Space age metrology

A workshop held at Cranfield University promoted discussion about how advances in metrology can help the aerospace and space industries. Steed Webzell listened in

During June, Cranfield University staged a metrology workshop focused specifically on the aerospace and space sectors. With keynote speakers lined up from Rolls-Royce, Surrey Satellite Technologies, Hexagon Metrology (event sponsor) and Cranfield University, the conference attracted around 70 delegates from across industry.

First up to the overhead projector was Dean Whitehead, measurement capability leader for blisks at Rolls-Royce. As a central figure in the establishment of a £1.3 million measurement cells at Derby, Mr Whitehead describes himself as "the lead protagonist for 5-axis scanning at Rolls-Royce".

He spoke in depth about a recent project that required the inspection of cooling holes in turbine blades used on the Trent 800 engine. The solution necessitated the integration of a specially developed vision system into an EDM cell capable of measuring the geometry, size and position of the cooling holes.

"We set out to develop a system that offered a total measurement accuracy of 0.015 mm," said Mr Whitehead. "The solution was based on a standard CMM fitted with a Renishaw ACR (auto change rack). A camera and lens were deployed using binary edge detection image processing software to determine the position of the features. The CMM was also fitted with a 2-axis rotary table so the turbine blade could be rotated as necessary."

The production of the Joint Strike Fighter engine by Rolls-Royce has prompted metrology initiatives

The project was deemed a huge success, out-performing by far the customer's previous system, where the cooling holes were measured manually by aligning crosshairs over the feature using a standard XY table. "The previous method was crude and fundamentally flawed as the datuming process was incorrect," said Mr Whitehead, who moved on to describe another recent project at Rolls-Royce.

It involved the measurement of blisks for the fan system within the F136 Rolls-Royce/GE engine used on the 'lift' variant of F-35 Joint Strike Fighter (the version intended to replace the Harrier).

"This level of NPI [new product introduction] is unprecedented at Rolls-Royce," said Mr Whitehead. "Beginning last year, one blisk was required every three months, while today, in pre-production, we are producing one every week. When we hit early production we will manufacture one every day, while in 2016, at peak volume, we will produce one blisk per shift. Major penalties lie in wait should any milestones be missed."

Initially, Mr Whitehead's team was faced with generating 120 new CMM programs for six new blisks in a 14-month period. Worse still, the task had to be completed without the hardware (the blisks) – to wait would add 22 weeks to the project which was deemed unacceptable.

"It was a tough challenge so we set ourselves a target of two days to write, run and prove each program," says Mr Whitehead. "However, we could only deliver 40-50 per cent of the functionality required because some of the complex features were not supported by our off-line system. This meant some programs had to wait for the arrival of the blisks, which in turn meant many long days to catch up."

According to Mr Whitehead one of the disabling factors was that the data relationships within a PLM (product lifecycle management) world should be intelligently linked, but this isn't the case with metrology.

"Where does measurement fit into PLM – it doesn't," he said. "We were sometimes working on CAD models that had been modified without the information filtering though to the metrology department which is very frustrating. We use Siemens PLM (formerly Unigraphics) but only now are we starting to understand how to migrate the measurement process into the software. It's a steep learning curve but one that I and my dedicated team are working hard to climb."

MODEL APPLICATION

Dr Helen Lockett, a lecturer in the Department of Aerospace Engineering within Cranfield University's School of Engineering, presented the work of students who are using 3D scanning to reverse engineer scale models of aircraft used for wind tunnel tests.

Scanning is performed using a Renishaw Cyclone 3D contact scanner and the data post-processed using CATIA V5. The scanned point cloud is overlaid against the original CAD model to attain a 'global' comparison. However, conclusions show that it is difficult to identify sources of error.

Improved model evaluation was subsequently achieved by constructing 'boundary curves' through the application of scanned geometry, although accuracy was not totally satisfactory. Better results have been obtained by comparing tessellated scanned surfaces with CAD surfaces which allows local surface differences to be investigated in detail.

Another research project (undertaken by a student from BAE Systems) that Dr Lockett shared with delegates involved the reverse engineering of legacy aircraft for CFD analysis (computational fluid dynamics). A 1:10 scale wind tunnel model of the Jetstream 31 aircraft was scanned using a Leica T-Scan handheld laser scanner. Using a 0.35 mm scanning grid density, over 1 million points were generated. Construction curves were generated using planar cuts through

The heat is on

Steve Shickell, UK sales manager for portable metrology at event sponsor Hexagon, presented a recent application regarding the use of equipment developed by group member CogniTens to aid the process of replacing damaged heat shield tiles on the NASA Space Shuttle.

CogniTens is patented rapid shot structured light and vision technology. The CogniTens Optigo collects 500,000 points per millisecond, displaying them instantaneously on-screen.

Working for customer United Space Alliance, a joint venture between Boeing and Lockheed Martin, the requirement was to accelerate the process of replacing heat shield tiles on the Space Shuttle which was becoming a bottleneck task between missions – hundreds of tiles sustain heat damage every flight.

"It sounds straightforward enough but because every tile has a different design, the tolerance build-up from surrounding tiles creates unique cavities that are not reflected in theoretical CAD data," explained Mr Shickell.

With large arrays of scaffolding around the Space Shuttle, conventional laser trackers were deemed unsuitable. With many people moving inside, fixed sensors would also prove ineffective due to airframe movement. Additionally there are issues regarding the varying colours and reflectivity of individual tiles.

"We proposed the use of CogniTens Optigo," said Mr Shickell. "This equipment can withstand structural vibrations as it accrues data so rapidly. It also has a very low sensitivity to changing reflectivity and ambient light levels."

According to Mr Shickell, a subsequent Six Sigma study predicts savings of £1 million per year due largely to reduced process time. The new technology was first adopted for mission STS-114 (July, 2005 – the first flight after the Columbia disaster) and is now standard for all Space Shuttle missions.

tessellated surfaces, while a smoothing operation was deployed through the curves to produce smooth transition and curvature across the aerofoil section with very few surface 'patches'.

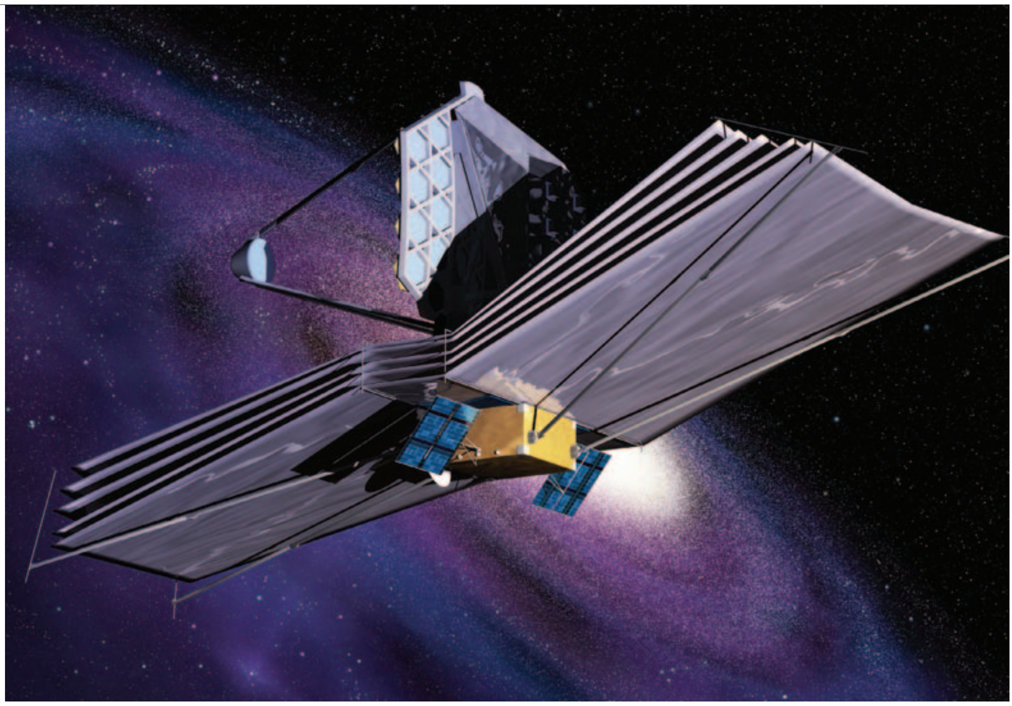
David Purll, chief space scientist and project manager at Surrey Satellite Technologies (currently part of a proposed sale to EADS Astrium) talked in depth about "changing the economies of space", largely through improving the techniques used to align and measure telescope optics.

SSTL has been involved with the build of many small imaging satellites, a number of which monitor natural disasters using their resolution of approximately 30 m. More recently SSTL played a vital role in the construction of the Beijing 1 mapping telescope, which features a panchromatic (black and white) camera with a resolution of 4 m. Better still, in current build is the 2.5 m resolution Nigeria Sat 2 satellite that houses two aspheric mirrors (primary and secondary).

Mounting such mirrors has proved a challenge as any clamps deployed must not distort the reflective surfaces beyond 50 nm form; conversely, the mirrors must be secure enough to withstand launch vibrations of 20 g-RMS. To evaluate the success of mounting, an interferometer used in autocollimation mode measures any distortion before and after glueing, providing contour maps to highlight problem areas.

Some systems, however, are not concentric, such as TMA (three-mirror anastigmatic) optics. Mr Purll said it is possible to spend months trying to align these off-axis aspheric mirrors. "With customers now requesting resolution of 1 m and better, a compact, short and efficient alignment method is required," he said.

SSTL's solution for alignment of primary TMA mirrors is to use a large volume CMM that defines the direction and placement of the optical axis by referencing an interferometer. Reflective spheres are used to transfer reference data between the CMM and the optical equipment.



Components for the James Webb Space Telescope have demanding metrology requirements

To align the convex secondary mirror, SSTL uses the Hindle sphere technique, while the final mirrors are aligned using interferometer autocollimation.

"The holy grail for our industry would be to complete the whole process using mechanical means alone," said Mr Purll. "Performing the entire process on a CMM would increase efficiency enormously and bring TMA systems within the reach of small satellite manufacturers with limited means. However, this is likely to prove beyond the scope of current research. An optimised hybrid approach is a more probable outcome."

OPTICAL CHALLENGE

Continuing the optics theme, Paul Morantz, an expert in the measurement and control of precision machines and components at Cranfield University's Precision Engineering Centre, presented work regarding the metrology surrounding MIRI, the Mid Infra Red Instrument used on the James Webb Space Telescope (the replacement for Hubble) which is due for launch in 2013.

The project involves the measurement of complex slicer 'mirror' components that are machined from solid using a high speed, 5-axis Kern micro-milling machine located in Cranfield's new Loxham Laboratory (see *Machinery*, January 2008, page 16). The components feature a relative surface location from slice to slice of ±0.030 mm, surface finish of 15 nm RMS, and 100 nm RMS form.

Milling operations leave a small quantity of material in place for ultra high precision diamond turning using Cranfield's Tetraform machine.

Various forms of metrology were deployed to measure the slicer mirror components, including a light ray test using a 'bread board' model, a standard contact CMM and non-contact surface profiling, but all proved unsatisfactory.

The eventual solution was provided in the form of an adapted technique based on interferometry. The process begins by using 'radius of curvature' measurement principles on an ultra-stable grinding machine that moves the component relative to an interferometer in three axes of motion. The technique acts as a form of 'analogue probe' and is transferred to a specially modified Leitz PMM-F 1000 CMM which provide the radius of curvature co-ordinates.

"The work we did with Leitz to improve the stability of the CMM was pivotal to the success of this project," says Mr Morantz. "Conventional roller bearings were replaced with air bearings that allow us to 'jog' the CMM as little as 20 nm without any impact on measuring process stability."□