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HELICOPTER HEALTH AND USAGE MONITORING SYSTEMS - OBJECTIVES AND PHILOSOPHY FOR SYSTEM IMPLEMENTATION

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1. Abstract

During the last years the evolution in the field of helicopter operation has clearly revealed that there is an upcoming demand for application of health and usage monitoring systems. Certification authorities and operators ask for these systems which can provide improved helicopter operation safety and reduced operating costs.

For that reason, in particular the european helicopter industry has started the development of corresponding Health and Usage Monitoring Systems (HUMS).

Within these research activities a major task for Eurocopter Deutschland (ECD) is the development and implementation of a usage monitoring system for main gearboxes.
As a first step for system implementation ECD has tested a prototype system for on-board data acquisition. The trials were carried out on a BO 105 helicopter. The objective of these trials was gathering of data sets which can represent the load spectrum actually applied to the maingearbox during helicopter operation.
The data will be used as a basis for further system development so that, together with the gearbox design spectrum, the actual gearbox usage status can be determined.

In addition to the presentation of the trials with the on-board data acquisition system this paper provides some general ideas concerning objectives and philosophy for implementation of HUMS.

2. Definitions

For discussion of health and usage monitoring systems the following definitions can be used as a basis:
a) Health monitoring is a process which provides a means of determining the continued serviceability of components, systems, or structures, without the need for component removal for inspection.

b) Usage monitoring is a process which assesses the life consumption of limited-life components, systems, or structures, by monitoring actual damage/wear exposure.

3. General Aspects

The major objectives for application of health and usage monitoring systems are:
- Increase of aircraft operational safety through well-timed detection of incipient failures and wear as well as identification of the components concerned.
- Creation of economic benefits for the operator through reduction of maintenance expense.

In order to gain a maximum benefit from the use of health and usage monitoring systems, they should be applied to such helicopter sub-systems, where
- a failure can cause a flight critical condition
- maintenance means high expenditure for the operator
- system reliability cannot be enhanced by simple design measures.

Such helicopter sub-systems are essentially gearboxes, engines and rotors.

Gearboxes: Health monitoring will mainly be achieved by application of vibration analysis and oil debris monitoring.
Usage monitoring is based on measurement and analysis of loads actually applied to the gearbox as well as logging of actual operating time together with automatic history file management.

Engines: For health monitoring the following techniques are relevant: Power check analysis, gas path analysis, high frequency vibration analysis, oil system debris monitoring, gas path debris monitoring.
Usage monitoring comprises cycle counting, turbine blade creep monitoring and detection of limit exceedance.
Since modern engines already provide monitoring relevant parameters in their electronic control units (FADEC), engine HUMS should be operated in communication with the FADEC unit.

Rotor systems: Health monitoring can be based essentially on the assumption that any significant damage to a rotor blade, or to any other vital component of the rotor system, will manifest itself through a measurable change of the vibration signature.

Consequently rotor systems health monitoring can be performed by measurement and analysis of rotor vibration signatures.

For development of such systems, modern rotor track and balance systems can be used as a starting basis, since these systems already use algorithms for rotor vibration analysis.

For usage monitoring logging of rotor speed and operating time will be necessary.

For implementation of health and usage monitoring systems two basis concepts can be envisaged (Fig.1):

a) The pure on-board system, where all units necessary for data acquisition, processing, storage, and presentation of monitoring results are accommodated on the aircraft.

b) The combined system, where the entire monitoring system is divided up in two parts:
   - The on-board part which comprises all units for data acquisition, pre-processing, and storage.
   - The ground station for detailed data analysis and presentation of monitoring results after flight. For the ground station a suitable PC can be used.

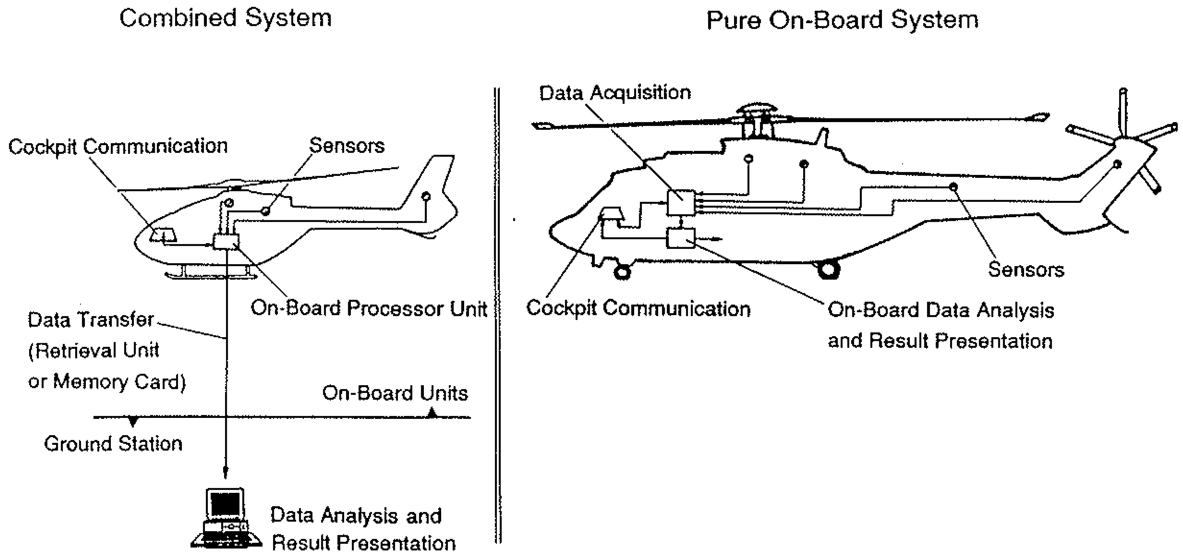

Fig. 1 Basis Concepts for Health and Usage Monitoring

Comparison of these basis concepts clearly reveals that the combined system provides some essential advantages:

- Vital monitoring functions can be shifted from the aircraft to the ground station.
- The on-board system necessary for performance of health and usage monitoring becomes less complex and requires less space for accommodation.
- Aircraft-related costs for implementation of a monitoring system can be reduced.
- One ground station computer can be used for several aircraft.
- The ground station provides large computing and memory capacity, so that detailed data analysis and result presentation is possible for each individual aircraft as well as fleet maintenance management.

Under consideration of the above advantages the combined system concept can be seen as the preferable solution for implementation of health and usage monitoring systems.
As far as in-service helicopters are concerned, it also provides good conditions for system retrofit.
The combined system requires data transfer between aircraft and ground station.
For this the memory card concept provides an attractive solution.
It requires memory card interfaces on the aircraft (card slot on the airborne data collection unit) and on the ground station (card reader unit of a suitable PC). The memory card allows convenient transfer of pre-processed data from the airborne monitoring units to the ground station.
Since the system also provides easy data transfer from the groundstation to the aircraft, programming of the airborne units by means of the ground station computer is also feasible (transfer of ground station data into the airborne system).

4. Consideration of Helicopter Size for Implementation of Health and Usage Monitoring Systems

A comparison of light and heavy helicopters shows that both fields of helicopter technology essentially comprise the same major subsystems (rotors, gearboxes, shafts, structure, etc.).

Thus the sources for generation of failures and wear which, if not detected well in advance, can lead to flight critical conditions, are identical for light and heavy helicopters.
This is also valid for monitoring functions providing reduction of aircraft operating costs through optimization of maintenance procedures.
In order to meet the requirements of the future helicopter market, heavy helicopters as well as light helicopters have to be equipped with monitoring systems.

Implementation of systems providing health and usage monitoring for light helicopters, however, requires a different philosophy than for heavy helicopters and that for the following reason:
In order to provide an attractive solution, the integration of all on-board units must yield a reasonable proportion related to costs, weight and space for the helicopter concerned.
Light helicopters require a more restricted cost and weight frame as well as they provide limited installation space for on-board units.
For that reason only the combined system concept is acceptable for light helicopter application, whilst heavy helicopters would also allow implementation of a pure on-board system.

A further contribution to realize a low cost monitoring system for light helicopters is simplification of on-board monitoring functions.
This, for instance, can be achieved through application of manually controlled data acquisition

sequences in lieu of automatic collection of monitoring data. Automatic data collection procedures reduce pilot workload, but they require additional on-board monitoring functions (e.g. flight regime recognition for rotor vibration monitoring) leading to enhanced system procurement costs and additional space demand for on-board installation.

For application of health monitoring functions consideration must be given to the philosophy of failure detection in order to realize an optimum monitoring system:
Whilst detection of critical failures requires release of in-flight warning signals (cockpit indication), post-flight maintenance information is sufficient for well-timed detection of incipient failures and wear.
As far as possible, the monitoring system should be designed such that in-flight warning signals are not necessary.
This objective means, that a monitoring system should have the capability to detect failures or wear already at a stage where they do not yet create a flight crititcal condition, so that the flight during which the failure is detected can be completed without restriction or abort.
Monitoring systems providing in-flight warning signals may require the system to be certified as flight critical, which may increase certification efforts. On the other hand, however, consideration must be given to the fact that monitoring systems having an early failure detection capability may require enhanced technical efforts to obtain this, and consequently will lead to higher system procurement costs.
Thus, for definition of an optimum system, trade-off studies are necessary considering a system concept providing in-flight warning signals with the respective certification expense as well as an early failure detection concept with the technical efforts necessary.
For a final concept definition consideration must also be given to the following aspects:

- helicopter system/component to be monitored
- failure analysis
- practical experience (failure propagation rate etc.)

5. Implementation of a Gearbox Usage Monitoring System based on the Combined System Concept

5.1 General Background:
HUMS activities at ECD are mainly related to light helicopters.
An important field of application is gearbox monitoring.
Since gearbox health monitoring by means of vibration analysis requires quite complex on-board systems, this technique should not be used for light helicopters. For this group of aircraft a gearbox usage monitoring concept should be realized together with a health monitoring function which is based on oil debris monitoring.
ECD have started their gearbox HUMS activities with development of the usage part.
The combined system concept will be used as a basis.
As a first step the on-board part of the system, comprising all units for in-flight data acquisition, pre-processing and storage has been implemented and is subjected to trials on a BO 105 helicopter (Fig.2).

Fig. 2 Test Aircraft for the On-Board Data Acquisition System - BO 105

First ground run tests have demonstrated that the system operates satisfactory.
The results are presented in chapter 5.4 of this paper. Long-term flight tests are planned to follow which will be combined with development, testing and validation of ground station algorithms.
The final concept will provide ground station processing of in-flight gathered data and design data in order to determine the actual gearbox usage status.

5.2 Technical Background:
Gearbox design and definition of gearbox maintenance instructions (inspection intervals, TBO etc.) are mainly based on a certain design load spectrum. During operation the actual load spectra may deviate from the design load spectrum to higher or lower values.
Application of load spectra higher than the design level will lead to premature component wear and thus to enhanced gearbox life consumtion whilst application of load spectra lower than the design level can result in an extension of gearbox life.
Practical experience has revealed that many operators perform helicopter missions at which they are below the gearbox design load spectrum and thus could extend the gearbox maintenance intervals.
However, the assumption for such an extension is that the actual loads applied to the gearbox during operation are carefully monitored and evaluated.
For this the gearbox usage monitoring concept has to provide the following major functions:

- During flight in the on-board monitoring units:
  Collection and pre-processing of gearbox load data which can represent the actual load spectrum applied to the gearbox.
- After flight on the ground station:
  Determination of the remaining gearbox operating time by means of comparison between actual load spectrum and gearbox design load spectrum.

5.3 System Description (Fig.3):
The presently available system for in-fligh acquisition of basis data for gearbox usage monitoring comprises the following units:

a) On-board:

- a four channel processor unit (Fig.4)
- four signal pick-ups (main gearbox)
  ° input torques 1 and 2
  ° oil temperature
  ° mast bending moment
- one interface (connector) for data transfer to the ground station.

b) Ground station:
During the first trials ground station processing is used only for presentation of the load spectra acquired during flight.
For this a laptop computer was chosen which can also be used as data retrieval unit.

The final system configuration for gearbox usage monitoring will essentially have additional functions on the ground station for detailed comparison and evaluation of load spectra (Fig.3).
For ground station operation then a suitable PC will be used.

The core part of the presently available data acquisition system is the on-board processor unit (Fig.4).
This unit allows four parameters to be simultaneously and permanently measured, processed and stored, as long as the processor unit receives external electrical power.
The electrical power has to be taken from the helicopter's electric power supply system.
The on-board processor software provides a classification of measured data based on the "time at level" concept, at which the measuring range for the monitored parameter is divided up in a certain number of classes.

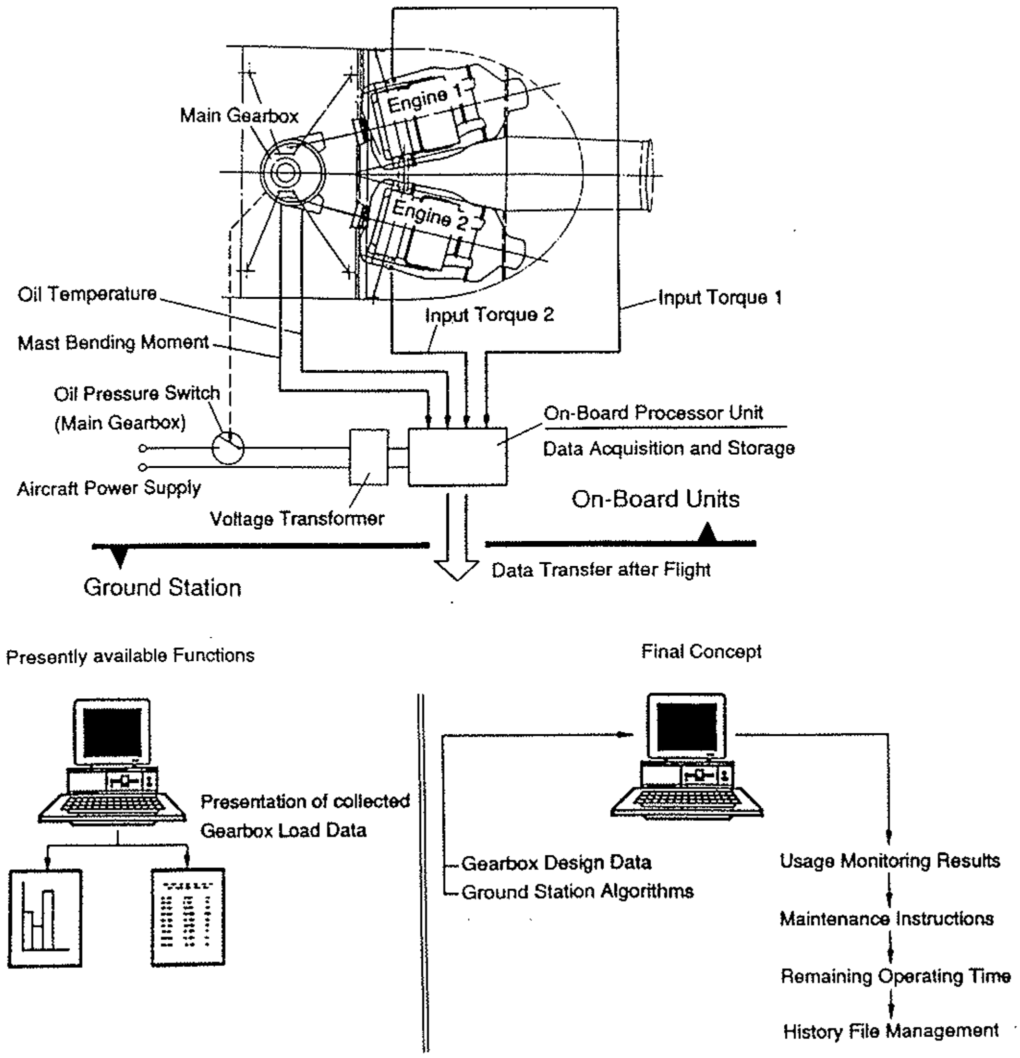

Fig. 3 System Concept Gearbox Usage Monitoring

Measuring points are acquired with an adjusted scanning rate and are assigned to the corresponding classes.
After transfer of these data sets to the ground station, the scanning rate together with the number of measuring points accumulated in each class provide an operating time related spectrum as well as the total gearbox operating time.

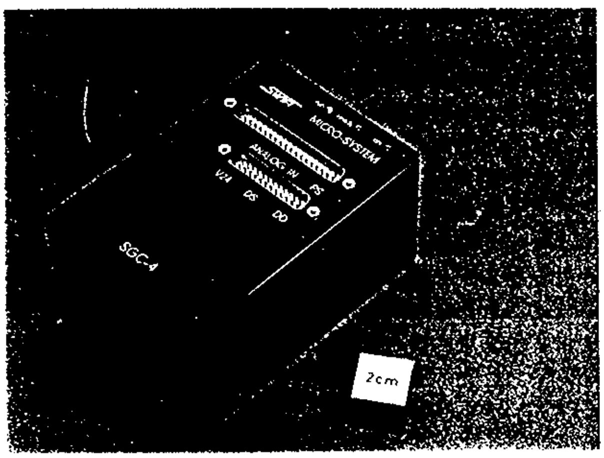

Fig. 4 On-Board Processor Unit

5.4 First Trials and Results:
For first trials on an ECD test aircraft (BO105-Fig.2) the on-board

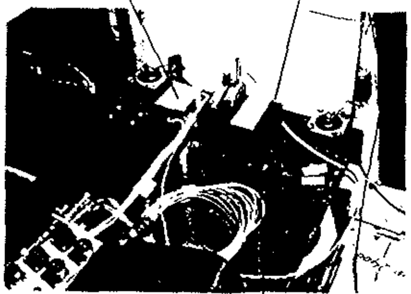

Fig. 5 On-Board Processor Unit installed on Test Aircraft

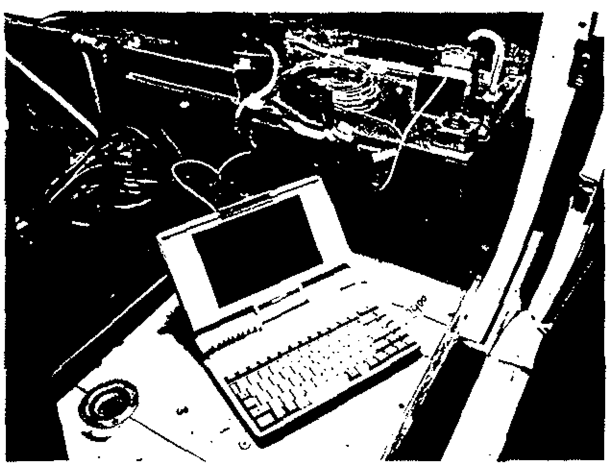

Fig. 6 Data Transfer to Ground Station (Laptop) after Flight

processor unit was mounted on a special test instrumentation platform inside the cabin (Fig.5/6). The first data sets were gathered during a ground run at which main gearbox input torque was increased in defined steps.
After each increase the torque was maintained for a short period.
The data sets collected during aircraft operation can be presented either as tables (Fig.7 gives an example for one torque input) or as diagrams (Fig.8 and 9).

Torque Classes (Nm) upper Limit	Torque Classes (Nm) lower Limit	Period of Dwell (msec.)
438.78 -	432.88	539.
432.88 -	426.98	6078.
426.98 -	421.08	16897.
421.08 -	415.10	11424.
415.10 -	409.20	4206.
409.20 -	403.30	1781.
403.30 -	397.40	2603.
397.40 -	391.50	6241.
391.50 -	385.60	14298.
385.60 -	379.70	15021.
379.70 -	373.80	7640.
373.80 -	367.82	2445.
⋮	⋮	⋮
60.53 -	54.63	1904.
54.63 -	48.73	723.
48.73 -	0.0	0.

GESSUM= 395119·

Total Operating Time (msec.)

Fig. 7 Data Sets for one Torque Input

The data which were gained during the ground run have demonstrated, that the on-board data acquisition system provides the actual gearbox load conditions with sufficient accuracy which gives a good basis for further development work in order to implement the entire gearbox usage monitoring system.

5.5 Benefits expected through Application of a Gearbox Usage monitoring System:

- Optimum utilization of gearbox components
- Controlled on-condition operation providing economic benefits as well as improved operating safety
- Reduced expense for inspections/maintenance

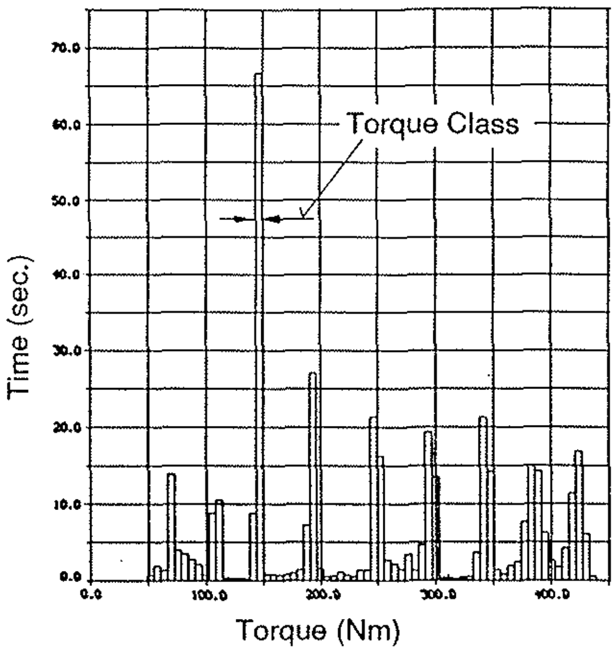

Fig. 8 Spectrum for one Torque Input

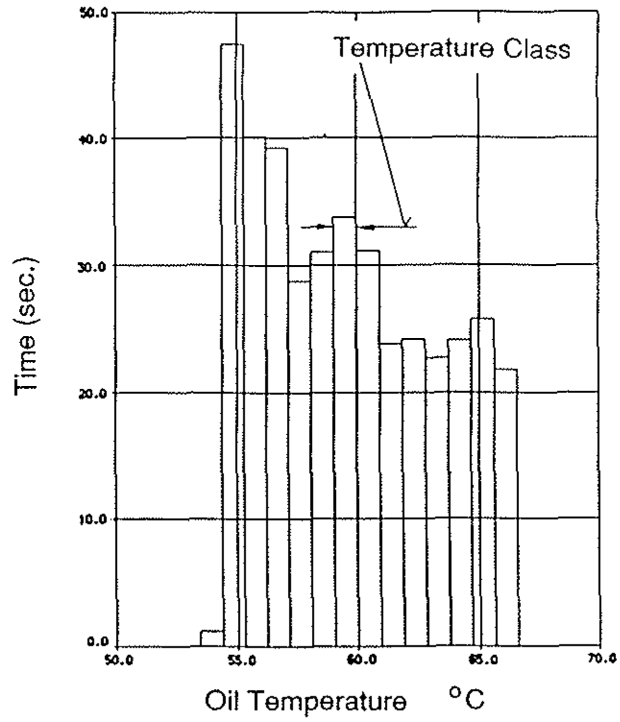

Fig. 9 Gearbox Oil Temperature Spectrum

- Capacity for automatic up-date of historic files and fleet maintenance management.

6. Conclusions

The combined system concept provides an optimum solution for implementation of Health and Usage Monitoring Systems (HUMS), because this concept allows simple and compact design of on-board HUMS units. Helicopter sub-systems for which application of HUMS can be important are essentially gearboxes, engines and rotors.

ECD have started their activities for implementation of HUMS in the field of gearbox usage monitoring. The system will be based on the combined system concept and consequently comprises the following parts:

- On-board units for acquisition, pre-processing and storage of actually measured gearbox load data representing the load spectrum applied to the gearbox during aircraft operation.
- A ground station for detailed load spectrum analysis after flight in order to determine the actual gearbox usage status.

Since the gearbox monitoring system is presently being developed for application to smaller helicopters (BO105), the final gearbox HUMS configuration will comprise an advanced oil debris monitoring module (gearbox health monitoring) in addition to the usage monitoring function.

The on-board part of the gearbox usage monitoring system has already been implemented and successfully tested on a BO105 helicopter. For this, simple ground station procedures were used to represent only the data gathered during aircraft operation. Go-ahead activities will mainly concentrate on development of ground station algorithms to enable performance of a full usage monitoring procedure for the main gearbox.

The presently available on-board processor is a prototype unit. Because of its small dimensions (Fig.4) it can be easily accommodated even on smaller helicopters.

For the final configuration of the on-board part this processor unit has to be designed as a standardized HUMS module to allow easy combination with other modules which could be necessary for monitoring of other helicopter sub-systems like engines, rotors, etc. (depending on aircraft type, mission, operator demand etc.). This modular HUMS concept would allow easy compilation of specific HUMS configurations.

7. References

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