# Equipment for a possible thermo-mechanical test facility Oxford – RAL – Liverpool

## *Introduction*

This document lists the existing or planned equipment at Oxford, RAL and Liverpool, which could be part of a thermo-mechanical test facility within the AIDA II framework. It gives a short description of each component, explaining its capabilities, location and status. The list is intended as an input to the discussion whether such a facility would be useful for the community and what capabilities it should include for this. Not all this equipment would be necessarily part of the facility and for some of the components the exact mode of access will need to be discussed. It is quite possible that further institutions and equipment will be added to this list as a result of our discussions.

## Contents

## *Cooling plants*

### Fluorocarbon plant

Left over from ATLAS SCT assembly
Capacity: 100W @ -25° (estimated)
Location: Oxford (but easily movable)
Status: available, would need to be reactivated
Plans: no immediate plans, could be used for low-pressure evaporative cooling

### $CO_2$ blow-off plants

Built for ATLAS phase II upgrade prototype work
Capacity: 300W @ -35°
Location: 1 in Oxford (ESPI setup), 1 in Liverpool
Status: In use for ATLAS phase II R&D
Plans: continued use for ATLAS phase II R&D

**Figure 1: $CO_2$ blow-off plant.**

### TRACI plant

Recirculating $CO_2$ with 100W+ cooling power down to -30°C. A high-quality flowmeter system will accurately measure mass flow though devices.
Location: Oxford
Status: under construction
Plans: to be used for LHCb upgrade microchannel cooling work

## *Thermal chambers*

### Oxford cold room

Internal dimensions: 7.9×3.5×2m$^3$. The height is between a false floor and cable supports on the ceiling. The actual room height is 2.8m. We also have plans to move this cold room to a new location, in which case we will have to reduce the internal length to about 6.7m.
The cooling was done by an external chiller, which was cooling two internal heat exchangers with air ventilators. Dry air comes from a desiccating system.
The room was used during ATLAS SCT assembly down to -7°C, limited by the dew point in the room, which was relatively high due to moisture leaks along cable bundles used for testing complete structures. Those cables are now removed and cables for future use would be better sealed.
In the room we have two 3.3×1.5m$^2$ support tables on air springs, and another 5×1.5m$^2$ support table is available as well (usually used to set up optical systems).
Location: Oxford
Status: In use as a dry room with smaller thermal test boxes (current prototypes are small), cooling system would need to get re-connected
Plans: continue use as a dry room until larger structures need to be studied

**Figure 2: Cold room (with ESPI system in front and thermal test box in rear).**

### Liverpool Cold Room

Internal dimensions: 3.5 x 3 x 2m. 25x20cm ‘tunnel’ for services.
Operating conditions: dew point down to -30°C, Temperature down to -25°C
Used for testing ATLAS SCT endcap C and LHCb VeLo Modules
Current Status: Being re-conditioned after use as test enclosure for $CO_2$ cooling tests

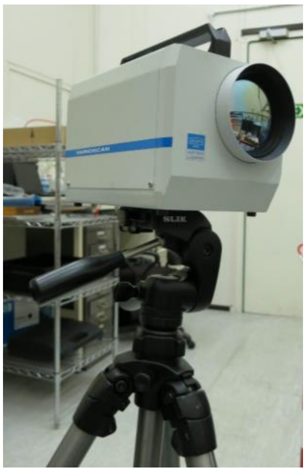
## Vacuum tank

A cuboid vacuum tank. A regular vacuum of $5\times10^{-6}$ is targeted.
Inside the tank there will be an x-y table such that large samples can be manipulated under a vertically mounted thermal camera with (32mm x 24mm) FOV and 50µm pitch.
Location: Oxford
Status: under construction
Plans: to be used for LHCb upgrade microchannel cooling work

## *Thermal imaging systems*

### InfraTec Varioscan VS3011

Fairly old camera, but updated readout and software. Was used during ATLAS assembly.
Location: Oxford
Status: available



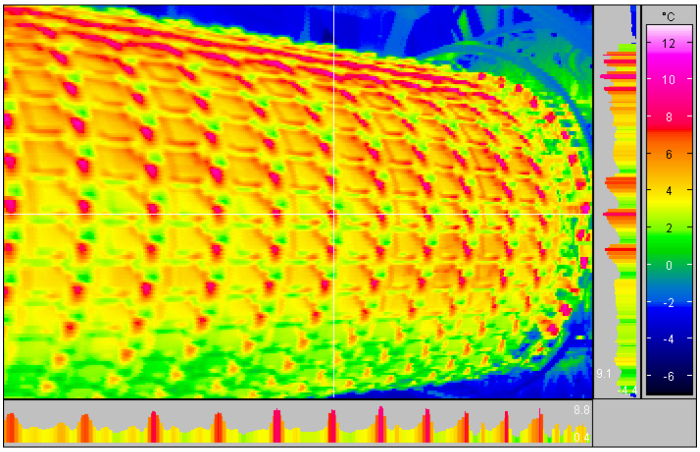



**Figure 3: Infratec thermal imaging camera. Image of ATLAS SCT barrel4 (D~60cm, L~140cm) in Oxford cold room during assembly, cooled with $C_3F_8$ evaporative cooling system.**

### FLIR

Recently purchased two cameras for LHCb microchannel cooling and ATLAS activities.
Location: Oxford
Status: available

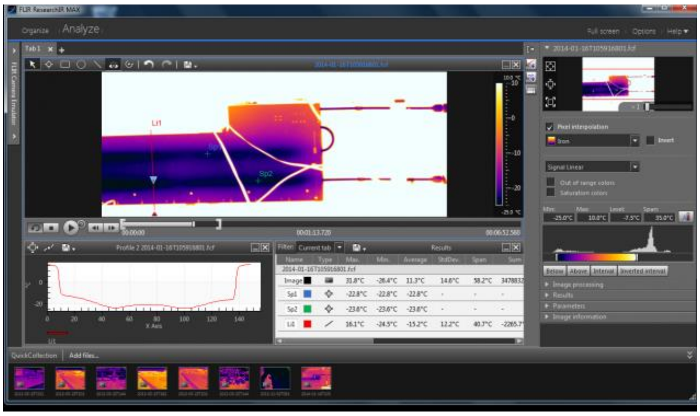



**Figure 4: FLIR thermal imaging camera. Image of ATLAS upgrade prototype stave with $CO_2$ blow-off cooling.**

## Thermal imaging systems at Liverpool

FLIR A410 and SC640 Thermal Imaging cameras and close-up lenses allowing minimal pixel sizes of 0.05mm. Vacuum chamber with germanium window and x-y scanning table used for sensor breakdown thermal imaging.

Location: Liverpool
Status: available

## *Deformation tracking*

## Electronic Speckle Pattern Interferometry (ESPI)

For a detailed description of the technology see for example [i] Allows for sub-µm deformation tracking over large areas. Also known as TV Holography, is a technique which uses laser light, together with video detection, recording and processing to visualise static and dynamic displacements of components with optically rough surfaces. The visualisation is in the form of fringes on the image where each fringe normally represents a displacement of half a wavelength of the light used (few hundred nm).

The component under investigation must have an optically rough surface, which typically means that the object needs to be covered in a reflective powder.

There are different modes of operation:

- Out-of-plane displacement measurement
- Out-of-plane vibration ESPI to study mode shapes and frequencies
- In-plane measurement displacement measurement

The area to be studied depends on the power of the laser and the optics. Currently we have a-spherical optics and can cover an elliptical area of about 1m×0.2m$^2$.

ESPI does not give an absolute measurement, but allows following small deformations over large areas. If the deformations are large/fast it becomes difficult to count the number of fringes.

For vibrational ESPI we currently use a loudspeaker to excite the object under study at a defined frequency.

Location: Oxford

Status: out-of-plane setup operational, in-plane measurements would need setup

Plans: continued use for ATLAS phase II R&D

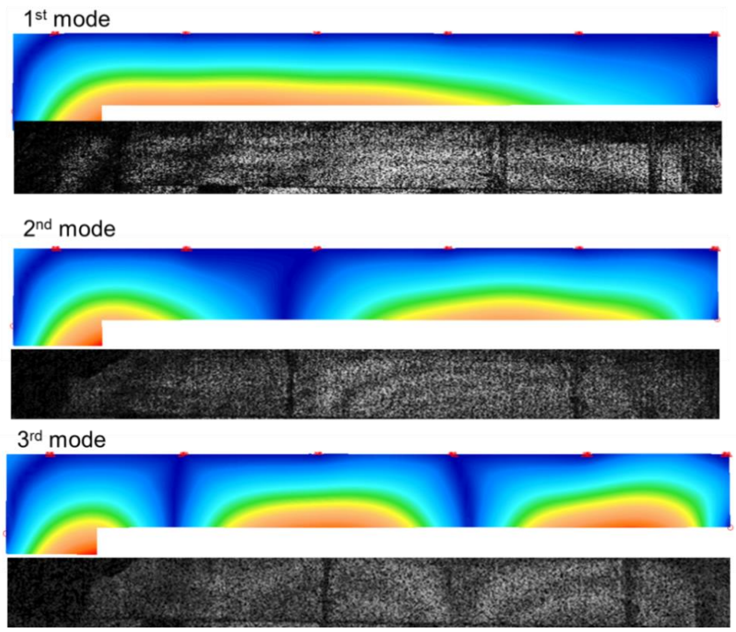



**Figure 5: Comparison of mode shapes of ATLAS upgrade strip stave prototypes from FEA (colour) and ESPI measurements (grey). Acoustic excitation. Frequencies are 61, 112 and 164 Hz, respectively. Maximum amplitudes are a few µm.**

## Digital Image Correlation (DIC) displacement measurement system

DIC is a 3D, full-field, non-contact optical technique to measure contour, deformation vibration and strain on almost any material. Tests include tensile, torsion, bending and combined loading for both static and dynamic applications, temperature and humidity. The expected precision is ~0.01px ≈ 4µstrain. A particular feature of this system is the ability to track discontinuous deformations (i.e. 'jumps') in response to external stimuli (e.g. cooling, power cycles, etc…) over mm-scale distances.
Location: Liverpool
Status: under construction. The image correlation system has been purchased and is being used to analyse material properties of CFRP and adhesives used in the construction of ATLAS prototype strip tracker staves. The equipment required to extend this to a system for the measurement of the vibrational properties of structures has been identified.

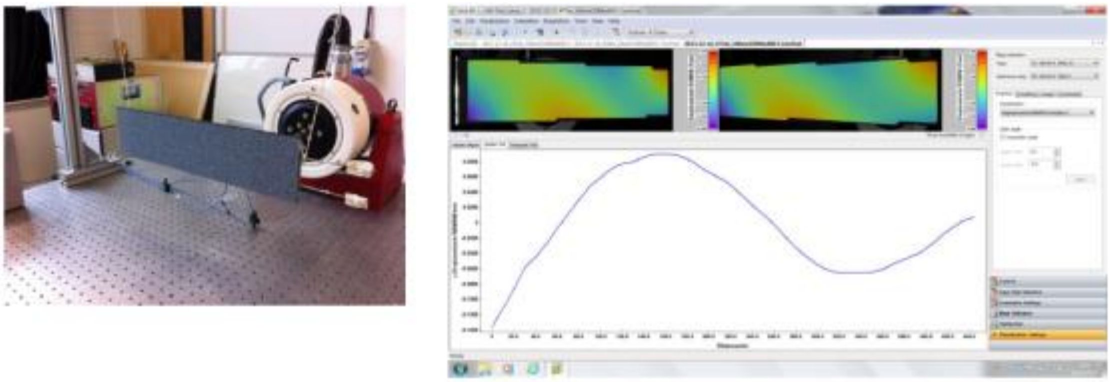


**Figure 6: DIC prototype measurements at Liverpool.**

## 32 channel absolute distance interferometry system

This system is a system of absolute distance measurements using Frequency Scanning Interferometry (FSI) and is the copy of a commercial system developed at Oxford from the FSI system used in the ATLAS SCT (software is not the commercial one but a scientifically minded one with a little more flexibility and less comfort).
For each distance one wants to measure one puts down a fibre collimator on the one end of the line and a retro-reflector on the other end. These can be up to 20m apart. You then point the beam at the retro and measure. One can measure up to 24 lines simultaneously and with a few more boards for our crate we could get up to 88 lines (for little extra cost). The accuracy is limited by turbulence in the air and on a well aligned line will be about 0.5 microns per meter. The resolution is much higher and in the few 10nm range on short distances.
Location: Oxford
Status: being used for development of commercial system, available spring 2015

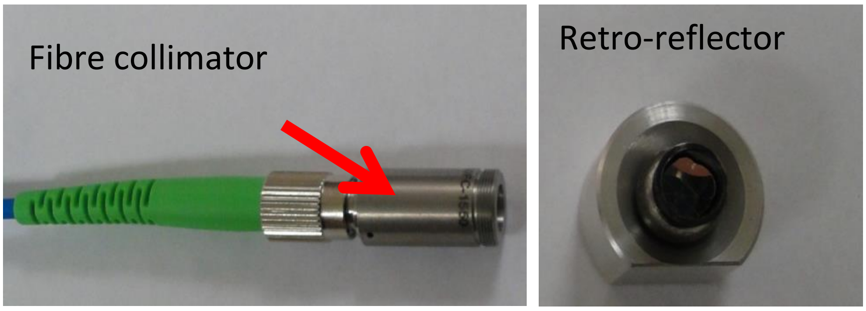



**Figure 7: FSI components**

## V-Stars video survey system

V-STARS/S is a 3D coordinate measurement system that uses a single camera to make fast, accurate measurements. The system measures retro-reflective targets. Images are taken from several locations. The images are then automatically processed using V-STARS software.
The V-STARS/S system is capable of measurement accuracies better than 5µm + 5µm/m (0.025mm @ 4m, 0.001" @ 160").
Location: Oxford
Status: under procurement
Plans: continued use for ATLAS phase II R&D

## Laser Tracker

FARO Vantage Laser Tracker capable of precise position measurements at distance scales of 10s of metres.
Location: Liverpool
Status: Available

## Capacitive displacement sensor system

Capacitive system with currently 5 sensors with sub-µm precision. Measures distance to a conductive surface (CF works).
Location: Oxford & Liverpool
Status: operational
Plans: continued use for ATLAS phase II R&D

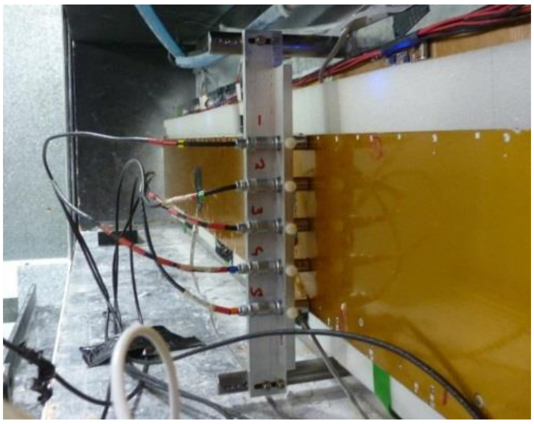


**Figure 8: Capacitive sensor system monitoring deformations of ATLAS upgrade stave core prototypes.**

## *Other equipment*

### Shaker table for low vibration levels

This shaker table is an attempt to build a system reproducing the low vibration conditions in a common particle detector (ASD up to $10^{-7}$ $g^2$/Hz). The size is $0.2\times1.3m^2$ (ATLAS barrel strip staves). We are still learning how to best do this; further iterations of the setup will be required.
Location: Oxford
Status: under construction

**Figure 9: Shaker table for low vibration levels. The table is support on three points (only front support visible) and excited by a piezo in the front support.**

### CMM

This unit is part of our workshop, but could provide supporting measurements within the framework of a thermo-mechanical test facility. The size of this CMM is up to 1.2m. Currently we do only have touch-probes, but we are considering upgrade to optical heads.
Location: Oxford (further, larger CMM systems available at RAL and at Liverpool (Wenzel LH87 and Wenzel LS2010) with commercial access)
Status: Available


**Figure 10: CMM at Oxford.**

## Electrical tape testing robot

This robot is being developed to test large (up to 1.6m long) flex circuits for connection and isolation (incl. HV isolation). Ultimately the robot should be able to automatically test all traces on a tape with a given geometry.
Location: Oxford
Status: Commissioning

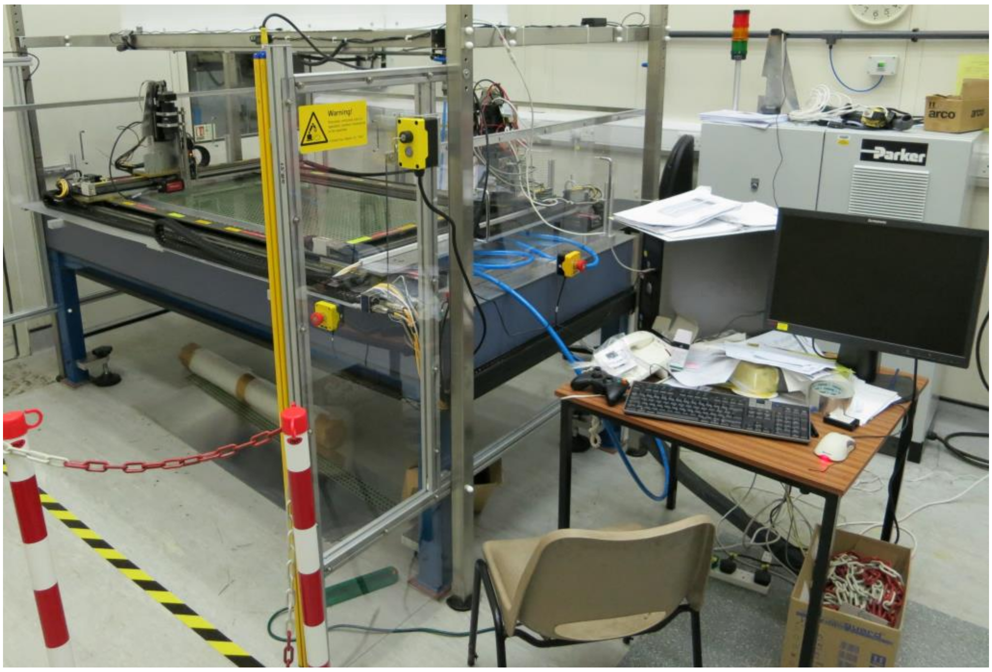



**Figure 11: Tape-testing robot.**

## *Materials testing*

### Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis is a technique for measuring mechanical and dimensional changes in a material as a function of temperature. The setup at RAL can measure properties of materials such as thick pastes up to very stiff fibres. It is particularly useful for measuring glass transition temperatures and thermal expansions in polymer materials.
In static, TMA, mode, very precise measurements of dimensional changes can be measured such as thermal expansion and shrinkage due to moisture loss or chemical reaction.
Maximum specimen dimensions (for flexural test) are approximately $20\times10\times5mm^3$. For tensile or thermal expansion samples, maximum sample size is approximately $5\times5\times20mm^3$.
Location: RAL & Liverpool
Status: operational

### Differential Scanning Calorimetry (DSC)

Differential Scanning calorimetry is a technique for measuring heat (enthalpy) changes in a material as a function of time or temperature. It can be used for determining levels of cure, glass transition temperatures, heats of fusion, melting points and other solid state reactions and changes.
Sample sizes are normally limited to less than 20mg in mass and no more than 6mm across.
Location: RAL
Status: operational

### Thermogravimetric Analysis

Thermogravimetric Analysis detects small mass changes in a material as a function of temperature. It is used to detect thermal decomposition reactions and measure moisture absorption in various materials.
Sample pan size is 60µl and maximum sample mass is limited to less than 1.3 g. Maximum temperature is 1000°C.
Location: RAL
Status: operational

### Fourier Transform Infrared Spectrometry (FTIR)

Fourier Transform Infrared Spectrometry is a technique for analysing materials to determine their chemical structure. It works best with organic molecules, but can be used with any material that has an infrared spectrum. It can for example be used to determine bond types in polymers.
Spectra can be obtained on small samples (for liquids ~0.1ml, and for solids ~2mm diameter). The larges samples size is limited by the sample chamber size ($190\times240mm^2$).
Location: RAL
Status: operational

## Servo-Hydraulic Testing Machine

This is a setup which can apply loads to a sample material or assembly to test its response. It is most commonly used to test materials to destruction in order to obtain failure data such as ultimate tensile strengths or bond strengths. However, it can also be used to proof-test assemblies prior to their use, determining how much they move by in response to a simulated service load.

The maximum load available is 100kN. With 2 subsidiary load cells of 5kN and 0.5kN, very small loads (<1N) can be detected.

Specimen dimensions are limited only by what can be fitted within the loading frame, although other limits may apply depending on the test fixtures required. Specialist fixtures can be manufactured to hold and load specimens, which in the past have ranged from 5μm diameter wires to 4m wind turbine blades. Whole assemblies can also be tested. Fatigue tests are limited in frequency due to the small 9L/min hydraulic power unit.

Extensometry is limited to a 10mm (±1mm deflection) clip gauge, ±2.5mm LVDTs and a video extensometer. The clip gauge and LVDTs have been used at 4K. The video extensometer requires good uniform lighting and high contrast markers to operate.

Location: RAL

Status: operational

## Single-column Materials Testing Machine

This single-column system has a similar functionality to that at RAL except that the load is limited to 5kN. Various load cells, extensometers and jigs exist for measuring tensile, compressive and flexural properties.

Location: Liverpool

Status: Available

## *Pipe testing*

### Pressure and leak testing

**Hydraulic pressure test:** Up to 400 bar with deionised water, limited volume (10s of $cm^3$)
**Gas pressure test**: Up to 200 bar – Helium or Nitrogen
**Vacuum leak test:** Using Leybold L200 leak detector, leak rates down to $10^{-9}$ mbarl/s in principle but usually dominated by environment
**Ability to do pressure and leak tests cold** (Down to -80°C, in principle temperature can be cycled, but cycling is very slow)
Location: RAL
Status: operational

### Pipe QA

**Optical Micrometre**: Used to measure pipe OD and look at ovality and cross-section reduction around bends
Location: RAL
Status: operational

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[i] R. Jones and C. Wykes, *Holographic and Speckle Interferometry (Cambridge Studies in Modern Optics), 1989, Cambridge University Press, ISBN 0521344174*.