MAS-Lab
Multipurpose Aircraft Simulation Laboratory

PROJECT FINAL REPORT

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1. Final publishable summary report

1.1. Executive summary

MAS-Lab (Multipurpose Aircraft Simulation Laboratory) is intended for use as a generic aircraft model by the Clean Sky – System for Green Operation – Consortium, within a mathematical optimization tool, to develope technologies to reduce emissions of (CO2, NOX) and noise in the way the aircraft manages its trajectory. MAS-Lab is a software tool implementing the flight dynamic models for three different aircrafts: a civil commercial mainline, a regional aircraft and a business jet. It is intended to be a tool for:

- flight trajectory optimization and validation;
- trajectory guidance functions validation, when purposely interfaced to a simulator environment (Airlab),

according to the Clean Sky intendments. It is supposed to be integrated and run in a MS Windows XP Operating System, sharing processing resources with other applications. Quasi real-time and accelerated functioning are both contemplated.

MAS-Lab major component are:

- Simulated Air Vehicles
- Simulated Automatic Flight Control System.

MAS-Lab is supposed to be interfaced with:

- the Airlab components, encompassing the Flight Management System (FMS), the Flight Control Unit (FCU), the Radio Management Panel (RMP) and the Cockpit (sidestick/yoke, pedals, gear extension/retraction commands, secondary surfaces control surfaces such as flaps, slats and airbrakes)
- a separately procured Environmental Impact Model
- a separately procured Atmosphere Model
- a separately procured Sensors model

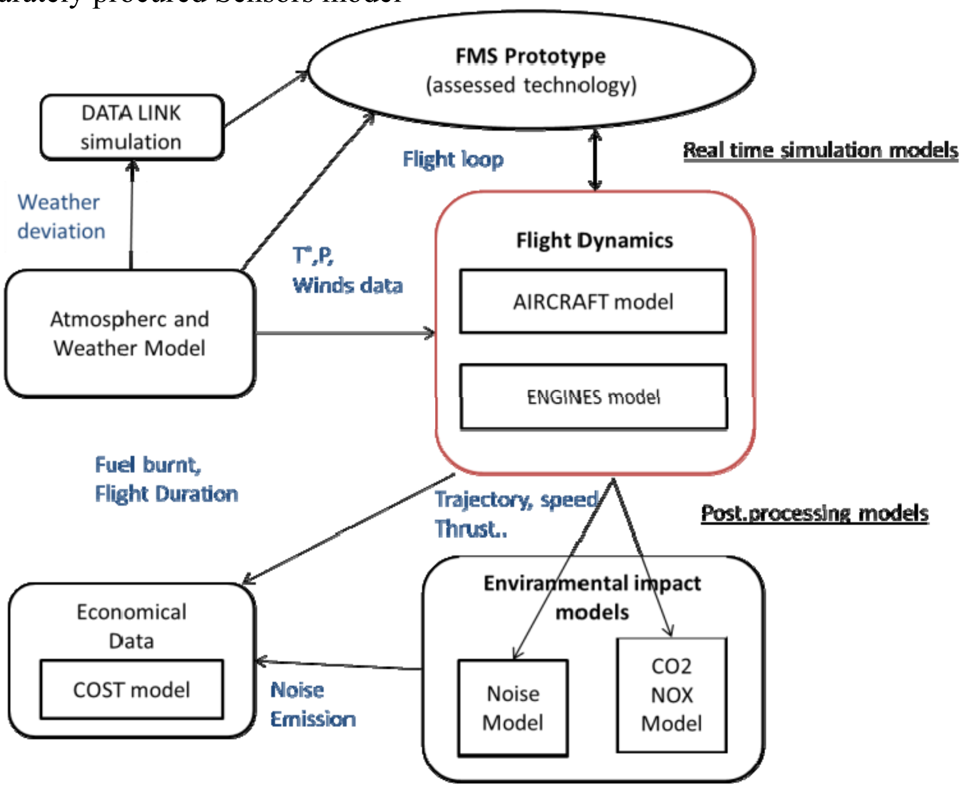

Figure 1- MAS-Lab integration plan

The three aircraft models are related to:
- Boeing 747-100, in the large aircraft category;
- ATR 42-500, in the regional turbo-prop category;
- Cessna Citation CJ3; in the business jet category;

Moreover, the possibility of developing a simplify model to be parameterized as a generic aircraft model has been investigated.

1.2. Summary description of project context and objectives

The tendency of the past to build and test in aeronautics has clearly been overridden by a very extensive simulation activity for many reasons, one of these being the risk associated to safety-critical or safety-related systems. Simulation is hence strategic to develop and test all the key aircraft elements, such as flight control systems, and is now being used effectively also beyond the design purposes, to conceive and evaluate mission strategies, for example, Humane-Machine-Interfaces or operational procedures. During the last decade, many commercial simulation environments and advanced software codes have been released and made available to research centers and industrial entities, which now share very powerful and versatile simulation tools. It is now possible to simulate very complex multi-variable multi-dynamic non linear aircraft systems in real time on a single personal computer. There are tools for testing, verification and validation of the related flight control systems and for automatic generation of executable codes, which comply with the main avionic standards (such as the DO-178B).

In this context, MAS-Lab (Multi-purpose Aircraft Simulation Laboratory) is a ultimate state-of-the-art multi-aircraft simulator, primarily meant to be interfaced with Airlab, a pilot operated Flight Simulator, developed within the framework of the two major European programs for civil air transport, SESAR and Clean Sky Joint Technology Initiative (JTI). Scope of the MAS-Lab project was to develop a mathematical model for three different aircraft categories, wide-body, business jet and regional transport aircraft, to test new technologies such as an innovative flight management system, designed to reduce emissions (CO2, NOx) and noise through the 4D trajectory optimization.

As shown in Figure 1, the models developed for trajectory and mission optimization are integrated in a wide context, in which both the environmental and the economical impacts are evaluated. Within the integrated system, in fact, the outcomes of the Flight Simulator are post-processed by two external modules:

- an environmental model to compute the noise related to the aircraft operations as well as the amount of carbon dioxide, nitrogen oxides and water vapour released in the high atmosphere;
- a cost model to evaluate the economical impact of innovative trajectory on the commercial flight operators

The MAS-Lab project consists, more in detail, in the design of a so called Master Model (red box in Figure 1) representing four models, three of which are referred to existing aircrafts: B747-100; ATR 42-500 and CESSNA Citation CJ3. The fourth model refers to a virtual aircraft, for which the parameters can be defined by the user within limited ranges imposed by physical constraints. The latter is referred to as the Generic model. As the simulator was primarily meant to be used for the validation of a novel Flight Management System, it needed accurate modelling of all aircraft subsystems that have a significant impact on flying qualities and fuel consumption.

More specifically the project was divided into 6 Work Packages, according with the following scheme:

WP Number	1	
WP title	Definition of model requirements and functional architecture	
WP Objective	The objective of this work package was to define the simulator specifications in terms of major features, such as hardware/software, development environment, but also in terms of what the simulator must be able to model and why	
Number of Deliverable	1	
D1.1	Model Technical Specification	This specification establishes requirements, for a Generic Aircraft Flight Dynamics Model, Nomenclature MAS-Lab, for a civil commercial mainline, a regional aircraft and a business jet. The Model Technical Specifications (MTS) document includes the model requirements and interface specification

WP Number	2	
WP title	Model verification and validation	
WP Objective	The objective of this work package was to verify and validate the model according to the definitions given by the VV&A Recommended Practice Guide of the DoD Model & Simulation Coordination Office. More precisely, the objective of this WP was to: • verify and validate and the dynamic model of the 747-100 and of the Cessna CJ3; • verify the dynamic model of the ATR42-500 and all the AFCSs.	
Number of Deliverable	6	
D2.1	Model Validation Test Plan	This document defines the Verification and Validation (V&V) Plan MAS-Lab. Within the document, the objectives of V&V are defined and the methodology to achieve them is described. The V&V Plan provides the basis for further expected V&V deliverables planned (2.2 – Validation Test Report and 2.3 – Reference Test Data Files). In detail, in order to establish the level of accuracy of the mathematical models developed, the FAA part 60 Appendix A “Qualification Performance Standards for Airplane Full Flight Simulators (FFS)” was used as reference to set up the right passing criteria for the tests accomplished on MAS-Lab. In particular the document establishes the standards for Airplane FFS evaluation and qualification. The NSPM (National Simulator Program Management) is responsible for the development, application and implementation of the standards contained within the document. The regulation presents the most stringent existing requirements that are used to certified the level (A,B,C or D) of the FFS. Even though MAS-Lab is not a FFS, it was decided to use this regulation as reference to guarantee the best results for the project purpose. As the four models have been developed differently, according to the characteristics of the data available for each aircraft, also the V&V tests are defined and scheduled differently. D2.1 is specifically detailed for the B747-100 model and its AFCS suite.
D2.2	Validation Test Report	This document represents the Validation Test Report for the B747-100 model for MAS-Lab. Tests refer to D2.1. Within the document, the achieved results are described and commented:

		table containing all the tests, their description, the systems involved and the limitations imposed by the regulation used as a reference are reported into two main sections: the first is related to the aircraft dynamic behaviour and performance, whereas the second concerns the AFCS mode response analysis.
D2.3	Reference Test Data Files	xlsx file (attachement to D2.2)
D2.4	Model Validation Test Plan update	This document represents the Validation Test Plan for the Cessna CJ3 and ATR42-500 models and their AFCS suites. It shares the main understanding of the V&V process with D2.1. This V&V Plan provides the basis for further expected V&V deliverables (2.5 – Validation Test Report)
D2.5	Final release of the Validation Test Report update	This document represents the Validation Test Report for the Cessna CJ3 and ATR42-500 models. This document assesses the level of accuracy, coherence and fidelity reached for the Cessna CJ3 and ATR42-500 models, according to the Validation Test Plan specified in D2.4.
D2.6	Reference tests data files update	xlsx file (attachement to D2.5)

WP Number	3	
WP title	Simulator implementation	
WP Objective	The objective of this work package was to implement the simulator, including model and interfaces. The static and dynamic performance, flying qualities, control reactions, and AFCS of the four aircrafts Boeing 747-100, ATR 42-500. Cessna CJ3 and Generic aircraft	
Number of Deliverable	5	
D3.1	Initial Aircraft Simulation model software	This software represents the initial release of the MAS-Lab simulator, which includes the Boeing 747-100 model and its AFCS suite. In this first release of the software the majority of the common utilities and simulation tools have been implemented. These parts are mainly related to: • the communication interfaces between MASLab and the users, including the VCOM interface; • the master model architecture; • the AFCS modes implementation and handling; • the AFCS validation strategies; • the utilities to extract performance data.
D3.2	User manual - Aircraft Model Description	This document describes all the aircraft model implemented for MAS-Lab. The description is articulated as to account for: • aircraft model components; • AFCS model components; • model internal and external interfaces; • input and output data files; • operative sequences.
D3.3	User Manual - Aircraft User	This document describes the B747-100 model implemented for MAS-Lab. The description is articulated as to account for:

	Guide	• aircraft short description; • aircraft limitations; • operating information; • AFCS modes; • performance.
D3.4	Complete Aircraft Simulation model software	This software represents the initial release of the MAS-Lab simulator, which includes the CJ3 and ATR42 models and their AFCS suite.
D3.5	Aircraft performance computation tool	The Performance Data Computation Tool a dedicated Matlab tool with a Grafical User Interface implemented by Polito on Thales specifications, which calculates the Specific Excess Power and Fuel Flow for different flight profiles and guidance modes

WP Number	4	
WP title	Problem fixing, updating, maintenance	
WP Objective	The objective of this work package was to maintain and improve the simulator software while updating the related manuals in successive releases. Feedbacks from partners and end users were to be organized and harmonized every time the simulator software and the related manuals are released. Comments were to b shared among the partners and taken under consideration for fixing problems or improve the simulator quality/reliability/portability.	
Number of Deliverable	5	
D4.1	Problem report and model modification request	Scope of this document is to collect problems and model modification requests following the deliverable of the MAS-Lab Boeing 747-100 mathematical model (D3.4).
D4.2	Model Technical Specification update	Scope of the document is to provide an updating for the Model technical Specification, deliverable D1.1, where the AFCS modes had not been addressed. This document, hence, outlines the proposed Automatic Flight Control System (AFCS) functioning modes to be implemented within the MAS-Lab simulation model. This includes both Autopilot and Autothrottle functions. Whereas specific modes may not be active for some aircraft, only modes described here are modeled. This document is the result of an activity conducted in cooperation with Thales and reported in the document series MASLab_AFCS Modes, whose main purpose was to ensure a common understanding and agreement on the autopilot modes.
D4.3	Final release of the Aircraft Simulation model software, with problem	The Final release of the Aircraft Simulation model software, with problem fixes (D4.3) has been issued as the final MAS-Lab software, ver.3.4. It includes the Generic Model for the three categories.

	fixes	
D4.4	Final Model User Manual and Aircraft Flight Manual update	The Final Model User Manual and Aircraft Flight Manual update has been issued in three different documents: D4.4a for Boeing 747-100, D4.4b for Cessna CJ3 and D4.4c for ATR 42-500
D4.5	Numerical model software and data package update for problem fixes or evolutions	The Numerical model software and data package update for problem fixes or evolutions (D4.5) has been issued to include the Generic Model for the three categories in the Performance Tool. A guide on how to select parameters of the Generic Model both for the MAS-Lab software ver.3.4 and for the Performance Tool has been included.

WP Number	5
WP title	Knowledge and technological transfer
WP Objective	The objective of this work package was to introduce the knowledge of the state-of-the-art simulation technology within the consortium and promote the dissemination of the technical and scientific results achieved during the project, among the partners and the international community also in non aeronautical contexts.
Number of Deliverable	-

WP Number	6
WP title	Coordination
WP Objective	The objective of this work package was to ensure that the tasks are execute within the specific deadlines and economical constraints. Main actions have been: • keep accurate financial records and submit these in a timely manner at reporting milestones; • verify the deliverable quality and timeliness; • attend regular project meetings; • monitor the project progress. • coordinate and supervise the activities of the WP leaders • write and submit regular progress of the project • observance of quality requirements
Number of Deliverable	-

1.3. A description of the main S&T results/foregrounds

The main results of the foreground obtained during the MAS-Lab are:

- the knowledge gained by the research leaders;
- the post-docs and the Ph.D. and undergraduate students educated and trained during the project;
- the software and documentation developed for the project;

- the methodologies implemented to obtained the expected results;
- the papers and reports published.

In what follows, a brief description will be given on how MAS-Lab project collected the state-of-the-art science and technology foregrounds to produce a powerful tool to support the design of innovative on-board systems, able to introduce substantial environmental and economic benefits in flight operations.

In May 1997 one of the major company dedicated in software development for simulation and model-based design, The Mathworks, released on a public FTP-server the Flight Dynamics and Control (FDC) toolbox for Matlab and Simulink. It was a free toolbox which provides flexible models and tools for flight simulation, flight dynamics analysis, and flight control system design.
The toolbox was built around a generic non-linear aircraft model, with a modular design that provided maximum flexibility to the user. The aircraft model was implemented as a Simulink block-diagram, which could be accessed both from the Matlab workspace and directly through the graphical user-interface of Simulink. The model was configured for the DeHavilland DHC-2 Beaver aircraft, but could be adapted for many different kinds of airplanes if required. Since then the toolbox has converted in an open source project and undergone an extensive updating process which has lead, through the years, to a very complex model which complies with the latest Matlab/Simulink releases. The toolbox also includes analytical Matlab routines for extracting steady-state flight conditions and determining linearized models for user-specified operating points

The Modeling process for MAS-Lab

In accordance with the FDC toolbox structure, MAS-Lab was developed to be modular, as showed in the block diagram of Figure 2, where several modules can be identified: Automatic Flight Control System (AFCS, modeling the entirety of autopilot suites), Actuators (modeling the operation of aerodynamic control surfaces), Engine (modeling the propulsion system), Ground (modeling the landing gear), Gravity (modeling gravitational forces on the aircraft), Aerodynamics (modeling the aerodynamic forces on the aircraft, including the effects of the operation of control surfaces), Atmosphere (implementing an ISA atmosphere model), Fuel System (modeling the fuel consumption and its effects on inertial properties), Equations of Motion (implementing the 6DOF equations of motion) and Sensors (modeling on-board sensors that provide data to the AFCS).

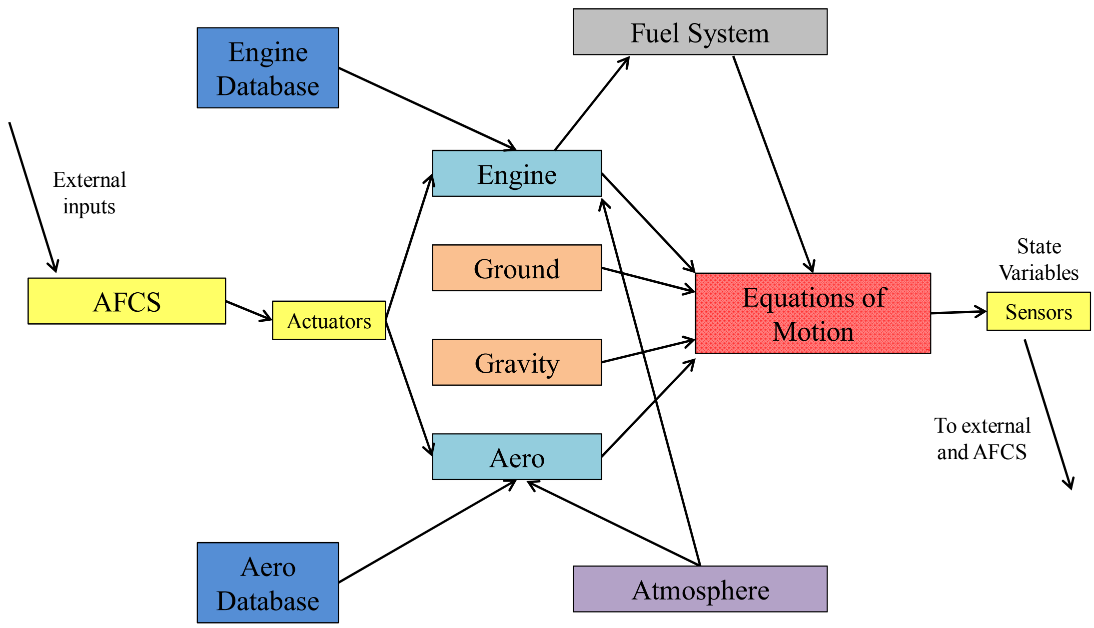

Figure 2 - MASLab Model Block Diagram

Two modules have proved to be particularly critical and required extensive discussion among the partners: the propulsion system and the AFCS suite. For the 4-D trajectory evaluation, in fact, an accurate modeling of the propulsion system was considered paramount, for correct estimation of the aircraft performance and fuel consumption. High-fidelity modeling of the propulsion system would require the aero-thermo-dynamic simulation of the entire engine and its components. This would require extensive knowledge of the engine characteristics, which belongs to data usually not disclosed by the engine companies. The engine model developed for MAS-Lab is based on a methodology which uses the off-line estimation of the engine main parameter trend in the entire operating range, in terms of Mach number and altitude. It is important to notice that the three aircraft selected to represent the three different categories are equipped with two different engine technologies, the turbofan and the turboprop, which implied differentiated modeling. This approach is interesting, as it is effective and computationally efficient and can be successfully adopt both for a turbofan and a turboprop engines. The methodologies used for the simulation of the two different propulsion systems present small differences, for this reason they will be described separately.

As for the two turbofan engines (JT9D-3 and FJ44-3A), the mathematical model reported in [1] was used as main reference. It consists mainly in mapping the following relations: *TH* (throttle) to *PLA* (power lever angle), *PLA* to *EPR* (engine pressure ratio) and *EPR* to thrust. The critical part in this modeling process is to obtain the complete database for the relations mentioned above from a relatively small set of available data. This last issue has been addressed through the use of commercial software such as the Gas Turbine Simulation Program (GSP) developed by the Netherland National Aerospace Laboratory (NLR). From data publicly available in [2], engine components working maps were theoretically obtained and then used off-line in the GSP to generate the database.

Once the engine and the aircraft dynamic mathematical models were fully validated, the fuel consumption models could be implemented by means of a heuristic function

$$TSFC\_adim=f(Thrust\_adim,Mach)$$

and validated with the flight manual data found in [3] and [4].

Regarding the turboprop engine, (PW 127-E) the difficulty was increased by the even greater lack of data; for example, data regarding the airfoils and pitch angles used for propeller blades, but also the gearbox reduction ratio, are not publicly disclosed. With reference to the formula reported in [5], and considering data available in [6] a simple model architecture was implemented to compute the following relation:

$$Thrust=f(rpm\%,TQ\%,V\_e,T)$$

where *rpm%* and *TQ%* are the pilot inputs. As for the fuel consumption, the same architecture described above for the turbofan has been implemented, substituting Thrust with *TQ%* and Mach with *H* altitude.

Also for the AFCS modeling, the main issue was the t lack of literature dedicated to the development of autopilots. More precisely, whereas theoretical aspects of autopilots are extensively analyzed ([7]-[8]), the actual modeling and development of an autopilot is not a common subject for literature, mainly because autopilots are a commercial products. Moreover autopilot functionalities depend on the specific aircraft and differ significantly from one category to another. For example the Boeing 747 is provided with an autothrottle, but that is not the case for the ATR 42 and the Cessna Citation. In order to simplify the model, it was decided that all modeled aircraft would be provided with the same AFCS capabilities; this also allowed to streamline the interface between the simulator and the Flight Management System.

The AFCS functionality can be split between three separate areas of operation: longitudinal control laws, lateral-directional control laws and autothrottle.

The following control laws were implemented for the longitudinal axis:

- Pitch Hold (Manual); maintains a fixed pitch angle
- Altitude Hold; captures and maintains the desired altitude
- Vertical Speed Hold; captures and maintains the desired vertical speed
- IAS Hold; captures and maintains the desired airspeed by manoeuvring the aircraft along the longitudinal axis
- Glide-Slope; captures and follows an Instrument Landing System (ILS) radio signal
- Take-Off/Go-Around (TOGA); maintains a pre-determined airspeed that ensures that the maximum safe climb rate is achieved

The following control laws were implemented for the lateral-directional axis:

- Roll-Hold (Manual); maintains a fixed roll angle
- Heading Hold; captures and maintains the desired heading
- Track-Hold; captures and maintains the desired track
- Localizer; captures and follows an ILS or VOR radio signal
- Take-Off/Go-Around (TOGA); maintains level wings (zero roll angle)

The following control laws were implemented for the autothrottle:

- Thrust Reference; switches between several pre-determined thrust values, such as TOGA, Climb and Idle
- Speed Hold; captures and maintains the desired airspeed, by operating on the throttle
- Mach hold; captures and maintains the desired Mach number, by operating on the throttle

In modern aircraft, autopilot mode activation and switching is governed by a large set of safety rules; for example, switching between certain modes could be prohibited, or the activation of a mode might require specific conditions to be met. Within MASLab, the most important of such rules were implemented as a mode selection logic that governs mode activation. This was modeled using Stateflow charts and continuously determines the current active mode for each AFCS axis by combining pilot inputs and flight data with the embedded rules. Figure 2 shows the Stateflow chart for the lateral-directional axis mode selection logic.

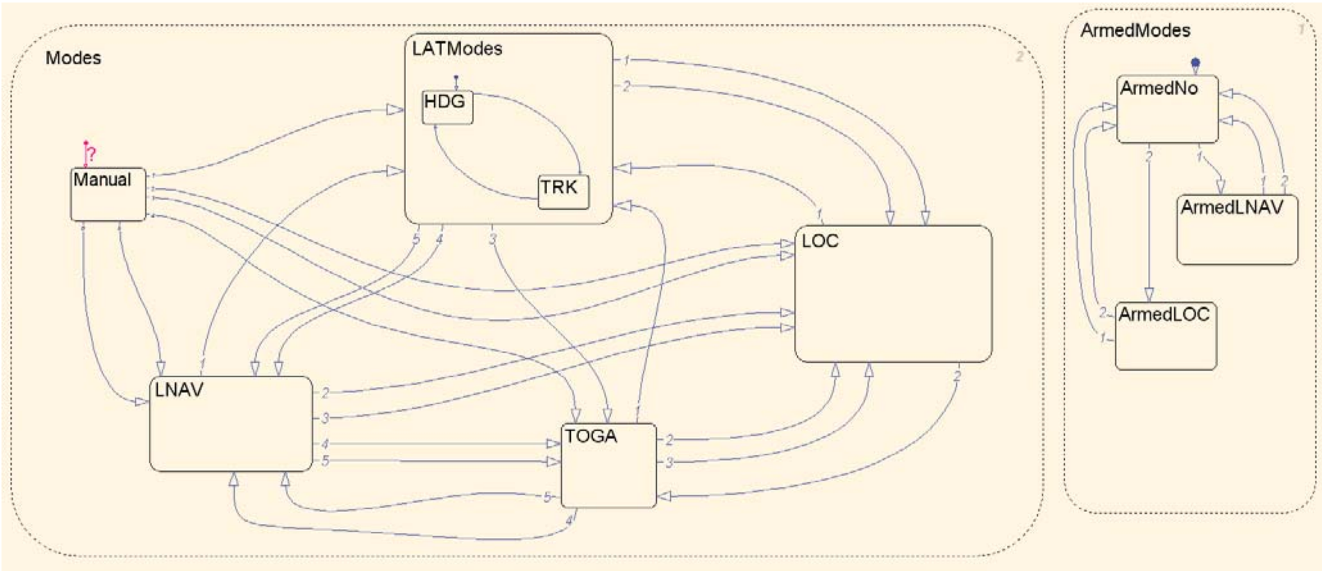

Figure 3 - Stateflow chart for the lateral-directional mode selection logic

The Verification and Validation process for MAS-Lab

The V&V process implemented for MAS-Lab was based on documentation published by the Defense Modeling and Simulation Office (DMSO) of the American Department of Defense (DoD). These Recommended Practice Guides (RPG) on Verification, Validation and Accreditation (VV&A) [9] allow to establish guidelines and methodologies that can be expected to result in meaningful V&V campaigns. The documentation is publicly available online at the following internet address: http://vva.msco.mil/Default.htm

In order to define the objectives of the entire Verification and Validation process for MAS-Lab, a number of definitions and theoretical concepts from the Recommended Practice Guides needs to be outlined. The first definition is that of Modeling and Simulation (M&S), which is defined as follows: “the use of models, including emulators, prototypes, simulators, and stimulators, either statically or over time, to develop data as a basis for making managerial or technical decisions”. While the terms modeling and simulation are often used interchangeably, a distinction exists: a model is defined as “a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process”, while modeling is the “application of a standard, rigorous, structured methodology to create and validate a model”. Note that the implementation of a model is normally considered to be static; producing output from the model requires a simulation. A simulation is defined as “a method for implementing a model over time.” Separating the definition of the model from the simulation is an extremely useful method for developing analytical tools. This modular approach, combined with well-defined interfaces, allows to update models as necessary without the need for updating the simulation software. It also supports a more thorough approach to V&V by allowing a V&V practitioner to separate the search for errors associated with the model from errors associated with the implementation of time.

Within MAS-Lab, the simulation environment is provided by the Matlab/Simulink software package. As this is a widely used simulation platform, which is well known and trusted by both the MAS-Lab User and Developer, it was assumed that V&V of the platform was outside the scope of the V&V process. This means that the V&V process was focused on determining whether the model itself was correct, rather than on checking whether the simulation environment provided sufficient fidelity.

However, due to its nature, the MAS-Lab model had to be tested under both static and dynamic conditions, since many aircraft characteristics are dynamic in nature.
It is important at this stage to distinguish between Verification and Validation, since the two terms are often used together and incorrectly treated as if they were interchangeable.
Verification is defined as “the process of determining that a model or simulation implementation accurately represents the developer’s conceptual description and specification”. Verification also evaluates the extent to which the model or simulation has been developed using sound and established software engineering techniques.
Validation is defined as “the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation”.
Within MAS-Lab, Verification consisted in ensuring that the developed models:

- were bug-free, both statically and dynamically;
- provided consistent output for all input conditions;
- were correctly interfaced with external components.

Validation instead consisted in ensuring that the models:

- reproduced the modeled aircraft with an acceptable degree of fidelity;
- provided output data where the error compared to the real-world was sufficiently small so that the simulation was useful for the purposes of the User

The Recommended Practice Guides define a large number of useful V&V techniques, such as debugging, assertion checking, special input testing, graphical comparison, functional testing and face validation and acceptance testing. This last technique is usually the final stage of each model delivery but is usually the most important, as it consists in testing the model operationally with the actual hardware and data to determine whether all requirements specified in the legal contract are satisfied. Requirements are usually related to standards which imply the availability of pre-defined input/output data-sets collected during specifically designed flight test. This means that if flight data are available: validation can be perform according to any of this standards:

- Australia → FSD-1, Operational Standards and Requirements, Approved Flight Simulators
- Canada → TP9685, Aeroplane and Rotorcraft Simulator Manual
- France → Projet d’arrêté relatif à l’agrément des simulateurs de vol 1988
- United Kingdom → CAP 453, Aeroplane Flight Simulators: Approval Requirements
- United States → Advisory Circular 120-40B Airplane Simulator Qualification

All these standards agree that the only mean of performing validation is through actual data, provided or verified and authorized only by the aircraft manufacturer. Validation on separate subsystems, moreover, is not a accepted as a way of validation. This process is obviously extremely expensive and time consuming and it is performed only if it actually gives economical/practical advantages, for example because it allows the simulator to be used extensively instead of the real A/C, such as for the Training Simulators. The aircraft constructors have a direct advantage in promoting Training Simulators, as they can be seen as a powerful tool to qualify pilots on their aircrafts, increasing acceptance and demand among the airliners. The advantage is so tangible that aircraft constructors accept to grant a sale of flight test data to the simulator developers. For each aircraft budgets are in the M€ range.

MAS-Lab falls in a different category, the Laboratory Simulators, where simulation data are used for prediction. Flight data were not available for the three aircraft but validation at a subsystem level was not considered acceptable or practicable. The problem of gathering reliable data and define an acceptable process for effective validation of the three aircraft models was a central issue for MAS-Lab and required extensive discussion among the partners.

Five main data sources were identified:

- Scientific literature, in the form of book chapters and papers, which is particularly useful to implement the Special Input Testing technique by providing example responses to specific input configurations. In particular, an extensive Boeing 747-100 documentation was found including responses to commands as well as modal parameters in different configuration and flight conditions.
- Data included in the Eurocontrol Base of Aircraft Data (BADA), from the Eurocontrol Experimental Centre, for which a license was requested and obtained for the length of the research project. BADA contains summary performance tables of true air speed climb/descent rates and fuel consumption at various flight levels for many different specific aircrafts. This data can be used as reference data both for Special Input Testing and Functional Testing techniques.
- Data released from the National Transportation Safety Board (NTSB) and related to flight data (including but not limited to Flight Data Recorders) recorded as a consequence of minor to major accidents. In this case, flight data from minor accidents, especially when related to the final phases of flight, can be used to test the simulator in realistic scenarios.
- Data released in the Aircraft Flight Manuals in forms of tables for different flight conditions. this data is usually related to the fuel consumption and performance prediction, which is a central issue for MAS-Lab.
- An American University, which was funded as sub-contractor, acquired, for a previous project, a wide set of geometric, inertial and flight data form Cessna. These data have undergone a PID process for the aerodynamic coefficients estimation. Following these procedure a flight simulator was implemented, and certified according to the FAA regulation (Level 6) by the American University. Due to the proprietary nature of the Cessna CJ3 flight data, however, the numerical estimates of the aerodynamic coefficients for the CJ3 were not directly available and were not released in any form. A process has been purposely defined and implemented to perform validation on the business jet model, without violating confidentiality agreements and property rights.

Reference

[1] C. Rodney Hanke and Donald R. Nordwall, The simulation of a jumbo jet Transport aircraft Volume II: modeling data, D6 -30643, The Boeing company Wichita division Wichita, Kansas, September 1970.
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[3] Citation CJ3 Flight Planning Guide, May 2006.
[4] Raymer D. P., Aircraft Design: A Conceptual Approach, 3rd ed., AIAA Education Series, 1999.
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[6] Stevens B. and Lewis F., *Aircraft Control and Simulation*, J. Wiley & Sons, 2004.
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[8] "*Flight control systems: practical issues in design and implementation*", Edited by Roger Pratt, Institution of Electrical Engineers, IEE Control Engineering Series, 2000.
[9] US Department of Defense, "*Validation, Verification and Accreditation Recommended Practice Guide*", http://vva.msco.mil/Default.htm (last accessed on 30/01/2013)

1.4. The potential impact and the main dissemination activities and exploitation of results

A team has been established, working in the total respect of the main research principles. Young researchers have been valorized, to support the grow of highly specialized profiles. In this context, no racial, gender, religious of political discrimination has been admitted in the selection of the new personnel. All the principles and dictates of the working discipline have been respected, for the employees and the environment work, both for the Politecnico and the companies (subcontractors) involved. No one has been somehow forced to act against his/her willing or political/ethical/religious precepts. On the contrary, differences have been valorized and harmonized within the group, as a form of cultural enrichment.

As in the tradition of a free and independent University, no rigid daily scheduling has been enforced. The group members had at their disposal all the most advanced communication tools to help them staying constantly connected with the rest of the group without having to commute daily or move permanently from their residence, causing discomfort for themselves or for their families. This is considered a strong measures to reduce the work cost, help reconcile work and private life and promote gender equality.

As far as the dissemination of project results is concerned, the group has worked respecting the principles of rights and duties of a research centre such as the Politecnico di Torino, which is to divulge and spread the most advanced knowledge. The group firmly believes in the importance to promulgate advance courses and lectures for highly specialized profiles (Ph.D. Students) which is expected to be absorbed by big industries, as well as SME. As in the tradition of the group, moreover, dissemination has been pursued through technical and scientific reports as well as the attendance of international conferences.

The foreground results are primarily the algorithms, the software, the models and the methods implemented to obtain the expected results. Dissemination during the project has been organized with two main objectives:

- to recruit and train researchers who had actively supported the MAS-Lab project or parts of it: in this case dissemination has been carried out through dedicated meeting during which the project documentation and the relevant bibliography has been made available, discussed and commented;
- to communicate effectively and ensure common understanding among the parties involved in the MAS-Lab project: in this case a glossary has been prepared, discussed, approved and included in the first deliverable of the project (D1.1). One of the criticality of the project, in fact, was that the parties had different backgrounds, besides belonging to different countries and kind of structures (academy and industry). The objective difficulties, moreover, was that different producers (for example Boeing and Airbus) have different names for systems with similar functionality. A common base was established among the parties, also, through periodic meetings in which the main theoretical issued were discussed from the different perspectives.

During the project communication with users outside the project has been mainly pursued at an academic level, within undergraduate courses in the Flight Mechanic area. In particular, a four-hour seminar has been prepared and proposed to the Bs. students within the course Aircraft Guidance and Control (8 credits). The seminar Automatic Flight Control System for Modern Civil Aircraft is focused on the most practical issued related to the AFCS use, especially in the category of the large aircraft. The outline is the following:

- AFCS functions in civil aircraft - SAS, CAS and autopilots: the command and control systems of two large aircraft (Boeing 474-100 and Airbus 330-300) are described in details and the main differences are outlined. Autopilots modes, their interaction and their limitations are presented. The simplified control schemes of the main autopilots are introduced and commented.
- Conceptual differences for the main constructors (Boeing and Airbus)
- Pilot interface with the AFCS: the interfaces for the main constructors (Boeing and Airbus) are presented. Flight Director (FD), Mode Select Panel (MSP) or Mode Control Panel (MCP), Flight Control Unit (FCU), (Multipurpose) Control Display Unit, Flight Management System are discussed in details.
- Typical mission profiles and interaction with the AFCS: practical examples of Boeing 747-100, Boeing 747-400, Airbus 330-300

As outlined in the List Dissemination Activities (Section A) many of the topics addressed during the project had been the subject of undergraduate Thesis. In particular 4 Ms. and 3 Bs. Thesis have been completed. Their content will be briefly described hereinafter:

Title: Modeling and validation of the B747-100 AFCS suite for the implementation of an innovative Flight Management System

Author: Mario Cassaro

Faculty Advisor: Manuela Battipede

Abstract

This report is the result of a graduation research, which has been carried out within the Clean Sky project for the development of the Multipurpose Aircraft Simulation Laboratory (Mas-Lab). The main objectives of this work was to verify and validate a B747-100 nonlinear aircraft dynamic model and also to implement and validate the Automatic Flight Control System. To achieve the proposed objectives it has been decided that classical control techniques would be used to develop the autopilot controllers. The steps to achieved the proposed objectives can be listed as follows: i) Non linear model implementation, validation and trimming; ii) Model linearization and dynamic response investigation; iii) Stability and control augmentation system design; iv) Control logic development; v) Non-linear testing of the complete model.

Title: Mathematical model turboprop aircraft for the implementation of an innovative Flight Management System

Author: John Paronitti

Faculty Advisors: Manuela Battipede, Paolo Maggiore

Abstract

This dissertation is the outcome of a eight-month long research work carried out at the Politecnico di Torino's Aerospace Engineering Department, whose aim was the implementation of a turboprop aircraft mathematical model that will be used for the development of an innovative Flight Management System. The first objective of this dissertation was the calculation the aerodynamic coefficients of a simplified geometric model of a modern commercial turboprop aircraft such as the ATR 42-500 through the U.S. Air Force-developed commercial software Digital DATCOM. Due to the inherent limitations of the DATCOM, it was very important to determine the plausibility of the results of its output file, they have therefore been compared with similar plots found in literature. The second objective was the development of the propulsion, aerodynamic, flight controls and *dynamic models of the ATR 42 that had to be implemented as modules into the MAS-Lab Master Model, in order to calculate the forces and the moments the aircraft is subject to.*

Title: Implementation of a mathematical model for the AFCS analysis for a large aircraft
Author: Davide Bietto

Faculty Advisors: Manuela Battipede, Paolo Maggiore

Abstract

This thesis describes the work carried out within the Clean Sky MAS-Lab (Multipurpose Aircraft Simulation Laboratory) project In particular, the task carried out and reported here concerns the implementation of the flight control systems (longitudinal, lateral and directional controls, flaps and stabilizer) and the propulsion system of the Boeing 747-100 and the validation of these models at a subsystem level.
It should be noted that all the work presented here, concerns one of the most complex model in the state-of-the-art and the first model implemented and tested in the MAS-Lab project. This thesis, hence, represent a reference for the other models (ATR42-500, CJ3 and the Generic) to be implemented verified and validated. The reader should be familiar with classical control theory as well as with the flight mechanics and dynamics main concepts. Matlab and Simulink are the basic modeling tools.

Title: Non linear dynamic modeling of the Cessna Citation CJ3 and implementation of the relevant autopilots

Author: Francesco Trifilò

Faculty Advisor: Manuela Battipede

Abstract

This thesis has been developed within the European research project called Clean Sky and was carried out at the Department of Mechanical and Aerospace Engineering (DIMEAS) of the Politecnico di Torino. The main objectives consisted in implementing and validating the Cessna Citation CJ3 nonlinear dynamic model and the relevant Automatic Flight Control System. The verification and validation process has been performed using specifications reported in MIL-DTL-9490E. The implemented model of the aircraft is part of the flight simulator platform called MAS-Lab (Multipurpose Aircraft Simulation Laboratory).
The steps involved in the development of the project are as follows: i) Implementation of the geometric model and its aerodynamic database obtained using DATCOM; ii) Model linearization and dynamic response investigation; iii) Stability and control augmentation system design; iv) Verification and validation of the complete non-linear model.

Title: Validation of a turbojet engine dynamic model for a for fuel consumption analysis

Author: Daniele Mazzotta

Faculty Advisors: Manuela Battipede, Michele Ferlauto

Abstract

The main objective of this Bs. Thesis was to validate the lumped element mathematical model of the Pratt&Whitney JT9D-3A turboprop engine, which equips the B747-100. The engine mathematical model is intended primarily for the evaluation of the trust and fuel consumption in the whole aircraft flight envelope and is part of a Clean Sky project, for which the main aim is to implement and validate a flight simulator: the Multipurpose Aircraft Simulation Laboratory (MAS-Lab). The

validation process consists in the identification of the coherence of data calculated through the use of commercial software such as the Gas Turbine Simulation Program (GSP) developed by the Netherland National Aerospace Laboratory (NLR). These data, in fact are extrapolated from the data available in the current literature, which is relevant to particular flight conditions, such a full throttle or zero speed. The behavior of data outside this flight condition has been analyzed and corrected at a subsystem level and with the model integrated in the full aircraft simulator.

Title: Implementation of a virtual flight control unit panel for a flight simulator

Author: Marco Sasanelli

Faculty Advisors: Manuela Battipede, Matteo Vazzola

Abstract

The objective of this Bs. thesis is to implement a software interface for MAS-Lab, with the same layout and the functionalities of the (Flight Control Unit) FCU Panel. In particular the panel is used as a human-machine interface, to set autopilot parameters such as:

- *cruise speed, vertical speed or flight path angle;*
- *heading angle;*
- *altitude;*
- *autopilot mode transition;*
- *autothrottle mode transition.*

The thesis is divided into three parts: the first part is dedicated to a description of the commercial software LabVIEW, and in particular to the add-on application SIT (Simulink Interface Tool) through which the FCU Panel has been implemented, interfaced and made run simultaneously with the MAS-Lab Master Model. The second part consists in the description of the features and functionalities of the FCU Panel developed for the MAS-Lab project. The third part is dedicated to the description of the programming details. Each virtual element is analyzed: criticalities in the implementation are discussed and validation tests are presented. A final test consists in the evaluation of the performance of the FCU Panel interface when functioning in real time as an embedded software.

Title: Feasibility analysis of a parametric mathematical model of a conventional aircraft

Author: Laura Novaro Mascarello

Faculty Advisors: Manuela Battipede

Abstract

The main objective of this Bs. Thesis is to provide a parameterization of some geometric features of a generic aircraft, identifying mathematical relationships between the geometric features and several aircraft performance parameters. The choice of the parameters to be analyzed is not random: on the contrary it is based to an appropriate strategy, partially echoes the preliminary design philosophy of the aviation companies when faced with a new project. The following steps were accomplished: i) statistical analysis over the geometrical and performance data of aircraft belonging to the categories of Large Aircraft, Business Jet and Regional Aircraft; ii) Detailed comparison between geometric and performance data of similar large aircraft made by the two most important aviation companies Boeing and Airbus; iii) Partially parameterization of the flight control block implemented in MAS-Lab using Matlab/Simulink programming language; iv) Identification of the influence of bounded gross weight variation over the geometrical and performance parameters of a generic aircraft.

As far as the exploitation of results is concerned, results have been made available for all the JU partners: the simulator modularity makes the platform suitable for different types of aircraft with different operational goals within and beyond the scope of the Clean Sky JTI.

1.5. The address of the project public website, if applicable as well as relevant contact details

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2. Use and dissemination of foreground

There are five main application areas for flight simulators:

- crew training;
- certifications and licenses;
- investigation on aviation accidents and incidents;
- research and development of innovative systems/procedures;
- educational tool in academies and universities.

The last two areas are particularly interesting for the POLITO group, for the nature of the institution it belongs. The Politecnico di Torino, in fact, is a research university of international level which attracts students from more than 100 countries and which activates about 800 collaborations per year with industries, public institutions and local organizations. At the Politecnico di Torino, research and teaching cover a wide spectrum of topics related to scientific investigations and industrial applications in aerospace engineering. The Politecnico di Torino, though, lack of a 6 DOF flight simulator which could be a very powerful tool to support undergraduate and postgraduate teaching and research into future aircraft systems. A recent study, in fact, has shown that a flight simulator would be beneficial for many Bs. and Ms. courses such as Flight mechanics, Flight Dynamics and Control, Aircraft Guidance and Control, on-board Equipment and Avionic Systems, Jet Propulsion, Modeling, Simulation and Testing of Aerospace Systems and Flight Simulation, among the others. Many European educational centers are equipped with flight simulators entirely developed by students and staff members and used as teaching tools:

- the Delft University of Technologies, for example has developed Simona, (Simulation Motion e Navigation) used for both automotive and aerospace applications. It is mounted on a 6 DOF platform and internally configured with a Fokker 100 cockpit. Simona has been developed with a budget of more that 10M€, justified by the acquisition of different packages of experimental data, necessary to validate the mathematical models;
- the University of Liverpool has two flight simulators, the non-movable X-Pit and the reconfigurable Heliflight, which has been developed with a budget of about 1.1M€;
- the Sheffield University has developed, with a budget of about 87K€, the flight simulator FSOS, characterized by a modular and flexible architecture.

The English universities are the most active, in this respect: the Merlin Flight Simulation Group, a leader company in this area, at the moment has 14 flight simulators operative just within the English universities.

One of the project that the POLITO group would like to pursue, in the future, is the development of a 6 DOF Flight Simulator equipped with a realistic motion system and visual cues to be used as a laboratory for students and research staff. Applications may include:

- analysis of performance in steady state and transient flight phases;
- analysis of response to pilot maneuvers;
- flight mission analysis;
- effect of the variation of the aerodynamic coefficients on flight qualities;
- design of automatic flight control systems
- injections of failures for reconfigurable control systems;
- human-machine interface.

The heart of the flight simulator is the mathematical model which is the most critical as well as the most expensive to implement, because it involves data to be acquired for validation. The MAS-Lab project has already produced three validated mathematical models, which could be easily integrated in the platform. In the next future opportunities will be sought for funding for the acquisition hardware components and for the development of the mechanical motion system.

In the next future, three papers are expected to be presented at international conferences. The abstracts are briefly reported hereinafter:

AIAA Modeling and Simulation Technologies Conference - Boston, Massachusetts - USA August 19-22 2013

Topic: Simulation/Simulator Testing and Validation

Title: Propulsion System Modeling For A Multi-Aircraft Simulator

Authors: M.Cassaro, P. Gunetti, M. Battipede, P.Gili

Abstract

The present work was carried out under the European CleanSky ITD Systems for Green Operations project. In order to test new technologies (i.e. an innovative flight management system) designed to reduce emissions (CO_2, NO_x) and noise through the 4D trajectory optimization, the Multipurpose Aircraft Simulation Laboratory (MASLab) was developed by our research team at the Politecnico di Torino. MASLab is a Simulink-based code able to model three different types of aircraft: wide-body, business jet and regional transport aircraft. In this context, accurate modeling of the propulsion system is paramount. This is true for both the calculation of forces and moments and the estimation of fuel consumption.

In reality, high-fidelity modeling of the propulsion system would require an aero-thermo-dynamic simulation of the entire engine and its components. This would require extensive knowledge of the engine characteristics, which belongs to data usually not disclosed by the engine companies. Moreover, implementing all the thermodynamic equations for each stage of a jet engine, added to a really complex and detailed multi-aircraft model, may cause heavy computational load to the point that real-time simulation might be compromised. This paper reports a methodology to solve these problems based on the off-line estimation of the engine main parameter trend in the entire operating range, in terms of Mach number and altitude. This approach has been successfully attempted both for a turbofan and a turboprop. Of course close matching between simulated and real aircraft dynamic behaviour must be guaranteed to obtain optimal results. According to the project requirements three specific aircraft were chosen as representative of the three different categories: a B747-100, a CESSNA CITATION CJ3 and an ATR 42-500. A precise aircraft model selection implies that data are referred to official data sheets of real propulsion system.

AIAA Modeling and Simulation Technologies Conference - Boston, Massachusetts - USA August 19-22 2013

Topic: Simulation/Simulator Testing and Validation

Title: Modeling Autopilot Suites For A Multi-Aircraft Simulator

Authors: P. Gunetti, M.Cassaro, M. Battipede, P.Gili

Abstract

MASLab (Multi-purpose Aircraft Simulation Laboratory) is a project that was undertaken at the Politecnico di Torino under the Clean Sky EU programme. The project involved the development of complete simulation models for several aircraft; in particular, three different aircraft were targeted, each representative of a different aircraft category: Boeing 747-100 (large commercial aircraft), ATR 42-500 (regional aircraft) and Cessna Citation CJ3 (business jet). The Matlab/Simulink software package was chosen for model development.

Since the simulator was primarily meant to be used for the validation of a novel Flight Management System being developed by Thales Aerospace under the same programme (Clean Sky), it needed accurate modeling of all aircraft subsystems that have a significant impact on flying qualities and fuel consumption. This means that the simulator was to include not only the dynamic model of the aircraft, but also a model of the autopilot suites.

The MASLab simulator was developed to be modular, and the block diagram is shown in figure 1. Several modules can be seen: Automatic Flight Control System (AFCS, modeling the entirety of autopilot suites), Actuators (modeling the operation of aerodynamic control surfaces), Engine (modeling the propulsion system), Ground (modeling the landing gear), Gravity (modeling gravitational forces on the aircraft), Aerodynamics (modeling aerodynamic forces on the aircraft, including the effects of the operation of control surfaces), Atmosphere (implementing an ISA

atmosphere model), Fuel System (modeling fuel consumption and its effects on inertial properties), Equations of Motion (implementing the 6DOF equations of motion) and Sensors (modeling on-board sensors that provide data to the AFCS).

This paper will illustrate in detail the Automatic Flight Control System (AFCS) components of the simulator. First, the desired control laws will be described, and the rules that determine their activation will be outlined; then, for each control law, a mathematical explanation will be provided, together with a description of the implementation method used in the simulator. Finally, the validation methodology will be described, and test results presented.

AIAA Aviation Technology , Integration and Operation Conference - Aviation 2013 - Los Angeles, California – USA, August 12-14 2013

Topic: Aviation Technology, Integration and Operations

Sub-Topic: Designing the Aircraft: Integrating the platform with the mission

Title: Overview Of The Multipurpose Aircraft Simulation Laboratory Experience

Authors: M.Cassaro, P. Gunetti, M. Battipede, P.Gili

Abstract

This paper reports the experience of the MASLab (Multipurpose Aircraft Simulation Laboratory) project, developed at the Politecnico di Torino within the Clean Sky ITD Systems for Green Operations. Scope of the MASLab project was to develop a mathematical model for three different aircraft categories, wide-body, business jet and regional transport aircraft, to test new technologies such as an innovative flight management system, designed to reduce emissions (CO_2, NO_x) and noise through the 4D trajectory optimization. MASLab is currently integrated in the Thales Aerospace Airlab, a pilot operated Flight Simulator, developed within the framework of the two major European programs for civil air transport, SESAR and Clean Sky Joint Technology Initiative (JTI).

Section A (public)

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
none										

A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	*Conference*	*POLITO*	*CEAS 2011 - The international Conference of the European Aerospace Societies*	*24-28 October 2011*	*Venice (Italy)*	*Scientific Community*		*International*
2	*Conference (paper 1)*	*POLITO*	*AIAA Modelling Simulation and Technology Conference*	*19 - 22 August 2013*	*Boston, Massachusetts (USA)*	*Scientific Community*		*International*
3	*Conference (paper 2)*	*POLITO*	*AIAA Modelling Simulation and Technology Conference*	*19 - 22 August 2013*	*Boston, Massachusetts (USA)*	*Scientific Community*		*International*
4	*Conference*	*POLITO*	*AIAA Aviation Technology , Integration and Operation Conference - Aviation 2013*	*12-14 August 2013*	*Los Angeles, California (USA)*	*Scientific Community*		*International*

5	*Ms. Thesis*	*POLITO*	*Modelling and validation of the B747-100 AFCS suite for the implementation of an innovative Flight Management System*	*September 2010-March 2011*	*Turin (Italy)*	*Scientific Community*	*100*	*Italy*
6	*Ms. Thesis*	*POLITO*	*Mathematical model turboprop aircraft for the implementation of an innovative Flight Management System*	*September 2010 - March 2011*	*Turin (Italy)*	*Scientific Community*	*100*	*Italy*
7	*Ms. Thesis*	*POLITO*	*Implementation of a mathematical model for the AFCS analysis for a large aircraft*	*June 2010 - November 2011*	*Turin (Italy)*	*Scientific Community*	*100*	*Italy*
8	*Ms. Thesis*	*POLITO*	*Non linear dynamic modelling of the Cessna Citation CJ3 and implementation of the relevant autopilots*	*September 2011 - March 2012*	*Turin (Italy)*	*Scientific Community*	*100*	*Italy*
9	*Bs. Thesis*	*POLITO*	*Validation of a turbojet engine dynamic model for a for fuel consumption analysis*	*June 2011-November 2011*	*Turin (Italy)*	*Scientific Community*	*50*	*Italy*
10	*Bs. Thesis*	*POLITO*	*Implementation of a virtual flight control unit panel for a flight simulator*	*June 2011 - November 2011*	*Turin (Italy)*	*Scientific Community*	*50*	*Italy*
11	*Bs. Thesis*	*POLITO*	*Feasibility analysis of a parametric mathematical model of a conventional aircraft*	*June 2012- October 2012*	*Turin (Italy)*	*Scientific Community*	*50*	*Italy*

Section B (Confidential or public: confidential information to be marked clearly)

Part B1

This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
none					

Part B2

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
NONE								

3. Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	255907
Title of Project:	Multipurpose Aircraft Simulation Laboratory
Name and Title of Coordinator:	Prof. Piero Gili

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	

• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	1	
Experienced researchers (i.e. PhD holders)	1	6
PhD Students	1	1
Other	-	-

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**4**
Of which, indicate the number of men:	3

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

- ☒ Yes
- ○ No

6. Which of the following actions did you carry out and how effective were they?

	Action	Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	☒
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- ☒ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ○ Yes- please specify
- ☒ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ○ Yes- please specify
- ☒ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ☒ Main discipline[1]: 2.3
- ○ Associated discipline[1]:
- ○ Associated discipline[1]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

- ○ Yes
- ☒ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

[1] Insert number from list below (Frascati Manual).

11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	X

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**0**
To how many of these is open access[2] provided?	**0**
How many of these are published in open access journals?	**0**
How many of these are published in open repositories?	**0**
To how many of these is open access not provided?	**0**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ☒ lack of time and resources ❑ lack of information on open access ❑ other[3]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑ Increase in employment, or	❑ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	☒ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*

[2] Open Access is defined as free of charge access for anyone via Internet.
[3] For instance: classification for security project.

Difficult to estimate / not possible to quantify	☒

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ☒ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ☒ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	☒	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☒	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 X Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

4. Final report on the distribution of the European Union financial contribution

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1. *Polito*	*250K€*
Total	*250K€*