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Concorde is shown being weighed by means of weighing-platforms beneath each landing wheel. The weighing-platforms have been calibrated at NPL. All aircraft must be weighed to conform to an Air Navigation Order.

FROM KILOGRAM (PLUS METRE AND SECOND) TO CONCORDE

R F Jenkins

The recent assistance provided by the Force Standards Section, DMOM, to British Airways on the problem of aircraft weighing, provides a starting point for a more general outline of the relevance of force standards to the aerospace industry. The measurement of force is a basic requirement for the testing of materials and components, for the development of jet engines and for the evaluation of aircraft designs in wind tunnels.

Safety

Before joining NPL, I worked as a progress chaser for Rolls-Royce one summer on the RB211 project. I soon realized the importance of the word 'traceability' and came to dread the word 'quarantine'! This was the storage area where all components and materials were placed if there was any doubt about their 'history', i.e. if they failed to satisfy inspectors at each stage of manufacture. The care with which each inspection stage of a complicated component is recorded, right back to the acceptance of the original batches of raw materials, is of the greatest importance in the aerospace industry - if there is a failure, the cause has to be pin-pointed as quickly as possible.

The accurate determination of several mechanical properties requires traceability to force standards. The proof stress of a material, i.e. the stress corresponding to a definite amount of permanent extension (commonly 0.2%), the fatigue life under carefully defined dynamic loading conditions and creep at elevated temperature are important properties that are determined by using appropriate materials testing machines. These machines range from the hand-operated machine with an analogue scale to the servo-hydraulic machine capable of operating under force or displacement control and incorporating a microprocessor in the control loop. All machines, however, must have their force-indicating scale(s) verified annually in accordance with a British Standard, BS 1610. The forces applied are generally less than 600 kN (a force equivalent to a deadload of approximately 60 tonnes) and have to be within $\pm$1% of nominal value for a Grade A classification. This is verified by means of force transfer standards which must have an uncertainty of less than 0.2%. The conventional proving ring - a steel ring of which the change of diameter caused by an applied force is measured by a dial gauge or micrometer - has been commonly used as the transfer standard for this range of force, but is being replaced in many cases by the strain gauge load cell with associated digital indicator.

Most testing machines are verified by their manufacturers, many of whom are approved by the British Calibration Service for this work. However, the great majority of transfer standards (about 400 each year) are calibrated at NPL by means of high accuracy force standard machines that meet the requirements of BS 1610. At present, there is only one industrial machine that has been approved by the British Calibration Service as meeting these requirements, - although we are currently investigating various possibilities of increasing the number of such machines.

The performance demands and the safety requirements in aviation inevitably lead to full-scale component testing, as there are always some uncertainties about the calculated stress values and the application of the laws relating to fatigue life. A good example of such a testing facility is the Concorde major fatigue rig at RAE Farnborough. Servo-hydraulic actuators apply forces to the aircraft through strain gauge load cells while at the same time the surface temperature is varied to simulate service loading conditions. The number of simulated flight cycles is kept well ahead of the actual cycles of the aircraft in service. The load cells used in the rig have calibrations traceable to NPL.

Design

Safety comes first - but it must be preceded by a successful design stage! The basic design tool of aircraft manufacturers is the wind tunnel, where 'sting balances' are used to support models in the air stream and to measure important parameters such as lift and drag forces on the model. Sting balances are elaborate, six-component, force and moment transducers which take their name from their slender shape. Their design is almost a science (and art) in itself and, as with load cells, the bonded electrical resistance strain gauge plays an important part. Having been designed, however, the sting balance must be calibrated. This can often be achieved by the direct application of weights, making allowance for the local value of free-fall acceleration and for air buoyancy, should the accuracy demand it. For larger sting balances, however, forces have to be applied through actuators and measured by force transducers, usually strain gauge load cells. For the sting balances of the 5 m wind tunnel at RAE, Farnborough, a special calibration rig has been manufactured which incorporates 'force generators'. These are air-operated piston-cylinder assemblies, capable of bi-directional operation, which have a specially developed seal to give low hysteresis. The air pressure is measured and controlled by means of quartz pressure transducers and the overall uncertainty aimed for is less than 0.01%. Such high accuracy is required, both for force measurement and alignment, to allow the detection of small differences and to facilitate the accurate measurement of the cross-sensitivities of the balance when one force component may be several times larger than another. Several actuators of different capacities have been evaluated and calibrated in the NPL 50 kN and 500 kN deadweight force standard machines. The article by R C Debnam in the January 1977 issue of NPL News described the use of NPL calibrated load cells of 500 kN capacity in a rig used for the evaluation of aircraft wheel assemblies. The 'cube-of-forces' system described in the article is equivalent to a rather large sting balance!

Performance

The measurement of thrust is of great importance in both the development of a jet engine and in the subsequent periodic monitoring of its performance in service. The specific fuel consumption (unit mass rate of fuel used per unit thrust produced) is an important economic parameter, especially when it is realized that the payload of an aircraft can represent a fairly small proportion of its total weight at take-off. A 1% improvement in specific fuel consumption could lead to a 10% increase in payload. High accuracy in force measurement is thus an economic necessity and is achieved by careful design of the engine test bed, where the thrust of an engine is measured by reaction against strain gauge load cells, and by ensuring traceability of the force measurement - the reference force transducers of Rolls-Royce, the National Gas Turbine Establishment and British Airways are all calibrated at NPL.

Aircraft Weighing

The same economic argument relating to payload applies to the need for an accurate determination of an aircraft's empty weight, i.e. without fuel or passengers. In addition, there is the need to determine the position of the centre of gravity so that the aircraft can be loaded correctly and to check both the known weight changes resulting from the embodiment of modifications and the unknown changes due to spillages and absorption of water in sound proofing materials. The Air Navigation Order, enforced by the Civil Aviation Authority, states that an aircraft should be re-weighed within two years of manufacture. Subsequent intervals between weighings are subject to agreement with the Civil Aviation Authority, but cannot exceed five years. Aircraft are weighed by the substitution method in which the downward force on the weighbridge due to an aircraft is equated to the force produced by known standard weights, stamped by the local Trading Standards Office. For convenience, British Airways have replaced the fixed mechanical weighbridges by portable weighing platforms which can be placed under either the undercarriage wheels of an aircraft or supporting jacks, as appropriate. The individual platforms are designed to weigh up to 25 000 kg but, because their loading area is only 1 m square, it would be very difficult to calibrate them by direct application of weights! After some discussion with British Airways, all the weighing platforms were brought to NPL for calibration. This was undertaken by loading a platform in series with a 500 kN reference load cell in a hydraulic machine, controlling the pressure to give forces equivalent to nominal values of cast-iron weights being placed on the platforms at Heathrow. The sensitivity of control enabled a given 'weight' to be applied to within ± 3 kg. A useful day was subsequently spent at Heathrow Airport seeing the weighing of a Concorde and special thanks are due to all those people who helped to obtain the photograph on the cover.

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A NEW STANDARD FOR DYNAMIC PRESSURE MEASUREMENT

G N Peggs

Familiar manometric devices like mercury columns and deadweight testers are ideally suited when the pressures to be measured are reasonably steady. However, none of these instruments can cope satisfactorily with dynamic pressures, i.e. pressures which vary with time in either an oscillatory or 'shock' fashion. The instrument industry has therefore developed a range of transducers (usually based on strain-gauges or piezo-electric effect) to cope with the measurement of dynamic pressures in gas and liquid environments over wide ranges of frequency and pressure. The fields in which measurements are required are equally wide ranging. In gas systems they range from the measurement of dynamic pressures at acoustic levels, to the transient pressures commonly