

# A Real-time Quantitative Condition Alerting and Analysis Support System for Aircraft Maintenance

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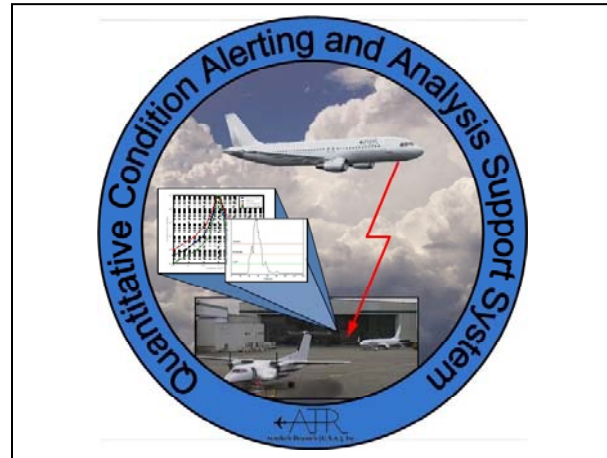
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## PROBLEM STATEMENT

Currently, aircraft operators (both civilian and military) are accruing significant operational costs due to unnecessary aircraft maintenance being performed and necessary maintenance being missed based on non-automated monitoring and aircrew subjective determination of specific conditions and events of interest to maintenance (e.g. severe loads, flap overspeed, hard landings, vertical and lateral loads at the tail). These operational costs include disruptions in flight schedules (flight delays, flight cancellations, etc.), rerouting and accommodations for passengers whose flights were canceled, disruptions in crew schedules, interruption or unavailability of sorties for military operations, missed business opportunities for corporate operators, and unnecessary maintenance man-hours.

An FAA and aviation industry committee formed to address NTSB concerns that aircraft may be returning to service before damage is found from an encounter of a high load event confirmed the above by finding that 'inspections may occur unnecessarily or not be correctly identified due to the reliance on the flight crew to report an event'.<sup>1</sup>

Additionally, since most aircraft are only equipped with accelerometers at the center of gravity (CG) location, little if any information is known about the loads experienced at the tail of the aircraft. This lack of loads data at the tail combined with the fact that aircraft operators do not have a clear and concise representation of an airframe's loads history, can result in either the aircraft being retired prematurely from service, or being in-service past their reliable operational lifespan.

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<sup>1</sup> "Best Practices Guide: Inspection Processes following High Load Events". Aerospace Industries Association Publication 05-01, September 1, 2005.

The Quantitative Condition Alerting and Analysis Support (QCAAS) system will reduce and eliminate some of the above operational costs.

### **WHO CAN BENEFIT?**

The QCAAS system will have numerous benefits to airlines (including regional jet operators) and business jet operators in their efforts to keep aircraft in top working condition, to ensure safe operation of aircraft, to reduce maintenance costs, and to reduce operational delays (and therefore costs) due to unscheduled maintenance. The system also has applications within the Department of Defense, including transport aircraft, tankers, patrol/command and control aircraft, and UAVs. Operators of high-end General Aviation aircraft may also benefit by having an improved awareness of some maintenance requirements for their aircraft – enabling maintenance to be performed at the right time (on-condition maintenance).

The system will also directly support the NASA Aviation Safety Program's focus on protecting and preventing damage to aircraft due to abnormal operations and system failures, and can be directly applied to two research thrusts of this program: 1) Integrated Vehicle Health Management (IVHM), part of whose focus is the development of computationally efficient tools for in-flight prognosis of aircraft health, self-awareness of airframe issues, mitigation of airframe failures, and the development of preventative and adaptive systems for in-flight operability and informed logistics and maintenance; 2) Aircraft Aging and Durability, whose focus is detection and mitigation/management of aging-related hazards of civilian and military aircraft. The fact that the QCAAS system comprises software only, lends itself to straightforward integration into simulations, laboratory tests, and flight experiments on NASA research aircraft.

Overall, QCAAS will provide NASA and the aviation industry a system that will assist in tailoring aircraft maintenance and optimizing life cycle decisions – resulting in reduced costs and increased reliability over the life of the airframe.

### **BASELINE TECHNOLOGY**

In current aircraft operations, the events that the QCAAS system automatically monitors for and provides a real-time report to maintenance on are presently:

- 1) Subjectively identified by the aircrew and manually reported to maintenance (e.g. severe loads identified by subjective determination of severe turbulence, brake overheating determined by aircrew noticing that a temperature has been exceeded on a temperature gauge, hard landing),
- 2) Manually reported by aircrew after an aural or visual warning (e.g. flap overspeed, overweight landings),
- 3) Determined by post-flight analysis of FOQA or FDR data (it is often done 7-14 days after the flight, if at all), and/or

- 4) Neither monitored for or analyzed post-flight due to lack of capability (e.g. tail loads).

Additionally, aircraft operators do not currently have a system in place to monitor for the cumulative loads on an aircraft. A loads analysis could be done at any point by an operator if the right flight data for all of the aircraft's flights were available.

Some systems do exist for capturing flight data, but they do not provide the real-time alerting on the events that QCAAS monitors for. Many of today's aircraft are equipped with a flight data recorder (FDR) that stores up to 25 hours of flight data (88+ parameters). The FDR data is not easily accessible and is typically used only for accident investigations. Some aircraft (airlines and business jet) are equipped with a quick access recorder (QAR) which can store flight data on an optical disk for up to 200 hours. The data from these QARs can be retrieved by a maintenance technician when the aircraft lands and sent for processing, but typically data is not available until 10-14 days after any particular flight. Analysis done on the QAR data can reveal events that require inspections, but the discovery is not generally timely. There are also some health monitoring systems (mainly for commercial airliners) that do provide real-time reports via data link, but most of these systems only monitor for and report on system faults identified by built-in-test-equipment (BITE) flags, and/or monitor for engine performance and malfunctions. The reports generally contain only a fault code that is deciphered by ground station software or maintenance to know which fault occurred. Some of these systems do have a load monitoring capability, but most of these look purely at a single acceleration value, do not assess the reasonableness of the value (i.e. the health of the reporting sensor), and report information that is routinely determined to be insignificant and is ignored by maintenance personnel. Few of the "real-time" systems provide any supporting flight data that helps the maintenance personnel examine in detail what happened when the fault was triggered or the maintenance event occurred. None of the systems that we know of provide any information on the loads that occur at the tail of the aircraft.

## TECHNOLOGY DESCRIPTION

AeroTech's Quantitative Condition Alerting and Analysis Support (QCAAS) system will reduce and eliminate some unnecessary operational and maintenance costs by enhancing aircraft health monitoring and maintenance decision-making through automatically generating real-time reports of specific events for which an inspection is necessary (e.g. load exceedances), reporting tail load information through a virtual sensor system, and providing reports of cumulative statistics on encountered loads.

The QCAAS system consists of software **only** (onboard software and a ground station database/interface) and maximizes the use of the myriad sensors, computational capabilities, and communication networks (e.g. ACARS and other datalinks) already available on most commercial airliner, business jets, and military aircraft. Since the software is considered non-flight critical and the outputs will comprise aircraft operations information only, it will not require FAA certification.

QCAAS provides real-time alerts and supporting flight data for the following events: severe loads encounters, severe maneuvers, maneuver  $n_z$  exceedance, flap overspeeds, landing gear speed exceedance, maximum operating airspeed exceedance, cabin pressure differential exceedance, cabin decompression, hard and overweight landings, landing with excess fuel imbalance, brake overheating, tail lateral and vertical load exceedances, and windshear encounters.

Two user interfaces at the ground will 1) enable maintenance personnel to view, sort, and track the QCAAS reports and corresponding information and 2) alert flight operations personnel that a maintenance inspection is required for one of their aircraft in service. The maintenance user interface will also enable the user to view and analyze cumulative load statistics for individual aircraft and across fleet types.

<b>Feature</b>	<b>Advantage</b>	<b>Benefit</b>
Real-time monitoring and reporting of need for certain inspections (see list above)	<ul style="list-style-type: none"> <li>- Quantitative determination of need for inspection</li> <li>- Autonomous reporting</li> <li>- Real-time awareness</li> <li>- Small Report Size</li> </ul>	<ul style="list-style-type: none"> <li>- Enables on-condition maintenance</li> <li>- Eliminate unnecessary inspections (savings in manpower, time, money, operational impact)</li> <li>- Real-time notification of inspection need enables Maintenance to develop a game plan for resolution of the problem (can reduce the overall time an aircraft is out-of-service for an inspection)</li> <li>- Enables aircraft operators to meet NTSB high load inspections recommendation</li> </ul>
Supplemental Flight Data for the Event	<ul style="list-style-type: none"> <li>- Quantitative summary of an event prior to aircraft landing</li> <li>- Automated</li> <li>- Small Report Size</li> </ul>	<ul style="list-style-type: none"> <li>- Enhances event analysis and preparation by Maintenance</li> <li>- Saves Maintenance time and labor by removing need to pull flight data from aircraft</li> <li>- Enhances maintenance decision making</li> </ul>
Tail Load Estimation	<ul style="list-style-type: none"> <li>- Tail load information without additional sensor/hardware</li> </ul>	<ul style="list-style-type: none"> <li>- Addresses NTSB recommendation</li> <li>- Enhances maintenance decision-making through improved understanding of loads experienced at locations other than the CG</li> </ul>

<b>Feature</b>	<b>Advantage</b>	<b>Benefit</b>
Cumulative Load Statistics Generator	<ul style="list-style-type: none"> <li>- Concise representation of experienced loads (CG and tail)</li> <li>- Automated report</li> <li>- Small report size</li> <li>- Enables tracking of aircraft exposure to loads</li> <li>- Enables comparison of loads experience for aircraft of the same fleet type</li> </ul>	<ul style="list-style-type: none"> <li>- Simplifies the tracking and analysis of A/C exposure to loads (reduces Maintenance man-hours)</li> <li>- Removes need to pull flight data for loads analysis</li> <li>- Enables a more quantitative approach to aircraft retirement or operational limits/life extension decisions</li> <li>- Could be used to optimize scheduled maintenance</li> <li>- Addresses FAA proposed rule change regarding prevention of Widespread Fatigue Damage (WFD)</li> </ul>
User Interfaces (Maintenance and Flight Operations) and Database	<ul style="list-style-type: none"> <li>- Immediate &amp; simultaneous awareness of aircraft inspection needs by Maintenance &amp; Flight Ops</li> <li>- Collaborative tool regarding inspections</li> <li>- Shared information</li> </ul>	<ul style="list-style-type: none"> <li>- Improves communication and collaboration between Maint. And Flight Ops</li> <li>- Improves decision making regarding operational schedules</li> <li>- Reduces impacts of inspections on operational schedule</li> </ul>

The QCAAS system will save maintenance time, manpower, and money (from unnecessary maintenance actions); assist in minimizing flight operation disruption due to required maintenance actions; enhance collaboration between maintenance and flight operations; will keep an aircraft in better condition; and enable aircraft operators to make better decisions with regards to specific aircraft maintenance plans, retirements, and extension of service life.

### **CURRENT STATE OF DEVELOPMENT**

The QCAAS algorithms and logic, including the tail loads estimator (virtual sensor) have been fully developed and tested using both simulated commercial quality and research quality flight data recorded on the NASA B757-200 research aircraft. The aircraft operator flight operations and maintenance interfaces are currently completing development and testing/evaluation using the research and simulated commercial flight data. With the completion of the ground station interface testing and evaluation the system will be at TRL 5. The next step will be to install the QCAAS system algorithms on an aircraft and perform a flight evaluation. The QCAAS system is based on AeroTech's Turbulence Auto-PIREP System (TAPS™), which is currently flying on over 180 commercial transport aircraft, so

there is high confidence that the QCAAS system will meet all performance levels in flight tests. Additionally, the aft loads estimator (virtual sensor) will need to be evaluated and validated on an aircraft other than a B757-200. We are currently in discussions with NASA to install and flight test the QCAAS algorithms/system on a transport aircraft other than the B757. We would also like to install the system into a business jet for evaluation and validation. We anticipate that the system could be fully flight tested/validated and ready for commercial use by Fall 2009.

## ABOUT THE COMPANY

AeroTech Research (U.S.A.), Inc., an aerospace engineering and consulting firm founded in 1994, is a recognized leader in Turbulence Detection and Avoidance Systems (TDAS™) and has provided innovative solutions to other complex engineering problems for a variety of organizations throughout the United States and internationally. AeroTech's pioneering Turbulence Auto-PIREP System (TAPS™) and Enhanced Turbulence Hazard Prediction Algorithms are currently being used by various commercial airlines. AeroTech has a diversity of experience in both aerospace and mechanical engineering, and has demonstrated a unique knowledge and capability in integrating various sensors' information, modeling and simulation, developing and implementing novel processing techniques, analyzing and developing sensors, and developing real-time situational awareness enhancement systems and displays for both pilots and ground personnel. AeroTech engineers have been nationally recognized by the American Institute for Aeronautics and Astronautics (AIAA), R&D Magazine, and the National Aeronautics and Space Administration (NASA). AeroTech has performed work for the DoD, FAA, and various NASA centers; and has worked with a wide variety of prime contractors including ARINC, Airbus, Boeing, Honeywell International, Lockheed Martin, Rockwell Collins, SAGEM, and Teledyne; and various airlines.