Diagnostics for Light Helicopters

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Abstract—This paper addresses the issue of providing affordable diagnostics for light helicopters. The latest monitoring techniques and sensors are also reviewed for application in these highly cost-sensitive applications. Health and usage monitoring functions are evaluated and approaches suggested to address both the light helicopter models with analogue instrumentation and those with digital instrumentation. The suggested architecture and features are compliant with the RITA HUMS Digital Interface Specifications while maximizing the use of COTS technology. Key barriers to fleet-wide implementation of diagnostics in light helicopters are addressed and include the following:

1. Cost barriers for light helicopter diagnostics equipment and sensors.
2. Equipment size barriers (installation space is extremely limited).
3. Weight barriers (installed weights must be a small portion of aircraft payload).
4. Fleet retrofit barrier (installation times must be minimized).
5. The recurring burdens of training, operating the systems, and interpreting the data.
6. Open systems barriers (compatibility with medium and large helicopter HUMS).

INTRODUCTION

Selecting a diagnostic system for light helicopters is challenging. Cost is the predominant system driver. Commercial helicopter operators have to stay lean and mean just to survive. A $250,000 diagnostic system can't be justified in light helicopters when the systems would be a significant portion of the aircraft acquisition cost. In addition, a major portion of this market is composed of smaller operators who can't justify non-mandatory expenditures regardless of the enhanced safety and operating cost benefits of the systems. It is often the smaller operators who might benefit the most from the added operational awareness and assured readiness that on-board diagnostic systems or health and usage monitoring systems (HUMS) could bring to their operations. Operators today understand the value of diagnostic systems, but comprehensive systems remain unaffordable for the majority of revenue-producing aircraft.

CHALLENGES

Specifying a diagnostic system for a light helicopter model amounts to finding "the Practical Solution." The predominant cost driver in diagnostic applications is the acquisition of flight data required to automate and enhance the systems. Flight data recorders (FDR) are not mandatory for helicopters with a capacity of less than ten passengers or with a gross weight of less than 2,730 kg. In aircraft with analogue instrumentation, data acquisition costs represent nearly half the system cost and account for 50% of the installation wiring. The complexity and time required to complete the installation is also significantly greater. For example, the HUMS for the Bell 412 requires almost one hundred wires for flight data acquisition. Aircraft of this type with analogue instrumentation require up to six weeks to complete an installation.

AIRCRAFT CHARACTERISTICS

Bell Helicopter has a number of helicopter models that are representative of the varying requirements encountered in fitting diagnostic systems. These models include the 206B, 206L, 407, 427, 430, 412, and BA 609 commercial models (see Fig. 1), and the U.S. Army's OH–58D. The Model 206 is an example of a light helicopter with conventional analogue instrumentation, as shown in Fig. 2. It is similar to the much larger fourteen-place Model 412. The Model 407 includes a full-authority digital engine control (FADEC) and LCD engine instruments that can be interfaced to a serial bus for transferring discrete event and exceedence data to a diagnostic system. The 427 and 430 models both have FADEC-controlled engines and integrated instrument display systems (IDDS) that include ARINC 429 digital output of the necessary engine parameters. Fig. 3 shows the cockpit configuration of an IDDS-equipped helicopter. The IDDS also provides automated power assurance and exceedence monitoring functions that are often included in the HUMS in an aircraft with otherwise analogue instrumentation. An optional electronic flight instrument system (EFIS) is available for the Model 430. For the sake of comparison, the BA 609 is a fully digitized aircraft that includes engine monitoring, power assurance, exceedence monitoring, and basic usage monitoring as built-in features. The BA 609 also includes vibration monitoring of the cross-shaft hanger bearings as part of the basic aircraft equipment. This means

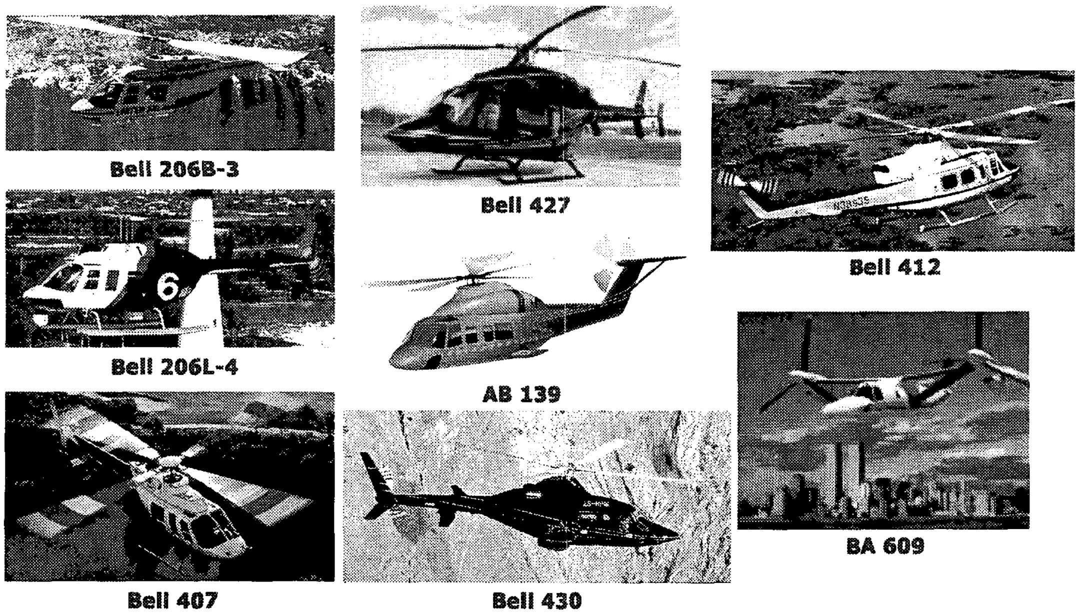


Fig. 1. Bell commercial helicopter models.

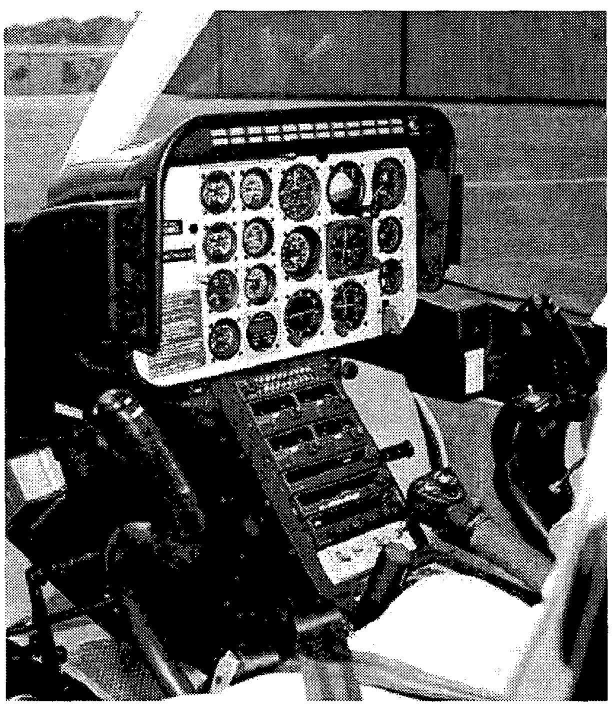


Fig. 2. Conventional analogue instrumentation.

that the cost of adding a kit with full diagnostic capabilities is considerably reduced for the BA 609. The U.S. Army's OH–58D is another example of an highly integrated aircraft. All required flight data and avionics bit data are available on the aircraft's MIL-STD-1553 data buses.

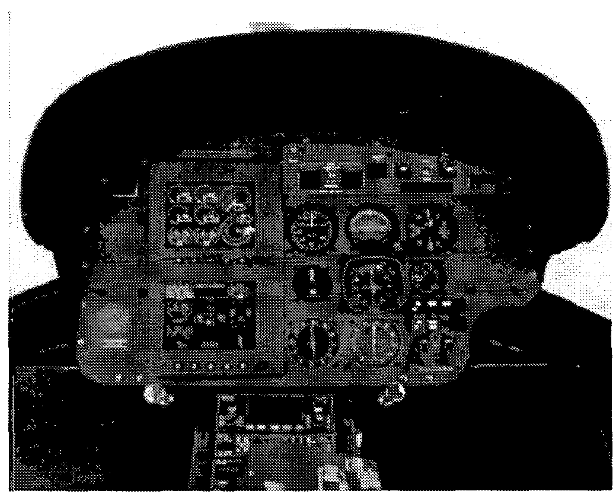


Fig. 3. Cockpit configuration of an IDDS-equipped helicopter.

Flight data parameters commonly required for diagnostic applications can be grouped into the following categories:

- Engine parameters
  1. Engine torque (each engine).
  2. Mean gas temperature, MGT (each engine).
  3. Engine gas producer speed, N_g (each engine).
  4. Engine power turbine speed, N_p (each engine).
  5. Main rotor speed, N_r (rotor).
  6. Engine oil pressure and temperature.

- Exceedence and warning, caution, advisory (WCA) discretes

- Oil debris data

- Heading/attitude data
  1. Aircraft heading
  2. Pitch attitude
  3. Roll attitude

- Control positions
  1. Collective position
  2. Pedal position
  3. Cyclic position, longitudinal
  4. Cyclic position, lateral

- Air data parameters
  1. Airspeed
  2. Outside air temperature (OAT)
  3. Pressure altitude
  4. Altitude rate

- Center-of-gravity (cg) acceleration

Table 1 summarizes the availability of these flight data sources for the helicopter models included in this review. Air data are required for automated data acquisition. Air data, control positions, heading/attitude data, and cg acceleration are generally required to implement usage monitoring and meet FDR requirements for larger aircraft. The table therefore gives some perspective of how the cost of implementing diagnostic systems changes for the various models. For example, the 206 models are predominately analogue aircraft and would require the same processing and sensors as the much larger Model 412 to achieve full HUMS functionality. The burden of analogue data acquisition as identified in the next section is too great to consider implementation of such a system.

Analogue Data Acquisition Cost Drivers

The market for HUMS has been slow to develop, primarily due to equipment acquisition costs and life-cycle costs associated with installation of such systems. HUMS have been fitted in larger aircraft where a flight data recorder was a mandatory requirement and/or when safety is a major concern, such as in the North Sea. To put things in perspective, the cost of installing a stand-alone FDR system in an analogue aircraft is approximately $90,000. It is not too difficult to understand why a HUMS is most often fitted when FDRs are required, since the acquisition of flight data is a prerequisite to many HUMS functions and a major cost driver. The lowest cost diagnostic systems are either engine monitors, utilizing a very limited set of flight data parameters, or some form of simple vibration monitoring based on pilot initiated data acquisition. Currently, the lowest cost vibration monitoring systems providing basic benefits and requiring manual data collection are offered at $25,000 to $30,000. Some in the aerospace industry have suggested that the cost of HUMS needs to fall within 2% of the helicopter's acquisition cost. For light helicopters, that translates to $20,000 at the low end for a $1 million aircraft, up to $80,000 for a $4 million machine. This is more than an order of magnitude lower than what is possible with current FDR/HUMS systems in large helicopters. As can be imagined, the choice of capability will be based on aircraft type and the extent to which required flight parameter data is available digitally.

A specialized data acquisition processor with high isolation inputs is required to make the necessary analogue to digital conversions. The following are some additional requirements for acquiring data not provided digitally in the aircraft.

- Engine parameters Requires as many as sixteen wires to existing ac sensors.

Table 1. Available flight data sources.

Helicopter Model	**206 B3**	**206 L4**	**407**	**427**	**430**	**412EP**	**BA 609**	**OH–58D**
Number of seats	5	7	7	8	10	15	11	2
Gross weight (lb)	3,200	4,450	5,000	6,500	9,000	11,900	16,000	5,500
Type of data:								
Engine parameters				X	X		X	X
Exceedence data			X	X	X		X	X
Oil debris data				X	X		X	X
Heading/attitudes							X	X
Control positions							X	X
Air data							X	X
CG acceleration							X	X

- WCA discretes — Requires as many as fifteen to twenty wires to existing aircraft circuitry.
- Chip detectors — As many as eight wires are required to record chip detector history.
- Heading/attitude — Existing sensors and nine additional wires are required.
- Air data — An air data computer must be added. Cost can range from $5,000 to $10,000, depending on the system selected. Interface to the aircraft's pitot-static system is also required.
- Control positions — Four control position sensors are required to ensure complete isolation from the flight controls. Twelve additional wires are required. Cost of the four-sensor set can approach $10,000.
- CG acceleration — Center of gravity accelerometer is required. Current units cost $2,500 and require an additional four to five wires.
- Weight on wheels (WOW) — A reliable "squat" switch or algorithm is required.
- Accelerometers — Cost of each accelerometer and mating ac connector can reach $600. A twisted shielded cable pair is required for each sensor installation. This adds $9,000 to $12,000 for a full complement of fifteen to twenty accelerometers as used on medium-to-large helicopters.
- Azimuth Sensors — Two to three sensors required at $500 each.

ENABLING TECHNOLOGIES

There are several potential technologies that show promise of providing important cost reductions or enhanced diagnostic capabilities for light helicopters.

Solid State Airspeed Sensors

Solid state airspeed sensors are being developed that show promise of lower cost, greater accuracy, and enhanced measurement capability down to zero airspeed. The sensors could interface directly with a diagnostic processor or be integrated into a stand-alone air data computer.

Piezoelectric Film Sensors

Piezoelectric film sensors may provide a potential low-cost alternative in some vibration-monitoring applications that currently use accelerometers. Performance is acceptable in lower frequency applications such as monitoring tail drive shaft hanger bearings. The film devices in their standard form cost less than $10, and less than $25 in shielded configurations. Piezoelectric cable is also available. The cost-saving potential of this technology is very attractive.

Stress Wave Technology

Stress wave technology offers an ultrasensitive sensor for detecting "friction" effects in rotating systems. The technology could potentially detect defects in couplings that are not detectable by other forms of monitoring. The technology's high sensitivity could detect gear tooth cracks earlier than current vibration-based methods.

Engine Gas Path Analysis

Engine gas path analysis is proving to be a good precursor of engine health. The technology is coming down in cost as the required sensors have been miniaturized. A good example is the EDMS System offered by Stewart Hughes of Smith Industries. Gas path technology adds diagnostic capabilities that can identify problems before collateral damage to the engine is detected by other means.

Wireless Sensors

Wireless sensors are actively being developed for a range of diagnostic applications. Temperature and strain-gauge sensors are already available, while development of wireless accelerometers is at the "drawing board" stage. The chief benefits of these devices is the reduction of wiring, reduction of installation weight, and the ability to monitor components in rotating systems without the need for slip rings.

While the above technologies are still in their development phases, they show promise in the future of reducing diagnostic system costs and/or enhancing diagnostic capabilities. The value of selecting a diagnostic system with open interface standards is crucial to the ease of implementing these enabling technologies as they become commercially available in the next few years.

ANALYSIS AND RECOMMENDATIONS

The most practical course to take for light helicopter diagnostics is a scaleable approach to the problem that makes use of existing aircraft data/sensors that are peculiar to each aircraft model.

Diagnostic Port Provisions

A good starting point for light helicopters is the installation of a vibration diagnostics port composed of a set of accelerometers, brackets, and cabling that can be used with portable vibration-monitoring equipment. The harness could be used for periodic monitoring of drive train balance and could be interfaced later to an on-board diagnostic system or HUMS. The recommendations of the aircraft manufacturer should be sought to ensure that the locations of the accelerometers and the design of mounting brackets is approved by the manufacturer. This will ensure that meaningful vibration levels are recorded and that the vibration levels will be compatible with manufacturer-supported diagnostic systems. A diagnostic port can be implemented for less than $10,000.

Basic (Non-Regime-Based) Vibration Monitoring for Light Helicopter with Analogue Instruments

Low-cost monitoring systems are available that take vibration data based on limited flight data information, such as engine/rotor speeds or torque. Manual data collection is required for acquiring data in the rotor track and balance (RT&B) flight regimes specified in the aircraft manufacturer's maintenance manual. These entry-level systems can provide basic vibration-monitoring data. Data sampling rates are sometimes lower (20–40 kHz) than the 100–200 kHz sampling rates required for gearbox monitoring in full-capability systems. In addition, these systems do not always include algorithms for determining RT&B adjustment moves, and sometimes may not be specified over the entire operational temperature range of the aircraft. The major shortcoming of these low-cost systems, however, is in using the data acquired for vibration trending. The system can not ensure that all of the data was taken under the correct flight conditions. Automated systems not only allow the collection of vibration data in specific regimes, but most importantly they ensure that the historical data base is not corrupted with data from casual button pushing or data collection by inexperienced personnel. The advantage of such is system is primarily its low cost. Systems deficiencies can be overcome with explicit crew training, strict operational procedures, and system integrity monitoring by a dedicated staff. Small helicopters like the 206 and 407 may be candidates for this type of system with an expected cost of $25,000 to $30,000.

Preferred Diagnostic Approach for Light Helicopters with Digital Instrumentation

The most capable and scalable diagnostic system for light helicopters would be an integrated version of the full-featured systems. The most cost-effective approach would provide the capability for a range of drive train diagnostics, engine monitoring, display, and PC card data storage in a single cockpit-mounted box. This unit would include the capability of interfacing to available digital data buses and to a limited number of analogue sensors (typically 12 to 18 parameters). If cockpit space is available, this single-box diagnostic solution would provide the most cost-effective diagnostics for light helicopters. The system would be suitable for aircraft such as the 427, 430 or OH-58D where a sizeable portion of the required flight parameters are available over digital data buses. The architecture of the proposed system is shown in Fig. 4. The Common HUMS Processing Unit (CHPU), when properly designed to RITA standards, could break today's barriers to the broad installation of HUMS in smaller rotorcraft.

Important aspects of the CHPU are its integrated Display and open RT&B adjustment interfaces. Existing HUMS are usually integrated with supplier/aircraft specific RT&B adjustment algorithms. In some cases, this capability is built into a unique portable maintenance aid that is also used for at-aircraft status and downloading data. The author proposes that a common interface for acquired RT&B data be developed that would allow an operator with a standard data conversion utility to use his choice of already available COTS RT&B adjustment equipment. This would allow significant flexibility in the operators choice of equipment and reduce the cost of including this capability in every system. The PC card download capability, open RT&B interfaces, and an integrated diagnostics display panel eliminate the need for a dedicated portable maintenance aide. A representation of a single-box diagnostic system is shown in Fig. 5. The complete unit is estimated to weigh less than 5 lb. With cabling and sensors, the overall system would be expected to weigh 10 lb, a significant reduction over the 40 to 50 lb of a HUMS for large helicopters. Acceptable dimensions of the CHPU are approximately 8.0 inches long by 5.75 inches wide by 4.5 inches high.

The CHPU as shown in the figure includes a removable control/display panel. In installations where the full CHPU height cannot be fitted in the cockpit, the lower processing module could be removed and located remotely with some additional cost, weight, and installation time penalty. The remaining control panel module height of 2.0 to 2.5 inches could then be fitted into a cockpit where additional space is not available.

The applicability of this approach to light helicopter diagnostics is considerable, since the design deals directly with the barriers of cost, size, weight, and installation complexity that have limited application of HUMS today. The CHPU also provides the open systems commonality required with the diagnostic systems of larger helicopters.

An entry-level system for light helicopters using the proposed architecture would include the following functions:

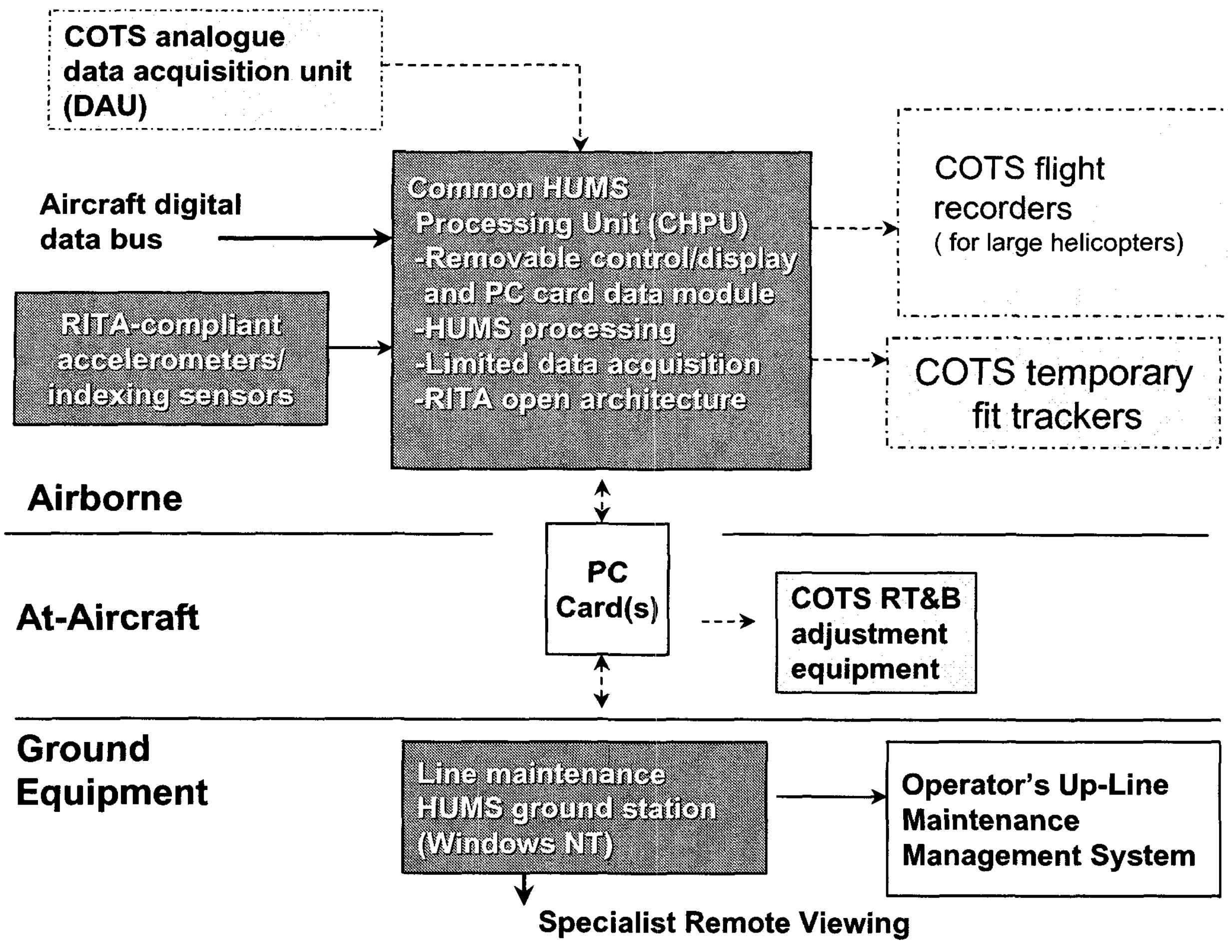


Fig. 4. Common HUMS architecture.

1. Engine monitoring meeting JAR OPS-3 Requirements
2. Engine power assurance, if not included in basic aircraft
3. Exceedence monitoring
4. Rotor track and balance of all adjustable components

Based on commercial quotations by one of the HUMS suppliers, the entry level regime-based system could be priced at $40,000 to $50,000, and would include the following components and features:

- The Common HUMS Processing Unit (CHPU).
- Air data computer.
- Seven accelerometers, used to monitor all drive train components that are monitored or adjustable for balance.
- Main rotor blade tracker.
- Engine monitoring, including JAR OPS-3 and power assurance, if required.
- Exceedence monitoring.
- RT&B, with interface to portable COTS RT&B equipment.
- Windows™-based ground station application software.

The system as proposed would be upgradeable to full HUMS functionality, including hanger bearing monitoring, gearbox monitoring, and structure usage, as desired by the operator.

Addressing the Recurring Burdens of Training, Operating the Systems, and Interpreting the Data.

Thus far our analysis has focused on the airborne system, its installation, and some of the open systems issues. Another aspect of the proposed system architecture is the Windows™ NT-based ground station with commercially available "remote viewing" or networking capabilities. The Windows platform provides an open systems platform in a format familiar to many Helicopter Operators. Most importantly, it is easily networked to provide essential and low-cost diagnostic support. While some of the larger

Fig. 5. Common HUMS processing unit (CHPU).

operators have undertaken the complete support for diagnostic systems, many operators do not have multi-aircraft bases or resources to afford dedicated diagnostic support personnel. Fortunately, such support can be easily and readily available from a remote diagnostic team of the operator or directly from the aircraft manufacturer or its diagnostic supplier. Some systems are being developed to provide easy internet-based support, which was unheard of just a few years ago.

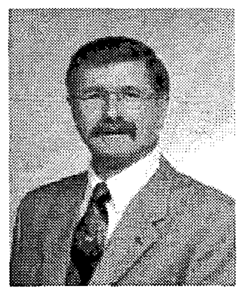
SUMMARY

Light helicopters with analogue instrumentation, such as the 206 and 407 models, are most suited to the *non-regime-based* diagnostic systems.

A next-generation *regime-based* diagnostic system has been proposed that directly addresses the barriers to the fleet-wide installation of diagnostic systems in light helicopters that have digital instrumentation. The architecture is applicable to the 427, 430, and OH–58D models, and can be expanded to medium and large helicopters due to the modular approach taken. A CHPU is technically achievable with today's technology. Low-current processors are now available to ensure that the heat dissipation of the CHPU will be acceptable. Few other hurdles remain. HUMS suppliers with the right resources and market vision are at work to provide this important technology at affordable prices to the light helicopter market.

Key features of the regime-based diagnostic system include the following:

1. Entry-level functionality for light helicopters at an affordable price.
2. Significant reductions in cost, size, and weight.
3. Reductions in installation complexity and time.
4. Modular hardware suited to light helicopters that will meet the full range of diagnostic requirements—with the addition of sensors and software only.
5. Commonality with medium and large helicopter diagnostic systems.
6. Elimination of a dedicated portable maintenance aid for the systems.
7. Use of the operator's choice of commercial RT&B adjustment equipment.
8. Incorporation of the HUMS open system architecture sponsored by RITA.
9. The ability to support emerging third-party technologies.
10. Use of a ground station with a common and open operating system that will be able to manage a mixed fleet of aircraft and diagnostic systems from all RITA-compliant suppliers.



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