ReMAP Real-time Condition-based Maintenance for Adaptive Aircraft Maintenance Planning

Newsletter #7, December 2021

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www.h2020-remap.eu

Work Progress

In this section we present the work-progress from the previous 6 months. Only technical work packages (from 2 to 8) are considered in this description.

List of abbreviations of ReMAP Partners:
ATOS – ATOS Spain S.A. | CETEC - CEDRAT Technologies | EMB - Embraer Portugal S.A. | ENSAM - Ecole Nationale | Supérieure d'Arts et Métiers | IPN - Instituto Pedro Nunes | KLM – Royal Dutch Airlines | ONERA - Office National D'Etudes et de Recherches Aerospatiales | OPT - Optimal Structural Solutions | STEC – Smartec | TUD - Delft University of Technology | UC - University of Coimbra | UPATRAS - University of Patras | UTRCI - United Technologies Research Centre Ireland

Work Package 2 Requirements Management & Development of the IT platform

The purpose of WP2 is to create the IT platform which will embody ReMAP's advances towards the Integrated Fleet Heath Management (IFHM) solution and enable condition-based maintenance.

WP2-Leader: ATOS
Main partners involved: IPN, ENSAM, KLM, TUD, UTRCI

After successfully delivering the initial version of ReMAP IT Platform in November 2020, WP2 team has been working in bug fixing and implementation of additional features according to partners' new needs. This comprises for instance further integration in the platform, repository the files from the airlines systems with information about the maintenance/repair tasks and availability of slots and workforce airline system so they can be used as input for the models and convenience methods for exporting the prognosis and models outputs to other formats.

In October 2021, two internal workshops with WP5 and WP6 modellers were organized by WP2 in order to provide training and guidance on how to use the platform programming SDK and integrate it with their models for i) accessing the aircrafts sensor observations and executing the model in the sandboxed environment and, ii) exporting the model output results back into the ReMAP platform so they can be further used by other models.

Finally, and as part of the demonstration phase the project is now running, the team has also supported KLM in the deployment of the ReMAP Node component in their IT infrastructure (and its federation with the Core component hosted by ATOS). The platform is currently being fully tested by KLM's personnel and actual data from KLM's aircraft sensors is being routinely fed into the system in order to assess its performance in a real environment and validate the three types of models developed by ReMAP (Remaining Useful Life (RUL), Health Indicator and Maintenance Planner).

Learn more about the ReMAP-IT-platform in this video.

Work Progress

Work Package 3 Sensor Technologies for Structural Health Management (SHM)

WP3 concerns the procurement, development and integration of the most promising sensor technologies for damage monitoring in aeronautical composite structures.

WP3-leader: CTEC
Partners involved: ENSAM, STEC, UPAT.

During 2021, 7 flat multi-stiffener panels made of Carbon-Fibre Reinforced Polymer (L2 coupons) have been equipped with 32 patches each. The corresponding interrogating channels, the Lamb Waves Detection System (LWDS45), has also been supplied up to 36 channels. The L2 coupons have been then delivered for damage monitoring testing at TUD with optic fiber and acoustic emission in the scope of WP4.

The hybrid method, combining piezo-electric excitation and optic fiber sensing with Fiber Bragg Gratings (FBG) has been applied on larger coupons (L2) campaign. The ability of FBG to capture the piezo-electric excitation, previously validated on small samples (L1), has been confirmed on L2 on lower eigenfrequencies (up to 1kHz). Frequency shifts have also been detected during quasistatic test on a first L2 coupon with a new user interface. The satisfying first results led to the integration of the hybrid method to the L2 test campaign of WP4 that has been continued during the second half of 2021.
In parallel, two self-diagnostic methods have been proposed. The first one, based on capacitance measurement, has been directly implemented in L2 campaign in order to programmatically detect the patch break during cycling. The second one, implemented in a new generation of LWDS45 electronics is using impedance method and is expected to detect more precisely partial detachment of the patch. This is part of the sensors' reliability assessment.

Other 12 L0 coupons have been equipped with piezo patches to challenge the ability of the impedance method for testing the piezo patches integrity. New investigation on a protective coating has also been performed to prevent the patch failure during impact, aiming to implement this method in the rest of L2 test campaign. A quasi-static strain test bench has been proposed to reproduce the transient bending of the impact, and to select a best candidate among 4 different protective coatings.

In the next 6 months, WP3 will continue to support the project with demonstration prototypes with piezo and optic fibers. The reliability test campaign will continue with the impedance self-diagnostic investigation and environmental protective coating. The improvement of the compactness and the user-friendliness of the LWDS45 will be investigated.

Watch our lamb waves detection system video here.
And discover lots of scientific publications on ReMAP's sensor technology here.

Work Progress

Work Package 4 Structural Health Management (SHM) – Diagnostics & Remaining Useful Life Prognostics

The main aim of WP4 is to develop validated multi-disciplinary Structural Health Management (SHM) system methodologies that go a step beyond damage detection and diagnosis, towards remaining useful life estimation (prognosis) in the presence of adverse conditions during flight.

WP4 Leader: UPAT
Partners involved: TUD, EMB, ENSAM, OPT

In the last six-month period of this work package, the main objective for WP4 was to setup and start the testing at Level-2 i.e., multi-stiffened panels. Engineers and researchers from UPAT, CTEC, STEC and ENSAM joined the team at TUD where the Level-2 test campaign is going to take place.

In the meantime, UPAT, TUD and ENSAM continued with their efforts in diagnostic methodologies development. Health Indicators based on static strains, Lamb waves and Acoustic Emission have been developed. TU Delft and ENSAM formulated a detailed sensors reliability test plan to assess the performance of the various sensing technologies implemented in ReMAP. Digital-twin based methodologies have been worked out by UPAT and TUD. In parallel we have been developing prognostic methodologies towards the data-driven probabilistic Remaining Useful Life estimation in Level-1 (single-stiffener panels).SHM data are being gathered, processed and published in a public data repository making it available for free in the research community here.

Work Package 5 System Level Diagnostics, Prognostics and Health Management

In WP5 the core analytics technology chain for system and component level diagnostics, prognostics and health management (PHM) technology will be developed.

WP5 Leader: UTRCI
Partners involved: ATOS, EMB, KLM, ONERA, UC

At present the aircraft maintenance mostly follows “preventive” and “reactive” paradigms. Innovative “predictive” condition-based maintenance (CBM) technologies will be developed in the ReMAP project, which are envisaged to result in significant improvements in aircraft operations. To achieve the objectives of CBM in WP5 prognostics and health management (PHM) methodologies for aircraft systems and components are being developed.

Work Progress

To achieve the objectives of these aforementioned tasks, between May and November 2021, significant progress has been made as follows:

1. Completion of integration and validation of developed PHM methodologies, with data from Boeing 787, 737 and 747 aircrafts.
2. Development of prognostics and health management methodologies for Embraer E-jet bleed air system.
3. Preparation of PHM methodologies for the upcoming demonstration in ReMAP platform.
4. Initiation of demonstration of some of the PHM methodologies in the ReMAP platform.

Watch our new video where we explain the ReMAP's PHM solution here.

Work Package 6 Maintenance Decision Support Tool

WP6 concerns the development of an innovative concept to develop adaptive maintenance plans.

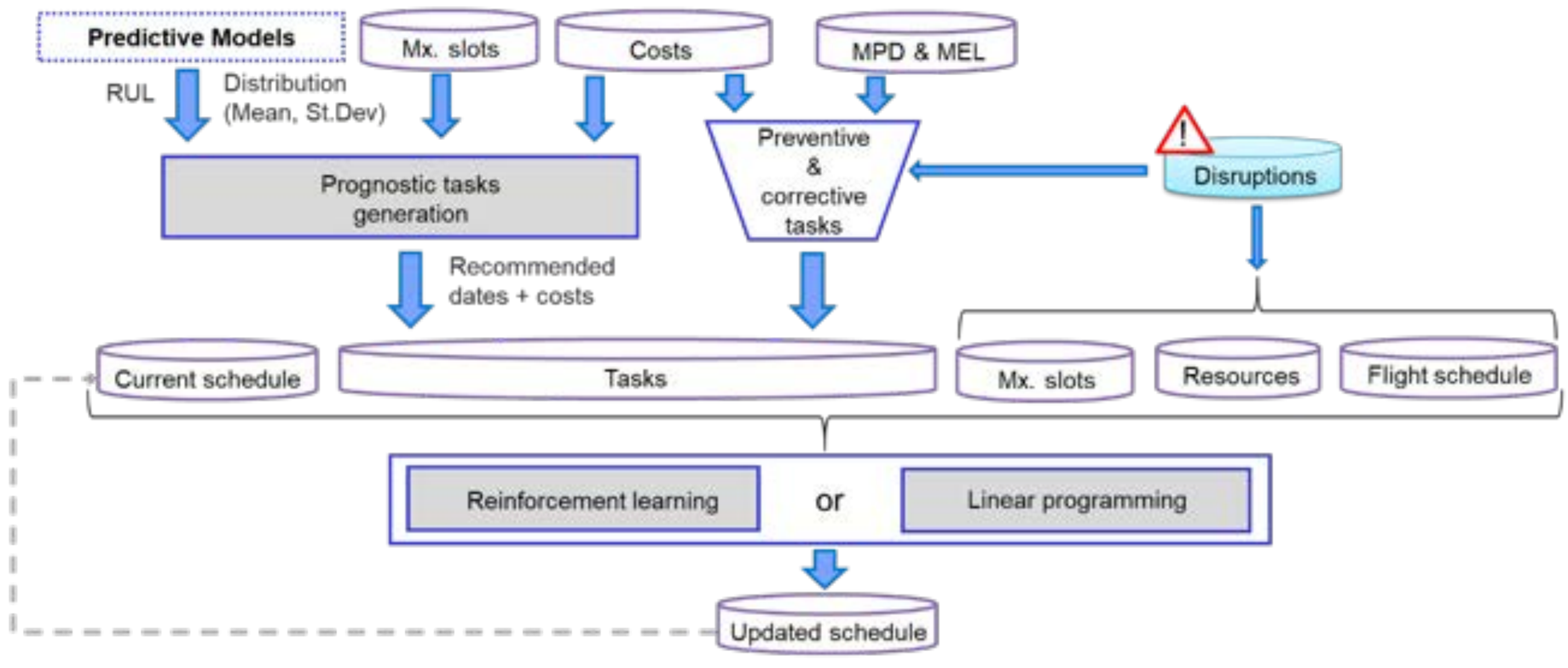
WP6 Leader: TUD

Partners involved: UC

The work from WP6 in the last period was mainly divided into two main activities: implementing the maintenance scheduling solution on the ReMAP IT platform and developing the scheduling tool prototype.

The maintenance scheduling solution developed is a multi-stage decision support algorithm to improve aircraft task scheduling in a disruptive environment, following a condition-based maintenance paradigm for some aircraft components. We use three models to produce maintenance schedules (grey blocks in Figure 1). The first one, the Prognostics Tasks Generation (PTG), is a probabilistic model that reads the outcomes from the predictive models to create belief states of the health degradation of multiple systems. Having these belief states, knowing the maintenance slots available to each aircraft, and having information about the maintenance costs associated with predictive and reactive maintenance, the PTG model prescribes the recommended dates for executing prognostic tasks. These tasks, associated with the respective costs, will be added to a pool of tasks to be scheduled. The other two models used in the maintenance scheduling solution are the two alternative schedule optimisation models. We have developed a linear programming model and a reinforcement learning algorithm. These models schedule the maintenance tasks in the maintenance slots available while considering the maintenance resources available. The goal of the schedule optimisation models is to produce an updated and feasible schedule when considering disruptions and the set of tasks to schedule. This framework was implemented and it is running in the ReMAP demonstration exercise from WP8.

Work Progress



1. *Maintenance scheduling solution framework and data flow*

In parallel, the WP6 team has also been working on the final prototype of user interface (UI) for this maintenance scheduling solution. The UI design displays the maintenance schedule for a fleet of aircraft for a time horizon of maximum 180 days. The schedule displays the hangar letter checks, other hangar slots, and line maintenance slots. For the latter two, the user can expand the view and visualise the tasks allocated to each maintenance slot, with the representation of either the due date for preventive or corrective task and with probability distribution function associated with the remaining useful life (RUL) estimation for prognostic-based tasks. The user can manually move tasks to other maintenance slots or even drag and drop maintenance blocks to another more suitable time slot. To help the planner dealing with maintenance resources, the UI also displays information about the hangar and workforce availability. The UI will be demonstrated in a workshop with maintenance planners to assess its value in facilitating the reading of prognostic indicators and the interaction with an optimisation framework.

A new video describing ReMAP's maintenance decision support tool will be released soon. Stay tuned!

Work Package 7 Integrated Safety Risk Assessment

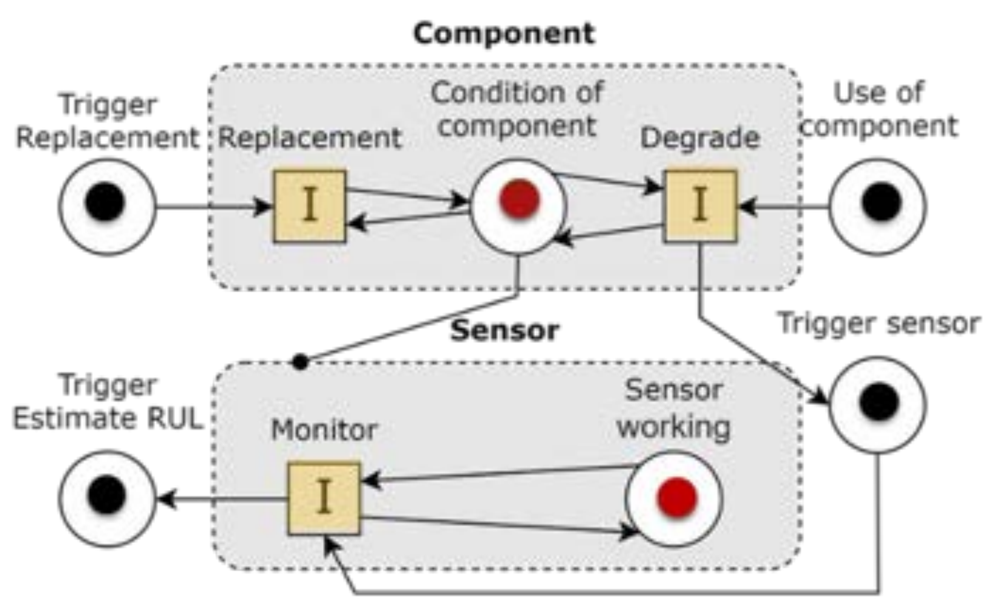
WP7 concerns the assessment of the safety of the condition-based maintenance technologies investigated by ReMAP. Probabilistic analysis and simulations of rare events will be used to quantity the safety of each technology and of the entire IFHM solution.

WP7 Leader: ONERA

Partners involved: EMB, ENSAM, KLM, TUD

Work Progress

TUD has developed an Agent-based Petri Nets model of aircraft maintenance that simulates various CBM strategies. With this model, key performance indicators such as CBM reliability and cost-efficiency are assessed. A case study on the maintenance of aircraft landing gear shows that the CBM approaches dominate traditional maintenance strategies. The results have been presented at the 31st European Safety and Reliability Conference (Lee, J., & Mitici, M. A. (2021). Predictive Aircraft Maintenance: Modeling and Analysis Using Stochastic Petri Nets. Proceedings of the 31st European Safety and Reliability Conference, pp. 146-153, and at Informs Annual Meeting 2021.
Further utilizing this model, TUD proposes a new framework to design multi-objective condition-based aircraft maintenance. This framework efficiently explores various CBM strategies to identify the Pareto optimal maintenance strategies that balance reliability and cost-efficiency. This new framework was recently published in the Journal of Reliability Engineering and System Safety (Lee, Juseong, and Mihaela Mitici. "Multi-objective design of aircraft maintenance using Gaussian process learning and adaptive sampling." Reliability Engineering & System Safety (2021): 108123). The paper can be read here.



2. *Stochastically and Dynamically Colored Petri Net (SDCPN) model for predictive aircraft maintenance. From: Lee, Juseong, and Mihaela Mitici. "An integrated assessment of safety and efficiency of aircraft maintenance strategies using agent-based modelling and stochastic Petri nets." Reliability Engineering & System Safety 202 (2020)*

Read these blogs to learn more about this subject:

- Your First Guide in Identifying Your Hazards in Condition Based Maintenance for Aircraft
- 5 steps to model and analyze condition-based aircraft maintenance

Work Package 8 Technology Integration, Demonstration & Validation

WP8 concerns the development and execution of a systematic Integration, Verification and Validation (IVV) strategy of the ReMAP approach. A laboratory validation and integration test will be performed first, in preparation of a demonstration test in a relevant environment.

WP8 Leader: KLM
Partners involved: All

Work Progress

We have started a 6-months real-life demonstration of the developed ReMAP technologies at KLM. In short, we are integrating the various machine learning and optimization models into the ReMAP platform, with real-time access to KLM's operational data.

What makes this demonstration special? We are deploying for the very first time, a fleet health management solution capable of facilitating Federated Analytics (FA). With FA enabled, airlines can leverage the value of each other's data, without centralizing or disclosing their data. We are also integrating prognostic models with scheduling decision support tools. This step has realized AI enabled, real-time decision making. Lastly, our platform is fully open; any model developer can run their models on real airline data.

Needless to say, our demonstration focuses exclusively on non-safety related issues. Airworthiness is still managed by our regular maintenance programs. Nevertheless, the platform is already delivering value. In the first weeks of the demonstration, we have scheduled two maintenance actions based on prognostic output from the platform. Learnings from the demonstration will be used to estimate the full future potential of Condition-based Maintenance for aircraft maintenance.

A Groundbraking Analysis on Fleet Earning Potential with CBM will be executed. Check the elements we consider here.

ReMAP & Science

ReMAP Scientific papers

ReMAP partners continue disseminating the project outcomes through the publication of scientific papers. Take a look at some of the most recent ones:

‘Multi-objective design of aircraft maintenance using Gaussian process learning and adaptive sampling’, Juseong Lee, Mihaela Mitici (Faculty of Aerospace Engineering, Delft University of Technology)
Published in Reliability Engineering and System Safety Journal — Read paper here

‘Age and Condition-Based Preventive Replacement Timing for Periodic Aircraft Maintenance Checks’, Floris C. Freeman (KLM), Paul J. van Kessel (KLM), Wim J.C. Verhagen (RMIT)
Published in European Conference of the Prognostics and Health Management Society — Read paper here.

‘An Adaptive Framework for Remaining Useful Life Predictions of Aircraft Systems’, Marie Bieber, Wim J.C. Verhagen, and Bruno F. Santos (Faculty of Aerospace Engineering, Delft University of Technology)
Published in Proceedings of the 6th European Conference of the Prognostics and Health Management Society 2021l — Read paper here.

‘Health monitoring of aerospace structures utilizing novel health indicators extracted from strain and acoustic emission data’, Georgios Galanopoulos (U.Patras), Agnes Broer (TUD), Dimitrios Milanoski(U.Patras), Dimitrios Zarouchas (TUD),Theodoros Loutas (U.Patras)
Published in 2021 IEEE International Workshop on Metrology for AeroSpace — Read paper here.

These are other scientific materials produced by ReMAP can also be found on the project’s webpage. Check them out here.

News highlights

International Conference for CBM in Aerospace

24th – 25th May 2020, Delft, The Netherlands

The ICCBM-A is the first conference entirely dedicated to the topic of Condition-based Maintenance (CBM) in the aerospace domain. In it, practitioners and researchers are invited to discuss research and promote development in the full CBM scope for the aerospace industry.

Five technical sessions, which include some of the most relevant topics in this area, were already selected. We invite you to take a sneak peek at each one of these sessions and submit your paper until December the 15th here.

1. Predictive aircraft maintenance integrating RUL prognostics

Chair: Mihaela Mitici (TU Delft) - M.A.Mitici@tudelft.nl

Main topics: The session aims to discuss topics such as: case studies of aircraft predictive maintenance using RUL prognostics, challenges of integrating RUL prognostics into the practice of aircraft maintenance, requirements for RUL prognostics to be useful for maintenance planning, reliability of RUL prognostics.
Read more about this session here.

News highlights

2. Advanced Maintenance Strategies

Chair: Kai Wicke (DLR) - Kai.Wicke@dlr.de

This session aims to address topics which allows for a paradigm shift of traditional decision-making processes in maintenance planning, leading to a globally optimized aircraft operation in terms of robustness, cost-effectiveness and sustainability.
Read more about this session here.

3. Establishing CBM as a Mainstream Maintenance Practice

Session Co-organizers: Luis Hernandez (Global Strategic Solutions)(luis@gssllc.net), Joao Malere (Embraer), David Piotrowski (Delta Air Lines), David Nelson (Andromeda Systems Incorporated), Kirby Keller (former Technical Fellow Boeing)

This session includes topics related to: (a) ongoing efforts by standards development organizations (SDOs) to help fleet operators, government regulators, and airworthiness organizations understand how to implement CBM as a mainstream business practice, and (b) specific CBM use case implementations and lessons learned at civil and defence organizations.
Read more about this session here.

4. Application of innovative health monitoring techniques

Main coordinator: Vis Dhanisetty (Netherlands Aerospace Centre) (vis.dhanisetty@nlr.nl)

Co-organizers: Marcel Bos (marcel.bos@nlr.nl), Frank Grooteman (frank.grooteman@nlr.nl), and Jason Hwang (jason.hwang@nlr.nl)

The goal of this session is to share the state-of-the-art research in these health monitoring techniques and learn from the challenges encountered through real-life applications.
Read more about this session here.

5. Operational Monitoring using Airframe Digital Twins in Aerospace

Organizer/Chair: Derk Daverschot (Airbus) - derk.daverschot@airbus.com

This technical session aims at presenting and discussing Airframe Digital Twin applications; the latest progress made towards establishing the twins for airframe structures and challenges ahead.
Read more about this session here.

ReMAP & Events

Previous events

MAKING CBM A REALITY IN AIRCRAFT MAINTENANCE OPERATIONS – THE WEBINAR

As we approach the end of the project, ReMAP reaches a big milestone in closing the CBM loop in real aviation, through a 6-month demonstration exercise at KLM. In the same week that this demonstration exercise was kicked-off, partners organised a webinar to disseminate the project's first findings. These results will now be validated, and their impact calculated in an operational environment.

In this webinar, we took a look at the IT structure developed in the project, and how airlines can take full benefit of artificial intelligence models to detect and predict the remaining useful life of systems and structures, while guaranteeing the privacy of their data. We've also presented our prognostics and health management (PHM) methodologies, through which machine learning algorithms are used to calculate the remaining useful life of aircraft systems. Finally, we've shown how ReMAP can help planners optimizing the schedule of maintenance tasks, having in consideration not only elements as the available resources, fleet availability, maintenance policies but also information taken from PHM algorithms regarding the health of aircraft systems and components.

ReMAP & Events

By the end of the session, ReMAP team answered some of the questions posed by the webinar attendees. Visit our Q&A page to see some of the answers.

Also, we invite all our stakeholders to watch or rewatch this webinar by clicking here.

Upcoming events

Summer School: 'The era of Digitalization and Artificial Intelligence for Structural Applications'

The Aerospace Engineering Faculty of TU Delf will organize the Summer School 'The era of Digitalization and Artificial Intelligence for Structural Applications', a course that will take place from the **14th** to the **16th** of J**une 2022**.

The course is dedicated to young researchers (PhD's and PostDoc's) and it aims to provide the fundamental knowledge for enabling AI, IoT, Big Data to transform conventional structures to cyber-physical assets.
The lectures will focus on the application of machine learning for design and failure analysis of lightweight structures, AI-based structural health monitoring, diagnostics and prognostics strategies, state awareness capabilities and digital twins.

Find out more information about this summer school here.

ReMAP Real-time Condition-based Maintenance for Adaptive Aircraft Maintenance Planning

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