HELIWISE

TOOL FOR HELICOPTER ADVANCED HUMS DATA ANALYSIS

Valerio Prece, Valerio.prece@leonardocompany.com, Leonardo Helicopters (Italy)

Abstract
Purpose of this paper is to describe a new Software tool (Heliwise) based on Web technology (Server-Client architecture) developed by Leonardo Helicopters S.p.A. for the analysis of Health and Usage data, aimed to increase the aircraft availability (reduction of unexpected Aircraft On Ground's) and to minimize the extraordinary maintenance activities.
In this paper will be shown how Heliwise can achieve these results by implementing an architecture which is modular, flexible and suitable to operate in a global environment (so called HUMS technical community) where all data are shared.

1. INTRODUCTION

During his operative life, the availability of an aircraft is assured by the maintenance activities. Maintenance activities are a cost for an aircraft operator, so an optimization of these activities means an increasing of revenues. Usually it is possible to identify three kinds of maintenance:

- ✓ Preventative Maintenance
- ✓ Corrective maintenance
- ✓ Predictive maintenance

Preventative Maintenance is consisting in mandatory (due to airworthiness regulations) periodical inspections based on counters (metrics or calendar dates). Usually the scope is to fix small problems before major ones develop. This maintenance is a recurrent cost for any aircraft operator with reduced margins for cost-saving.

Corrective maintenance is carried out after failure detection and is aimed to restore an asset to an operative condition. Since when a failure is detected is not possible to know in advance its root causes (for example if the identified malfunction can involve several parts or well can be caused by a multi-damage) the aircraft operator is obliged to put the aircraft on ground, to remove parts, to investigate all removed parts, to repair or replace parts and finally to re-install parts on board. This kind of maintenance can be very expensive due to down time during overhaul.

Predictive maintenance is consisting in definition and scheduling of activities following the continuous monitoring of some key parameters (in terms of historical trend). This approach, known as HUMS (Health and Usage Monitoring System) data analysis, can allow to evaluate the Health status of an aircraft, to identify potential failures before these happen and to define specific troubleshooting actions.

This process implies a significant improvement of the capability to identify and solve in advance issues and anomalies potentially critical with important margins of cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted.

In these last years, Leonardo Helicopters is investing energies in the HUMS data field in terms of:

- ✓ Diagnostic and Engineering (Leonardo is provided with a department in charge to define components to be monitored, methods for data monitoring, methods for data elaboration and methods for data analysis),
- ✓ Design and Manufacturing (Leonardo is pointing to provide each own helicopter model with HUMS integrated),
- ✓ Engineering Support (Leonardo is provided with a team of specialists HUMS to support customers).

The availability of dedicated HUMS resources and the availability of data from a huge operative fleet make today Leonardo Helicopters one of the most important actors in Health and Usage data analysis and for this motivation the exigency to have a robust and reliable tool for Health and Usage data analysis is become a priority.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

2. HELIWISE TOOL FOR HUMS DATA ANALYSIS

2.1. HELIWISE DESIGN PRINCIPLES

Starting from engineering tools (necessary for prototyping activities and to support diagnostic and engineering team activities), Leonardo Helicopters has developed the Heliwise Software tool.
Heliwise implements processes for HUMS data elaboration/management based on rules defined by Leonardo Helicopters diagnostic team as result of its own experience in such sector.
Heliwise HUMS data process is aimed to the generation of the following outputs:

- ✓ a list of maintenance alerts (so called Arising, generated when some data overcome limits/thresholds in accordance with rules defined by Leonardo Helicopters Engineering and Product Support);
- ✓ the visualization (through tables or plots) of all measurements/data/results received from the helicopter and processed by the ground station, including the possibility of comparing fleet data.

These outputs are not the solution to a (potential) anomaly but these are necessary for an HUMS specialist for troubleshooting purposes which usually encompasses a detailed analysis of displayed data (for instance, for VHM system, the ground station allows to also display the signals acquired on board and processed according to the VHM algorithms), for identification and reject of false alerts and for the definition and launch of activities of extraordinary maintenance in case of real alerts.
In particular by analyzing which sensors and which measurements are involved, an HUMS specialist is able to identify either the part(s) to be maintained or the type of action to be implemented.
The process of alert generation is based on the concept of thresholds: in Heliwise for each type of measurements/data a set of value-limits (thresholds) is defined and when measurements/data overcome such limits an alert is produced. Default thresholds for each supported helicopter model are defined by Leonardo Helicopters in accordance with its experience but, since each helicopter is provided with its own “foot print”, default thresholds can be either too conservative (in this case some false trues are generated) or too un-conservative (in this case same real alerts are not generated) so Heliwise provides the HUMS specialist with the capability to modify thresholds manually (in accordance with its own experience) or well by using learning processes (based on the recent history of the helicopter).

Differently than preventative and corrective maintenance, the HUMS data analysis is a no-deterministic process since:

- ✓ a huge quantity of data and measurements shall be analyzed and correlated
- ✓ Data and measurements analysis can provide information at single component level but at assembled components level as well.
- ✓ the correlation between parameters and anomaly types is as more reliable as the quantity of the analyzed cases is greater
- ✓ the capability to identify anomalies and define troubleshooting actions is based on the experience of the HUMS specialist and the learning process for an HUMS specialist is as faster as the quantity of aircraft to be monitored is greater

Today the commercial software tools available for HUMS data analysis are either specific for a well-defined HUMS equipment or in stand-alone configuration (provided as application to be installed in each PC) with limitations in data sharing and in implementation of non-deterministic processes.

In order to overcomes these limits and to allow the best management as possible of such non-deterministic processes, which makes the HUMS data analysis a complex activity, Heliwise is developed by applying the concept of “Globalization”.
In these last years, one of the most used words is “Globalization”: it is used in political sphere, in the economic and financial world but also when an interaction between different actors with a same interest is established by creating a social network.
Today a lot of social networks (for leisure as well as for work) are existing but all have the same target in common: to share information and data.
Why is it so important to share information and data?
The reply is very simply: to allow the community to benefit from the experience of each single member. This approach, well described by the motto “All for one and one for all”, can allow each member to obtain a knowhow impossible to be obtained on his own.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

Right now, could be possible to apply this approach also for HUMS data analysis field? The Leonardo Helicopter S.p.A. reply is yes.

In particular Heliwise is developed as a tool easily upgradable in order to support new helicopter models, easily to be customized by introducing new functions (valid for all supported helicopter models or dedicated to a specific one) and provided with a Web architecture which can allow an HUMS specialist to have access to all data and measurements downloaded from all monitored helicopters

2.2. Architecture: globalization applied to HUMS

In order to meet the concept of globalization, Heliwise is developed as a web-based system (see Figure 1) composed by a Data Center (in charge to elaborate HUMS data and to store results in a dedicated Database) connected through a Web Network to the user PCs (hereafter identified as PC Client and in charge to transfer HUMS data from the Helicopter to the Data Center and to visualize results by interrogating the Data Center).

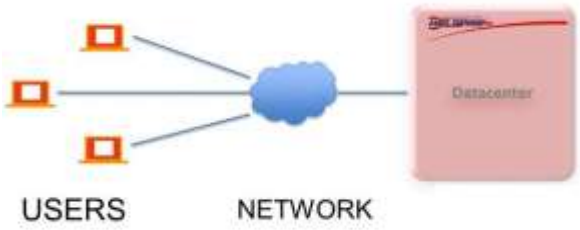

Figure 1. Heliwise architecture

The data exchange is organized into two flows as shown in **Figure 2**

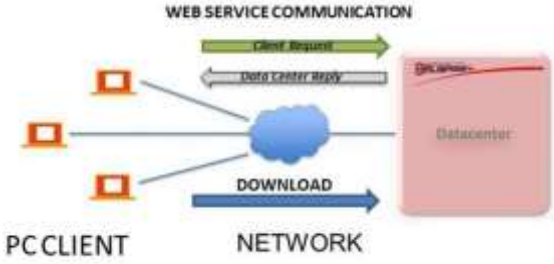

Figure 2. Data exchange process

The first flow is consisting in HUMS raw data transfer (hereafter identified as “download”) and elaboration. This flow is divided into three sequential steps:

1. the first one is the transfer of HUMS data from the helicopter to the PC Client,
2. the next one is the transfer from the PC Client to the Data Center.
3. Once the transfer is completed, the final step takes place: HUMS raw data are taken in charge by the Data Center for elaboration and archiving in the Database.

Figure 3. Download process

The second flow is consisting in visualization of stored data and results realized through the implementation of dedicated web services: following a Client data request towards the Data Center, the Data Center replies to the Client query by providing required data stored in the database. When the Client request is satisfied, the user can visualize the required information.

The web architecture of Heliwise can allow an HUMS specialist to have data of a whole fleet in real time.
At the same time the helicopter owner is always informed about the status of its machine and which actions have been implemented or suggested by the HUMS specialist even if these two actors are physically located in different sites.

A further advantages of the web architecture is at administration level: the helicopter operator shall maintain one Database only (in the stand alone solution each PC shall be provided with an own database) with an optimization of ICT management costs.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

2.3. Data Sharing: birth of an HUMS technical community

Heliwise architecture as described before (see Figure 1) allows to leave the approach stand-alone (HUMS tool installed in each user PC) and to meet the concept of data sharing in real-time:

- ✓ data downloaded by each single Helicopter are all stored in a same Database, so all Heliwise users can have access to all data of a fleet (or part of that in accordance with the user profile) directly using his own PC Client.

- ✓ solutions and troubleshooting identified by each user for a specific Helicopter (or a sub-set of Helicopters) are stored in the Database and available for consultation by all Heliwise users

An HUMS technical community is created.

Since exchanged data can have different level of confidentiality and since HUMS data can be considered for different purposes, the users of this HUMS community shall be provided with a well-defined roles: through a specific function of Heliwise, can allow the creation/editing of an user profile by selecting his hierarchical level (System Administrator, Master, basic user) and by enabling/disabling him to the access to each single Heliwise function. A such flexibility can allow a strong customization of user profiles.

Data sharing capability provides several benefit and advantages for an Heliwise user.
Operatively speaking, one only database means to work in real-time with a resulting reduction of lead-times and complexity to consult, compare, exchange, manage and analyze data of helicopters physically located in different sites. In particular Heliwise, as first dialogue, provides a concise visualization in real time of the status of all helicopters of the fleet (or part of that in accordance with the user credentials) as shown in Figure 4

Figure 4. Fleet status synthesis

The capability to interrogate one only database with a consistent amount of heterogeneous data can allow an HUMS specialist to define a set of parameters to be monitored for each specific anomaly in a way as more reliable as the quantity of the helicopters affected by the same anomaly is greater. In terms of troubleshooting, the recovery actions for a specific helicopters affected by an anomaly can be defined by considering the historical data of all the other helicopters of the fleet. This approach can allow the HUMS specialist to define new recovery actions or to improve the already existing ones in a sort of standardization of activities of troubleshooting.
In Figure 5 is shown a further benefit of the data sharing: Heliwise is provided with a function which in real-time can allow to compare the values of a specific parameter (TVM in the example in Figure 5) of the helicopters of a whole a fleet (or part of that). This kind of approach can allow the HUMS specialist to identify in real-time which helicopter is provided with an anomalous distribution.
In this case the trend under observation (indicated in Figure 5 with a solid arrow) is at lowest threshold level but following an exceptional maintenance, such trend is clearly returned at normal values (indicated by a dashed arrow in Figure 5)

Figure 5. Fleet TVM distribution

In Figure 6 is shown the capability of Heliwise to provide the HUMS specialist with the list of all alerts (also called arisings) concerning a fleet or part of that. Immediately the HUMS specialist can have an idea of potential activities to be implemented.

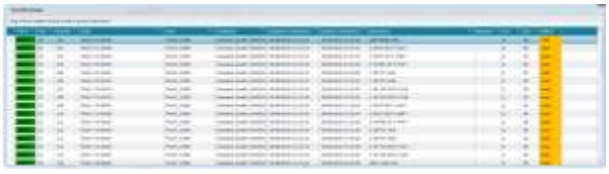

Figure 6. Fleet Arising

Another point of strength of Heliwise is the capability to correlate data and for several data to provide different ways of visualization necessary for different kind of analyses. For example each arising can be analyzed both by using the tabular approach (see Figure 6) and by visualizing

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

relevant data trend (see Figure 7). The first approach can provide a management overview of the arising (status, start date, owner, etc.), the second one can allow to understand if the arising is a false true.

Figure 7. Trends referred to arisings

As last benefit of the centralization of the database (which can allow to have the complete control of the fleet) together with the web-architecture (which can allow to operate in real-time and in remote) is the capability of the HUMS specialist to have the complete overview of the thresholds for each parameter and for each helicopter and to managed these when necessary with reduced reaction times.

2.4. Deployment: flexibility for each environment

Heliwise architecture as described before (see Figure 1) can be easily adapted in different operative scenarios in order to satisfy different kind of exigencies

2.4.1. Room configuration

Heliwise Data Center is physically located at the helicopter operator premises. For this kind of deployment the architecture as shown in Figure 1 is completely implemented in one only dedicated PC which is used both as Data Center and as Client. Actually this deployment can be extended by creating a network of PC Clients through an Ethernet connection (cable or Wi-Fi) by using a router/switch. This deployment is shown in Figure 8 where the solid arrows show the basic data flow and the dashed arrows show the data flow in case of PC Client network. This is a typical configuration for helicopter operators with one only base dedicated to the maintenance activities or with a restrictive security policy on the HUMS data transfer.

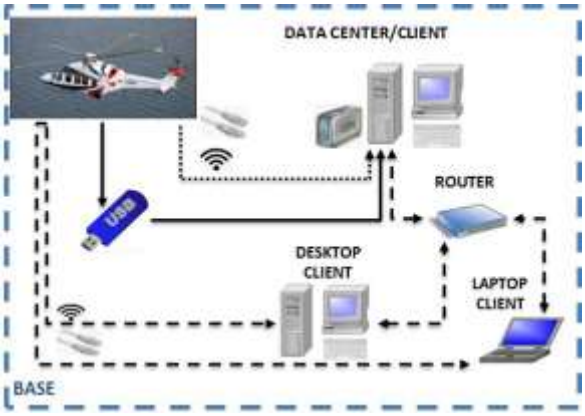

Figure 8. Room configuration

2.4.2. Local net configuration

Heliwise Data Center is physically located at the helicopter operator premises in a dedicated environment and the connection with Client PCs is realized by using the operator Intranet (Local net). This is a typical configuration for customers with a restrictive security policy on the HUMS data transfer.

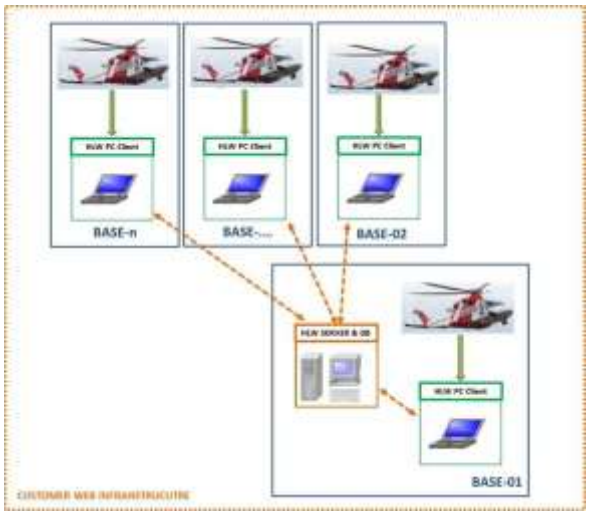

Figure 9. Local net configuration

2.4.3. Public net configuration

Heliwise Data Center can be located in a specific site or can be a located in a Cloud and the communication with Client PCs is realized by using the public network. In this case it is possible to receive data from whatever user in world and this world-wide scenario is typical for customers without any particular restriction on the HUMS data transfer. The Heliwise world-wide architecture is used by Leonardo Helicopters to providing HUMS support services.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

2.5. Modularity: a living tool in continuous improvement

Heliwise Software has been developed by using a modular approach: each Heliwise HUMS functionality can be enabled/disabled and if necessary new functions can be easily integrated in order to meet new exigencies and technologies of the market.
This approach can allow Leonardo Helicopters to have a product easily customizable in order to meet customer exigencies and easily upgradable in order to be always in line with the new technologies and processes.
Baseline functions for HUMS data analysis are enabled for all supported helicopters.
In accordance with Diagnostic department of Leonardo Helicopters, vibration data can be analyzed into two different ways: by analyzing the punctual distribution (distribution given by each single occurrence downloaded from the helicopter as per Figure 10) or by analyzing the deviation distribution (see Figure 11). Such distribution is obtained by elaborating the punctual values. Following this elaboration, the user can have a trend without any noise

Figure 10. Helicopter TVM Steady distribution

Figure 11. Helicopter TVM deviation distribution

The vibration of some single parts and assembled components is monitored by considering several parameters, so the real health status of the targeted part or component is not given by the value of each single parameter but by a weighted average of these so, to improve the capability of mechanical failure diagnostic for these parts and components, it has been necessary to develop an advanced vibration analysis function based on standard multivariate statistical methods, called AVDM (see Figure 12).

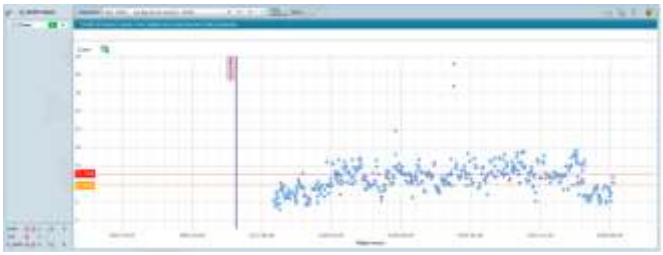

Figure 12. AVDM

Each AVDM occurrence is obtained by implementing statistical algorithms and for each AVDM occurrence three radar diagrams are available to provide the user with the probability of specific failures (see Figure 13)

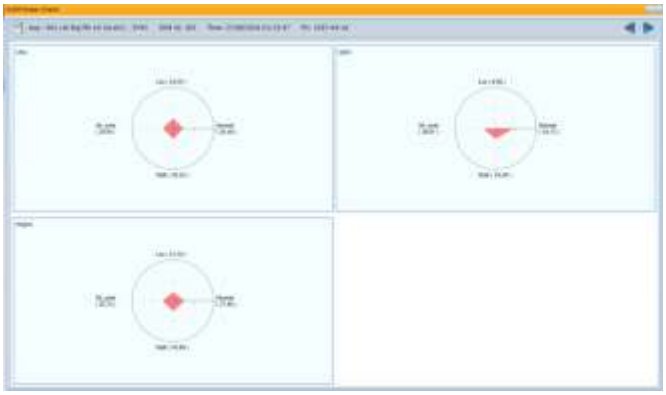

Figure 13. Radar

A further special function of Heliwise is the capability to receive HUMS raw data directly from the helicopter in flight.
This function can allow to make automatic the process of Download with an increasing of the helicopter availability

A last important special function is the capability of Heliwise to manage communications: all communications between operator and HUMS specialist are recorded in the database. Heliwise can allow to manage different kind of queries and the new ones can be easily introduced when necessary. In order to increase the reliability of communication process, Heliwise implements an email service as well.

3. CONCLUSIONS

The most important results introduced by the approach implemented in Heliwise are summarized below:

1 . The implementation of a system web-based can allow all user to share data in remote and in real-time even if the

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

helicopters are physically located in different sites with an evident reduction of lead-times and complexity for data exchange (necessary for HUMS data analysis)

2 . The architecture based on one only shared database can allow to have in real-time a complete overview of the status of the fleet

3 . The availability of all fleet data in real-time, can allow the HUMS specialist to identify a greater number of correlations and similarities with an evident improvement of the capability of mechanical failure diagnostic

4 . A system web-based can allow an HUMS specialist, when necessary, to apply a solution defined for a specific helicopter to the whole fleet (or part of that) in real-time with an important saving in terms of lead-times

5 . The modular architecture can allow the system to be easily upgraded in order to meet new exigencies and technologies of the market.

4. SYMBOLS AND ABBREVIATIONS

AOG	Aircraft On Ground
AVDM	Advanced Vibration Data Mining
HUMS	Health and Usage Monitoring System
ICT	Informatics Communication Technology
PC	Personal Computer
TVM	Transmission Vibration Monitoring
VHM	Vibration Health Monitoring

5. REFERENCES

1. Shewhart , David Van Nostrand, W. A., “Economic control of quality of manufactured product”, 1931

2. Hotelling, H., “Relations between two sets of variates”, Biometrika (28 (3-4)), 321-377, 1936

3. Kolmogorov, A., “Sulla determinazione empirica di una legge di distribuzione”, G. Ist. Ital. Attuari(4), 83-91, 1936.

4. K. V. Mardia, J. T. Kent, J. M. Bibby, “Multivariate Analysis”, Academic Press (Probability and Mathematical Statistics), 1979.

5. Shewhart, W. A.,”Statistical method from the viewpoint of quality control”, Dover Publications. 1986

6. Wickens, T. D.,”The geometry of multivariate statistics. Lawrence Erlbaum Associates, Incorporated”, 1995

7. Fraser, K.F., “Effectiveness of helicopter health and usage monitoring systems (HUMS) in the militaryenvironment.”, Defense Science and Technology Organization, Aeronautical and Maritime Research Laboratory, Victoria, Australia, March 1996.

8. A. Justel, R. Z., D. Pena, “A multivariate Kolmogorov-Smirnov test of goodness of fit.Statistics and Probability Letters”, 35(3), 251259, 1997.

9. J. Cronkhite, B. Dickson, W. Martin, G. Collingwood, “Operational Evaluation of a Health and Usage Monitoring System (HUMS)”, NASA/CR-1998-207409, DOT/FAA/AR-97/64 ARL-CR-420, April 1998.

10. Land, J.E., “HUMS- the benefits – past, present and future”, Aerospace Conference- IEEE, Big Sky, Montana, March 2001.

11. Hess, R., Duke, A., Kogut, D., “The IMD HUMS as a tool for rotorcraft health management and diasnostics”, Aerospace Conference- IEEE, Big Sky, Montana, March 2001.

12. Mobley, R. K., “An Introduction to Preventive Maintenance”, 2nd Ed., Elsevier, Woburn, MA. 2002.

13. A. C. Rencher, “Methods of Multivariate Analysis”, Wiley Interscience (Wiley Series in Probability and Statistics), 2002.

14. 1N. H. Timm, “Applied Multivariate Analysis, Springer (Springer Texts in Statistics)”, 2002.

15. A. J. Izenman, “Modern Multivariate Statistical Techniques: Regression, Classification, and Manifold Learning”, Springer (Springer Texts in Statistics), 2008.

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

16. Tyurin, Y. N., “Multivariate statistical analysis: A geometric perspective”, arXiv:0902.0408, 2009

17. Randall, R. B., “Vibration-based condition monitoring - industrial, automotive and aerospace Applications”, John Wiley and Sons, Ltd. Publications, 2011.

18. W. K. H¨ardle, L. S.,”Applied multivariate statistical analysis”, 3rd ed. Springer, 2012.

19. CAA-PARER-2011,” Intelligent management of helicopter vibration health monitoring Data”, Vol. 01 Based on a report prepared for the CAA by GE Aviation Systems Limited; Tech. Rep. No. ISBN 978 0 11792 403 1), Civil Aviation Authority - Safety Regulation Group, 2012

20. K. Liu, J. S., N. Gebraeel, “A data-level fusion model for developing composite health indices for degradation modeling and prognostic analysis”, IEEE T. Automation Science and Engineering, 3(10), 652-664, 2013

21. Gueorgui Mihaylov, Giovanni Jacazio, Franco Pellerey, Multivariate Methods For Mechanical Failure Diagnostics (Preliminary Analysis) Technical Scientific Report Vibmon-001, 15 October 2013

22. Gueorgui Mihaylov, Giovanni Jacazio, Franco Pellerey, “Multivariate Methods For Mechanical Failure Diagnostics (Analysis Of The Covariance Structure)”, Technical Scientific Report Vibmon-002, 27 December 2013

23. T. Zaman, A.E. Bayoumi, “Analysis of health and usage monitoring system (HUMS) users' perspective towards mission benefits using regression analysis”, AHS 70th Annual Forum & Technology Display, Montreal, Quebec, Canada, May 2014

24. Gueorgui Mihaylov, Giovanni Jacazio, Franco Pellerey, “Software implementation of an Integrated multivariate health Monitoring system”, Technical Scientific Report Vibmon-001, 10 September 2014

25. Gueorgui Mihaylov, Giovanni Jacazio, Franco Pellerey, “Calibration procedures andSoftware of an integrated”, Multivariate monitoring system, Technical Scientific Report Vibmon-003, 29 September 2014

26. P.J. Dempsey, D.R. Wade, L.J. Antolick, J. Thomas, “Investigation of Spiral Bevel Gear Condition Indicator Validation Via AC-29-2C Using Fielded Rotorcraft HUMS Data”, NASA/TM-2014-218406, November 2014.

27. Valerio Prece, “Heliwise tool for helicopter advanced hums data analysis”, Vertical Flight Society’s 75th Annual Forum & Technology Display, Philadelphia, PA, USA, May 13-16, 2019

6. BIOGRAPHIES

Valerio Prece is an Italian Aerospace engineer graduated in Aerospace Engineer cum laude at University of Naples “FEDERICO II” (Italy). Operating in aerospace environment since 15 years, during his career he has gained several international experiences working with the most important aerospace companies.

With a strong technical background (experiences in aerostructure engineering and systems integration), he is operating in the Program/Project Management environment.

Currently Valerio Prece is Project Leaders in Leonardo Company S.p.A. for the development of several Ground Stations to support Helicopters on ground.

The most recent accomplishments are the development of HUMS data analysis systems for both military (AW101, HH101, NH90) and civil (AW139, AW169, AW189) customers and the development of a military mission plan system (HH101).

Presented at 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019