torque and cruise guide parameters on this display. Only the display functionality and the software required RNLAf certification. The environmental qualification tests were certified by similarity.

The Electronic Flight Instrument System is FAA certified. However, dedicated flight director armed/capture annunciators were added for use in the RNLAf CH-47D Chinook. On request of the RNLAf minor color changes were introduced on bearing pointer and annunciator of the EHSl. The functionality of the changes were evaluated during flight evaluations of the RNLAf. The modifications were accepted by the FAA. As a result the RNLAf based the certification of the EFIS on similarity.

Table 1 specifies the qualification basis (military or civilian) of the major ACMS components per function group.

The ACMS components were environmental tested according to Mil-Std-810C or DO160C. The severeness of the tests is highly dependant on the chosen test category. The test conditions are similar, however, the exposure time differs. In general the tests described in DO-160C are less severe than the conditions of Mil-Std-810C. All components tested fulfill the RNLAf operational/environmental requirements. No exemptions were made.

The ACMS components installed in the Chinook are exposed to higher and different vibration levels than defined in their original user spectrum. Therefore, additional vibration tests were performed on all ACMS components to fulfill the more stringent vibration requirements.

ACMS COMPONENTS		
Subsystem	Qualification	Function
Symbol Generator	Civil	Pilotage
Electronic Attitude Direction Indicator	Civil	Pilotage
Electronic Horizontal Situation Indicator	Civil	Pilotage
EFIS Display Controller	Civil	Pilotage
Reversionary Panel	Mil-Std	Pilotage
Heading Course Controller	Civil	Pilotage
Flight Director Mode Select Panel	Civil	Pilotage
Optical Display Assembly	Mil-Std	Pilotage
Air Vehicle Integrated System Processor	Mil-Std	Air Vehicle
Air Vehicle Multi Function Display	Mil-Std	Air Vehicle
Torque Cruise Guide and RPM Display	Civil	Air Vehicle
Mission Integrated System Processor	Mil-Std	Mission
Mission Multifunction Display	Mil-Std	Mission
Control Display Unit	Mil-Std	Mission
Data Transfer System	Mil-Std	Mission

Table 1: Qualification Basis Matrix

During the course of the program the AVISP and MISP were EMI tested in the EMI lab at Honeywell. Specification exceedances (spikes) were detected for typical test conditions of the Mil-Std-461C tests: radiated emission, radiated susceptibility and conducted emissions. No problems were identified during the EMI ground test nor any EMI problems were identified during the development flight tests. It was determined that the outages occurred at four of the six ISP connectors affecting video, ARINC 429 and 1553 signals.

To expedite the solution to the EMI problems the majority of the signals were filtered instead of troubleshooting every signal. The selected capacitors avoid deterioration of the signals. As a result the Bit Error Rate (BER) of the digital signals was not effected. Boeing and Honeywell implemented a multi step test program to verify the ISP functionality. After implementation of the wafer filters in the four connectors both the AVISP and MISP passed the EMI lab. tests.



CSCI testing

Preceding the system integration test a computer software configuration item (CSCI) test is carried out. The performed CSCI test was a limited test, only the CSCI unique features were tested. Complete functionality of the software was tested extensively on system level during the system integration test (SIT).

- AV and Mission CSCI test: The communication with the other CSCI's was tested. The air vehicle and mission CSCI control the communication with the other CSCI's and determines if the ISP has to act as bus controller or back up bus controller.
- Bus Input Output Controller CSCI test: All kind of 1553 data signals to be processed by the BIOC CSCI were tested with an SBA-100 data bus test set.
- Display processor CSCI test: The graphics as embedded in the air vehicle and mission display processor were evaluated and checked against the Control Layer Document (CLD). Corrupted data is immediately visible because the object oriented architecture of the software.
- TCRD CSCI test: The display lay out and the pointer positions are tested. Corrupted data becomes immediately visible because the object oriented architecture of the software.
- MAP CSCI test, The mixing of two video signals was tested in combination with map control layers which represent the bezel functions.

The functioning of the software in both the MISP and AVISP are monitored by means of a continuously build in test function to ensure proper information. A checksum is continuously calculated from every CSCI and compared with a stored checksum. If the numbers do not match the system fails and the pilot receives an advisory.

System Integration Tests

The system integration tests were performed in the Boeing (BH) and Honeywell (HI) System

Integration laboratories. Both laboratories had their specific capabilities. Three system integration tests were distinguished depending on the software release.

- New software block release (SBR): required a full-up system integration test at both HI and BH and a functional evaluation in the aircraft on the ground.
- Software release (SR): required a regression system integration test at HI and BH. The delta testing was dependant on the changes made.
- Software engineering release (SER): a couple of parameters were different from the previous release, no tests necessary. The SER releases were especially used during the development of the in air alignment and kalman filter

During the development we had the following number of software releases: 4 SBR's, 34 SR's, 9 SER's.

The full-up system integration test was the major test before the a block software was released to the aircraft. All features e.g. the complete functionality of the ACMS system was tested during the comprehensive system integration test (SIT) in the system integration laboratory (SIL).

The regression system integration tests on the MISP software are different from the tests on the AVISP. The following tests are carried out during the regression tests:

AVISP:

- Warning Caution and Advisories. The inputs of the Aircraft sensors are simulated in such a way that the WCA's show in inverse video on the WCA page.
- The ARINC 429 bus traffic is monitored to register the WCA message to the HUMS system.
- the software modifications in the software release as described in the VDD's are verified.

MISP

- Various flight director modes are evaluated by means of simulations. This evaluation is



limited by the simulation.

- The ARINC 429 data necessary for long range navigation (LNAV) is monitored and evaluated.
- The software modifications as described in the VDD's are verified.

The SIL was also used to evaluate possible design solutions and for trouble shooting. The electrical system of the RNLAf CH-47D Chinook was modified from earlier designs. Therefore, the RNLAf took special interest in the power interrupt requirements because a power interrupt in a modern avionic system can be hazardous. The available power interrupt requirements Mil-Std-704 and test procedures were tailored to the RNLAf ACMS system. The tailoring resulted in evaluation of various single and multiple power interrupt cases.

Flight Testing

An extensive flight test program started in February 1995 to evaluate the capabilities of the ACMS and the other subsystems. The first six weeks of the test program was experimental and concentrated on the optimization of the AFCS and the verification of the stability and control with the newly set gains (ref. 2). After that the integration with the Flight Director(s) was evaluated. Two Flight Directors are installed in the Chinook, one in each mission ISP. The FD generate steering commands in the lateral, longitudinal and collective axis. The steering commands are displayed on the Electronic Attitude Display Instrument (EADI) for manual tracking or when coupled to the AFCS for automatic control.

- Lateral- by serial drive of the AFCS roll actuators.
- Longitudinal - by parallel drive of the Longitudinal CCDA.
- Collective - by parallel drive of the Collective CCDA

The following modes can be selected on the Flight Director Mode Select Panel (FDMSP):

1. HDG SEL
2. NAV
3. LNV
4. ILS
5. BALT
6. VS
7. RALT
8. APP
9. HVR
10. GSPD
11. Go Around

The development flight testing was initially based on fully tested software versions. During the course of the flight test program it became obvious that a more rapidly software change system was needed to support flight test. After a number of quality control hurdles it was possible to turn around software on (if needed) a daily bases. This worked out very well in software areas where many parameters are involved such as the kalman filtering (23 parameters) and the flight director. It also allowed for quick responses to the test team preferences.

The Boeing/RNLAf/Honeywell test team made more than 250 hrs of flight tests, which were necessary to optimize the ACMS functions, like flight director, kalman filtering, mission planning, digital map and air vehicle related information. The RNLAf CH-47D ACMS contains more than 52 avionics units in numerous locations. Since the RNLAf requires the MIL-E-5400 Class 1A specification a dedicated cooling evaluation program was conducted, this included cooling fan failures. The outcome of the tests showed that the forced air avionics cooling system was sufficient throughout the required environmental conditions.

During the flight test program a number of problem areas were identified which were not identified up by previous performed lab testing. Areas of concern/problem were specially



noticeable during the interchangeability trials which were conducted throughout the flight test program. To achieve an acceptable level of confidence it was decided to perform a sneak circuit analysis on the system. The outcome of this analysis lead to additional hard- and software modifications.

Part of the flight test program was the evaluation of the failure modes in various configurations (single / dual ISP's).

Conclusion

In January 1996 the first of the seven rebuild Chinooks came to the Netherlands. Last August marked the arrival of the last Chinook. Early 1998 six additional newly built Chinooks will be delivered to the RNLAf. At this moment the OT&E program and several Tactess courses are being conducted.

Typical qualification tests on COTS equipment were carried out as a supplement to the already existing qualification test results, because of a different operational environment. Certification of COTS components can partially be based on similarity and is therefore a cost effective solution.

Acceptance of civil avionics in military aircraft is a fact. The civil environmental requirements of DO 160C show similarities with Mil-Std-810E. We expect the reliability of civil qualified equipment to be sufficient for the RNLAf operational environment. The future will tell us, if these expectations are correct.

The object oriented programmed graphic displays made it possible to implement a limited CSCI test, in which only unique CSCI features were tested and functional tests could be deferred to SIT. The tested graphic displays were used during the comprehensive SIT test in which complete functionality was tested.

In general the RNLAf pilots are very pleased with the CH-47D and in particular the ACMS

and its transparent way to operate it. This shows that an on site multi discipline contractor team is of prime importance and over a longer period will be very cost effective. It is clear that this was inevitable in the final stage of development. The flexibility of all parties involved and the multi discipline team effort (Boeing/RNLAf/Honeywell) in the final stage of the ACMS development, lead to the successful type certification of the Dutch CH-47D Chinook.

References

- 1 Operational Evaluation Method for MMI's in Cockpits, A. Gebhard M.F.J.M. Ketelaars, H.G.M. Bohnen and P.G.A.M. Jorna d.d. 01-10-'93
- 2 Verification of the automatic Flight Control System of the RNLAf CH-47D Chinook Helicopter, J.D. Stegeman, d.d. 09-03-'95