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PUBLISHABLE SUMMARY

Grant Agreement Number:	**FP7 – 338539**
Project Acronym:	**LORD Open-Rotor S2**
Project Title:	LORD Engine Mounting System for the SAGE2 Open-Rotor demonstrator
Period:	1 to 4
Period Covered:	01/09/2013 to 01/12/2016

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Objectives

Aircraft engine mount systems in use currently are designed to transmit the engine thrust force to the airframe and to retain the engine on the aircraft under all specified certification conditions. This is normally achieved by the use of a two plane mounting system with lateral and vertical loads reacted at each plane and thrust being taken out at one of the two mounting planes. For some aircraft specific compliant elements, usually made from an elastomeric or metallic mesh material, are designed into the mounting systems to allow for isolation of the engine vibration from the airframe and a reduction in transmitted dynamic forces. This is usually done to provide improvement in the aircraft interior cabin environment but also to provide a reduction in airframe vibration benefiting the life of other airframe mounted equipment. The all metallic mount systems without compliant elements are typically termed as hard mounts and the systems with compliant elements are often termed isolated engine mounts.
Isolated engine mount systems are designed with the same structural requirements as hard mounted systems, but an additional compliance is added to provide further isolation. These systems can be either isostatic or include additional constraints. As the stiffness in an over constrained compliant engine mounts is a known and controlled value, load distribution in these system is calculated using finite element approaches.

The goals of this project, for LORD, was to create an engine mount system capable of mounting the open rotor engine demonstrator. As such, the primary objectives of this project were:

1. Mount the SAGE2 open rotor engine demonstrator to the test stand.
2. Evaluate innovative noise control means within the mounting system.
3. Assess certification challenges as they may pertain to the engine mounting system.
4. Effectively transfer engine mounting design knowledge from the US technical centre to the European based technology group

Performed work

The activities carried out during the second period of the project are:

- Kick-off meeting with the Engine Manufacturer and the Consortium's team
- Mount system Preliminary Design
- Preliminary Design review with the Engine Manufacturer
- Validation of the Preliminary Design review without critical feedback
- Progress on the final interface 3D
- Preparation of the Critical Design review
- Material and hardware requirements reviewed with Engine Manufacturer
- Preliminary manufacturing plan and testing approaches suggested and discussed with Engine Manufacturer
- Provision of final interface 3D model for Engine Manufacturer master digital mock-up
- Critical Design Review
- Kick-off of the manufacturing activities
- Develop a testing plan
- Agree on the list of instrumentation to be installed on the engine mount
- Ongoing project management focused on delays absorption and cost reduction
- Finalization of the mount system detailed design substantiation document for the Critical Design Review
- Completion of the Critical Design Review with the Engine Manufacturer
- Finalization of the manufacture of the components, parts and full engine system assembly
- Delivery of the full engine system to the engine test stand
- Delivery of the full engine system to the component test facility
- Component test activities and readiness review
- Dynamic performance test activities and report
- Static strength test activities and report
- Fatigue test activities and report
- Engine readiness activities and review

The work carried out was focused on all Work Packages of the grant agreement.

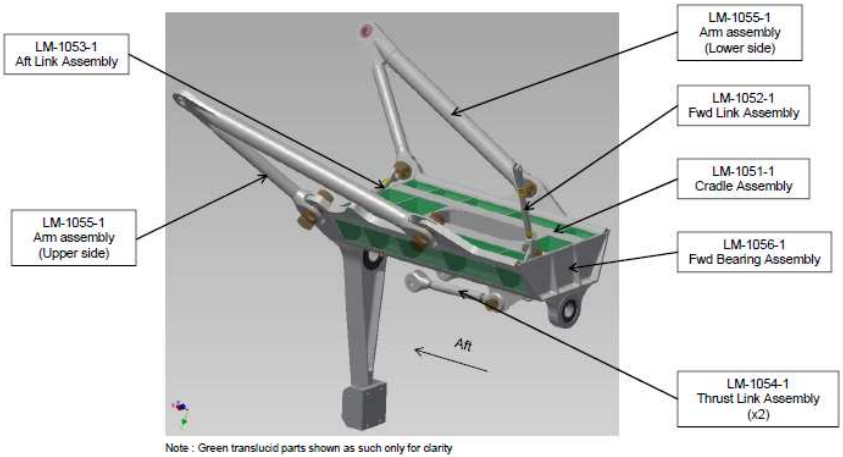
Work Package 2 – Design and Development

The Preliminary Design Review, which took place in July 2014, has developed some recommendations such as dynamic performance of the engine mounting system and issues with the integration into the pylon profile, implementation of a risk mitigation plan for the next steps of the program, design improvements, and reviewing the assumption for the fatigue calculation.

Engine Mount System Structure proposed at the time of the Preliminary Design Review

The preliminary design has been developed based on six different sub-assemblies in the Engine Mount System:

1. 1 Cradle Assembly
2. 1 Forward Link Assembly
3. 1 Aft Link Assembly
4. 2 Thurst Link Assembly
5. 2 Arm Assembly
6. 1 Forward Bearing Assembly



Following the results presenting during the PDR, the Consortium and the Engine Manufacturer have both agreed to implement and maintain a matrix and mitigation plan.
This plan has been used and reviewed regularly throughout the project in order to keep the right level of focus on the key challenges and potential exposures.
The PDR has been held on 16 of July 2014 and as there was no critical recommendation, the PDR has been considered as validated. The activity has been fully completed within the period 2, the deliverables can be considered has achieved.

After the validated preliminary design review, the Engine Manufacturer has decided to remove the Propeller Blade Release loads from the design loads deck and requested to reduce the PDR design envelope to fit in the original aeroline of the pylon. As a result, LORD has been able to completely re-think the design concept, including new assembly means which allowed weight saving and integration in the given space envelope without physical clashes.

The Consortium has focused its activities during the period 2 on the complete redesign of the system due to the new technical requirements provided by the Engine Manufacturer. This change has significantly delayed the initial timing and schedule we had.

The Consortium has developed a new design of the sub-assemblies. The approach taken by the Consortium was to:

1. Apply the new technical requirement on the current design
2. Identify potential or possible crash (identified in the slides below as “PDR design”
3. Provide new design complying with new requirements (identified in the slides below as “Pre-CDR design”)

The Consortium has been working significantly on the Critical Design Review deliverables. In between End of March 2015 and July 2015, several changes in the engine mass and torque resulted in several loads deliveries from the Engine manufacturer to the consortium. A first intermediate Critical Design Review milestone date has been defined in April 2015 in order to review technical achievement and decide consequently to perform Critical Design Review in October 2015, and to target the delivery date to the first quarter of 2016.

The Consortium has followed the below approach to prepare the Critical Design Review deliverables:

- Review of the updated requirements and presentation of the associated compliance matrix
- Review of the loads strategy, review of the new Loads and comparison with previous ones
- Review on Engine Mounting System design
- Review of static, fatigue Strength and dynamic methodologies

To avoid limitation during the ground test, the consortium presented partial re-design solution that could be implemented at the Aft Arm to Cradle attachment. The consortium has investigated the redesign of two critical components taking into consideration additional manufacturing constrains due to parts already machined and the project schedule expectation.

This partial re-design was requested by the Engine manufacturer.
As a result, Critical Design Review could not be closed in October 2015, and had to be pushed back to 2016 (period 4).

LORD has presented the results of the initial study of two design variants that were investigated in order to solve the AFT ARM to Cradle Joint Issue. During the review meeting of the 8th December it was agreed to move forward with the Design Variant 1. In 2016, the effort consisted in finalizing the analysis of the new design, updating drawing and releasing new drawings for the new parts. On March 4, 2016 it has been held a final review of the design solution affecting the aft-arm cradle joint which has been successfully closed with no additional actions or recommendations.
Due to this effort and due to the fact that the design has been justified through several design review meetings and presentation materials (see period 3), it has been commonly agreed to push the submission of the Detail Design Substantiation Document by the End of September 2016.

Work Package 3 – Manufacture and Delivery

The design review activities performed between the PDR and the Preliminary CDR held in October has been leveraged for the manufacture of the mount system.

The Consortium had to face to new additional requirements, change of design and new assumptions coming from the Engine Manufacturer, which are creating significant delays in the initial planning.
A risk mitigation plan has been put in place, in collaboration with the Engine Manufacturer, in order to identify opportunities and reduced the significant delays on the schedule.
As highlighted in the grant agreement, the Consortium has been working with the Engine Manufacturer in validating the technical requirements to accelerate the procurement activities of the main components, securing the availability of the raw materials and avoiding future delays in the schedule.

As agreed with the Engine Manufacturer, the consortium has continued the manufacturing activities during the year 2015 with a short stop from September to November during the time we had to consider the redesign of the two critical components. Prior to the request of redesign, the Engine Manufacturer had pushed the start of the ground testing to September 2016, consequently the delivery of the Engine Mounting System to 2016.

Despite significant changes of load requirements (several update provided by the Engine Manufacturer after the Preliminary Design Review) and a late need for redesign, the Consortium has been able to absorb the additional activities and respect the update project schedule expectation from the engine manufacturer (reducing the overall delays to ~ 9 months versus the original project schedule).

The objective for the year 2016 was to ship the two units for the ground demonstration test and the Full Scale System Test by the first half of the year, including the rework for the aft arm cradle joint.
Unfortunately, the calibration and instrumentations of the links for the first unit required a longer harmonization process of the requirements (especially due to the high temperature calibration) and the learning curve was longer than expected, due to this the units have been shipped only in October 2016. The manufacturing activities have been fully completed and the system have been shipped to the Engine Manufacturer for the Ground Test and our Testing Facility.

Picture of the finalized Engine Mount System
delivered to the Engine Manufacturer and Testing Facility:

Work Package 4 – Performance and Qualification Tests

Activities performed during the period 3 were the harmonization of the testing plan of the Engine Mounting System and material testing. Initially, a full scale fatigue testing was scheduled through the description of work within the frame of a 36 months program. The significant delays taken in the first steps of the design due to un-validated assumptions from the Engine Manufacturer and late need for redesign have driven the Consortium and the Engine Manufacturer to move forward with a different approach: full scale static test, under limit load only.
The scope of the Full Scale System test is to verify the stress and displacements of the Finite Element Models to validate the analysis results in order to guarantee the correspondence of the Design to the new loads and permit the successful execution of the Ground Demonstrator Test.

LORD has executed a static test on the full System using a dummy engine-able to replicate the applied forced and moments from the engine to the EMS. The Engine Mount System has been attached to a standard frame structure in Steel to simulate the pylon.

The Fatigue Test has been waived due to the low amount of fatigue cycles (1000) and the high margins the fatigue analysis results have shown.

Dynamic performance test have been performed on elastomeric components at different values of frequencies, temperatures and amplitude. This data has been used by the Engine Manufacturer to assess the sensitivity of the natural frequencies of the Engine-EMS-Pylon Systems and the impacts on the dynamic forces.

Work Package 5 – Support to Engine ground test

During the period 3, the consortium and the Engine manufacturer worked together to define the instrumentation to be installed on the engine mounting system in order to be able to collect data during the ground test. The data collected will be used for correlation purpose and dynamic optimization if needed. The period 3 activities were on agreeing the instrumentation type, location and total amount, define installation, routing, Digital mock-up study and requirements for calibration performance.

LORD team has supported the Engine Manufacturer in providing answers to all the above points:

- No design limitations
- All CDR recommendations closed
- Manufacturing of the EMS on going.
- Compliance Status Agreed (see following pictures)
- No major risks or open mitigations actions

Unfortunately, the Engine Ground Test has been pushed, as per the request from the Engine Manufacturer, to 2017. The results of the test will be known in the next few months. The Consortium and the Engine Manufacturer will then investigate options to disclose and publish the results if necessary.

Conclusion

Over the four periods during which the Consortium ("LORD") has been working with the Engine Manufacturer ("Topic Manager"), the team has been able to deliver and to complete most of the activities scheduled through the grant agreement by November 30, 2016. The pressure on the costs as well as the change of the requirements and design throughout the project has considerably affected the activities and work performed. Despite all of these challenges, the Consortium has been able to design, manufacture and deliver the Engine Mount System within the budget and deadline agreed with the Engine Manufacturer.
The ground test has not been completed as per the request from the Engine Manufacturer. The Consortium's team was available for that activity and it will remain available in the next few months in order to identify the lessons learned and the results from the final test. Publication of such results will be investigated at a later stage if necessary.