Fleet Life Management support for the NH90 community

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Abstract

This document contains a paper describing background, rationale, objective, technical content and growth potential of a multi-nation shared helicopter usage database and service available for the NH90 community.

This so-called NH90 Supportability Data Exchange (SDE) system currently provides 9 participating nations with a common shared NH90 usage database and analysis toolbox with automated web based user data input. Main functionalities are automated storage, dedicated analysis and standard reporting for occurrences, reliability calculations and structural integrity evaluations. The SDE service is supplemented with a website, a moderated forum and a yearly NH90 SDE users conference to discuss results, to exchange views and to plan future developments associated with optimized NH90 fleet ownership.

Introduction

One of the new military helicopter types currently entering service is the NH90, a 10 ton class medium-sized multi-role twin-engine helicopter of innovative design. The main innovations concern an all-composite crashworthy fuselage with low radar signature, advanced fly-by-wire controls, helmet mounted sight and display, an autonomous on-board monitoring and diagnostic system. All these components and systems are built employing a high level of system integration and modularity.

The NH90 design may be considered quite successful with a firm order book showing, to date, more than 500 helicopters for 14 Nations, with some 300 intended orders in the pipeline. To serve the numerous customers' requirements NHI, the manufacturer of the NH90, has developed - or is currently developing - more than 20 different NH90 variants, which may be considered a quite complex development, production, engineering and operational challenge.

The NH90 comes in two basic variants:

- a Tactical Transport Helicopter (TTH) version intended for transport of personnel (up to 20 fully equipped troops) and material (up to 4,000 kg of cargo, internal or external, including rescue hoist) and for Search and Rescue (SAR) missions over land and sea

- a Naval Frigate Helicopter (NFH) version primarily conceived for autonomous Anti-Submarine Warfare (ASW) and Anti Surface Warfare (ASuW) missions, incl. applications for Anti-Air Warfare support, Vertical Replenishment, SAR and troop transport with various derivatives from these basic versions, i.e.:

- a Marinised TTH (MTTH) with foldable main rotor blades and a ruggedized landing gear allowing ship operations

- a Tactical NFH (TNFH) for transport duties from ships, e.g. a "land scoped" version of the NFH, without some of the operational NFH role equipment components

- a Tactical Troop Transport & International Mission (TTT/IM) version, primarily intended for humanitarian relief and peace-keeping missions offering 24 additional centimeters of cabin height to provide a more flexible operational environment.

Any new weapon system forces its owner (here: military helicopter operator) to assess whether improved asset management procedures will be necessary to meet current life cycle costing requirements and objectives. With this in mind the new NH90 helicopter operator community, through NAHEMA, generated a requirement to provide NH90 operators with a service for a centralized multi-nation NH90 Supportability Data Exchange (SDE) system.
This NH90 SDE system should operate in a secure environment, enabling automated data input, web based access, storage, analysis and reporting of relevant data. The character of this data will be widespread consisting of e.g. occurrences, incidents, maintenance data, reliability figures, operational usage statistics and structural integrity assessments. The SDE system also comprises a website, a web based forum and a yearly users conference to communicate results, to exchange views and to harmonize future developments.

Considering helicopter weight as an important design feature, as a rule of thumb the in-service empty weight of a military helicopter grows by approximately 0.5% per year (equivalent to approximately 50 kg for the NH90) because of design improvements, operational capability upgrades and new sensors [1]. If it is realized that the NH90 is designed for 10,000 flight hours or 30 years, a projected weight increase of more than thousand kg's may be expected during its intended operational service life. As a consequence, meeting some of the NH90 Integrated logistics support (ILS) design requirements over time may be quite challenging. These requirements address various metrics such as Mission Reliability (e.g. > 97.5%), Mean Time Between Failure (e.g. MTBF > 4 hours) or Maintenance Man Hours Per Flying Hour (e.g. MMH/FH = 2.5). With the SDE system, the users will be enabled to calculate these metrics themselves and to share and compare them within the NH90 community. This will greatly enhance the helicopter operators insight into the severity of certain operational deployments and the efficiency of maintenance tasks.

This document describes backgrounds and most relevant features of the now-existing NH90 Supportability Data Exchange system, up and running at NLR in the Netherlands and currently providing 9 participating nations with an affordable, powerful, flexible and state-of-the-art NH90 asset management tool.

Optimizing Life Cycle Costs

The goal of Life-Cycle Costing is to minimize costs throughout the life span of an asset, here: the NH90 helicopter fleet. To achieve this goal, the operator must gain insight into cost drivers and has to answer a variety of questions, such as:

- what is the relation between operational usage and degradation of the fleet?
- what are the maintenance costs during the life span of the fleet?
- what is the life of a given component?
- what are lead times for spares and replacements?

Roughly, the costs distribution within a typical military aircraft program such as the NH90 is:

- 60%: Support (ILS, Direct Maintenance Costs etc.)
- 30%: Acquisition
- 10%: Operation [1].

In all three of these areas, a significant detrimental or advantageous effect on life cycle costing can be observed. For example, in the acquisition process, a non-optimized or non-mature design may lead to increased mechanical loads, enhanced degradation, short inspection intervals and low MTBF values. Operational costs (e.g. engine fuel consumption) may be higher than desired due to built-in design features. And most profoundly, direct maintenance costs always heavily depend on the operational usage environment the helicopter has to endure. Direct maintenance costs are costs due to modifications, scheduled/preventive and unscheduled/corrective maintenance actions (inspections, repairs and replacements etc.) and can be design driven (e.g. failure rate/MTBF, time between overhauls, maintenance schedule) or ILS process driven (e.g. spares stock allocation, transport times, repair TAT's, purchase lead times, spares prices and repair prices).

Realizing that typical flight hour costs for a complex helicopter such as the NH90 can be as high as €5,000, it can be concluded that for a fleet of, say, 20 helicopters a 5% flight hour costs improvement (by any means) can save the operator up to 1M€ per year, assuming an average helicopter flight hour rate of 200 FH/yr. From this it is clear that lowering support costs in MRO, logistics, spares, training etc. is crucial to achieve potential savings.
It also is important to note that these support costs directly depend on the helicopter operational usage environment which - in turn - is determined by a variety of different external factors: operational mission requirements, the technical ambition and political arena of a particular nation and environmental and geographical circumstances (high/low altitude, cold/hot temperature, corrosive-salt, erosive-sand etc.).

Optimal management of physical assets (here: NH90 fleets of the multi Nation NH90 community) needs to span the entire life cycle process, recognizing design, manufacturing, commissioning, operating, maintaining, repairing, modifying, replacing and - finally - decommissioning of the asset at the end of the operational service life. To optimize total life cycle costs, the fleet owner or asset manager should assess all these elements, as was also mentioned in a NL MinDef Fleet Life Management (FLM) survey [2].

Although the NH90 design comes with state-of-the-art asset management tools delivered by the OEM, such as the advanced Maintenance Diagnostic System (MDS) and associated Ground Logistics Information Management System (GLIMS), the above life cycle costing considerations generated enough motivation for the NH90 user community to think of meaningful (extra) operator oriented ways to support and optimize future NH90 fleet life management, i.e. to maximize operational availability of the NH90 at the lowest possible costs and effort, while maintaining flight safety at a desired level.

Supportability Data Exchange

Based on the above, the new NH90 community realized a need for a thorough understanding of the complex future operational NH90 environment and associated wear and degradation of the helicopter as a whole. Important factors demanding this are:

- the immaturity of the new design of the helicopter and it's many (sub)systems
- the high level of (sub)system integration
- the application of new materials (the all-composite fuselage)
- the expected weight growth issue.

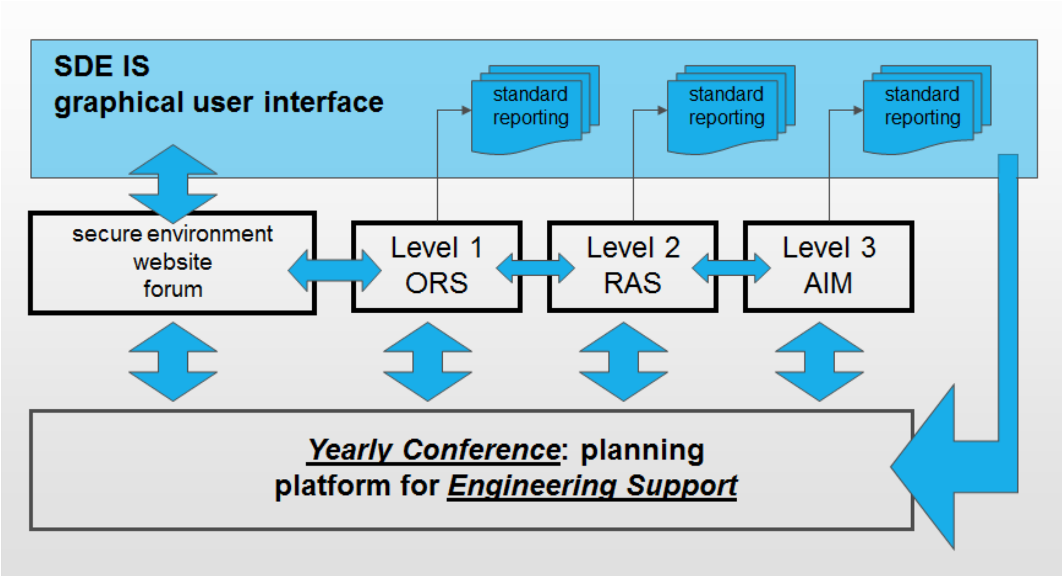
Responsibility for this should not be transferred solely to Industry, but the operators themselves should also invest in an own operator-oriented and optimized loads & usage assessment process. For this purpose, the NH90 customer NAHEMA produced a requirement for the development and implementation of a so-called *NH90 Community's Supportability Data Exchange (SDE) Information System*, shortly "NH90 SDE system" [3]. A working group with 9 participating NH90 nations generated the Statement of Work for the SDE system and the NAHEMA contract for its development and implementation was issued to NLR in the Netherlands in July 2011. Over the past 1.5 years, this operator oriented fleet life management support tool has been developed and has come to full operational deployment, just recently, in February 2013.

The NH90 SDE system provides the NH90 community with a service for a centralized multi-nation shared service to jointly exploit NH90 supportability data to support airworthiness, configuration management and integrated logistic support activities and to assess helicopter design, production and operational in-service issues. The service operates within a secure environment at NLR in the Netherlands, enabling integrated input, web based access, storage, analysis and sharing of relevant NH90 helicopter data such as occurrences, incidents, reliability analyses, operational usage, structural integrity assessments etc.

The NH90 SDE system covers three basic information sharing functionalities:

1. an *Occurrence Reporting System* (called: SDE Level 1 ORS) to store and share technical occurrences or anomalies (events, incidents, issues, failures) for which no standard maintenance actions are defined. This occurrence reporting system provides a capability to store, analyze, report and share NH90 SDE occurrence data in a flexible, secure environment, allowing adequate communication of occurrence reports between military headquarters, operational fields and maintenance facilities. Each participating nation has the task to provide occurrence data for the SDE Level 1 ORS module and the SDE system has been designed to minimize manual input. Therefore, a B2B interface and corresponding Interface Control Document (ICD) is available to allow for automated occurrence data input. A Library function and a Search function are included allowing

storage of files in various formats, such as JPEG, PNG, TIFF, Adobe PDF, Microsoft Word or Open Document Text ODT documents. Finally, a Notification module is available informing users of newly added or changed occurrences. Specific to this Level 1 functionality is the graphical user interface for the end users to work with the SDE system.



Interrelation of the various NH90 SDE system components

2. a *Reliability Assessment System* (called: SDE Level 2 RAS) providing the NH90 operator with the capability to determine experienced failure rates (MTBF's) of different helicopter components based on parts and equipment failures and maintenance task information. The SDE system contains provisions to extend reliability calculations towards *Availability* and *Maintainability* calculations, in the future. Each SDE participating nation is tasked to provide input data for the SDE Level 2 RAS module. Similar to the Level 1 ORS functionality, the B2B interface is available to allow for automated level 2 type data input. Level 2 RAS generates standard reports presenting MTBF calculations in various ways: over the past 12 months and trending (e.g. trend breaks) considering 5 past periods of 12 months. These reports are generated quarterly and are available through the SDE system's dash board.

3. an *Aircraft Integrity Management* module (called: SDE Level 3 AIM) offering a threefold (see below) state-of-the-art structural integrity and fleet life management tool with a standard reporting facility. Input data for SDE Level 3 AIM can be from different sources, e.g. MDS-GLIMS, Flight Data Recorder or a nation specific non-integrated retro-fit multi-channel data acquisition unit for strain gauge measurements, fed by data from the helicopter digital data buses. SDE Level 3 AIM provides the operator with a set of (either proven or new and experimental) tools with a standard reporting facility addressing operational usage, experienced loads, accumulated damage and lifing aspects of helicopter components, for example:
    a. to quantify the operational service usage spectrum and to compare this with design assumptions from Industry
    b. to monitor and derive fatigue life consumption figures for various components
    c. to determine the relation between airframe degradation (cracks, delaminations, corrosion etc.) and operational usage elements (relatively severe high speed regime, hard landing, heavy weight, underslung loads etc.)
    d. to break down missions into separate and subsequent flight events or regimes

e. to construct new, imaginary missions, to estimate future usage (prognostics capability).

SDE Level 3 AIM reporting consists of the following three features:

- Summary of *Usage Statistics* (per nation, per deployment, per tail number, per mission and per mission type) showing
  - altitude, airspeed, weight distributions
  - mission administration (c.g. position, no. of persons on board, geographical location, mission type, role equipment etc.)
  - discretes (no. of FH, no. and type of landings, no. of blade/tail foldings etc.).

- Indication of *Usage Severity*, with severity indices (per nation, per deployment, per tail number, per mission and per mission type) for
  - airspeed regime
  - bank angle regime
  - hook load regime.

- *Structural Integrity* analyses tools, comprising
  - Flight Regime Recognition FRR (separate from and additional to equivalent OEM procedures for Flight Condition Recognition FCR)
  - determination of damage indices per component per flight regime
  - damage prognostics for future NH90 mission scenario's
  - studies of composites behavior, hinges, etc.
  - etc.

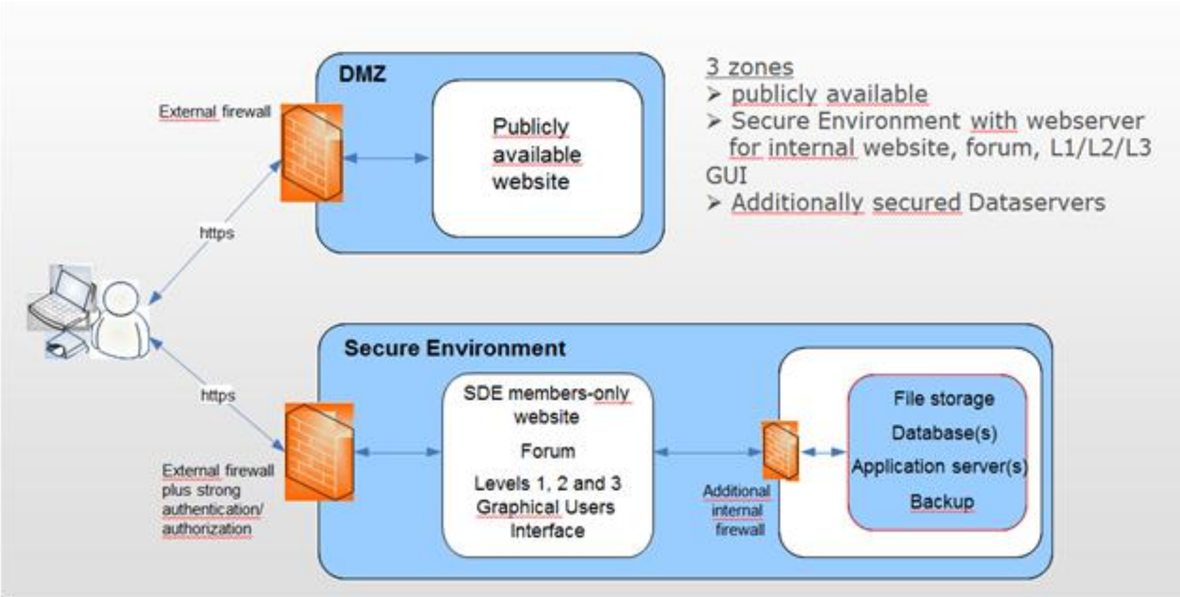
The above list of SDE Level 3 AIM structural integrity tools is 'open-ended' in the sense that each participating nation can provide its own tools - at any given point in time - to be incorporated in the NH90 SDE system architecture.

The SDE system as a whole also provides the users with extra features, such as a:

- *Website*: the publicly accessible SDE website (https://sde.nlr.nl) is intended as an access door for sharing information among the participating nations on news and relevant topics, announcements, agendas, etc. and to serve as an entry point for forum access and SDE data processing functionalities, as described above

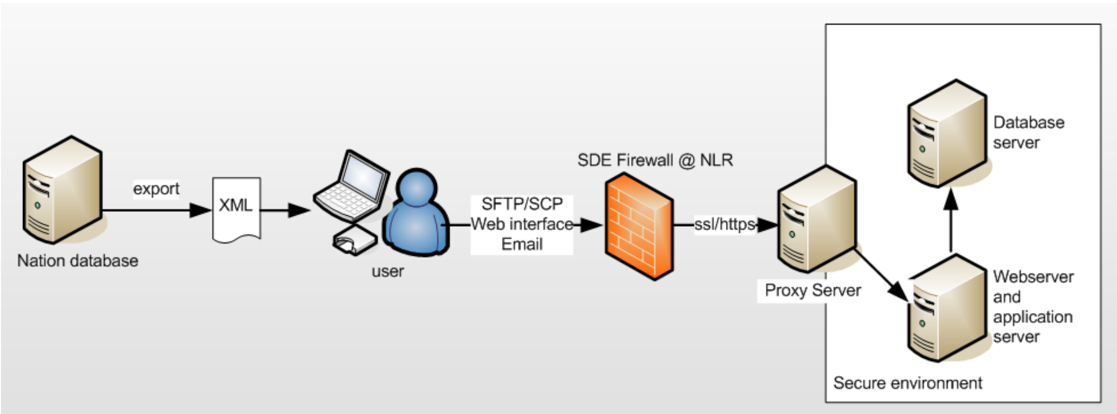
- *Forum*: the forum is the platform for exchanging technical information between NH90 operators to address in-service issues, maintenance issues, and for discussing technical findings and problems that come up from any operator

➢ *Users Conference*: the users conference allows the end users to meet in person and provides the community with a platform for evaluating, sharing and comparing analysis results, findings on operational usage, system reliability and airframe degradation, to direct engineering support recommendations and - last but not least - to allow a harmonized discussion between NH90 operators and Industry.



The NLR Secure Environment for the NH90 SDE system

The SDE system is implemented in a secure environment allowing dedicated access through various user profiles with automated data input through a Business-to-Business (B2B) interface.



Schematization of the SDE B2B interface

NH90 SDE system objectives and potential

SDE Level 1 Occurrence Reporting

It will be clear that a web based shared service for storing, analyzing and reporting occurrences (covering the findings of hundreds of NH90's operated by 9 different nations) provides a powerful tool to the operator community to derive optimal life cycle management procedures. Although each individual nation will have its own national logistics data base system in place, that particular nation will not be capable to look beyond its own horizon. The objective here is that by constructing an overall multi-nation occurrences data base it becomes possible for the community to see "the larger picture", to decide whether a specific occurrence has an isolated character or if a root cause for a failure can be detected and understood by analyzing as much as possible occurrences of the phenomenon. Moreover, by sharing data from the overall occurrence data base with Industry, the NH90 community will also benefit from a far more focused support by Industry.

The NH90 SDE Level 1 Occurrence Reporting dashboard

SDE Level 2 Reliability Assessment

The same applies to the SDE Level 2 Reliability Assessment functionality. By putting together available data from multi nations concerning component/equipment failures and maintenance tasks, the data pool size to derive MTBF figures will increase dramatically generating more accurate results.

The SDE Level 2 Reliability Assessment dashboard (Administrator profile)

The following types of data are used:

- event data: information about events that resulted in the removal of a part
- maintenance data: information about maintenance actions, performed to remove and fix the parts, if applicable
- component life: information about the life consumed by a component.

This leads to the calculation of the following reliability metrics:

- MTBF: Mean Time Between Failure
- MTBUR: Mean Time Between Unscheduled Removal
- MTBR: Mean Time Between Removal
- MTTF: Mean Time To Failure.

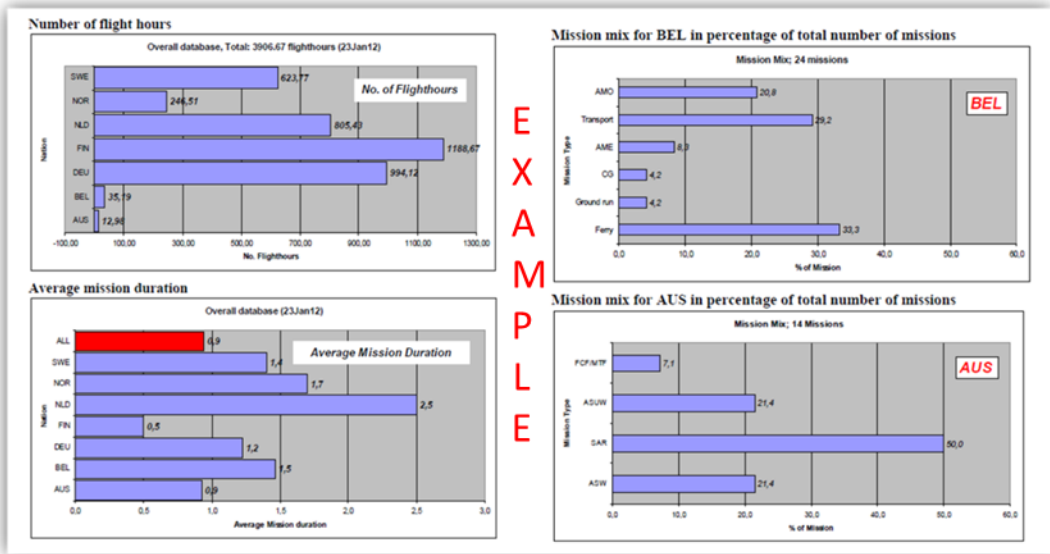
The benefit of a larger data pool to achieve more reliable and more accurate analysis results is rather obvious for SDE Levels 1 and 2 ("more shared data = more knowledge"). Because SDE Level 3 has more dimensions than Levels 1 and 2 (it considers SDE Level 1 and 2 data plus usage-, loads-, maintenance and lifing data), it is within the SDE Level 3 AIM functionality where the sharing of multi-nation information is expected to have the largest potential to be beneficial and may lead to the development and NH90 SDE community wide implementation of powerful and innovative techniques. This will be explained in greater detail in section 4.3 below.

SDE Level 3 Aircraft Integrity

As said earlier, the SDE Level 3 AIM functionality offers the operator a multi-module NH90 fleet life management tool with a standard reporting facility on usage statistics, on usage severity and on structural integrity topics.

Usage statistics reports will have the format of e.g.:

- flight hour distribution per nation
- mission utilization per tail number
- number and type of landings per deployment
- average mission duration per nation, as shown in the artificial example in the example figure, below.



Example of NH90 SDE Level 3 AIM Usage Statistics reporting

For structural integrity management purposes, such usage statistics overview data is informative but not very technically relevant for e.g. lifing purposes. This is because differences in usage statistics do not automatically reveal root causes for detrimental effects. Therefore, it will be more informative to weigh the severity of a certain helicopter usage scenario, instead of reporting the occurrence frequencies of certain events.

For this purpose, a second SDE Level 3 AIM functionality exists in which relative severity indicators are calculated. Initially, the following severity indicators are being used:

- an airspeed severity index
- a bank angle severity index
- a hook load severity index.

An example of such a severity index for the bank angle spectrum of an imaginary NH90 usage scenario is shown in the example figure, below.

Example of NH90 SDE Level 3 AIM Usage Severity indicator

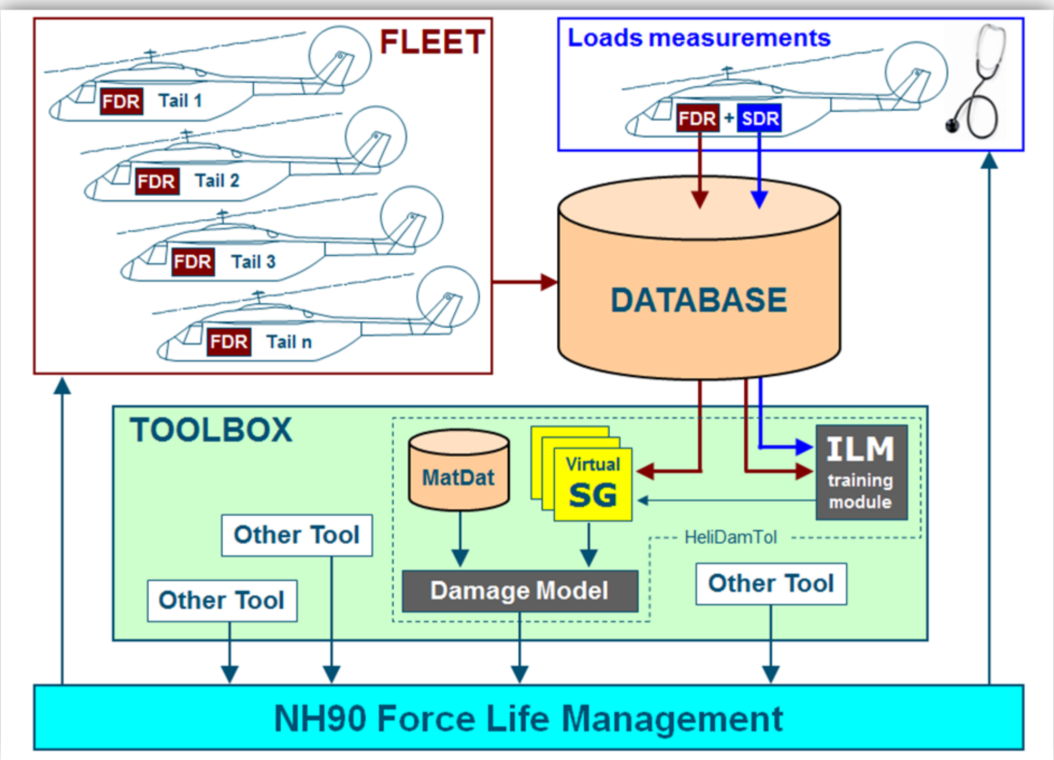
By adding this kind of severity data to the basic input data for each mission in the data base, an enrichment of the SDE data base will occur, enabling deep-level structural integrity assessments.

The next, third, functionality within SDE Level 3 AIM is the determination of damage indices for different NH90 components during different flight regimes or events, such as landings and autorotations. Based on available loads data from on-board load monitoring devices it will be possible to calculate accumulated fatigue damage for each mission flown or to perform NH90 damage prognostics through calculating the severity of (future) mission utilization.

The process of this SDE Level 3 AIM structural integrity analysis tool, called the stethoscope method, will be explained in more detail below.

The NH90 Stethoscope Method

Over the past years, NLR developed a powerful fleet life management tool called the "Stethoscope Method", which to a large extent is already operational for another helicopter type, i.e. the CH-47D helicopter fleet of the RNLAF [4]. The same concept will be implemented for the NH90 and this part of the SDE Level 3 AIM functionality will be made available for all nations participating in SDE Level 3 AIM.



The Stethoscope Method for NH90 Fleet Life Management

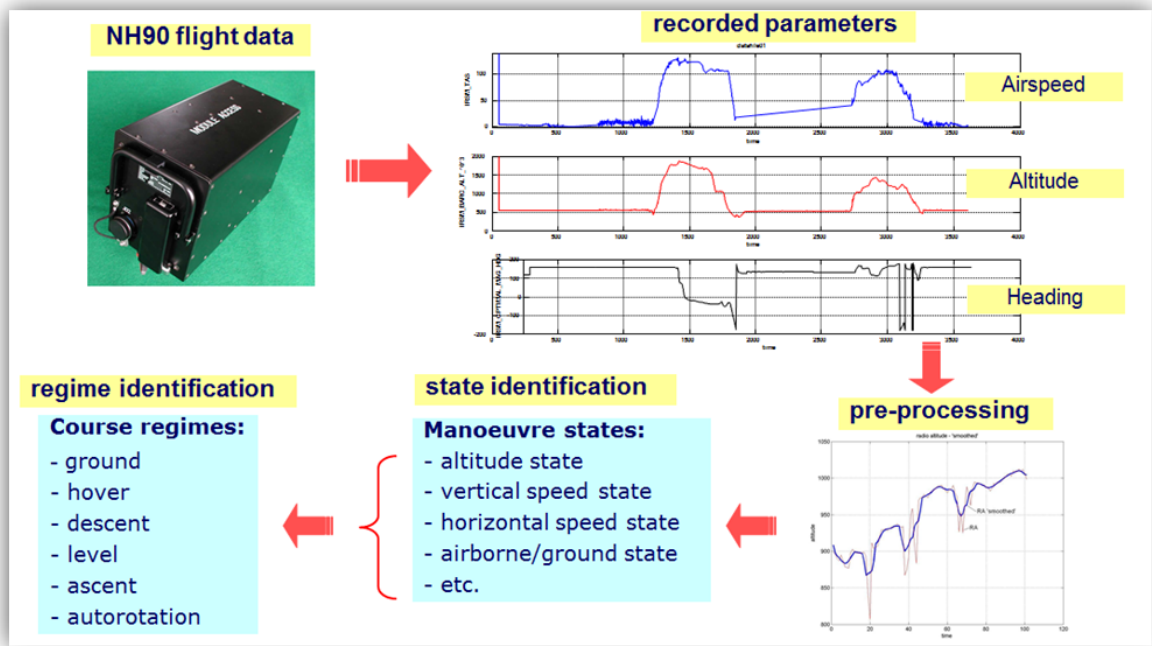
The stethoscope method is based on so-called virtual strain gauges, in which the measured strain at a particular point in the airframe is correlated to the flight and engine parameters that are routinely collected from the digital data bus. This can be done by means of an Artificial Neural Network (ANN) or through a deterministic regression technique [4]. Once such a correlation has been established for all possible mission events or flight phases of the NH90, the strain gauge that has been used to measure the strains at this particular location is no longer needed.

Within the stethoscope method, virtual strain gauges are the key to lifing calculations of any structural component of the NH90. This method is outlined in the figure above. It involves the fleet wide collection and storage of all relevant flight, engine and control parameters that are available from the digital data bus(es), plus the simultaneous collection of loads data in one or more dedicated Operational Loads Measurement (OLM) aircraft. Obviously, the OLM aircraft will need an additional structural data recorder or, alternatively, an additional FDR loads monitoring functionality. The loads data from the SDR or FDR in the OLM aircraft is then used to continually train and improve the neural network based virtual strain gauge models. By moving the strain gauges in the OLM aircraft around on a regular basis, models will be obtained for more and more separate hot spots or control points of the NH90 airframe. In combination with appropriate material data and damage models this will, for example, allow the calculation of Remaining Useful Life (RUL) and the assessment of the severity of service induced fatigue cracks for a critical point.

To be able to process all operational usage, it is essential to start collecting bus data from the very first moment that an aircraft is commissioned. It will be clear that the present SDE tool has become available at a right point in time, as NH90 operations throughout the world is just starting up. For the virtual strain gauge models this is less crucial: when developed at a later stage these models can use the historic bus data that are stored in the SDE database to 'roll back' to day one.

Flight Regime Recognition and damage indices

In Chapter 3 it was mentioned that Flight Regime Recognition (FRR) will be part of the underlying structural integrity tools of the NH90 SDE system. FRR is the NLR proprietary software algorithm that will run within SDE Level 3 AIM to break down all mission data entered into the data base, regardless of operator or nation, and is illustrated in the figure, below.



The NLR NH90 Flight Regime Recognition procedure

Using the stethoscope method, explained in Chapter 5, and assuming adequate damage models will become available in the near future, it will be possible to allocate damage indices (i.e. damage per unit of time) to FRR flight regimes for specific helicopter components.

On the other hand, NH90 mission utilization will also be determined and reported routinely - for all helicopters - through the on-board MDS/GLIMS data acquisition system. So-called Flight Condition Recognition (FCR) software from Industry will break down all missions flown into flight conditions (equivalent to FRR regimes).

Through mapping FRR information onto FCR, it will be possible to allocate damage per FCR regime. In this way, severity of usage can easily be compared among the nations participating in SDE. This will be a powerful SDE Level 3 AIM functionality.

Summary and Outlook

By now, the NH90 SDE system is a well-established service that is used in support of the sustainment of the NH90 helicopter fleet. Its goal is to provide the NH90 operator with a tool to maximize operational availability at the lowest possible costs and effort, while maintaining flight safety at a desired level. In this way it is expected that the SDE system becomes a useful tool to reduce life cycle costs.
Currently, the NH90 SDE system, physically located in a secure environment at NLR-Flevoland in the Netherlands, provides 9 participating nations of the NH90 community with a common shared NH90 usage database and structural integrity toolbox. It allows automated 24/7 web based user data input through a B2B interface for a maximum of 200 NH90 users. Additional to the 3-level storage, analysis & reporting functionalities, the NH90 SDE system provides a website, a moderated forum and operators can discuss results, can exchange views and can plan future developments during the yearly NH90 SDE users conference. Although operator defined, the NH90 SDE system data and results will provide an excellent basis for fruitful co-operation between operator and Industry.

Although set up by 9 NH90 operating nations, originally, NAHEMA contacting and SDE system architecture is such that additional NH90 users can be added to the system easily.

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