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"AEROSPATIAL 2020"

Bucharest, Romania |15-16 October 2020

Virtual Conference

AEROSPATIAL 2020

AEROSPATIAL 2020

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"AEROSPATIAL 2020"
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Virtual Conference

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Agenda

Day 1 | Thursday, 15 October 2020

Time (CET)		Plenary ROOM (Clik to join the Virtual Meeting)
9:00	9:10	**Welcome and introduction** by the Conference Chairman Dr. Eng. **Catalin NAE**, President & CEO, INCAS − National Institute for Aerospace Research "Elie Carafoli", Bucharest, Romania
Plenary 9:10 – 10.10		**Chair: Catalin NAE** *(INCAS)*
9:10	9.40	**"Towards a full composite large passenger aircraft: some critical environmental aspects"** Plenary Lecture speech by Prof. **Sp. G. PANTELAKIS** and **Ch. V. KATSIROPOULOS** | Laboratory of Technology & Strength of Materials, Dept. of Mechanical Engineering & Aeronautics, University of Patras, Greece
9:40	10.10	**"Unsteady High-Lift Aerodynamics – Unsteady RANS Validation. An Overview on the UHURA Project"** Plenary Lecture speech by Dr.-Ing. **Jochen WILD** | German Aerospace Center DLR, Institute of Aerodynamics and Flow Technology, Dep. for Transport Aircraft - High-Lift Aerodynamics Group, Braunschweig, Germany
10:10	10:30	**Break**

ROOMs Session 10:30 – 12:30		ROOM 1 Clik to join the Virtual Meeting ROOM 1	ROOM 2 Clik to join the Virtual Meeting ROOM 2	ROOM 3 Clik to join the Virtual Meeting ROOM 3
Session Title		**Flight Mechanics**	**Workshop Project "FITCoW"**	**Workshop Project "CONTUR"**
Session Chair(s)		**Ion STROE** *(UPB)* **Dan N. DUMITRIU** *(UPB)*	**Cesar BANU** *(INCAS)* **Albert ARNAU** *(ROMAERO)*	**Aurelian Andrei RADU** *(ISS)* **Ioan URSU** *(INCAS)*
10:30	10:50	S2.1 **Satellite attitude dynamics using the 3D rotation matrix parameters** ***Dan N. DUMITRIU***, *Ion STROE, Octavian MELINTE*	W4.1.1 **Presentation of the OPTICOMS program and introduction for the FITCoW and ELADINE projects** *A. NATHAN, Y. YUROVITCH, Y. OFIR, C. BANU, A. PAVAL*	W5.1.1 **Correlation Based Analysis Between Pilots CAT Reports and the Meteorological Forecast** *Cristian-Emil CONSTANTINESCU,* ***Octavian Thor PLETER****, Irina STEFANESCU, Marius STOIA-DJESKA*
10:50	11:10	S2.2 **Calculus of compass robotic arm in inertial and non-inertial reference frames** *Sandra Elena NICHIFOR,* ***Roxana Alexandra PETRE****, Andrei CRAIFALEANU, Ion STROE*	W4.1.2 **Composite Tool design challenges in the frame of manufacturing of a 7-meter-long CFRP wing (skin-spars assembly) in a one-shot process (pre-preg and LRI)** *C. BANU, A. ARNAU, L. TERSIGNI, A. PAVAL, D. DANILA, I. BRINZA, R. VASILE, A. CORRADO*	W5.1.2 **Influence of wind shear and gusts on the aeroelastic response of an elastic aerial vehicle** ***Marius STOIA-DJESKA****, Laurentiu MORARU*
11:10	11:30	S2.3 **Issues on Quadcopter Design Customized for Urban Aerial Surveillance** *Javier LINARES, Timothee Pol DUCROST, Alexis BILLEREY, Bastien FONTANA-CASTETS,* ***Radu MIHALACHE****, Irina-Carmen ANDREI, Gina Florica STOICA, Nicoleta CRIŞAN, Delia PRISECARU, Cristian STOICA, Anca GRECULESCU*	W4.1.3 **High temperature laboratory testing of epoxy resins system meant to correlate mechanical properties with temperature variation** ***C. BANU****, L. FIRTAT, G. PELIN, O. OPREA, R. MARIN, A. PAVAL*	W5.1.3 **Regarding the dynamics of an airplane in a gust** ***Laurentiu MORARU****, Marius STOIA-DJESKA*
11:30	11:50	S2.4 **Issues on Light Payload Quadcopter Design Customized for Transporting Staple Foods and Medicines** *Dries BIERENS, Adrien THIBAULT, Vincent BURRE-ESPAGNOU, Martin DILLINGER,* ***George ZDRU****, Irina-Carmen ANDREI, Gina Florica STOICA, Nicoleta CRIŞAN, Delia PRISECARU, Cristian STOICA, Anca GRECULESCU*	W4.1.4 **Challenges in the process of manufacturing the 7-meter Spar Tool subcomponents by Liquid Resin Infusion process** ***A. ARNAU****, D. DANILA, M. MARIN, R. VASILE, K. MAYRHOFER*	W5.1.4 **Stability of a wing model with delay on switching control** ***Ioan URSU****, Adrian TOADER, Daniela ENCIU, George TECUCEANU*
11:50	12:10	S2.5 **Inertial Couples in the Dynamics of Mechanical Systems with Rotors** ***Sorin Stefan RADNEF***	W4.1.5 **Challenges in the process of designing and manufacturing the Caul Plates elements for a 7-meter tool** ***L. TERSIGNI, A. CORRADO***	W5.1.5 **CAT detection using a synergy of lidar and wind profilers** ***Razvan PIRLOAGA****, Livio BELEGANTE, Sabina STEFAN, Aurelian Andrei RADU*
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12:30	13:10	**Break**		

ROOMs Session 13:10 – 15:10		ROOM 1 Clik to join the Virtual Meeting ROOM 1	ROOM 2 Clik to join the Virtual Meeting ROOM 2	ROOM 3 Clik to join the Virtual Meeting ROOM 3
Session Title		Materials and Structures	Workshop Project "FITCoW"	Experimental Investigations in Aerospace Sciences
Session Chair(s)		**Adriana STEFAN** *(INCAS)* **Viorel ANGHEL** *(UPB)*		**Ion FUIOREA** *(UPB)* **Mihai-Victor PRICOP** *(INCAS)*
13:10	13:30	S4.1 **3D Phase Shift Measurement Technique with High Definition Images, a Great Achievement of Remote Visual Inspection** ***Mark GRIFFITHS, Frederic NERRIERE***	W4.1.7 **Challenges of complex monitoring of the curing parameters in coupons for LRI manufacturing** ***A. TORRE****, E. RODRÍGUEZ, T. GRANDAL, A. PINTO, R. TRAVIESO*	S6.1 **Deep Learning Aircraft Glide Path and Artificial Horizon Estimation for Visual Navigation Enhancement** *Ion FUIOREA, Ana-Maria Adriana PISO,* ***Mihai Alexandru BARBELIAN***
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14:10	14:30	S4.4 **Compositionally complex fluorite oxide ceramics for thermal barrier coatings applications – a review** ***Vasile-Adrian SURDU****, Ecaterina ANDRONESCU*	W4.1.10 **Scanning and inspection of composite parts and tools. Processing of raw data and geometry validation** *S. PALAS, A. PAVAL, C. BANU*	S6.4 **Brief history of flight data recording** *Dumitru POPOVICI, Radu Sebastian ZAHARIA,* ***Peter KALMUȚCHI***
14:30	14:50	S4.5 **Particularities of the early design phase for a single skin paraglider wing** ***Adrian SALISTEAN****, Carmen MIHAI*	Q & A	S6.5 **Processing of flight data records** *Radu Sebastian ZAHARIA,* ***Peter KALMUȚCHI****, Dumitru POPOVICI*
14:50	15:10	S4.6 **Influence of Preload on Failure Modes of Hybrid Metal-Composite Protruding Bolted Joints** ***Calin-Dumitru COMAN***		S6.6 **Shortt-Synchronome Time synchronization in distributed data collection systems- an old solution to a new problem** ***Alexandru- Marius PANAIT***
15:10	15:40	**Break**		

Time (CET)		Plenary ROOM (Clik to join the Virtual Meeting)
Plenary 15:40 – 16:40		**Chair: Catalin NAE**, President & CEO, INCAS
15:40	16:10	**"Urban Air Mobility – The Electric VTOL Revolution"** Plenary Lecture speech by **James (Jim) SHERMAN** | Director of Strategic Development, Organization: Vertical Flight Society, USA
16:10	16:40	**Artificial Neural Networks New Methodology Application for Aerodynamic Coefficients Calculations for Airfoil Shape Design** Plenary Lecture speech by **Ruxandra Mihaela BOTEZ** | Canada Research Chair Tier 1 in Aircraft Modeling and Simulation Technologies, ÉTS, University of Quebec, Montreal, Que., Canada

ROOMs Session 16:40 – 18:40		ROOM 1 Clik to join the Virtual Meeting ROOM 1	ROOM 2 Clik to join the Virtual Meeting ROOM 2	ROOM 3 Clik to join the Virtual Meeting ROOM 3
Session Title		Systems, Subsystems and Control in Aeronautics	Workshop Project "FITCoW" Q & A	Aerodynamics
Session Chair(s)		**Alina-Ioana CHIRA** *(INCAS)*		**Mihai-Victor PRICOP** *(INCAS)*
16:40	17:00	S5.1 **Human Performance Envelope Model Study Using Pilot's Measured Parameters** *Alina-Ioana CHIRA, Florin COSTACHE, Ana Maria DUMITRESCU, Cătălin Sever MOISOIU,* ***Cristian-Alexandru TĂNASE***		S1.1 **CFD Analysis of a Propfan for Modern Airplanes** ***Mihai Leonida NICULESCU****, Mihai Victor PRICOP, Ruxandra Maria Ileana DUSMANESCU, Alexandra STAVARESCU, Alexandru DUMITRACHE*
17:00	17:20	S5.2 **ENOVIA Business Tools for Concurrent Engineering** *Ana Lavinia PETRACHE,* ***George SUCIU****, Gabriela IOSIF, Iulian IORDACHE*		S1.2 **Propeller low-fidelity constrained optimization for eVTOL** ***Alexandra STĂVĂRESCU****, Mihai-Victor PRICOP, Georgiana ICHIM, Ion FUIOREA*
17:20	17:40	S5.3 **Research on nose landing gear of a military school and training aircraft** *Ilie NICOLIN,* ***Bogdan Adrian NICOLIN***		S1.3 **Low-speed airfoil optimization using constrained differential evolution** ***Mihai-Vlăduț HOTHAZIE****, Matei-Mihai MIRICA*
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		Ilie NICOLIN, ***Bogdan Adrian NICOLIN***				***Victoraş-Florentin ANGHEL***, *Laurenţiu PĂDUREANU, Omar ŞARIF, Mihai-Victor PRICOP*
18:00	**18:20**	S5.5 **Development of dielectric elastomeric actuation structures for morphing wings** ***Ştefan URSU***				S1.5 ***In-house Code for Optimal Design of Horizontal-Axis Wind Turbine Using Blade Element Momentum Method*** ***Matei-Mihai MIRICA***
18:20	**18:40**	S5.6 **H_∞ robust control design for lateral-directional dynamics of the Rockwell B-1 aircraft** ***Costin ENE***, *Valentin PANA*		**End of the Workshop Project "FITCoW"**		

End of the 1st Day of the 9th "AEROSPATIAL", Virtual Conference

Day 2 | Friday, 16 October 2020

Time (CET)		Plenary ROOM (Clik to join the Virtual Meeting)
9:00	9:10	**Welcome and introduction** by the Conference Chairman Dr. Eng. **Catalin NAE**, President & CEO, INCAS − National Institute for Aerospace Research "Elie Carafoli", Bucharest, Romania Dr. Fiz. **Adriana STEFAN**, President of the Scientific Council of the INCAS − National Institute for Aerospace Research "Elie Carafoli", Romania
9:10	10:00	**The "Nicolae TIPEI" – Prize Award Ceremony** **The "Gheorghe VASILCA" – Prize Award Ceremony** - ***Tribute presentation of awards*** *by Dr. eng.* ***Victor MANOLIU*** *(INCAS)* - ***The winners' speech***
10:00	11:00	**Presentation of the awarded works**
11:00	11:20	**Break**

ROOMs Session 11:20 – 15:00		ROOM 1 Clik to join the VirtuaMeeting ROOM 1	ROOM 3 Clik to join the Virtual Meeting ROOM 3
Session Title		**Materials and Structures**	**Management in Aerospace Activities**
Session Chair(s)		**Victor MANOLIU** *(Aerospace Consulting)* **Radu Robert PITICESCU** *(IMNR)*	**Casandra Venera PIETREANU** *(UPB)*
11:20	11:40	S4.7 **The effects of thermal-shock tests on the surface texture and on the micro-abrasion wear resistance of a micro-composite refractory enamel designed to protect some turboreactor parts** ***Ramona Nicoleta TURCU****, V. MANOLIU, Georgiana CHIȘIU, I. PENCEA, M. BRÂNZEI, G. IONESCU, M. BOȚAN, A. C. POPESCU-ARGEȘ, M. ION, C. E. SFĂT, G. C. CRISTEA*	S8.1 **Risk Management and Organizational Considerations for Enhancing Safety State Given the Continuous Technological Development Processes** *Valentin Marian IORDACHE, Sorin Eugen ZAHARIA,* ***Casandra Venera PIETREANU***
11:40	12:00	S4.8 **Effect of thermal shock testing on the thermal barrier efficiency of a new micro-composite refractory enamel designed to protect the hot working parts of aircraft engines** ***Ramona Nicoleta TURCU****, V. MANOLIU, M. BRÂNZEI, I. PENCEA, G. IONESCU, Adriana STEFAN, A. C. POPESCU-ARGEȘ, M. ION, C. E. SFAT, G. C. CRISTEA*	S8.2 **A Survey on Composite Applications in Aerospace Engineering and Management** *Corina-Elena BOȘCOIANU, Emil COSTEA, Radu BOGĂȚEANU, Adriana ȘTEFAN,* ***Irina-Carmen ANDREI***
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13:00	13:20	S4.12 **Eddy Current Technologies: Surface products, Aerospace Challenges** ***Laurent ROUFF***	
13:20	13:40	S4.13 **Universal thermal shock test installation of materials** *Mihail BOTAN, Victor MANOLIU,* ***Gheorghe IONESCU****, Radu Robert PITICESCU, George Catalin CRISTEA, Alina DRAGOMIRESCU, Radu BOGATEANU*	
13:40	14:00	S4.14 **Thermal Barrier Coatings based on Rare Earths doped Zirconia Materials obtained by EB-PVD process and their thermal shock properties** ***Anca Elena SLOBOZEANU****, Sorina Nicoleta VALSAN, Mircea CORBAN, Radu Robert PITICESCU, Mihail BOTAN, Victor MANOLIU, Bogdan St. VASILE*	
14:00	14:20	S4.15 **Surface manufacturing of materials by direct energy deposition**	

		Mihail BOTAN, *Victor MANOLIU, Gheorghe IONESCU, George CRISTEA, Stoica NICOLAE, Alina DRAGOMIRESCU*				
Session Title		**Astronautics and Astrophysics**				
Session Chair(s)		**Adriana STEFAN** *(INCAS)*				
14:20	**14:40**	S3.1 **Effect of Aerodynamics Drag and Radiation Pressure on Orbit and Attitude Dynamics Coupling of Small Spacecrafts** ***A. M. ABDELAZIZ***				
14:40	**15:00**	S3.2 **On the Earth Gravitational Waves** *Horia DUMITRESCU,* *Vladimir CARDOS,* ***Radu BOGATEANU***				
End of the 2rd Day of the 9th "AEROSPATIAL", Virtual Conference						

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***<u>Note</u>*:**
- ***The works are published in the volume by sections, in order of their presentation at the conference "AEROSPATIAL 2020, according to the Program of the conference (see the Program, pp. iii).***
- ***We mention that the authors is responsible for the correctness of the English language.***

BOOK OF ABSTRACTS

International Conference of Aerospace Sciences "AEROSPATIAL 2020"

15 - 16 October 2020, Bucharest, Romania

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Plenary Lectures

(in alphabetical order of the first author)

Artificial Neural Networks New Methodology Application for Aerodynamic Coefficients Calculations for Airfoil Shape Design

Ruxandra Mihaela BOTEZ

Abstract: The minimization of drag during aircraft flight is the first step towards a greener industry that is the scope of this presentation. The objective of this work was to create a new methodology, based on Artificial Neural Networks, to generate an airfoil shape from the knowledge of aerodynamic lift, drag and moment coefficients of a wing, in this case, a horizontal tail. The application of neural networks for pattern recognition, as well as airfoil parameterization using the Class Shape Transformation (CST) and the Particle Swarm Optimization (PSO) was discussed.
A number of 1636 airfoils were selected from the Airfoiltools.com database. These airfoils had various parameters, such as thicknesses, cambers, and shapes. This database was selected to be used for the training, validation and testing of the neural networks.
The Horizontal Tail (HT) of the Cessna Citation X business aircraft was considered in this work. The wing considered its airfoils and their parameters selected from Airfoiltools.com; therefore, the aerodynamic lift, drag and moments coefficients of the HT are calculated using the inputs of the aerodynamic model presented in Fig. 1, and DATCOM (Data Compendium) method. This semi-empirical well known method, developed by the United States Air Force, uses interpolation of reliable data coming from flight tests and wind tunnel studies to determine the HT aerodynamic coefficients.

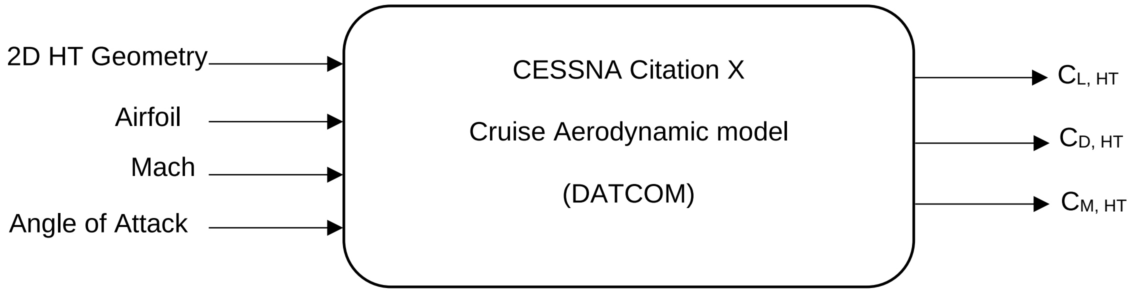

Fig. 1 Aerodynamic Model Used to Compute Aerodynamic Coefficients

Several artificial intelligence methodologies were designed using Feed-Forward Neural Networks, and their results were compared to each other for their comparison. For this application, two types of neural networks were considered, Feed-Forward Back-Propagation (FFBP) and Radial Basis (RB) neural networks. Both of these types are based on Feed-Forward Neural Networks that are networks where connections are made from the previous layer to the next, without forming cycles. FFBP uses a comparative signal, between the response of layers and the target set, and propagates the signal from layer to layer. RB neural network uses a single layer and memory-based learning. The FFBP networks will all have one single layer. These networks will be trained using the Levenberg-Marquardt algorithm, and will use hyperbolic tangent sigmoid transfer function. The Neural Network Toolbox available in the MATLAB environment was used to generate different networks by various data sets to compare the quality of the results obtained using these networks.
The generated airfoils were excellent as their shapes and curvatures were found. Finally, the aerodynamic coefficients obtained were found to be acceptable, with a maximum error below 10%. The next step will be to implement this solution for a higher number of flight cases, and also to a morphing structure, and to control it using the neural network methodologies. It is concluded that an interesting methodology was found for obtaining the airfoil shapes from aerodynamic coefficients.

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Towards a full composite large passenger aircraft: some critical environmental aspects

Sp. G. PANTELAKIS and Ch. V. KATSIROPOULOS

Abstract: During the recent 20 years a real revolution in the material use in aircraft structural components has taken place: the use of composites for the fuselage as well as for most of the materials of the wing. The use of composites on both, the Boeing 787, first released in 2011, as well as the wide body A350, released in 2015, exceeds 50% whilst the use of aluminum alloys hardly reaches 20%. A number of studies is anticipating that the percentage of composites will further increase and reach soon 70% or even more [1]. It is worth recalling that just a few years ago, the use in materials on the A380, which had his first flight on 2005, has been 61% Aluminum alloys and 22% composites. In the present work the environmental issues which are related to this revolutionary change will be critically discussed. The utilization of composites has contributed to the reduction of weight and thus to less emissions. This is in line with the target set by the European aeronautical community for carbon-neutral Aviation by 2050. Yet carbon-neutral does not necessarily mean environmentally-neutral. The positive impact of less weight on reducing emissions is compromised by the fact that the vast majority of composites used in aircraft are thermosetting and hence non-recyclable. In numbers it means that within the next two decades an estimated production of 3,5 million tones of non-recyclable aircraft materials is expected [2]. What is more, the processes which are currently commonly in use to re-use or recycle these materials are still far from being satisfactory. In the USA the most popular approach is landfill which consists of simply burying the materials at an isolated district [3]. In Europe grinding or flaking are popular [4, 5]. The recycled materials are used in road constructions or for producing parts of appreciably reduced quality as compared to the quality of the parts produced by using new materials. [e.g. 6]. Pyrolysis as a process to regain the fibers is also involved [5]. Yet, a number of challenges needs to be faced before a wide range use of recycled fibers can be achieved. To overcome the environmental drawbacks which are associated to the increased use of thermosetting composites in aircraft composites a number of approaches are attracting currently considerable attention. They include: i) the development of bio-composites offering sufficient quality for aircraft applications [e.g. 7], ii) the development of low cost, low temperature processed thermoplastics, offering sufficient technological features for aircraft use as well as out-of-autoclave low cost manufacturing processes capable to ensure sufficient quality [e.g. 8], iii) the development of holistic concepts which allow for the optimization of aircraft composite components and manufacturing processes with regard to quality, cost and environmental footprint of the component by considering quality, cost and environmental aspects as interrelated aspects which need to be accounted for already at the design phase of the component [e.g. 9], iv) the development of a new generation of alloys, namely the nano-crystalline alloys which are expected to offer mechanical properties comparable to those of carbon-fiber reinforced epoxies [e.g. 10], etc. Said efforts are running in parallel and most of them are complementary. Yet, despite the progress achieved on the above it is still a long way to go and significant efforts will be needed before the environmental issue related to the use of thermosetting composites is properly addressed.

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Urban Air Mobility – The Electric VTOL Revolution

James (Jim) SHERMAN

Abstract: Over the past few years there has been a groundswell of interest in electric- and hybrid electric-powered vertical take-off and landing (VTOL) aircraft for personal air vehicles, urban air taxis and even military missions. Electric VTOL obviates the need for mechanical power transmission, allowing new aircraft design freedom through approaches such as distributed electric propulsion. More than 250 electric VTOL designs are being developed today, with many now in advanced stages of flight testing. This presentation will detail the status of the Electric VTOL revolution to date, identify the key technology barriers, highlight the challenges to adoption, and the needed collaborative efforts required to ensure a safe implementation of a new transportation system.

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Unsteady High-Lift Aerodynamics – Unsteady RANS Validation An Overview on the UHURA Project

Jochen WILD

Abstract: Laminar wing technology is seen as the major single source for drag reduction on the airframe of a transport aircraft and will be a key technology to achieve the targets for emission reduction. In recent EC funded projects, the Krueger flap leading edge device was found to be the most promising concept of a dual-functional leading-edge device for laminar wings. While the these studies focused on the general performance and integration, the behavior of the system during its deployment or retraction proves to be a major issue due to the very different kind of motion compared to conventional leading edge high-lift devices. The risks of this concept are identified in the areas of load estimates, handling qualities and asymmetric failure cases.

During the deployment, the Krueger device is deflected from the lower side against the flow, passing critical stations when perpendicular to the flow, forming large scale separated flow on the lower side when moved around the leading edge (Figure 1). Current conservative estimations require the installation of many independently driven Krueger flap elements to prevent examination of critical situations along the whole wing span. The multiplication of drive stations leads to increasing complexity, weight and maintenance costs. On the other hand, despite the great progress in numerical simulation methods in the past years, there have up to now been no investigations on the validity of the current methods for predicting the behavior regarding these critical topics. The aerodynamics during movement of high-lift devices have not yet been addressed in detail.

The project UHURA is focusing on the unsteady flow behavior around high-lift systems and will first time deliver a deeper understanding of critical flow features at new types of high-lift devices of transport aircraft during their deployment and retraction together with a validated numerical procedure for its simulation. UHURA performs detailed experimental measurements in several wind tunnels to obtain a unique data set for validation purposes of Computational Fluid Dynamics (CFD) software, including detailed flow measurements by Particle Image Velocimetry (PIV) and other optical measurement technologies. Advanced CFD methods promising significant improvements in the design lead time are validated against this database to obtain efficient and reliable prediction methods for design.

UHURA is a follow-on of the DeSiReH project (2009-2013) funded by the EC within the 7th Framework project, where the type of leading edge device has been established and further matured within the 7th Framework project AFLoNext. From this experience, the suitability of the leading edge device to enable laminar flow wing technology is known for at least the steady flow of the fully deflected device. Nevertheless the unsteady flow behavior of such kind of device has not yet been investigated, but bears significant risks for loads due to high deflection speeds, flow separation up to full wing separation during leading edge passage, load and pitching moment changes during deployment.

With the Research and Innovation Action UHURA we address the following objectives:

- Validation of numerical simulation methods for prediction of the unsteady aerodynamics and dynamic loads during the deployment of high-lift systems - We expect to obtain an accuracy comparable to steady state calculations (less than 1% error in lift, drag and pitching moment).
- Quantification of the completely unknown aerodynamic characteristics of a slotted Krueger device during deployment - We aim to improve the load estimation and eliminate a current 10% uncertainty in comparison to state-of-the-art approaches.
- Accuracy improvement for the load determination for the sizing of structure and kinematics - We expect to achieve a system complexity reduction of about 70%. Further on, we expect a resulting 10% weight reduction due to the higher accuracy of load calculations.
- Qualification of impact on handling qualities and certification - We expect to save the above mentioned 70% of system complexity without any impact on the reliability of the system, handling qualities and certification issues.

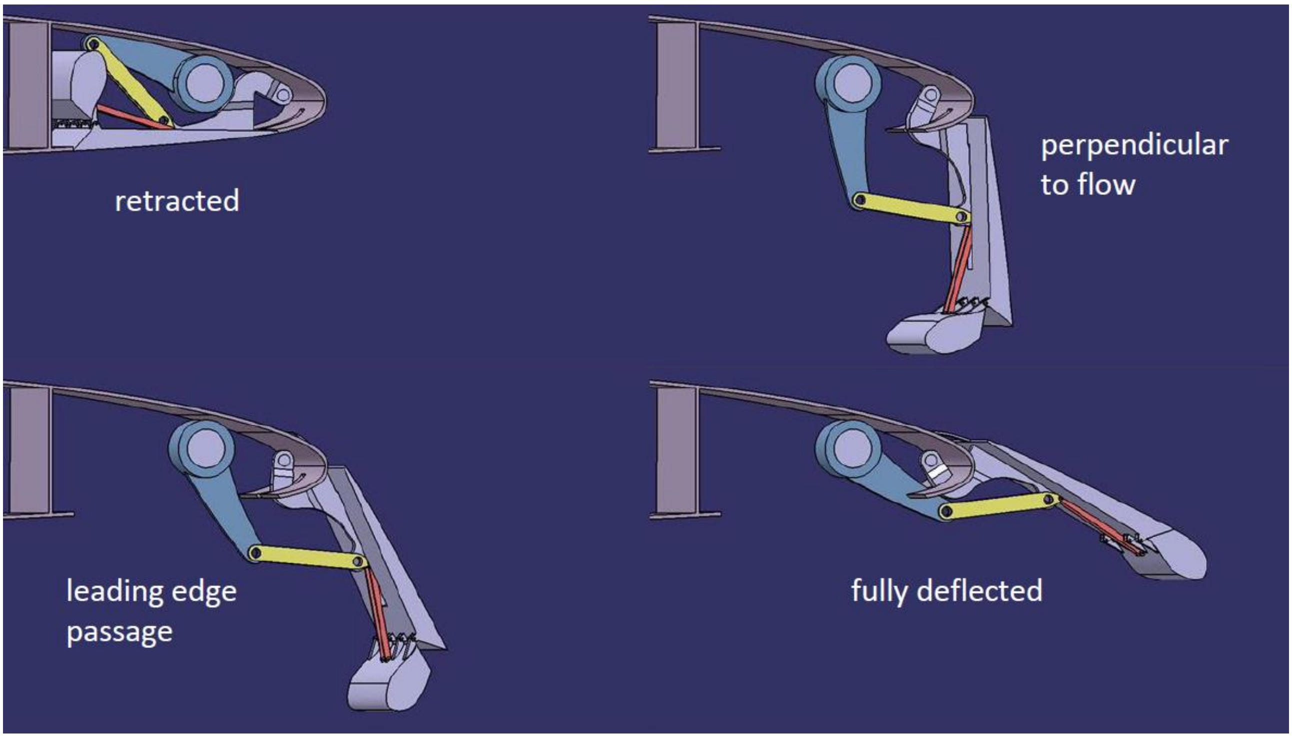

Figure 1: Deployment of vented folding bull-nose Krueger device developed in EC-FP7 funded project DeSiReH

Key Words: High-Lift Aerodynamics, Unsteady CFD, Validation, Krueger device, Laminar wing

Acknowledgments

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Section 1 – Aerodynamics

(in alphabetical order of the first author)

Preliminary performance estimation of a new 15m class glider

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Mihai-Victor PRICOP[2]

Abstract: The national aviation industry suffered major changes in the last three decades. Glider production began in the 1940s and continued in a number of locations until 2008, when the last IS-28B2 was assembled at IAR Brașov. At the moment, a lot of outdated gliders built between 1970-1980 are still in use. Twelve years after the last IS-28B2 was built and more than 35 years after it was designed, the development of a new all composite glider is started. As part of the development process a number of Computational Fluid Dynamics simulations are performed, in order to produce a good characterisation, to enable the computation of the speed polar. Standard turbulence models in the relevant regimes where found to severely overestimate the drag. Therefore, a transition-based turbulence model has been used with the proper meshing for a Reynolds number interval of 0.87 to 2.75 million, producing good drag estimations. The glide ratio predicted considering the transition is in the range of other standard 15m class gliders. Multidimensional regression and an in-house routine were further developed to enable the speed polar calculation.

Key Words: shape, airfoil, optimization, evolutionary algorithm, differential evolution, constraints

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Low-speed airfoil optimization using constrained differential evolution

Mihai-Vlăduț HOTHAZIE*[,1], Matei-Mihai MIRICA[2]

Abstract: Nowadays, algorithms designed to optimize the shape of an airfoil are being developed by many researchers. In this paper, to achieve an optimum shape configuration, a methodology based on an evolutionary algorithm is proposed. The main objective is to find the optimum shape of a known airfoil that, for a fixed lift coefficient, gives the best aerodynamic performance. For the airfoil parametrization, the class-shape method is used to develop a well-behaved geometry. The paper underlines the implementation of a constrained differential evolutionary algorithm using the free penalty scheme by varying the coefficients of the shape parametrization function to obtain a better aerodynamic performance for a predetermined lift coefficient by imposing a fixed maximum airfoil thickness interval. The method is a general optimization procedure and can be implemented in a wide range of engineering design problems.

Key Words: shape, airfoil, optimization, evolutionary algorithm, differential evolution, constraints

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In-house Code for Optimal Design of Horizontal-Axis Wind Turbine Using Blade Element Momentum Method

Matei-Mihai MIRICA

Abstract: Optimization of small power HAWT is a topic by itself, where a number of formulations and optimizers can be coupled. The classical Blade Element Method is used as performance evaluator because of its low computing cost requirements. The preferred optimizer is evolutionary of

Differential Evolution type, because it can provide the global solution, while gradient or non-linear programming methods can provide rather local solutions. Although some free implementations of the Differential Evolution are available, most of them do not handle constraints. However, a lot of work has been dedicated to the handling of the constraints and therefore a suitable method has been identified as Superiority of Feasible Solutions, that was implemented and validated against a standard benchmark. HAWT optimization has been successfully performed for rotors with different number of blades, in a repeated manner in order to demonstrate the self-consistency of the method and the repeatability, as good indicators for the localization of the global solution.

Key Words: HAWT, Blade Element Momentum, optimization, Differential Evolution, constraints

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CFD Analysis of a Propfan for Modern Airplanes

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Abstract:

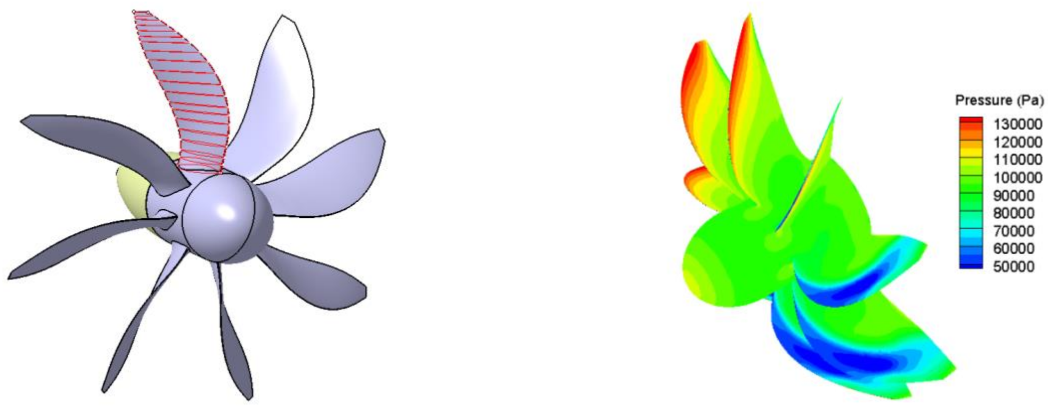

Fig. 1. Geometry reconstruction and pressure distribution on propfan at take-off

In order to decrease the CO_2 and NOx emissions due to the plane transport, it is very important to decrease dramatically the fuel consumption of current aircraft gas turbine. Nowadays, the most promising way to decrease the fuel consumption is to introduce a new generation of gas turbines, i.e. to replace the current high bypass ratio gas turbine with the propfan ones. Unfortunately, the airplane makers are sceptical to adopt this solution because it is very noisy and still immature. Furthermore, very few papers deal with this topic. For this reason, the present authors have studied aerodynamically a propfan whose geometry is given in [1]. The RANS (Reynolds Averaged Navier-Stokes) were solved using the Roe method as implemented in commercial CFD code Ansys Fluent using Menter' SST k-ω turbulence model in a non-inertial rotating reference frame. The numerical simulation was employed rotational periodicity in order to decrease impressively the computational effort. It is worth to mention the good agreement between numerical and experimental results and the presence of strong shock waves near the blade tip which trigger the boundary layer separation and are a major source noise. In the future, the present authors will try to decrease the intensity of these shock waves in order to mitigate the boundary layer separation and noise.

Key Words: Propfan, CFD, Aircraft Gas Turbines

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Propeller low-fidelity constrained optimization for eVTOL

Alexandra STĂVĂRESCU*[1,2], Mihai-Victor PRICOP[1], Georgiana ICHIM[1], Ion FUIOREA[2]

Abstract: Since urban air mobility became a popular topic in the past few years and along with it, the growing need for new electric vertical take-off and landing (eVTOL) vehicles, the rotor optimization for this type of vehicle became a subject of interest. This paper focuses on blade optimization, in terms of radius, twist and chord, using as a performance evaluator the Blade Element Momentum Method (BEMT), which has its computing cost advantages. The evolutionary algorithm used as optimizer is the Genetic Algorithm (GA), due to its capability of providing the global solution, unlike gradient methods. In order to prove the code's robustness, the optimization process is performed for propellers with different number of blades.

Key Words: Blade Element Momentum, optimization, Genetic Algorithm, eVTOL, propeller

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Section 2 – Flight Mechanics

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Issues on Light Payload Quadcopter Design Customized for Transporting Staple Foods and Medicines

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Abstract: The topic of this paper is in line with the efforts to reduce the spread of the pandemic effects; the objective is to design a light payload quadcopter in purpose to transport essential goods, as staple food and medicines for the people in self- isolation. The specificity of the work is given by the requirements of the European Project Semester EPS, where international teams of students actively experience a multidisciplinary and multicultural project for one semester in another university, which has developed research and industrial partnerships. For developing such project, the approach provided by INCAS as Research Partner is oriented towards Problem Based Learning and Project Organized Learning. The University as Organizer provides Project Related Courses and some complementary Project Organized Learning. The research was oriented towards the customized design of a drone able to efficiently achieving the objective. The benefits of the research project are related mainly to the potential applications of the drone, with the prospective development of a data base connecting the medical prescriptions issued with the local pharmacies, closest to the beneficiary patients, and in the subsidiary to allow the students learn valuable professional lessons and experience from this research project.

***Key Words**:* Quadcopter, design, light payload, transportation, staple foods and medicines, people in selfisolation

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Satellite attitude dynamics using the 3D rotation matrix parameters

Dan N. DUMITRIU[1,2], Ion STROE[2], Octavian MELINTE[1]

Abstract: The 3D rotation of a solid with one point fixed, for example a satellite, can be simply parameterized using the full 3x3 rotation matrix **R**, more precisely all 9 elements of this rotation matrix. In this case, the rotational motion equations are written in Lagrangian formulation as follows [1]:

$$\begin{cases} \ddot{\mathbf{R}} = \left[\frac{1}{2}\mathrm{j}(\mathbf{M}_{\mathrm{ext}})\mathbf{R} + \mathbf{R}\boldsymbol{\Lambda}\right]\mathbf{K}_0^{-1} & (1a) \\ \mathbf{R}^{\mathrm{T}}\mathbf{R} = \mathbf{I}_3 & (1b) \end{cases}$$

where Λ is a Lagrange multipliers symmetric matrix ($\Lambda_{ji}=\Lambda_{ij}$, i,j=1,2,3), introducing 6 independent scalar Lagrange unknown multipliers, associated to the six independent scalar equations of the orthogonality matrix condition (1b). Here $\mathrm{j}(\mathbf{M}_{\mathrm{ext}})$ is the skew-symmetric matrix made from the external torque vector $\mathbf{M}_{\mathrm{ext}} = [\mathrm{M}_{\mathrm{ext,x}};\ \mathrm{M}_{\mathrm{ext,y}};\ \mathrm{M}_{\mathrm{ext,z}}]^{\mathrm{T}}$, finally $\mathbf{K}_0 = \frac{\mathrm{tr}(\mathbf{J}_0)}{2}\mathbf{I}_3 - \mathbf{J}_0$ is the Poinsot inertia matrix of the satellite calculated at the initial time in its center of mass O≡G, with $\mathbf{J}_0$ the classical inertia matrix.

In this context, the dynamics equations of a rigid body with one point fixed, e.g., a satellite, take the form of the algebra-differential system (1a,b). There are 15 variables/unknowns at each time step of integration between [0,T]: the 9 components R_{ij} (i,j=1,2,3) of the rotation matrix **R**, plus the 6 independent Lagrange multipliers Λ_{ij} (i≥ j), gathered in the symmetric matrix Λ. There are 15 dynamics equations, for 3 DOF of the rotational motion: 9 differential equations (1a) to be integrated by classical 4th order Runge-Kutta method at each time step, plus 6 independent algebraic equations (1b), to be fulfilled at each time step.

To solve the direct dynamics problem, the actuation torques $\mathbf{M}_{ext}$ are known and the algebra-differential system (1a,b) can be solved as follows, at each step of time:

- either using a "shooting method", where the unknown Lagrange multipliers are initialized using guessed or previous step values, then these values are iteratively adjusted so that, by integrating (1a) between t_k and t_{k+1} , to obtain an orthogonal rotation matrix $\mathbf{R}_{k+1}$, i.e., fulfilling the orthogonality condition (1b). There are no special convergence issues related to this "shooting method", since the differential part (1a) is linear in variable **R** which has to be integrated. This "shooting method" was used here, with no convergence issues;
- or using Artificial Intelligence (AI), which will analyze the labeled dataset and train the model as part of the linear regression process using artificial neural networks in order to infer a learning algorithm. Based on this, the model will be able to predict relationships between unlabeled information or data which were not previously used in the training process. Using a machine learning model, the AI will find a linear relationship between the unknown Lagrange multipliers Λ and the orthogonality constraint $\mathbf{R}^{\mathrm{T}}\mathbf{R} = \mathbf{I}_3$, in a supervised manner. The AI model will be able to provide high performances in terms of accuracy, precision, recall, sensitivity, specificity, f1-score.

The inverse dynamics problem is quite straightforward to solve: the rotation matrix **R** is known during the entire motion between [0,T], being obviously orthogonal, so (1b) is fulfilled. Since the evolution of **R** is known, then $\ddot{\mathbf{R}}$ is also known, so from (1a) it comes: $\frac{1}{2}\mathrm{j}(\mathbf{M}_{\mathrm{ext}})\mathbf{R} + \mathbf{R}\boldsymbol{\Lambda} = \ddot{\mathbf{R}}\mathbf{K}_0$. This is a purely algebraic system of 9 scalar equation, with 9 scalar unknowns: $\mathbf{M}_{ext}$ and Λ. Considering the same case study as in previous paper [2], the $\mathbf{M}_{ext}$ external torque values computed using this matricial dynamics formulation are very close to the results obtained using the classical Euler's equations of motion in the context of the non-redundant parameterization by the x-y-z sequence of rotation, or by Rodrigues parameters, etc.

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Issues on Quadcopter Design Customized for Urban Aerial Surveillance

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Abstract: The topic of this paper is in line with the efforts to reduce the spread of the pandemic effects; the objective is to design a quadcopter in purpose to perform urban aerial surveillance, focused on monitoring the urban traffic of cars and monitoring the traffic of groups of people, which should not gather in groups larger than three persons. The specificity of the work is given by the requirements of the European Project Semester EPS, where international teams of students actively experience a multidisciplinary and multicultural project for one semester in another university, which has developed research and industrial partnerships. For developing such project, the approach provided by I.N.C.A.S. as Research Partner is oriented towards Problem Based Learning and Project Organized Learning. The University as Organizer provides Project Related Courses and some complementary Project Organized Learning. The research was oriented towards the customized design of a drone able to efficiently achieving the objective. The benefits of the research project are related mainly to the potential applications of the drone, with good effect to cost ratio and in the subsidiary to allow the students learn valuable professional lessons and experience from this research project.

Key Words: Quadcopter, design, urban aerial surveillance, mobile/ car and people groups traffic monitoring, Problem Based Learning, Project Organized Learning

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Calculus of compass robotic arm in inertial and non-inertial reference frames

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Abstract: Lagrange equations for motions with respect to large size non-inertial frames (planets, orbital stations), that are not influenced by the relative motion of the studied parts, are presented in the first part of the paper. For the calculus of the internal forces, a new method based on Lagrange equations in non-inertial reference frames is presented. If an internal force has to be determined, a supplementary mobility is considered in the system. The internal force corresponding to the new mobility is found if zero mobility is imposed. In the second part of the paper, the application of the method is illustrated by determining the bending moment in a Compass Robotic Arm. The geometry of this system is inspired from the European Robotic Arm (ERA). The geometry of the open loop mechanism is studied, but the method can be also used for closed loops. Results regarding internal forces for the known motion of the robotic arm are obtained by numerical simulations. The models and the elaborated method allow the solving of a large number of problems concerning the systems of dynamics of bodies.

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Inertial Couples in the Dynamics of Mechanical Systems with Rotors

Sorin Stefan RADNEF

Abstract: The mechanical movement around the center of mass of a mechanical assembly which has in its composition rigid bodies in relative rotation is influenced by the inertial interaction between the rotors and the rest of the constructive assembly. This paper determines the inertial terms that appear in the extension of the kinetic moment theorem for the case of a basic supporting structure, on which is mounted a rigid body in relative rotation with respect to it. The particular case is that of an air vehicle equipped with a jet engine whose turbine has a kinetic moment comparable to that of the carrier structure. The work done was conducted to highlight those inertial couples that have not been brought to light so far.

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Section 3 – Astronautics and Astrophysics

(in alphabetical order of the first author)

Effect of Aerodynamics Drag and Radiation Pressure on Orbit and Attitude Dynamics Coupling of Small Spacecrafts

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Abstract: Most of the spaceflight propagators decouple the orientation of spacecraft from their trajectory to simplify the overall problems. However aerodynamic drag and radiation pressure forces, contrary to the gravity force, depend on the spacecraft orientation and can have a substantial impact on the spacecraft trajectory. Since most of the current nanosatellites do not have thrusters to perform orbital correction due to the complexity of the system and space limitations, they are exposed to both radiative and drag force without correction maneuvers. The aim of this paper is to investigate the effects of both forces on the orbital–attitude coupled problem focused on nanosatellites in LEO orbits. This paper focuses on near-circular LEO orbits since most of the current nanosatellites are put into similar orbits. The model uses a Keplerian two body gravity model along with aerodynamic and radiation pressure forces. More complex gravity models, third body perturbations or other non-gravitational perturbations are not accounted for. The radiation pressure forces include solar radiation, albedo radiation and earth planetary radiation. The geometry of the spacecraft is modeled as a collection of flat plates with uniform material properties.

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On the Earth Gravitational Waves

Horia DUMITRESCU[1], Vladimir CARDOS*[,1], Radu BOGATEANU[2]

Abstract: The gravity or mass energy (heavy mass) is the outlet of the genetic impact, known as “BIG BANG”, creating a bounded ordered/structured universe along with the solar system, including the EARTH-world with its human race. Post-impact, the huge kinetic energy is spread into stellar bodies associated with the light flux under strong mutual connections or gravitational bundle. The Einstein’s general relativity theory including the gravitational field can be expressed under a condensed tensor as

$$E_{\mu\nu} \equiv R_{\mu\nu} - 1/2\, R g_{\mu\nu} = \chi\, T_{\mu\nu}{}^2$$

where $E_{\mu\nu}$ defines the geometry via a curved space-time structure ($R_{\mu\nu}$) over the gravity field ($1/2Rg_{\mu\nu}$), embedded in a matter distribution $T_{\mu\nu}$. The fundamental (ten non-linear partial differential) equations of gravitational field are a kind of the space-time machine using the curvature of a four dimensional space-time to engender the gravity field carrying away material structures. For Einstein, the space-time machine is the tensor formalism, needed to express the space-time curvature in four dimensions along with a gauge connection or bundle connection that is simply gravity, for bodies orbiting freely in the presence of light speed (cosmic wind). Gravity after the curvature space-time theory is not regarded as a gravitational force, but this manifests itself in the relativistic form of space-time curvature needing the constancy of the light speed. But, the constant light velocity makes impossible tidal wave/pulsating energy, a characteristic of the solar energy. The Einstein’s field equation, expressed in terms of the tensor formalism along with the constants light speed postulate needs two special space-time tensors (curvature and torsion) in 4-dimensions, where for the simplicity the torsion/twist tensor is ignored leading to a constant/frozen gravity. The non-zero torsion tensor plays a significant physical role in the planetary dynamics as a finest gear of a planet, where its spinning rotation is directly connected with the own work and space-time structure (or clock), controlling the light fluctuations (Sun is power). The spin correction of Einstein’s gravitational field refers to the curvature-torsion tensor coupling to control fluctuating light speed. The mutual curvature-torsion bundle self-sustained by the quantum fluctuations of light speed engenders helical gravitational wave fields of a quantum nature. In contrast to the Einstein field equation describing a gravitational frozen field, a quantum tidle gravity model is proposed in the paper.

Key Words: Einstein's field equation, structured space-time universe, helical torsion gravitational waves, singularity at the beginning of universe-BIG BANG, astrophysics

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Section 4 – Materials and Structures

(in alphabetical order of the first author)

Bending Vibration Analysis of Nanobeams using the Nonlocal Motion Equations solved by an Integral Approach

Viorel ANGHEL, Ștefan SOROHAN

Abstract: This paper deals with the dynamic characteristics for bending vibrations of Euler-Bernoulli type nanobeams taking into account the scale effects via the nonlocal motion equations. An integral method, based on the use of Green's functions, has been used in order to obtain the corresponding eigenvalue problem. The proposed integral approach it is an approximate matrix method. Effects of different boundary conditions and of an elastic foundation have been also included. The presented numerical examples show good agreement when compared to results from literature. The proposed method can be used in the case of nanodevices analysis modelled as beams (MEMS, NEMS).

Key Words: Nanobeams, Scale Effects, Vibrations, Green's Functions, Winkler Foundation

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Universal thermal shock test installation of materials

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Abstract: To achieve higher performances both in the aeronautic industry and in the others industries, designers need new advanced materials, equipment and testing systems. Advanced materials for turbo engines and other spacecraft devices are actually thermal barrier coatings (TBC). An important direction to obtain advanced material is represented by industrial coating techniques - Spray Deposition Processes, Chemical Vapor Deposition Processes (CVD) and Physical Vapor Deposition Processes (PVD). One of the equipment utilized for coating, both for aeronautic and machinery industries is EB-PVD (electron beam-physical vapor deposition). New type of coatings and materials are under development, necessary for local repair, Thermal barrier Coatings (TBCs) for aeronautical and turbine industries, coatings for machining tools and forging die industries, etc. The news materials must work in the presence of complexes wear factors such as erosion, chemical corrosion, fretting wear, moderate and quick thermal shock at heating and cooling, all these factors acting simultaneously at high temperature values. The testing of the resistance at quick thermal shock to evaluate the properties of the EB-PVD multilayered structures type Nimonic/ NiCrAlY/ Y2O3-Yb2O3-GbO3-Nd2O3-ZrO2/ ZrB2 was performed on INCAS U-QTS installation. The investigation to perform further will evidence the modification induced by the quick thermal shock of the elaborated protection structure.

Key Words: quick thermal shock, TBC coatings, EB-PVD, multilayered structures

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Surface manufacturing of materials by direct energy deposition

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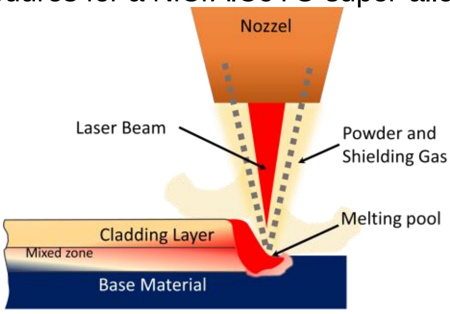
Abstract: This work investigates materials to envisages the development of new metallic, non-metallic coatings and their composites by the method of Direct Energy Deposition. The coatings are obtained, melting the precursor powder by the laser beam and directed to the adherent substrate. Multifunctional layers with thicknesses between 0.1 mm and few mm can be obtained. The aerospace and automotive industries are interested in applying the method for obtaining protective layers, parts manufacturing, repair, and refurbishment, being competitive with classical methods. Preliminary results consist of the development and realization of Direct Energy Deposition procedures for a NiCrAlCoYO super-alloy and 316LSi stainless steel.



316L-SI nickel chromium stainless steel deposition on the metal shaft

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Influence of Preload on Failure Modes of Hybrid Metal-Composite Protruding Bolted Joints

Calin-Dumitru COMAN

Abstract: The development of finite element method gives the today researcher very convenient tools to perform deep studies in structural analysis of aeronautical components. The objective of this presentation is to define some capabilities and some working techniques for specific topics of interest. The software used for these studies are MSC Nastran, MSC Patran and MSC Adams. The finite element analysis topics discussed in the presentation are: **nonlinear buckling**, **pre-stressed assemblies** and **the influence of vibrations in screw-nut assemblies**.

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Conceptual Design of a Low Cost Linear Actuator for Variable Span Wing Application

Aynul HOSSAIN

Abstract: Aerospace actuators can be found throughout modern commercial and experimental aircraft, as well as in military and space exploration. The aerospace industry is not only growing, but also rapidly changing and the demand for aerospace actuators is growing. Linear actuator have been able to push, pull, and hold objects in a way that our bodies cannot. Additionally, electrically powered technology provides more sophisticated control options. They drive many different functions that are essential to safe and efficient aircraft operation. Manufacturers and hobbyists alike are always on the hunt for new ways to automate functions while keeping development costs low. Providing a cost-effective linear solutions for aerospace application is one of the biggest challenge. This research will provide a cost effective actuator conceptual design for variable span morphing wing UAV. The cost effective design will be presented along with the application based selection of linear actuators for morphing wing UAV.

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Researches concerning the lubrication of profiled surfaces with slip boundary conditions

Alexandru Valentin RADULESCU*, Irina RADULESCU

Abstract: The paper investigates the squeeze film process for non-Newtonian fluids between two circular parallel profiled surfaces. The lower surface is characterized by the existence of a cylindrical or spherical dimple in the center, which is specific for profiled surfaces by texturing. In order to integrate the Reynolds equation, the slip boundary conditions on the upper surface have been assumed. Finally, there are obtained the pressure distribution and the load carrying capacity for the non-Newtonian film.

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Experimental study on rheology of animal fats

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Abstract: In our days, there is a priority to diversify the sources of energy, in order to prevent the negative effects of human activity on the environment. One of the interesting solutions is to use the animal waste from the food industry. Turning animal fat into combustible would allow substituting it to oil in systems like boilers. But for using animal fat as energy in these systems, we should characterize it before by studying its rheological properties and especially the viscosity, in order to design the systems as well as possible. The purpose of the following study is to establish the main rheological properties of the pork fat, which is one of the most important waste source of animal fat from the food industry.

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Particularities of the early design phase for a single skin paraglider wing

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Abstract: This paper depicts the early phase in the research development for an integrated support system tailored for emergency response actions and remote sensing. The support system is envisioned as an integrated Unmanned Aerial System (UAS) system that consists of one or more ultralight multifunctional aerial units with a configuration that can be adapted to the nature of the intervention: monitoring, mapping, observation and logistics etc. These aerial units comprise of para-motor type UAVs that use textile paraglider wings of a special design. The overall development and theoretical design aspects that are involved in this research is subject of change bein part of an ongoing research study. Starting from wing airfoil and material selection, a design phase is under development for a single sail paraglider wing that can meet the operational demands for the envisoned system. The wing is designed mainly to have an easy handling and to have a predictable deployment at all times. The entire system and the aerial units are designed with increased modularity in order to be tailored for specific operational requirements of the intervention. An experimental model was manufactured and is currently under rigorous testing tailored to validate the theoretical aspects and the design choices.

Key Words: Unmanned Aerial System (UAS), Parachute, Paraglider, Single Sail, Technical Textiles

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Thermal Barrier Coatings based on Rare Earths doped Zirconia Materials obtained by EB-PVD process and their thermal shock properties

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Abstract: Necessity for better performance and efficiency in applications across stationary power plants, aerospace and automotive industries has led to the development of thermal barrier coatings (TBCs) and multi-layer coating systems over the last years. Thermal protective coatings based on ultra-high temperature ceramics have been developed to fulfil the harsh environmental requirements required for successfully implementation of coatings. Actually Yttria-stabilized zirconia is the gold standard for TBCs applied in aerospace. The paper presents new coatings based on Zirconia doped with mixed rare earth oxides and zirconium perovskites that have been obtain by a combinatorial EB-PVD process in high vacuum. The influence of the process parameters on the microstructure, morphology, thermal shock resistance and tribologic properties of these coatings are discussed. The effect of TBC coatings on improving the turbine performances and reducing CO2 emissions are finally considered as a key factor for process sustainability.

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Correlation between the anisotropy of an AA2021-T351 aluminium rolled thick plate and the occurrence of the stick-slip phenomenon

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Abstract: The stick-slip phenomenon is a dynamic instability that appears at the contact interface of two sliding surfaces. Its occurrence is influenced by the relative sliding speed, the contact pressure, and the system rigidity, but also by the state of contact between the two sliding surfaces. The present paper aims to study the influence of the anisotropy of an aluminium AA2024-T251 plate on the stick-

slip phenomenon. For this, using the CETR UMT II tribometer, linear sliding tests have been performed on the aluminium alloy thick plate surface using a cylindrical pin made of ultra-high-molecular-weight polyethylene (UHMWPE) along three directions: a longitudinal one, corresponding to the rolling direction of the sample (0°), a transverse one, perpendicular to the rolling direction (90°), and a median direction (45°). Varying the sliding speed, the contact pressure, and the system rigidity, it was possible to observe the influence of the material anisotropy on the specific parameters of the stick-slip phenomenon.

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Compositionally complex fluorite oxide ceramics for thermal barrier coatings applications – a review

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Abstract: Configurational entropy has been recently used to develop innovative materials with multiple different cations or anions, belonging to different crystallographic systems. Fluorite oxides exhibit chemical stability, thermal stability and thermal insulating properties and therefore are of interest in high temperature applications. These properties are highly demanded in environmental of thermal barrier coatings. Configurational entropy leads to unexpected properties for ceramics such as high hardness, low thermal conductivity or catalyst support. The unexplored compositional space is vast, so that design methods and models of such materials would decrease the number of experiments performed on intuition of researchers. Stabilizing fluorite structure by entropy engineering is difficult to track due to high temperatures where this phenomenon occurs, for which in-situ characterization techniques are not available. The weaknesses addressed by recent papers in what concerns processing may be overcome by alternative techniques, such as processing powders in liquid phase or pressure assisted sintering.

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The effects of thermal-shock tests on the surface texture and on the micro-abrasion wear resistance of a micro-composite refractory enamel designed to protect some turboreactor parts

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Abstract: Latest micro and nano composite enamels were considered effective solutions as they can compete with consecrated coatings used in aircraft industry. These coatings are subjected to severe thermal shocks during service. Thus, thermal shock resistance is a critical characteristic of an enamel coating.

By a collaborative work, a micro-composite refractory enamel (MCRE) has been developed to be used as a protective and thermal barrier for aircraft engine parts. The MCRE was designed to coat hot working pieces made of EI 435 and EI 868 superalloys. The MCRE was subjected to thermal shock tests (TST) in the [900 ;1150] oC range. The paper addresses the roughness and micro-wear resistance induced by these TSTs aimed to assess the amplitude and the correlation between roughness and micro-wear resistance. An innovative autocorrelation algorithm was introduced to detect whether there are systematic effects that induce the roughness. The correlation between roughness parameters and Calowear results is another novelty addressed in the paper. As the TST temperature increases, the amplitude of the detrimentally effects upon enamel coating increases. Summering, micro-wear resistance is a critical parameter as an enamel having very good corrosion resistance, also good TBC property, can irremediably fails if it has a poor wear resistance.

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Effect of thermal shock testing on the thermal barrier efficiency of a new micro-composite refractory enamel designed to protect the hot working parts of aircraft engines

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Abstract: A new multifunctional enamel coating, namely MCRE, was obtained at INCAS, Romania. The MCRE is designed to coat pieces made of super alloys sheets as EI 435, EI 468 grades. The thermal shock resistance is one of the critical characteristics of a thermal barrier coatings (TBC). Hence, EI 435 specimens coated with MCRE were subjected to 900 oC up to 1150 oC thermal shock tests (TST). The TSTs induced structural changes of enamel coating, and, implicitly, modified the thermal properties of the coating. The thermal diffusivity of the MCRE - EI 435 systems was measured by Flash method using a FLASHLINE3000 equipment. A new concept was introduced to quantify the thermal barrier effect (TBE). The TSTs outcomes show that as the upper temperature increases, the TBE decreases. The paper presents the microstructural changes of MCRE coating induced by the TSTs and thermal diffusivity values associated to each TST in the [125, 746] oC range. The increasing of the upper temperature of the TST leads to the decreasing of the thermal diffusivity of the coat-substrate system. Summering, the paper addresses two main novelties i.e. a new concept for TBE quantification and the TBE behavior depending on the TST parameters.

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Section 4.1 – Workshop Project "FITCoW"

Presentation of the OPTICOMS program and introduction for the FITCoW and ELADINE projects (IAI+INCAS)

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Abstract: The presentation is an introduction of the OPTICOMS project and its aims of manufacturing a 7-meter-wingbox through a one-shot curing procedure. The project's purpose of developing the methodology of a low-cost, low-volume production through means of automation are also being presented. Furthermore, the projects FITCoW and ELADINE are being introduced with respect to OPTICOMS necessities. FITCoW's objective is to design and manufacture the tooling assembly that is dedicated to producing the composite wingbox as an integral structure. Meanwhile ELADINE studies the composite material post-manufacturing distortions and means of mitigating these issues. This subject is of high relevancy in the bigger frame of OPTICOMS as the tooling in FITCoW must be compensated for such deformations in order to assure the much-needed dimensional control and stability in the final assembly stage of the composite wing.

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Composite Tool design challenges in the frame of manufacturing of a 7-meter-long CFRP wing (skin-spars assembly) in a one-shot process (pre-preg and LRI) (INCAS +TEKNO+ROMAERO

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Abstract: Designing composites is often challenging, as their manufacturing paradigm is fundamentally different from the one deployed in the manufacturing of their metallic counterparts. The complexity of this activity can only increase when the designed composite tooling assembly shall enable the manufacturing of a 7-meter-wingbox through a one-shot process. Additionally, the tooling shall be compatible with both Liquid Resin Infusion and pre-preg manufacturing techniques, proving its functionality, versatility and cost-efficiency. The article presents the challenges encountered during the conceptual design of these complex tools, as well as the various solutions developed in order to mitigate the shortcomings. When designing assemblies, all the manufacturing steps need to be known and accounted for. The evolution of the workflow by adding, removing or improving its phases has been the core of the tooling concept development. The technical evolution of these solutions is outlined in the presentation. Extra emphasis is put on the over-all accuracy and quality of the targeted results and precise functionality of the tooling subcomponents.

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High temperature laboratory testing of epoxy resin systems meant to correlate mechanical properties with temperature variation (INCAS)

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Abstract: Epoxy resins are a widely spread component in the manufacturing of aerospace structures. These types of materials have good mechanical properties which deteriorates rapidly with the increase in temperature. The main goal of this article is to determine the variation of the epoxy resins properties with the temperature in order to numerically estimate the laminate mechanical properties. A number of specimens manufactured out of EPOLAM 2080 and EPOLAM 2092 will be subjected to tensile strength test at four predetermined temperatures. The experimental results will lead to Young's Modulus vs temperature plots. The results will be subsequently used in a thermo-mechanical analysis which will determine how well the tooling structure made entirely out of composites will behave during the curing process of a one-shot spars-skin assembly. The final step is to integrate the results in a full scale thermal-structural analysis of a 1.2m and then a 7m composite tooling system.

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Challenges in the process of manufacturing the 7-meter Spar Tool subcomponents by Liquid Resin Infusion process (ROMAERO)

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Abstract: In the past years, the search for lower cost composite manufacturing technologies has focused, among other technologies, in out-of-autoclave (OoA) processes. These processes allow or higher productivity and lower manufacturing costs. The manufacturing of composite tools through out-of-autoclave technologies has the potential for significantly reduced costs in the production process but also for the reduction in the environmental impact of the production process. The present paper reviews the main advantages and challenges in the manufacturing of tooling subcomponents using OoA technologies.

The subcomponents manufactured are part of an integrated tooling for the manufacturing of the spars for a composite wing. These subcomponents are integrated by a composite body in which metallic inserts and features are assembled either through bonding or bolting. The different challenges faced in the process definition and manufacturing are presented.

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Challenges in the process of designing and manufacturing the Caul Plates elements for a 7-meter tool (TEKNO)

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Abstract: Molded parts used in assembled structures need to have a good geometric accuracy since of the molding phase in order to reduce or avoid additional rework. The structural integrity is an additional requirement to take in account in molded composite parts but, usually, the designed structural characteristics of composite part are obtained in molding phase as the geometry shape. A good geometric accuracy means use part without or with reduced surface machining, therefore a part without cut of fibers, with low risk of damage and/or thickness reduction and/or delamination. These two requirements are difficult to obtain at the same time as much as the geometry is complex, the thickness is variable, and when a vacuum bag is used. In this case, the caul plate tools are used. Caul plate is a slave tool that is commonly positioned between vacuum bag materials and laminated part during the vacuum bag construction.

The aim of this paper is to show the design and manufacturing approach of caul plates that have a very small section compared to the length (slender caul plates), three zone connected with two radii as fillet, and the ability to adapt themselves to the composite part geometry during the cure process. The manufactured caul plates are used in a Liquid Resin Infusion (LRI) or pre-preg process in order to mould correctly a C-spar part co-cured with a skin surface (wing-box sub-assembly). Two type of material rubber and composite material (LTM) have been employed and, therefore, two types of process parameter has been used to manufacture this soft and semi-rigid version of same tool.

This work should be considered a possible approach to design and manufacture complex tools where different material are involved and with a good cost effectiveness is desired.

[1]Tekno Compositi

Concepts for safe and effective de-moulding process of the 7-meter wing (IAI + INCAS)

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Abstract: De-moulding of tools from their produced parts can often be a difficult process. This task is subject to a sum of factors such as: the part geometry, the type of manufacturing process that is deployed, the magnitude of tool – part adhesion force developed throughout this process, the types of release agents used and tooling material. All of these variables bear an important role in this final stage of composite manufacturing.

The article presents the de-moulding methods considered in the FITCoW project throughout the design phase, where four male carbon tools must be safely extracted from the final part. Up to nine individual methods and devices had been conceived and proposed in order to facilitate this task. Various operating principles had been approached, ranging from the use of brute force and up to pressure-based concepts.

An extraction method trade-off study was carried out in order to determine the ideal concept considering its applicability and repeatability, all with respect to the geometrical and technological constraints. The article winds up with a more detailed description of the chosen extraction method with respect to this particular application, where tooling and part integrity are crucial requirements.

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Challenges of complex monitoring of the curing parameters in coupons for LRI manufacturing (AIMEN)

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Abstract: In the aerospace industry, Liquid Resin Infusion (LRI) is gaining more and more importance as an out-of-autoclave alternative manufacturing technique to traditional pre-impregnated (prepreg) fabrics. The research in this field has been focused on understanding the cure and the process parameters of these materials, aiming to optimize the manufacturing process and reduce costs. A major problem derived from these technologies is how the LRI process induces distortions, which occurs in composite parts due to non-uniform distribution of residual stresses. Such distortions can lead to non-uniform parts with shape distortions, which is critical issue when trying to assembly with other parts due to mismatches in shape, leading to the rejection of such component.

In this context, ELADINE project aims to understand and quantify the key manufacturing parameters that cause shape distortions on composite coupons (such as spring-in of curved parts) using an integrated numerical experimental approach. The manufacturing process will be accurately monitored through Fiber Optic Sensors (FOS) and Dielectric sensors (DC) to understand how the process variables affects the distortion phenomena. The monitored data will feed the simulation tool for spring-in prediction for large integral composite wing structures.

This talk will cover the fundamentals of cure monitoring and process parameters of thermosetting composites along with monitoring strategies for parts manufactured by LRI.

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Numerical analysis of a curing process for a laminate panel (INCAS)

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Abstract: Composites are one of the main materials used in the present manufacturing of the aircraft components (ex: spars, skins, ribs etc.). These types of materials are being used more due to their high mechanical properties and lower weight compared to metals. During curing process composites suffer chemical and mechanical modifications. Their behaviour during such manufacturing process has been an important topic in the last few years. The mismatch in the CTE (coefficient of thermal expansion) between the manufactured parts and the tools, combined with the volumetric shrinkage due to the contraction of the composites and the irregular degree of cure on the entire surface will determine distortions in the final product. These distortions will lead to noncompliance to the desired tolerances of the parts. The repercussions of such problems will have a big impact on the cost and manufacturing time. This article objectives are to present the factors that influence the characteristics of the final products, the mathematical models used to predict the properties of the parts during the manufacturing process and also the results obtained in the numerical simulation.

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Impact of composite parts distortion (spring-in) in the overall manufacturing process. Means of mitigation and costs estimation (IAI + INCAS)

Y. YUROVITCH[1], Y. OFIR[1], C. BANU[2], A. PAVAL[2]

Abstract: The presentation will first explain the distortions (spring in) influence on the manufacturing and, especially, the assembly of composite structures. Based on the previous experience of the manufacturer, a summary of challenges induced by composite parts distortion will be presented. Main points of interest with regard to these non-conformities: a) the maximum geometrical distortion threshold encountered at which parts are not being scraped, b) the costs and circumstances under which the distorted parts can be repaired and c) the influence of the distortions in the overall manufacturing cost. In the second part of the presentation, the composite parts distortions that might impact OPTICOMS project will be discussed. Finally, in the last part of the presentation, the expected improvements in the OPTICOMS project through the results obtained in ELADINE will be approached. The main conclusions will be represented by: **a**) the expected accuracy of the parts after the implementation of the ELADINE experimental results; **b**) Costs and time saved due to good accuracy of the assembly tolerances.

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Scanning and inspection of composite parts and tools. Processing of raw data and geometry validation (INCAS)

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Abstract: The ELADINE project deals with the evaluation of spring-in and warpage of carbon composite test coupons. Therefore, the tools used for manufacturing the test coupons are highly relevant from every aspect. The manufactured composite mould geometry is slightly different from the CAD model – that is mainly due to the process-induced displacements that the project tries to qualitatively assess. The formed coupon will initially inherit the mould’s geometrical characteristics but, as this surface is unknown, it has to be assessed in order to obtain the true reference geometry. This technical note describes the activity of scanning the ELADINE tooling at high resolution. Ultimately these high-fidelity scanned surfaces will be processed into accurate and easily usable geometries. These will subsequently serve as datum in the ELADINE numerical tool and the over-all evaluation of test coupons shape distortions. The preliminary deviations report for the tooling with respect to the theoretical part is also presented, along with the processing methodology of the scanned surfaces in CATIA V5.

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Section 5 –Systems Subsystems and Control in Aeronautics

(in alphabetical order of the first author)

Human Performance Envelope Model Study Using Pilot's Measured Parameters

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Cătălin Sever MOISOIU[1], Cristian-Alexandru TĂNASE*[,1]

Abstract: Taking into consideration that nowadays aerospace industry focuses a lot on safety, more durable and stable systems are developed. While the system itself is safer, there is another element that can have a high impact on the overall safety of a flight, the human factors. Pilot physiological parameters were measured during a full flight in a fixed cockpit environment using application-specific equipment. The recorded or calculated parameters are used to compute a performance envelope model with the scope of determining the pilot's condition degradation during different flight phases or events. Several standardized tests were realized on subjects given flight instructions before the test, without knowing beforehand the scenery and events that will occur. This study helps in identifying limits of pilots in different flight scenarios and the impact on their presumed performance.

Key Words: human factors, safety, pilots, flight simulator, eye tracking, heatmap, ECG, HPE

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H_∞ robust control design for lateral-directional dynamics of the Rockwell B-1 aircraft

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Abstract: Squeeze film dampers (SFD) are perhaps the most efficient devices that, nowadays, can be used to control the shafts in airworthy turbo-compressors. Various other devices can be successfully used in land-based rotating machinery, however, due to space and weight constraints they can not be used for the lateral vibrations control in on-board ball bearings supported turbines. SFDs are basically thin oil films (surrounding the ball bearing housings), that, in conjunctions with various elastic elements and antirotational devices provide the stiffness and damping required for adequate shaft behavior. Fluid films in SFDs are strongly influenced by the oil supply and drain pressures. Some aspects regarding the effects of the supply and drain pressures on a SFD are discussed below.

Key Words: Squeeze film dampers (SFD), hydrodynamic bearings, rotor dynamics

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Research on nose landing gear of a military school and training aircraft

Ilie NICOLIN[1], Bogdan Adrian NICOLIN*[,1]

Abstract: This report shows documentary research on nose landing gear of military aircraft. Military aircraft are equipped with a tricycle landing gear (a nose landing gear and two main landing gear positioned left and right under the wings) in a strongly reinforced area. The nose landing gear of military aircraft is a complex system composed of structural elements, electric and hydraulic components, energy absorption components, aircraft tire wheels etc., which is dimensioned according to the weight of the aircraft. Additional components attached to the nose landing gear include a landing gear extension and retraction mechanism and a steering system. The landing gear

must withstand the weight of the aircraft in all phases of take-off (maximum weight: fuel, armament, ammunition, other equipment, flight crew etc.) and landing (impact from landing and a lower weight after completing the mission due to fuel consumption and ammunition use).

Key Words: Nose landing gear, main landing gear, steering system, extension and retraction mechanism

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Preliminary calculation of the landing gear of a military school and training aircraft

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Abstract: Preliminary calculation of the landing gear includes estimating the loads on landing and determining the position of nose landing gear and main landing gear of a military school and training aircraft. Another purpose of the preliminary calculation is to ensure the stability of a military school and training aircraft on landing and take-off, as well to ensure the lateral stability of the aircraft during ground operations such as taxiing, landing or take-off.

Key Words: Nose landing gear, main landing gear, landing, take-off

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ENOVIA Business Tools for Concurrent Engineering

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Abstract: This paper is about business tools for concurrent engineering. In this regard, ENOVIA is presented, a business tool that helps enterprises to develop in this area. It helps business customers to achieve experience and gives them a platform to collaborate in a secured manner. ENOVIA can bring marketplace advantages for concurrent engineering of complex systems. ENOVIA helps build a business plan based on requirements engineering providing continuous optimization, real-time progress tracking and compliance with standards and regulations. Also, we introduce Arrowhead framework for real time data handling and scalability of local clouds for automation systems.

Key Words: enovia, 3ds, business, simulation, workflow, concurrent, engineering

I. INTRODUCTION

Workflow mechanisms and concurrent engineering are parts of a business tool. Business tools help more business partners to collaborate and their purpose is to bring efficiency in this matter. Concurrent engineering is related to the development phase of a product and is about managing tasks. A Workflow is about making a number of tasks to run in a pattern, in a pre-configured order. Workflow enables data processing in a concurrent engineering environment [1].

II. ENOVIA

ENOVIA’s features are flexibility and optimization. It also provides real-time progress tracking. This tools is powered by 3DEXPERIENCE®. It allows stakeholders to contribute to economic development. The ENOVIA platform provides a collaborative framework for any function within a company. This platform is accessed through the Business Process Services (BPS) interface. BPS is easy to configure. It creates a working environment for applications, facilitating collaboration between internal and external users (for example, providers), while maintaining control over access to content. It also provides metrics reporting capability to evaluate performance considering the content of the product. From ENOVIA platform, any company can access its features.

Through BPS, collaboration between partners is possible. BPS provides control over access too. BPS provides metrics reporting capability to evaluate performance considering the content of the product [3].

III. CONCLUSION

ENOVIA helps improve collaboration between business partners. It provides optimization and security for concurrent engineering of systems and sub-systems. As future work we intend to integrate ENOVIA with Arrowhead framework for building time critical local clouds.

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Development of dielectric elastomeric actuation structures for morphing wings

Ștefan URSU

Abstract: In the last decades, wing morphing structures have shown great interest because of their capability for improving the aerodynamic efficiency of modern aircraft. DE actuators, also known as „artificial muscles" due to their ability to exhibit large actuation strains at high voltages, are perfect candidates for morphing applications. This paper focuses on the research and development of miniature dielectric elastomeric actuators for the active optimization of the wing airfoil profile. A conical elastomeric actuation configuration has been proposed, consisting of a VHB4910 dielectric membrane preloaded with a spring mechanism and constrained to a rigid circular ring. The mini-actuators are developed to be fixed in an actuation array, mounted to the wing skin. This new electromechanical actuation system is designed to be integrated on thin airfoil wings, where conventional morphing structures cannot be used, due to restricted mass and space requirements. Controlling the thickness distribution using the proposed actuators, we expect to be able to maintain and delay the location of the laminar-turbulent transit towards the trailing edge, promoting laminar flow over the wing surface. This research project is currently in progress, and further experimental models and prototypes will be developed and tested using specific procedures.

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Section 5.1 – Workshop Project “CONTUR”

(in alphabetical order of the first author)

Correlation based analysis between pilots CAT reports and the meteorological forecast

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Abstract: Clear Air Turbulence (CAT) are hard to predict phenomena and also hard to detect ore sense in advance. Unlike other types of turbulence, for CAT there are no radar returns for the Airborne Weather Radar). This paper is an attempt to find a correlation between the CAT encounters as reported by pilots, and the relevant weather parameters obtained from the meteorological nowcast. The focus was on the gradients of the atmospheric pressure and temperature. Pilot reports (PIREPs) and weather data were retrieved from international databases (Iowa University Mesonet and National Oceanic and Atmospheric Administration).

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Influence of wind shear and gusts on the aeroelastic response of an elastic aerial vehicle

Marius STOIA-DJESKA*, Laurentiu MORARU

Abstract: Wind shear and gusts are weather phenomena dangerous for aviation as well as for terrestrial systems. The objective of this work is to investigate the aerodynamic effects of these atmospheric phenomena on the elastic light structures specific for aerial vehicles. The calculations are done with a vortex-lattice method and a fluid-structure interaction solver. The results include an evaluation of the aerodynamic force changes in the case of an elastic wing and on the aeroelastic response of the wing.

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Regarding the dynamics of an airplane in a gust

Laurentiu MORARU*, Marius STOIA-DJESKA

Abstract: The current paper deals with calculating the accelerations on an airplane subjected to a gust. The longitudinal equations of symmetric flight of the airplane are written to include the effect of the vertical wind. Analytical solutions originating in the linearized equations of motion of the longitudinal channel (with wind effects included) are discussed.

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Stability of a wing model with delay on switching control

Ioan URSU*, Adrian TOADER, Daniela ENCIU, George TECUCEANU

Abstract: The main objective of the work is the validation of a control strategy for the wing model tested in the wind tunnel (WT) for several air speeds. The mathematical model of the wing, obtained by experimental identification, is a set of linear systems associated with several air speeds in WT. Introducing the actuator delay into the model is a common paradigm in the field. It is defined a problem of active control synthesis for a switching system with delay on the actuator. A predictive feedback method is used to compensate the actuator delay of the associated linearized system. Thus, the time-delayed control is replaced by a state delay, and the effect of the control appears in a non-homogeneous term in the linearized system. A theorem that gives sufficient conditions for stability, recently published by the authors of the present work, is now applied in the case of the wing model. Numerical simulations will highlight some aspects regarding the conservative character of the theorem.

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CAT detection using a synergy of lidar and wind profilers

Razvan PIRLOAGA*[,1,2], Livio BELEGANTE[1], Sabina STEFAN[2], Aurelian Andrei RADU[3]

Abstract: Atmospheric turbulence in lower troposphere or in upper troposphere and lower stratosphere (UTLS) is a current issue in modern days in the context of airline safety since no feasible technical solution is available to detect and avoid it. Project CONTUR ("Emerging Technologies to Counteract the Effects Induced by the Turbulent Flows of Fluid Environments") aims to develop emerging technologies to detect the presence of clear air turbulence (CAT) in UTLS layer, by remote sensing lidar techniques in order to solve the specific problems generated by the turbulence phenomena in airline transportation. The know-how collected during the first part of the project showed that using a singular lidar instrument is insufficient to clearly detect turbulent episodes. Therefore, the third campaign performed in the framework of CONTUR was focused on using a synergy of 3 instruments to validate lidar data in detecting CAT events. The focus of this campaign was to study thermal turbulence that occur in the lower troposphere (in atmospheric boundary layer up to 5 km altitude). A synergy of lidar and wind profilers could increase the resolution of the investigated area (Magurele, Romania) and provide information to complex factors responsible on turbulence. The results obtained in this campaign emphasized that using synergetic data obtained in boundary layer allow comparison between atmospheric different turbulence types. Thus, physical processes in UTLS can be explained by some parameters obtained in the turbulent processes in lower troposphere.

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A tenable interinstitutional collaboration beyond the completion of the CONTUR project

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Abstract: The CONTUR project has open up new horizons for the activities aimed at counteracting the effects induced by the atmospheric turbulent flows. A tenable interinstitutional collaboration beyond the completion of the CONTUR project is to be implemented. The institutional developments with an impact on turbulent flow studies have to be considered. The most relevant topics to be included in the future joint program for research, development and innovation (CDI) will be presented and discussed.

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Section 6 – Experimental Investigations in Aerospace Sciences

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Development of damping rigs for trisonic wind tunnel

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Ruxandra DUȘMĂNESCU[1]

Abstract: The necessity of the development of aerodynamic damping rigs is coming from the new requirements for experimental investigation in the 1.2m*1.2m trisonic wind tunnel of the National Institute of Aerospace Research - INCAS. There, two damping rigs will be developed, the first rig is created for damping in roll and the second one is developed for damping in pitch and yaw movements. The pitch and yaw damping rig is quite similar, the difference between them involves a 90o rotation of the model's sting. In this paper, the requirements of the rigs, the technique for measurement and the devices used for actuation and measurement will be presented. The roll damping rig uses a brushless motor to roll the aerodynamic model, an electromagnetic clutch to engage and disengage the torque between the motor and the model's shaft, and a Hall sensor to measure the spinning of the model during the experiment. The pitch /yaw rig uses a hydraulic actuator and a rod-crank system to initiate the oscillation around of pitching or yawing axes and three strain-gages to measure the oscillations. To identify the aerodynamic damping coefficient, which is the main objective of this paper, the damping rigs for roll and pitch/yaw shall be tested into a vacuum chamber to determine the structural component of the damping coefficient. The results from the wind tunnel tests shall be corrected, extracting the structural component mentioned above from the total damping measured in the trisonic wind tunnel.

Key Words: roll damping rig, pitch damping rig, trisonic wind tunnel, damping rigs design

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Deep Learning Aircraft Glide Path and Artificial Horizon Estimation for Visual Navigation Enhancement

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Abstract: The latest achievements in the aircraft automated visual landing opens a new aviation research area for computer vision applications. Glide path estimation, runway alignment represents essential information in the final approach for visual navigation procedure and also for data redundancy in the continuous descent approach procedure for ICAO required navigation performance. The computer vision algorithms, used on this paper, are based on artificial intelligence and aims for runway detection and artificial horizon identification in order to increase the safety level of navigation in both aircraft operating modes, IFR and VFR. This goal is attained through training of the deep learning neural network with Flightgear parameterized visual data.

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Approaches on flight data recordings

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Abstract: This paper is brief presentation of flight data records used currently for design, maintenance and safety investigation. It is an overview on the approaches in processing the flight recorder data, focusing on flight recorders and records provided by other on-board equipment. The data analysis is focusing on CVRs and the other recording facilities on-board, rather than FDRs, which were extensively approached by another paper. To underline the importance of all sources, as well as the volume of work the papers includes brief practical case studies selected from the investigation reports issued by the Romanian SIAA. Information on processing flight records is provided as a flight data processing practices overviews. The paper is intended to inform aircraft operation' and maintenance', as well as SIAs' specialists about the large amount of available data, provided by flight recording devices, which, if properly processed, enable increased flight safety and avoidance of severe occurrences, being the third of a series, on developments on safety data.

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Shortt-Synchronome Time synchronization in distributed data collection systems- an old solution to a new problem

Alexandru - Marius PANAIT

Abstract: Distributed data collection systems are often, in practice, heterogeneous constructs using various technologies or combining equipment of different manufacture and/or vintage. Synchronization of the various autonomous or semi-autonomous data acquisition subsystems (called "nodes" in the specialty literature) is crucial whenever analyzing time-variant correlated signals or whenever measurements involving durations of time or timed responses appear. Because of the structure of such systems, a mechanism to generate, distribute and coordinate permanently all subsystems by generating unified clock pulses might not be practical. The solution is to use a form of distributed architecture with the added task to synchronize all clocks of all the nodes so that collected data is coherent and proper measurements involving frequencies, timed responses and simultaneity can be conducted. The Shortt-Synchronome system was first used in high precision scientific electric pendulum clocks more than a century ago but allowed for accuracies of 200 microseconds per day, that is approximately one second every 12 years. The paper discusses a modern implementation of the concept using a low data rate logical signal to correct or correlate clocks in distributed data collection nodes.

Key Words: Shortt-Synchronome, precision timing adjustment, hit and miss synchronizer, distributed data acquisition systems, cost-effective GPS disciplined oscillator (DO)

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Brief history of flight data recording

Dumitru POPOVICI[1], Radu Sebastian ZAHARIA[2], Peter KALMUȚCHI[3]

Abstract: The paper is intended to provide brief information on the flight data recording, focusing on reviewing the developments in this branch, the points of view of specialists involved in several aviation branches such as R&D, manufacturing, operation and maintenance and safety investigations. The intension is to keep more or less closed to the developments in our country and to enable co-operation. The paper is reviewing the history and the used of flight data recording, trying to underline developments closely connected with the aviation industry in our country. It provides also support on the information papers regarding processing of flight data records and their use in benefit of maintenance and safety investigation. The result of such work is enabling operational safety improvement, fitting and retrofitting aircraft with recording and data link equipment, as well as design improvements.

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Processing of flight data records

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Abstract: This paper s is providing a view on the processing of data recorded on-board of aircraft. Since CVR and FDR are the most familiar recording devices, the paper is focusing on the processing of FDR data. It is important to underline that this processing is a routine operation for any air operator, since for operational improvement and maintenance these data provide most valuable information. It is very important also for the safety investigation. Mainly the investigators concentrate on reconstructing the final parts of the flight ending in an occurrence, but operation history may provide some times very important clues, and supporting safety recommendations, together with all other investigation finding, so the different kind of reports generated by FDR data processing can be also important tools. This is the second part of a papers series, deemed to brief the interested specialists on developments on safety data and its processing.

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Section 8 – Management in aerospace activities

(in alphabetical order of the first author)

State of Art on Automated Fiber Placement with Applications in Aerospace Engineering and Management

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Abstract: The topic of this paper is in line with the continuous efforts to improve the world of aviation, in terms of performances and costs of the specific products, to alleviating the environmental impact, for all the phases through life cycle. The use of composites in aerospace engineering provides significant reduction of costs for manufacturing, technology and operation, provided adequate management. A key element is the Automated Fiber Placement, which represent the focusing line of this study, in correlation with the presentation of the most important applications in aerospace engineering. Management in composites manufacturing and technology enable to achieving performance and cost-effectiveness for the targeted products.

Key Words: Composite Materials, Automated Fiber Placement, Technology, Manufacturing, Applications, Aerospace Engineering, Management

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A Survey on Composite Applications in Aerospace Engineering and Management

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Abstract: The intent of this paper is to present the most important applications of composite materials in aerospace engineering, that can be related to aerostructures, jet engines parts such as fan blades, wind turbine blades, and most often used the Vertical Axis Wind Turbine VAWT. Last but not least are the application of composites to other industries, that can be related with the environmental impact as ground vehicles or industries relatable with human care and wellbeing, e.g. reconstructions of damaged human body parts, prosthetics and dentistry. The use of composites in aerospace engineering provides significant reduction of costs for manufacturing, technology and operation, provided adequate management. Management in composites manufacturing and technology may allow to achieving performance and cost-effectiveness for the most significant products, as aerostructures, fan blades, VAWT blades are.

Key Words: Composite Materials, Applications, Aerospace Engineering, Aerostructures, Jet Engine Parts, Fan Blades, Wind Turbine Blades, VAWT, Management

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Risk Management and Organizational Considerations for Enhancing Safety State Given the Continuous Technological Development Processes

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Abstract: Decision making processes within aeronautical organizations are becoming more challenging not only due to social, economic or flight planning threats, but also due to the need to properly implement new technologies that may require different approaches for enabling a high performance operational state in air transport. The paper outlines organizational management improvements in the complex and dynamic operational environment and analyses decision making processes that are linked with different risk levels which require a strong commitment from organizational management in the context of operational objectives. The authors also analyze the implementation of new technologies multiple impacts that are affecting the processes carried out within the organization and propose ways of adapting organizational management with the purpose of controlling safety processes.

Key Words: commercial aviation, decision making, new technologies, organizational management, risk analysis, safety state

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Project Management Applied for Composite Materials Used in Aeronautics. Carbon Fiber and Nano-Additives

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Science Advisors and Coordinators: Adriana ŞTEFAN[5], Irina-Carmen ANDREI*[,5], Gina Florica STOICA[6], Nicoleta CRIŞAN[7], Delia PRISECARU[6], Cristian STOICA[8], Anca GRECULESCU[6]

Abstract: This paper presents the results of theoretical and applied research related to composite materials, carbon fiber and nano-additives. The objective is to investigate the properties and behavior of custom designed composite materials which are intended for applications in aerospace engineering. The holistic approach is expressed by the structure of this research project which consists of the technical part and the economic part, that is analyzed in terms of project management. The specificity of the work is given by the requirements of the European Project Semester EPS, where international teams of students actively experience a multidisciplinary and multicultural project for one semester in another university, which has developed research and industrial partnerships. For developing such project, the approach provided by INCAS as Research Partner is oriented towards Problem Based Learning and Project Organized Learning. The University as Organizer provides Project Related Courses and some complementary Project Organized Learning. The research was oriented towards the customized design and analyzing of composite materials samples for potential use in aerospace engineering, the development and validation of materials and methodologies. The benefits of the research project are related to the applications of composite materials and in the subsidiary to allow the students learn valuable professional lessons and experience from this research project.

Key Words: Project Management, Composite Materials, Carbon Fiber, Nano-Additives, Aerospace Engineering, Applications

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EXTENDED ABSTRACTS

Inertial Couples in the Dynamics of Mechanical Systems with Rotors

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Abstract: *The mechanical movement around the center of mass of a mechanical assembly, which has in its composition rigid bodies in relative rotation, is influenced by the inertial interaction between the rotors and the rest of the constructive assembly. This paper determines the inertial terms that appear in the extension of the kinetic moment theorem for the case of a basic supporting structure, on which is mounted a rigid body in relative rotation with respect to it. The particular case is that of an air vehicle equipped with a jet engine whose turbine has a kinetic moment comparable to that of the carrier structure. The work done was conducted to highlight those inertial couples that have not been brought to light so far.*

Key Words: *Mechanics, rotors, inertial couples*

1. INTRODUCTION

Most real technical systems have a supporting structure and some other equipment, among them with an rigid body rotating relative to this basic structure with the angular velocity ω.

Due to this rotating body there are inertial interaction between it and the rest of the constructive structure, which has its own angular velocity Ω.

These interactions are to be considered mainly when kinematic moments of rotors are comparable to the rest of the mechanical structure and there are no mechanical damping torques.

On the other hand the classical books regarding the classical mechanics, as the references [1], [2], [3], give no proof for the kinetic moment theorem, considering a system of rigid bodies, based on well known newtonian principles.

This paper is intended to emphasize the inertial torques due to interaction just mention above and to derive the kinetic moment theorem for a mechanical system consisting of a supporting structure on which is mounted a rigid body in relative rotation with respect to it.

2. THE KINETIC MOMENT THEOREM

We will consider valid the Kinetic Moment Theorem, denoted here as KMT, extended to a mechanical system of rigid bodies in the same way as for a system of material points.

The complete deriving of the Kinetic Moment Theorem based on the validity of such a theorem for a single rigid body will be done in a full paper concerning mechanical system with rotors. So, we state the KMT, relative to the supporting structure on which is mounted a rotating rigid body with respect to it, to have the expression:

$$\frac{D}{Dt}\vec{K}_c = \vec{M}_C^R + \vec{M}_C^B \tag{1}$$

where $\vec{K}_c$ is the angular moment of the whole system, $\vec{M}_C^R$ is the moment of momentum for the rotor and $\vec{M}_C^B$ is the moment of momentum for the body structure. The rotor in the particular mechanical system considered, is that in the following figure:

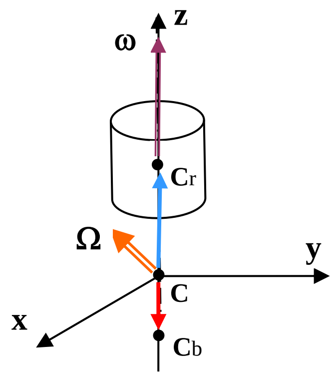

Fig. 1 – Rotor in the reference frame of the whole mechanical system

For such a scheme, the kinetic moment is:

$$\begin{gathered}\vec{K}_{C} = \vec{K}_{C}^{R} + \vec{K}_{C}^{B} \\ \vec{K}_{Cr}^{R} + \overrightarrow{CC_r} \times m_R \vec{V}_{CrC} = \vec{K}_{C}^{R} \\ \vec{K}_{Cb}^{B} + \overrightarrow{CC_b} \times m_B \vec{V}_{CbC} = K_{C}^{B}\end{gathered} \tag{2}$$

with a structure of the angular moment:

$$\vec{K}_{C} = \vec{J}_{C} \cdot \vec{\Omega} \tag{3}$$

We proceed to analyse and expend the expression of the KMT taking into account the well-known formula for time derivatives expressed in the primary reference frame (an inertial one), denoted (RF_1), with the time derivatives expressed in a reference frame rotating relative to it, denoted (RF_2), with an angular velocity $\vec{\omega}_{21}$

$$\left.\frac{d\vec{K}}{dt}\right|_{(RF_1)} = \left.\frac{d\vec{K}}{dt}\right|_{(RF_2)} + \vec{\omega}_{21} \times \vec{K} \tag{4}$$

That is why, in (RF2) the considered rigid body has constant inertia moment because it has no relative movement relative to this reference frame, so that:

$$\left.\frac{d\vec{K}}{dt}\right|_{(RF_2)} = \vec{J} \cdot \left.\frac{d\vec{\Omega}}{dt}\right|_{(RF_2)} \tag{5}$$

The strategy followed to emphasise the inertial torques due to interaction between the rotating body and the rest of the constructive structure and to derive the kinetic moment theorem for such a mechanical system consists of a succesive steps to:

-express all derivatives with respect to the reference frame of the basic structure,

-tack unto account that the inertia tensor, denoted here as **J**, is not variable only in the proper referential of the respective rigid body,

-group the terms so to highlight inertia moments, kinetic moments for the basic structure and for the rotating body, determined in their own proper reference frames and then expressed in the central reference frame of the basic structure.

Using the superscript B and R for the Basic Structure and Rotor and subscript C for mass center of the entire structure, with supplementary letters r and b regarding rotor and basic structure, we proceed to the proposed strategy.

These first successive stages of such an attempt are as follows:

$$\begin{aligned}&\frac{D}{Dt}(\vec{K}^{R}_{Cr}+\overrightarrow{CC_r}\times m_R\vec{V}_{CrC})+\frac{D}{Dt}(\vec{K}^{B}_{Cb}+\overrightarrow{CC_b}\times m_B\vec{V}_{CbC})=\\&\frac{D}{Dt}\vec{K}^{R}_{Cr}+\frac{D}{Dt}\overrightarrow{CC_r}\times m_R\vec{V}_{CrC}+\frac{D}{Dt}\vec{K}^{B}_{Cb}+\frac{D}{Dt}\overrightarrow{CC_b}\times m_B\vec{V}_{CbC}=\\&\frac{d}{dt}\vec{K}^{R}_{Cr}\Big|_{(C_r x_r y_r z_r)}+(\vec{\Omega}+\vec{\omega})\times\vec{K}^{R}_{Cr}+\frac{D}{Dt}\overrightarrow{CC_r}\times m_R\vec{V}_{CrC}+\\&\frac{d}{dt}\vec{K}^{B}_{Cb}\Big|_{(C_b x_b y_b z_b)}+\vec{\Omega}\times\vec{K}^{B}_{Cb}+\frac{D}{Dt}\overrightarrow{CC_b}\times m_B\vec{V}_{CbC}\end{aligned}\tag{6}$$

The next step is to group the termes in their proper reference frames:

$$\begin{aligned}&\frac{d}{dt}\vec{K}^{R}_{Cr}\Big|_{(C_r)}+(\vec{\Omega}+\vec{\omega})\times\vec{K}^{R}_{Cr}+\frac{d}{dt}[\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})]\Big|_{(C_b)}+\vec{\Omega}\times[\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})]+\\&\frac{d}{dt}\vec{K}^{B}_{Cb}\Big|_{(C_b)}+\vec{\Omega}\times\vec{K}^{B}_{Cb}\qquad+\frac{d}{dt}[\overrightarrow{CC_b}\times m_B[(\vec{\Omega}\times\overrightarrow{CC_b})]\Big|_{(C_b)}+\vec{\Omega}\times[\overrightarrow{CC_b}\times m_B(\vec{\Omega}\times\overrightarrow{CC_b})]=\\&\vec{J}^{R}_{Cr}\frac{d}{dt}(\vec{\Omega}+\vec{\omega})\Big|_{(C_r)}+\overrightarrow{CC_r}\times m_R[\frac{d}{dt}(\vec{\Omega}\times\overrightarrow{CC_r})]\Big|_{(C_b)}+(\vec{\Omega}+\vec{\omega})\times\vec{K}^{R}_{Cr}+\vec{\Omega}\times[\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})]+\\&\vec{J}^{B}_{Cb}\frac{d}{dt}\vec{\Omega}\Big|_{(C_b)}\qquad+\overrightarrow{CC_b}\times m_B[\frac{d}{dt}(\vec{\Omega}\times\overrightarrow{CC_b})]\Big|_{(C_b)}+\vec{\Omega}\times\vec{K}^{B}_{Cb}\qquad+\vec{\Omega}\times[\overrightarrow{CC_b}\times m_B(\vec{\Omega}\times\overrightarrow{CC_b})]=\\&\vec{J}^{R}_{Cr}\cdot\frac{d}{dt}(\vec{\Omega}+\vec{\omega})+\overrightarrow{CC_r}\times m_R[\frac{d\vec{\Omega}}{dt}\times\overrightarrow{CC_r}]+\vec{\Omega}\times[\vec{K}^{R}_{Cr}+\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})]+\vec{\omega}\times\vec{K}^{R}_{Cr}+\\&\vec{J}^{B}_{Cb}\cdot\frac{d}{dt}\vec{\Omega}\qquad+\overrightarrow{CC_b}\times m_B[\frac{d\vec{\Omega}}{dt}\times\overrightarrow{CC_b}]+\vec{\Omega}\times[\vec{K}^{B}_{Cb}+\overrightarrow{CC_b}\times m_B(\vec{\Omega}\times\overrightarrow{CC_b})]=\end{aligned}\tag{7}$$

Using this last form of the KMT we are able to bring into evidence the inertia torques:

$$\begin{aligned}&\vec{J}^{R}_{Cr}\cdot[\frac{d}{dt}(\vec{\Omega}+\vec{\omega})\Big|_{(C_b)}+(-\vec{\omega})\times(\vec{\Omega}+\vec{\omega})]+\vec{j}^{R}_{C_rC}\cdot\frac{d}{dt}\vec{\Omega}+\vec{\Omega}\times[\vec{K}^{R}_{Cr}+\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})]+\vec{\omega}\times\vec{K}^{R}_{Cr}+\\&\vec{J}^{B}_{Cb}\cdot\frac{d}{dt}\vec{\Omega}\qquad+\vec{j}^{B}_{C_bC}\cdot\frac{d}{dt}\vec{\Omega}+\vec{\Omega}\times[\vec{K}^{B}_{Cb}+\overrightarrow{CC_b}\times m_B(\vec{\Omega}\times\overrightarrow{CC_b})]=\\&(\vec{J}^{R}_{Cr}+\vec{j}^{R}_{C_rC})\cdot\frac{d}{dt}\vec{\Omega}+\vec{\Omega}\times(\vec{J}^{R}_{Cr}+\vec{j}^{R}_{CrC})\cdot\vec{\Omega}+(\vec{J}^{R}_{Cr}\cdot\frac{d}{dt}\vec{\omega}+\vec{\omega}\times\vec{J}^{R}_{Cr}\cdot\vec{\omega})+\\&\qquad(\vec{\Omega}\times\vec{J}^{R}_{Cr}\cdot\vec{\omega}+\vec{\omega}\times\vec{J}^{R}_{Cr}\cdot\vec{\Omega})+\vec{J}^{R}_{Cr}\cdot(\vec{\Omega}\times\vec{\omega})+\\&(\vec{J}^{B}_{Cb}+\vec{j}^{B}_{C_bC})\cdot\frac{d}{dt}\vec{\Omega}+\vec{\Omega}\times(\vec{J}^{B}_{Cb}+\vec{j}^{B}_{C_bC})\cdot\vec{\Omega}\end{aligned}\tag{8}$$

where we have used the notations:

$$\vec{j}^{R}_{C_rC}=\overrightarrow{CC_r}\times m_R(\vec{\Omega}\times\overrightarrow{CC_r})$$

$$\vec{j}^{B}_{C_bC}=\overrightarrow{CC_b}\times m_R(\vec{\Omega}\times\overrightarrow{CC_b})$$

The final expression of KMT derived using the above algebraic expressin is:

$$\vec{M}_C^R + \vec{M}_C^B = (\vec{J}_C \cdot \frac{d}{dt}\vec{\Omega} + \vec{\Omega} \times \vec{J}_c \cdot \vec{\Omega}) + (\vec{J}_{Cr}^R \cdot \frac{d}{dt}\vec{\omega} + \vec{\omega} \times \vec{J}_{Cr}^R \cdot \vec{\omega}) + (\vec{\omega} \times \vec{J}_{Cr}^R \cdot \vec{\Omega} + \vec{\Omega} \times \vec{J}_{Cr}^R \cdot \vec{\omega}) + \vec{J}_c^R \cdot (\vec{\Omega} \times \vec{\omega}) \quad (9)$$

3. THE INERTIAL COUPLES

In the former expression (9) of KMT we may bring into attension the following inertia torques for:

-Dynamics of the kinetic moment of the whole structure, WS, with its angular velocity

$$\vec{J}_C \cdot \frac{d}{dt}\vec{\Omega} + \vec{\Omega} \times \vec{J}_c \cdot \vec{\Omega} \overset{not}{=} \frac{D}{Dt} K_C^{(B,R)} \quad (10)$$

-Inertia moment produced by the motion of the rotor in relation to WS, as rotor own dynamics

$$\vec{J}_{Cr}^R \cdot \frac{d}{dt}\vec{\omega} + \vec{\omega} \times \vec{J}_{Cr}^R \cdot \vec{\omega} \overset{not}{=} - M_C^{ir} \quad (11)$$

Iertia torque as dynamics of symmetrical coupling phenomena of the rotor with WS:

$$\vec{\omega} \times \vec{J}_{Cr}^R \cdot \vec{\Omega} + \vec{\Omega} \times \vec{J}_{Cr}^R \cdot \vec{\omega} \overset{not}{=} - \vec{M}_C^{is} \quad (12)$$

-Inertia moment of coupling of the rotor rotation at WS rotation as dynamics of relative coupling phenomena of the rotor at WS

$$\vec{J}_c^R \cdot (\vec{\Omega} \times \vec{\omega}) \overset{not}{=} - \vec{M}_C^{ic} \quad (13)$$

Considering these new mechanical quantities the final formula for KMT becomes:

$$\frac{D}{Dt}\vec{K}_c^{(B,R)} = (\vec{M}_C^R + \vec{M}_C^B) + (\vec{M}_C^{ir} + \vec{M}_C^{is} + \vec{M}_C^{ic}) \quad (14)$$

4. CONCLUSIONS

The main conclusions that may be derived from the final expression form, (9), of the Kinetic Moment Theorem are as follows:

For an aerial vehicle without aerodynamic damping and with rotors, there are "inertial torques" that can have unpredictable mechanical effects.

In order to be able to synthesize an efficient control system it is necessary to build the mechanical flight model sufficiently rigorous in determining these inertial effects.

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Bending Vibration Analysis of Nanobeams using the Nonlocal Motion Equations Solved by an Integral Approach

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Abstract: *This paper deals with the dynamic characteristics for bending vibrations of Euler-Bernoulli type nanobeams taking into account the scale effects via the nonlocal motion equations. An integral method, based on the use of Green's functions, has been used in order to obtain the corresponding eigenvalue problem. The proposed integral approach is an approximate matrix method. Effects of different boundary conditions and of an elastic foundation have been also included. The presented numerical examples show good agreement when compared to results from literature. The proposed method can be used in the case of nanodevices analysis modeled as beams (MEMS, NEMS).*

Key Words: *Nanobeams, Scale Effects, Vibrations, Green's Functions, Winkler Foundation*

1. INTRODUCTION

An actual subject, related especially to design of nanodevices, is the mechanical behavior analysis of nanostructures as nanorods, nanobeams, nanoplates etc. As experimental measurements are difficult at nanoscale levels, there are available the molecular dynamic simulations which are computational expensive or the use of continuum modeling of nanostructures modified in order to capture the size-effects at nano or micro scale [1]. Scale effects play an important role for nanostructures, less for microstructures, while for the macrostructures one can use the classical continuum-based theories which are scale-free. In the classical elasticity theory, the local stress in a point of a structure depends only the local strain. Different so called nonlocal elasticity theories have been developed based on the idea that the strains at all locations of a structure affect the stress in a given point. A nonlocal coefficient μ has been defined as:

$$\mu = \frac{e_0 \cdot a}{L}, \tag{1}$$

where e_0 is a calibration coefficient, a is an internal characteristic length and L is the external characteristic length.
The Fig. 1 shows such characteristic lengths for the case of Carbon Nanotubes (CNs).

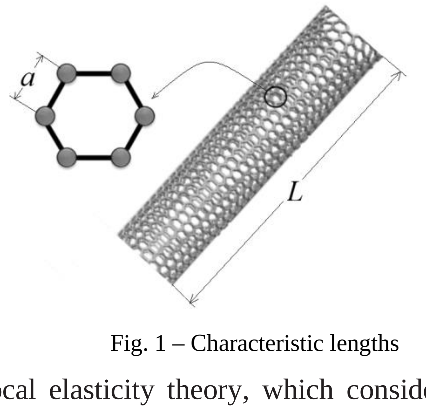

Fig. 1 – Characteristic lengths

One of the first and simplest nonlocal elasticity theory, which considers the size-dependent effects, was proposed by Eringen [2]. His theory was also proved to be in accordance with some experimental conclusions on phonon dispersion [3]. The author obtained the following relation for the nonlocal operator:

$$L_{nl}(*) = [1 - (e_0 a)^2 \nabla^2](*) \tag{2}$$

Another theory named Nonlocal Strain Gradient Theory (NGST) was presented in [4]. After the appearance of carbon nanotubes these theories were used to obtain the size dependent differential equations for buckling, bending, vibration and wave propagation for nanostructures as beams, rods, plates and shells.

When one apply the nonlocal theory in the case of a nanoscale beam, the constitutive equation relating the axial stress σ_x with the corresponding strain ε_x, can be written as:

$$[1-(e_0 a)^2\nabla^2]\sigma_x = E\varepsilon_x \tag{3}$$

For the Euler-Bernoulli beams, the following equation describing the nanobeams transverse vibration behavior is obtained in [1] :

$$EI\frac{\partial^4 w}{\partial x^4} + (e_0\cdot a)^2\left[\frac{\partial^3}{\partial x^3}\left(N\frac{\partial w}{\partial x}\right) - m\frac{\partial^4 w}{\partial x^2\partial t^2}\right] - \frac{\partial}{\partial x}\left(N\frac{\partial w}{\partial x}\right) + m\frac{\partial^2 w}{\partial t^2} = 0, \tag{4}$$

where E is the Young modulus, I is the moment of inertia of the cross-section and $m = \rho A$ is the mass of unit length of the nanobeam.

2. PROBLEM FORMULATION AND INTEGRAL FORM OF EQUATIONS

The analyzed nanobeam configuration is presented in Fig. 2 where an elastic support of Winkler type was also considered (K_w is the stiffness of the elastic support). In the absence of the axial force N, the corresponding equation of motion for bending vibration analysis is of the form, [5]:

$$EI\frac{d^4 w}{dx^4} = \rho A\omega^2\left[w-(e_0\cdot a)^2\frac{d^2 w}{dx^2}\right] - K_w\left[w-(e_0\cdot a)^2\frac{d^2 w}{dx^2}\right] \tag{5}$$

where ω is the natural circular frequency of the beam.

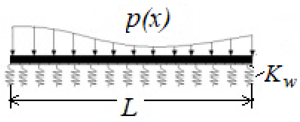

Fig. 2 – Beam on elastic foundation loaded transversally

The differential equation governing the bending behavior of a straight beam, loaded transversally by the distributed force $p(x)$ is given by:

$$\frac{d^2}{dx^2}\left(EI\frac{d^2 w}{dx^2}\right) = p(x), \tag{6}$$

It can be written in the integral form, [6-8]:

$$w(x) = \int_0^L G_w(x,\xi)p(\xi)d\xi \tag{7}$$

using the Green function which represents the bending deflection $w(x,\xi)$ at distance x due to a unity force applied at distance ξ (Fig. 3).

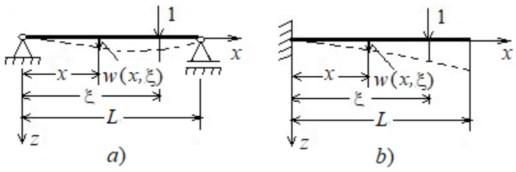

Fig. 3 – Green's functions for simply-supported and cantilever beam

The Green functions and all the integrals (7) are computed by numerical integration, considering n sampling (collocation) equally spaced points ξ_i, where $f_i = f(\xi_i)$, with a relation of the form:

$$\int_0^L f(\xi)d\xi = \sum_{i=1}^{n} f_i\cdot W_i \tag{8}$$

where W_i are weighting coefficients. The relation (7) can be used to compute deflections $w(x)$ arranged in the vector form $\{w\}$, for known distributed load $p(x)$. The matrix form of relation (7) is:

$$\{w\} = [G_w][W]\{p\}, \tag{9}$$

where the $(n\times n)$ matrix $[G_w]$ contains the coefficients $G_w(\xi_i, \xi_j)$,
$[W]$ is a weighting matrix corresponding to the Simpson integration rule

and $\{p\}$ is a column vector with the distributed loads in the n sampling points. The equation (5) is considered in the form (6) with $p(x)$ given by all the right term of (5). With the notation $\eta = (e_0 a)^2$ the integral form of the equation (5) becomes:

$$\{w\} = \rho A\omega^2[G_w][W](\{w\}[I_n] - \eta[D_2]\{w\}) - [G_w][W][K_w](\{w\}[I_n] - \eta[D_2]\{w\}) \tag{10}$$

where $[I_n]$ is the identity matrix of size n, $[D_2]$ is a differentiation matrix and $[K_w]$ contains the Winkler coefficients (for nonconstant support stiffness). Relation (10) can be arranged in the alternative form:

$$\{w\} = \omega^2[A_1]\{w\} - [A_2]\{w\} \tag{11}$$

where:

$$[A_1] = \rho A\omega^2[G_w][W]([I_n] - \eta[D_2]);\ \ [A_2] = [G_w][W][K_w]([I_n] - \eta[D_2]). \tag{12}$$

Multiplying at left the relation (11) with the inverse of the matrix $[A_1]$ one obtains:

$$\omega^2\{w\} = [A_1]^{-1}([I_n] + [A_2])\{w\} = [A_3]\{w\} \tag{13}$$

The square of the natural circular frequencies can be obtained as eigenvalues of the matrix $[A_3]$.
In order to avoid the differentiation matrix $[D_2]$, one can use the collocation functions approach [7,9], where for the bending deflection $w(x)$ one uses the formula:

$$w(x) = \sum_{k=1}^{p} C_k\, f_k(x) \tag{14}$$

where $f_k(x)$ are p known functions depending on the boundary conditions and C_k are constant coefficients (vector $\{C\}$). In the case of the use of n collocation points, and $p < n$ functions, one can obtain the following matrix form relations:

$$\{w\} = [F]\{C\};\quad \{w''\} = [F_2]\{C\}, \tag{15}$$

where $[F]$ and $[F_2]$, are $(n\times p)$ size matrices containing the values of $f_k(x)$ in collocation points and their corresponding second derivatives, respectively. Using the relations (15) in (10) it becomes:

$$[F]\{C\} = \rho A\omega^2[G_w][W]([F] - \eta[F_2])\{C\} - [G_w][W][K_w]([F] - \eta[F_2])\{C\} \tag{16}$$

Multiplying (16) at left with the transpose of the matrix $[F]$ and making the following notations:

$$[A] = [F]^t[F];\, [F_\eta] = [F] - \eta[F_2];\, [B_1] = \rho A[F]^t[G_w][W][F_\eta];$$
$$[B_2] = [F]^t[G_w][W][K_w][F_\eta], \tag{17}$$

the matrix relation (16) can takes the form:

$$[A]\{C\} = \omega^2[B_1]\{C\} - [B_2]\{C\}. \tag{18}$$

Multiplying at left the relation (18) with the inverse of the matrix $[B_1]$ one obtains:

$$\omega^2\{C\} = [B_1]^{-1}([A] + [B_2])\{C\} = [A_4]\{C\}. \tag{19}$$

The size of the eigenvalue problem in relation (19) is $p < n$, therefore this form is preferable instead of (14). In this case the square of the natural circular frequencies are the eigenvalues of the matrix $[A_4]$.
For the simply-supported (S-S) beam case, the collocation functions, according to the Boundary Conditions (BCs), are:

$$w_i(x) = sin\left(\frac{i\pi x}{L}\right), i = 1..p. \tag{20}$$

For other BCs one can use the mode shapes for bending vibrations of uniform Euler-Bernoulli beams from [10]. They are written using the Krylov-Duncan functions:

$$S(x) = \frac{chx + cos\, x}{2}, \rightleftarrows \quad T(x) = \frac{shx + sin\, x}{2} \tag{21}$$

and:

$$U(x)=\frac{chx-\cos x}{2},\quad V(x)=\frac{shx-\sin x}{2}. \tag{22}$$

3. NUMERICAL EXAMPLES

In order to check the presented approach, a first comparison with the results presented in [11] was performed. They concern a simply supported beam having the diameter d =1nm (solid nanoshaft), L = 100d, E= $2.1\cdot10^{11}$ Pa, ρ = 7800kg/m^3. For different values of the nanoscale parameter μ, the following frequency parameter λ has been computed:

$$\lambda=\sqrt{\frac{\rho AL^4\omega^2}{EI}}. \tag{24}$$

In the reference [11] the results have been obtained using the Rayleigh-Ritz approach. Table 1 presents the results in terms of the square roots of the frequency parameter for the first two modes of vibration for different BCs at ends namely S-S: (simply-supported), C-C(clamped-clamped), C-S(clamped-simply supported).

Table 1. Results comparison for a nanoshaft having different BCs ($\sqrt{\lambda}_{1,2}$)

Mode/BC	μ=0		μ=0.3		μ=0.5	
	[11]	Present	[11]	Present	[11]	Present
1/S-S	3.1415	3.1415	2.6800	2.6799	2.3022	2.3021
2/S-S	6.2832	6.2822	4.3013	4.3006	3.4604	3.4598
1/C-C	4.7300	4.7300	3.9184	3.9185	3.3153	3.3155
2/C-C	7.8532	7.8532	5.1963	5.1988	4.1561	4.1586
1/C-S	3.9266	3.9266	3.2828	3.2829	2.7899	2.7900
2/C-S	7.0686	7.0686	4.7668	4.7673	3.8325	3.8331

Table 2 presents the results in terms of the square roots of the frequency parameter for the first two modes of vibration for a cantilever beam (CF) having L = 10d. This case has been reported in [12] and was solved using Differential Quadrature Method (DQM).

Table 2. Results comparison for a cantilever nanoshaft ($\sqrt{\lambda}_{1,2}$)

Mode/BC	μ=0		μ=0.1		μ=0.3	
	[12]	Present	[12]	Present	[12]	Present
1/C-F	1.8751	1.8751	1.8792	1.8792	1.9154	1.9154
2/C-F	4.6941	4.6941	4.5475	4.5476	3.7665	3.7673

The presented results show good agreement in comparison with the available results of other methods. Our results have been obtained using n = 100 collocation points, and p = 5 collocation functions.

4. CONCLUSIONS

This paper presents the bending free vibrations analysis of nanobeams starting from the equations of motion obtained with the Eringen non-local theory and Euler-Bernoulli beam model. These equations are taken from literature where they have been obtained for example using Hamilton principle. A nonlocal parameter μ makes the difference with respect to the equations used for dynamic analysis of classic (scale-free) beams.
The *integral method* presented in this paper is based on the use of Green's functions. This approach uses collocation (sampling) equally spaces points on the beam and takes a matrix form using *integration* and *differentiation matrices*. Finally, an eigenvalue problem is obtained allowing the calculation of dynamic characteristics. To reduce the dimension of this eigenvalue problem one can also use *collocation functions* depending on the boundary conditions of the beam. Four different boundary conditions types have been considered and the mode shapes for bending vibrations of classic uniform Euler-Bernoulli beams have been used as collocation functions reducing the dimension of the eigenvalue problem from n = 100 to p = 5. The results comparison was performed with results from literature obtained by Rayleigh-Ritz and Differential Quadrature Method (DQM). It shows a very good agreement. The small scale plays a significant role and affects the natural frequencies. Depending on nonlocal (small-scale) coefficient μ, the corresponding frequency

parameters for nanobeams are smaller than those obtained for the classic beams especially for higher modes. The presented approach is developed in a matrix form, one easy to be implemented and to use it for parametric studies.

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Particularities of the early design phase for a single skin paraglider wing

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Abstract: *This paper depicts the early phase in the research development for an integrated support system tailored for emergency response actions and remote sensing. The support system is envisioned as an integrated Unmanned Aerial System (UAS) system that consists of one or more ultralight multifunctional aerial units with a configuration that can be adapted to the nature of the intervention: monitoring, mapping, observation and logistics etc. These aerial units comprise of para-motor type UAVs that use textile paraglider wings of a special design.*
The overall development and theoretical design aspects that are involved in this research is subject of change bein part of an ongoing research study. Starting from wing airfoil and material selection, a design phase is under development for a single sail paraglider wing that can meet the operational demands for the envisioned system. The wing is designed mainly to have an easy handling and to have a predictable deployment at all times. The entire system and the aerial units are designed with increased modularity in order to be tailored for specific operational requirements of the intervention. An experimental model was manufactured and is currently under rigorous testing tailored to validate the theoretical aspects and the design choices.

Key Words: *Unmanned Aerial System (UAS), Parachute, Paraglider, Single Sail, Technical Textiles*

1. INTRODUCTION

The laws of mechanics and aerodynamics apply to the performance and stress analysis of parachute systems. However, the textile fabrics used in parachute construction have distinctly different mechanical and environmental characteristics than metals or composites.
This paper depicts the early phase in the research development for an integrated support system tailored for emergency response actions and remote sensing. In this phase we try to develop a fabric that is tailored for use in the manufacturing process of a paraglider type wing design [1] that utilizes a single skin construction [2] and solid reinforcements in the sewing for shape stability.
In order to achieve this we used as a baseline several commercial fabrics and tried to determine the best combination of yarn, weave and finishing method in order to best suite our paraglider wing. Please keep in mind that this is a preliminary work and is subject to change if the prototype performances will not fall within the projected limits.

2. MATERIALS AND METHODS

In order to establish a baseline for the fabric characteristics several readily available fabrics were analyzed. The fabrics used in the testing were selected so they cover a wide array of parachute types.
Therefore we selected as material one (S1), a fabric commonly used in paraglider manufacturing. This fabric is a rather heavy fabric having polyurethane and silicone coating for UV protection.
The second material (S2) is a fabric used in most of the Ram-Air parachutes available today. It's a light fabric with polyurethane coating for zero air permeability.
The third material (S3) is a fabric with similar structure as S2 but without polyurethane coating. This fabric is only calendered and it is commonly referred to as F111 type fabric. This type of fabric has some air permeability therefore is mainly used in reserve ram-air parachutes or partially on the intrados side of main parachutes.

Figure 1: H5KT dynamometer

Testing of the tear resistance of the samples was done on the Tinius Olsen Dynamometer H5KT dynamometer

(figure 1). The device is designed to test a wide range of materials (yarns, fabrics, leather) for traction, flexion, and assembly strength (made by sewing, thermofusion, etc.).
Further on we extracted yarns from the fabrics in order to determine the yarn characteristics.
The values of the structural parameters of the fabrics (air permeability, mass, thickness, etc.) were used in conjunction with the extracted yarn test results to determine the multivariate regression equations in which the independent variables were considered the breaking strengths in warp and weft (figures 2). In this figure on x-axis we have the displacement of the clamping device, in mm. We notice a very inconsistent reading, as if the yarn is partially slipping, compared with the clean regular Nylon 6.6 yarn. We suspect this to be because of the residual polyurethane coating present on the extracted yarns. S3 sample, that was not coated, had smaller reading spikes. A statistical smoothing of the readings puts the breaking strength of the extracted yarns roughly on a value that is double than that of the regular Nylon 6.6 yarn. This is the tell-tale sign that we are dealing with HT Nylon 6.6 yarns. At the time of the testing we did not have stocked HT Nylon 6.6 to make a direct comparison.

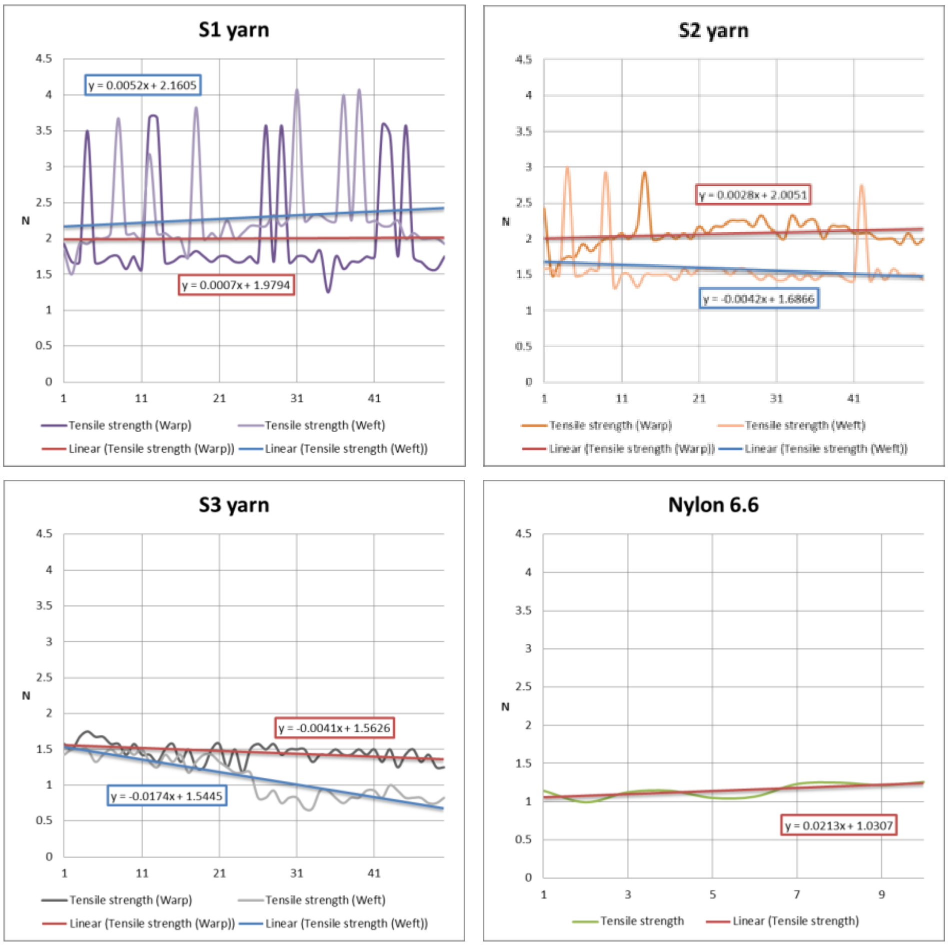


Figure 2: Breaking strength and trend line for each analyzed yarn

3. RESULTS AND DISCUSSION

Further on we try to assess the strength transfer coefficient [3] given mathematically as:

$$C = \frac{Tf_2}{Tf_1} \tag{1}$$

where Tf_1 - yarn tenacity before its integration in fabric expressed in N/Tex calculated with the equation:

$$Tf_1 = \frac{F_{bkg(t)}}{Tex} \tag{2}$$

Tf_2 is theoretical yarn tenacity after its integration in woven structure, including the influence of the weave structure/finishing treatments and is expressed also in N/Tex:

$$Tf_2 = \frac{F_{bkg(t)}}{P \times b \times Tex} \tag{3}$$

The strength transfer coefficient C for the given samples has the following values:

- *S1 sample:* Warp 1.14; Weft 0.97;
- *S2 sample:* Warp 0.78; Weft 1.03;
- *S2 sample:* Warp 1.16; Weft 1.56.

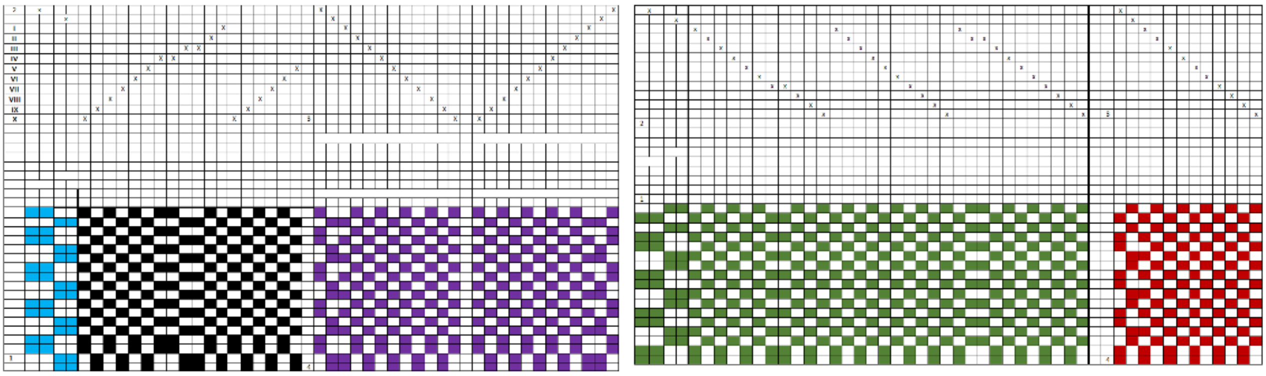
Closer these coefficients are from unity the more linear is the transfer rate, above one means the existing woven structure and treatment strengthens the yarn properties. From this we observed S1 and S3 structures to be superior in this regard.

One of the most important properties for these fabrics is the air permeability [4] and we tried to reduce this by catering several aspects:

- Yarn torsion of the two systems;
- The use of specially designed connections like ripstop or double ripstop type, with a binding segment of maximum two which interrupt the tendency of the wires of one system to slide towards the wires of the other system (not recommended to use the connections D2 / 1, R2 / 1, R1 / 2 or P2 / 2).
- Finishing treatment, polyurethane coating.

Two woven types of fabrics were developed accordingly to the following weave diagrams and general characteristics:

- Yarn fiber composition: 100% PA6.6HT;
- Yarn linear density: 30 den/32 f;
- Yarn count warp: 495 threads/10 cm;
- V1 Yarn count weft: 504 threads/10 cm (figure 3a);
- V2 Yarn count weft: 508 threads/10 cm (figure 3b).



(a) (b)

Figure 3: Programming card for weave structure V1 (a.Ripstop weave) and V2 (b.Double ripstop weave)

Four fabric variants were developed as follows:

- a fabric with ripstop connection (V1 and V3) and
- another double-ripstop (V2 and V4).

Each connection variant was made in two finishing variants:

- calendering (V1 and V2) and
- polyurethane coating (V3 and V4) thus resulting in four variants of finished fabrics.

Table 1 - Finished fabrics test results

Test Name		**Fabric V1**	**Fabric V2**	**Fabric V3**	**Fabric V4**	**Testing method**
Fabric mass (g/m^2)		40	51	47	59	SR EN 12127:2003
Yarn count (threads/10cm)	Warp	495	495	495	495	SR EN 1049-2:2000
	Weft	504	508	504	508	
Fabric breaking strength (N)	Warp	440	554	422	541	SR EN ISO 13934-1:2013
	Weft	445	484	410	480	
Fabric elongation at breaking force (%)	Warp	28.6	23.6	26.7	24.9	
	Weft	32.7	26.2	38.4	29.1	
Fabric tearing strength (N)	Warp	34.4	21.3	65.2	20.7	SR EN ISO 13937-2:2001
	Weft	32.7	22.5	65.5	20.7	

Fabric bursting strength (KPa)	330.3	368.4	330.2	370.8	EN ISO 13938-2/2002
Fabric bursting strength (mm)	35.4	36.3	42.5	43.2	
Fabric air permeability (l/m^2/sec) at 200Pa	10.53	10.34	0	0	SR EN ISO 9237:1999
Raw material	100% PA66HT	100% PA66HT	100% PA66HT	100% PA66HT	SR 13231-95
Coating	Calendered	Calendered	PU coating	PU coating	SR ISO 1833-95
Link type	Ripstop	Double-ripstop	Ripstop	Double-ripstop	-

4. CONCLUSIONS

The fabric breaking strength is in line with the breaking strength of the yarn, this validates the testing methods and yarn extraction method. A strength transfer coefficient greater than one means the woven structure has higher theoretical tenacity than all the yarns combined. This means that the calendared fabric S3 woven structure amplifies better the yarn tenacity than coated fabrics; however the S1 fabric is not far behind and has way better breaking strength, lower elongation and also lower air permeability, probably because of the double-ripstop structure.

The highest yarn elongation of S2 influences in an interesting way the tearing behavior and tearing strength results. The S2 fabric gets the highest tearing resistance due to this but is not necessarily the correct one since the fabric torn incompletely. Some threads remained in structure and influenced the results.

Due to the nature of the single sail wing, the amount of fabric used in the manufacture is almost halved therefore the fabric can be a little heavier and also can have a less than perfect air permeability because the shape is maintained by several rigid members. Thus, we conclude that the fabric must use yarn of high tenacity Nylon 66; then make use of the rip-stop weave link and polyurethane coating.

The fabric variants obtained were tested and these conclusions were drawn:

- Regarding the air permeability, the most performing variants were the coated ones (V3 and V4)
- Considering the specific mass, the lightest fabric is the V1 variant.
- Considering the breaking resistances, all variants are in the same performance class but with significantly higher values in the case of double-ripstop variants V2 and V4. However, increased tear strength is observed in the case of the V3 variant, this is due to the tearing mode which opposes the propagation of the rupture. This type of tearing behavior is presented by both V1 and V3.
- Further testing is required to decide if the fabric can be functionalized with hydrophobic [5] properties in order to expand the operational capabilities of the UAV for rainy weather or with applied heating elements [6] for use on sub-zero temperatures or high altitude flying.
- Analyzing the results and given the desirable tearing behavior of the V3 variant, we choose this working variant for the UAV textile structure prototype manufacturing in the next stages of system design.

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Influence of Preload on Failure Modes of Hybrid Metal-Composite Protruding Bolted Joints

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Abstract: *This paper presents the effects of torque preload on the damage initiation and growth in the CFRP (Carbon Fiber Reinforced Polymer) composite laminated adherent of the single-lap, single-bolt, hybrid metal-composite joints. A detailed 3D finite element model incorporating geometric, material and friction-based contact full nonlinearities is developed to numerically investigate the preload effects on the progressive damage analysis (PDA) of the orthotropic material model. The PDA material model integrates the nonlinear shear response, Hashin-tape failure criteria and strain-based continuum elastic properties degradation laws being developed using the UMAT user subroutine in Nastran commercial software. In order to validate the preload effects on the failure modes of the joints with hexagonal head bolts, experiments were conducted using the SHM (Structural Health Monitoring) technique. The results showed that the adherent torque level is an important parameter in the design process of an adequate bolted joint and its effects on damage initiation and failure modes were quite accurately predicted by the PDA material model, which proved to be computational efficient and can predict failure propagation and damage mechanism in hybrid metal-composite bolted joints.*

Key Words: *Hybrid bolted joints, progressive damage analysis, finite element analysis, bolt preload, failure modes.*

1. INTRODUCTION

The aerospace industry became the most common application field for fiber-reinforced polymer matrix composites (PMCs) due to their lightweight properties [1]. Up to nowadays, the researchers studied the failure analysis of composite bolted joints using a method that combines continuum damage mechanics (CDM) [2] with finite element analysis (FEA).

The major disadvantage of the CDM models is the huge amount of test data required for model calibrations. The progressive damage analysis (PDA) in composite materials, which is based on the stress-strain law, showed that the material orthotropic properties reduction due to damage initiation is essential for the stress field analysis [3-7].

A lot of PDA models in research field [8-11] incorporated shear nonlinearity, Hashin-type failure criterion and constant elastic properties degradation low for orthotropic materials, which makes the method quite easy to implement and computational efficient.

In this study it is described and developed a progressive damage analysis using an adequate material model for composite adherent that can predict the bolt preload effects on structural behavior and failure modes of hybrid metal-composite bolted joints taking into account all the nonlinearities phenomena involved in load distribution through the joint as the geometric nonlinearity which imply large deformations, friction based nonlinear contact and material nonlinearities due to shear deformations of the lamina, Hashin-type failure criterion and strain-based continuous degradation law implemented using an user subroutine coded in Fortran programming language and commercial Nastran SOL 400 solver.

A series of experiments were conducted in order to validate the FE model and PDA results involving the influence of bolt preload on the failure modes of the hybrid-metal composite joints. The experimental and numerical results were quite accurate.

2. PROBLEM DESCRIPTION

- Joint geometry description

Single-lap joints (SLJ) with single hexagonal head bolt were manufactured using both metal and composite materials for the adherents. The geometry design parameters were chosen in accordance with ASTM standard [16] to induce bearing failure.

The in plane dimensions of the adherents are presented in Table 1 and Fig.1. The adherent thicknesses are different, 4 mm for the metal adherent and 3 mm for the laminated adherent. Hexagonal head stainless steel bolts with nominal diameter of 5 mm were used. The applied torque levels to the bolt shank are presented in Table 1.

The composite adherent was manufactured from carbon-epoxy pre-pregs with fiber volume fraction of 32%. The stacking sequence is as follows [0/90/0/90/0/90] using 0.33 mm thickness unidirectional lamina, with the elastic properties presented in Table 2. The metal adherent was manufactured from aluminum alloy AA 7075T6 [17] and the bolts, nuts and washers were made from stainless steel A2-70 [17] with the elastic properties presented also in Table 2.

Table 1. Experiment set-up

Length [mm]	Width [mm]	e [mm]	Torque [Nm]	Temperature [^oC]
150	34	10	0.5/2/3/4/5	+50

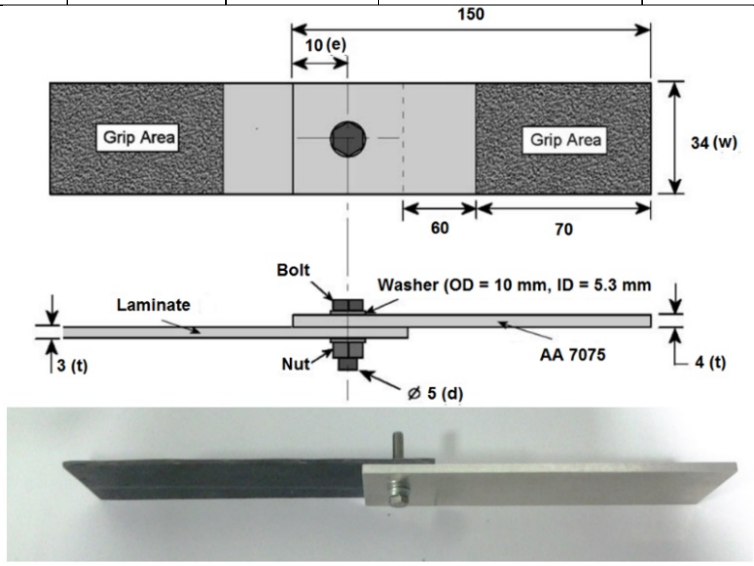

Figure 1. Joint geometry, dimensions in mm

Table 2. Mechanical properties of the materials

Property	CFRP Lamina	AA 7075T6 [17]	A2-70 [17]
Longitudinal modulus E_{11} [MPa]	34433	71016	206000
Transversal modulus E_{22} [MPa]	3610		
Through-thickness modulus, E_{33} [MPa]	3610		
Shear modulus G_{12} [MPa]	2421	26890	75842
Shear modulus G_{23} [MPa]	2421		
Shear modulus G_{13} [MPa]	1561		
Poisson coefficient ν_{12}	0.36	0.33	0.36
Poisson coefficient ν_{23}	0.45		
Poisson coefficient ν_{13}	0.35		
Longitudinal tensile strength $\sigma_{11,\,max}^{T}$, [MPa]	253		
Longitudinal compression strength $\sigma_{11,\,max}^{C}$, [MPa]	230		
Transversal compression strength $\sigma_{22,\,max}^{C}$, [MPa]	74		
In plane shear strength τ_{12}^{max}, [MPa]	25		
Out plane shear strength τ_{23}^{max}, [MPa]	37		
Out plane shear strength τ_{13}^{max}, [MPa]	37		

Note: (1, 2, 3) are the lamina on-axis coordinate system.

The unidirectional lamina properties presented in Table 2 were obtained using ASTM [18]-[20] standards on the unidirectional laminated specimens.

The bearing tests were conducted in accordance with ASTM standard [16]: the specimens were gripped into a 30 kN Instron testing machine, the torque level was applied to the bolt shank and then the displacement controlled tensile loading of 0.3 mm/min was applied until ultimate failure. The experiment set-up is shown in Fig. 2.

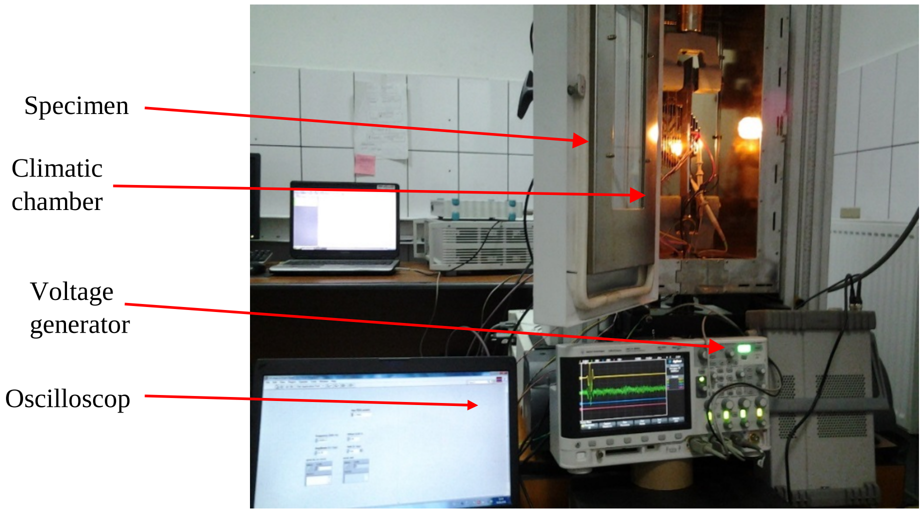

Figure 2. Experimental workbench

3. RESULTS AND DISCUSSIONS

A summary of the bolt preload effects on the progressive failure of the metal-composite hybrid joints is presented in Table 3 and Fig 3. In Table 4, $F_{L.L}$ and $F_{U.L}$ represent the limit and ultimate forces of the joint to axial quasi-static tensile loading and are corresponding to the limit and ultimate loads points from the characteristic force-displacements curves.

Table 3. Bolt torque effect on joint strength

M [Nm]	$F_{L.L}$ [N]		$F_{U.L}$ [N]	
	EXP.	FEM	EXP.	FEM
0.5	1447.37	1500.03	2175.83	2153.89
2	1960.15	2025.22	2436.18	2385.31
3	1978.69	1950.52	2561.98	2552.97
4	2305.15	2280.59	2497.64	2470.22
5	2446.33	2394.58	2557.81	2530.38

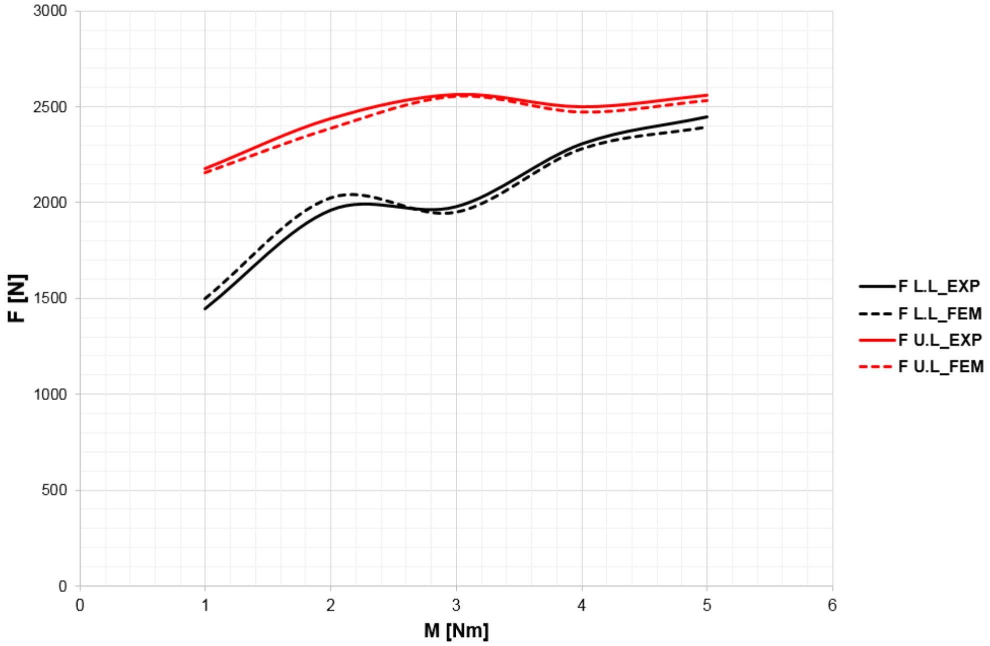

Figure 3. Preload torque effects on the force capacity of the joint

4. CONCLUSIONS

The simulation results were in good agreement with the experiments in terms of load-displacement behavior, FPF and ultimate failure loads, which denoted that the 3D FEM model including full nonlinearities and explicit solver are quite accurate and can predict the metal-composite joint's mechanical behavior on both linear-elastic and nonlinear elastic ranges, including the failure modes as bearing and shear-out. Regarding the bolt preload effects on the load-displacement curves, it can be seen from the Fig.3 that the bolt torque levels increase the axial stiffness of the joint, but have no major effect on the joint ultimate load, as it can be seen from Table 3 and Fig 3. Regarding the FPF and strength predictions, the SHM technique proved to be quite accurate in evaluating the damage initiation and accumulation until final failure.

ACKNOWLEDGEMENTS

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Enabling co-polymerization: A scalable composite tooling demonstrator concept

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Abstract*: This technical paper describes the philosophy and general guidelines in designing a scalable, multi-part carbon composite tooling assembly for a 19-pax commuter aircraft wing box. The tooling concept complies to both LRI and prepreg manufacturing methods and enables co-polymerization of four different structural components into a one-part assembly through a one-shot manufacturing technique.*

Key Words: *one-shot, co-polymerization, co-curing, integral structure, tooling assembly, composite materials, primary structures*

1. MOTIVATION

Aerospace is evolving and no aircraft is left behind. The race towards climate neutrality impacts all industry layers, pushing the boundaries of innovation even further. In response, the engineers, researchers, key industrial players and academia must work together and surpass the technological barriers that stand in the way of progress.

One of the key areas that profits off this technological development is, with no surprise, the composite materials industry (focusing on Carbon Fiber Reinforced Polymers, hereinafter referred to as *CFRP*). While the materials themselves benefit from constant improvements in terms of quality and performance, it is mandatory to keep an eye on the processes and techniques that turn the raw material into high performance, highly desirable structures. Producers are constantly searching for manufacturing process with repeatability at shorter manufacturing times, maximum efficiency and productivity, good part quality with respectable geometrical accuracy and, of course, improved cost efficiency. One might find herself wondering *how* can all these major checkpoints be achieved and, more important, *if* they can be achieved at once.

This technical note aims at covering all of these subjects. The achievements that are to be presented throughout this read are the product of two years' worth of hard work and valuable collaboration between manufacturing engineers, design engineers, researchers, academia and enthusiastic students.

2. INTRODUCTION

The concept presented in this article represents the very core of the FITCoW (*Full-scale Innovative integrated Tooling for Composite material Wing-box)* project, part of the Clean Sky 2 OPTICOMS program. OPTICOMS (*Optimized Composite Structures for Small Aircraft*) aims to demonstrate automation in low-volume composite structure manufacturing with respect to cost reduction.

In this respect, FITCoW's main objective within OPTICOMS is to develop a composite tooling system capable of co-curing four different aircraft primary-structural components (three spars and the upper wing skin) into a single, unitary part. This is attainable through co-polymerization (more commonly referred to as *co-curing*): a manufacturing technique that implies simultaneous consolidation of two or more separate bodies into a single part. The manufacturing concept promises solid advantages if the technological difficulties are to be overcame. Firstly, the implicit workflow in manufacturing a CFRP wing structure is considerably shortened and simplified. Having the four components already assembled right off the oven or autoclave reduces the manufacturing costs, manufacturing effort, required manpower and could simplify the final assembly structures (jigs and tools) as their functionality becomes less intricate. This principle allows for more complex parts to be manufactured, although part complexity and tooling complexity are in a direct relation. Applying a co-curing manufacturing philosophy for very complex geometries might not be technologically feasible when high-volume manufacturing is required. Nonetheless, it has a positive impact on the carbon footprint when compared to traditional manufacturing processes, as the energy-expensive curing is performed simultaneously for multiple components. Implicitly, the duration of the manufacturing chain is also significantly reduced, which translates into lower operational costs. In figures, the project aims at demonstrating appealing Key Performance Indicators (KPIs) improvements, quantified as:

- 50% manufacturing cost reduction per produced part;
- 30% tooling cost reduction when compared to conventionally deployed metallic tooling
- 20% manufacturing time reduction in comparison with currently deployed autoclave and Out-of-Autoclave (commonly shortened as *OoA*) manufacturing techniques;
- 40% CTE mismatch reduction in comparison to Invar metallic tooling;
- 20% decrease in tool heating and cooling time;
- 40% inspection time reduction due to advanced shape control capabilities.

3. CO-CURING

Co-curing aircraft components represents an alternative to the traditional manufacturing solutions that are generally deployed, where the parts are individually formed and subsequently joined through adhesive bonding or mechanically fastened (by riveting and/or bolting). The latter, even though mechanically simple and well understood by technicians and engineers, is still an undesirable solution as induces discontinuities in the reinforcing lattice and promotes delamination. The adhesive bond is a viable solution in joining CFRP components. It offers more design flexibility and adds negligible weight, making good use in lightweight composite structures. However, adhesive bonding requires rigorous surface pre-treatment. Due to the nature of the manufacturing process, the parts' surfaces are always contaminated with release agents and show a thick polymer layer on the top. These features cause an insufficient bonding behavior. Pre-treatment can add significantly to the product's costs, as it implies grinding, abrasive blasting, plasma treatment, or UV/IR laser treatment of the joining interfaces. [1]

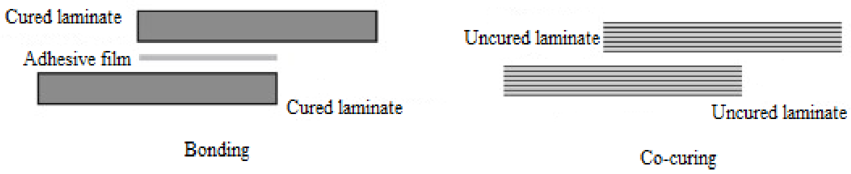

Figure 1. Bonding and co-curing schemes

Each of these two distinct methods have their own advantages and drawbacks in terms of process repeatability, final surface quality, required infrastructure and implicit costs. In terms of mechanical analysis, any joining method will induce extra factors to account for, thus greatly increasing the complexity of the FEA model. Even though adhesively bonding the components might be considered by some to be the better practice, certificating such primary structure is a resource consuming action. Unlike co-curing, the bonding process requires proofing that each and every adhesively bonded joint will not separate and lead to structural failure should it reach its critical design load. [2] Therefore, the manufacturer might find itself stuck in a vicious loop of shortcomings, in which the appropriate design solution is downgraded towards a more economically-feasible one.

4. TOOLING CONCEPT DEFINITION

The project aims at manufacturing two demonstrators: a 7-meter tooling assembly that must produce the 7-meter unitized wing box and a smaller proof-of-concept downscale demonstrator. The downscale demonstrator, measuring 1.2 meters in length, was manufactured with the intent of testing out every technological feature that is to be implemented in the larger-scale sibling. In order to reach a feasible configuration, three major design versions had to be iterated. Nonetheless, the presented tooling concept is designed to be easily scalable with minimum modifications.

As in any mold application, the part geometry serves as the geometrical datum. Therefore, it must be thoroughly studied in order to assess the tooling complexity and preliminary define their functionality. The geometry will also reveal significant information regarding the release angles and joggles – very relevant in the extraction process. This integral structure features three spars: two C-shaped end spars and a central I-shaped spar, the latter being also formed out of two C-shaped spars that touch webs. These three primary structural elements are held together by an airfoil – the outboard wing skin.

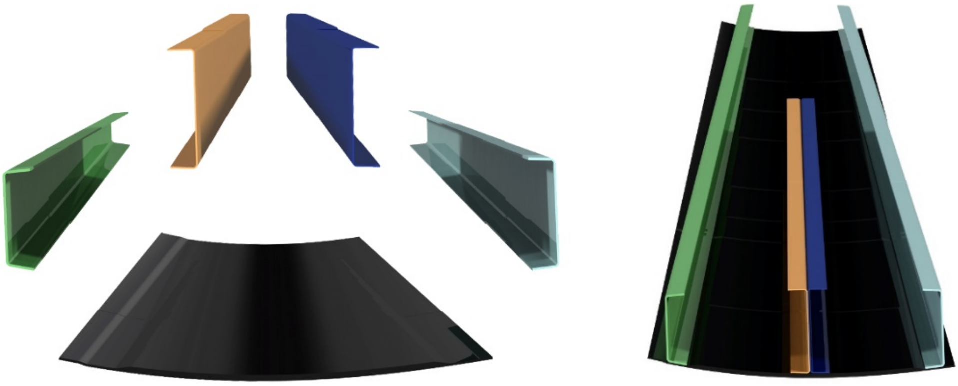

Figure 2. Left: five individual structural components Right: Co-cured structure

A list of requirements had to be compiled before the commence of the design activities. The technical factors and demands had to be identified and solved for in order to assure the overall quality of the tooling and compliance to the beneficiary project requirements: Consequently, the tooling assembly should:

- Enable co-polymerization;
- Allow for LRI and prepreg manufacturing;
- Be compatible with ATL preforms and manual lay-ups alike;
- Clear any CTE mismatches;
- Ensure system stability under vacuum pressure;
- Withstand and maintain structural stability at high temperatures (<185° C);
- Minimize risk of human error wherever possible;
- Facilitate manipulation of tooling;
- Assure good surface quality of the produced parts.

As the tooling will also function as an assembly jig, extra emphasis has to be made on accuracy – initial positioning accuracy and maintaining the components' correct position throughout the high-temperature curing process. The tools must also be carbon made – this way clearing the problematic part-tool CTE mismatch eventually leads to distortions and rejected parts. On a lighter note, the tooling will not undergo autoclave curing – it should be compatible with an OoA curing process that only uses vacuum at elevated temperatures for consolidation.

Thus, with respect to our wing geometry, five individual carbon tools must work together into forming the expected product. In addition to the tools themselves, the auxiliary positioning and supporting items must be also designed.

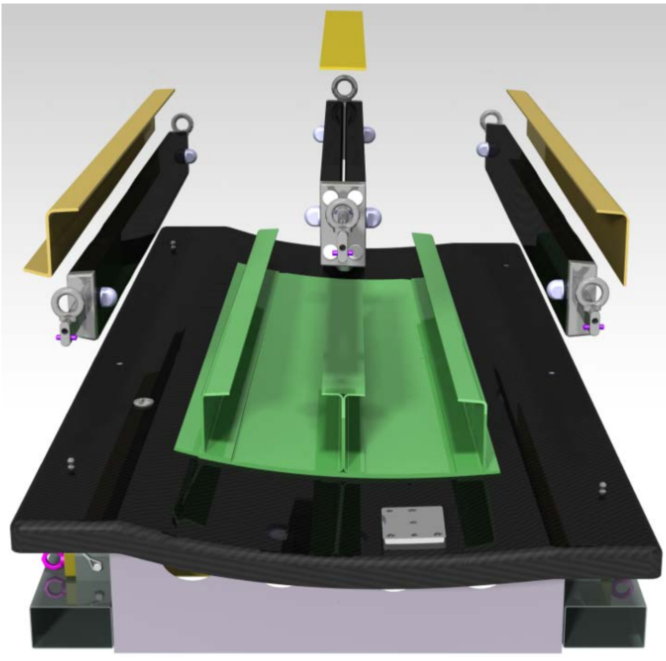

Figure 3. Bottom: Skin Tool with produced part. Upper: Spar Tool. Top: Caul plates. All components are CFRP-made

But the produced integral structure is not the final structure as ribs and the inboard skin must be bonded in order to complete the wing-box. Therefore, the part surface quality is an important factor to account for. This issue is addressed through the introduction of caul plates – carbon counter-moulds that act as pressure distributors. Caul plates aid in leveling the part thickness and transfer their surface finish on to the produced part’s outer surface, acting as a quality control method. Two types of cauls will be tested with the configuration: *soft* caul plates – rubber-reinforced CFRP and *hard* caul plates, integrally made out of CFRP.

In the proposed configuration, the Skin Tool is the central element in the assembly, hosting all other tools, allowing for positioning, fixture, bag making, manipulation and vacuum routing. Completely avoiding metallic elements was deemed complicated and not feasible: some metallic inserts had to be used. Generally, their purpose is that of positioning and fixture.

However, an open CTE-loop was kept, allowing for orderly thermal expansion while avoiding mechanical over-constraints at elevated temperatures. The Skin Tool also hosts the preform positioning mechanisms, if ATL preforms are to be employed into manufacturing.

Laser targets are also installed along this component’s perimeter, allowing for laser-guided manual stratification. Should none be desired (or available), the Skin Tool is fitted with subtle notches that mark the assemblies’ relevant reference points. As additional functional features, the Skin Tool is also fitted with integrated vacuum couples and a supporting metallic frame that enables correct leveling of the assembly (this issue is relevant to resin flow during Liquid Resin Infusion) and provide extra rigidity during all manufacturing stages.

The Skin Tool’s understructure is also designed to allow constant airflow beneath the skin mold during curing – uneven heating is undesirable, especially when producing large parts.

For the down-scale demonstrator, no thermocouples were integrated, considering its smaller size. However, these are important quality control elements that should be present in any large-area tooling in order to assure even temperature distribution during manufacturing’s key stages.

The tooling assembly features four male Spar Tools, of which two act as individual tools (corresponding to the end C-shaped beams).

The remaining two must work together into forming the central I-shaped beam. While the C-shaped tools are rather simple in design, the I-shaped double tool proved to be challenging when trying to find the optimal design solution.

Many design iterations were made on the ideal device that enables joining of the two halves, assure accurate Spar Tool positioning, maintain a firm linkage between the two parts and allow for optimum vacuum bag sealing.

Yet, such part should be constructively simple enough in order to allow for an efficient sealing. For this purpose, metallic components could have not been avoided. However, steel was chosen over Aluminum for its lower thermal expansion. In the earlier manufacturing stages, the tools should also be capable of shaping the flat ATL preforms (dry or pre-impregnated) through Hot Drape Forming, as the preforms must be shaped prior to the final assembly on the Skin Tool.

Sealing, as mentioned above, is one of the most challenging design issues encountered within this project. Complex assemblies can not be built without a minimum number of fasteners or joining mechanisms, regardless of their nature.

However, due to the fact that resin is very invasive, sealing these functional areas is critical since any resin infiltration might bring permanent damage to the tooling. As viscous as it may seem at room temperature, epoxy resin is very fluid at elevated temperatures and manages to break into every cavity it finds along the flow path, aided by the continuously pulled vacuum.

This raises serious concerns for threads, sliding surfaces or positioning pins. From this very same rationale, Allen or Phillips keys are to be avoided if such mechanical fasteners are needed. Hence, this issue is to be granted serious attention during the design phase.

While the Spar Tools themselves are robust in design, some additional support was needed during the curing process.

In terms of positioning and fixture, auxiliary CFRP elements were designed with this purpose. These are installed on the Skin Tool and transversally cross over the Spar Tools. Being fitted with rubber-padded fixture elements, these grip firmly onto the Spar Tools and keep restrain them from unwanted movement (twisting or, more unlikely, bending) during the curing process.

As a final addition, the assembly was fitted with two drilling jigs. These would allow the technicians to drill pilot holes into the manufactured parts, holes that would serve as reference elements for the post-forming operations (trimming and bonding) and enable accurate positioning on the final assembly jig.

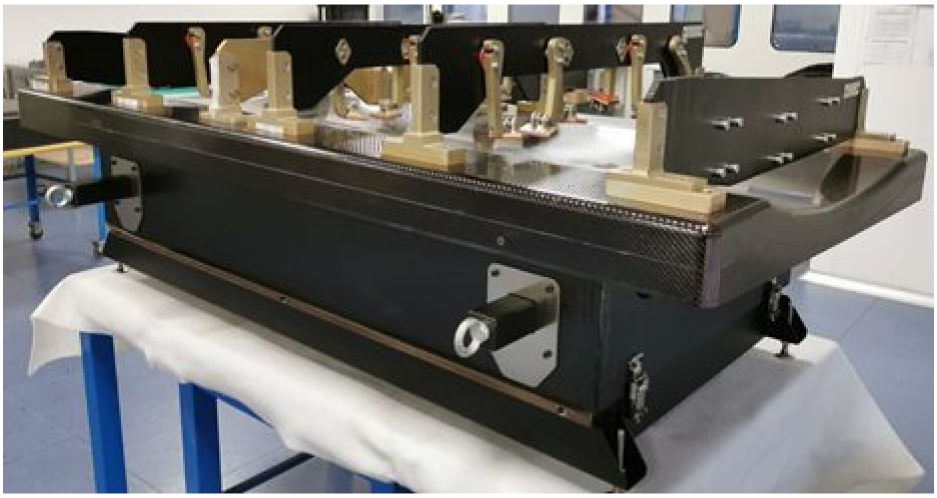

Figure 4. Skin Tool hosting the transversal fixture elements

5. MATERIAL SELECTION AND THERMAL-STRUCTURAL ANALYSIS

The tools are manufactured out of LTM 12, a tooling prepreg produced by Solvay. Besides a reasonable out life duration, this prepreg is capable of low temperature curing (five hours at 70ºC) while having a 200ºC service temperature. Curing tools at low temperature is important: the difference between the temperature at which the epoxy pattern has been machined and used to cure the prepreg tools results into a CTE mismatch. This very mismatch could cause a large part out to fall out of the permissible error limit (considering a 7-meter wing, the size of the final demonstrator). Another aspect that needs to be taken into account when selecting materials for such applications are the limitations that the exothermic reaction induce. If a very thick lay-up is required it is usually recommended to cure at lower temperatures. But as autoclave time is usually scarce, longer curing times might be hard to achieve. However, no matter the rationale, exothermic reactions are not to be overlooked as they might severely compromise a project in an advanced phase by destroying the material and the epoxy masters.

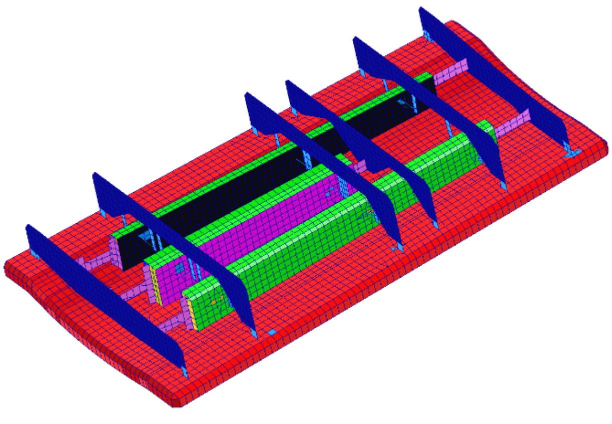

Figure 5. FEM model of the tooling assembly

The thermal-structural analysis was performed for the down-scale demonstrator in order to validate the concept. Most importantly, the thermal expansion pattern had to be verified in order to assure that the thermal deformations occur as designed. It is very important to define and foresee the CTE-caused geometry modifications early into the modelling phase. As the part cures at 180º and the assembly cools down, the tools go back to their nominal shapes and dimensions. But, if the CTE has been miscalculated, the part has already been cured from a shape-altered pattern and will most likely have to be discarded.

The results from the analysis came out to be satisfactory. The stacking sequence was validated as the FEA calculus showed no sign of coupling and thus, containing the anisotropic characteristic of the material. A reserve factor of 3.3 was found for the Interlaminar Shear Strength which was deemed satisfactory. The Tensile Strength reserve factor was calculated to be around 30 for the whole assembly. Additionally, the maximum displacement at 185º C (maximum curing temperature) was found to be well under 1mm at the assembly level. Besides the maximum curing temperature, a pressure load equal to the atmospheric pressure at ideal vacuum was applied over the forming part. It is important to remind the fact that this tooling system is designed to work OoA. Should one be interested in manufacturing a tooling system that is compatible with autoclave curing, additional stiffening elements and a thicker lay-up would be reasonable modifications.

6. CONCLUSIONS

As the Digital Mock-Up was frozen, the model contained approximately 80 unique components made in CFRP, steel, Aluminum and rubber. The whole assembly, including the epoxy patterns and manufacturing pre-requisite elements surpassed the 800 components mark (but this figure also takes into account every off-the-shelf part as well). The complexity of such an application can only increase as more elements must be co-cured into the one-shot manufacturing process. A smart concept and lay-out approach might simplify the task of designing such systems, but auxiliary components can not and should not be avoided, as the final part’s quality is the main reasoning factor. A compromised component of the integral structure will, unfortunately, compromise the whole structure, leading to significant losses in terms of resources and time. Nonetheless, the proposed philosophy promises greater design flexibility, manufacturing capability at a lower cost and production time. The project demonstrates that attractive KPIs are attainable at a fraction of the manufacturing effort while stepping closer to a cleaner manufacturing process.

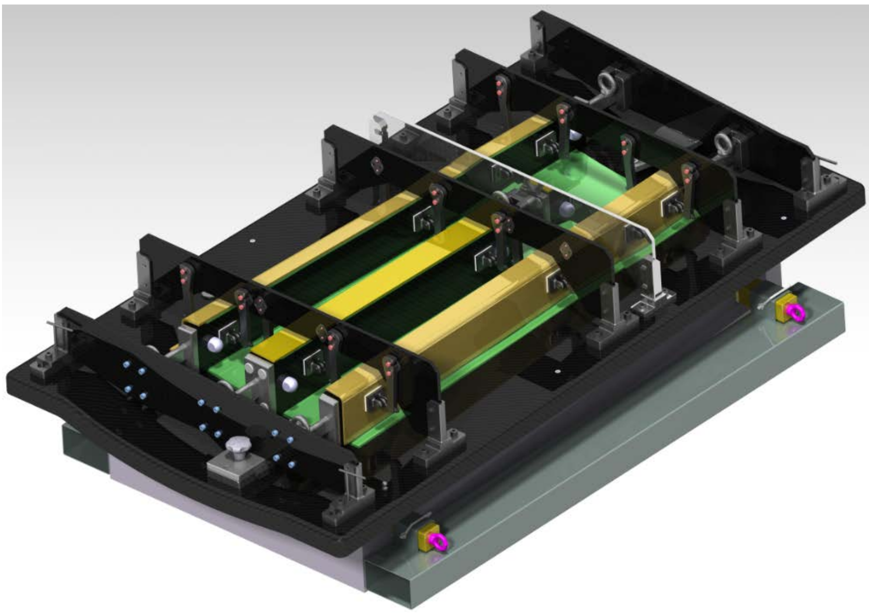

Figure 6. FITCoW Small-scale Tooling Assembly in its final configuration

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Deep Learning Aircraft Glide Path and Artificial Horizon Estimation for Visual Navigation Enhancement

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Abstract: *The latest achievements in the aircraft automated visual landing opens a new aviation research area for computer vision applications. Glide path estimation, runway alignment represents essential information in the final approach for visual navigation procedure and also for data redundancy in the continuous descent approach procedure for ICAO required navigation performance. The computer vision algorithms, used on this paper, are based on artificial intelligence and aims for runway detection and artificial horizon identification in order to increase the safety level of navigation in both aircraft operating modes, IFR and VFR. This goal is attained through training of the deep learning neural network with Flightgear parameterized visual data.*

Key Words: *deep learning, glide path estimation, pattern recognition, artificial intelligence, runway detection, convolutional neural networks.*

I. INDRODUCTION

Based on ICAO navigation performance requirements an aircraft should maintain a constant glide path on continuous descent approach (CDA) procedure as in the Fig. 1. The CDA it is introducing to reduce the aircraft engines noise, the approach route and the fuel consumption (Carbon Emissions Footprint) [1].

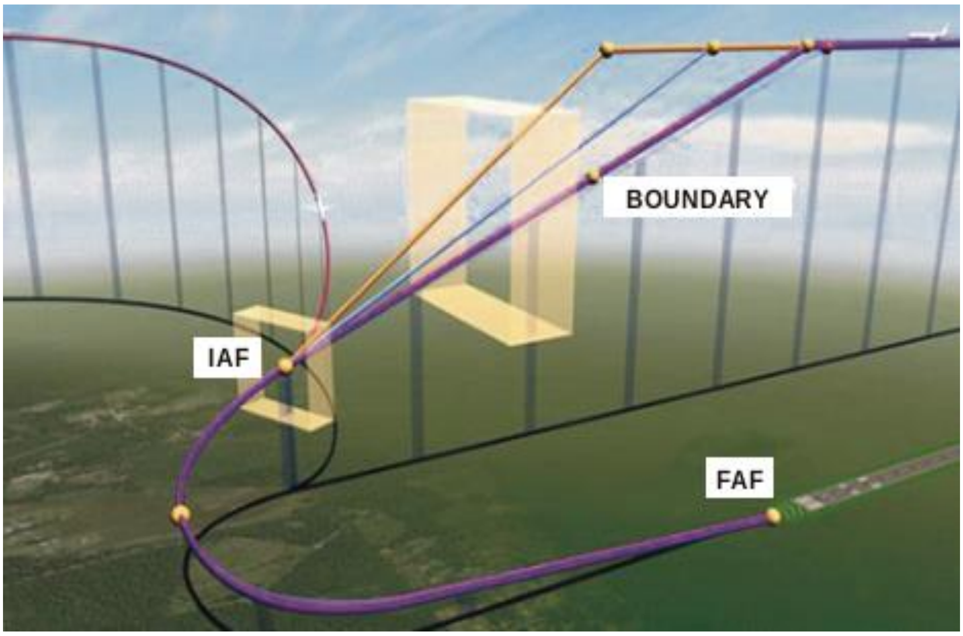

Fig. 1 The CDA tailored arrivals of aircrafts [1]

The aircraft in order to perform a CDA approach procedure in the performance based navigation (PBN) require certified navigation equipments and specialized pilots. This paper presents a research regarding the development of artificial horizon estimator and runway detection system based on computer vision and deep learning technology. The gained data from the developed computer vision applications it is used to estimate the relative position of the aircraft to the required glide path on the CDA approach or to a path angle requested by the pilot. The estimation of the glide it is based on deep learning convolutional neural networks (CNN) trained with synthetic images obtained from the Flightgear aircraft simulator.

This type of information represent an alternative for training pilots on constant glide path operations and a possible redundancy help for critical aircraft situations.

II. CONSIDERATIONS AND LIMITATIONS FOR ARTIFICIAL HORIZON AND GLIDE PATH ESTIMATION

For the developed computer vision application a high resolution wideview video camera it is required to be mounted outside, on the fuselage, în the front of the aircraft.

For best results two cameras are required, first camera solidary to the aircraft reference system and the second camera solidary with an object (runway, horizon line) from the earth reference system, which require a stabilzed pan tilt zoom PTZ system. Curently only a few aircrafts are equiped with video camera on the fuselage. The Boeing company mounted cameras on the B777 – 300, under the fuselage and on the tail, to help pilots for ground manuvering during taxi operations.

The Ground Maneuvering Camera System (GMCS) is a standard equipment on B777 - 300 and is accomodating up to 6 cameras, only 3 are used, one for the nose gear and two for the main gear[2]. Also a tail mounted camera monitoring system is fitted on the Airbus A380 for In-fligh Entertainment System (IFE) and also for ground maneuvering support.

One important limitation, identified onto the computer vision application, is the requirement of permanent observation for the objects of interest which are the runway and/ or the horizon line (Fig. 2). As a result the best results are given only on very good visibility conditions or under the clouds level. Another major impediment is the certifying procedures în order to approve the use of the application onboard aircraft.

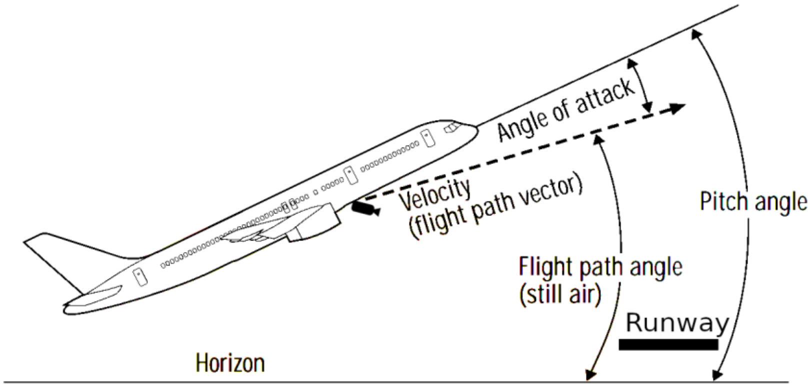

Fig. 2 Aircraft camera positioning [3]

Environmental conditions have, also, a direct impact to the quality of the obtained images from the onboard camera.

The image definition depend on the illumination level, light direction, air medium quality (haze, rain, fog) and frames resolution.

Deep Learning Robustness it is reached by different design concepts as enhancing the robustness of deep learning with respect to norm-bounded perturbations [4], by using Noise Sensitivity Score(NSS) in adversarial training of the models [5].

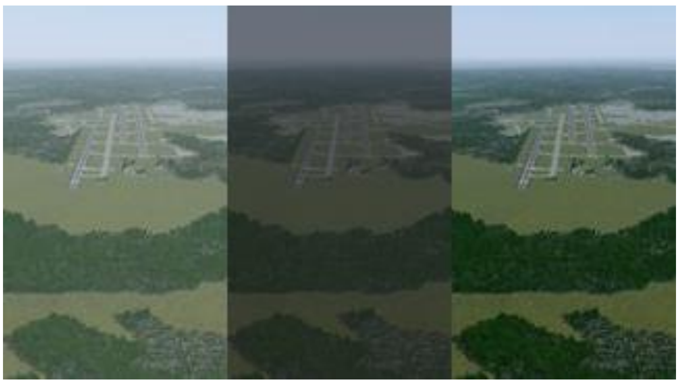

Fig. 3 Different light intensity for the same frame

Other considerations are about the feasibility of the application to be used onboard aircraft and has two important sides.

The first criteria, about the system output rate, is analyzed by the Software In the Loop (SIL) capability and Hardware In the Loop (HIL) capability. Second criteria relates to the Deep Learning Robustness of the designed system.

SIL models are analyzed for I/O compatibility (data format, specific data framerate) and HIL models are analyzed for integration level compatibility and real-time application performance.

III. GENERATION OF THE LEARNING DATABASE

The images from the database are generated with the help of two dedicated processing units, one responsible for trajectory generation linked to the second one through the User Datagram Protocol (UDP) protocol over Internet Protocop (IP), which is responsible for scenery generation based on the input trajectory, as one can see in the fig. 4.

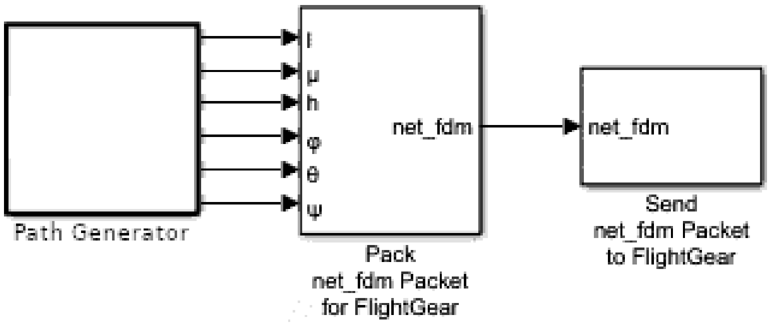

Fig. 4 Matlab Trajectory Generator and routed to UDP

The generated frames from the scenery generator are sent to the machine learning where are preprocessed în order to extract the objects of interest, in fig. 5.

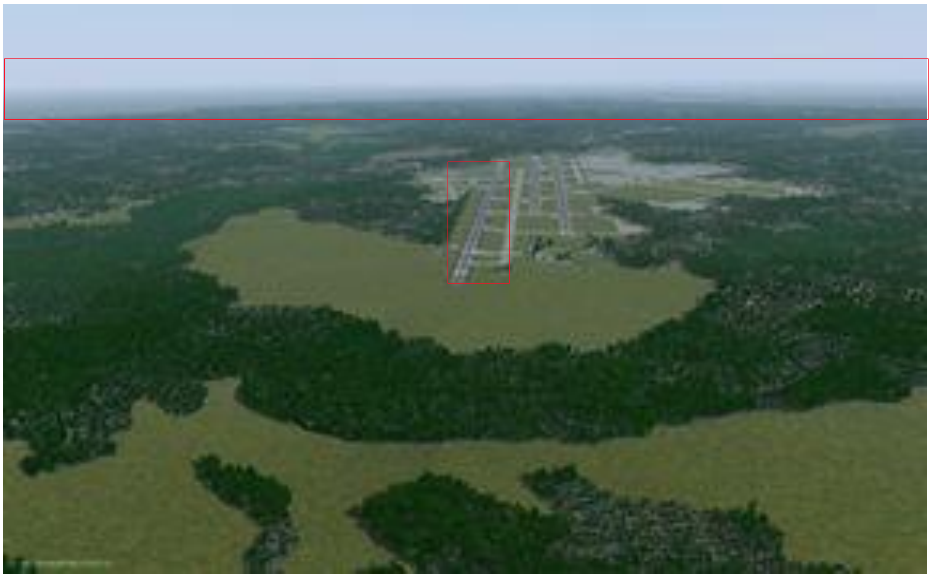

Fig. 5 Flightgear generated frame with objects of interest

The data structure is defined as frame number origin, box size coordinates, target class value/ name, and the information is used as output source for the training algorithm.

In the following table (table I), there is an example for the three target classes (horizon, runway), frames, boxes coordinate from the used database:

Table I. Elements of database classification

Db_nr	Img_path	Fr_nr	Class	x_min	x_max	y_min	y_max
249	..\frames\	F128.png	1	0	600	50	116
250	..\frames\	F128.png	2	284	375	127	212

IV. DEEP LEARNING TRAINING

The processing architecture for the developed application require distributed computing configuration

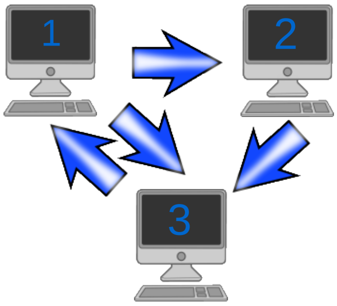

Fig. 6 Software in the loop, distributed computing configuration

Detection performance for each class it is depicted in the next table

Table II. Performance detection for three classes

Method	Supevision	mask	train	IoU back_gr	IoU horizon	IoU runway
BoxSup	Weakly(box)	6k	video	92.4	87.6	67.5

V. CONCLUSIONS

Principal factors that are affecting the accuracy of the results are determined by:
- The aicraft flying altitude.
- Visibility conditions and air quality
- Illumination conditions(intensity and direction)
- The number of targets per unit area
- The image stabilizer and the number of frames per second
- The architecture of the image processing system.

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Approaches on flight data recordings

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Abstract: *This paper is brief presentation of flight data records used currently for design, maintenance and safety investigation. It is an overview on the approaches in processing the flight recorder data, focusing on flight recorders and records provided by other on-board equipment. The data analysis is focusing on CVRs and the other recording facilities on-board, rather than FDRs, which were extensively approached by another paper. To underline the importance of all sources, as well as the volume of work the papers includes brief practical case studies selected from the investigation reports issued by the Romanian SIAA. Information on processing flight records is provided as a flight data processing practices overview. The paper is intended to inform aircraft operation' and maintenance', as well as SIAs' specialists about the large amount of available data, provided by flight recording devices, which, if properly processed, enable increased flight safety and avoidance of severe occurrences, being the third of a series, on developments on safety data.*

1. FLIGHT RECORDERS

Modern aircraft are equipped with flight recorders and different automation or navigation equipment includes also flight data memory facilities. The purpose of all this equipment is to provide information on the operation of the aircraft. The information/data is used for safety and maintenance reason, being also included in the R&D and manufacturing processes.

Modern communication developments such as Datalink facilities and cloud technologies enable gathering of huge data amounts which are then available for use by engineers in development and maintenance, by pilots in training and improvement of flight techniques and by air safety investigators to determine causes of occurrences and provide important targets for safety improvement. This paper as an overview for different interested specialist is looking the use of flight data recordings.

1.1 FDR Data Analysis

Data provided by flight recorders is downloaded and needs to be processed so that different flight parameters and other information to be correlated enabling conclusions for maintenance, development/ manufacturing and air safety investigation. Most common recordings are those provided by the FDR.

The analysis process is usually carried out by a multi-disciplined team that includes experienced flight data analysts in consultation with performance engineers, aeronautical engineers, operations specialists and systems specialists. During the analysis of recorded flight data and/or voice, graphical plots, transcripts and flight animations are all effective techniques to begin to document the relevant aspects of the recordings that begin to tell a story.

Deriving additional parameters mathematically, interpolation, extrapolation and other techniques are used to understand the data.

A fundamental part of the flight data recorder process is to verify whether or not the aircraft is performing as per the data or if the data is incorrect. Flight simulators were used for this verification, however with today's modern computer it is now practical to perform certain performance validation tasks on a personal computer with suitable software and expertise.

The manufacturer should be intimately involved in this process due to the high degree of aerodynamic parameters required and the high level of expertise required. A full motion simulator is useful when motion and/or ergonomic issues are such that the replicated flight deck and motion sensations are potential factors in the study or investigation.

Detailed information FDR data analysis is included in the paper "Processing of flight data records", which is the second part of this overview papers' series.

1.2 Cockpit Voice Recorders

The need to install cockpit voice recorders on transport aircraft results from the fact that in many accidents and serious incidents, the actions or lack of actions of the flight crew are a significant component to understanding the investigation. In addition to valuable inter-crew communications, the acoustic environment of the flight deck can shed important light on many investigations. The primary purpose of the cockpit voice recorder is to provide a record of the communications on the flight deck, the radio communications with the ground controllers as well as a record of the general acoustic environment onboard the aircraft, e.g. switches being actuated, flap and landing gear selectors being operated, aural warning signals, engine noise, cockpit noise associated with changes in airspeed, etc. This information is considerable significant, especially when the precise time of each sound can be determined.
Cockpit voice recorders normally record the following:
a) Voice and/or digital communications transmitted from or received on-board by radio;
b) Voice communications of flight crew members on the flight deck;
c) Voice communications of flight crew using the aircraft's interphone system;
d) Voice or audio signals identifying navigation or approach aids introduced into a headset or speaker; and
e) Voice communications of flight crew members using the passenger loud speaker system
To record effectively the voices of flight crew members on the flight deck, a cockpit-mounted area microphone is installed in the best position to record voice communications originating at the first and second pilot stations as well as voice communications of other crew members on the flight deck when directed to those stations. Location of the microphone and adjusting or supplementing the preamplifiers and filters of the recorder assure a high level of intelligibility of the recorded communications under cockpit in-flight noise conditions. Cockpit voice recorders are installed so that each source of information described above can be recorded on a separate channel. This could be achieved as follows:
a) The first channel, each microphone, headset or speaker used at the first pilot position;
b) The second channel, each microphone, headset or speaker used at the second pilot station;
c) The third channel, the cockpit-mounted area microphone;
d) For the fourth channel, from each microphone, headset, or speaker used at the station for the third or fourth cockpit crew members or, when not in use for this purpose, from microphones associated with the airplane's loud speaker system.
A cockpit voice recorder is installed so that the probability of inadvertent actuation and operation of the bulk erasure device during crash impact is minimized.

1.2.1 Readout and analysis

Readout and analysis of CVRs include data extraction (similar FDRs), and the transcription/analysis processes. The data extraction stage provides a recording for the purposes of transcription and sound analysis. It is necessary to employ specialized playback equipment designed to reproduce the tape from a specific type of CVR. For solid state CVRs, the memory is extracted similarly to a SSFDR, using the proper interface protocols to communicate with the memory device.
For tape recorders, it is necessary to time correct the recording since it cannot be played back at precisely the same speed as it was recorded. Small speed errors will result in large timing errors over time. There are several techniques known by experienced investigation labs, such as using the 400 Hz aircraft frequency to time adjust and, a better solution, correlating the VHF keying with the recorded flight data using a linear regression over the full duration of the CVR. For solid state CVRs, timing can also be an issue. Some modern systems record GPS time on all recorders, making synchronization relatively easy.
For CVRs a digital industry lossless compression standard such as (wave or .wav file) is normally generated at a sampling rate of 22 kHz or higher. Experienced labs have techniques to slow down speech while maintaining proper pitch, perform noise filtering and perform spectral analysis to identify sounds and engine behavior. All of these applications can be employed to greatly enhance the quality of a CVR transcript.
A CVR transcript is usually conducted by a group of multi-discipline specialists including acoustic analysis specialists, operations specialists and systems specialists, targeting to produce an accurate transcript of relevant conversation. SIAs should apply considerable privilege and protection to CVRs. There shall be transcribed only relevant information; usually it's no need to transcribe personal information that does not contribute to the investigation. If personal conversation is consuming an inappropriate amount of time during the flight, an editorial observation may be used to note that. The need for using the actual words must be balanced against the privacy issues of the crew and the needs of understanding. It is an accepted practice to substitute symbols

(#) for expletives. Other useful symbols for transcripts include () to denote specific words translated from a specific language.
Audio CVR recording or its transcript shall not be released to the public. Recordings and transcripts should be adequately protected to prevent inadvertent release. It may however, be essential to the analysis and understanding of the occurrence to include relevant parts of the transcript in the final report or its appendices. It is more convenient to include a description of what was said is included rather than a quote of the actual words of a personal conversation. Not essential transcript parts shall not be disclosed (See also Ch.5 in ICAO Annex 13!).

1.2.2 Operational/ human factors analysis

The primary purpose of the cockpit voice recorder is to record the flight crew's communication. The analysis of the CVR record typically includes a review of operating procedures, crew interaction and crew performance. The analysis can be broad to encompass generalized events or it can be very specific to analyze the speech patterns of a crew member or the pronunciations of specific syllables. The analysis can also provide valuable insight into crew physical actions through evaluation of grunts or straining during speech. CVR records' analysis in conjunction with findings from other areas can facilitate identification of crew actions, crew state, and any other potential factors affecting human performance (such as impairment due to medical conditions).

1.2.3 Acoustic analysis

The CVR's primary purpose is to record voice communications. Most CVR systems have a bandwidth and/or filters that optimize the recording of the human voice. The CVR is not an acoustic recorder – that is, although the cockpit voice recorder record all audio that is received by the microphones, the microphones may not pick up all of the audio in the aircraft.
Since each aircraft and its cockpit may be subject to different environmental conditions, the fidelity of the microphones may be vastly different between aircraft. Integrity of the installation and age of the CVR system is also a quality factor of the recording. It is still possible to obtain acoustic information useful on several aspects, including engine speed, propeller rotational speed, rotor speed, transmission operation, hydraulic pump operation, and ground speed.
This information may be recorded on the cockpit area microphone channel. Usually it isn't possible to determine precise location of an acoustic source using the area microphone, since it is a single source recording. In an engine failure, the recording would simply show a signal reducing in frequency, but it is not possible to determine if it is the left, right or center engine.The interpretation of the acoustics can vary and should be confirmed through physical evidence or other data sources.

1.2.4 Flight Animation

Airlines routinely monitor their flight data for improved efficiency and safety. Flight animation is increasing in popularity, especially with the advent of flight data analysis programs whereby Flight animations may not be able to portray a complex occurrence accurately and perhaps lead to misinterpretation. Airline animations are typically automatic systems that can generate an animation in minutes, mainly used to rapidly replay relatively benign in-service events, primarily for flight crews.
Benefits of animating data include assimilating complex information and facilitating analysis. In some instances, flight animation can lend credibility to findings and subsequent recommendations. Flight animation pitfalls include pretty picture syndrome (Seeing is believing!), fabrication, subjective information, and drawing conclusions without understanding underlying principles.
Limitations of sample rates, resolution, aircraft architecture (if the parameters are available), interpolation, and difficult to measure factors such as weather, will affect the objectivity and quality of a flight animation. The use of any automated tool represents a considerable risk. Any conclusions based on animation should be thoroughly reviewed in light of the manner in which it was produced' or similar caveat should be considered by the investigation agency.
Due to the subjectivity of flight animations and the fact that they are powerful and compelling, SIAs need to take great care in ensuring that the animation is an accurate representation of what really happened. Investigators should resist the temptation to use a tool designed for "normal" routine flight sequences on accident data that typically contains abnormal out of the "envelope" flight scenarios.
It is also recommended that any flight animation shall not be largely dispatched until the experts responsible for developing it are satisfied that it is accurate and any assumptions used to generate it are well understood and documented. The expertise generally required is a strong aircraft performance or professional engineering background combined with operational flying experience.

2. OTHER RECORDING DEVICES

2.1 Flight data collection devices

Many aircraft have on board, other than FDRs and CVRs, devices used routinely for daily airline operations. While these are not crash-protected, they may contain valuable information for a safety investigation. Advancements in technology have made it possible for aircraft manufacturers and operators to collect and use data to track maintenance procedures, problem diagnoses, establish data trends and identify safety concerns. Airlines using such data on a routine basis have been able to improve operational efficiency.
Flight Operational Quality Assurance (FOQA) or Flight Data Analysis Program (FDAP) for aircraft or Health and Usage Monitoring Systems (HUMS) for rotorcraft are not mandatory in many ICAO States, but are highly encouraged. Frequent review of flight data provides a possibility to check systems which may contribute to the flight recording system integrity and highlight any abnormalities, enabling avoidance of future problems. The mandatory FDR unit is the basic recording device, the flight data is most commonly collected by an additional Quick Access Recorder (QAR) or Digital Access Recorder (DAR) which is not crash-protected. QARs and DARs may record an identical set or, sometimes, more or less information than the FDR. These usual located near the cockpit, a position more accessible for daily retrieval. Older QAR or DAR units may use optical disks or tape as storage medium. QARs and DARs currently produced are solid state or employ a memory card (PC card or PCMCIA). The latest technology allows wireless transfer of data straight from the aircraft to a ground station without any human interaction. Air operators utilize automated software to identify predetermined exceedences within hundreds of flight hours. Although data from QARs and DARs can enhance the process, it should always be obtained in the rawest format available since there is no certification of the software tools used. In safety investigation these additional data collection devices be used to assist in an investigation.

2.2 Other flight data sources

Many of the instruments and avionics in modern digital aircraft contain non-volatile memory (NVM), which can provide critical information not captured anywhere else. These devices are particularly useful when no FDR or CVR is present on an aircraft. In such case, NVM is the sole source of information. Though these units are not crash-protected, it is often possible to recover useful data even in a catastrophic accident. Some systems that commonly employ NVM are the Flight Management Computer (FMC), Full Authority Digital Engine Control (FADEC), EEC, Radio Stacks, Fuel Gauges, Global Positioning System (GPS), Engine Instrument Crew Alert System (EICAS), Power Analyzer Recorder (PAR) or Enhanced Ground Proximity Warning System (EGPWS). EGPWS systems record parametric data over the period from 10 seconds before to 20 seconds after any event that triggers an EGPWS warning. This data includes: AGL altitude as calculated and corrected based on all sources; altitude rate; aircraft pitch and roll angles; aircraft body angle of attack (AOA); longitudinal acceleration; normal acceleration; inertial (earth axis) acceleration; glideslope deviation; temperature in centigrade (Celsius); range settings for navigation display 1, 2; aircraft airborne flag; and approach-mode flag. Certain panel mount devices, such as multi-engine monitors, are capable of storing and downloading engine-related information including: RPM; cylinder head temperature; exhaust gas temperature; oil temperature; manifold pressure; fuel flow; total fuel used; and battery voltage.
The use of GPS navigational units are increasingly common on even single-engine, piston-driven, general aviation aircraft. Before 1990 units usually employed volatile static random access memory (SRAM). Newer generation devices generally employ NVM and, depending on the model, these devices may hold a history of the flight plan, position, altitude, track, radio frequencies, and transponder codes. Handheld and portable units will be found to contain more historical data than a typical panel mount unit. Non-powered aircraft, such as gliders, will generally contain a special purpose-built data logging device fitted to record parameter-data for post flight training and use in scoring contest.
Handheld GPS units and data loggers are designed with interfaces permitting the download of any recorded information to a PC running the appropriate commercially available software. These devices require little expertise to download, the software tools are readily available, and the data can be presented in an easy-to-understand format. Multi-function displays employ flash memory cards, similar to those in digital cameras. Such devices may require somewhat more expertise to download and analyze, but the resources should be readily available. Certain primary flight displays and EGPWS systems contain internal interfaces available for downloading data under special circumstances, such as factory troubleshooting or maintenance. These devices will generally require manufacturer support and the recovered data will require a fair amount of design expertise to interpret. Devices as certain engine displays, altitude heading reference units, flap control units, etc., may contain varying amounts of information related to exceedences or internal errors. This information

may be retained on NVM within the unit and will require special expertise to recover and interpret the data, since no interface is available for routine data downloading. Battery power should be preserved for any unit employing volatile memory. If a unit has been subject to water exposure, especially salt-water, it is imperative that the unit be flushed with clean pure deionized water as soon as possible and rapidly dried, ideally under a weak vacuum. If necessary, the unit should be transported submerged in clean pure deionized water to a specialized lab.

Battery should be removed from NVM containing units, as this power is not needed for data preservation, but might contribute to data loss if corrosion occurs or the unit begins to over-write old data. All units contain internal backup batteries to preserve volatile memory for the system clock and other operating system data. Moisture containing salts or mineral impurities will promote corrosion which can, within a matter of hours, eats through circuit traces and other metal parts, ultimately removing backup power from any volatile memory devices and possibly damaging an NVM unit beyond normal recovery.

Since most water contains trace salts and some amount of dissolved free oxygen, this process can and will occur even if the unit remains totally immersed. This corrosion process is accelerated in a warm place. De-ionized water contains nearly no dissolved oxygen and, if kept cool, this environment is far preferable to storage in natural water.

Since most of them are not crash-protected, damaged NVM units will normally not be recoverable using normal means. Often, due to their small size and low mass, the flash memory devices within these units will survive and extensive manufacturer expertise is necessary to reconstruct the data stored directly on these devices. The recovery method involves recovering the flash memory device or devices containing the parametric data of interest, and installing these devices into an operable unit of the same type and model. Manufacturer expertise is needed to determine which chip contains the recorded data and/or other operating system code to successfully recover the information using the surrogate unit.

3. VISUAL RECORDINGS

Increasing contributor to investigations is the digital camera or video data. In some cases, passengers on board or witnesses on the ground have digital or video cameras or an aircraft may be equipped with a recording device to capture scenic flights. Security cameras on the airport may show information on loading, or on bridges, tolls or buildings in the vicinity of the accident or on the airport. Many of these devices record their data in compressed or proprietary formats. Videos and recorded images are providing valuable information, especially for safety investigators. Devices recording image data include, but are not limited to: image recorders, camcorders, video recorders/cameras, digital cameras, digital video recorders, and flight-test equipment. In addition to images of the accident or incident, images from a prior time period may also be of investigative value.

When using images or video during an investigation, it is important to make every effort to obtain the original recorded media. Down-sampling could remove valuable information contained in the original image. It is always best to obtain a digital copy of the original stored media. If it is not possible to copy the original, then the entire machine or storage device should be retained so a digital copy can be made at a later date.

It's also important getting technical specifications about the recording device or system, the camera(s), and information about the recording system setup and configuration. For fixed cameras, such as security systems, providing an engineering drawing depicting the camera location relative to surrounding landmarks, such as buildings, roads, taxiways and runways, etc. is very important.

These drawings are often available from the airport authority or a city/county planning office. For video from a hand-held camera, it is important to have the location of the camera operator at the time the recording was made. Information about several of the predominant features that are visible in the scene is needed to calibrate the recorded accident image.

4. RADAR DATA AND ATC TRANSCRIPT

Analogue and digital recorders are used in ground air traffic control services (ATS) centers and units. Recordings may cover not only air-ground voice and data link communications, but also voice, radio, satellite and land line communications between the various ground services or stations.

It may be necessary to collect data linked information transmitted from the Aircraft Communications Addressing and Reporting System (ACARS) or Aircraft Condition Monitoring System (ACMS). Operators may also record communication between the aircraft and ground personnel that covers a period not contained on the CVR.

5. DATALINK RECORDINGS

Exchanges between ATC and the crew were normally preserved on the CVR. In the future it might be mandated for CNS/ATM information to be recorded. Some CVRs are already equipped to meet this requirement. The recording time will be the same, usually two hours.

6. AIRBORNE IMAGE RECORDING

Accident investigators have also recommended the implementation of Airborne Image Recorders (AIR). There was already developed a technical standard and the technology is available to employ them (EUROCAE). Additional information could be gained from an inside view of the cockpit, such as: the human-machine interaction (switches, throttles and controls), the ambient cockpit environment (smoke, lighting), non-verbal communications (hand signals) and crew interaction. Potentially it could record hundreds of additional parameters not currently recorded.
Additionally, on aircraft that are not equipped with FDR or CVR, an airborne image recorder might be a low cost means, instead equipping the aircraft with an FDR or a CVR. An AIR would provide parametric data from the cockpit instruments.

7. EXAMPLE OF DATA GENERATED BY DIFFERENT SYSTEMS

7.1 GPS data

GPS systems include usable records for safety investigation and maintenance. To highlight the use of these data, here is an occurrence investigated by the Romanian SIAA:
During summer time a glider pilot planned a flight in the region of the mountain massif "Postăvarul". The weather condition was adequate for glider performance flights. The glider took – off by aero – tow from. Reaching the intended flight area and altitude, the glider disconnected the towing cable. The tug airplane returned to the aerodrome.
Since there rising air current was week, the pilot decided fly over the "Muchia Cheii" ridge. There, the pilot succeeded to get into an ascending current and started spiral flight, after completing 4.5 circles the pilot the flight altitude increased about 100 m.
After the 4th turn, the pilot increased the rotation radius and after two minutes the speed decreased with 33 km/h in 2 seconds. The glider engaged, sliding on the right wing and entered an uncontrolled motion and crashed.
The flight was recorded by the GPS LX9080 device on-board the glider. The decoding (raw data processing) of GPS equipment records enabled a reconstruction of the flight pass and the flight profile, as well as altitude and speed of the aircraft from the take-off until the crash. Raw data processing generated a table, as in table 1.
Processing GPS data with a specific modeling program generated the flight profile in Fig. 1 and the trajectory reconstruction in Fig. 2. Superposing the reconstruction over a Google Earth Image resulted following image of the final section of the trajectory, Fig. 3.
Flying over the mountain ridge the pilot was flying in an ascending current, in fact one part of a turn was ascending while the other one was descending. During the last turn, the pilot intended to increase the turn radius, to avoid the descendent current over the ridge and to center the turn over the ascending current.
Stick and the rudder have not reduced the roll angle, but increased the turning radius from 110.63 m to 140.92 m. Unable to control the glider's roll the pilot initiated the emergency parachuting procedure. The uncontrolled glider reduced speed with 33 km/h during 2 seconds, engaged on the right side and descended abruptly. Available height over the ground didn't enable parachuting.

7.2 Data generated by FADEC

As previously mentioned, flight data information is provided also by control systems like the FADECs. The abbreviation stays for full authority digital engine control. FADEC is a system consisting of a digital computer, called an "electronic engine controller" (EEC) or "engine control unit" (ECU), and its related accessories that control all aspects of aircraft engine performance. FADECs have been produced for both piston engines and jet engines. Here below we would like to show the result of FADEC data processing, for another occurrence investigated by the Romania SIAA.
The FADECs were removed from the twin engines of an aircraft involved in a severe occurrence. The devices were brought to a laboratory where the download and data processing included following steps:

1. Case details: information concerning the aircraft, engines, event, etc. and the identification of each FADEC unit to be downloaded.
2. Relevant additional information enabling the laboratory to involve altos in other steps of the investigation.
3. The condition of the device when received, mainly taking into account the fact that the device will not be reusable after the download (basically it could be used again, only after throw overhaul).
4. The laboratory investigation steps included following operations:
   4.1. The two ECU units of FADEC were separately powered to avoid electrical damage of PCB (printed circuit board). There was checked that all power measurements shall be in normal ranges, i.e. unit is virtually undamaged.
   4.2. The use of the manufacturer download software yielded an event log file and both logger data (ECU A & ECU B), comprising the same number of frames, generated a zip file.
   4.3. Unzipped record data was further read with other manufacturer software. This software was used to enable preliminary evaluation of recorded data. The next two images show the list of parameters.
   4.4. To enable data export to final processing programs or apllications the file were converted to a portable format.

To enable the use and data interpretation, the data files were used for plotting graphs, such the one in Fig. 6:

7.3 Data generated by altimeter

It might look a little strange, but according to latest legal developments the parachute is considered an aircraft. Parachute jumpers frequently use multifunctional altimeters. Such altimeter provides different functions and also records several flight parameters.

These devices produce records which can be downloaded as data files. Such data files are easily converted into tables which can be further converted into graphs, enabling the evolution analysis for improving flying technique or to support flight safety analysis, in case of severe occurrences.

Further there is an example of altimeter data processed from the devices used by parachute jumpers during an occurrence investigated by the Romanian SIAA. The multifunctional altimeter device (manufacturer's denomination Visio) and its functions are shown in Fig. 7.

Ref#	Time	IAS	Alt	Vertical speed	Height above impact	Rate of Turn
	LT	km/h	feet	m/s	m	°/sec
1	13:08:56	109.3	5369	1.0	173	
2	13:08:57	112.3	5382	4.0	177	14
3	13:08:58	112.9	5379	-0.9	176	15
4	13:08:59	108.2	5389	3.0	179	18
5	13:09:00	120.4	5382	-2.1	177	20
6	13:09:01	127.6	5376	-1.8	175	20
7	13:09:02	112.9	5379	0.9	176	16
8	13:09:03	118.4	5389	3.0	179	15
9	13:09:04	118.0	5395	1.8	181	18
10	13:09:05	105.5	5405	3.0	184	18
11	13:09:06	85.0	5402	-0.9	183	15
12	13:09:07	95.5	5395	-2.1	181	19
13	13:09:08	119.7	5343	-15.8	165	23
14	13:09:09	114.0	5326	-5.2	160	27
15	13:09:10	94.6	5284	-12.8	147	27
16	13:09:11	86.1	5241	-13.1	134	25
17	13:09:12	4.7	5208	-10.0	124	36
18	13:09:13	129.5	4959	-75.7	48	47
19	13:09:14	208.0	4801	-48.0	0	232

Note: The complete data table is stored as investigation evidence according to applicable legal and regulatory provisions

Table 1 GPS raw data processing results

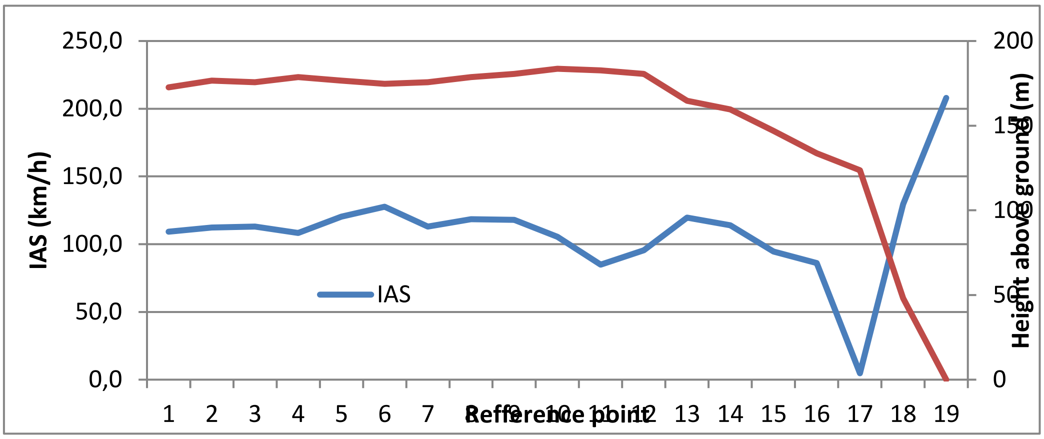

Fig. 1 Indicated air speed and height above the ground

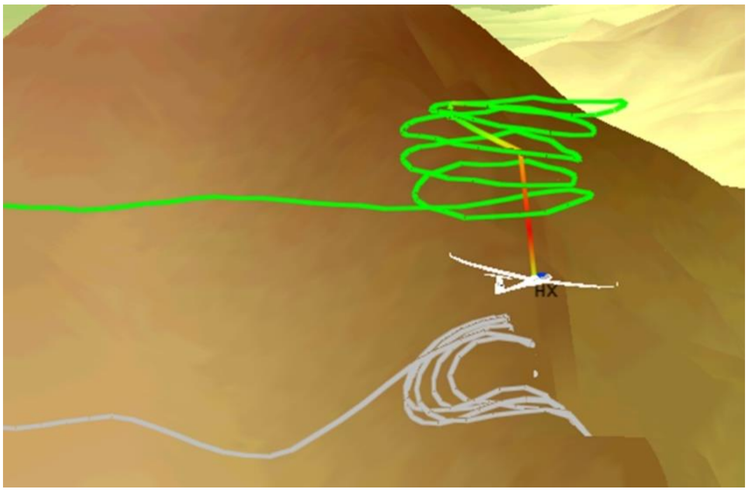

Fig. 2 3D trajectory reconstruction with GPS data

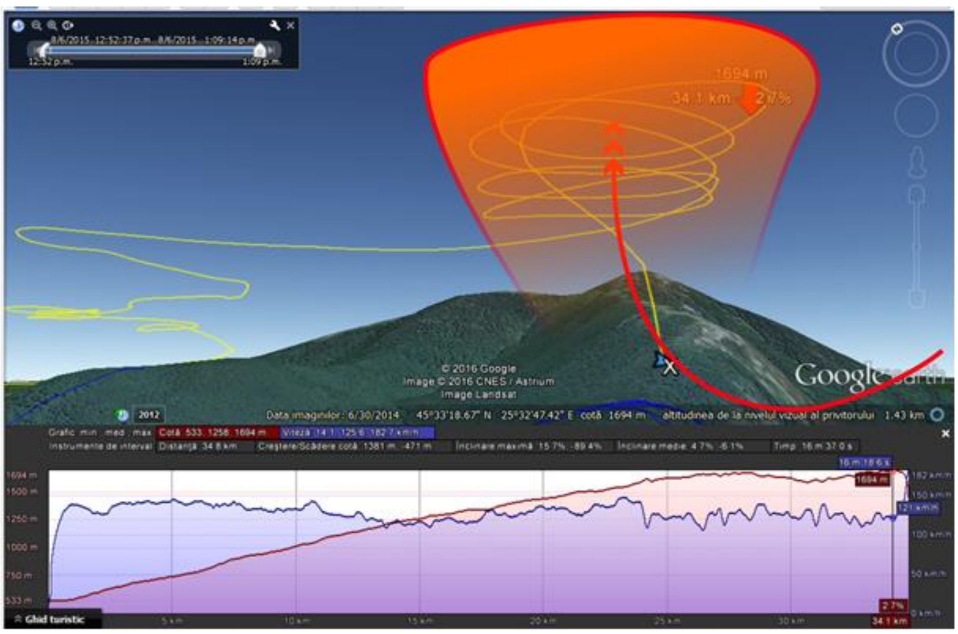

Fig. 3 Reconstruction of the final part of the trajectory
over the mountain ridge "Muchia Cheii",
based on GPS recorded data and Google Earth physical maps

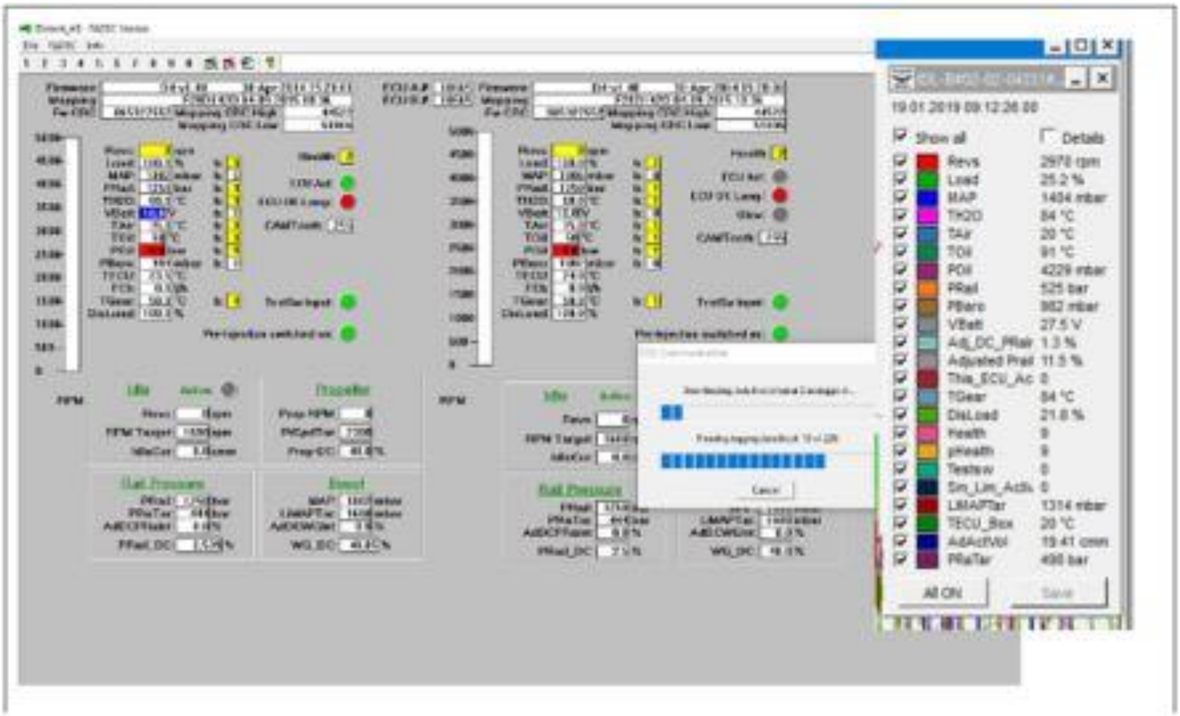

Fig. 4 Conversion interface of the FADEC data processing program including the explanation of the recorded parameters

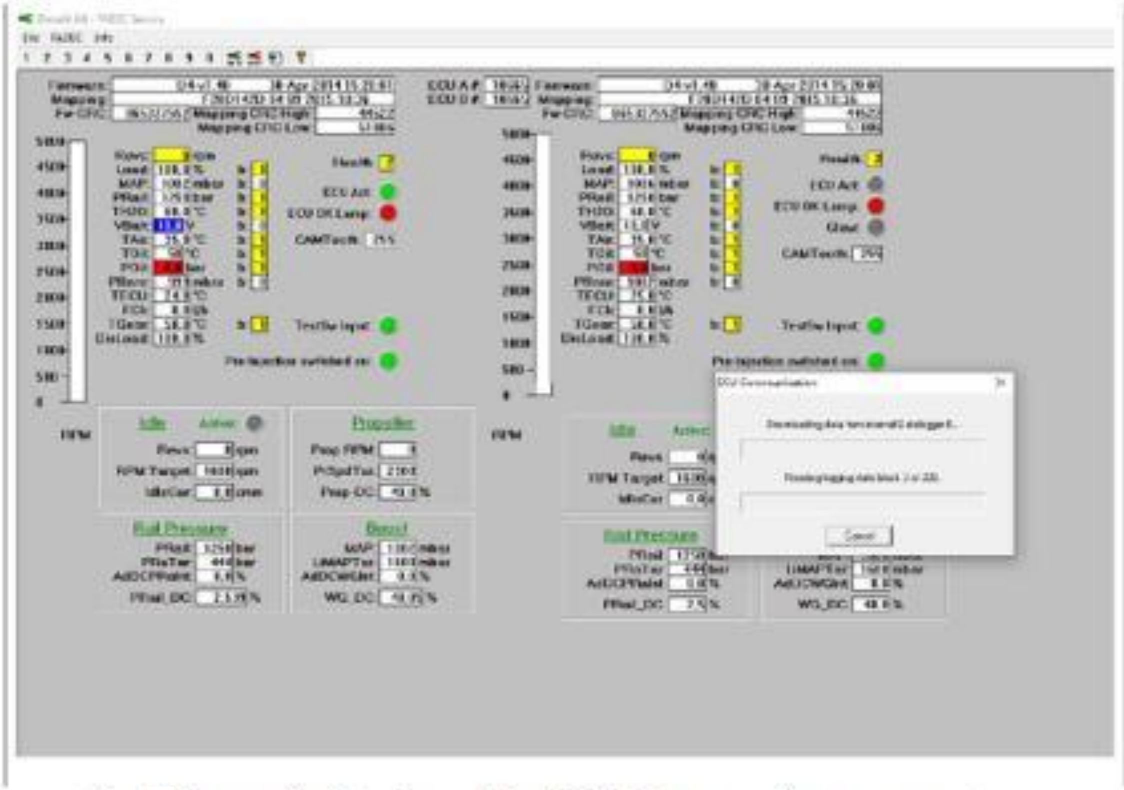

Fig. 5 Conversion interface of the ECU data processing program and explanation of the recorded parameters

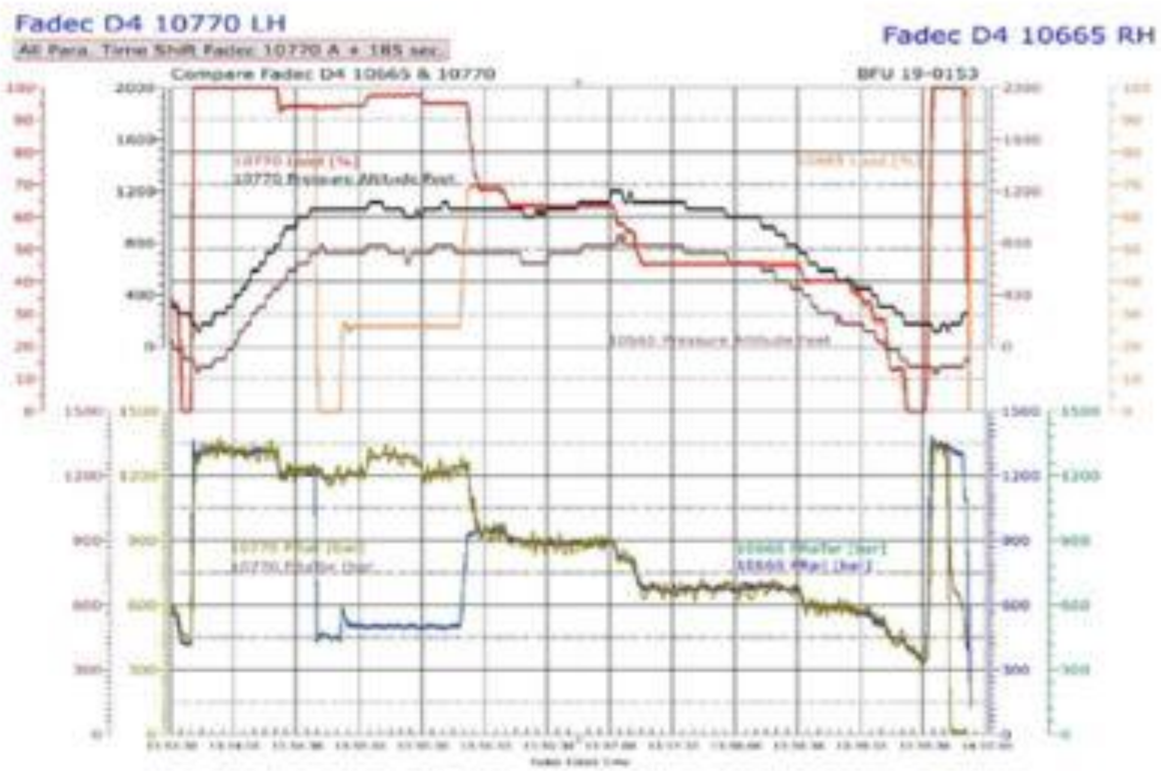

Fig. 6 Graph of the different FADEC parameters during the last part of the flight, before crashing

Fig. 7 The altimeter. The display of the different functions/data is selected with the scroll keys keys, on the device used for our example these are located on the left of the display.

The device shown in Fig. 7 is providing following functions:

- Jumping altitude,
- The number of the jump;

- Free descent time;
- Free descent speed;
- Parachute/canopy opening height;
- Descent speed with open canopy.

Data retrieved from the device are MS Excel tables, such as:

Timp (sec)	Altitudine (m)	Viteza (km/h)
0.5	4030	-
1	4030	-
1.5	4020	-
2	4000	-
2.5	3990	-
3	3970	-
3.5	3950	-
4	3930	-
4.5	3910	-
5	3890	-
5.5	3860	-
6	3840	106
6.5	3810	119
7	3780	129
7.5	3760	136
8	3740	140
8.5	3710	146
9	3680	150
9.5	3660	150
10	3640	153
10.5	3610	159
11	3580	160
11.5	3560	162
12	3530	162
12.5	3500	163
13	3470	166
13.5	3440	168
14	3410	172
14.5	3380	174
15	3350	176
15.5	3320	181
16	3290	183
16.5	3260	185
17	3230	189

Table 2. Example of data retrieved from a parachuting altimeter (ref. for the graphs in Fig. 9)
The complete table includes 523 records.

Data can be processed into graphs, which enable efficient data analysis. The resulted graphs would look like one of those in Fig. 8 or Fig. 9.

Note: The sections of the evolutions marked on the graphic served to understand that specific flight / jump

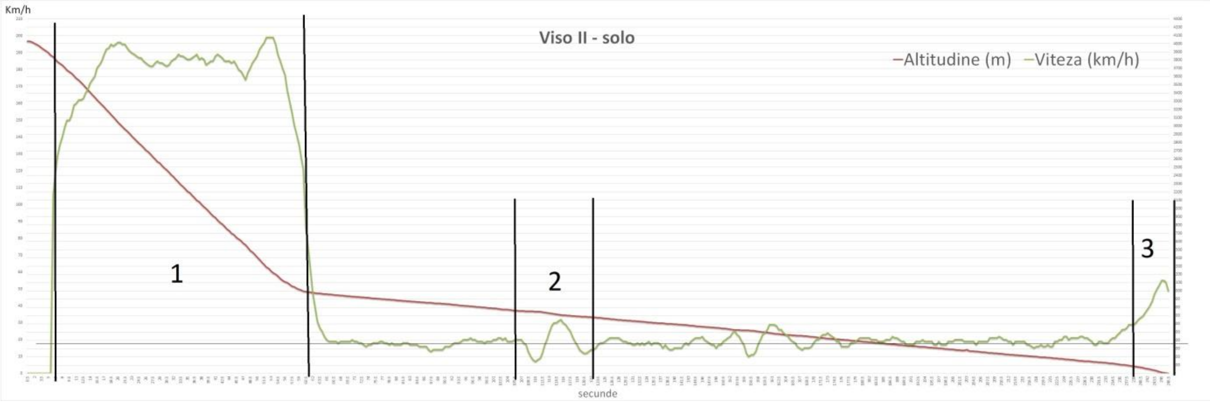

Fig. 8 Example of a flight profile for parachuting (the jump resulted in an accident)

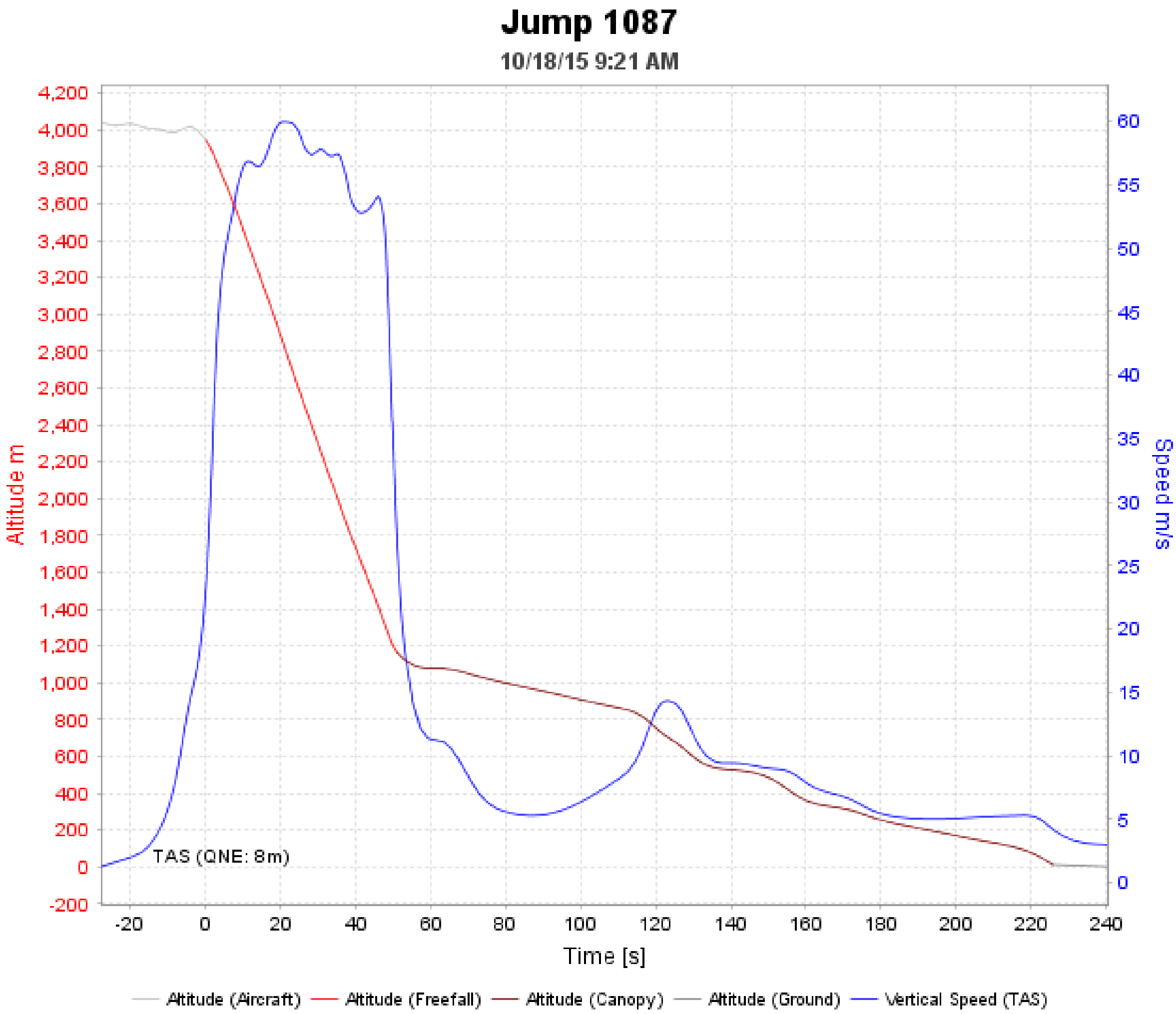

Fig. 9 Processed flight parameters graph

8. CONCLUSIONS AND REMARKS

A flight data recorder (FDR) is designed to collect and record data from a variety of sensors. These sensors are mounted throughout the aircraft structure picking up data from appliances being used during the time before and at the time of an accident. This data is collected and stored digitally within a reflective - fluorescent yellow or orange crash-proof container.

The collected data is critical in assisting accident investigators to try and understand what went wrong to cause an aircraft accident- especially if there are no survivors. Without such information- there is a high probability that the same accident might reoccur on another aircraft under similar circumstances. With FDR data available, faults causing an accident might well be designed or trained out of the system, thus eliminating a disastrous repeat of history. The data gathered can provide vital clues as to faults, maintenance, operations of systems and actions on board, a crucial component within a condition monitoring and reliability. Effective data collection programs are a significant step towards incident and accident prevention. Investigation and data gathering techniques must constantly be improved to keep abreast of technology.

Data provided by devices enabling recording facilities on-board aircraft, raw and processed, including resulted data bases are very useful during entire life of the aircraft from research, designing board, over testing, operation, maintenance, upgrade and scraping, Data needs to be used and stored to avoid damage or misuse.

Modern aircraft, their systems and powerplants, as well as air navigation facilities, testing, operation and maintenance facilities enable a wide range of records, supporting:

- Storing / transmission of data for operational, maintenance or engineering analysis;
- Statistics of different phenomena, operational & technical issues;
- Maintenance,
- Creation of device data bases enabling autonomous operation of devices;
- Checking of the flight route / trajectory in-flight or afterwards;
- Safety investigations of severe occurrences, accidents and incidents investigation.
- Validation of numerical models c by correlating results with real life data

Flight data records used in civil aviation have to be protected according to:

- ➢ Provision of Regulation (EU) No 996/2010
- ➢ ICAO SARPs, as follows:
- For routine operations (outside the scope of a safety investigation) the protection provisions are contained in ICAO Annex 6 and ICAO Annex 19.
- For records in safety investigations as defined by ICAO Annex 13, protection provisions are in ICAO Doc 10053, Manual on Protection of Safety Information 6 and ICAO Annex 19.
- ➢ Legal provisions on classified documents, as applicable for professional information.

This paper is intended to inform research, manufacturing, operation and SIAs (Safety Investigation Agencies) specialists about the large amount of available data, provided by flight recording devices, which, if properly processed, enable major technical improvement, increased flight safety and avoidance of severe occurrences, accidents and incidents, being the third of a series, deemed to brief the interested specialists on developments on safety data.

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Brief history of flight data recording

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Abstract: *The paper is intended to provide brief information on the flight data recording, focusing on reviewing the developments in this branch, the points of view of specialists involved in several aviation branches such as R&D, manufacturing, operation and maintenance and safety investigations. The intension is to keep more or less closed to the developments in our country and to enable co-operation. The paper is reviewing the history and the used of flight data recording, trying to underline developments closely connected with the aviation industry in our country. It provides also support on the information papers regarding processing of flight data records and their use in benefit of maintenance and safety investigation. The result of such work is enabling operational safety improvement, fitting and retrofitting aircraft with recording and data link equipment, as well as design improvements.*

1. INTRODUCTION

Already in the 1920s the aviation services started to extend and the number of aircraft increased quickly. The development of aviation required also careful maintenance and operation since services were destined to involve more and more persons and goods. The necessity of increased safety also determined the need to investigate all kind of dangerous occurrences, accidents and incidents, to enable measures to reduce the probability to occur. R&D, maintenance and safety investigation require proper information to provide safety of operations and development of the safety. AS a consequence there was necessary to get information on the flight during the operation of the aircraft, leading to the necessity to record flight parameters and operational communications on-board of aircraft during their operation.

The result was different kind of recording equipment installed on board of aircraft, also known as "black boxes". In 1960s ICAO required that the black boxes – Flight Data Recorders and Cockpit Voice Recorders shall be painted in orange so they could be easier located in case of an accident.

During the development and improving of technology, especially supported by extended automation, engine control systems and navigation equipment also included different recording systems, initially deemed only to support the automation, but further also to provide information for maintenance, R&D and for safety investigations.

2. LITTLE HISTORY OF THE "BLACK BOXES" (FLIGHT RECORDERS)

The Flight Data Recorder (FDR) has been around for more than 70 years. The first unit was invented in 1939 and slowly developed into a useable flight unit in the late 1940s. In 1954 was issued a patent for the Cockpit Voice Recorder (CVR).

First FDR systems were entirely electro-mechanical units using foil as the recording media which motored between spools- and had five styluses that scratched readings for Heading- Altitude- Airspeed- Vertical Accelerations and Time (five parameters) on one-side of the foil. Soon this system was enhanced by adding three more styluses on the opposite side of the foil- thus adding Pitch- Roll and Flap information (total of eight parameters). Those spools of foil contained 300 hours of recorded data and were not reusable unlike the magnetic tape or wire units that were introduced to aviation industry next.

The magnetic tape/wire FDRs were newer units that utilized Mylar or stainless steel magnetic tapes or wires as the recording media- were able to record 25 hours of data- and continually re-record over the data that was older than 25 hours. Virtually all were of an endless loop- single spool design- which normally allowed 16 parameters of data to be recorded. Data processing was quite slow and involved a lot of work. Here is an image of a former soviet data processing facility, Luch 74:

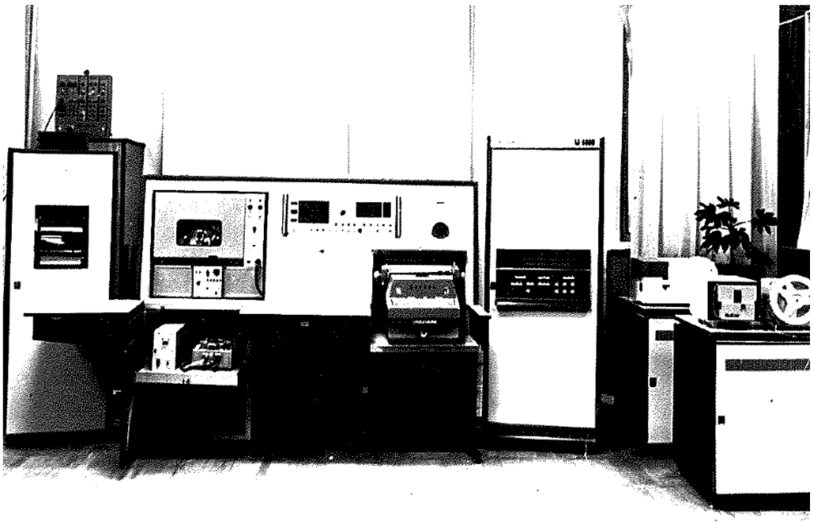

Fig. 1 The soviet decoding/downloading system Luch 76

In 1982 the International Civil Aviation Organization (ICAO) recommended that all Flight Data Recorders should have 32 parameters- and subsequently in 1989 the FAA called for the retrofit of all Foil Recorders and units that only recorded five parameters with at least 10 parameter tape units by May of 1994.
With the arrival of the Solid State FDRs (SSFDR) or more accurately the Digital Flight Data Recorders (DFDR) eliminated tapes, drive motors, drive belts and all other moving parts that were necessary for all previous versions.
Prior to the introduction of the DFDR all recorded and stored data was in an analog format. Analog data transmission systems easily pick up any noise along its transmission wiring, caused by poor insulation, local interference and also the random thermal vibrations of the atomic particles in the wire conductors.
Digital data transmission systems convert the base data inputs into a binary signal - i.e. a 'square-wave' signal that is a pulse that represents either an "on" or "off"- or specifically "1" or "0." This digital signal is not affected by noise- and therefore delivers pure- unaltered data to the receiving DFDR without the need of filtration- and the fear of lost or scrambled signal data.
The internationally recognized standard for digital data transmission on-board aircraft through an open digital-data-bus is ARINC standard 429- which employs unidirectional transmission of 32 bit words over two-wire twisted pairs. Messages are transmitted at a bit rate of either 12.5 or 100 kilobits per second to other system elements- which are monitoring the bus messages. For many years the ARINC 563 serial binary data standard allowed for a bit-rate of 768 bits/second. This is equal to 64 words/second. ARINC system standards have increased to 128 words/second and beyond. Effectively the rule of thumb here is: the higher the ARINC number- the faster the system. ARINC specifications include 419- 561- 573- 582- 615 and 717. Instead of two-wire systems- the higher the speed- the more twisted pairs are needed (naturally adding weight).
The use of devices which, currently, would be designated as flight recorders started just before WWII, basically as mission support devices. During World War II both UK and US air forces successfully experimented with aircraft voice recorders.
One of the earliest steps towards flight recorder was created in 1939 by François Hussenot and Paul Beaudouin in 1939 at the Marignane Flight Test Center, in France, the "type HB" flight recorder; these were essentially photograph-based flight recorders, the record support was a scrolling photographic film 8 m long and 88 mm wide. The image was generated by a thin ray of light deviated by a mirror tilted according to the magnitude of the data to be recorded. Some of these recorders remained in use in French flight test centers until the mid-1970s. The advantage of the film technology was that it could be easily developed afterwards and provides a durable, visual feedback of the flight parameters without needing any playback device. On the other hand, unlike magnetic tapes or later flash memory-based technology, a photographic film cannot be erased and reused, and so must be changed periodically. The technology was reserved for one-shot uses, mostly during planned test flights: it was not mounted aboard civilian aircraft during routine commercial flights. Also, cockpit conversation was not recorded.
Another type of flight data recorder was developed in the UK during World War II, a unit that could withstand a crash and fire to keep the flight data intact, developed by Len Harrison and Vic Husband. This was a forerunner of current recorders, withstanding conditions that aircrew can't. It used copper foil as the recording medium. Various styli, corresponding to various instruments or aircraft controls, indented the foil. The foil

was periodically advanced at set time intervals, giving a history of the aircraft's instrument readings and control settings. (British patent 19330/45).
The first modern flight data recorder was created in 1942 by Finnish aviation engineer, Veijo Hietala. It was a black high-tech mechanical box, able to record important details during test flights of fighter aircraft at the Finnish aviation factory in Tampere, Finland.

3. USE OF FLIGHT PARAMETERS RECORDING DEVICES

Collection of flight data or flight parameters data is critical in assisting aviation safety. Data records are useful assets during the entire "life" of an aircraft. During the development and designing data accumulated during the operational testing enables improvement of models and stress calculations, further during operations the recorded flight data enable analysis improving both the skills and training of the operating pilots and improvement of maintenance process by detecting failures or possible failures, finally accident investigators are using these data to understand what happened during an occurrence and to recommended measures to tackle those problems.
Without such information- there is a high probability that the same accident might reoccur on another aircraft under similar circumstances. Faults causing an accident might well be designed or trained out of the system, thus eliminating a disastrous repeat of history while recording systems, mainly FDR systems become crucial components within condition monitoring and reliability programs.
First FDR unit was invented in 1939 and slowly developed into a useable flight unit in the late 1940s. It wasn't until 1954 that the Cockpit Voice Recorder (CVR) was invented.
The term "Flight Recorders" encompasses several types of recorders that can be installed on aircraft for the purpose of complementing all kind of engineering or operation analysis. ICAO requires crash survivable recorders for the purposes of accident investigation. However, many aircraft also have other recorders which are not crash survivable that are used routinely for daily operations and maintenance. Combination recorders, recorders which record multiple functions in the same unit, are also becoming increasingly common. Different types of recorders, both survivable and non-survivable, are often referred to as 'flight recorder' in a general sense but specifically they are:
a) Flight Data Recorder (FDR) is a crash-survivable system for recording data parameters from the aircraft's data systems. Parameters may be dedicated to the FDR but more commonly on newer aircraft, parameters are needed and used by the aircraft to operate and in these cases the data is readily available to be recorded by the FDR. Most States require that a minimum number of parameters be recorded that are considered mandatory but most current aircraft manufactured record vast numbers of parameters on the FDR that often exceed the mandatory minimum number required.
b) Cockpit Voice Recorder (CVR) is a crash-survivable system for recording the internal acoustic environment of the flight deck and internal cockpit crew conversation along with inter-aircraft radio communications through a cockpit area microphone (CAM), boom microphones and Public Address system (P.A.) and radio-telephony communications.
c) Airborne Image Recorder (AIR) is a crash-survivable system intended to capture and record cockpit images. Image recording is not yet required by any State. However, several severe occurrences highlighted the potential benefits of this capability. Five frames per second are considered adequate to capture motion and longer recording duration is favored over higher frame rates for any image recording device.
d) Data Link Recording is a crash-survivable recording which records digital messages transmitted between the aircraft and the ground. This method of communication replaces many of the traditional voice exchanges between an aircraft and air traffic control. Data link recordings are typically the same length of duration as the CVR.
e) Combined Recorder, "combi", refers to a crash-survivable unit which records more than one function in one box. Typically, a "combi" incorporates the FDR and CVR functions, but can accommodate Image and Datalink recording capabilities.
f) Quick Access Recorder/Direct Access Recorder (QAR/DAR) is a non-crash survivable system for recording data parameters that typically contains data for a longer duration than the FDR, with either a removable memory unit or a wireless download option. (Also used is WQAR – Wireless Quick Access Recorder).
g) Memory units included in navigation equipment such as GPS devices.
h) Digital engines control units (e.g. FADEC – Full Authority Digital Engine Control Unit).
i) Engine panel mounted devices, such as multi-engine monitors, storing and downloading engine-related information.

4. DATA PROVIDED BY FLIGHT RECORDERS

In everyday language referring to flight recording equipment points towards the FDR and CVR equipment.
The Cockpit Voice Recorder is multiple channel recorder, the different channels include the audio environment in the cockpit, communication of each pilot (headsets and microphone), communications between crew and air traffic controllers /ATS providers, intercommunication with cabin crew or other crew which are not directly involved in operating the flight, information for passengers provided from the cockpit, etc. A time reference shall enable correlation of the discussions/communications with other events or records.
The cockpit voice recorder's primary purpose is to record voice communications. Most cockpit voice recorder systems are designed for voice and have a bandwidth and/or filters that optimize the recording of the human voice. The cockpit voice recorder is not an acoustic recorder, although the CVR records all audio received by the microphones, the microphones may not pick up all of the audio in the aircraft. Since each aircraft and its cockpit may be subject to different environmental conditions, the fidelity of the microphones may be vastly different between aircraft. Integrity of the installation and age of the CVR system are also influencing the recording quality.
FDR / DFDR, data needs specific processing of the recorded data, usually defined as raw data. The processing system is used to import raw flight recorder data into System, transforming it into a system-compatible format. This system also automatically archives and deletes older flight data on a pre-determined schedule.

5. TODAY'S VIEW' ON FLIGHT RECORDERS

The term "Flight Recorders" encompasses several types of recorders that can be installed on aircraft for the purpose of complementing accident/incident investigation. ICAO requires crash survivable recorders for the purposes of accident investigation which incorporate the functions commonly associated with a Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR). However, many aircraft also have other recorders which are not crash survivable that are used routinely for daily airline operations. These recorders can be very useful to investigators and will often survive a crash even though they are not crash-protected. Combination recorders, recorders which record multiple functions in the same unit, are also becoming increasingly common. Crash survivable recorders are designed to withstand high impact forces, short and long duration fires, penetration and other environmental conditions in order to maximize the potential of surviving an accident. Generally speaking, fire is the most common cause for the recording medium not to survive. These different types of recorders, both survivable and non-survivable, are often referred to as 'flight recorder' in a general sense but specifically they are:
a) Flight Data Recorder (FDR) is a crash-survivable system for recording data parameters from the aircraft's data systems. Parameters may be dedicated to the FDR but more commonly on newer aircraft, parameters are needed and used by the aircraft to operate and in these cases the data is readily available to be recorded by the FDR. Most States require that a minimum number of parameters be recorded that are considered mandatory but most current aircraft manufactured record vast numbers of parameters on the FDR that often exceed the mandatory minimum number required.
b) Cockpit Voice Recorder (CVR) is a crash-survivable system for recording the internal acoustic environment of the flight deck and internal cockpit crew conversation along with inter-aircraft radio communications through a cockpit area microphone (CAM), boom microphones and Public Address system (P.A.) and radio-telephony communications.
c) Airborne Image Recorder (AIR) is a crash-survivable system intended to capture and record cockpit images. Image recording is not required by any States, however, several major accidents have highlighted the potential benefits of this capability in the future. The term 'video' recording was intentionally replaced with 'image' recording to reinforce that voice is a separate function and that the frame rate required for images for accident investigation is far less than the typical 30 frames/second of standard video. Five frames per second are considered adequate to capture motion and longer recording duration is favored over higher frame rates for any image recording device.
d) Data Link Recording is a crash-survivable recording which records digital messages transmitted between the aircraft and the ground. This method of communication replaces many of the traditional voice exchanges between an aircraft and air traffic control. Data link recordings are typically the same length of duration as the CVR.
e) Combined Recorder, "combi", refers to a crash-survivable unit which records more than one function in one box. Typically, a "combi" incorporates the FDR and CVR functions but can accommodate Image and Datalink recording capabilities, as applicable. For redundancy, most States will require at least two boxes installed on

any large commercial aircraft if a combined recorder is used. One may be located forward and one may be located aft.
f) Quick Access Recorder/Direct Access Recorder (QAR/DAR) is a non-crash survivable system for recording data parameters that typically contains data for a longer duration than the FDR with either a removable memory unit for convenience of obtaining the flight data or a wireless download option. QARs and DARS may record the identical data stream as the FDR or, in some cases, receive different data streams that may capture additional parameters.
It is desirable that the accident investigation authorities of each State maintain a list of the type and location of flight data and voice recorders in respect of each operator and aircraft type registered in that State.
FDRs, QARs and DARs frequently record voluminous information that, combined with the CVR, in many cases can provide all of the necessary information to thoroughly investigate the accident. High priority must be given to their recovery from the wreckage and readout should take place as soon as possible. If the State conducting the investigation does not have adequate replay and analysis capability, then the recorders should be taken to an adequate facility in another State.

5.1 Installation and protection of flight recorders

Flight recorders are intended to survive accidents and they are typically installed in the tail of the aircraft (either in the pressurized or non-pressurized area) where they are most likely to experience less physical damage in the crash environment. In the case of combined recorders (where two combined recorders are installed), it is recommended that the two recorders be separated by placing one in the tail and one in the nose of the aircraft. While the nose of the aircraft is a more hostile environment in terms of crash conditions, it also represents a shorter distance to the cockpit microphones, thereby improving the possibility of capturing the final milliseconds of acoustic information which can be critical to an investigation.
The crash protective enclosure for flight recorders is designed to meet accepted international standards that have been published for this purpose. EUROCAE standards are an accepted international standard in terms of crash protection.
Flight recorders should receive their electrical power from the bus bar that provides the maximum reliability for operation of the recorder without jeopardizing service to satisfy other essential or emergency loads.

5.2 Location and retrieval of flight recorders

After a catastrophic aircraft accident, the retrieval of the flight recorders may be a difficult task. The familiar appearance may be altered during an accident involving fire and impact, rendering the devices not immediately recognizable. While the recorders are tested to stringent survivability standards, they are not indestructible. The circumstances of an accident sometime exceed the design limitations and the recorder housing is compromised. In this case, the recorders may be more difficult to locate. For example, if there has been an intensive post-crash fire, the recorders may be blackened and no longer bright orange. Also, the crash-protected enclosure protecting the recording medium, usually the heaviest piece of the unit may be jettisoned from the distinctive housing during a severe impact. For recovery purposes, it is important to obtain this module that houses the recorder memory, not the section of the recorder that does the signal processing.
In some cases, the crash-protected enclosure may have been compromised, exposing the inside recording medium. Care should be taken to prevent further damage to these delicate components. All pieces of tape, electronic boards, or chips present in the vicinity of the recorder should be collected within reason. Exposed solid-state chips should be placed in an electrostatic bag if available.
It is important to note the location of the flight recorders and to document the conditions to which they were subject at the accident site. For instance, if there was fire, the intensity and duration should be noted to better aid in determining the best procedure to recover the accident data.

5.3 Underwater retrieval

If the aircraft wreckage is located underwater and the location of the recorders is not apparent, special equipment may be necessary to identify and retrieve the devices. The FDR and CVR are equipped with an underwater locator beacon (ULB) commonly referred to as a "pinger". Upon contact with moisture this device will activate and send out a sonar signal for approximately 30 days. This ULB must be maintained every 2-6 years (depending on the model), with the replacement of a battery in order to be effective. This device is not meant to operate after impact on land, only when submerged in water. Special equipment and often collaboration with maritime organizations is needed in order to pick up a locator signal and further recover the units depending on the circumstances. Several investigative laboratories have previous experience in this procedure that States may draw upon for assistance.

5.4 FDR Investigations

Within an investigation team the flight recorders investigators are responsible for examining and analyzing the on-board and ground-based flight recorders, including the flight data recorders, cockpit voice recorder(s), and cockpit airborne image recorders. There is necessary to arrange through the Investigator-in-charge for their read-out. The calibration of the parameters in the flight data recorder must be taken into consideration in the interpretation of such read-outs; this work will often require coordination with manufacturers, vendors, or the operator to ensure proper conversion of the parameters. The results of the read-outs must be closely coordinated with the investigators in Operations Group and other specialized teams as the circumstances indicate.

Due to the high importance of flight recordings, extreme care must be taken in handling the recorders as well as the recording media, to prevent damage. Only fully qualified personnel should be assigned to recover and handle the recorders. Handling and transportation of the flight recorders from the accident site to the read-out facilities should be carried out by a member of the civil aviation investigation authority.

Additionally to the FDR records, the investigators shall be also recover and analyze of information contained on other aircraft computers (for example, flight management systems, traffic collision avoidance system, and terrain awareness and warning system), on memory units containing satellite navigation information, and on other portable electronic recording devices that can store some data related to the accident.

An import issue is collecting and synchronizing flight data, audio and video information stored on ground-based devices, especially used by ATM/ATS units.

An investigator acting as chairperson of the Flight Recorder Group is responsible for the location, retrieval and transportation of the aircraft flight recorders to the flight recorder playback facility, as well as for the extraction, calibration and technical analysis of the data on these recorders.

FDR investigation specialists will also assist in the operational, technical and human performance analysis of the information derived from the aircraft flight recorders.

The flight recorder specialists acting within an investigation, the members of the Flight Recorders Group will have to observe specific rules and precautions

a) BEFORE LEAVING FOR THE ACCIDENT SITE

1. Attend the Investigator-in-charge's pre-departure briefing;
2. Consult with the Investigator-in-charge to determine an appropriate method of ensuring the locating and securing of the recorders;
3. Brief the personnel, as required, on the appropriate measures required for the preservation of data contained in the recorders;
4. Arrange to obtain the most recent flight data recorder calibration information from the operator;
5. Determine the location of a suitable readout facility; and
6. Coordinate the method of recovery and transportation of the flight recorders to the playback facility.

b) AFTER ARRIVING AT THE ACCIDENT SITE

1. Attend the Investigator-in-charge's organizational meeting;
2. Conduct an initial survey of the accident site;

c) FLIGHT RECORDER RECOVERY

1) Locate the flight recorders, as well as any other recorders such as standby recorders and quick-access recorders;
2) Photograph the flight recorders in situ;
3) Examine and record the condition of the flight recorders;
4) Recover the flight recorders;
5) Prepare the flight recorders for transportation;
6) Arrange for the timely and secure transport of the flight recorders to the playback facility; and
7) Carry the flight recorders by hand to the readout facility. Due to the importance of flight recordings, the recorders must be handled with extreme care to prevent damage. Only fully qualified personnel should be assigned to recover and handle the recorders. A member of the investigation authority should handle and transport the flight recorders from the accident site to the read-out facilities.
8) Submit all original documents and flight recorders information to the investigating Administration Coordinator.

d) POST-FIELD PHASE

1. Determine and brief the members of the Flight Recorders Group on their respective assignments. Flight recorder information SHALL NOT be released publically.

e) READ-OUT OF FLIGHT RECORDERS

1) Obtain the most recent flight recorders' calibration information from the operator;

2) Copy and playback the CVR data and provide the Investigator-in-charge with an initial written précis of the information;
3) Copy all CVR channels separately and present them on a storage medium in a format applicable for the Investigator-in-charge, normally, a four-channel copy;
4) Make a transcript of the CVR and transmit it to the Investigator-in-charge;
5) Contact the Investigator-in-charge to determine the gross FDR requirements;
6) Copy the FDR data and provide the Investigator-in-charge and the pertinent group chairpersons with the required initial data plots along with an appropriate written briefing;
7) Using crosschecks and data obtained from other group chairpersons, determine the reliability of the flight recorder data, and refine the FDR data and CVR transcripts;
8) Synchronize timing of the FDR and CVR records together with the air traffic services data, if possible; and
9) Forward the refined information to the Investigator-in-charge, the Operations Group Chairperson and other group chairpersons needing this information.
e) ANALYSIS OF FLIGHT RECORDERS DATA
1) In concert with designated group chairpersons and assigned specialists, conduct a detailed examination of the flight recorders information;
2) In coordination with the Structures Group, Systems Group and Powerplants Group determine the in-flight serviceability of the aircraft, systems and powerplants; and
3) In coordination with the Operations Group, Witness Group, and the Air Traffic Services and Airport Group, reconstruct the flight path, taking into account the satellite navigation systems data, if available.
f) Analysis and Report of the flight recorders investigators' group
1) Review, evaluate and analyze all information collected; and
2) Prepare and submit the group report to the Investigator-in-charge.
g) OPERATIONS ANALYSIS AND FINDINGS
1) This event should be chaired by the Investigator-in-charge with the following specialized investigators / investigators' groups chairpersons attending:
– Operations;
– Medical/Human Factors;
– Witness;
– Flight Recorders;
– Meteorology;
– Air Traffic Services/Airport;
– Survivability;
– Cabin Safety; and
– Other parties, as dictated by local regulations and procedures.
2) Review all group findings to determine adequacy of information, areas of conflict, errors and inconsistencies;
3) Identifying the areas requiring clarification;
4) Determine the procedure for achieving clarification;
5) Complete operations analysis and determine findings with assistance from the technical groups;
6) Identify safety hazards and deficiencies; and
7) Suggest safety recommendations.

5.5 Underwater recovery of flight recorders

If the FDR and CVR are underwater, it is necessary to retrieve and transport them in the proper manner to mitigate further damage. Watertight containers, such as ordinary coolers, which are slightly larger than the recorders, should be brought to the retrieval site. Once the recorders are located, they should be rinsed in fresh (distilled or deionized) water and placed in the watertight container. They should be transported fully submerged in fresh water (or water from the site if clean water is not available). Both recorders should be kept in water at all times as oxidation will occur rapidly which can lead to damaging the recorder data.
The top of the containers may be sealed with silicone during transport, which minimizes exposure to air. Immediate transfer to a qualified laboratory facility is vital. Experienced laboratories will normally disassemble the recorder in water so as to minimize exposure to the air until it is time for the playback.
Recorder readout preparation
Irrespective of the type of recording system, no attempt should be made to conduct readout at the accident site: either in the aircraft or on playback units. Even if the recorder appears to be in good condition, there could be

internal damage due to heat or impact. Critical safety data has been lost as a result of attempted premature playback.
Some of the risks include the tape recording medium being broken, stretched, melted, or intertwined with debris. A flight recorder's circuitry could be shorted out, internal memory boards cracked, or memory chips melted. Playing back FDRs or CVRs without proper precaution could destroy the data permanently.
The flight recorders should be hand-carried to an adequate playback and analysis facility where suitable processing by qualified personnel can take place. When shipping or transporting the flight recorders, they should be packaged adequately to avoid further damage. No attempt should be made to clean the recorder at the scene, with the exception of rinsing with fresh water if the recorder is already wet. If possible, avoid exposure to x-ray and other radio waves, for example, from automatic doors.
If the Authority conducting the investigation does not have adequate replay and/or analysis capability, then the recorders should be taken to an adequate facility of another State in a timely manner. Whenever possible, all flight recorders from an event should be taken to the same facility. The information on the units is often complimentary and cross-correlation and validation of data is simplified. Additionally, the FDR and CVR information can be readily combined into a comprehensive flight reconstruction with integrated audio and voice transcript.
Before taking a recorder to an investigative facility to perform readout, it would be beneficial to provide as much information ahead as possible regarding the recorder such as the faceplate information (manufacturer, part number and serial number), modification history and description of overall condition and digital photos of the unit. Additionally, details about the event such as aircraft type and serial number, event location and description will aid in readout preparation.

5.6 Flight Data Recorders

Flight data, voice, images, and data link messages can be recorded on three distinct types of recording media: tape, optical disk or solid state memory chips. All current FDRs in service record digital data but this digital data may be recorded on tape media or solid state media. Optical disks are only used for QARs and DARs as they cannot be effectively crash protected. Most QARs and DARs today are solid state, like their FDR counterparts.
The primary purpose of the FDR is namely accident investigation; although more and more airlines are using the FDR or a comparable QAR for routine monitoring and accident prevention.
The primary purpose of a modern FDR system is to capture all significant data related to the operation and performance of the aircraft from the voluminous data available on the aircraft's data bus systems. Often there is sufficient information to derive the flight path of the aircraft in three dimensions, to determine the attitude of the aircraft, to determine the forces acting on the aircraft and to determine the precise manner in which the aircraft was being operated. Often the FDR will also record the status of numerous systems as well as any warnings that may have triggered. QARs and DARs essentially record the same or more information as the FDR but are more readily accessible for routine use and/or the investigation of incidents. It should be noted that optical QARs should not be used for incident investigation alone (the FDR should always be secured) since optical disks frequently have data losses due to the inability to record during turbulence or violent motion.

5.7 Crashworthiness of FDRs

A DFDR must obviously have a high degree of 'crashworthiness.' The first units were required to withstand a momentary shock force of 1-000gs- the latest test standards now call for a test to 3-400gs for 6.5 milliseconds. The units also have to withstand a static crushing force at all of its six axis points of an applied load force of 5-000lbs for 5 minutes on each axis. The unit must withstand a 500lbs piercing force test conducted by dropping it onto a ¼ inch steel pin from 10 feet. Lastly it must withstand a 1-100°C fire test for 60 minutes- and a 260°C oven test for 10 hours.
It is also required that these units are mounted within the tail area of an aircraft- away from the potential crushing force of any engines mounted nearby. The DFDR must be watertight to a depth of 20-000 feet in sea water- and survive at this depth for 30 days - and it must be fitted with an underwater locator beacon which will act like a sonar transmitter- by 'pinging' a signal through the medium of water that it might be laying in.
There are four basic types of flight recording media currently in use, namely the optical disk (older QARs and DARs), PCMCIA cards (QARS and DARs), tape (older recorders) and solid state.

5.8 Aircraft tracking

A new development in aviation safety is also the Global Aeronautical Distress Safety System (GADSS). ICAO started preparation of such activity having in view a wide range of occurrences when a proper tracking would have enabled limiting the consequences of failing safety. During the ICAO Second High-Level Safety Conference in 2015 it was concluded that “ICAO should encourage the International Telecommunication Union (ITU) to discuss allocation requirements at the World Radio Communication Conference, to provide allocations for global air traffic services surveillance as a matter of urgency”. GADSS should enable:

- Aircraft tracking
- Autonomous Distress Tracking
- Post Flight Localization and Recovery

These facilities shall enable support of two very important actions, i.e. Search & Resque and Accident Investigations.

ICAO issued recommendations to upgrade aircraft such as:

- 90 days ULB “Underwater Locator Beacons” (37,5Khz) attached to recorders, CVR and DFDR (replacement of 30 days ULB), since January 2018 Forward fit & Retrofit.
- 90 days Low Frequency ULD “Underwater Locating Devices” (8,8Khz) attached to the aircraft for long-range over-water flights, since 2019 Forward fit & Retrofit (ICAO: Not later than 1 January2018 ; EASA: By 1 January2019.
- 25 hours CVR, applicable from January 2021 -Forward fit.
- Aircraft Tracking Normal (& Abnormal) Conditions, since November 2018 Forward fit & Retrofit.
- Location and tracking of an Airplane in Distress, applicable from January 2021 -Forward-fit.
- Flight Data Recovery, two alternative means: Data streaming (CVR and FDR data content) or ADFR “Automatic Deployable Flight Recorders” (with integrated ELT). Applicable from January 2021for new type certifications.

Aircraft tracking under GADSS enables following:

- Automatic A/C position provision once every 15 minutes.
- Improved use of ATS surveillance
- Can be isolated by flight crew
- Multiple solutions
- May include airline defined triggers for abnormal operations with higher reporting rate.

There is very important to properly use the Datalink communication means such as VHS Datalink usable in continental areas, Satcom Inmarsat usable worldwide except the Polar Regions, HF Datalink applicable worldwide, etc. ICAO issued Doc 10054 Manual of Guidelines/Requirements of the various means of compliance for both Autonomous Distress and Post Flight Localization & Recovery.

New on-board recording systems architecture shall include:

- Combined Cockpit Voice and data Recorder (CVDR)
- Automatic Deployable Flight recorder (ADFR), and
- A Recorder Interface Unit.

6. SOME REMARKS

The flight recording equipment, especially the CVRs and FDRs, need to be extremely reliable devices since the recorded data is providing precious information on the daily operation of aircraft. This operation information is critical for improvement of aviation safety and technology.

Severe occurrences since the mid-1980s until today also determined requests for continuous transmission of data, i.e. flight parameters, to be recorded not only by on-board facilities, but also at the airlines’ operations and maintenance bases. Developments in IT and communications technology, and cloud storage techniques, enable high performance of such facilities and provide information for maintenance, safety investigation and R&D.

Safety investigation agencies with very important background and experience revealed that in certain occurrences the missing information because of difficult location and recover of the flight recorders could be replaced, in a certain degree, by information gathered by other facilities not located on board of the aircraft.

It should not be ignored the fact that certain flight parameters records provide also valuable information for aviation security. Security is considered to be a part of safety, but it’s also a very specific branch and its importance is increasing in the current international social developments.

This paper is intended to provide information on the importance of flight recording devices on aviation operations, triggering cooperation between experts involved in R&D, maintenance and investigation, i.e. research, manufacturing, operation and SIAs (Safety Investigation Agencies) This is the first part of series of three papers deemed to brief the interested specialists on developments on safety, in maintenance and investigations

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Processing of flight data records

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Abstract: *This paper is providing a view on the processing of data recorded on-board of aircraft. Since CVR and FDR are the most familiar recording devices, the paper is focusing on the processing of FDR data. It is important to underline that this processing is a routine operation for any air operator, since for operational improvement and maintenance these data provide most valuable information. It is very important also for the safety investigation. Mainly the investigators concentrate on reconstructing the final parts of the flight ending in an occurrence, but operation history may provide some times very important clues, and supporting safety recommendations, together with all other investigation finding, so the different kind of reports generated by FDR data processing can be also important tools. This is the second part of a papers series, deemed to brief the interested specialists on developments on safety data and its processing.*

1. INTRODUCTION

As know on-board flight data recording is a very important issue for aviation safety, since it provides valued information for maintenance, air accident and incident investigation, R&D and manufacturing. Since common understanding on recorded flight data refers to the "black boxes" we will approach data provided by the flight recorders, with a brief look to data recorded by other equipment

2. THE DATA PROVIDED BY FLIGHT RECORDERS

The Cockpit Voice Recorder is multiple channel recorder, the different channels include the audio environment in the cockpit, communication of each pilot (headsets and microphone), communications between crew and air traffic controllers /ATS providers, intercommunication with cabin crew or other crew which are not directly involved in operating the flight, information for passengers provided from the cockpit, etc. A time reference shall enable correlation of the discussions/communications with other events or records.
The cockpit voice recorder's primary purpose is to record voice communications. Most cockpit voice recorder systems are designed for voice and have a bandwidth and/or filters that optimize the recording of the human voice. The cockpit voice recorder is not an acoustic recorder, although the CVR records all audio received by the microphones, the microphones may not pick up all of the audio in the aircraft. Since each aircraft and its cockpit may be subject to different environmental conditions, the fidelity of the microphones may be vastly different between aircraft. Integrity of the installation and age of the CVR system are also influencing the recording quality.
The FDR / DFDR, data needs specific processing of the recorded data, usually defined as raw data. The processing system is used to import raw flight recorder data into System, transforming it into a system-compatible format. This system also automatically archives and deletes old flight data on a pre-determined schedule.

2.1 Process Life Cycle

Processes follow a life cycle, progressing through a series of phases from when flight data files are imported to when they are archived and deleted. When flight data is imported, it must be translated from binary format into a system-compatible format, and then analyzed for events. The process life-cycle begins with four phases that convert data, detect events, and store the data: Identification, Transcription, Flight Analysis and DBLoad. These phases can take as little as two minutes to complete, depending on the length of the flight recorder files. Raw flight data is processed into a set of files (the data set), which hold flight data and information about the recording. The data set includes the transcribed data file and the flight files. The transcribed data file (also called the raw data file) holds acquired data transcribed from the flight recorder. Flight files hold derived flight parameters in engineering units. The folders holding the data set are identified by the transcribed data file name. See Datafile Name in Processes Table. Once these initial phases are completed, the flight data is ready for analysis in System. After a default delay (six months for example), the flight data is archived and deleted, completing the process life cycle. A list of flights remains, along with associated events and parameter snapshot data. The default delay can be changed.

Process Status

The status of each process is indicated in the Processing Status column of the Processes results table. The process status consists of two parts: the phase the process is in, and the status of the process. The status of a process is one of the following:

Canceled The phase was canceled by the user

Created The process has been created, but is waiting on the phase that comes before it.

InError The phase could not be completed. For example, if the wrong aircraft is chosen, the system will not be able to correctly transcribe the flight data. In this case it will mark the process as 'InError' and halt processing.

N/A The system' status cannot be determinate. This will be indicated for data that originated from System A.

Running The phase is in progress.

Waiting The previous phase is completed, and the current phase is waiting on a predetermined time delay.

2.2 System process phases

Each process in the system represents all data on a particular flight recording medium. Depending on the media and media rotation cycle that your airline follows, a single process can contain many flights over several days, or it may contain just one flight. WGL-generated processes usually contain one flight per process, whereas solid-state flight recording media might store dozens of flights before the flight data is transferred to System and processed. A process takes flight data through a life-cycle, from importing raw flight data into System, through to archiving and deleting the flight data. The process progress includes following phases:

1. Identification
2. Transcription
3. Flight analysis
4. Database load
5. Archive
6. Delete

The first four phases (identification, transcription, flight analysis and database load) must complete before you can access the flight data in System.

Flight data remains available until the archive and delete phases are executed. These phases automatically run a fixed number of days (typically 180) after the data initially processed. The delay is specified by the metadata file which is defined by the process template.

After the archive and delete phases are finished, flight data is no longer available for the advanced tools such as List and Trace or Flight Replay. Events and basic flight information is maintained in the database and can still be reviewed after archive and delete processes have completed. Flights listed in the Flights results table are displayed as red text if the associated flight data has been deleted. Here is a more detailed description of each phase:

Identification Attaches aircraft registration, cartridge ID, cartridge date in and date out, and metadata file to the process. (This information is derived from operator input, the WGL base station, folder names and/or the config file for FIM, from operator input and/or the data file for processing.)

Transcription Identifies all frames and subframes in the flight files.

Copies Copies data to the hard drive in a system-compatible format.

Flight analysis Applies the FAP to the flight files, converting the flight file data into a system-compatible format and detects events.

DBLoad Transfers flight data, events and event parameter snapshot data into the database.

Archive Moves raw data and flight files from the System operational folder to an archive folder.

Delete Removes raw data and flight files from the System operational folder.

Following table shows examples of recorder types and path/file descriptions:

Table 1. Recorder types and path/file descriptions

Description	Type of Path Required	Alternative Path Type
Dassault Optical QAR	Drive holding EQAR disk	Folder containing EQAR image
P&G OQAR	Drive holding OQAR disk	Folder containing OQAR image
Honeywell FDAMS	Drive holding PCMCIA card	Folder containing card image
TDY Tagged	Drive holding OQAR disk	Folder containing OQAR image
L3 FA1000 SSFDR	Single .FDT file	
TDY No Tags	Drive holding OQAR disk	Folder containing OQAR image
FDR milked by the Avionica RSU	Single .TSC file [1]	Folder containing a single TSC file [1, 2]
P&G QAR	drun:\left [3]	drun:\right [3]
SFIM DMU	Folder containing .REC files	
Allied Signal SSFDR	Single .SDF file	
L3 FA2100 SSFDR	Single .FDT file	Single .FDR file
Generic Byte Synchronized Data File	Single ARINC data file	
FDIMU QAR	Drive holding PCMCIA card	Folder containing card image
FDIMU DAR	Drive holding PCMCIA card	Folder containing card image
Honeywell DLU	Single .DLU file	Folder containing a single DLU file
Bit Sync	Single packed data file	
A380 Virtual QAR	Single VQAR file	
SAGEM AFDAU/AFDAMU	Folder containing .REC files	
AirFASE or FLIDRAS Raw Data File	Single raw data file	
P&G QAR data from DRU dump file	Single .DRU file	

2.3 Flight Data Analysis (FDA)

FDA starts by downloading the data recorded onboard aircraft and the copying information in a computer/server within Maintenance & Engineering Division. The data are stored on two data recorders: QAR and FDR. QAR stands for Quick Access Recorder and is an airborne flight data recorder designed to provide quick and easy access to raw flight data. FDR is also a data recorder which collects and records data from the aircraft in a medium designed to survive an accident. Same data are stored on both QAR and FDR, the important difference being the accessibility to retrieve the information, making the QAR the one used for the regular need of obtaining flight data. Once the data recorded in onboard aircraft format (raw data) is obtained, it has to be processed in order to obtain engineering data of the recorded parameters and further, following an automated analysis by the program package, e.g. AirPHASE, the flight events and data are obtained, events which can detect any deviations from standards or abnormalities. The analyzing process is done in a consistent and standard manner. Soft updates when appear are implemented based on the contract between the companies. Analysis soft translates aircraft flight data into meaningful information (parameter data that can be interpreted) and so it offers the possibility to evaluate flight operation trends, identify risks and initiate information-based, preventive/corrective actions. Analysis soft provides tools to manage two types of flight data: the detailed flight measurements recorded for the duration of each flight, and the events that are triggered by analyzing the flight data for values that exceed reasonable values. The flight events so obtained are then manually analyzed. Analysis soft performs the major functions of the flight data monitoring process: data processing, flight analysis, and reporting and flight data animation. Following an analysis, three event classes can be identified:
- "Low" category, with minor influence; for operation in common conditions with the purpose of ensuring passenger comfort and to avoid excessive stress or wear of aircraft components or systems;
- "Medium" category, which can have a significant influence; exceedences of recommended values inside the operational limitations of aircraft operation, or operation beyond company limits;
- "High" category, may have a major influence on flight safety, situations where the limits given in the operation manual or by the Airline policy are exceeded.

Within an airline the Flight Analysis Compartment (FAC) is the subdepartment from the Safety, Security & Compliance Monitoring Department that monitors the flights of Airline by using the mentioned program above. The FAC has flight data analysts who are responsible with the interpretation and analysis the data received from the Maintenance and Engineering Division. The access to the program used by FAC is restricted with username and password. The FAC flight data analysts are trained and qualified periodically in order to maintain a high level of performance. Following an analysis, actions may result: Reporting to DSC, Reporting to CIFS, Reporting to the Maintenance and Engineering Division

All the described processes in this document apply to all the aircraft in the fleet of the specific airline.

Monitoring the data from the flights, it will allow to:

1. Identify the areas of operational risks and to quantify the current safety margins by determining in which event class (low, medium, high) a flight is framed; ex: current rates of rejected take-offs, hard landings, unstable approaches, etc. In the same time by classifying the events based on the severity levels, levels which are stabilized according with the Operational Manual of each aircraft, it can be assessed what is acceptable or unacceptable in terms of service.

2. Identify and quantify operational risks by highlighting when non-standard, unusual or unsafe circumstances, like for example: increases in event rates mentioned above, new events, etc., by charting and making periodically statistics using the flight data monitoring analysis and visualization tool (AirFASE is the tool developed by Airbus and Teledyne Controls).

Fig. 1 Main page of recorded data processing program

The used flight parameters shall be defined:
- Recorded parameters, such as radio altitude, CAS. EGT, acceleration
- Derivate (calculated) parameters, such as long touchdown distance, TFQ.

3. Detect unsafe aircraft states by analyzing from the data if the recorded events are real or they are triggered by a faulty spare part or improper installation of a spare part.

4. Elaborate procedures to correct what was found to be an unacceptable level event. Also based on the predictions made from the data that is possible to appear an unacceptable risk in the future, proactive actions can be made.

5. Confirm or infirm the effectiveness of any remedial action by continued monitoring, allowing a comparison of the safety levels prior to and after the action.

The FDA program is designed and conducted in accordance with the air operator's SMM, using following techniques:

1. Exceedences detection:

i. All aircraft have an operational manual which gives the limits within which the flight operations must be done. The analysis program (FAP) is including the limitations imposed the aircraft manufacturer.

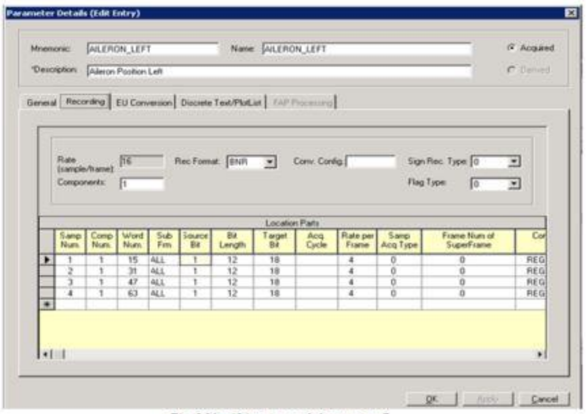


Fig. 2 Identifying a recorded parametrer

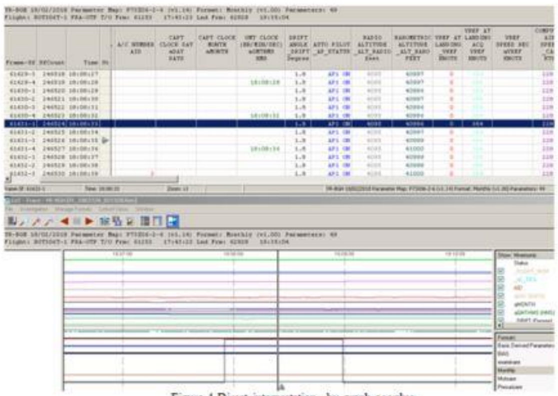


Figure 4 Direct interpretation, by graph or value

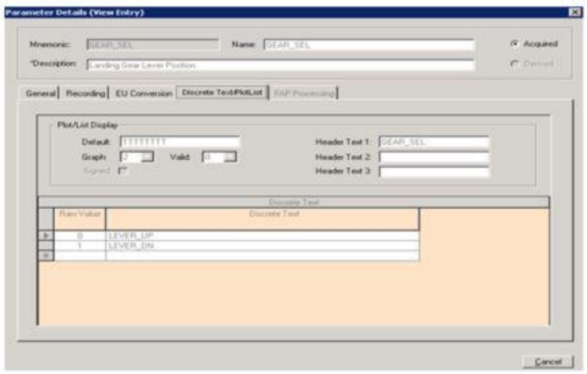
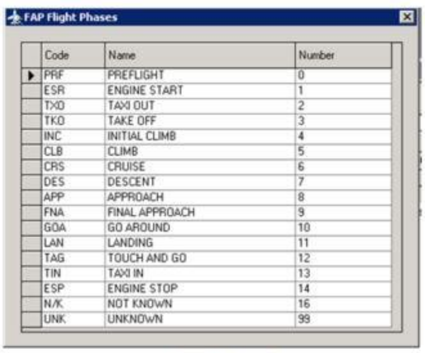


Fig. 3 Example of a discrete parameter (2bits)



FAP Flight Phases

Code	Name	Number
PRF	PREFLIGHT	0
ESR	ENGINE START	1
TXO	TAXI OUT	2
TKO	TAKE OFF	3
INC	INITIAL CLIMB	4
CLB	CLIMB	5
CRS	CRUISE	6
DES	DESCENT	7
APP	APPROACH	8
FNA	FINAL APPROACH	9
GOA	GO AROUND	10
LAN	LANDING	11
TAG	TOUCH AND GO	12
TIN	TAXI IN	13
ESP	ENGINE STOP	14
N/K	NOT KNOWN	16
UNK	UNKNOWN	99

Fig. 5 Flight Phases

Fig. 6 Defining a flight event (occurrence)

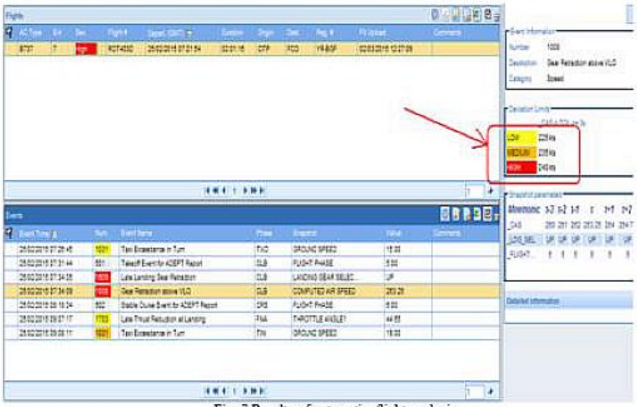


Fig. 7 Results of automatic flight analysis

Fig. 8 3D animation

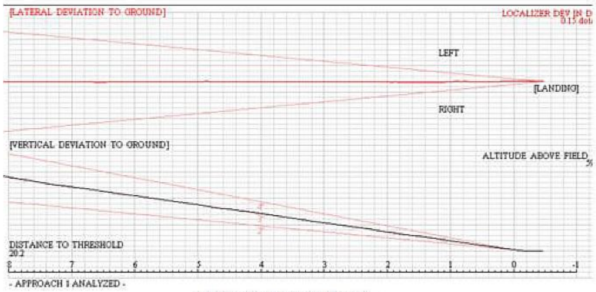


Fig. 9 Lateral and Vertical Deviation

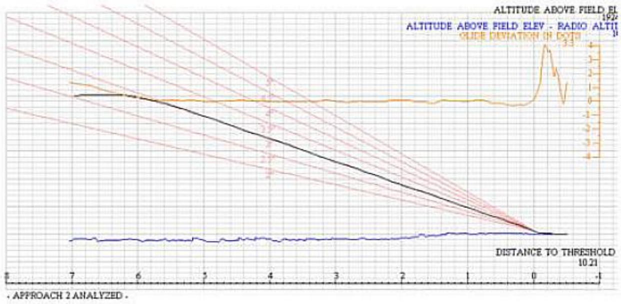


Fig. 10 Geometric path 3000ft to ground

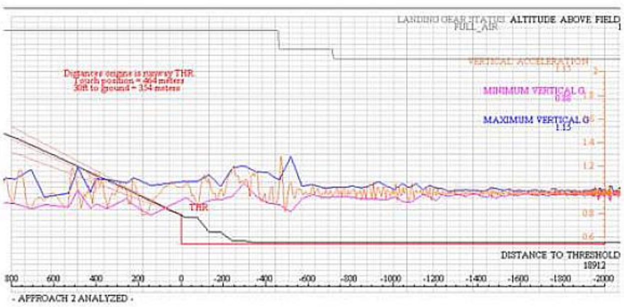


Fig. 11 Geometric Flare

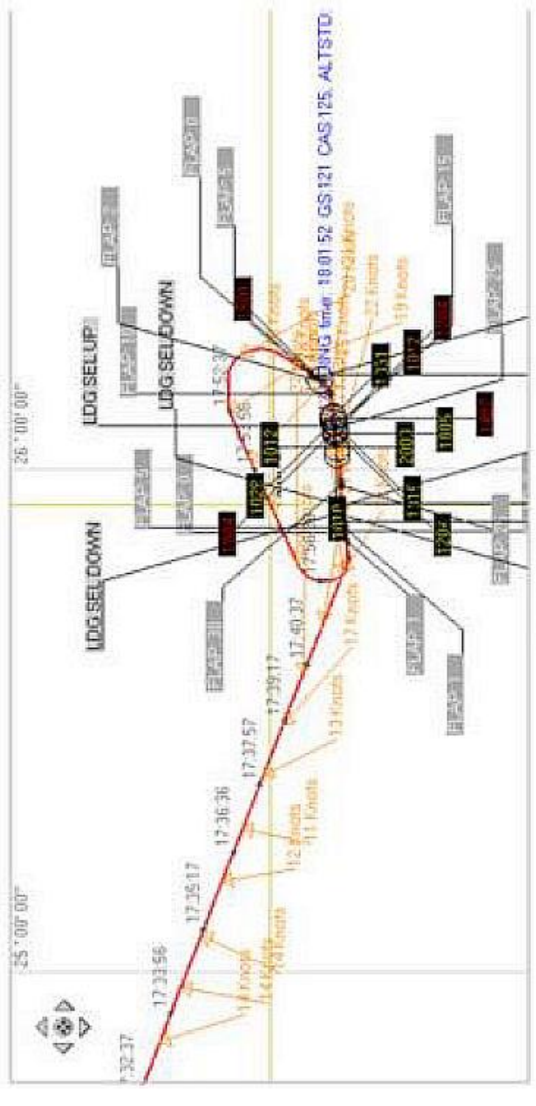


Fig. 12 Trajectory plot

These boundaries for flights enable, in case one of them exceeds a certain limit, an event will be triggered, if a boundary is exceeded.

In this way it can be assured that proper actions will follow to correct the problem. Also, due to the fact that not all limits are hard limits and can be grouped in 3 categories as mentioned above, the program will also categorize the events based on the severity set by the constructor.

ii. Due to the fact that not all the limits imposed by the designer are mandatory, some of them are recommended allowing the operator to impose own limits.

Example: the category "high" for a long landing for an airplane can be set by the operational manual of the aircraft at a maximum of 1200 meters; in order to increase the safety level it can be chosen a value set at 1150 meters for long landings.

The Analysis program offers the possibility to set new operational limits which become the new references for the exceedences detection technique. (Those modifications are provided on request by the flight data monitoring analysis and visualization tool developer).

2. All flights measurement:

The data retrieved from the flight data recorders are processed using Analysis soft as mentioned above. In this operation all the processed flights are stored and kept in the database. By having all the flights with their events and also those in which no event was triggered together it can be defined a wide range of further operational analysis when needed.

3. Statistics:

By collecting a large number of data it can be done when necessary statistics to show the trend of the events. When an event starts to show as a regular basis, corrective actions will be taken by those which have the duty to fix the problem.

After a corrective action is implemented it must be followed to ensure it reaches the desired objective to correct the problem. Statistics will also show if it had the desired result. The Analysis program has a statistics part which allows the just mentioned actions to be followed.

According to European regulations the data are encrypted and de-identified. The data access and security policy is restricting the information access to authorized persons.

When data access is required for airworthiness and maintenance purposes a specific procedure is in place to prevent disclosure of crew identity.

Data access and security policy restrict access to information to specifically authorized persons identified by their position.

The access to the analysis soft database of flight is restricted based on personal identification and password. The analysis program does not contain the data of the flight crew. When analyzed by the FAC the flight data are de-identified, ensuring objective and correct analysis. Findings shall determine non-punitive action.

As already understandable, processing of FDR data enable, issuing a wide range of statistics or graphs, such as the processing results shown in following figures and tables, e.g.:

- Report showing overall total exceedances by fleet during a period, e.g. one month;
- Overall Exceedances by Event Group for an aircraft type;
- Individual exceedences for a specific aircraft type ;
- Report on overall exceedences by phase of flight, for a specific period;
- Exceedences count by aircraft tail number (registration marks);
- Periodical report on top 10 arrival/departure airports by event ratio for an aircraft type;
- Total events of a specific aircraft type month;
- Operational trend analysis.

3. FINAL REMARKS

The flight recorders are some of the many valuable sources of data that can help during an investigation and maintenance.

Especially in modern, electronic aircraft the data gathered can provide vital clues as to faults, maintenance, operations of systems and actions on board.

Effective data collection and processing programs are a significant step towards incident and accident prevention.

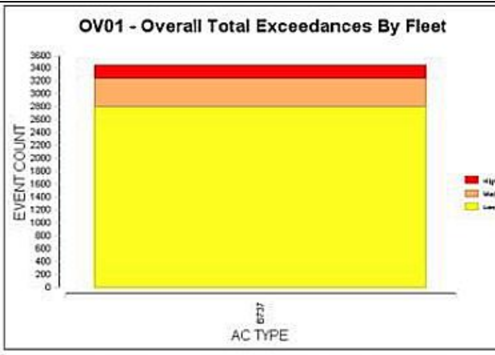


Fig. 13. Monthly report showing overall total exceedances by fleet

	B737
Low Ratio	2.58
Low Count	2810
Medium Ratio	0.399
Medium Count	435
High Ratio	0.191
High Count	208
Number of Flights	1089

Table 2 Overall Exceedances by Event Group for B737 (ref. for fig. 15)

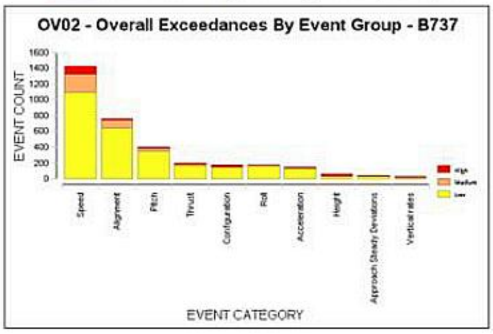


Fig. 14. Monthly report. Overall Exceedances by Event Group for B737.

	Taxi Exceedance in Turn Speed	Delayed Braking at Landing Speed	Climb Out Speed Low (High ALT) Speed	Long Flare Alignment	Long Touchdown Alignment	Pitch Rate High at Landing Pitch	Excessive Bank Angle Above 1000 Feet AFE Roll	Late Thrust Reduction at Landing Thrust	Late Flare Alignment	Late Reverser use at Landing Configuration
Low Ratio	0.342	0.089	0.176	0.117	0.12	0.098	0.109	0.097	0.093	0.085
Low Count	372	97	192	127	131	107	119	106	101	93
Medium Ratio	0.046	0.079	0.0073	0.025	0.017	0.0092	0	0.0046	0.009 2	0.0018
Medium Count	50	86	8	27	18	10	0	5	10	2
High Ratio	0.012	0.054	0	0.0028	0.0028	0.0064	0	0.00092	0	0.0055
High Count	13	59	0	3	3	7	0	1	0	6
Number of Flights	1089	1089	1089	1089	1089	1089	1089	1089	1089	1089

Table 4. Overall exceedances – part 1 (ref. for fig.16)

	Late Rotation Speed	High Acceleration at Touch down Acceleration	Low Pitch Rate at Takeoff Pitch	Deviation below Glideslope below 500ft Altitude Above Field Elevation Alignment	Approach Speed High (Low ALT) Speed	Thrust High on Ground During Taxi Thrust	Short Flare Alignment	Pitch High in Initial Climb Pitch	Taxi Speed Exceedance Off Runway Speed	Pitch Low at Lift Off Pitch
Low Ratio	0.062	0.06 2	0.062	0.066	0.065	0.053	0.046	0.061	0.043	0.04
Low Count	68	89	67	72	71	58	50	66	47	44
Medium Ratio	0.019	0	0.01	0.0046	0.0055	0.011	0.023	0	0.011	0.0055
Medium Count	21	0	11	5	6	12	25	0	12	6
High Ratio	0.00092	0	0	0.00092	0	0.0046	0	0	0.0046	0.0028
High Count	1	0	0	1	0	5	0	0	5	3
Number of Flights	1089	1089	1089	1089	1089	1089	1089	1089	1089	1089

Table 4. Overall exceedances – part 2 (ref. for fig.16)

	Speed	Alignment	Pitch	Thrust	Configuration	Roll	Acceleration	Height	...h Steady Deviatio...	Vertical rates
Low Ratio	1.006	0.597	0.321	0.155	0.132	0.156	0.128	0.031	0.026	0.016
Low Count	1095	650	350	169	144	170	139	34	28	17
Medium Ratio	0.211	0.087	0.035	0.016	0.01	0.0037	0	0.0092	0.0064	0.01
Medium Count	230	95	38	17	11	4	0	10	7	11
High Ratio	0.089	0.0092	0.01	0.0055	0.021	0.0018	0.0018	0.015	0.0064	0.0083
High Count	97	10	11	6	23	2	2	16	7	9
Number of Flights	1089	1089	1089	1089	1089	1089	1089	1089	1089	1089

Table 3 Individual exceedences for the B737 ref. for fig.16)

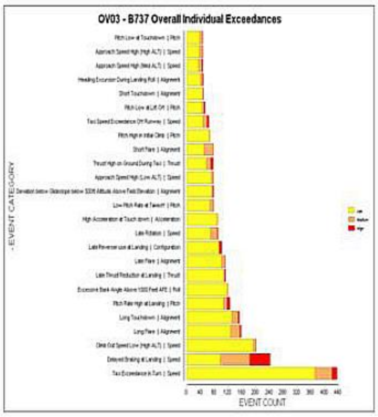


Fig. 15. Monthly Report: Top 25 individual exceedances for the B737

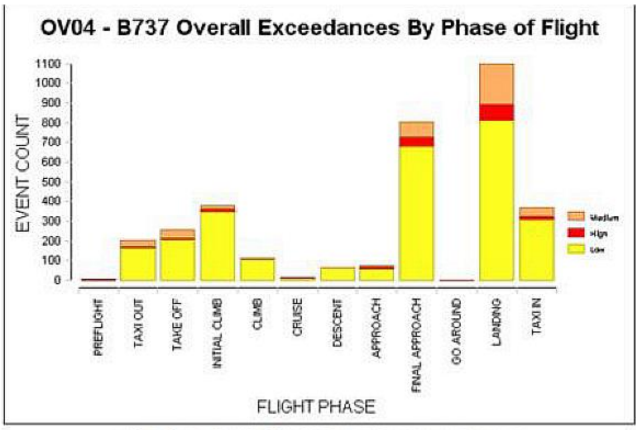


Fig. 16. Monthly Report B737 Overall Exceedances by Phase of Flight

	YR-BGB	YR-BGI	YR-BGD	YR-BGE	YR-BGF	YR-BGH	YR-BGG	YR-BGK	YR-BGJ	YR-BGA
Low Ratio	2.625	2.477	2.553	2.845	2.534	2.271	2.127	2.948	3.299	2.73
Low Count	399	374	337	313	294	293	251	227	221	101
Medium Ratio	0.493	0.358	0.417	0.409	0.302	0.395	0.314	0.519	0.433	0.378
Medium Count	75	54	55	45	35	51	37	40	29	14
High Ratio	0.263	0.185	0.258	0.209	0.293	0.109	0.136	0.104	0.075	0.162
High Count	40	28	34	23	34	14	16	8	5	6
Number of Flights	152	151	132	110	116	129	118	77	67	37

Table 5. Exceedance Count by Aircraft Tail Number (Registration Mark) (ref. for fig. 17)

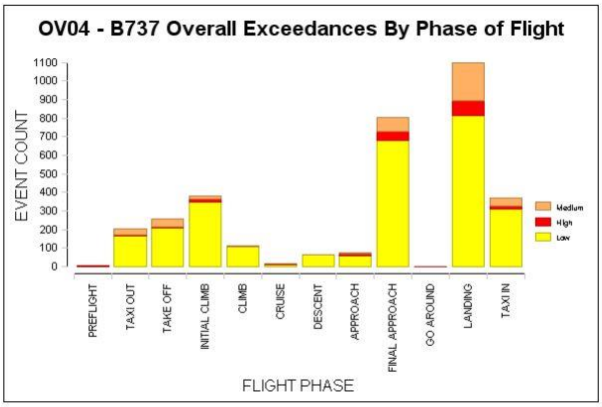


Fig. 17. Monthly Report B737 Overall Exceedances by Phase of Flight.

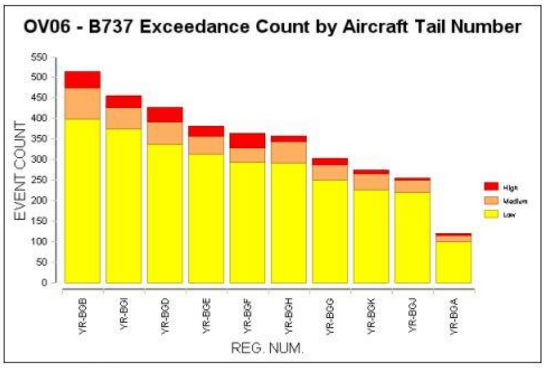


Fig. 18 Exceedance Count by Aircraft Tail Number (Registration Mark)

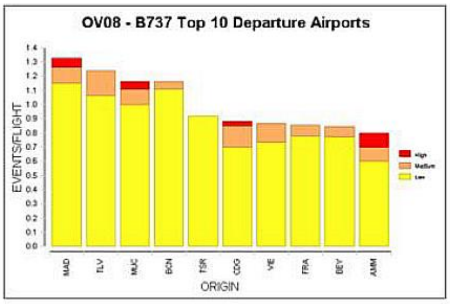


Fig. 19. Example of Monthly Report: B737 Top 10 Departure airports by event ratio.

	MAD	TLV	MUC	BCN	TSR	CDG	VIE	FRA	BEY	AMM
Low Ratio	1.147	1.059	1	1.105	0.917	0.697	0.733	0.778	0.769	0.6
Low Count	39	36	56	21	11	23	22	42	10	6
Medium Ratio	0.118	0.176	0.107	0.053	0	0.152	0.133	0.074	0.077	0.1
Medium Count	4	6	6	1	0	5	4	4	1	1
High Ratio	0.059	0	0.054	0	0	0.03	0	0	0	0.1
High Count	2	0	3	0	0	1	0	0	0	1
Number of Flights	34	34	56	19	12	33	30	54	13	10

Table 7 Example of Monthly Report: B737 Top 10 Departure airports by event ratio.

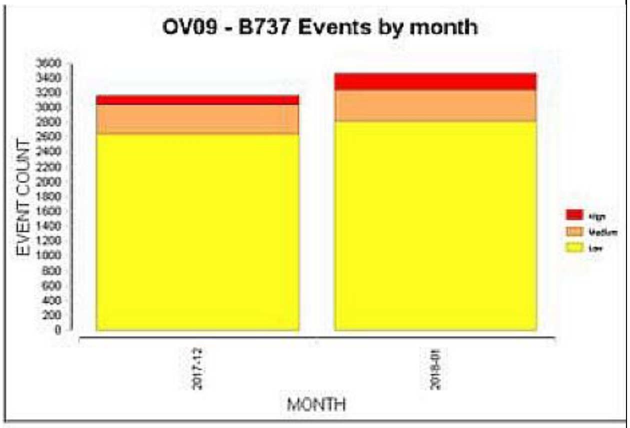
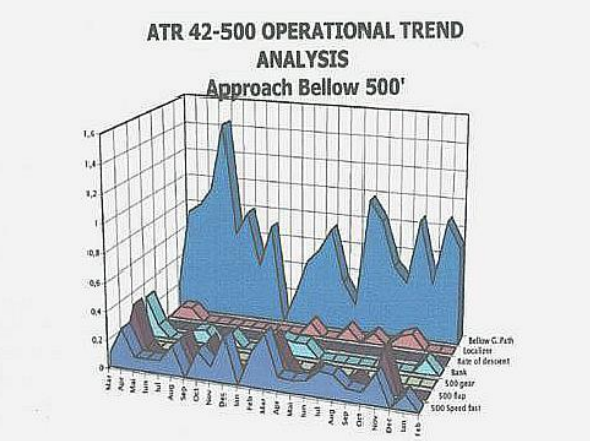


Fig. 20 Example of Monthly Report: B737 total events by month.

	2017-12	2018-01
Low Ratio	2.487	2.58
Low Count	2649	2810
Medium Ratio	0.362	0.399
Medium Count	386	435
High Ratio	0.117	0.191
High Count	125	208
Number of Flights	1065	1089

Table 8. Example of Monthly Report: B737 total events by month. (ref. for fig. 20)



ATR50003 08/03/07

ATR 42-500 OPERATIONAL TREND ANALYSIS
APPROACH BELOW 500'

Month		02-06	03-06	04-06	05-06	06-06	07-06	08-06	09-06	10-06	11-06	12-06	01-07	02-07
No.of flights		845	1046	953	1096	1010	1135	1208	1176	1234	927	710	819	867
Speed fast	no	2	4	1	1	1	2	2	1	1	2	0	1	0
500 feet	pct	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.0	0.1	0.0
Flap	no	1	3	1	0	1	1	0	1	0	3	0	0	0
500 feet	pct	0.1	0.3	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.3	0.0	0.0	0.0
Gear	no	0	0	0	0	0	0	0	0	0	0	0	0	0
500 feet	pct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank	no	1	1	1	0	0	0	0	0	0	0	0	1	0
Below 500'	pct	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Rate of Descent	no	0	0	0	0	0	0	0	0	0	0	0	0	0
Below 500'	pct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Localizer	no	0	1	0	0	1	0	1	0	1	1	0	0	0
Below 500'	pct	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0

Fig. 21 Example: Operational trend analysis

The benefits of proactive data use in terms of both safety and cost guarantee its future development. In addition, technological advancements will continually change the aircraft and cockpit environment and create a greater reliance on data during an investigation. Information previously obtained through interviews is now stored on disk drives, computer cards, and portable units. Investigation and data gathering techniques must constantly be improved to keep abreast of technology.
Data provided by devices enabling recording facilities on-board aircraft, raw and processed, including resulted data bases are very useful during entire life of the aircraft from research, designing board, over testing, operation, maintenance, and upgrade and scraping. Data needs to be used and stored to avoid damage or misuse. Modern aircraft, their systems and powerplants, as well as air navigation facilities, testing, operation and maintenance facilities enable a wide range of records. Those records support several activities:

- Storing / transmission of data for operational, maintenance or engineering analysis;
- Statistics of different phenomena, operational issues, technical issues, supporting operational and engineering analysis and decisions.
- Design data;
- Maintenance,
- Creation of device data bases enabling autonomous operation of devices;
- Checking of the flight route / trajectory in-flight or afterwards;
- Safety investigations of severe occurrences, accidents and incidents or their precursors;
- Validation of numerical models by correlating results with real life data

Flight data records used in civil aviation require protection according to regulations such as:

- Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation;
- ICAO SARPs for routine operations in ICAO Annex 6 and ICAO Annex 19;
- ICAO SARPs for in safety investigations are defined by ICAO Annex 13, the ICAO Doc 10053, Manual on Protection of Safety Information and ICAO Annex 19.
- Legal provisions on classified documents, as applicable for confidential professional information.

This paper is intended to inform research, manufacturing, operation and SIA (Safety Investigation Agency) specialists about the large amount of available data, provided by flight recording devices, which, if properly processed, enable major technical improvement, increased flight safety and avoidance of severe occurrences, accidents and incidents, being the second of a papers series, deemed to brief the interested specialists on developments on safety data.

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Shortt-Synchronome Time synchronization in distributed data collection systems- an old solution to a new problem

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Abstract: *Distributed data collection systems are often, in practice, heterogeneous constructs using various technologies or combining equipment of different manufacture and/or vintage. Synchronization of the various autonomous or semi-autonomous data acquisition subsystems (called "nodes" in the specialty literature) is crucial whenever analyzing time-variant correlated signals or whenever measurements involving durations of time or timed responses appear. Because of the structure of such systems, a mechanism to generate, distribute and coordinate permanently all subsystems by generating unified clock pulses might not be practical. The solution is to use a form of distributed architecture with the added task to synchronize all clocks of all the nodes so that collected data is coherent and proper measurements involving frequencies, timed responses and simultaneity can be conducted. The Shortt-Synchronome system was first used in high precision scientific electric pendulum clocks more than a century ago but allowed for accuracies of 200 microseconds per day, that is approximately one second every 12 years. The paper discusses a modern implementation of the concept using a low data rate logical signal to correct or correlate clocks in distributed data collection nodes.*

Key Words: *Shortt-Synchronome, precision timing adjustment, hit and miss synchronizer, distributed data acquisition systems, cost-effective GPS disciplined oscillator (DO)*

As hybrid and distributed systems for data acquisition and process control are increasingly implemented due to their modularity, flexibility and robustness, the problem of dissimilar subsystems that need to be synchronized to a common time reference also gained importance.
Many solutions to this problem exist, and while all implement robust synchronization algorithms, most bring along unwanted complexity in an already complex and crowded communication protocol that must unify all dissimilar subsystems or nodes.
The centralized architecture is an early answer to the problem, with a central clock generator that drives the operation of all the tightly integrated subsystems in a monolithic system. All subsystems use the master clock as an input and time all their operations with this centralized signal. Such systems are necessarily complex as circuitry must consider delays and characteristics of each signal and design the shortest signal paths for the timing signal to ensure synchronicity.
This architecture while high performance and highly integrated, is expensive and not flexible at all. Modern systems need to be able to adapt to new requirements all the time and in some cases several configurations are used in the same experiment, merely days or hours apart.
Some devices are to be embedded in wind tunnel models or placed near the installation while others can be closer to the control room for example.
All equipment is required to function semi-autonomously and be able to record time-stamped and correlatable data. The modern solution to synchronizing independent, heterogenous and distributed data acquisition modules is of course phase-lock-looping the clocks to a master.
In its most modern implementation, a phase-locked loop is digital, with timing pulse length of a slave clock adjusted as the error signal comparing its phase to the master clock arrives at the input.
Earlier analog systems comprised a voltage-controlled oscillator governed by a command signal resulted from filtering its output and feeding it to a phase comparator that was connected to the master clock. Even earlier than that, the Shortt-Synchronome system of high precision pendulum regulator clock implemented an electromechanical form of an analog phase-lock loop around 1920.
The principle uses two oscillators, one master and one local lower precision one that is to be periodically corrected by the control signal.
Independently of the physical substrate the synchronization is acquired by adjusting the free (natural) period of the slave clock(s) with the required error signal to bring them in step with the master clock.

OPERATING PRINCIPLE OF THE SHORTT-SYNCHRONOME PRECISION CLOCKS (SSC)

The SSCs use two pendulums to keep accurate time: a normal precision pendulum that acts as a slave clock, having an auxiliary mechanism that generates impulses every 30 seconds, impulses a second, high precision, free swinging master pendulum. This pendulum had no other mechanism and after it was impulsed using the same mechanism that applied the impulse to close a set of electric contacts to relays connected to the gravity arm , generated a pulse that was applied as a phase correction to the slave pendulum. Whenever the slave pendulum lagged, it would receive a correction impulse from the master pendulum. The electric contacts and electromagnets shifted the forces from the pendulum to the electromagnetic armatures, minimizing interactions and keeping the free-swinging pendulum as disconnected as possible. The slave pendulum had a naturally adjusted losing rate (it did swing a little slower than the master pendulum) so that the correction would restore the precise rate for a good long-term stability. Corrections were applied by a so-called hit and miss synchronizer- a device that compared pendulum phases. By adjustment, the cycle of impulsing and not impulsing the pendulum would alternate, hence the name hit and miss.

A hit was a correction that needed to be applied by impulsing the slave pendulum to restore correct rate, while a miss was when the phase difference between pendulums being too small and the arm applying the correction would miss the impulse pallet and therefore leave the slave pendulum rate unaffected. This cycle ensures long term stability and was the first implementation of a phase locked loop in timekeeping devices.

MODERN COUNTERPARTS- THE ELECTRONIC PHASE LOCKED LOOP CIRCUITS

The problem with modern digital PLLs is that data throughput is continuous and intensive. Moreover, it is a system that if poorly implemented, acts more like a direct control of the local oscillator(s), that leads to a lower autonomy for the distributed system and a performance and cost penalty. The way it was implemented around 100 years ago has some unforeseen benefits: it allows various subsystems to adjust their error between known limits, just like a modern PLL clock driver does, but left data throughput at a minimum, and checks and adjustments were made less frequently. This way the autonomy of each subsystem increases, and the needed timing data throughput is reduced while the precision requirements for the local clocks are not dramatically increased. The master clock can be, for example, an integrated caesium fountain IC such as the Microsemi CSAC SA 45.S. This miniature apparatus is a chip-scale atomic clock comprised of a cesium-gas filled resonant cavity excited by a VCSEL (vertical Cavity Surface Emitting) laser diode. A sensitive photodetector on the other end of the resonant cavity completes the circuit.

The best economical solution is to use decent quality clocks on all data acquisition subsystems such as their clock drift for the duration of the test is not larger than one second. Pulses from a GPS receiver can double as a prime source for timing signals in a master clock for laboratory use. A lower cost but good enough precision oscillator can be built using the "disciplined oscillator" paradigm": a reasonably low drift but conventional quartz stabilized VCO (Voltage Controlled Oscillator) has an adjustment input that is driven by a high precision source: either a timing GPS signals, a chip scale atomic clock PPM synchronization pulse or a combination of the two to account for bad GPS reception or GPS-denied environments (deep underground or hostile space with GPS jamming). In this paper I analyze the possibilities of a very cost-effective off-the-shelf master clock reference and timing system using the DO (Disciplined Oscillator) paradigm.

The master clock structure is comprised of a GPS (positioning type, as timing GPS are prohibitively expensive), a controller interface to extract the timing signals and generate the 1PPS (1 pulse per second) timing square wave for synchronizing the other devices, and a primary TCXO oscillator (thermally compensated quartz oscillator) in the shape of a DS 3231 real time clock IC.

This IC includes the quartz crystal and is capable of thermal compensation for the oscillator period. he RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Address and data are transferred serially through an I2C bidirectional bus.

MODERN TYPES OF PRECISION TIMING DEVICES

A typical GPS of the positioning type variety, such as the UBlox Neo-6 M still has the capability of outputting highly accurate 1 pulse per second synchronization signals (square wave with deviations no larger than 30 ns

from UTC). While low frequency, these pulses can be used to drive most sync enabled data acquisition devices using clock pulse length internal error compensation (clock tick is adjusted until the new clock rate is achieved). Using this system one can expect high temporal coherence (better than 30ns for systems designed for PPS SYNC) once the system has settled. The NMEA GPS "propositions" are strings of specially formatted ASCII data that any GPS receiver generates after a summary processing of raw satellite data. It typically includes the starting character $, a type code, the current time, a latitude and longitude N and E , GPS fix, number of satellites being tracked, horizontal dilution of position, receiver altitude in meters, the reference geoid height above sea level , time from the last update, station number and a checksum. The components of the proposition are in the form of a comma separated string to be easily parsed by computer or microcontroller.
A basic GPS time reference architecture uses a GPS receiver tied to a microcontroller. The microcontroller parses the NMEA proposition and extracts the time portion of the signal. A time signal is then generated by outputting the decoded time in ASCII format over serial, for example or by incrementing a counter for each clock tick. More advanced systems make use of the modules that process this internally and output a highly precise 1 PPS pulse – a 100 ns square pulse of configurable polarity with a 10% fill factor. Rising edges mark exactly one second. Commercial solutions use an oven-controlled oscillator that is corrected and a multiplier that uses the 1 PPS pulse to generate a 10 MHz pulse (another typical frequency standard).

THE SIMPLEST DIRECT-READ GPS CLOCK

It is built with a GPS receiver and a microcontroller of some kind and offers direct readout of time and a good precision. Its granularity is high and has an added software jitter component of 20-30 ns. Pulses are also delayed by approximately 460 ns – an offset introduced by NMEA proposition processing.
Initially such a system processes the NMEA data packets and extracts UTC time and date, applies corrections and loads /outputs the results over a 9600 baud serial line (or UART).
In total, after achieving GPS lock this first sync and processing takes approximately 465 to 485 ms on a typical ATMEL 328P microcontroller. After this processing time is spent, the microcontroller can output pulses to count for the next cycle, but operation is in bursts and has a variable (jitter) component due to slight variations in NMEA proposition processing time.

A BETTER SOLUTION: GPS DISCIPLINED OSCILLATOR WITH AN RTC

The next tier just above the direct readout GPS clock uses a real time clock module that only checks on the primary oscillator once every 30 seconds for example, reducing clock jitter and phase noise. A real time clock, using for example a temperature compensated crystal, is used to keep time and generate timing pulses. Every 30 seconds (or at an adjustable but not too short interval), time registers are overridden and written into by the GPS clock. Long term stability is improved in detriment of short time stability. Such devices can easily reach errors of 10^-12 seconds per year. This solution is preferred in technical applications as it is easily implemented and robust.

THE BEST VERSION YET: THE MODERN SHORTT-SYNCHRONOME

Using the same components as the previous solution, a GPS receiver (a timing receiver is best suited) and a RTC with a high quality oscillator (OCXO for example) we can easily improve the performance by adopting a hit-and-miss synchronizer style device- either software simulated or hardware implemented. The hit and miss synchronizer from the days of yore decided if the freely oscillating master pendulum received an impulse or not (correction of rate) basically if the amplitude of its oscillation dropped below a certain threshold every 30 seconds. Whenever this was the case, a rate increase was implemented by impulsing the pendulum from the slave device. The master pendulum itself kept time and generated the necessary pulses to correct the slave pendulum period.
In the modern approach, the master oscillator is a precise, timing grade GPS receiver that generates the 1 PPS sync signal. A slave oscillator in the guise of a real time module has a temperature compensated or better oven-controlled oscillator that is used for general timekeeping.
Every 10 seconds a synchronization check is conducted by the included microcontroller and corrections applied if drift error is greater than a millisecond (or other programmable user-defined value within the range of 100 ns up to a millisecond).
If this is the case, the RTC is set to the time indicated by the GPS receiver and correction pulses are applied to the PLL oscillator for the high frequency reference.

OTHER VARIANTS

Historically, the high precision SSCs were superseded by quartz standards and then very quickly afterwards by the cesium beam or fountain clocks (atomic clocks) in the US but in the UK the Observatory relied on a mean of several clocks both in and out of the premises for a better long term stability and lower expenses (as well as less complicated maintenance) effectively establishing the statistical timekeeping.

TIME SYNCHRONIZATION IN CURRENT DAY DISTRIBUTED DATA ACQUISITION SYSTEMS

Contemporary DAQ systems usually have two different paradigms for clock sync: the central synchronization protocol with a master clock that is physically wired and transmits timing pulses to all networked subsystems ; and distributed synchronization protocols that implement a type of disciplined local precision oscillator and time corrections, usually via network.

From the latter category we can name the ubiquitous NTP protocols and for the first, its precision counterpart, PTP and other interesting implementation variants such as EtherCat timing and even the White Rabbit Protocol that implements sub-nanosecond precision over PTP.

The Precision Timing Protocol requires dedicated hardware such as a designated master clock and slave clocks usually connected by PTP aware switches, and a root sync clock called a "grandmaster clock" that synchronizes all master clocks on the network.

Other subnets may be connected by means of the so-called "frontier clocks" that interface between master clock domains. Apart from EtherCat that is somewhat decentralized with master and slave exchanging places as needed and data packets that are doubly stamped by master and receiving slave and again by master at return to calculate delays, all other distributed timing protocols use a layered structure. Both NTP and PTP have levels of assumed clock precision or strata as they are called.

The lowest stratum -stratum 0 – is normally reserved for an atomic or GPS clock with a high precision oscillator as a secondary carryover source.

For installations where GPS reception is poor or unreliable the PTP protocol is used – with supplemental importance given to the grandmaster clock as it takes over the stratum 0 duties.

It is noteworthy that apart from hardware details the basic principle of time stamping, comparing, and compensating by delay or setting is the same. Basically, the master clock issues the timestamp on data packets that the slave clocks respond to by restamping them and sending them back. In the assumption of symmetrical forwards and back data routing the roundtrip is estimated and if greater than a given value, the time is either compensated by signaling delays or by overwriting (setting) the slave clocks ; the process is repeated until a good synchronization is acquired.

A SIMPLE PRECISE STRATUM 0 TIME REFERENCE FOR EASY SYNC

The main components of the simple stratum 0 time reference are: a real time module, a GPS module and a controller with a display. The operating principle is the oscillator to be disciplined is a temperature compensated RTC module.

Time is set at start using GPS reference timing signals when available, by decoding NMEA strings/propositions. If GPS is not available, time is to be manually input (set) and with the first occasion it should be synced with GPS. The RTC module outputs a good accuracy 1PPS signal that is useable to build a data sync system.

Each minute the process is repeated whenever in GPS friendly environment. The NMEA decoding is taking approximately 450 nanoseconds on an Atmel 328P microprocessor and the lag can be compensated by adding the time error for the conversion to the readout time.

The time value is loaded in the RTC memory and after this step it can take over the timekeeping functions. The periodic adjustment routine can intervene less and less often as differences between RTC time and GPS time are reduced so that in the end a mean accuracy of about 500 ns is possible.

Of course, more advanced architectures and precisions up to 1-2 nanoseconds exist and even sub-nanosecond sync rates are possible, but they require exceptional dedicated hardware. For most measurements, a 500 ns accuracy is considered excellent [3].

Further development resulted in the configuration presented in this paper, using a non-interruptible 1PPS source generated by a temperature controlled RTC TCXO that is periodically adjusted at dynamic intervals.

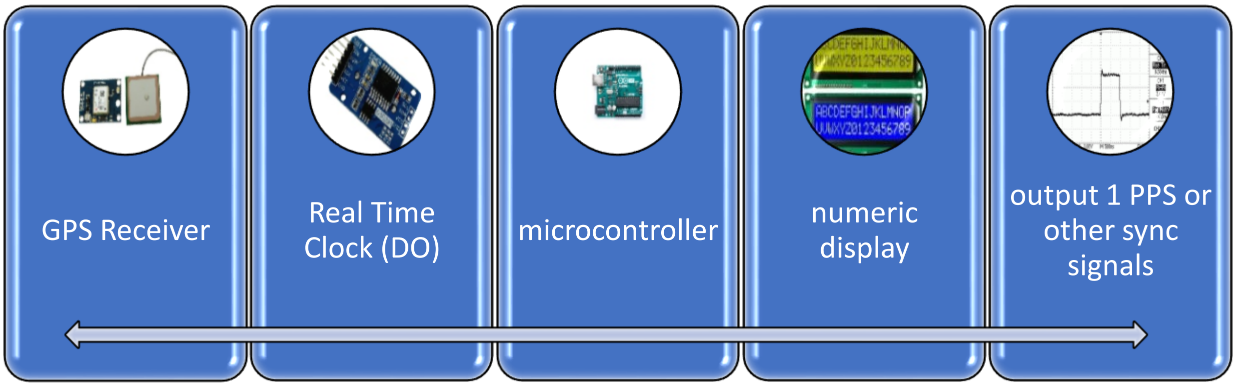

Figure 1. Basic elements of a GPS disciplined oscillator: from left to right, the GPS receiver with its antenna, the real time module, the microcontroller, the numeric display and the 1PPS output.

The operating algorithm for a simple GPS DO is as follows (figure 2):

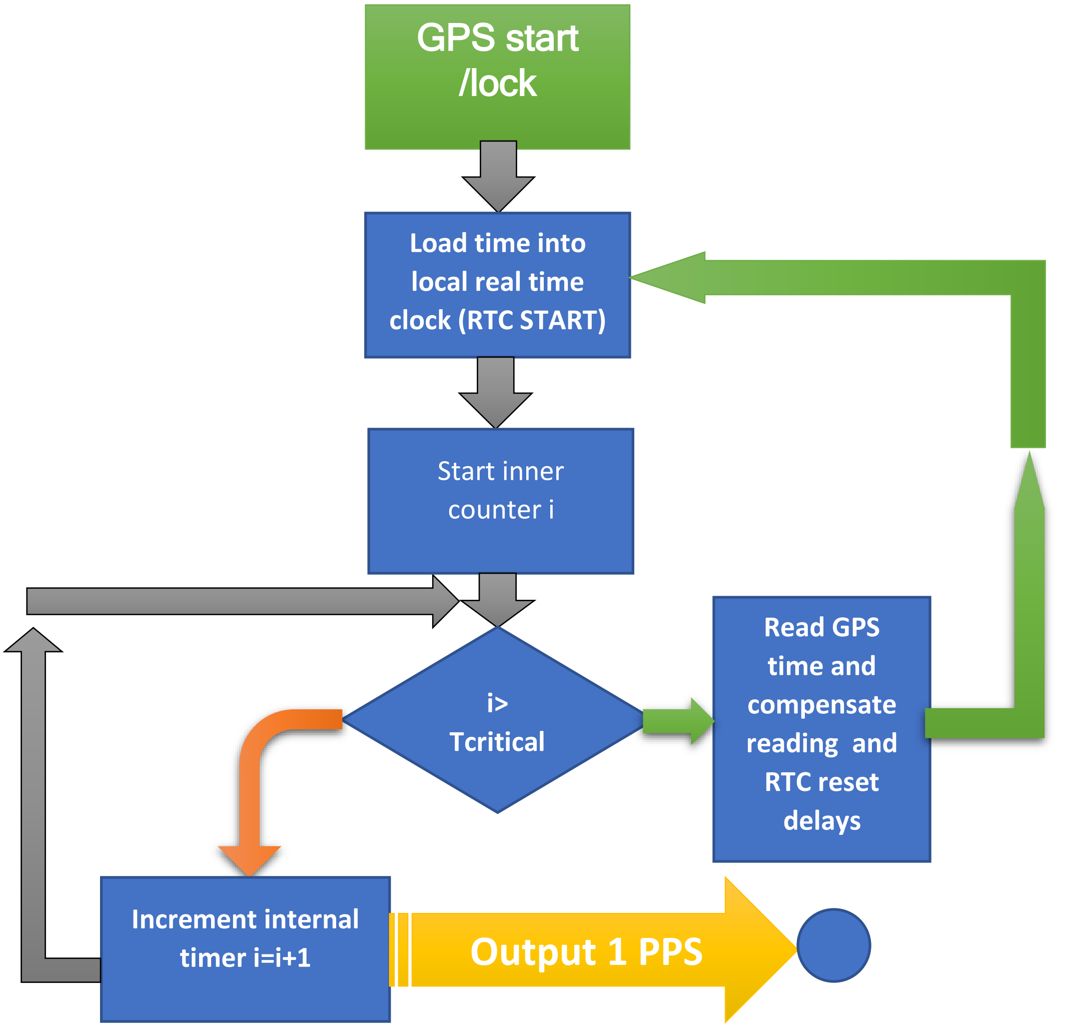

Figure 2. The basic functioning of a GPS -DO standard version. The long-term stability of the clock is ensured by periodic resets of the RTC and appropriate compensation for the reset time, load time and NMEA parsing/GPS data reading.

While there is nothing inherently wrong with the structure presented in Figure 2, an optimized algorithm first checks if the accumulated RTC error justifies the correction procedure. This correction procedure is time consuming and it can lead to pauses in the 1 PPS signal as the RTC is reset. The pauses are however in the hundreds of milliseconds range as the normal 1 PPS signal from the GPS module is stopped whenever there is no fix and the RTC stops also during resets. Expected precisions are in the range of plus or minus 10 nanoseconds delay or advance to each GPS second. Sync times between two similar units have been found to be under 30 ns once both have a lock on. An improved version is shown in figure 3, and its main difference is the inclusion of an error checking mechanism- the GPS is questioned periodically and the error between RTC and GPS is compared but not at a fixed time length but at varying intervals that consider the error value and keep it steadily under a predetermined value.

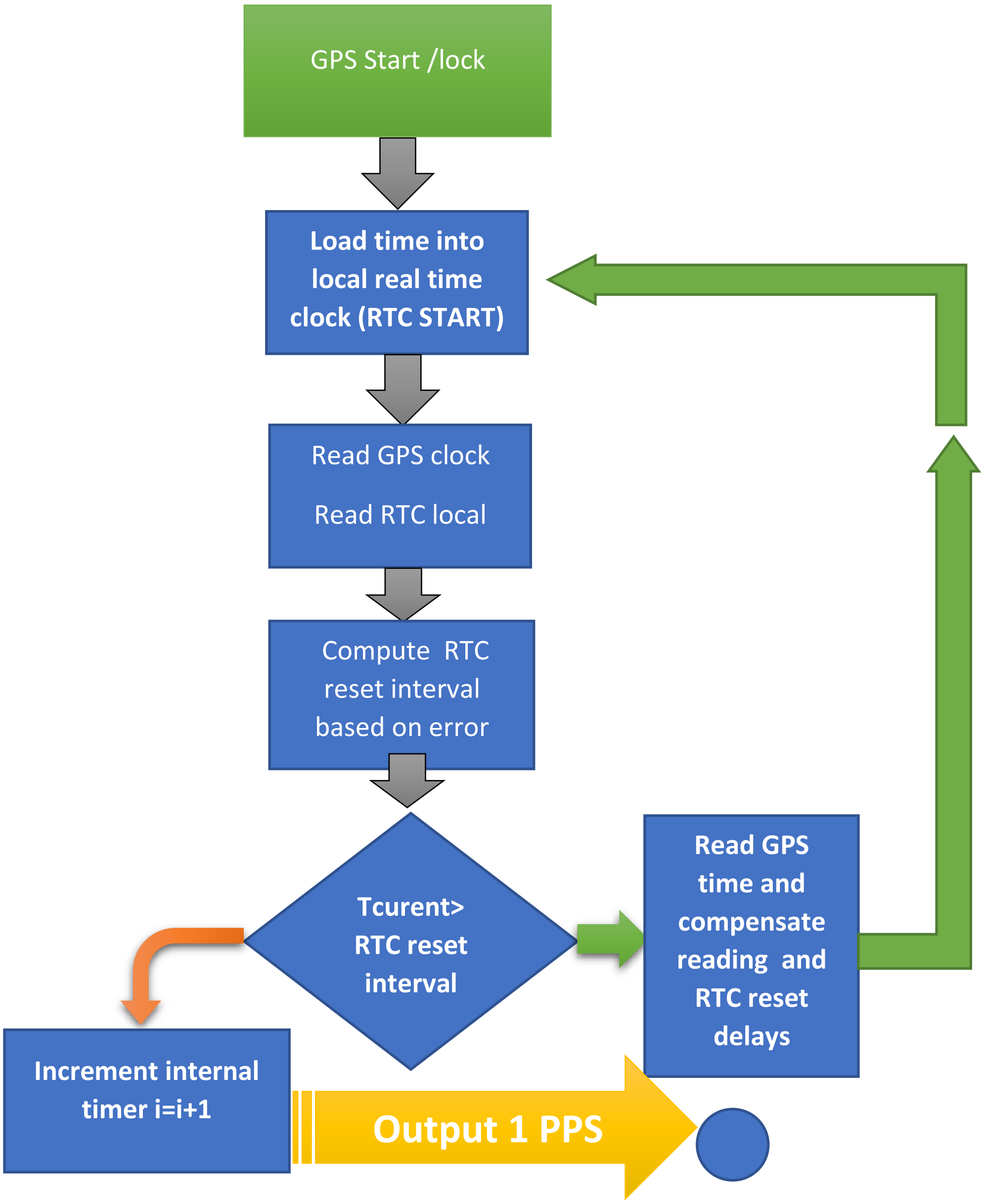

Figure 3. The improved functioning of a GPS -DO, Shortt-Synchronome digital equivalent. The long-term stability of the clock is ensured by aperiodic resets of the RTC and appropriate compensation for the reset time, load time and NMEA parsing/GPS data reading. The time intervals to reset the clock are chosen as a function of the error value.

TIMING PERFORMANCE AND PARAMETERS

Clock Synchronization Terminology

Offset, Skew, and Drift Section 10 of RFC 2330 Framework for IP Performance Metrics (and by reference RFC 1305) defines clock offset to be the clock's reported time Terminus true time Tt, with true time in the world of IP being UTC. Clock errors are defined as the short- or long-term deviations from a theoretical "true time" that is practically inaccessible. In theory though, if we consider a certain timing device of sufficient enough precision to substitute for the true time then we can compare the clock under test to this "real time reference" and establish its errors. One important observation is that timing errors are divergent, as no clock is naturally stable and despite various compensation techniques used, the time measured by the clock under test will drift (as we call th deviations) or wander.
Each high precision disciplined oscillator has a varying error, and its value improves after a while. The explanation for this peculiarity is that initially there is no GPS lock; after finding it and settling, the cycle of corrections and compensations stops being repeated so often and in the end normal performance is reached (when errors are to be corrected at increasing time intervals up to the hardware stability limitations).Figure 4 shows the clock error variation and the effects of compensation.

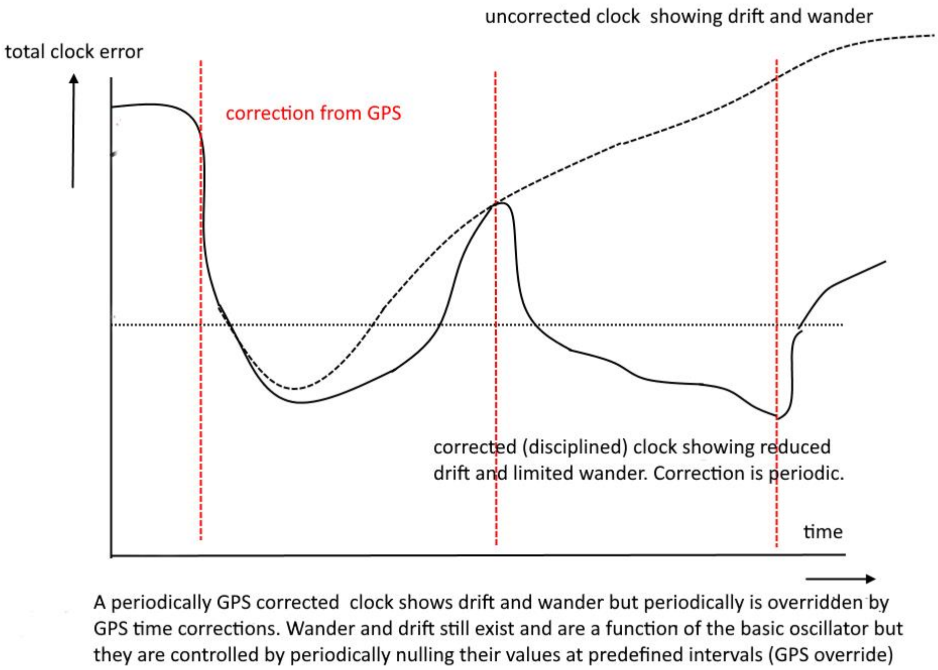

Figure 4. The simplest DO (Disciplined Oscillator) is a periodically corrected oscillator. At pre-established intervals time is read from the GPS device and overrides the existing local oscillator time. Errors are reduced to the time it takes for the GPS time to be decoded and the time it takes to reset the local RTC (real time clock).

The analysis of the errors in figure 4 shows such a DO still has the basic oscillator's native drift and wander, and while it is periodically reset to real time plus write./reset time that has to be compensated (200 ns plus some additional 10 ns for reset) it shows sufficient variation to be considered short-time relatively unstable. For longer periods the error averages out but on shorter intervals a better solution is required. A better oscillator and a smarter, error-value dependent correction logic (a P controller) offers a better control on both short- and medium-term precision. Figure 5 shows the error evolution for the improved solution.

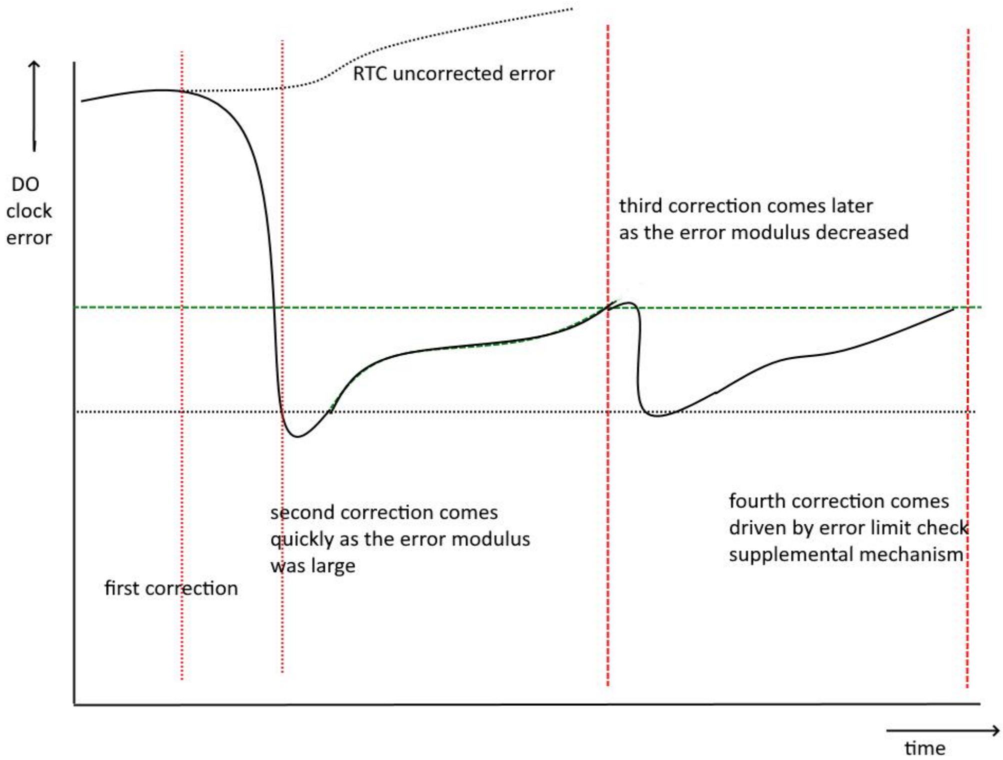

Figure 5. A proportionally disciplined oscillator shows increasing delays in GPS timer check/ RTC overwrite cycles as error is reduced. Supplemental error bound checks are implemented to ensure short time performance

ANALYTIC ASPECTS OF PRECISION TIMEKEEPING

A clock is a time measuring device comprised of an oscillator (as precise as practical) and counter-accumulator of some sort. Clock precision is a matter of frequency stability of the internal oscillator [1].
A sine signal is the best representation for a frequency discussion- it is elementary and moreover, any type of waveform can be well approximated by summing various sinusoidal signals (the superposition principle, and the basis of Fourier analysis and signal synthesis). So, let us consider an electrical signal with voltage given by (1):

$$V(t) = [V_0 + \varepsilon(t)]\sin[2\pi f_0 t + \varphi(t)] \tag{1}$$

where: V_0 *is the nominal peak output voltage*
$\varepsilon(t)$ *is the amplitude deviation*
f_0 *is the nominal frequency of the signal*
$\varphi(t)$ *is the phase deviation*

From all these terms, $\varphi(t)$ is of special interest for frequency stability. For a high precision oscillator, we define the instantaneous frequency as the derivative of the total phase, described by the following equation (2):

$$f(t) = f_0 + \frac{1}{2\pi}\frac{d\varphi}{dt} \tag{2}$$

and the fractional frequency y(t) described by equation (3) below:

$$y(t) = \frac{\Delta f}{f} = \frac{f(t) - f_0}{f_0} = \frac{1}{2\pi f_0}\frac{d\varphi}{dt} = \frac{dx}{dt} \tag{3}$$

From (3) we get an expression for the phase error x(t)

$$x(t) = \frac{\varphi(t)}{2\pi f_0} \tag{4}$$

Frequency stability uses time series from the phase error $x(t)$ indexed as xi and fractional frequency error $y(t)$ indexed as yi where the "i" index indicates the sample number.

NOISE MODELS FOR OSCILLATORS

Noise in clock type oscillators is best described by its spectral density of the fractional frequency fluctuations (3) [2]. Long term observation has arrived at a power law type equation, dependent on frequency and a classification was made to differentiate the noise types. Equation (5) describes the spectral density of such fluctuations:

$$S_y(f) = h_\alpha f^\alpha \tag{5}$$

with f = the Fourier frequency for the noise component
h_α = amplitude coefficient for the type of noise described
α= power law coefficient that describes the noise type.

We thus discern for α=-2, white power modulation, α=1 ,flicker power modulation, α=0 -white frequency noise, α= -1 describes flicker frequency modulation, α= =-2 shows random walk frequency modulation, α= -3 describes flicker walk frequency modulation and α==-4 models the random run frequency modulation.
Instability in clock oscillators can be best described by a sum of terms described by equation (5) and further characterized by parameters such as the overlapped Allan variance and single sideband phase noise. This set of tools is particularly useful in comparing precision oscillator performance [2].
Currently the author's GPS-DO is undergoing testing and evaluation, by comparison with a NTP client form Meinberg A.G., installed on the laptop and running 1 second update cycles for consistency with the time refresh of the GPS unit.
The GPS-DO built for this work comprises a 8 bit ATMEGA 328 Prn microcontroller with 32 Kbytes of memory, running at 16 MHz, a two line 16X2 backlit dot matrix display , a NEO -6M V2 positioning type GPS with an integrated patch antenna, and a Dallas Semiconductors DS 3223 high precision real-time clock with a temperature-controlled, integrated crystal capable of excellent short-time stability. The long-time stability is ensured by the GPS unit retrieving timing data.
A schematic for the GPS DO is given below in figure 6.

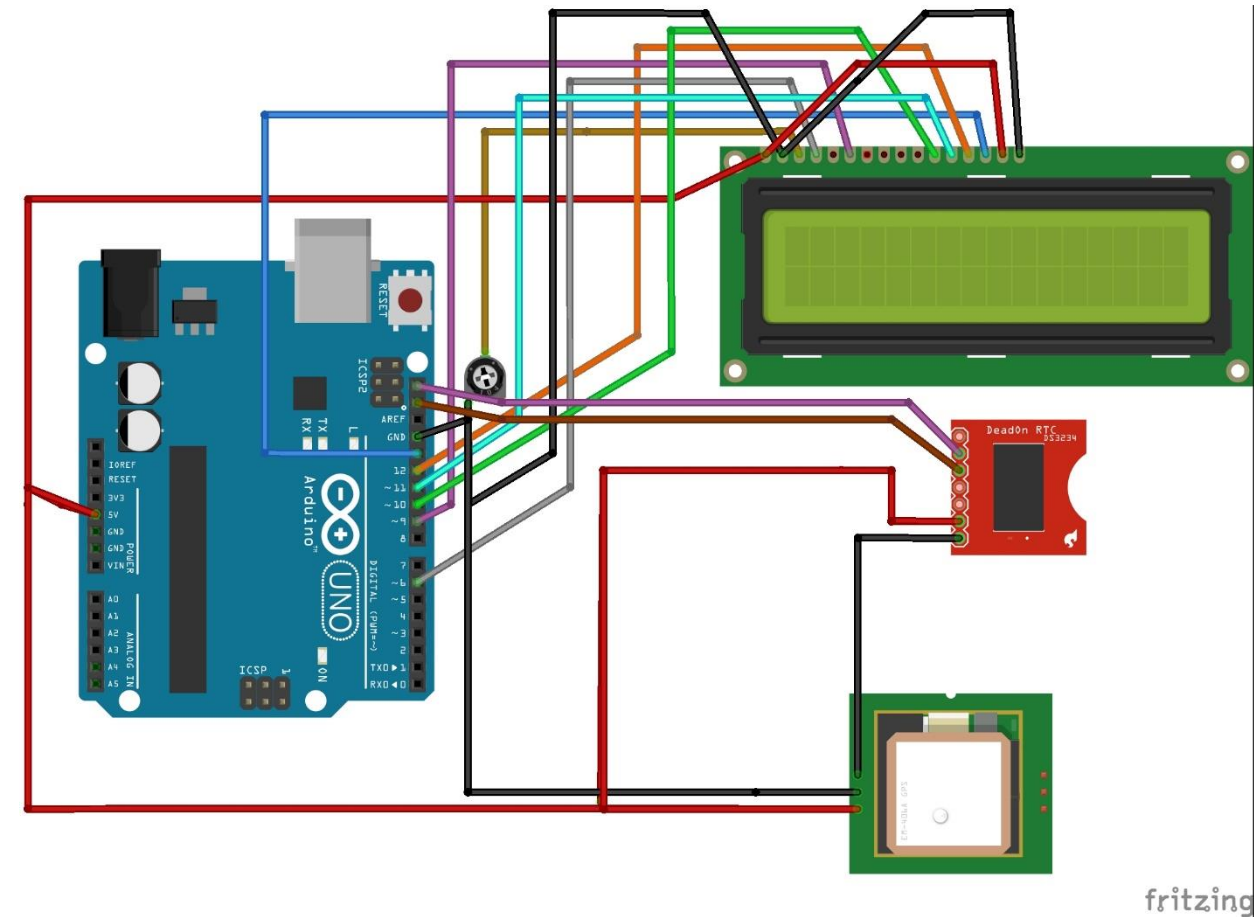

Figure 6. The GPS disciplined oscillator presented in [3] was modified to include a real time clock backup that also works as a GPS hot start.

At the moment of this paper's presentation, long term stability measurements for clock real-world performance are under way.

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