A Systems Approach to Design of an Intelligent Data Management Tool for Health and Usage Monitoring Systems – Further Developments

Dipesh K. Parekh* and Arvind K. Sinha#
Sir Lawrence Wackett Aerospace Centre
GPO Box 2476V
Melbourne, 3001, Victoria.
Phone: +61 3 9645 4536
Fax: +61 3 9645 4534
Email: *dipesh.parekh@rmit.edu.au; #arvind.sinha@rmit.edu.au

Abstract

A Health and Usage Monitoring System (HUMS) provides the status of functionality and structural integrity for diagnosis and prognosis of the rotorcraft components. This research is part of a major helicopter acquisition program. The program aims to rationalise the number of helicopter types operated, simplify operational requirements and reduce through-life-support costs. A Fleet Management System (FMS) is to be designed and developed including a coherent HUMS system for the rationalised number of helicopter types. This paper adopts a systems approach based on systems engineering to the design of an Intelligent Data Management Tool (IDMT) for HUMS systems – HUMS IDMT. An advanced military rotorcraft platform is intended to be the application platform. A systems approach is implemented to develop a systems hierarchy in order to identify the key components of the total HUM Management System (HUMgtS) at all levels. Furthermore, a systems structure is established to identify the relationships and attributes. Having established a systems hierarchy and structure, a discussion pertaining to the design of HUMS IDMT is provided in terms of the health and usage monitoring capabilities. The key capability to be developed was identified to be Flight Regime Recognition System (FRRS). It is envisaged that the HUMS IDMT will be integrated with the FMS tool which is being concurrently developed. The resultant customised fleet management maintenance tool will aid the maintenance personnel via increasing efficiency and economy of fleet management. Future work will focus on the development of FRRS for the HUMS IDMT.

Keywords

Systems Approach, Health and Usage Monitoring System, Intelligent Data Management, Flight Regime Recognition, Fleet Management

1 INTRODUCTION

The primary purpose of a Health and Usage Monitoring System (HUMS) is to provide the status of functionality and structural integrity for diagnosis and prognosis of the rotorcraft components. As such, a HUMS system provides the merits of automated monitoring and automated inspection. The implementation of HUMS systems has surged over the past decade leading to an improvement in safety and reduction of maintenance costs associated with rotorcraft fleet management. Additionally, the growing need for safety enhancement and operational cost reduction of aging rotorcraft fleet has directly impacted HUMS design and development [1].

This research is part of a major helicopter acquisition program. The program aims to rationalise the number of helicopter types operated, simplify operational requirements and reduce through-life-support costs. A Fleet Management System (FMS) is to be designed and developed including a coherent HUMS system for the rationalised number of helicopter types. The first phase of investigations covered the requirements analysis of the system & software to identify the monitoring needs [2]. The second phase reviewed the helicopter platform and HUMS systems in service to stipulate the design requirements based on the monitoring needs [3]. The two phases resulted in the establishment of the design and development requirements of the HUMS software.

Sir Lawrence Wackett Aerospace Centre has collaborated with industrial partners in order to cater for a current problem faced by the industry in relation to usage monitoring for an advanced military rotorcraft platform. Usage monitoring for HUMS equipped aircraft entails deduction of actual usage of a component over time. It allows actual usage/damage encountered during a flight to be assigned to components instead of designating a more conservative usage. This can result in extended component life, reduced maintenance costs and increased safety. Usage monitoring requires accurate representation of regimes encountered by a rotorcraft platform during flight (Sec 3.2) [4-6]. Consequently, the Intelligent Data Management Tool (IDMT) is to be developed as an integrable HUMS software to address this issue.

This paper adopts a systems approach based on systems engineering to the design of an IDMT for HUMS systems – HUMS IDMT. An advanced military rotorcraft platform is intended to be the application platform. A systems approach is implemented to develop a systems hierarchy in order to identify the key components of the total HUMS Management System (HUMgtS) at all levels. Furthermore, a systems structure is established to identify the relationships and attributes. Having established a systems hierarchy and structure, a discussion pertaining to the design of HUMS IDMT is provided in terms of the health and usage monitoring capabilities and the key capability to be developed is identified.

The development of the HUMS IDMT will be integrated with the FMS tool which is being concurrently developed. The resultant customised fleet management maintenance tool will aid the maintenance personnel via increasing the efficiency and economy of fleet management.

2 SYSTEMS PERSPECTIVE – HEALTH AND USAGE MONITORING SYSTEMS

The Systems Age which began in 1940s led to the development of systems thinking to explain complex phenomena which remained inexplicable. It proved that systems had emergent properties peculiar to themselves which can not be derived from its parts, that is, whole is greater than the sum of parts. Furthermore, two major types of thinking evolved, analytic thinking & sythentic thinking. Analytic thinking is an outside-in thinking which provides an explanation of the whole derived from explanations of its parts. Synthetic thinking is an inside-out thinking in which something to be explained is viewed as part of a larger system and is explained in terms of its role in that larger system. Both types of thinking are essential and as such, neither negates the value of the other. However, synthetic thinking aids in gaining understanding which can not be obtained via analysis, particularly of collective phenomena.

The synthetic mode of thought when applied to systems problems is called "systems approach." This mode of thinking implies that when each part of a system performs as well as possible, the system as a whole may not perform as well as possible. Consequently, the sum of the functioning of parts is seldom equal to the functioning of the whole. As such, the sythentic mode seeks to overcome predisposition to perfect details and ignore system outcomes.

Based on "systems thinking" there are several systems approaches which may be utilised to address systems problems. Systems approaches include operational research, systems analyses, viable systems dynamics, general systems theory, socio-technical systems, contingency theory, social systems design, strategic assumption, interactive planning and systems engineering [7, 8]. Details of the various types of systems approach is provided in [7].

This research utilises the systems engineering method which is an interdisciplinary approach to address the customer's need throughout the system's life cycle. It transfers the customer's operational needs into system performance parameters and preferred system configuration via: a) Functional analysis; b) Optimisation; and c) Design, test & evaluation [7, 9].

A systems approach based on systems engineering is adopted to develop the systems hierarchy in order to identify the key components of the total system. The definition of a system and its elements is provided by Sinha in [10] as follows: *"A system is composed of (i) components; (ii) attributes; and (iii) relationships. The components are also referred to as subsystems. The attributes are the functional characteristics of the components. Relationships are the inter and intra relationships between components and attributes. A system may be part of a larger system in a hierarchy, and its components may be referred to as a system. The purpose of the system is achieved by the system elements and their corresponding attributes."*

The system may be referred to as a total system, at any level governed by the system/component under investigation. The system structure comprises of the components, its attributes, the inputs from the environment into the system and the output to the environment. The HUMS system will be analysed in this context (*Figure 1* Input-Process-Output Configuration) from a systems perspective for a holistic analysis.

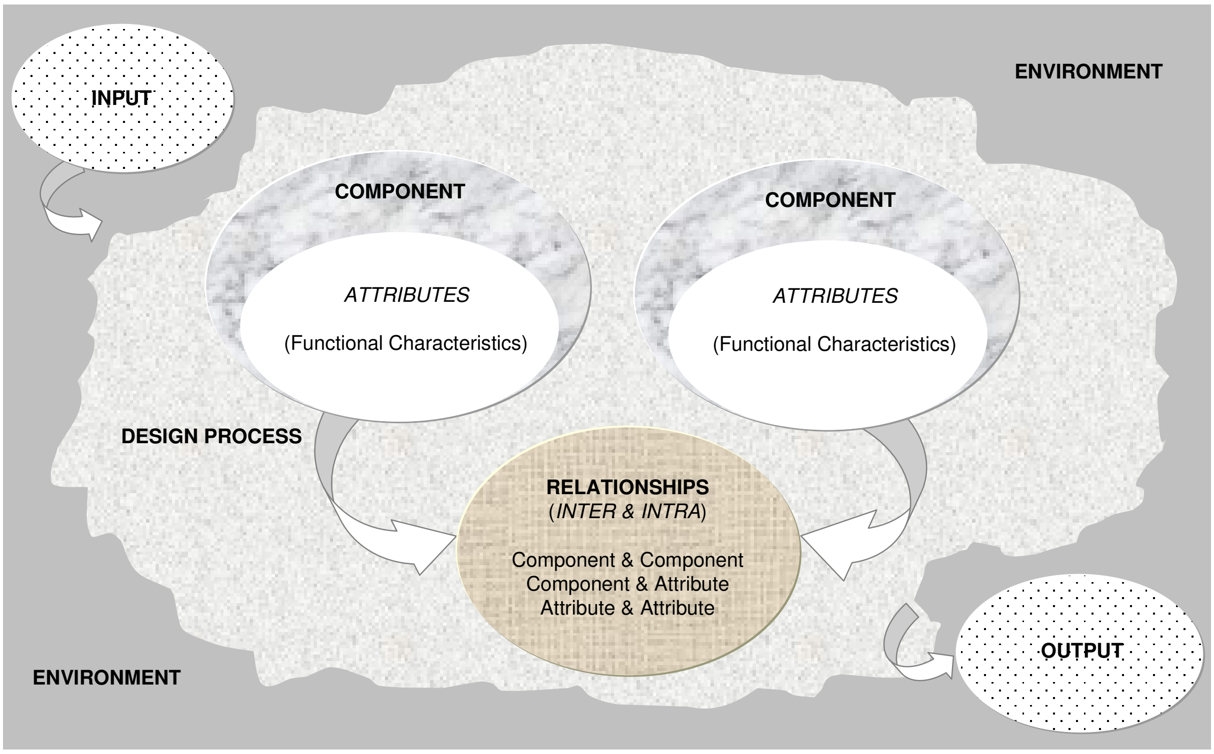

Figure 1: System Structure in an Input-Process-Output Configuration

2.1 System Configuration

The HUMS system is considered in a typical input-process-output system configuration. The HUMS system is to be developed for an advanced military rotorcraft platform. Consequently, the "monitoring needs" for the operation of the rotorcraft fleet needs to be considered. These monitoring needs are to be the inputs of the HUMS design process. The monitoring needs will comprise of the data transfer, diagnostics & prognostics for the designated roles and missions of the platform. It will also comprise of the "operational environmental needs" on the foreseen spectrum of conditions in which the platform will need to operate. The platform and HUMS systems technology will form an additional critical input dimension to the HUMS design process.

The analysis of the monitoring needs for the HUMS process will stipulate the design & development requirements (functional attributes) of the HUMS. The design process transforms the design & development requirements into the required HUMS capability as an output of the system with the required functional attributes.

The HUMS in the input-process-output context from a systems perspective provides the base for a holistic analysis to develop the HUMS capability for application on a specific technology – the advanced military rotorcraft platform. The systems perspective of the HUMS in an input-process-output configuration is presented in *Figure 2*.

2.2 System Hierarchy and Elements

Utilising the preceding definition of a system, the total system is considered to comprise of the Health and Usage Management Systems (HUMgtS) with the various subsystems located at lower hierarchical levels. Via establishing a systems concept of the various hierarchical levels, the attributes and relationships of the system components can be identified [2].

2.2.1 Hierarchy Levels I to III

The total system is at the top level of hierarchy whilst other subsystems and components are located at different levels of hierarchy. Each of these subsystems and components needs to be further investigated. The HUMgtS system is at Level '0' of the hierarchy, being the total system. The subsystem at the next level (Level I) comprises of the Structural Usage Monitoring Systems/Structural Data Recording Systems & HUMS (SUMS/SDRS & HUMS). The HUMS component is further analysed and the two subsystems comprises of the aerial and ground systems at the next level (Level II).

Presently, the ground system comprises of the maintenance management system (MMS). An additional system, namely, the HUMS IDMT needs to be considered to automate the flight regime recognition (FRR) process & data interpretation analyses in conjunction with MMS (Level III) (Sec 3). The data is transmitted utilising a Data Transfer Unit (DTU) which is a component of both the aerial and ground systems. As the focus of this research is on the HUMS system, a partial system hierarchy from Levels I to III is presented in *Figure 3*.

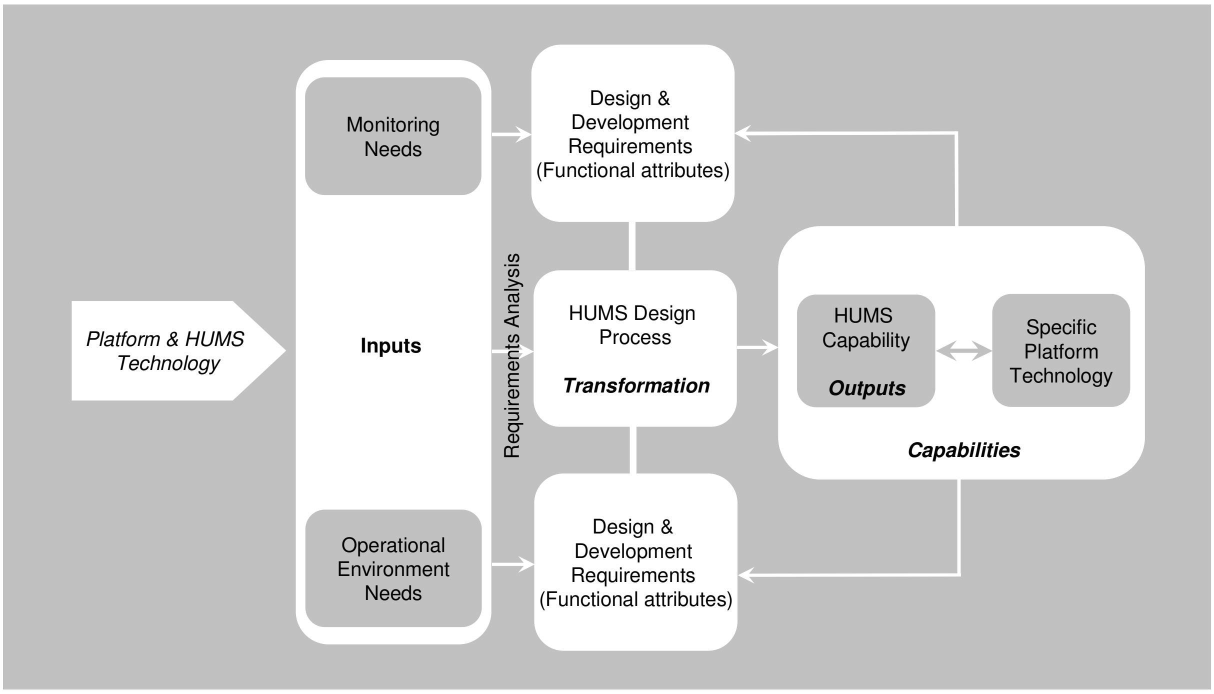

Figure 2: Systems Perspective of HUMS system for Holistic Analysis

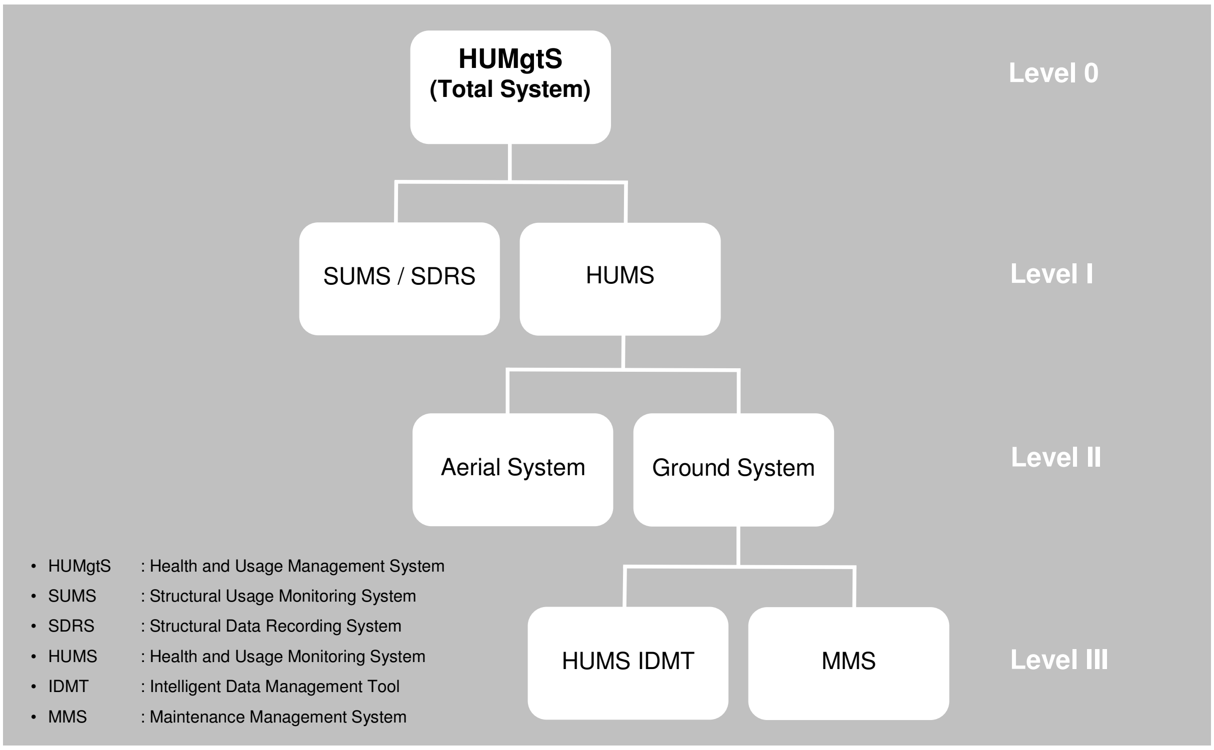

Figure 3: Partial System Hierarchy – Levels I to III

2.2.2 System Elements – Level I

The analysis of the system elements (components, attributes, and relationships) requires the identification of subsystems of the total system. A total of two components of the HUMgtS have been identified by a categorisation processes. The functional characteristics (attributes) of the components need to be slated in line with the logistics/support needs of the HUMgtS. The detailed HUMgtS system analysis for the identification of the attributes is as follows [11].

- SUMS/SDRS*:* Based on the safe-life and fail-safe design philosophies, the SUMS/SDRS monitors the status of the structural elements to assess its structural integrity. To illustrate – the aircraft rib-stringer structure may be monitored for usage and impending failures. Key aircraft sections are monitored with only a squadron/flight of the aircraft fleet instrumented. Flight regime information which encompasses kinematics, control positions and key flight events are also collated in addition to strain information. This information provides the Original Equipment Manufacturer (OEM) and the fleet operator an avenue to establish system-life status of the components.
- HUMS*:* It monitors aircraft flight regime and loads similar to SUMS/SDRS systems. Additionally, such systems may collect rotor and powertrain vibration data, conduct engine monitoring functions, exceedance monitoring and log critical life/performance information (typical HUMS functionalities). These systems are integrable with existing maintenance systems to provide diagnostic and prognostic analyses.

2.2.3 System Structure – Level I

Upon identifying the attributes of the components, the inputs, outputs, relationships and environment needs to be identified in order to develop a system structure. The environment may be classified as man-made and natural and may be further classified in detail at the next hierarchical level(s).

The input to the system primarily comprises of the logistics and support needs whilst the output will be the requisite logistics and support capabilities. The relationships are inter and intra – component & component, component & attribute, and attribute & attribute. *Figure 4* presents the system structure based on the identified system elements and the environment.

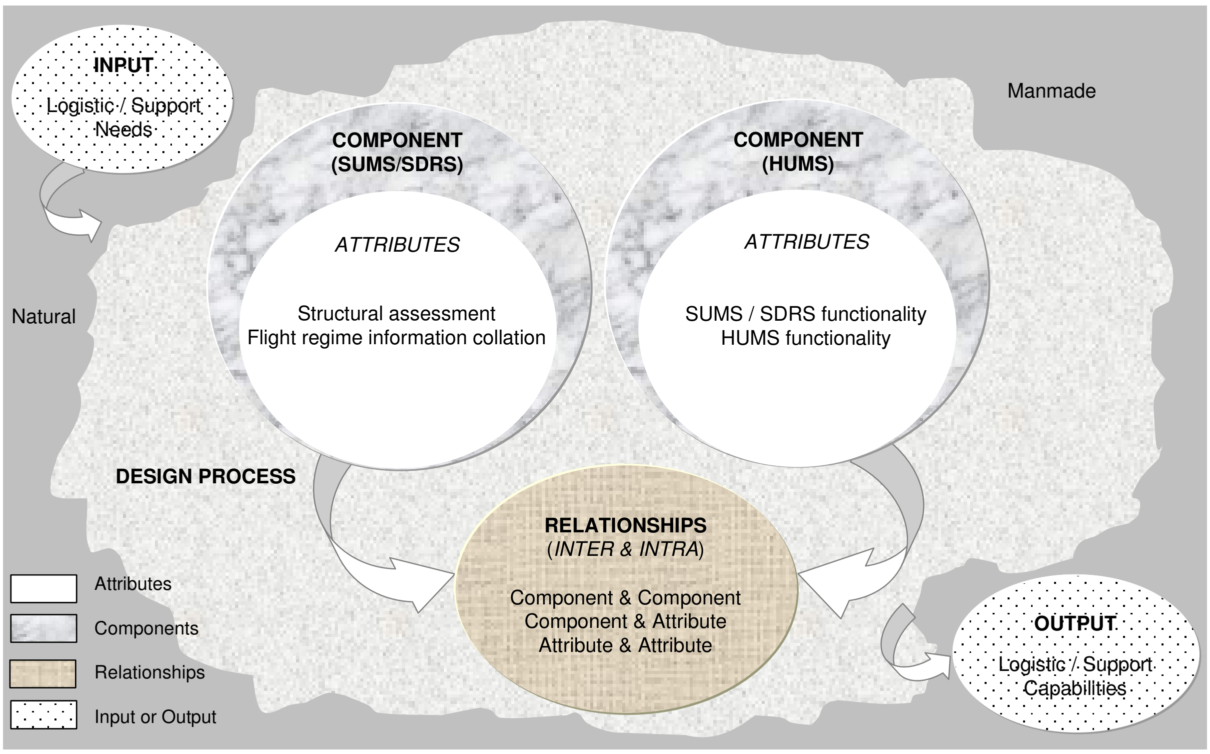

Figure 4: System Structure – Level I

2.2.4 System Elements – Level II

The formulation of the system structure at Level II identified the components, attributes, and relationships. The system hierarchy (*Figure 3*) identified the components at Level II, which comprised of the aerial and ground systems. The functional characteristics (attributes) of the components need to be slated in line with the monitoring needs of the HUMS system. The detailed HUMS system analysis for the identification of the attributes is as follows [2, 12-15].

- Aerial System: The aerial system comprises of the original helicopter fitted with additional HUMS equipment which involves hardware and instrumentation. The attributes of an aerial system are as follows:
  - Engine performance assessment;
  - Rotor track and balance (RTB);
  - Absorber tuning;
  - Mechanical diagnostics;
  - Exceedance monitoring; and
  - Usage monitoring.
- Ground System: The ground system comprises of a series of networked ground stations which are responsible for configuring flight specific analysis to support either pilot or maintainer queries. Generally, the ground station and existing maintenance system make extensive use of commercial-off-the-shelf (COTS) hardware and software. More specifically, the attributes of a ground system are as follows:
  - Flight data analysis which involves diagnostic & prognostic analyses; and
  - Fleet maintenance planning.

2.2.5 System Structure – Level II

The system structure is developed similarly to Level I via identifying the inputs, outputs, relationships, and environment. The environment at Level II is further analysed in detail and identified as time, weather, threat and terrain.

The input comprises of the monitoring needs of the HUMS systems, and the output is the monitoring capabilities of the HUMS systems. The relationships are as previously identified inter and intra – component & component, component & attribute, and attribute & attribute. The system structure at Level II based on the identified system elements and the environment is presented in *Figure 5*.

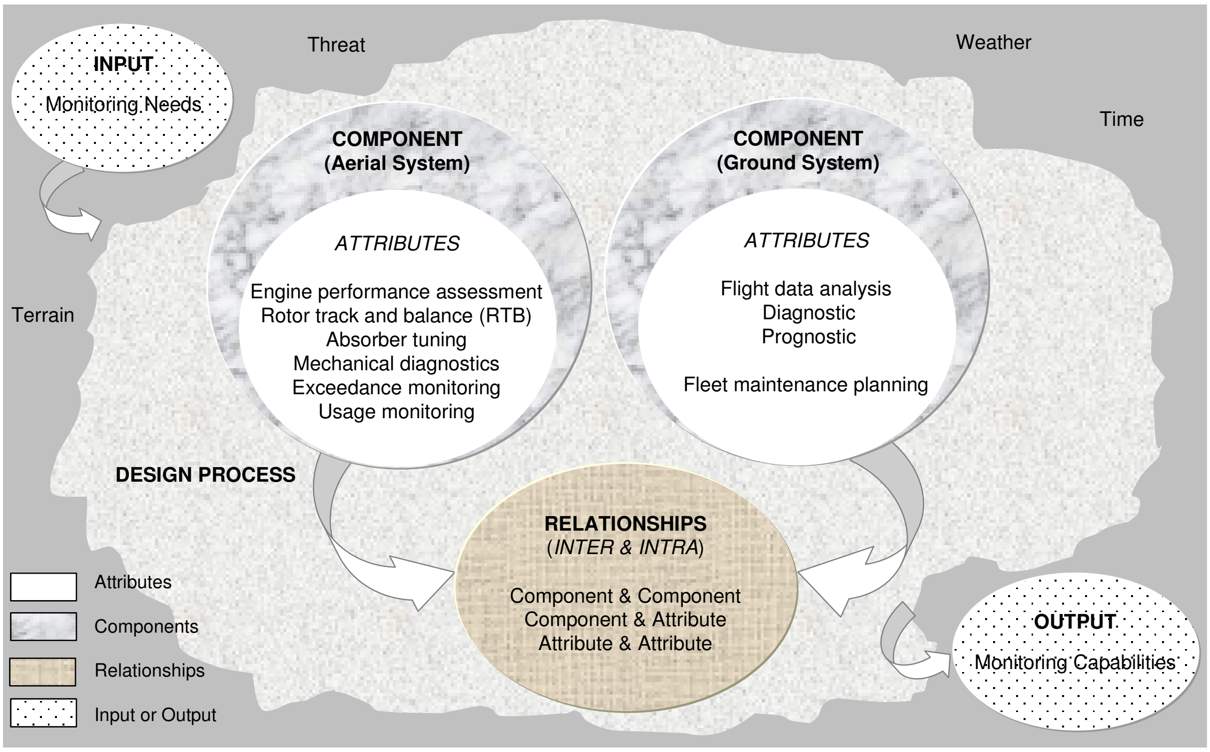

Figure 5: System Structure – Level II

2.2.6 System Elements – Level III

The system elements at Level III comprises of the primary components of the ground system – HUMS IDMT and MMS (*Figure 3*). The primary objective of this research is to focus on the development of a Flight Regime Recognition System (FRRS) for the HUMS IDMT (Sec 3.3). Consequently, the primary components identified at Level III illustrate the interactions between the IDMT and existing MMS. The system structure at Level III is developed based on the identified components, attributes, and relationships.

The functional characteristics (attributes) of the components need to be slated in line with the flight regime recognition need of the ground system. The detailed ground system analysis for the identification of the attributes is as follows [2, 6].

- HUMS IDMT: The envisaged functional attributes of the HUMS IDMT is to conduct flight regime recognition and damage index analyses. The envisaged damage index will denote the usage of the rotorcraft platform and will thus influence the rotorcraft maintenance schedule.
- MMS: The MMS will utilise the information from other ground stations and the HUMS IDMT to conduct comprehensive flight data analyses. Based on the analyses conducted, fleet maintenance planning will be executed.

2.2.7 System Structure – Level III

The system structure is developed similarly to Level II via identifying the inputs, outputs, relationships, and environment. The environment at Level III is adequately analysed and identified as time, weather, threat and terrain.

The input comprises of the FRR need of the ground system, and the output is the FRR capability of the ground system. The relationships are as previously identified inter and intra – component & component, component & attribute, and attribute & attribute. The system structure at Level III based on the identified system elements and the environment is presented in *Figure 6*.

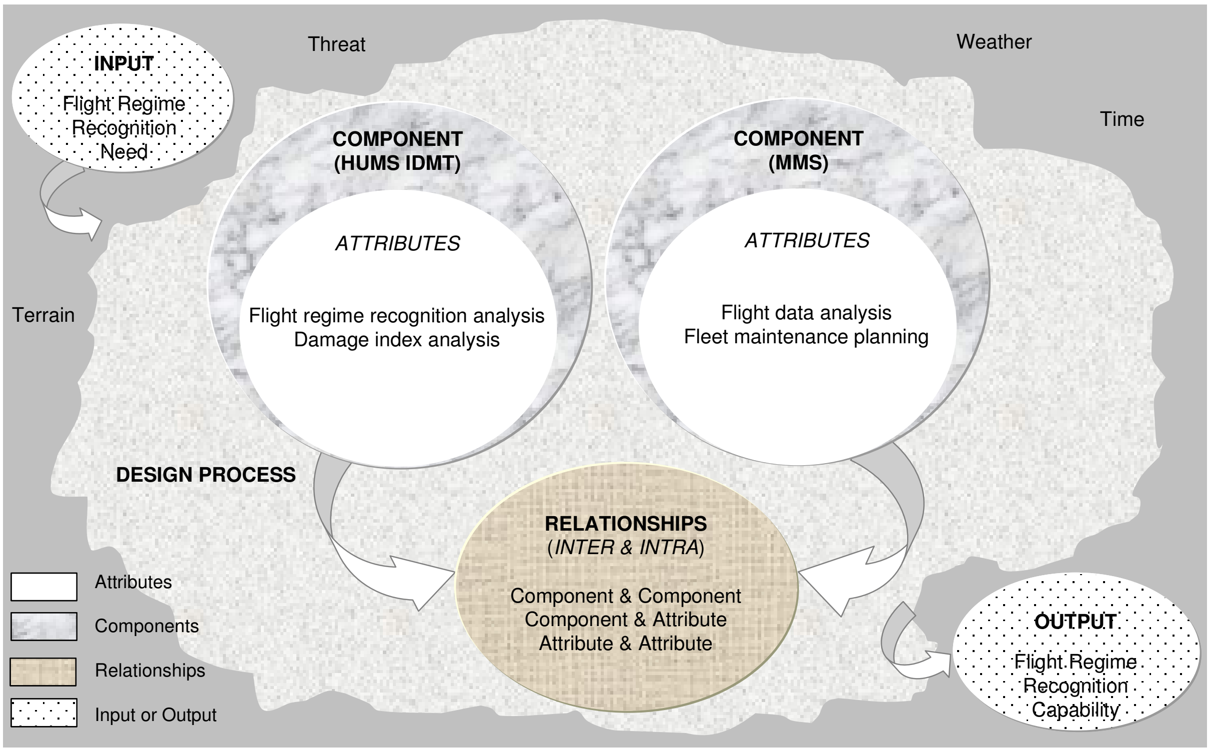

Figure 6: System Structure – Level III

3 HUMS IDMT DESIGN

In order to design and develop the HUMS IDMT it is essential to consider the functionality of a HUMS system in detail. The following sections define the health and usage monitoring functionalities of a typical HUMS system. Furthermore, a description of the envisaged FRRS is provided as it is the key capability to be developed for the HUMS IDMT.

3.1 Health Monitoring

The health monitoring aspect of a HUMS system involves the detection of component faults before they become critical. It is essential to detect the faults with accuracy to avoid the generation of false alarms. Health monitoring includes: (i) Rotor system monitoring which includes RTB with both continuous and prompted monitoring; (ii) Engine monitoring with prompted checks and condition monitoring; and (iii) Drive train monitoring which conducts mechanical diagnostics of all drive train components, bearings and gears. Furthermore, certain health monitoring functions can be accessed via the Flight Data Recorder (FDR) interface [6, 16].

3.2 Usage Monitoring

The usage monitoring aspect of a HUMS systems involves automated tracking of life-limited components and retirement of these components based on actual rotorcraft usage rather than “worst case” conservative usage estimations used for certification. Via measuring the actual usage of the rotorcraft, the life of the components can be extended to true lifetime.

The usage monitoring system typically determines the percentage of flight time the rotorcraft has spent in each flight regime as well as the specific regime(s) sequence. The regime data is utilised to compute the usage rate of the various structural components. Based on this information, the components are removed from service to maintain the required reliability rate [6, 17]. Consequently, accurate regime recognition is an essential requirement for determining component usage and will thus form the key capability to be developed for the HUMS IDMT.

3.3 Flight Regime Recognition System

The HUMS IDMT is to be developed in order to automate the data processing and analyses concerned with health and usage monitoring. Holistically, it will operate in conjunction with the FMS for efficient and economical fleet management. It is envisaged that the health monitoring capability of the HUMS IDMT will result in a Health Recognition System (HRS). Additionally, other capabilities may be added since the HUMS IDMT will be designed to operate as an open system architecture.

The usage monitoring aspect of the HUMS IDMT is the key focus of this research project. This aspect requires an accurate representation of the flight regimes experienced by the rotorcraft based on which the component usage is computed. Hence, the key capability of the HUMS IDMT will be the FRRS. The complete functional architecture of HUMS IDMT is presented in *Figure 7*.

Regime recognition is conducted to map recorded rotorcraft parameter data to a set of ground/flight regimes. The actual recognised flight regimes flown by the rotorcraft is determined and compared to the flight spectrum used for certification to determine the effect on established component lives [6, 18].

Typically, the process output includes several summary reports in addition to calculated adjustments to the useful life of specific components. A regime sequence report (flight profile) represents the time history of rotorcraft operation and provides a listing of the sequence of regimes encountered. A flight spectrum report provides a summarised distribution of time spent in each regime and how often the regime is repeated. Computed component usage is then aggregated to the sum of the usage already carried by the system for that specific component [6, 18]. It is envisaged that the FRRS of the HUMS IDMT will incorporate the FRR capabilities to output a regime sequence report and a flight spectrum report to compute the aggregate component usage.

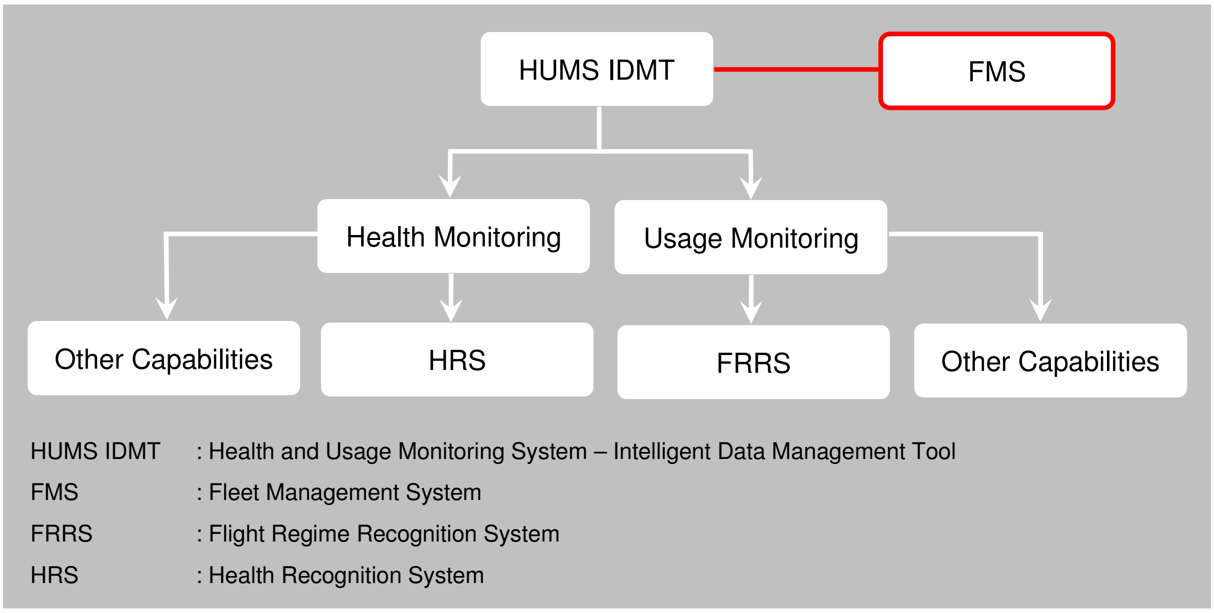

Figure 7: HUMS IDMT functional architecture

4 DISCUSSION

In this paper, research effort has been directed towards the establishment of a comprehensive systems approach to the design of an envisioned software system, namely, the HUMS IDMT. A systems approach based on systems engineering was adopted to identify the key components of the system. Additionally, a systems hierarchy and structure was established at all levels (Levels I-III) in order to identify the inputs and outputs of the total system (HUMgtS system) and the subsystems.

The design of HUMS IDMT was considered in terms of the key capabilities of the system. Health and usage monitoring were defined and the key capability to be developed was identified – FRRS. The FRRS will form the critical capability for usage monitoring of the rotorcraft components. Consequently, it will aid the maintenance personnel via increasing the efficiency and economy of fleet management. The evolution of HUMS IDMT will be continual as the desired capabilities are incorporated to meet the current and future requirements stipulated by the industrial collaborators.

5 CONCLUDING REMARKS

The research work undertaken thus far has led to the development of a comprehensive systems approach based on systems engineering to the design of HUMS IDMT. An analysis of the system hierarchy and elements was conducted. The establishment of the system hierarchy aided in the identification of the key components of the total system at all levels (Levels I-III). Additionally, a system structure was developed in order to identify the relationships and attributes. The systems analysis establishes the location of the HUMS IDMT within the total system – HUMgtS.

The design of HUMS IDMT was considered in terms of the health and usage monitoring capabilities. The envisaged key capability to be developed was identified to be FRRS. Future work will focus on the development of key capabilities for the HUMS IDMT. It is envisaged that the HUMS IDMT will be integrated with the FMS tool which is being developed concurrently. The resultant customised fleet management maintenance tool will aid the maintenance personnel via increasing efficiency and economy of fleet management.

6 REFERENCES

[1] Staszewski, W., Boller, C., and Tomlinson, G., 2004, *Health monitoring of aerospace structures: smart sensor technologies and signal processing*, 1st Edition, John Wiley & Sons Ltd, Chichester, UK.

[2] Parekh, D.K. and Sinha, A.K., 2008, *Health and Usage Monitoring System (System & Software - Requirements Analysis),* Report ADCO TN-2006-06-1b, Sir Lawrence Wackett Aerospace Centre, RMIT University, Melbourne, pp. 1-43.

[3] Parekh, D.K. and Sinha, A.K., 2008, *Health and Usage Monitoring System (Design Requirements),* Report ADCO TN-2006-06-2b, Sir Lawrence Wackett Aerospace Centre, RMIT University, Melbourne, pp. 1-44.

[4] Bechhoefer, E., 2008, 'The best regime recognition algorithm for HUMS', in *American Helicopter Society Specialist's Meeting on Condition Based Maintenance, Huntsville, Alabama, February 12-13, 2008*, pp. 1-7.

[5] Dere, A.M., 2006, 'Flight Regime Recognition Analysis for the Army UH-60A IMDS Usage', Master's Thesis, Naval Postgraduate School.

[6] Romero, R., Summers, H., and Cronkhite, J., 1996, *Feasibility study of a rotorcraft health and usage monitoring system (HUMS): Results of operator's evaluation,* E-10092, Louisiana, pp. 1-52.

[7] Rathore, A. and Sinha, A.K., 2006, 'A Systems Approach to Model the Conceptual Design Process of Vertical Take-off Unmanned Aerial Vehicle', PhD Thesis, RMIT University.

[8] Blanchard, B.S. and Fabrycky, W.J., 2006, *Systems Engineering and Analysis*, 4th Edition, Prentice Hall, Melbourne, Australia.

[9] Lacy, J.A., 1992, *Systems Engineering Management - Achieving Total Quality*, 1st Edition, McGraw-Hill, Inc, USA.

[10] Sinha, A., Kam, B., Wood, L. A., 1995, 'A design decision support system for helicopter multi-mission modifications', in *Proceedings of the 1st Australian Systems Conference, Perth, Australia,* pp. 1-6.

[11] Hess, R., 2005, 'From health and usage monitoring to integrated fleet management - evolving directions for rotorcraft', in *Aerospace Conference, IEEE Proceedings., n.p, n.d*, pp. 1 - 6.

[12] Parekh, D.K. and Sinha, A.K., 2007, 'Recent applications of health and usage monitoring systems to rotorcraft - A survey', in *6th Australian Vertiflite Conference on Helicopter Technology, Melbourne, VIC, March 19-22, 2006*, pp. 1-10.

[13] Parekh, D.K. and Sinha, A.K., 2007, 'A systems approach to design of an Intelligent Data Management Tool for health and usage monitoring systems', in *AHS Specialists Meeting, Seoul, South Korea, October 15-17, 2007*, pp. 1-6.

[14] Muldoon, R.C., Gill, J., and Brock, L., 1999, 'Integrated mechanical diagnostic (IMD) health and usage monitoring system (HUMS): An open system implementation case study', in *Proceedings of the 18th Digital Avionics Systems Conference, St Louis, MO, USA, October 24-29, 1999*, pp. 9.B.4-1-9.B.4-8.

[15] Augustin, M. and Priest, T.B., 1997, 'The certification process for health and usage monitoring systems', in *American Helicopter Society 53rd Annual Forum, Virginia Beach, Virginia, April 29-May 1, 1997*, pp. 1242-1247.

[16] Wiig, J., 2006, 'Optimisation of fault diagnosis in helicopter health and usage monitoring systems', PhD Thesis, I'Ecole Nationale Superieure d'Arts et Metiers.

[17] Wu, S., Bechhoefer, E., and He, D., 2007, 'A practical regime prediction approach for HUMS applications', in *American Helicopter Society 63rd Annual Forum, Virginia Beach, USA, May 1-3, 2007*, pp. 1-8.

[18] Gill, J., 1999, 'Integrated mechanical diagnostics (IMD) health usage and management System (HUMS)', in Workshop on Helicopter Health and Usage Monitoring Systems, Melbourne, Australia, pp. 7-15.

COPYRIGHT