Paper No: 1682 – 36th MATADOR Conference

The Metrology Enhanced Tooling for Aerospace (META) Framework

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Abstract. Aerospace manufacturers typically use monolithic steel fixtures to control the form of assemblies, this tooling is very expensive, has long lead times and has little ability to accommodate product variation and design changes. Since the tool setting and recertification process is manual and time consuming, monolithic structures are required in order to maintain the tooling tolerances for multiple years without recertification.

This paper introduces the Metrology Enhanced Tooling for Aerospace (META) Framework which interfaces multiple metrology technologies with the tooling, components, workers and automation. This will allow rapid or even real-time fixture re-certification with improved product verification leading to a reduced risk of product non-conformance and increased fixture utilization while facilitating flexible fixtures.

Keywords: dimensional metrology, measurement, tooling, fixture, assembly, META.

1.1 Introduction

Traditional aerospace assembly fixtures are monumental steel and concrete structures configured for one aircraft type only. The traditional build philosophy maintains and verifies assembly tolerances by locating component in the fixture using pins and build slips. The combined tolerance of the fixture and location pins / slips must therefore be less than the assembly tolerances (ideally <10% although this is rarely possible). Verification involves manually rotating pins and moving slips to ensure that the assembly is not straining against the fixture, Fig 1 shows the traceability route for the assembly verification process.

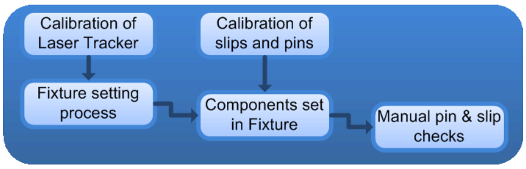

Fig 1. Traceability Route for Assembly Dimensional Uncertainty

Currently fixtures are set with a laser tracker during both commissioning and re-certification. This manual recertification process is a significant improvement on previous processes but still takes a number of days for a large fixture. Therefore tooling is typically only re-certified a number of years after its commissioning with an increased risk of non conforming products moving to the next process step undetected. Ensuring that the tooling remains stable during the periods between recertification is critical and this is one of the key drivers for employing such monolithic fixtures.

The size and complexity of fixtures means that they typically have construction lead times in excess of 6 months making late design changes or the employment of concurrent engineering a challenge. It is estimated that assembly tooling accounts for approximately 5% of the total build cost for an aircraft [1] or 10% of the cost for the air frame [2]. Fig 2 shows how these issues are a consequence of the traditional build philosophy.

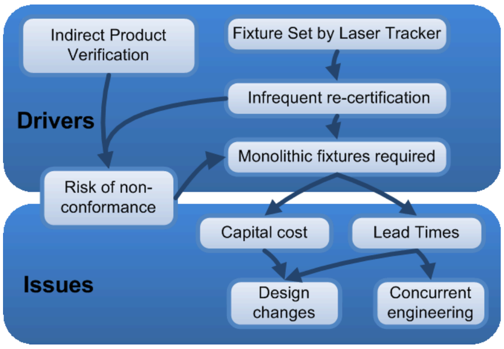

Fig 2. Issues caused by Traditional Build Philosophy

Quality issues, lead times and initial non-recurring costs (NRCs) could be reduced through the increased use of metrology in aerospace tooling. Improved metrology could allow rapid fixture re-certification and direct product verification. These changes would reduce the risk of product non-conformance and increase tooling utilization while facilitating a move away from hard tooling and towards soft tooling, that is: away from large, static structures and towards reconfigurable and flexible tooling [3]. However, in order to achieve this [paradigm shift] a strong metrological infrastructure is required to maintain accuracies within the tooling and the assembly process, Maropoulos et al [4] enforce [that]: *the key requirement for large-scale assembly is to overcome the constraints associated with the physical size of products and assemblies and the corresponding dimensional and form tolerances*

1.2 Metrology Enhanced Tooling for Aerospace

The key to moving beyond the traditional build philosophy, with its dependence on monolithic fixture structures, is the increased integration of multiple metrology instruments. This integration allows the use of large scale instruments to monitor the fixture structure and to locate localized instruments which measure product features and tooling pick-ups. Furthermore, environmental monitoring can be used to increase accuracy by applying corrections for errors due to effects such as thermal expansion.

Using current metrology hardware and software it is possible to create such a network but it requires considerable time from highly skilled experts and there are many issues involved in data capture, storage and reuse in multiple formats. These difficulties are preventing the benefits of metrology from being realized.

The Metrology Enhanced Tooling for Aerospace (META) framework is a metrological software environment providing a common platform for the design of metrology enhanced tooling, the acquisition of measurement data and for the subsequent storage and processing of that data. The advanced nature of this framework will facilitate the use of sophisticated multi-instrument networks integrated within tooling to remove the current barriers to low cost, rapid and high quality manufacture of aerospace structures.

A large scale measurement network would effectively surround and monitor key characteristics of the tooling using photogrammetry, interferometer networks or an indoor GPS system. Located within the large scale measurement network would be, localized scanning or single targeting measurement devices such as: laser radars, 6 DOF portable coordinate measuring machines (PCMMs), actuators, sensors, CMM arms, scanners, etc. These instruments would provide fine measurement of difficult features, freeform surfaces and tooling pick-ups, consequently enhancing part location and verification.

Utilising local metrology systems seated within a larger metrological environment can widen the scope of data collection and control. For example linear scales could be placed on slide ways, actuators could measure blind bores (with additional encoders), and force feedback could ensure forces are correct, thus removing human influences – especially in relation to easily deformed wing skin panels.

Potentially this [META environment] could provide a platform for automation, determining the sources and magnitude of any dimensional variations of the components that are presently being experienced during the manual assembly stage [5]. Personnel working within the META environment could also benefit from the metrology; augmented reality could enable accurate positioning and manufacture of assemblies. Additionally, health and safety legislation considerations could be integrated into the system – ensuring workers are safe before automated processes commence.

1.2.1 META Framework Architecture

The META framework relies on the effective synergy of complimentary instruments and interfaces accommodated by a strong software platform (Fig 3). The software is split into three levels: the top-level is a graphical user interface (GUI), which runs off of a low-level analytical core which in turn feeds to/from a database where measurement results are stored. In order to fully integrate with the Product Lifecycle Management (PLM) system the GUI should be within *Catia* for design, within *Delmia* for process planning and is a stand-alone appication for shop floor use, giving essential information for a non-metrology specialist that could be tailored to the different working environments. The GUI utilises information generated from the core software. The core is where a majority of the instruments interface and associated algorithms are carried out; this could be based on a commercially available software package, such as *SA*. Webb *et al* suggest the integration of multiple metrology systems for metrology assisted assembly by employing a decentralized service oriented software architecture [6].

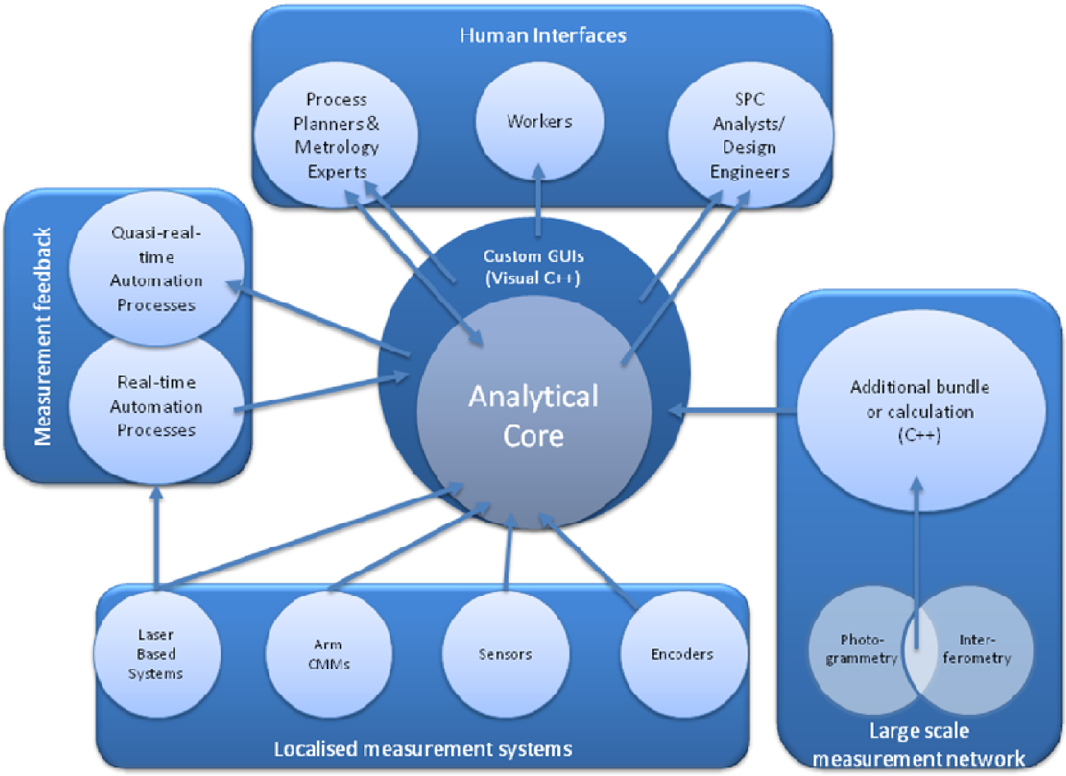

Fig 3. META Framework Architecture

1.2.2 Functions of the measurement network

The measurement network is separated into three sets of functions; primary functions checking the position of the tooling, components and assemblies. A set of secondary functions aiming to enhance the assembly process directly; and lastly the tertiary functions that collect data for future learning's and documentation – these [functions] are detailed in Fig 4.

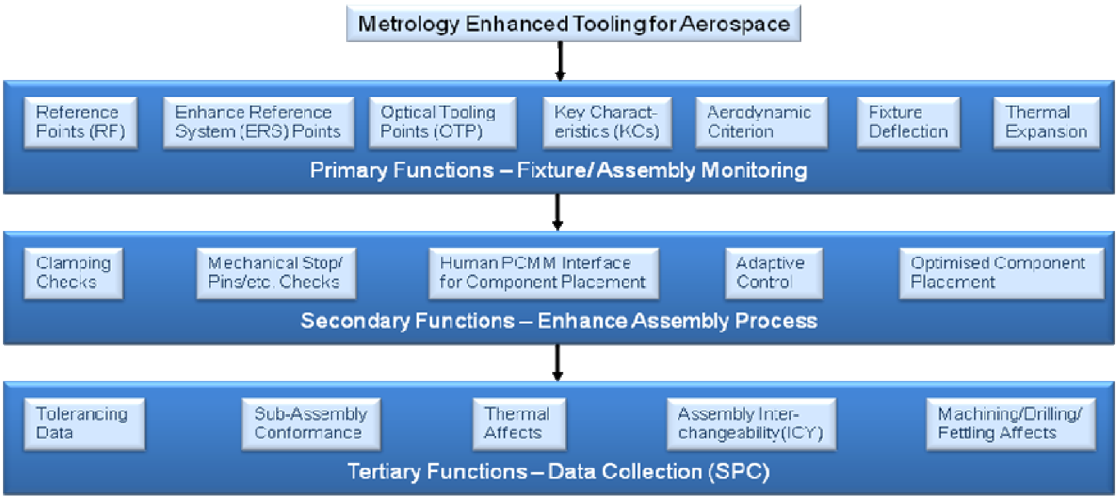

Fig 4. Measurement network functions

META's primary functions require a quasi-real-time metrology system to monitor the key characteristics of the tooling and assembly which are in a quasi-static configuration. This monitoring eliminates the need to recertify fixtures periodically removing the need to take the fixture out of production –current practice can take weeks to recertify and rework a fixture, causing down time that will have increasing impact as production rates increase. Control of tooling does not require real-time feedback as the movements can be iterative, unlike a machining operation. Machining operations and automation where an iterative loop is not appropriate must run directly from information fed from the instrument – for example a laser tracker – and not through the core software.

The tertiary function is the collection of information. This [information] could not only enhance the tooling and assembly during operation, but begin a large scale data collection for the use of SPC, providing learning for future optimization of the assembly processes.

1.3 Future considerations

Metrology Enhanced Tooling for Aerospace (META) encompasses: hardware development, integration of existing technologies, automation, human interfaces and industrial deployment within a framework where the metrology creates an environment surrounding the tooling; measuring the tooling itself, assembly features, automation and the employees working within the tooling environment. Enabling technological advances in large volume metrology are paramount in order to achieve this.

Currently the main disadvantage associated with laser based systems (such as a laser tracker) is their ability to only take a single measurement at one given time; even though 6 DOF tracking is achievable with laser trackers, this can only be applied at one point of interest at a time, and without the reduced uncertainty of multilateration. On the other hand, photogrammetry can make many measurements within the field of vision; however, the single roving camera typical in industry cannot track a point of interest – essential for re-setting/re-work or automation. Commercially available stereo pairs of cameras allow the tracking of points but with a loss of accuracy and a considerable rise in NRCs, additionally, placement of metrology systems within the control loop of a manufacturing cell must satisfy prerequisites such as: autonomous operation, high reliability, high speed measurement, and flexibility [7]. Specific metrology hardware solutions that enable the META framework are not currently available.

It follows that, a key prerequisite for the META framework is the availability of instruments that are capable of making multiple measurements simultaneously in real time. Currently cost is prohibitive due to the large number of instruments required. Solutions to this might include calibrated versions of consumer grade digital camera or to construct the laser based systems inexpensively so that a multitude of stations can work together in a mass instrument network. Without such advances, line-of-sight issues and real-time monitoring will not be resolved.

A successful geodetic network of frequency scanning interferometers fed from a single laser source [8] has been achieved at CERN when monitoring the ATLAS particle detector – this makes multiple stations very inexpensive, line-of-sight issues can be resolved, and low measurement uncertainty obtained using multilateration. In addition, these metrology systems must be robust to ensure that every-day factory floor occurrences do not affect the stability of the system. It is also important that cultural factors are addressed, such as changing the industrial perception that metrology should be employed at the verification stage - following production and assembly - rather than being an active element of the manufacturing sequence [4].

The core of the META framework relies on developments in creating an accurate, robust, and flexible metrological environment, from which many tooling, assembly and manufacturing processes and applications can reside.

1.4 References

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