Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Enhanced Platform Availability Through New FLM Concepts

Problem area
Some 10 years ago the RNLAF realized that a sound policy had to be developed and implemented to handle an increasingly growing amount of helicopter data from a variety of sources from the different RNLAF helicopter types Chinook, Apache and Cougar. Examples of such data sources are flight administration files, different on-board data-acquisition systems, maintenance, repair and overhaul databases, sources of logistical data etc.

Simultaneously, it was realized that ownership of a wealth of admin and loads\usage data can benefit the operator in a far more direct and cost effective way than historically experienced. It was felt that often the OEM is called in, while the operator has not yet fully observed and analyzed available information due to a lack of appropriate tools.

As a consequence, research activities were developed within the RNLAF to identify and work out possible improvements.

Who is the 'operator'?
Within the context of the study addressed in this document, the 'operator' represents the ensemble of fleet owner, weapon system manager, fleet maintainer and flight crew. In this, the 'operator' is a separate entity apart from the various OEM's and the Airworthiness Authority.

Description of work
A research program was initiated to develop flexible concepts to adequately handle the many information streams, and to develop improved, innovative and validated fleet life management procedures for different 'users', e.g. the fleet owner, the squadron leader, the flight planner, the maintainer, the trainer, etc.
The present paper is intended to describe backgrounds and results of the RNLAF Chinook pilot program, and to introduce a few of the new and innovative structural integrity concepts that currently are being implemented on an operational level within the RNLAF.

Results and conclusions
The Royal Netherlands Air Force (RNLAF) and the National Aerospace Laboratory (NLR) in The Netherlands successfully finalized a Structural Integrity Pilot Program for the RNLAF CH-47D Chinook helicopter. Innovative fleet life management concepts have been developed, directly linking airframe degradation to operational

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usage. This information is used to optimize Chinook maintenance, operational availability within the RNLAF and flight safety issues.

Also, a number of structural integrity features have been brought to the level a military helicopter manager or operator experiences on a daily basis, activities and functionalities that normally are being addressed by an OEM on an ad-hoc basis. The helicopter fleet owner or fleet maintainer is enabled to monitor - and possibly to influence and optimize - fleet life management issues, such as component end-of-life calculations, spare parts inventories, logistics footprints for out-of-area deployment, training needs, effects of future usage scenario's etc. A better insight is gained into the relation between operational usage and it's effect on material degradation, such as cracking, corrosion, delamination, etc.

The research program, addressed here, consisted of a number of test flights, followed by a long-term measurement campaign consisting of appr. 1,000 operational (peacetime) flying hours. From this, some newly developed Chinook load monitoring concepts were developed, as well as a number of practical structural integrity tools for fleet management and damage prediction, e.g.:

– a validated Chinook Flight Regime Recognition (FRR) algorithm
– a RNLAF Chinook Damage Index (CDI)
– a fatigue damage prognostics tool (PROUD – PROjected Usage Damage tool)
– HELIUM, a large flexible database designed to cover all RNLAF generated helicopter data from all possible sources of the different helicopter types Chinook, Apache and Cougar
– RAVIOLI, an IT environment for the military aircraft operator and maintainer with an innovative, fully integrated toolbox for analysis of loads, usage and maintenance data with web based applications of acquisition, processing, storage, visualization and reporting of that data.

Applicability

This paper addresses the rationale behind the above research activities, the RNLAF vision on developments in Helicopter Integral Weapon System Management (HIWSM), and introduces a few new flexible, yet powerful structural integrity tools for the helicopter manager, operator and maintainer. In principle, applicability is for all RNLAF used helicopter types Chinook, Apache, Cougar and NH-90 (in the near future).

This paper strives to support the NL MinDef organisation in its effort to maximize international co-operation and information exchange.

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Enhanced Platform Availability Through New FLM Concepts

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Contents

Abbreviations and acronyms

AFB	Air Force Base
CAMS	Core Automated Management System
CDI	Chinook Damage Index
CVFDR	Combined Voice Flight Data Recorder
DMO	Defense Materiel Organization of The Netherlands
FDR	Flight Data Recorder
FH	Flight hours
FLiP	Fleet Life Planning
FLM	Fleet Life Management
FRM	Flight Recreation Module
FRR	Flight Regime Recognition
GenHUMS	Generic HUMS (Chinook)
GLIMS	Ground-based Logistic Information Management System (NH-90)
GUI	Graphical User Interface
HELIUM	HElicopter LIfe and Usage Monitoring
HIWSM	Helicopter Integral Weapon System Management
IT	Information Technology
KD	Knowledge Discovery
MatLab	High level technical computing language and interactive environment
MDS	Monitoring & Diagnostic System (NH-90)
MinDef	Ministry of Defense of The Netherlands
MPA	Mission Profile Analyser
MPG	Mission Profile Generator
MSPU	Modern Signal Processing Unit (Apache)
NL-DMO	Defense Materiel Organization of The Netherlands
NLR	National Aerospace Laboratory NLR
OEM	Original Equipment Manufacturer
OLAP	Online Analytical Analysis tool
PROUD	PROjected Usage Damage tool
RA	Radio Altitude
RALT	Altitude Rate of Change
RAVIOLI	Reporting, Analysis, VIsualisaton Of Aircraft Lifecylce Information
RF	Reporting Facility
RNLAF	Royal Netherlands Airforce
SQL	Structured Query Language
T/O	Take-off
V_h	Maximum cruise speed

ENHANCED PLATFORM AVAILABILITY THROUGH NEW FLM CONCEPTS

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ABSTRACT

Recently, the Royal Netherlands Air Force (RNLAF) and the National Aerospace Laboratory (NLR) in The Netherlands finalised a Structural Integrity Pilot Program for the RNLAF CH-47D Chinook helicopter. The aim was to develop innovative concepts for monitoring and controlling aircraft degradation to optimise the balance between maintenance costs and efforts, operational availability and flight safety.

Apart from technical goals, the aim also was to bring a number of relevant structural integrity features - normally being addressed by an OEM on an ad-hoc or contract basis - down to the level the military helicopter operator experiences on a daily basis.

In other words, enabling the fleet owner or maintainer with new techniques to directly monitor - and possibly influence and optimize - fleet life management issues, such as component end-of-life calculations, spare parts inventories, logistics footprints for out-of-area deployment, training needs, effects of future usage scenario's etc.

To achieve this, good insight was necessary into the relation between operational usage and it's effect on material degradation, such as cracking, corrosion, delamination, etc.

The initial RNLAF Chinook research program consisted of a number of test flights, followed by a long-term measurement campaign consisting of appr. 1,000 operational (peacetime) flying hours. From this, some new Chinook load monitoring concepts were developed, as well as a number of practical tools to support fleet management and damage prediction, e.g.:

- *a validated Chinook Flight Regime Recognition (FRR) algorithm*
- *a RNLAF Chinook Damage Index (CDI) for non-rotational components*
- *a fatigue damage prognostic tool (PROUD – PROjected Usage Damage tool)*
- *a flexible, fully integrated state-of-the-art helicopter data management system, called HELIUM (HELIcopter Usage Monitoring)*
- *an IT environment for the military helicopter and fixed wing aircraft operator and maintainer with an innovative, fully integrated toolbox for analysis of loads, usage and maintenance data with web based applications of acquisition, processing, storage, visualization and reporting of that data, called RAVIOLI (Reporting, Analysis, VIsualisation Of aircraft Lifecycle Information). The RAVIOLI-toolbox will provide a number of new and innovative features, such as:*

- *Knowledge Discovery (KD) techniques*
- *a Mission Profile Analyser (MPA)*
- *a Mission Profile Generator (MPG)*
- *Fleet Life Planning (FLiP) procedures.*

While the initial pilot programme focused on the Chinook fleet, by the end of 2008 NL-DMO/NLR R&D attention will start to include the RNLAF fleet of Apache helicopters. Fleetwide installation of a new Apache HUMS system is planned for end 2008 and this will provide an excellent opportunity for the RNLAF to develop and implement improved load and usage monitoring procedures for the Apache, also.

Although some of the concepts, described here, have been developed for helicopter applications, their validity and usefulness is not exclusively adequate for helicopters, but can also be applied for fixed wing aircraft.

The paper will address the rationale behind the above research activities, the RNLAF vision on developments in Helicopter and Fixed Wing Integral Weapon System Management (IWSM) and Fleet Life Management, and will address the various new flexible powerful structural integrity tools that are available, by now, for the military manager, operator and maintainer to maximize operational availability.

INTRODUCTION

Recently, the Royal Netherlands Air Force (RNLAF) and the National Aerospace Laboratory (NLR) in The Netherlands successfully finalized a Structural Integrity Pilot Program for the RNLAF CH-47D Chinook helicopter (Refs. 1-4). The aim was to develop innovative fleet life management concepts, directly linking airframe degradation to operational usage, and to use this information in an effort to optimize Chinook maintenance, operational availability within the RNLAF and flight safety issues.

Apart from the above technical goals, the aim was also to bring a number of structural integrity features, normally being addressed by an OEM on an ad-hoc basis, down to the level that a military helicopter manager or operator experiences on a daily basis. In other words, enabling the helicopter weapon system manager to influence and - possibly - optimize fleet life management issues, such as component end-of-life calculations, spare parts inventories, logistics footprints for out-of-area deployment, training needs, effects of future usage scenario's etc.
To achieve this, good insight is necessary into the relation between operational usage and it's effect on material degradation, such as cracking, corrosion, delamination, etc.

The RNLAF Chinook research program, addressed here, consisted of a number of test flights, followed by a long-term measurement campaign consisting of appr. 1,000 operational (peacetime) flying hours. From this, some newly developed Chinook load monitoring concepts were developed, as well as a number of practical structural integrity tools for fleet management and damage prediction, e.g.:

- a validated Chinook Flight Regime Recognition (FRR) algorithm
- a RNLAF Chinook Damage Index (CDI)

- a fatigue damage prognostics tool (PROUD – PROjected Usage Damage tool)
- HELIUM, a large flexible database designed to cover all RNLAF generated helicopter data from all possible sources of the different helicopter types Chinook, Apache and Cougar; after introduction into service of the NH-90, in 2009, this helicopter type will also be covered
- RAVIOLI, an IT environment for the military aircraft operator and maintainer with an innovative, fully integrated toolbox for analysis of loads, usage and maintenance data with web based applications of acquisition, processing, storage, visualization and reporting of that data.

This paper will address the rationale behind the above research activities, the RNLAF vision on developments in Helicopter Integral Weapon System Management (HIWSM), and will introduce a few new flexible, yet powerful structural integrity tools for the helicopter manager, operator and maintainer.

1 FLIGHT REGIME RECOGNITION

One of the methods for performing helicopter usage (severity) monitoring is based on automatic Flight Regime Recognition (FRR), also known as Flight Condition Recognition. Since - at start of the present research program - the RNLAF did not own rights to any existing Chinook FRR algorithm, it was decided to independently develop validated FRR (and thus RNLAF-proprietary) routines for the Chinook. One of the reasons to decide for this quite cumbersome approach was that independent development of FRR procedures very well fits RNLAF's ambition to be a 'smart operator' and 'smart maintainer'.

The technical approach to derive FRR routines for the Chinook will be worked out below.

1.1 From Flight Data To Flight Regimes

Pre-defined flight regimes are being recognized from measured flight data, employing some multi-channel data-acquisition system, installed in the helicopter. If the regimes to be recognized are matched with the regimes for which the OEM has developed damage rates, it is possible for the operator/maintainer to determine usage severity and percentages of life consumed, based on actual operational data gathered by the data-acquisition system. For this purpose, in 2005, the RNLAF performed a fleet-wide install of a digital L3COM Combined Voice Flight Data Recorder (CVFDR), which is very suitable for the task (Fig. 1).

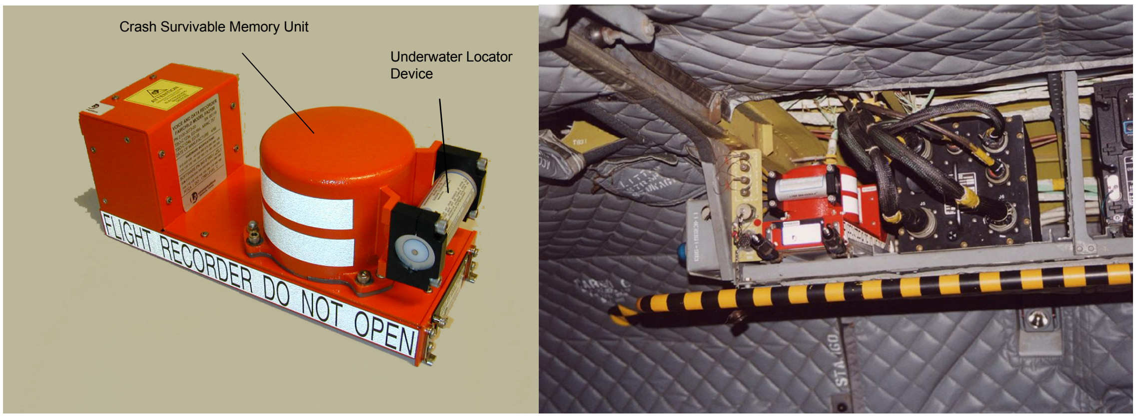


Figure 1: L3COM CVFDR installation in the RNLAF Chinook

Chinook flight regime definitions, as used for the present purpose, are similar to the basic mission profile for fatigue analysis, as composed by the OEM, see Table 1, giving the *coarse* sub-division into six major flight regimes. A *fine* sub-division into 98 flight regimes does also exist for the Chinook, and was also considered in the analysis (Ref. 4).

Chinook Flight Regime	**FR coarse**	**FR fine**
Ground	1	1-7
Hovering	2	8-15
Ascent	3	16-25
Level	4	26-95
Descent	5	96-97
Auto rotation	6	98
Time gap/No recognition	0	0

Table 1: Chinook flight regime (FR) classification

Thus, all parameters required for proper flight regime recognition were available through the RNLAF Chinook's CVFDR. To generate flight regimes from measured data, the following routines were developed:

1. Parameter processing routines to smooth and clean the measured CVFDR data
   In the basic parameter processing routines, each parameter (signal) was filtered to correct spurious values, was 'smoothed' with a moving average (if necessary) and was used as input to derive other parameters (such as rates of change).
2. Basic 'state identification' routines that handle one measurement parameter
   In the basic 'state identification' routines, the data was reduced as follows: each (measured or derived) parameter history was segmented according to specific conditions that needed to be identified. For example, angle of roll (ϕ) conditions were defined as: $|\phi| < 5°$ for *level flight*, $\phi \geq 5°$ for *banked flight to the right* and $\phi \leq -5°$ for *banked flight to the left*. For each roll condition identified, the routine provided a so-called structural array with the following properties: sequence number, identifying code, the starting time and duration for the 'banked flight' conditions and, also, the maximum (extreme) ϕ value reached. Likewise, for the altitude parameters several altitude bands were defined. The resulting 'state' history was then filtered to remove states that had a time duration

that was too short. Also, starting times and/or durations of adjacent states were adjusted to ensure no undefined time periods would exist.

All basic 'state identification' routines also identified a possible 'time gap' condition. Therefore, the routines provide complete coverage of the flight time experienced.

3. Additional state identification routines that handle two or more basic states

   Additional state identification routines were developed and were applied to combine two or more basic state histories, generated by the previous step. For example, the identification of the vertical speed combines the information from the RALT (altitude rate of change) state history and the (derived) rate of change of RA (radio altitude) state history. It takes into account that the RALT signal has no meaning below a specific (low) altitude and reverts to radio altitude data. Some of these additional states have been introduced to facilitate comparison with OEM regimes.

4. Regime identification routines that combine states to extract flight regimes

   Regime identification routines define the respective regimes, based on a logical combination of states. These routines were developed to provide full coverage of the recorded data (*i.e.* no time gaps) and to arrive at unique definitions (*i.e.* no overlaps).

As an illustration, Fig. 2 gives an example of the logical combination of states for the various flight regimes. All FRR routines were initially developed and implemented in Matlab. In a later phase these routines were converted into 'C'-code to improve processing speed.

PROCESSING/CALCULATING PARAMETERS			DETERMINING STATE ID's			
INPUT	SCRIPT	OUTPUT-INPUT	SCRIPT	OUTPUT		
name		name		name	info/properties	filtering/postprocessing*
GSFMS	ProcessingGSFMS	GSFMSClean	GrSpAxbAybID	GSSTATE	starttime, duration, type: 'TG': time gap 'HO': hover (w.r.t. the ground) 'A' or 'D': acceleration resp. deceleration 'Sn' where n: '1' (2-20 kts), '2' (20-40 kts) or '3' (40-70 kts) '>=70' for ground speed >= 70 kts	none
AYB	ProcessingAYB	AYBSmooth		AYBSTATE	starttime, duration, type: 'TG': time gap 'NS': not side slipping 'Ra' or 'La': side slipping to the right resp. left	skip for duration <=2, time gap merging
AXB	ProcessingAXB	AXBSmooth		AXBSTATE	starttime, duration, type: 'TG': time gap H': probable hover (not necessarily w.r.t. the ground) 'F': probable forward flight (or hover in head wind) 'R': probable rearward flight (or hover in tail wind)	skip for duration <= 2
RA, RALT	ProcessingRA ProcessingRALT	RAClean, RALTClean	VertiAirspeedID	RALTSTATE	Starttime, duration, type: 'TG': time gap 'X': radio altitude <= 30 ft, RALT data not accurate 'SL1': level flight (abs(RALTClean) < 100 ft/min) 'SCn' where n: '2' to '24' for the following climb speed bands: 100-250, 250-500, 500-750, …., 5500-6000 'SDn'	none
RA	ProcessingRA	RAClean, RARateDTime, RARateDouble		RARASTATE	Starttime, duration, type: 'TG': time gap 'X': radio altitude > 30 ft, data not needed 'SL1': level flight (abs(RaRateDouble) < 100 ft/min) 'SCn' where n: '2' to '24' for the following climb speed bands: 100-250, 250-500, 500-750, …., 5500-6000 'SDn' wher	none
				VERTSTATE	Uses RALTSTATE and RARASTATE. Starttime, duration, type: identical to RALTSTATE code if ~= 'X', otherwise identical to RARASTATE code.	none
				VERTBSTATE	Equivalent to VERTSTATE but with different processing/filtering.	time gap merging, skip for duration <= 5

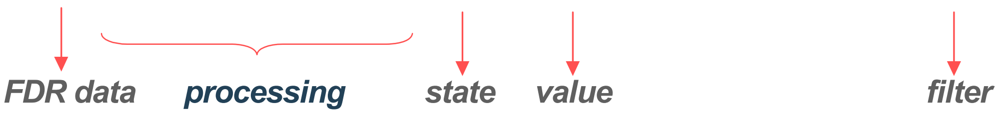


Figure 2: Example of data processing and state determination

1.2 Validation of FRR algorithms

The FRR algorithms were validated by comparing the flight regimes, as determined from the CVFDR data (Combined Voice and Flight Data Recorder), with those deduced from pilot cards for a number of sorties. The referenced pilot card flight regimes were obtained by assigning them manually to the available pilots' description of the flown manoeuvres, and by performing logical 'gap filling' based on engineering judgement (*e.g.* between level turns at high altitude and hovering at low altitude, there must have been a deceleration and descent manoeuvre).

Fig. 3 shows an example of such a flight regime validation for one sortie for the coarse flight regime classification into 6 classes. It is seen that the flight recognition tool performs adequately, since the blue dots from the CVFDR data almost completely coincide with the red crosses from the pilot cards events. Largest deviation for the coarse charts occurs for the flight regimes 'ascent' and 'descent'. This is understandable since during flight, by definition, the helicopter is constantly (unintentionally) moving in the vertical direction, which will be recorded by the FDR, but which will not be registered by the pilot.

The validation was also done for the fine classification, see Fig. 4, where the comparison showed that the special manoeuvres (*e.g.* straight and level with increasing speed, level turns, hover turns, rearward flight, landings, pick-up load and drop-off load, auto rotation) were all well-recognized.

The above validation should be considered as a successful first effort. Validation activities are currently ongoing to mature the procedures and to refine the results.

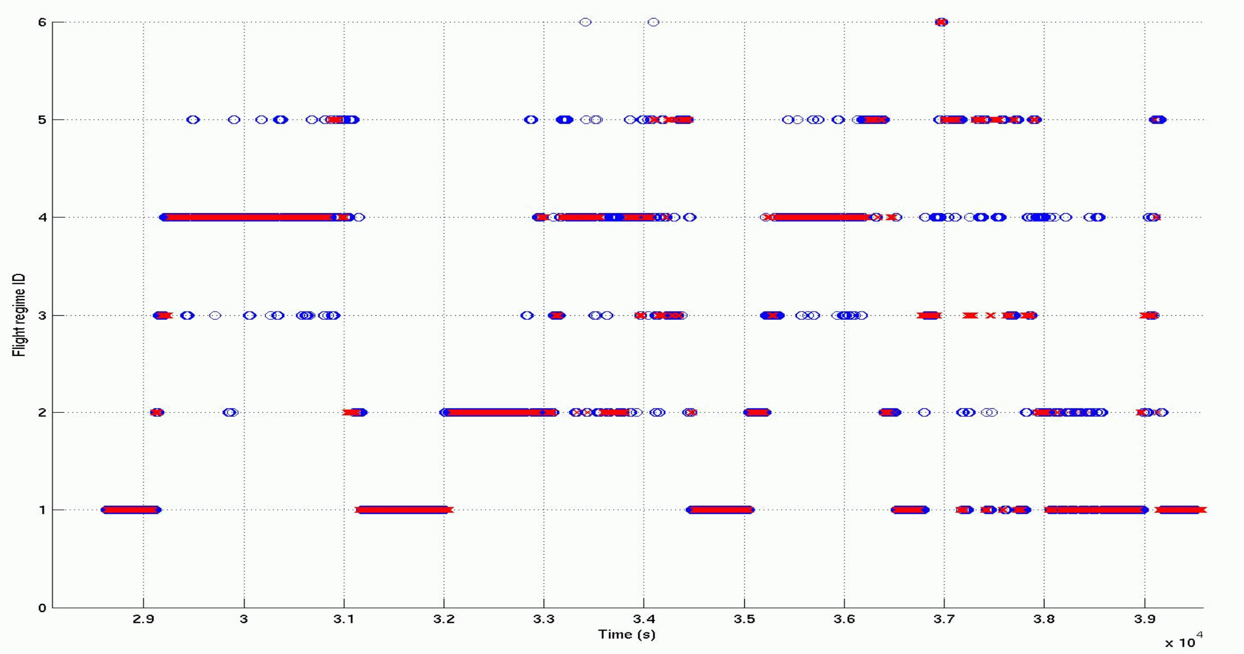


Figure 3: Example of FRR algorithm validation (coarse classification, legend: red dots = pilot cards, blue dots = FRR)

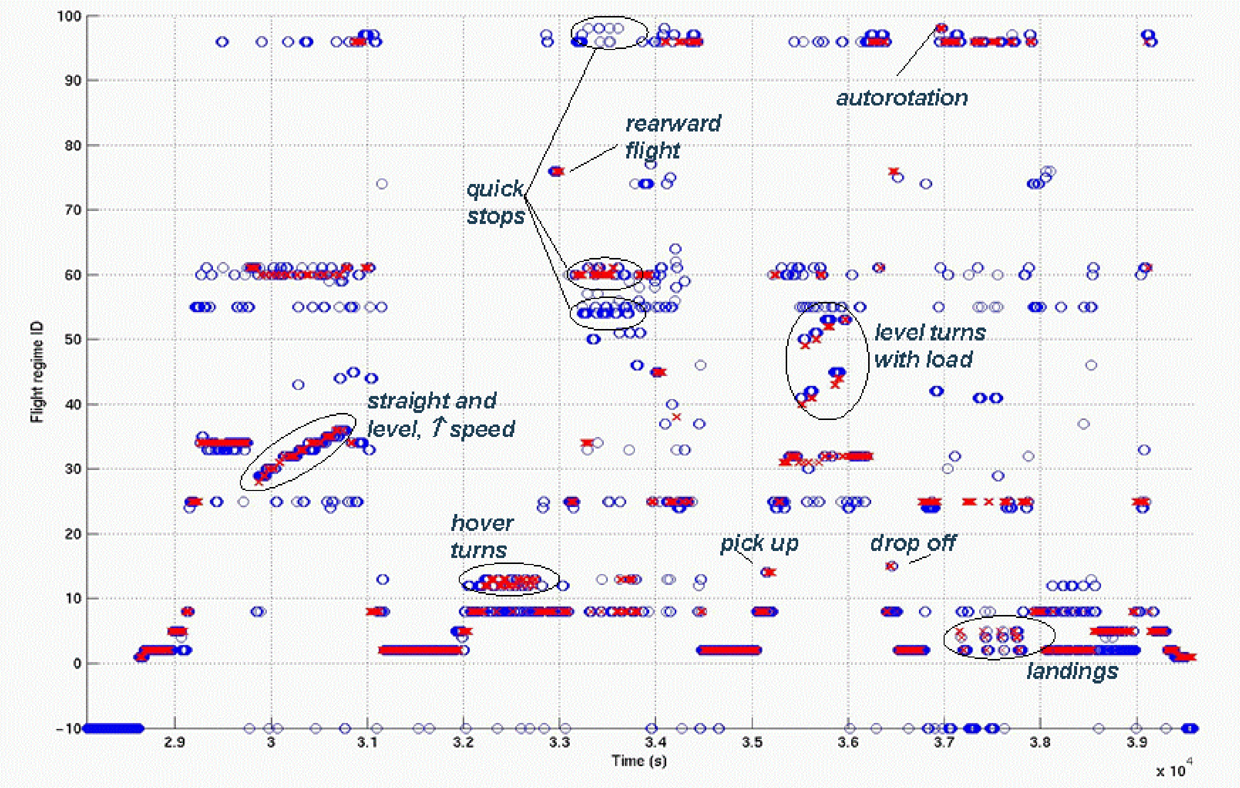


Figure 4: Example of FRR algorithm validation (fine classification, legend: red dots = pilot cards, blue dots = FRR)

2 RNLAF USAGE VERSUS DESIGN USAGE

During the pilot program, an operational Chinook measurement campaign of appr. 1,000 flight hours was performed under peace-time conditions, out of AFB Soesterberg in The Netherlands. Some major findings of this measurement campaign are (Ref. 4):

- within "hover", the percentage of "steady hovering" is much higher for RNLAF than assumed in the design spectrum; almost no hover turns are made in 1,000 hours of operational peacetime usage
- within the "level" flight regimes, Straight and Level (S&L) flying occurs less by RNLAF than assumed in the design spectrum
- manoeuvres occur almost a factor of two more often than assumed
- S&L flying occurs predominantly at 0.6 - 0.9 V_h, where the design spectrum assumed also much S&L flying at low speed (<0.3V_h)
- level turns (including yawing) and acceleration/deceleration occur more often in RNLAF peacetime usage than assumed in the design spectrum.

Differences in actual vs. design usage are also illustrated in Table 2, reproduced from Ref. 4:

Flight regime	RNLAF peacetime [%]	OEM design assumption [%]
Ground	**21.0**	**3.5**
Hover	**5.9**	**11.0**
Level Flight	**48.0**	**59.5**
Straight & Level	**26.8**	**47.5**
Manoeuvring	**21.1**	**12.0**

Table 2: RNLAF Chinook usage vs. Design usage (excerpt)

Weight, speed and altitude usage comparisons were made, also. Relative to the OEM design spectrum, RNLAF peacetime usage showed that:

- more flight time (FH) is spent in low weight (<33,000 lbs) regimes
- more flight time (FH) of RNLAF operations is at low altitudes <6,000 feet, where in the design a substantial percentage of flights is expected to be between 6,000 and 10,000 feet
- more flight time (FH) of RNLAF operations (40%) is with air speed < 45 knots, which matches with the design spectrum
- more flight time (FH) of RNLAF operations (37%) is with 100 kts < V < 140 kts, where a considerable amount of these flights hours was assumed to be above 140 kts.

3 CHINOOK DAMAGE INDEX

As a next step in the process to develop new useful fleet life management tools, it was decided to define (based on the newly acquired capability to determine flight regimes) a so-called Chinook Damage Index (CDI). Such a CDI could then be considered as a measure for the ‘global’ load transfer throughout the airframe (engines - gear boxes - drive train - rotor), and thus, possibly being a main indicator for degradation of the airframe and subsequent maintenance costs and efforts (leading to a decrease in availability). As primary load case to base this CDI on, the load case of *lateral bending of the fuselage* was chosen, see Fig. 5.
The fatigue damage calculation consists of a Rainflow counting procedure on measured operational loads (after conversion into stresses), followed by a basic Miner summation with standard material coefficients. Fig. 6 shows an example of the lateral bending output from a strain gauge located at the web of a Chinook LH longeron at frame station 331 (upper fuselage tunnel). As a result, Fig. 7 shows (imaginary) examples of calculated CDI damage values for different operational missions, relative to an arbitrary in-flight steady state situation (which is considered to have a severity of 1.00).

The relevant feature here is that the RNLAF determines a CDI value for each individual mission, which is subsequently stored in the usage database HELIUM (see Section 5).

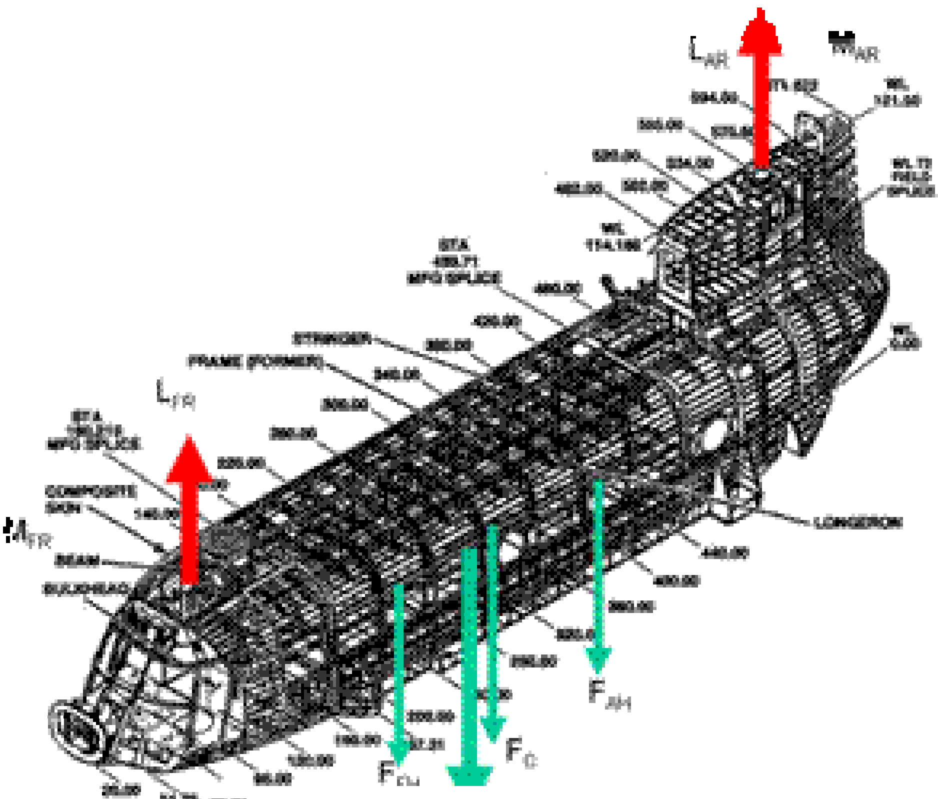


Figure 5: Lateral bending of the fuselage

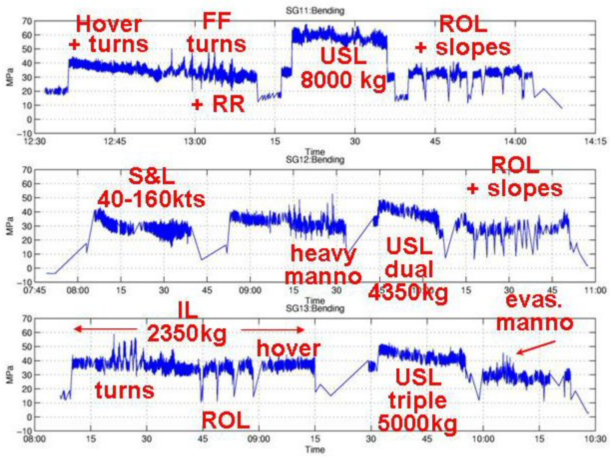


Figure 6: Lateral bending for various events

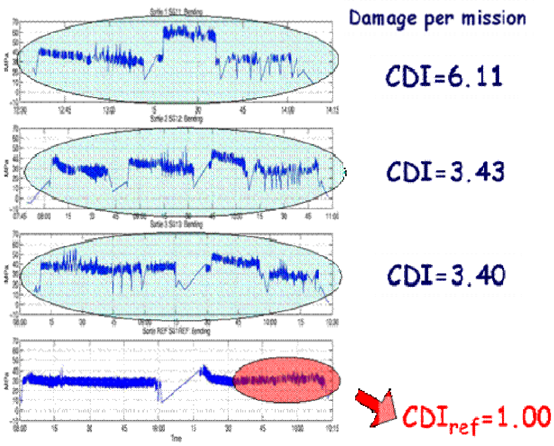


Figure 7: CDI damage per individual mission

The innovative aspect is that, from now on, each individual RNLAF Chinook mission is allocated with a certain CDI damage value from the lateral bending component. Later-on, through IT techniques, such as data-mining, knowledge discovery etc. (see below), it is envisaged to generate 'new' (not manually discoverable) information that can be used to e.g. extend fleet lives or to adapt inspection intervals of rotating and non-rotating components, to optimize maintenance engineering efforts and/or to improve maintenance and spare parts planning.

4 DAMAGE PROGNOSTICS TOOL 'PROUD'

Having acquired the (abovementioned) capability to calculate quantitative damage information per individual mission (or mission segment), this knowledge can subsequently be applied for prognostics purposes. For example, it becomes possible to predict the theoretical (projected) relative severity of out-of-area operations, assuming certain usage planning information is available (such as mission types, number of landings, helicopter take-off weight etc.).
To illustrate this meaningful prognostics capability, a prediction tool was developed - as a prototype, first - based on the FRR and damage calculation procedures. This damage prediction tool for the Chinook is identified by the acronym PROUD (PROjected Usage Damage tool). The following requirements for PROUD were defined:

- it shall be able to predict the relative usage (compared to common RNLAF usage) of a usage scenario, employing multiple missions
- it shall be able to handle global flight characteristics as input parameters
- it shall be easy to use, without the need for knowledge about underlying FRR algorithms and damage indices.

If, in practice, the PROUD exercise proves to be a meaningful tool in FLM procedures, a maturisation process will be effectuated to refine it, and to broaden it's applicability to the other RNLAF helicopter types Apache and NH-90.

4.1 Development of PROUD

The PROUD requirements specified a simple, Microsoft Excel-based tool, which can run on any standard Windows (ruggedized – for out-of-area use) laptop. The input is a set of global flight characteristics, like (per mission type) the mission duration, number of landings, T/O weight, external/internal load info (weight pick-up time and drop time) and, per deployment, the expected mission type distribution or mission mix (e.g. 60% cargo pick-up and 40% transportation of troops), plus total number of expected flight hours of the deployment considered. From these 'management type' of usage description parameters, the flight severity can now be determined from the damage key figures available in the database.

Although the detailed calculation procedure cannot be reproduced here, this predictive tool PROUD is based on the average damage values for the *coarse* flight regimes per weight class, and the usage spectrum, as determined from the 1,000 hour measurement campaign.

Fig. 8 shows the flow chart of the PROUD tool. Starting point is a planned scenario with a mission mix, discriminating between n mission types. For each mission type 1 to n, the planner gives some global flight characteristic data. Then, the program calculates the expected time spent in each different flight regime / weight class combination, based on the usage from Table 2. The weight class is determined from a few inputs: (1) the T/O weight, (2) the possible presence of an internal or external load and (3) the decrease in weight due to fuel consumption.

Next, the damage for that particular flight is calculated, similar to the procedure for a flight with CVFDR data available:

- by multiplying the number of landings with the average damage per landing, D_{GAG}

- by multiplying the time in each flight regime/weight class combination with the corresponding average damage, $D_{FR,wt}$.

This exercise is repeated for the other mission types and the total damage for a given scenario (D) is determined from the mission mix and the total number of flying hours (T), which are both input information items, given by the PROUD user.
Since the damage value is a nondescript number, the damage value is expressed relative to so-called 'reference RNLAF usage', *i.e.* the average damage from the 1,000 hours campaign data, D_D. Hence, the Chinook Damage Index is determined by:

$$CDI = \frac{D}{T \cdot D_D} \qquad (1)$$

The program output is the Equivalent Flight Hours with Reference Usage, T_{eq}, given by:

$$T_{eq} = T \cdot CDI\,. \qquad (2)$$

4.2 Example of PROUD calculation

After starting the PROUD tool, the opening screen is shown where for a certain scenario the expected total Chinook flying time (default 100 hours) and the number of different mission types (default is 1) have to be entered. For each mission type, an Excel sheet (screen) is automatically generated, allowing specification of the following fields:

- description of mission type
- flight duration (in minutes)
- number of landings
- takeoff weight (aircraft + fuel)
- load (external or internal), with for each load application:
    - weight (lbs)
    - pick-up point in time (no. of minutes after take-off)
    - drop-off point in time (no. of minutes after take-off).

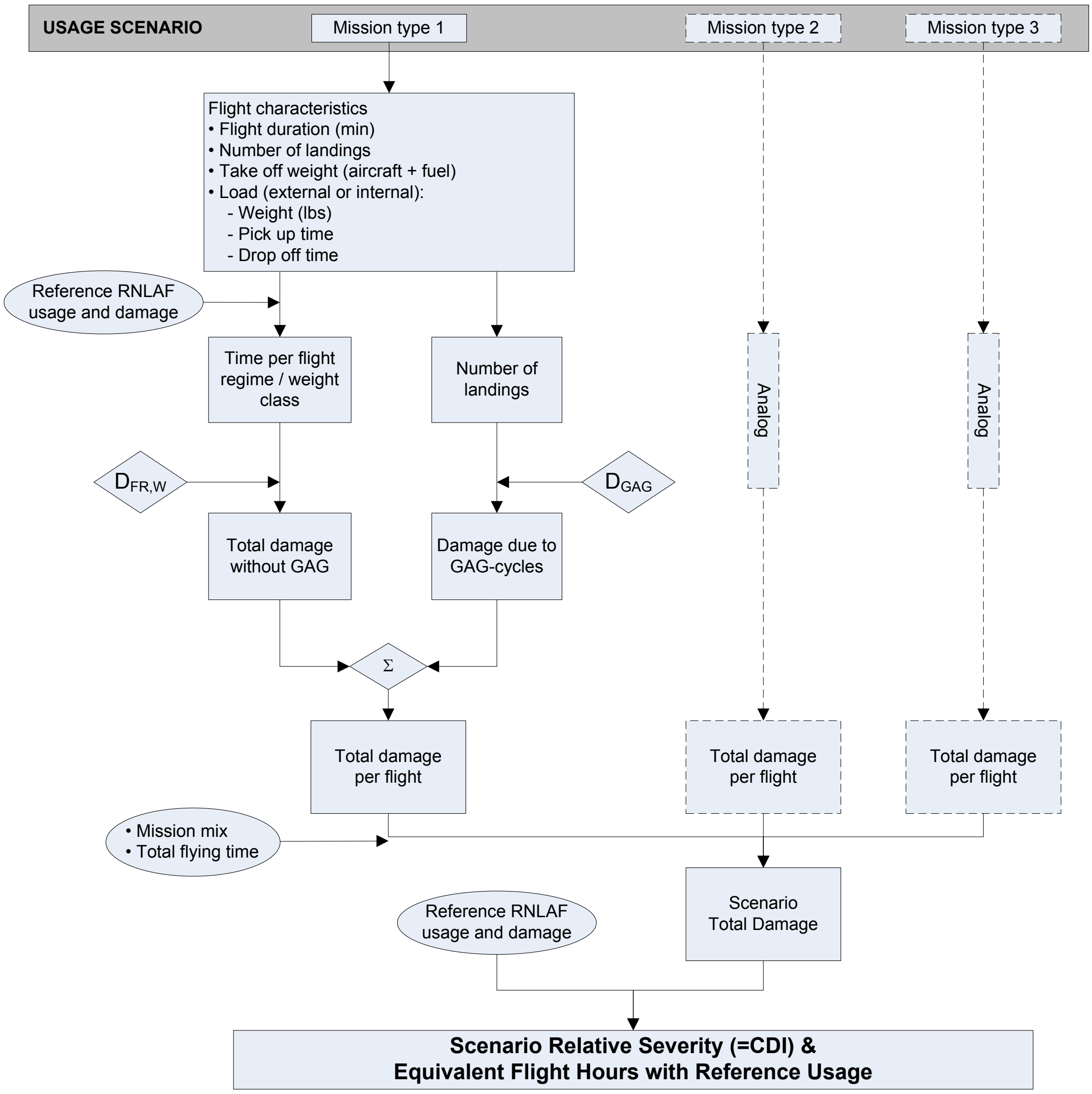


Figure 8: PROUD flow chart

The three last sub items can be entered for multiple cargo's during a flight, see the example below. After completing each sheet, the flight information will automatically be processed by clicking on the appropriate 'scenario evaluation' tab.

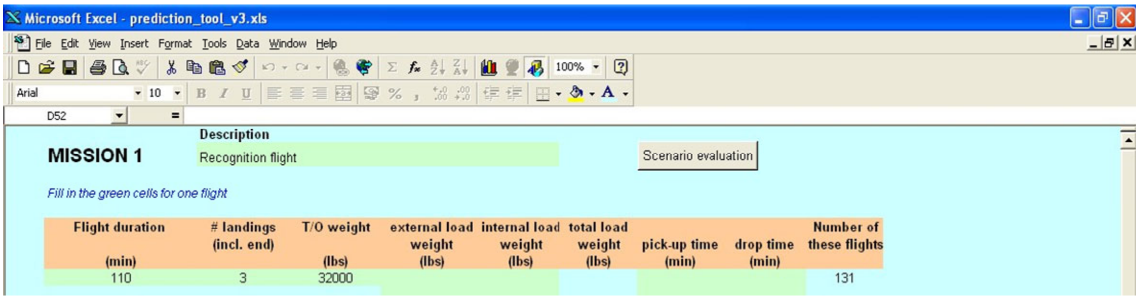
Suppose, the following imaginary Chinook usage scenario has to be analyzed, with an expected total flying time of 600 hours and consisting of the following three mission types (mission mix fraction between parentheses):

- Recognition (40%)
- Cargo Pick-Up (50%)
- Para Drop (10%).

Then, Figs. 9 a, b and c show the corresponding Excel sheets with flight profile characteristics for each of the above mission types. When all necessary information is provided, the results screen in Fig. 10 gives a bar chart with the relative severity of each mission type, separately, together with the complete scenario outcome. At the left top corner of the screen, the equivalent flight hours with ‘reference usage’ is given, according to equation 2 (above).

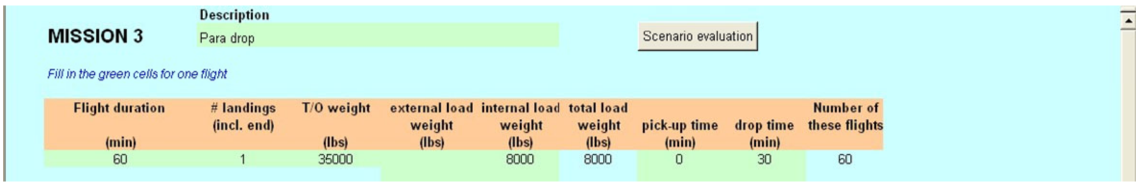
In Fig. 10 the example shows that mission type "Recognition" is less severe (82%) than Reference Usage (by definition at 100%) and that the mission types "Cargo Pick-Up" and

"Para Drop" are more severe (125% and 171%, respectively). The high severity of the latter is because half of the flight is in the highest weight class (35,000 + 8,000 = 43,000 > 40,000 lbs). Overall result: the total projected scenario is 12% more severe than standard Dutch peacetime (reference) usage. In other words, employing reference usage a total of 675 hours (compared to 600 hrs of the mission mix usage) could have been flown to accumulate the same amount of fatigue damage in the Chinook fuselage.



a)

b)



c)

Figure 9: PROUD calculation with 3 fictitious mission types

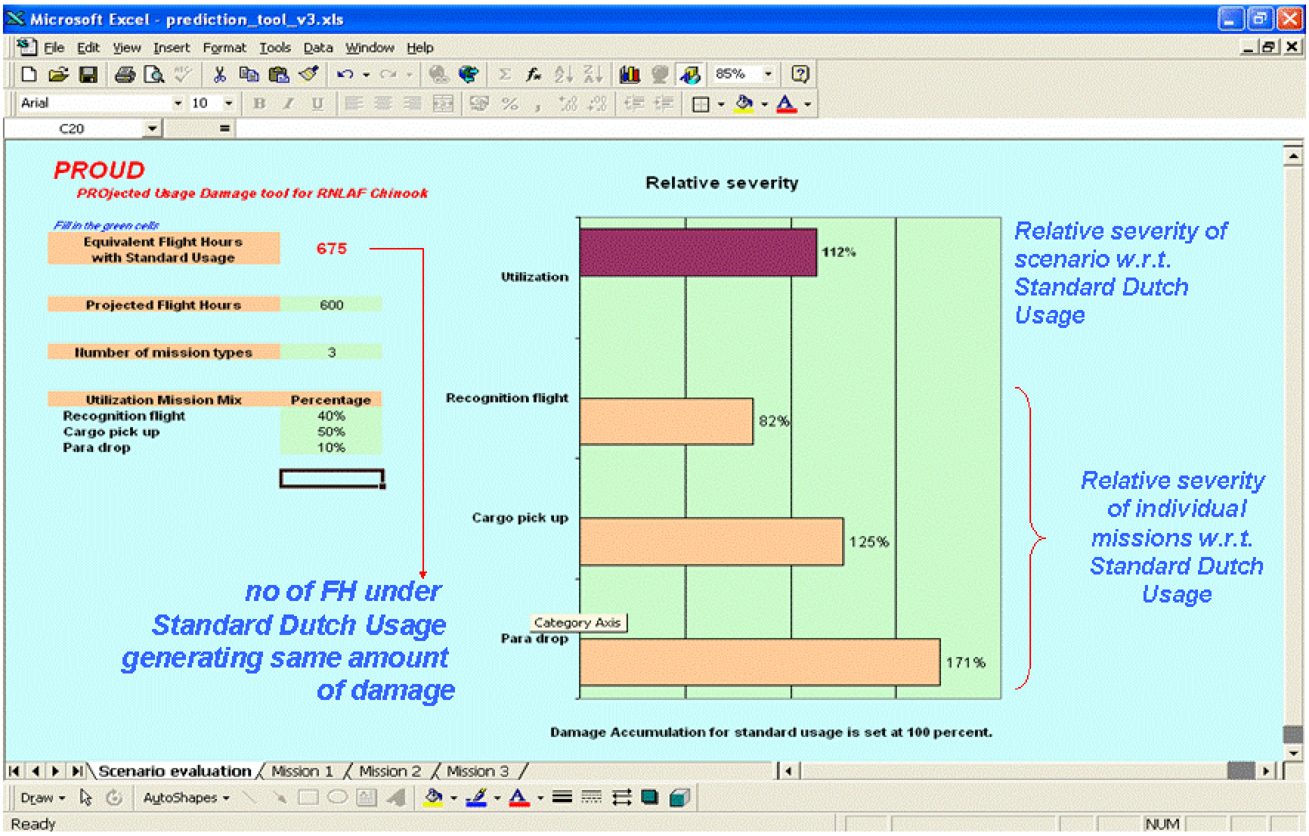


Figure 10: PROUD Scenario Sheet with results

PROUD is one of the potentially new and innovative fleet life management tools, that may be adopted by the RNLAF for Chinook management purposes, in the future.

5 INTEGRAL HELICOPTER DATABASE HELIUM

In 2005, a major decision by the RNLAF was to have an integral RNLAF helicopter database developed and implemented (Ref. 5). By the end of 2007, a prototype solution existed, capable of storing, processing and ad-hoc analyzing of all sorts of RNLAF generated helicopter data, regardless of origin, quality, character, size or format of that data. Subsequently, until end 2009 activities within the HELIUM development team will be aimed at growing, maturing and stabilizing the initial prototype of the RNLAF HELIUM helicopter database.

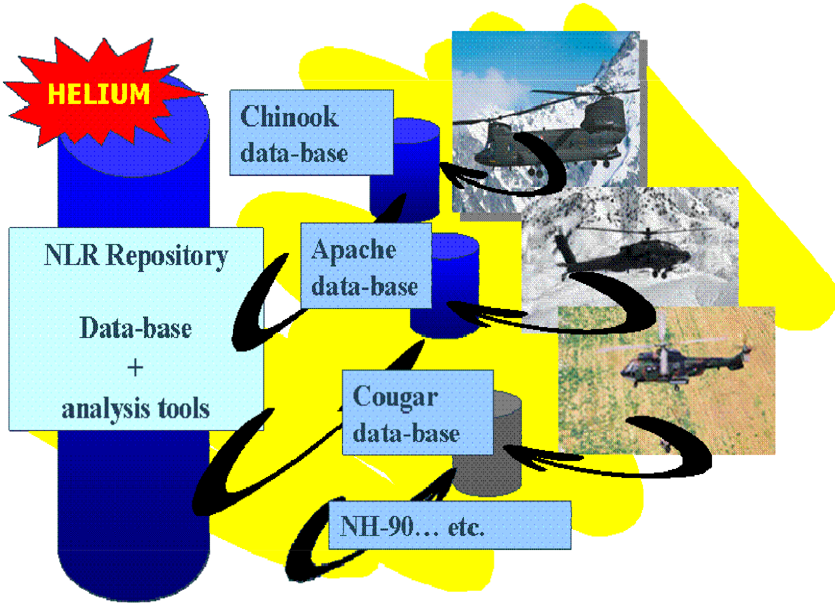


Figure 11: Integral RNLAF HELIUM helicopter database

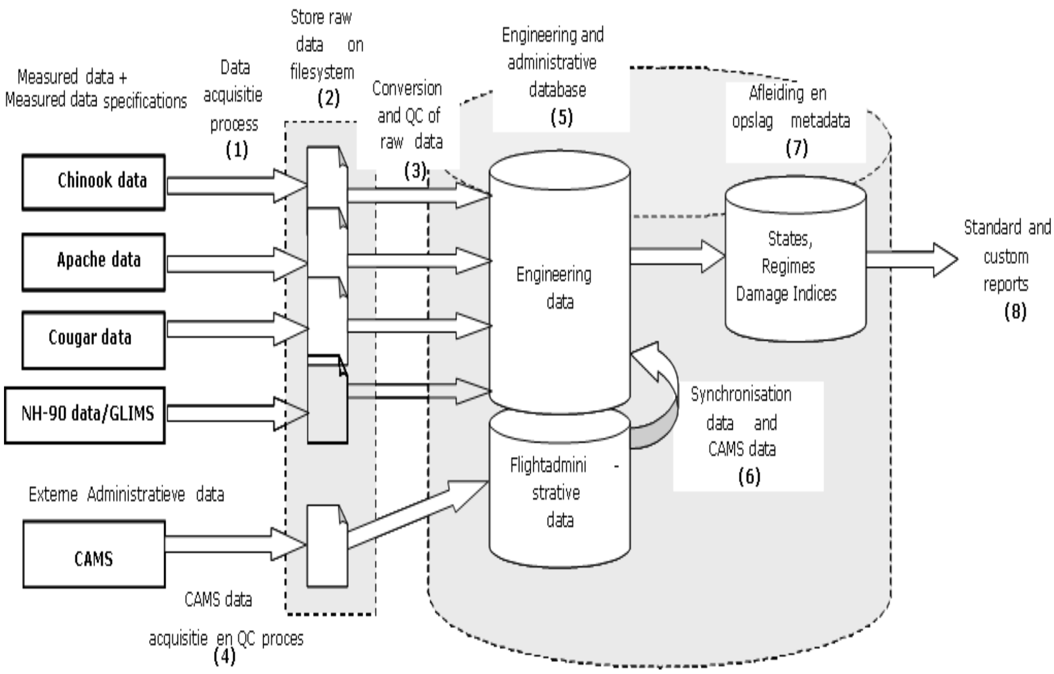


Figure 12: The HELIUM database structure

HELIUM is basically a state-of-the-art container (in the format of an XML database) of administrative data, logistics data, loads and usage data etc. for all RNLAF helicopter types, with limited reporting capabilities. Data from the following RNLAF helicopter data sources can - at the least - be handled:

- Chinook: CAMS, GenHUMS, CVFDR, Acra-box, Spectrapot-4, Crack and Corrosion LogbookApache: CAMS. Safety and Maintenance Download, MSPU (to be installed by end 2008)
- Cougar: CAMS, EuroHUMS
- NH-90: MDS, GLIMS, separate data acquisition system (if applicable).

Fig. 11 depicts the basic idea of HELIUM, being a container of all sorts of RNLAF generated helicopter data. Fig. 12 lists the various data processing steps recognized within HELIUM.

6 RAVIOLI

With HELIUM being the helicopter data 'container', the operator will still have a need for a graphical user interface (GUI) and infrastructure, enabling the various users to work with the fleet life management concepts that are implemented. To meet this reporting or 'output' requirement, a new NL MinDef funded research task has been defined for the years 2008-2010, called RAVIOLI (Reporting, Analysis, VIsualisation Of aircraft Lifecycle Information). The planned RAVIOLI solution can best be described as: "an 'IT-environment' for the military operator with an innovative, fully integrated toolbox for the analysis of usage, loads and maintenance data in a web-based application of acquisition, processing, storage, visualization and reporting of data".

RAVIOLI provides a standard set of components for performing fleet management, individual flight analysis and prognostics (future or projected usage damage calculation) and allows easy extension with new functionalities. The components that are provided are detailed in the following paragraphs:

- *Mission Profile Generator* (MPG) with which the user can construct a mission profile in a simple, interactive and graphical way. The mission profile consists, for instance, of an altitude-time profile, combined with weight, fuel consumption and speed. Using these inputs, the corresponding damage can be calculated. A prognostics capability exists, also. Planned operations (mission types, durations, mission mix scenarios) can be processed in order to determine their expected severity (fatigue damage accumulation). This information can then be used to e.g. determine which tailnumbers are best candidates for an upcoming deployment or what logistic footprint may be expected (spares).
- the *Mission Profile Analyser* (MPA) is a companion tool of the MPG. The MPA is capable of generating a prototype mission profile, based on data retrieved from a flight data recorder. In the MPG, such a profile can later be optimized and used for associated damage calculation.
- *Fleet Life Planning* (FLiP) is a set of procedures and a GUI (Graphical User Interface) with which the operator can create scenarios for enhanced operational availability and improved maintenance effectiveness. The fleet life planning GUI will also provide easy access to the individual flight analysis tools, like the flight recreation module (FRM, see below). The fleet life planning feature will combine the following set of components and technologies in an intuitive and effective graphical user interface:
  - Mission Profile Generator (MPG)
  - Mission Profile Analyser (MPA)
  - Online Analytical Analysis (OLAP)
  - Projected Usage Damage (PROUD)
  - Damage Indices (eg. CDI).
- *PROUD* will also be part of RAVIOLI, a detailed description is given in Section 4, above.
- The *Flight Recreation Module* (FRM) is an advanced replay tool for replaying an existing flight. The FRM is capable of using data from the flight data recorder (FDR) to show maneuvers, positions, directions, flap deflections etc. in a 3D environment. Interfaces are provided for viewing the instruments, 2D graphs and events (generated by the aircraft as

well as custom defined events). The replay tool is easily configurable to view flight data from several weapon systems, such as Chinook, Apache, C-130 and F-16. In future, RAVIOLI will be extended with a flight recreation functionality of F-35 and NH-90.

- *Flight Regime Recognition* (FRR), as discussed in Section 1, will be generalized and the generic implementation will be made available for the implementation of flight regime recognition of, for instance, the Apache and the NH-90. The regimes extracted using the FRR will be made available to the fleet life planning component, allowing a generic approach to using flight regimes for all aircraft.
- In RAVIOLI, *Knowledge Discovery* (KD) will play an important role. Applying knowledge discovery to available measurements, hidden and not yet known relations and features can be extracted and analyzed. This should provide new insights into the usage of the aircrafts which then should result in better management of the fleet.

While HELIUM only addresses helicopters, RAVIOLI is more generic in providing functionality for all weapon systems in the RNLAF. Its infrastructure is a secure, web-based environment in which users with different roles (e.g. weapon system managers, maintenance engineers, flight planners, aircrew, trainers) can access the appropriate toolset and data. The infrastructure provides (1) authorization (who may access what tool and data), (2) authentication (username and password), (3) logging (who did what when) and (4) a common gateway to all tools and data for all weapon systems.

As illustrated in Fig. 13, the various military users (fleet owner, weapon system manager, maintainer, flight crew, trainer, maintenance engineer etc.) will use RAVIOLI to interrogate the database with queries through an intuitive *Graphical User Interface* and a *Reporting Facility*.

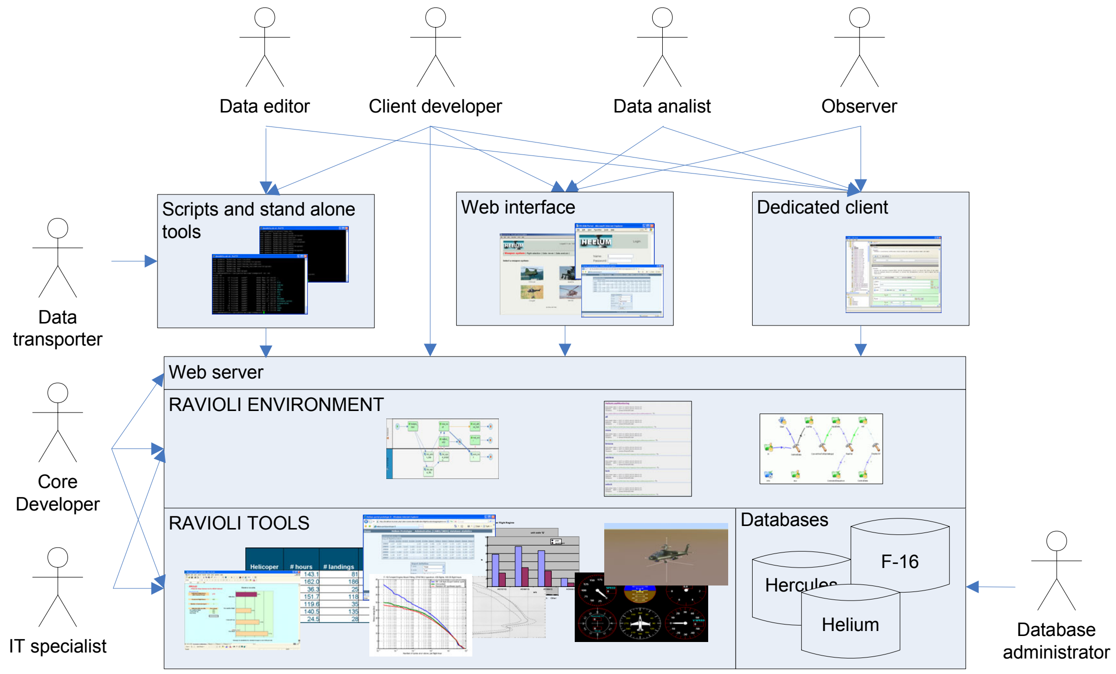


Figure 13: Schematic impression of the RAVIOLI toolbox

7 APACHE CONCEPT DEVELOPMENT

The RNLAF plans a fleet wide installation of company IAC's (now: Honeywell) MSPU (Modern Signal Processing Unit) system in their fleet of Apache helicopters. This will provide DMO/NLR with an excellent opportunity to develop and implement state-of-the-art procedures for optimum Apache fleet life management, similar to those that were developed for the RNLAF fleet of Chinook helicopters.

However, the MSPU system "as is" has not been adapted, modified or prepared to incorporate most of the earlier mentioned NLR developed FLM concepts. It will be the task of DMO/NLR to list the various options and to try to incorporate these features as much as possible in the fielded product.

8 CLOSING REMARKS

The present paper tries to illustrate the ambition of NL-DMO (RNLAF) to be a 'smart' operator, heavily investing in structural integrity issues. The underlying goal is to optimize Integral Weapon System Management of the - by now - relatively large, diverse and heavily used helicopter fleets, often in support of UN peacekeeping forces worldwide.

This paper is of descriptive nature and introduces the various ongoing NL-DMO funded helicopter research activities. NL-DMO strives for international co-operation and a continuous information exchange, and intends to continue sharing research results.

Last, but not least, the authors wish to thank representatives of the following military organizations for their discussions that helped developing the views presented herein: USArmy/AED, Boeing Philadelphia, USNavy/NAVAIR and MoD-UK/ASI Group.

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