JETT Safety

An SwRI-developed trending tool helps analyze jet engine performance data

By Matthew B. Ballew

U.S. Air Force photo by Master Sgt. Val Gempis

In early 2003, a U.S. Air Force crew took flight in a KC-135 Stratotanker powered by four F108 turbofan engines. Unknown to the crew, one of the engines was operating with a critical component having failed. The component was a high-pressure turbine shroud hanger clip, which supports a metal shroud that expands and contracts around the rotating turbine blades to ensure proper operation and increased efficiency. The clip had broken, which caused the shroud to fall and rub against the rotating turbine blades. This condition, known as "shroud droop," can result in structural damage to the turbine and excessive operating temperatures as the engine attempts to compensate for the increased friction to maintain thrust levels.

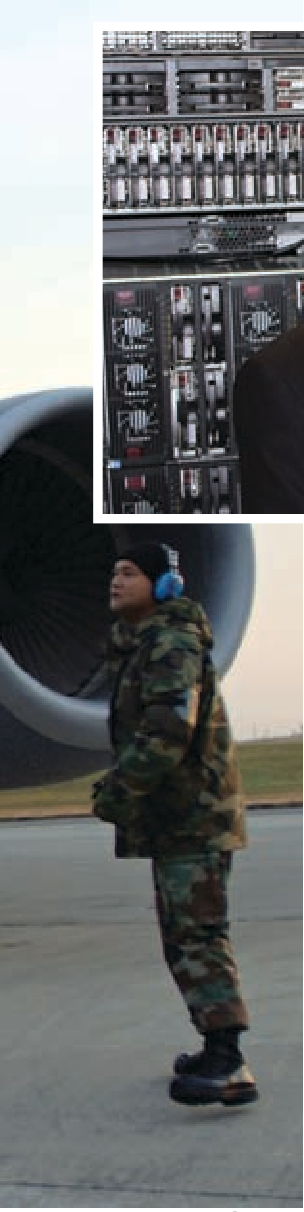
Shroud droop can cause an in-flight engine shutdown if the failure is immediate and catastrophic. However, in many cases, as in the example above, the system degradation can be more gradual. Although safety risks were increasing with each subsequent flight, the aircraft remained in service for several months before the engine's operating temperatures exceeded limits and forced an inspection.

SwRI engineers and analysts are conducting research into the analysis and presentation of engine performance data so that maintenance personnel can detect impending failures earlier, improving safety and reducing costs.

Current fault detection and diagnostics

U.S. Air Force jet engine monitors, maintainers and engineers use Engine Trending and Diagnostic (ET&D) software to analyze engine performance. Engine performance data are generally steady-state data obtained immediately after takeoff or during cruise (straight and level flight) conditions. Data are also reported when an engine event, or pre-defined fault, occurs.

The current trending tool stores the takeoff, cruise and event data, but allows the user only to view cruise and event records. These data are manually analyzed by plotting past flights and notifying the user when a parameter is exceeding predetermined limits, as was the case in 2003. The trending tool is run every day at each base after flights are completed to help maintenance personnel ensure the engines are capable of



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performing the required missions.

Indecisive results presented by the current trending tool are not unique and occur regularly, causing the Air Force to determine a need for improved ET&D. The data processed by the current trending tool, and the resulting analysis, generally remain at the local base. Fleet-wide data aggregation and analysis are difficult due to the distance and time required to transport the data. As a result, there is little opportunity to detect trends within the fleet or to identify differences in engine performance between bases or commands.

Other important engine data are gathered when an engine is run in a test cell to diagnose problems or to release the engine after repair or overhaul. The software used to automate the engine-run and gather data provides the test cell operator with results, but those results generally remain at the test cell.

Similarly, during engine repair, an analysis of engine oil is performed to determine if the sample contains an abnormally high metal count, which would indicate potential bearing wear or other internal damage. The results of the oil analysis are sent to the Navy's Joint Oil Analysis Program. A copy of the data remains at the operating base but is often not correlated to performance data already obtained.

In light of these issues, the Air Force has determined there is a need to store all related engine data in a central location for improved analyses. That central location was recently created and is called the Engine Health Management Plus Data Repository Center (EHM+DRC). The EHM+DRC is a data warehouse from which software tools can mine and analyze data. This system will receive engine performance data gathered during flight and ground runs, vibration data, test cell runs, failure data, maintenance actions and additional details. The primary site for the EHM+DRC is in Pennsylvania, and a backup system is located in an SwRI facility located in Oklahoma City.

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SwRI past work

A team of SwRI engineers has supported the Air Force with technical expertise and guidance for its gas turbine Engine Health Management Plus (EHM+) program for many years. The team has analyzed flight data, test cell data and engine cycle models and provided recommendations to improve the effectiveness of previous trending tools. The team has also generated technical manuals and has worked with SwRI training experts to develop and deliver ET&D training to engine performance monitors, managers and maintainers.

JETT development

The SwRI team has developed many software tools to support EHM+ activities, gaining insight into many common data acquisition, data manipulation and

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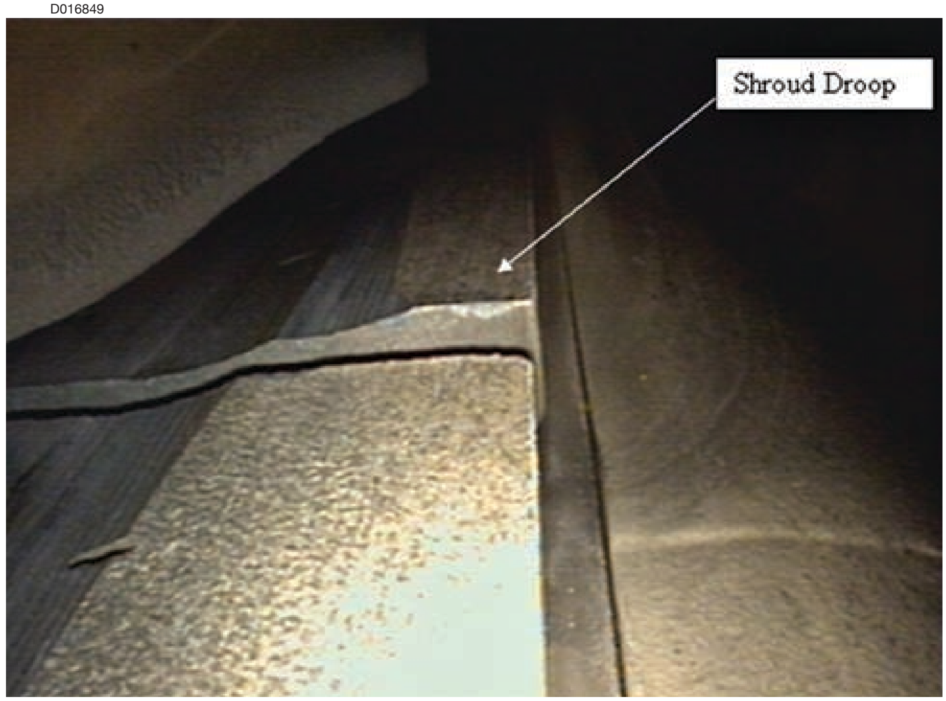
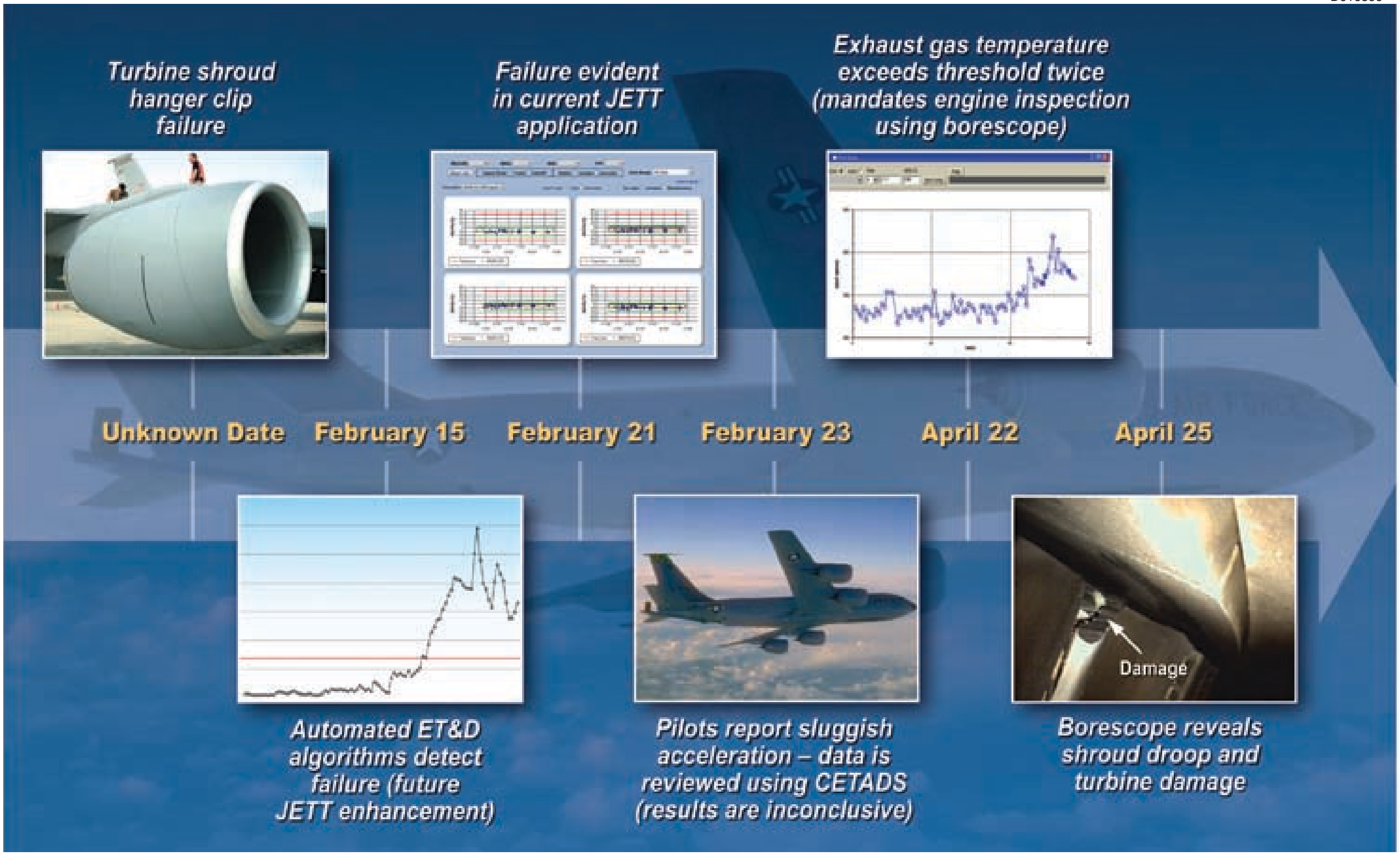


The shroud droop and damaged turbine blades are shown in the borescope images from the maintenance inspection.



The timeline shows the progression of the shroud droop example mentioned in the article. The date that the shroud droop was initiated is unknown. February 15 represents when the problem was detected using algorithms developed through internal research projects. February 21 represents the date a user would have noticed the problem if JETT had been available at that time.

engine performance issues. Many of these relate to assessing the overall health of an engine. After studying all available data being processed by current software programs and then developing and applying correction and analysis methodologies that accurately reflect the operational health of an engine, the team developed the Jet Engine Trending Tool (JETT).

The JETT program is a web-based application that consolidates, processes and provides steady-state cruise, takeoff, vibration and maintenance information and results to engine health management personnel, maintainers, engineers, logisticians and program management personnel. It not only provides engine-level performance analyses and results to be used to detect impending and current engine failures, but it also presents engine performance information that can be summarized at every level from fleet, to major command, base, aircraft and engine.

JETT reports timely, accurate performance information about the Air Force's assets and allows maintenance and management personnel to analyze engine performance obtained from the aircraft's flight data recorder; display engine performance values in graphical formats; print reports useful in planning operations, maintenance and overhaul schedules; calculate engine performance

The chart shows the fleet-level view of a health metric called Remaining EGT Margin, an indication of cumulative performance degradation based on the number of degrees remaining before a hard temperature limit is incurred and the engine must be removed.

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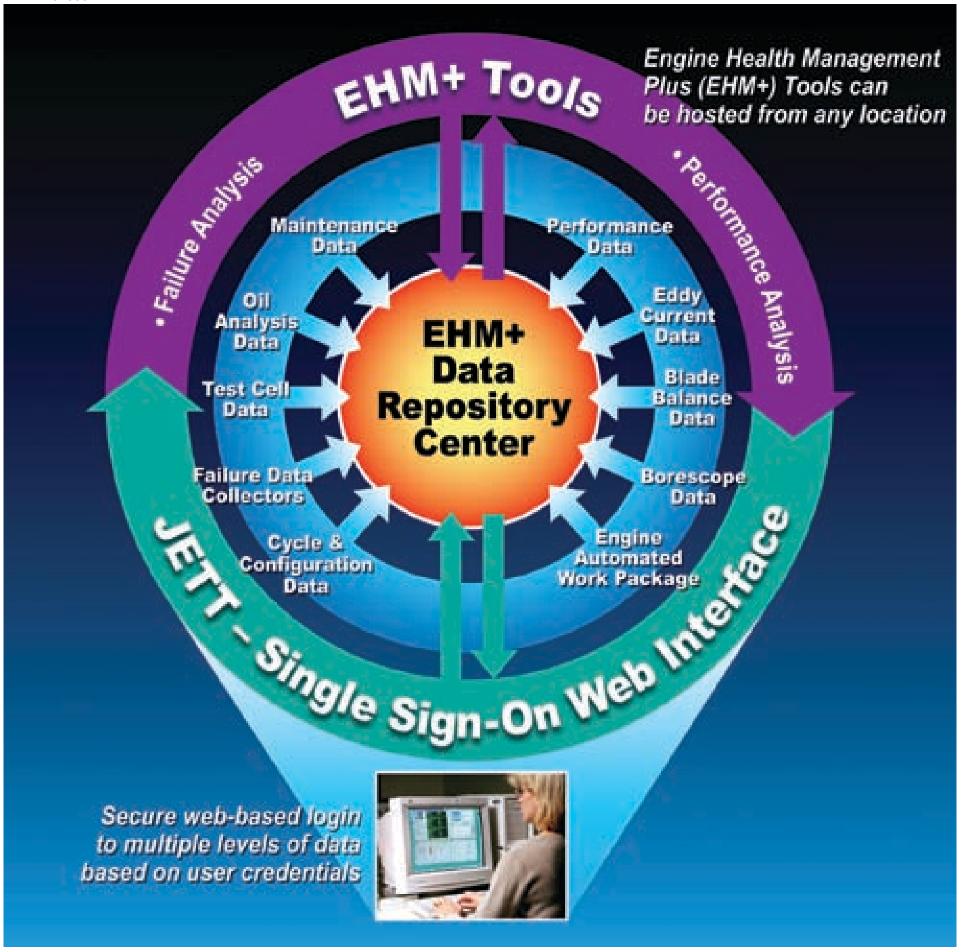

The diagram shows the many different types of data that will be stored in the EHM+DRC. Some data elements, like performance data, are currently housed in the EHM+DRC. There are several EHM+Tools that are used to analyze these data. JETT is currently being used to analyze performance data stored in the EHM+DRC.

values; and store constants and limits required by technical order operating guidelines.

Although not the principal focus of JETT, the data that it provides in terms of remaining engine-temperature margins can be used to support aircraft deployments. For example, transferring an aircraft with an engine that indicates little remaining exhaust gas temperature (EGT) margin to a hotter climate will likely result in the engine exceeding its temperature limits sooner, thus triggering a need to remove the engine, sometimes in less than ideal conditions.

Air Force propulsion engineers are using JETT to identify potential problems with engines that would require additional investigation. They are looking at engines for trends or shifts in performance that would indicate potential problem areas. Until JETT was developed, the Air Force had no consolidated view of the fleet nor the capability or methodologies to perform such analysis with ease.

Planned improvements to JETT

Future JETT improvements will focus on advancing ET&D to the automated detection and isolation of anomalies. This will involve implementing multivariate statistical analysis techniques developed under SwRI's internal research program. Further fault isolation can be achieved and automated using a fusion of physics-based and empirical models applied to the diagnostic process. These tools will reduce the time required to diagnose engine problems as well as reduce the costs associated with unnecessary maintenance caused by misdiagnoses. ❖

Questions about this article? Contact Ballew at 405-741-5420 or matthew.ballew@swri.org.

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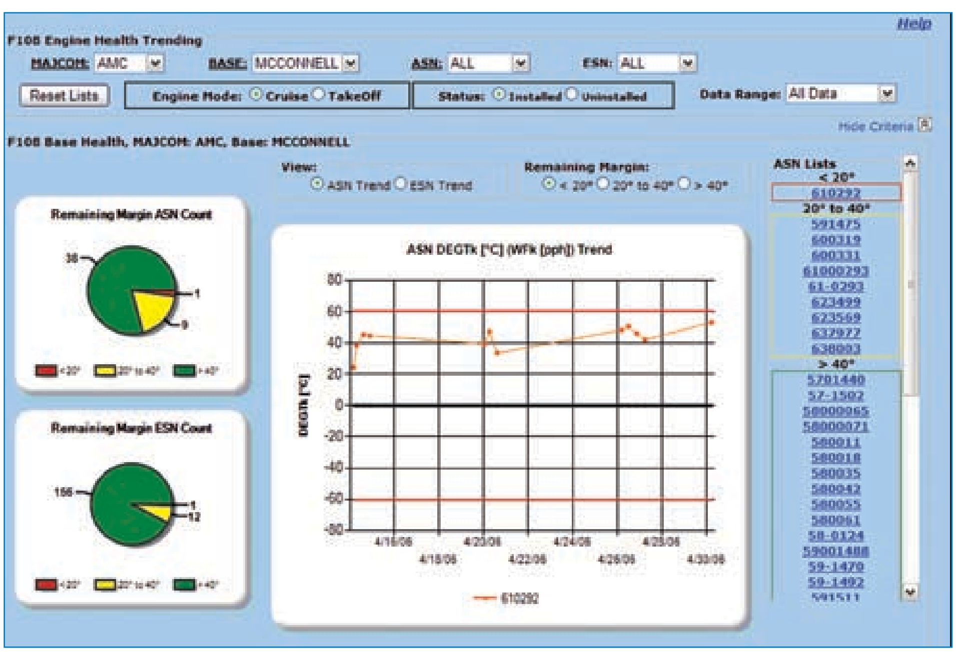

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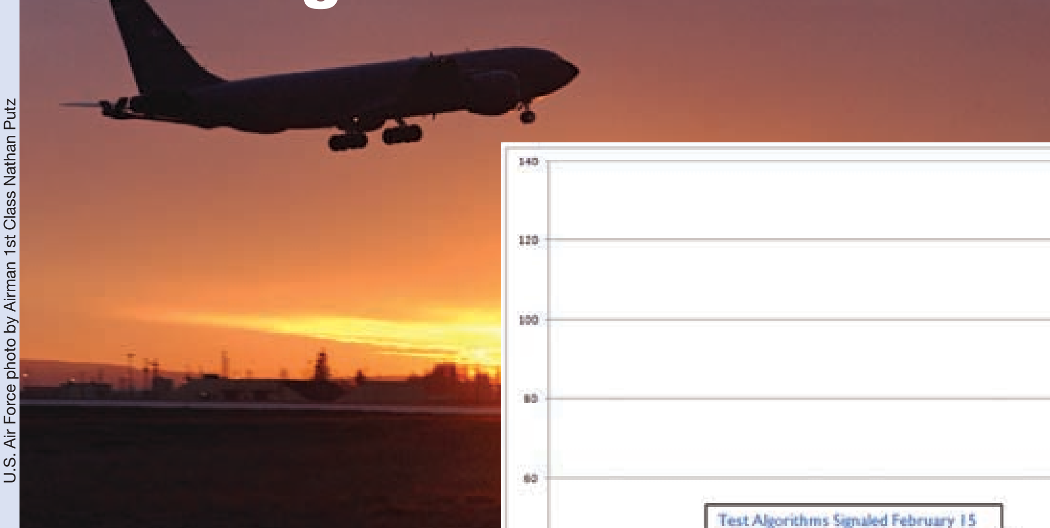
The aircraft data depicted here show an engine operating with less than 20 degrees of EGT margin remaining. That engine will exceed the hard operating temperature limit soon.

Advanced Statistics for Improved Engine Trending and Diagnostic Assessments



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U.S. Air Force photo by Airman 1st Class Nathan Putz

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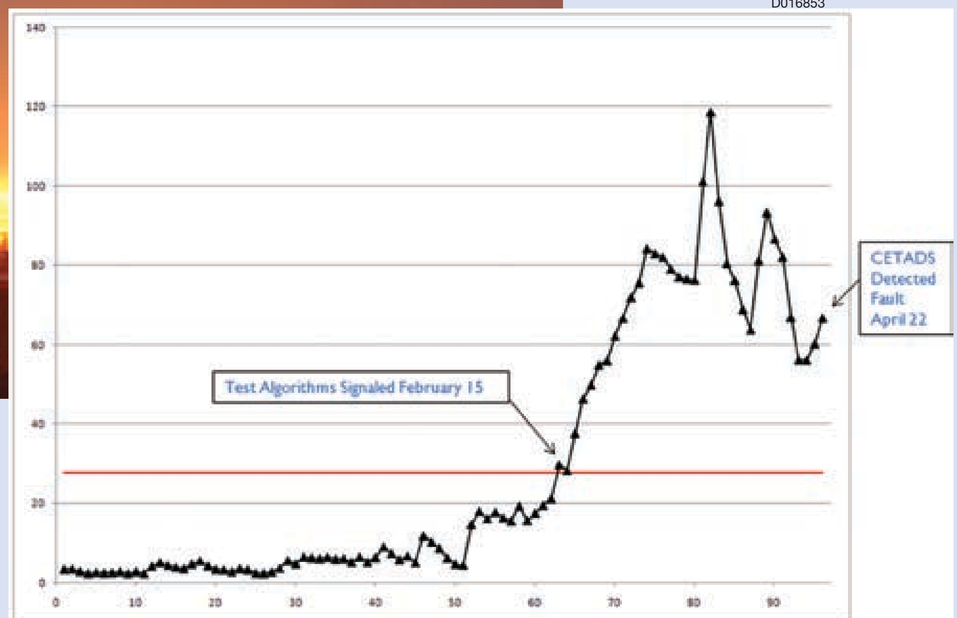

A test statistic applied to shroud droop is depicted in this line chart. The signaling observation on Flight 63 represents a detected anomaly with 99.9 percent confidence. This automated methodology detected the problem earlier and with more confidence than the manual processes currently employed.

Two recent internally funded research projects at Southwest Research Institute (SwRI) examined methods for improving the state of the art in analysis and prediction of jet engine performance and reliability. Both are adaptations of the Jet Engine Trending Tool (JETT) system, which improved Engine Trending and Diagnostic (ET&D) capabilities for Air Force jet engines.

The Advanced Statistics for Improved and Automated ET&D project sought to develop automated detection and diagnostic capabilities to better determine the health and condition of expensive military assets. The project succeeded in demonstrating that multivariate statistical process control techniques can be applied to gas-turbine engine data to accurately detect performance shifts.

A separate SwRI internal research project examined the comparative usefulness of analyzing transient, in addition to steady-state, engine performance data. Previous work with gas turbine engines had led SwRI engineers to believe that currently ignored high-stress, high-temperature transient data contains information that is more useful than the currently analyzed low-stress steady-state data. The F108 Transient Data Analysis project aimed to determine if more accurate system-level fault detection tools could be developed by analyzing transient engine data that is currently being ignored. The SwRI team developed a set of analytical tools, then used those tools to perform an analysis of transient (non-steady state) gas turbine engine data for ET&D purposes.

The primary challenge was to correlate multiple engine parameters over a wide range of transient conditions when the parameters' values vary due to throttle excursions, ambient conditions, aircraft loads and mission profiles. This correlation effort required the development of algorithms that quantified the parameters' relationships during these varying conditions. Another challenge was to define an automated process that filters flight data to extract the desired transient data.

Transient data were conditioned by applying standard day corrections and filtered based on throttle angle, steady-state definitions and time. The transient data sets that displayed a correlation between parameters were targeted for analysis in the baselining task. The data filter was applied to multiple engines over dozens of flights to produce a sample population. These data were analyzed to develop performance algorithms that baseline engine performance across transient conditions. The correlating parameter relationships were then quantified by the developed algorithms. Results confirmed the hypothesis that transient engine performance data are indeed more sensitive to performance issues than steady-state data.