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FIBRE-STEERING FOR LIGHTWEIGHT AND COST-EFFICIENT SPACE STRUCTURES

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Executive Summary Report of Project 4000141769/22/NL/RK/cb

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Contents

1 Document Details

1.1 Revision History

Current Revision	**1.0**

Revision Number	**Date**	**Author**	**Detail**
1.0	12 November 2024	Samuel Lam	Release
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1.2 Document Contributors

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2 Introduction

This document constitutes the Executive Summary Report for the Fibre-Steering for Lightweight and Cost-efficient Space Structures project initiated by the European Space Agency under GSTP Contract No. 4000141769/22/NL/RK/cb.

The work has been performed by iCOMAT Limited, United Kingdom, and in partnership with MT Aerospace AG, Germany.

2.1 Acronyms

RTS	Rapid Tow Shearing
GSTP	General Support Technology Programme
TRL	Technology Readiness Level
ESA	European Space Agency
MTA	MT Aerospace

2.2 Background

2.2.1 iCOMAT Limited

iCOMAT is a manufacturer of advanced composite structures for the aerospace and automotive industries. Their innovative and patented technology, Rapid Tow Shearing (RTS), is the world's first automated composites manufacturing process that can place carbon fibre tapes along curved paths without generating defects. The fibre steering capability realises ultra lightweight composite structures beyond the limit of the conventional straight fibre designs and complex geometry which is not manufacturable using current automated manufacturing technologies.

2.2.2 MT Aerospace AG

MT Aerospace AG (MTA) is a leading international aerospace company. More than 500 employees develop, manufacture and test components for institutional and commercial launch vehicle programs, for aircraft, satellites and for applications in the automotive and defence industries.

Thanks to manufacturing technologies that are unique worldwide, MTA creates high-performance products that combine maximum performance and minimum weight. With many years of expertise in the fields of additive manufacturing, metalworking, CFRP and hydrogen technology, MTA is ideally placed to implement sustainable solutions for the future.

2.2.3 Thin-walled cylinder

Thin-walled cylindrical sections form the major structural components of launch vehicles as well as many satellite central tubes. In both cases, the cylindrical section is subjected to very high axial compression loads during take-off from the launch pad. As structural mass is a premium for launch vehicles, the wall thickness is reduced as much as possible, making compression buckling the dominant load case for these structures. As captured in the NASA SP-8007 design guideline, the onset of buckling in axially compressed thin-walled cylinders is extremely sensitive to loading and geometric imperfections (e.g., waviness in the cylinder wall). In particular, imperfections can lead to a large spread of buckling loads, and in the worst case, lead to buckling at 20% of model predictions. As a result, the buckling load prediction of a perfect cylinder in an FE model is “knocked-down” by a very conservative safety factor that attempts to account for the worst-case scenario.

2.2.4 Previous Activities

Under GSTP de-risk activity ESA Contract No. 4000132051/20/NL/BJ/va, iCOMAT have demonstrated the ability to manufacture cylindrical components using to an industry-standard quality and the performance of this cylinder was confirmed by structural test.

The data used to verify computational finite element models that account for the RTS manufacturing method and its impact on the performance of the cylinder. The performance of the RTS cylinder was compared to a baseline cylinder manufactured with conventional AFP process, using the same materials and with a conventional quasi-isotropic skin layup. The outcome of the tests demonstrated that the optimised RTS design achieved a slightly higher mean buckling load across the distribution of considered imperfections and also a considerably reduced variance in the distribution of buckling loads under the influence of different imperfections. When established with greater maturity this could lead to an order of magnitude performance increase in the 99.9% reliability load that could lead to lighter weight structures.

3 Overview of Activity

This GSTP activity is a direct follow on from the de-risk activity described in the background information. The aim of the project is to advance the RTS technology and prepare for demonstration of TRL6 with a satellite central tube application.

The activity is intended to be executed in two technical phases, with this report capturing the activities performed within Technical Phase 1. Technical Phase 1 has the following objectives:

- To develop a bespoke RTS head, focusing on direct-to-3D deposition of cylindrical satellite central tubes.
- To integrate process control into the deposition head to allow for in-line automated process control during lay-up.
- To perform preliminary design of a representative breadboard compression specimen, utilising the updated 3D-RTS hardware.

Technical Phase 2 has yet to be executed. Phase 2 continues the activity by completing manufacture design, manufacture, and test of representative breadboard compression specimen.

iCOMAT performed the development and building of the bespoke 3D RTS Head. MTA assisted in performing analysis of the test specimens manufactured by the 3D RTS Head and provided expertise and input into the requirements and load cases of a representative satellite central tube application.

4 Work Performed and Main Results

4.1.1 Preliminary Design of a Representative Breadboard Compression Specimen

The objective of designing a representative breadboard compression specimen is to demonstrate the potential of the RTS fibre-steering technology developed by iCOMAT with respect to space structures.

In this work package, a fictitious central tube structure representative of a satellite is investigated. All requirements have been derived from equivalent structures within the MTA portfolio.

The component geometry is a flared cylinder, with two cutouts (not aligned with global axes).

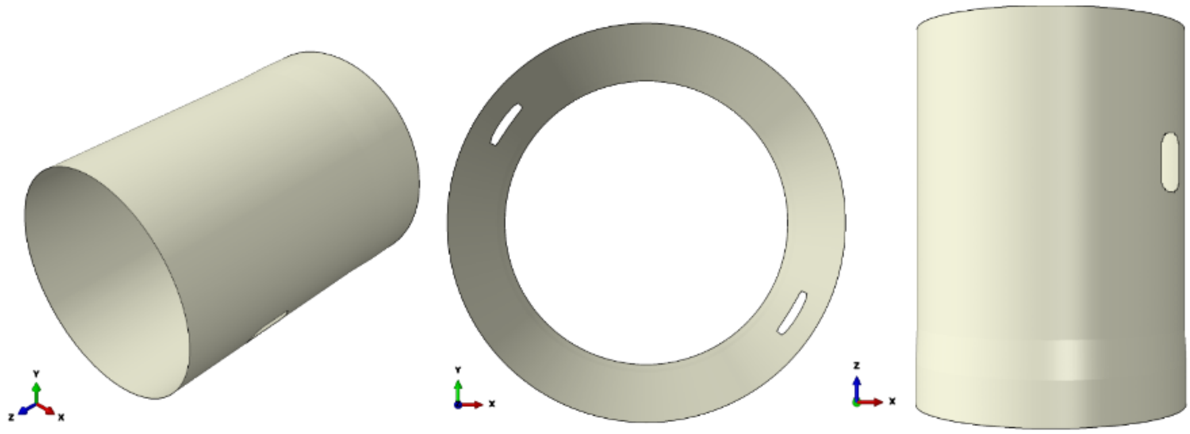

Figure 1 Demonstrator Geometry

A total of eight constraints applied, four kinematic constraints, and four continuum distributed coupling constraints; as well as four different load cases defined.

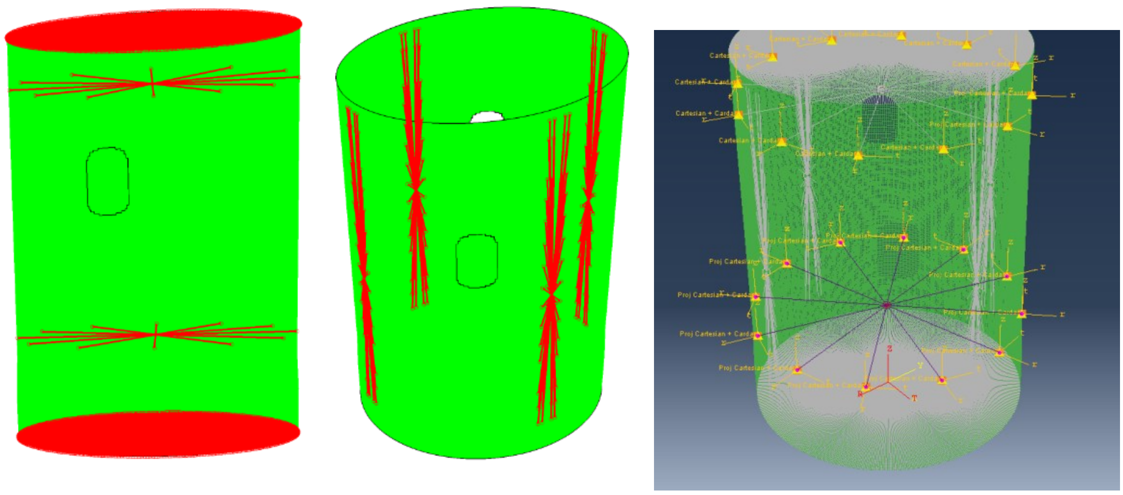

Figure 2 Demonstrator Constraints and Load Cases

In addition to the physical constraints, design requirements were induced based on in-house evaluations at MTA of the MTA design and the selected tooling approach. This included a total mass requirement, central tube global stiffness requirement, buckling requirement, and required a safety margin.

A preliminary design study was performed with:

- Straight fibre design (no circumferential ply needed)
- Steering the circumferential ply
- Steering the axial ply

Using an RTS layup design with steered axial plays, the calculated mass of the structure is **4.6% lighter when compared with a straight fibre design.**

4.1.2 Direct to 3D RTS Deposition Head and Control Software Development

The development of the RTS deposition head was intended to demonstrate direct 3D deposition of a cylindrical vessel with consideration for other applicable space structures, however, may require further development to accommodate different structures.

The development process initiated with a detailed review of the current 2D head against the requirements for space applications and central tube demonstrator (central tube structure). The review highlighted the components/sub-systems to be modified for 3D part manufacture.

Following a standard design and development process, iCOMAT developed a 3D RTS Deposition Head capable of laying direct to a 3D (cylindrical) mould. Furthermore, a laser projection system was developed for overall accuracy and a Laser Measurement system to be used for surface and defects detection. The entire system underwent a commissioning process upon which all sub-systems were verified to be functional and operating within the required specifications.

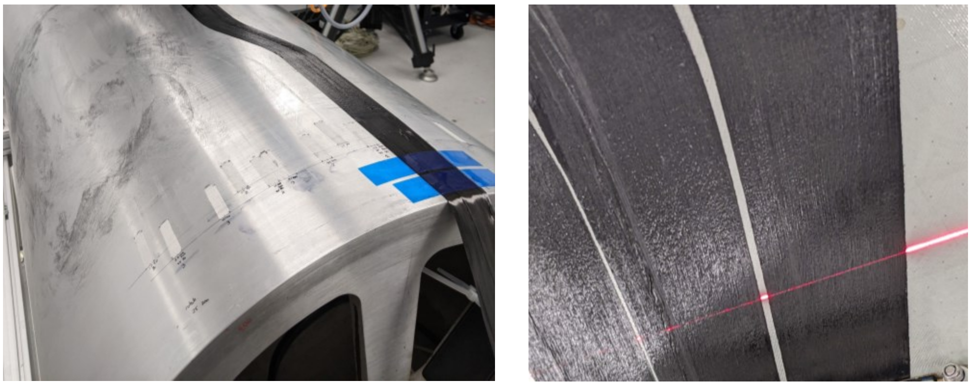

Figure 3 Deposition onto 3D Mould and In-Line Laser Measurement System

4.1.3 Manufacture Quality Verification of 3D RTS Deposition Head

Following the commissioning of the 3D RTS Deposition Head, a number validation test coupons were manufactured. The objective was to perform mechanical and permeability testing on the test coupons to validate the capability of the new RTS Head.

A variety of test coupons were manufactured to verify and demonstrate the capability of the 3D RTS Deposition Head:

- 2D Straight Course and Panel
- 2D Sheared Course and Panel
- 3D Straight Course and Panel (on quarter mould)
- 3D Sheared Course and Panel (on quarter mould)
- 3D Full cylinder straight path wrap around structure (both parallel and perpendicular to central axis)
- 3D Full cylinder sheared path wrap around structure (both parallel and perpendicular to central axis)

The test coupons demonstrated the 3D RTS Deposition Head met the design requirements and specifications of positional accuracy, shear angle, direct to 3D mould capability, and overall full system functionality.

The final full cylinder wrap demonstrates the 3D RTS Deposition Head has the capability to lay full 360° structures, ready for Technical Phase 2 where the Breadboard demonstrator will be manufactured at full scale.

From the 2D Panels, test specimens were produced and sent to MTA for tensile and permeability testing.

4.1.4 RTS Design Handbook

A first draft of the RTS Design Handbook was completed during this phase of work. The handbook provides key information and guidelines to design, analyse and fabricate tow-sheared composite components. The aim of the handbook is to inform designers on how to manufacture using the iCOMAT proprietary Rapid Tow Shearing technology.

The Design Handbook is a living document, it will continually update as the technology matures, advancements are made to the Deposition Head and other developments related to the RTS manufacture process.

5 Conclusion

During Technical Phase 1, the 3D RTS Deposition Head was successfully developed and commissioned. The validation tests of manufactured coupons showed the head is producing up to the defined specifications. The preliminary design of the breadboard compression specimen was also completed and demonstrated a weight advantage of using RTS axially sheared paths.

The progress enables the activity to move into Technical Phase 2. The breadboard compression specimen design will be completed, ready for manufacture on an 3D RTS Deposition Head. The compression specimen will be manufactured direct to a cylindrical mould, demonstrating the benefits and advantages of the 3D RTS Deposition Head. The full-scale demonstrator will be tested and assessed.