DOI: 10.13009/EUCASS2019-925

8TH EUROPEAN CONFERENCE FOR AERONAUTICS AND AEROSPACE SCIENCES (EUCASS)

DOI: ADD DOINUMBER HERE

# System Identification and Testing for a VTVL vehicle

*Ana-Maria Neculaescu*⋆*, Alexandru Marin*⋆*, Adrian Toader*⋆†*, Alexandru-Gabriel Persinaru*⋆*,*
*Alexandru-Mihai Cismilianu*⋆*,Mihai Tudose*⋆*, Camelia-Elena Munteanu*⋆*,*
*Ionel Popescu*⋆*, Hans Strauch*⋆ ⋆ *and Stephane Dussy*⋆ ⋆ ⋆
⋆*National Institute for Aerospace Research Elie Carafoli - INCAS*
*Bucharest, Romania, 061126*
⋆ ⋆*Airbus DS GmbH*
*Bremen, Germany, 28361*
⋆ ⋆ ⋆*ESA HQ-Daumesnil*
*Paris, France, 75015*
neculaescu.ana@incas.ro · toader.adrian@incas.ro
†Corresponding author

## Abstract

There is a shift of perspective and paradigm when it comes to space technologies through the space community by the recovery and reusability of several components of a vehicle. A consequence of this new way of doing things is the rising number of companies and institutes that are in the race to demonstrate and validate some key technologies related not only to recover and potentially reuse of some parts of space vehicles, but also from being able to test faster, provide reliability through previous proven procedures for technology maturation.

INCAS is a part of this race by designing and developing a testing platform in the frame of ESA - FLPP3, called Demonstrator for Technologies Validation - DTV. This platform is a turbojet engine powered vehicle which can be considered as a test bench with the goal to mature the technologies under evaluation, both software and hardware, to a higher TRL. The purpose of this article is to present the testing platform itself, the testing plan and procedures, together with the results of the sub-system testing. An efficient, incremental and innovative way to perform sub-system testing coupled with an inter-disciplinary process elaboration in order to achieve this goal is to be presented in this paper.

## 1. Introduction

At this moment, in Europe and worldwide, there is a huge interest in the development of reusable systems. The immediate goal of this project is to build a turbojet engine flying (VTVL) vehicle, able to perform an autonomous low speed, low altitude flight. The vehicle can be viewed as test bench to mature the technologies under evaluation (software and hardware) to the TRL which involves flight tests. Technology readiness depends on the rapid maturation of innovative concepts. One of the reasons for its slow adoption is high costs involved with in-flight demonstration. Flying payloads of launcher technology components (software and hardware) on the proposed technology demonstrator can increase the speed of development. The main reason for the conservatism is of course the high penalty of failure. Therefore, a demonstrator (or a family of demonstrators), where a risk can be taken more easily, plays an important role in order to increase confidence into new techniques and designs. The step from a pure simulation-based assessment to one based on hardware-in-the-loop is a true test on the robustness of a new, advanced design. An in-flight platform allows demonstration of the real-world applicability of the envisaged techniques within a controlled risk/low penalty environment. The demonstrator will be reusable and will allow a fast turn-around cycle of testing, design and upgrade. Although the emphasis of the flight experiments is guidance, navigation and control related, it is not limited to this. A payload capability is foreseen in order to allow testing of new equipment with the intention to operate it in a specified dynamic environment, which is provided via certain trajectories flown by the demonstrator.

## 2. DTV design approach

The approach taken for the design of the reusable testing platform is iterative and based on the interaction of the disciplines involved, as presented in the picture below.

DOI: 10.13009/EUCASS2019-925



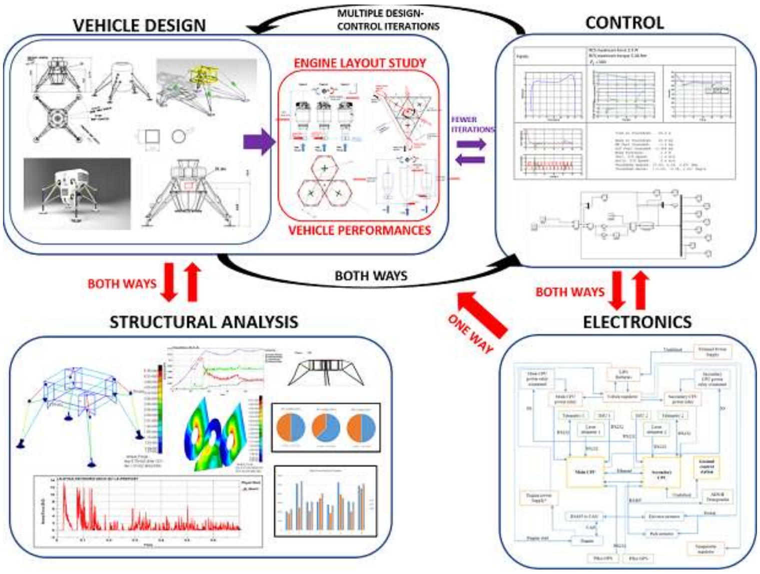



Figure 1: Design approach for the DTV vehicle

One of the more challenging connections in the design philosophy is the vehicle design and control interaction. Communication and information sharing is more frequent between the two disciplines. This leads to multiple iterations between the disciplines because until the design is frozen, it is very volatile and there are frequent and drastic changes that might change the control manners and the way the control is applied. A solution to diminish the amount of iterations between control and design team was to implement an intermediate step within the vehicle design research.

#### 2.0.1 Mechanical design

### 2.1 Internal structure

The internal structure was designed to be as modular as possible in such a way to allow the possibility of upgrading the vehicle with minimum effort. The profiles used for the internal structure are L and T angles and also round pipes. The material chosen for all profiles used for the internal structure is EN AW-6060 AlMgSi. This aluminum alloy was chosen because it is fairly common and used for such aluminum profiles, it is resistant to corrosion, it is a medium hard alloy and has very good weldability. Especially the last characteristic is appealing because the individual structure blocks are welded and not riveted.

The structure is divided in simple modules, Fig. 3 such as fuel structures that have the role of supporting the fuel tanks and other accessories and the central structure that has the role to support the engine and to tie in all the components. Above the structures that use regular angled aluminum are placed special designed plates, fuel plates and engine plate. The plates have the role of interfaces between the rest of the structure. Although the structure is held in by bolts, the additional plates are fitted above the structure also with bolts to the yellow structure and to themselves. The plates were created because the engine has a unique manner of attachment and so, a special engine plate was designed to accommodate the engine and to absorb the stresses in case of a harder landing and also during flight. Due to the fact that a separate plate was made for the engine, additional fuel plates were made in order to transfer loads more easily to the structure. The fuel plates also act as a base for the fuel tanks.

### 2.2 Landing gear

The vehicles landing gear is composed of 4 completely independent landing gear which are referred to as legs, Fig. 4. Each leg is designed like a parallelogram, thus having the great advantage that during landing or take-off the outer horizontal circular beam remains always parallel to the vehicle, independent of the stroke of the dampener. This can prove to be a great advantage because otherwise the foot pad has to slide in order to properly use the dampener efficiently. The major advantage of having 4 independent legs is that the vehicle can land almost in any terrain. In general, the vehicle will take-off and land from a tarmac platform, but, in case of emergency landing when the vehicle cannot finish the mission this feature will prove to be useful. To further improve the advantage of landing in rudimentary conditions, the landing gear is also fitted at the contact point with the land with a foot pad. The foot pad can move on

DOI: 10.13009/EUCASS2019-925



(a) DTV design

(b) DTV design section

Figure 2: DTV - layout of the vehicle

a circular manner along the clevis end placed at the end of the horizontal circular beam of the landing gear, quickly adapting to any inclination.

DOI: 10.13009/EUCASS2019-925



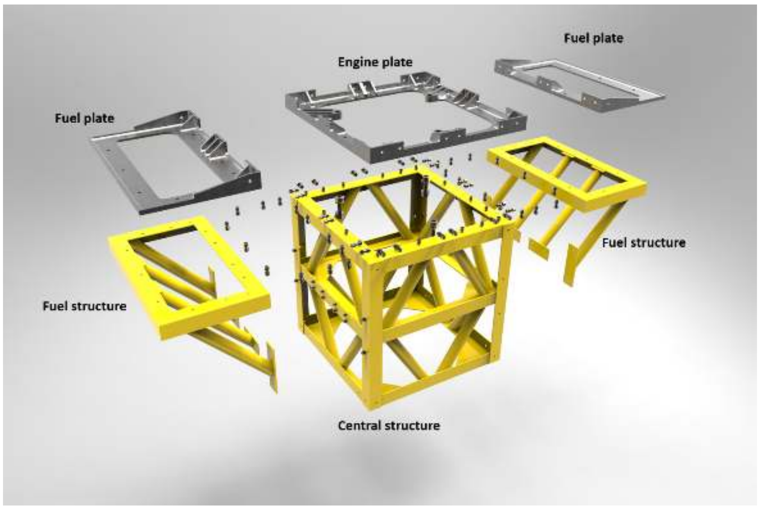



Figure 3: DTV - internal structure

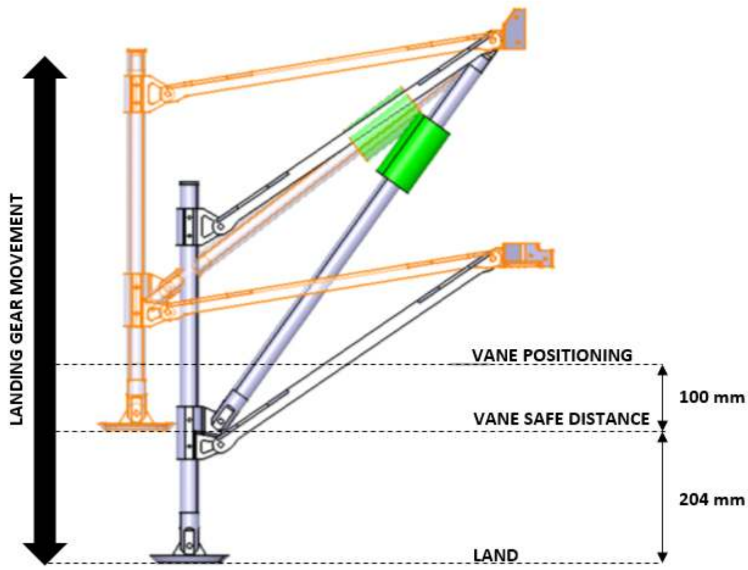



Figure 4: DTV - landing gear design

### 2.3 Vane subsystem

The vanes system has the role to provide thrust vectorization. The control of the vehicle is made by precisely by rotating the vanes at the needed deflection. From the controllability of the vehicle point of view, the vanes prove to be a critical component. For this reason, all the components of the vane system have been designed to contain either redundant components, or tough enough components to withstand the impact of the landing. The vane system contains two vanes which can be deflected independently as in Fig. 5.

### 2.4 Roll control system

The roll control system is used mainly to counteract the engine torque that appears when there is variation in RPM. The types of studied RCS system is based on the Electric Ducted Fans (EDF). For the EDF RCS system, 6 two electric motors were chosen. EDFs prove to have a higher thrust to weight ration than other electric motors. EDF unit is compact, it can be mounted inside a fuselage or externally depending on the design of air vector, the EDF unit does not need an ignition systems (pipes, spark plugs, throttle servo), so easier to build, propeller intubations is better than a free propeller (because of loss due to the vortices extreme), the potential benefit to the concept of vectored thrust by

DOI: 10.13009/EUCASS2019-925



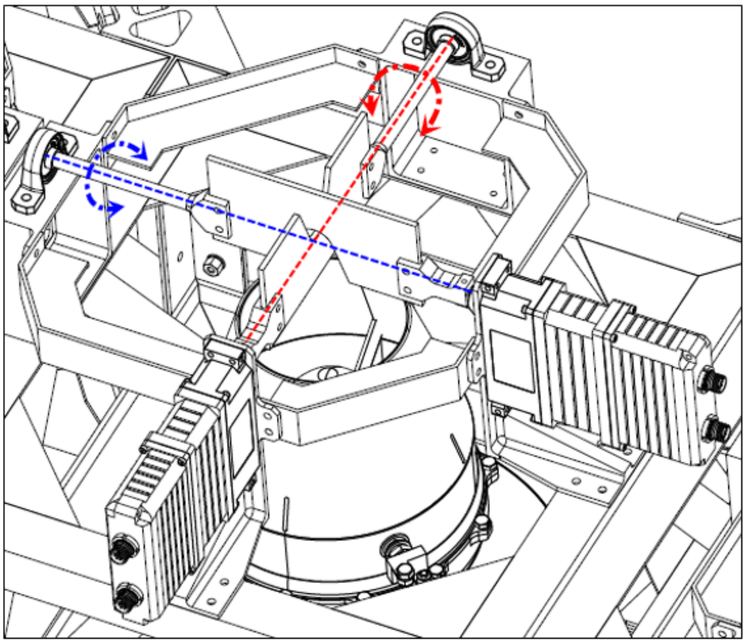


Figure 5: DTV - vane system design

diverting the air flow even with smaller angles which results in a high manoeuvrability of the vector air.

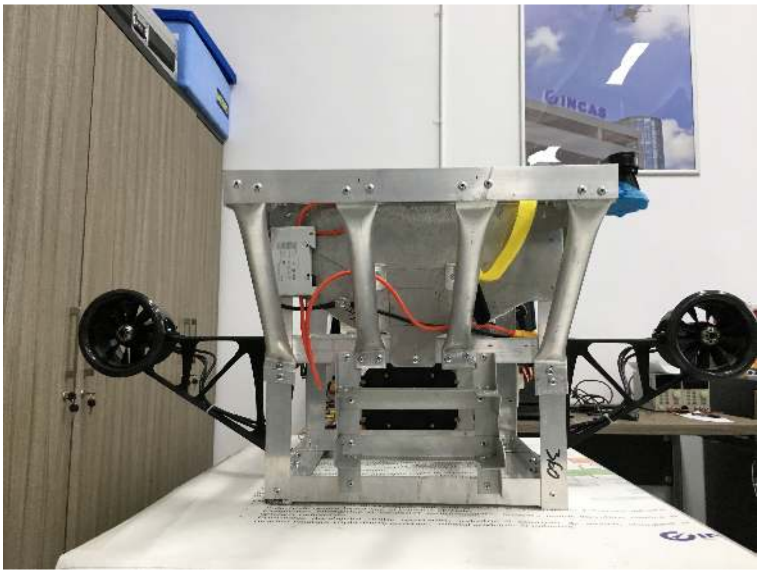


Figure 6: RCS on vehicle structure mock-up

The electrical motor provides 30N of thrust and weighs in 120 g. The control team has provided the required torque to be achieved by the RCS system. By establishing constructively, the length of the lever arm, the necessary thrust per motor was obtained. A market study was made in order to properly identify the right motor for the system, a motor that has a high thrust to weight ratio and also a low consumption with respect to thrust.

## 3. Experimental setup for DTV - The test bench

The purpose of this section is to present the experimental setup and the results obtained in the tests dedicated to the evaluation of the vanes efficiency and turbojet engine performances. In these tests, the thrust generated by the engine and the lateral forces (aerodynamic force) as a result of the vanes deflections were measured.

DOI: 10.13009/EUCASS2019-925



The test bench is designed to measure the lateral forces due to the vane deflections and engine trust. This test rig is metallic frame, Fig. 7 a), with fixing points paired with the fixing points of the engine. This frame accommodates four uniaxial force transducers, Fig. 7 b), mounted on a rigid structure.

To alleviate the inherent vibrations induced by the engine shaft rotations (over 50 000 RPMs), special screws have been designed to mount the engine on its support structure Fig. 8 a). These screws allow insertion of rubber dumper, between the mechanical frame and the screw. The mechanical links between the engine support and lateral force sensors are presented in Fig. 8 b).

(a) Engine fixing frame (b) Connection points

Figure 7: Test bench for vanes and engine testing.

(a) Joining points engine-frame (b) Mechanical connections between engine frame and sensors

Figure 8: Engine fixing on the test bench.

DOI: 10.13009/EUCASS2019-925



## 4. System identification

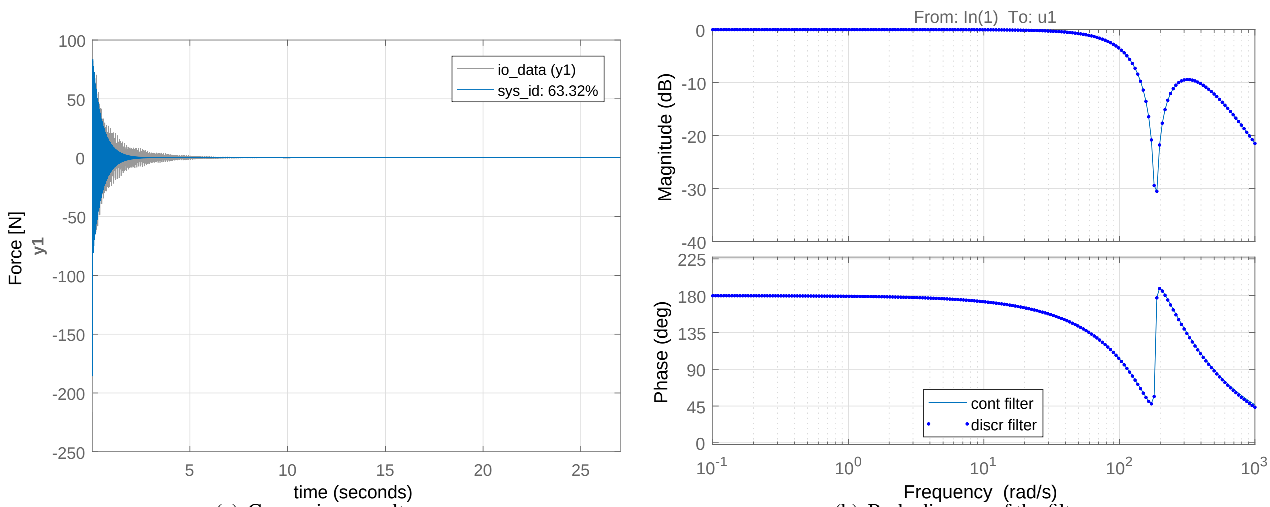
### 4.1 Test bench identification

The motor is placed several meters above ground in order to avoid the exhaust/ground interaction. The structure for mounting the engine is not completely rigid. This sub-section describes the identification of the structural flexibility including the noise filtering.

In order to excite the structure, a mass of several kilograms was extended from the mounting frame of the motor. The rope ended a couple of centimetres above the ground. This static weight puts a little downward stress onto the structure. The rope was then cut with a scissor. The result was a step-wise excitation of the structure. The measurements of the forces and moments are then subject to a system identification procedure.

Before estimating a transfer function using the data, it was necessary to first filter the measurements. A cascade of two low-passes have been used. The filter frequency of the first one was $30Hz$ and the for the second one it was $48Hz$ with damping of 0.6 and 1.0, respectively.

From the Mathworks Identification toolbox the non-linear least-squares search algorithm for minimizing the weighted prediction error norm of a discrete transfer function is used to estimate a transfer function which models the flexible mode.



(a) Comparison results (b) Bode diagram of the filter

Figure 9: Bode diagram of the structural filter and comparison results.

Fig. 9 a) illustrates the response of the identified transfer function and the measurement. The transfer function is then inverted and the two low passes are added. This is shown in 9 b). This filter is used for post-processing of the measurement data. Fig. 10 shows the results of the filtering. As can be seen the effect is reasonably cancelled out.

### 4.2 Vanes transfer functions identified from the experimental data.

This section presents the results of the system identification for the vanes actuators dynamics. These transfer function, (1), (2) where derived @ 80 % engine RPM level using the Mathworks Identification toolbox.

$$H_{Fx}(s) = \frac{Fx(s)}{\delta_{cmd}(s)} = \frac{8372}{s^2 + 127.4s + 1993} \tag{1}$$

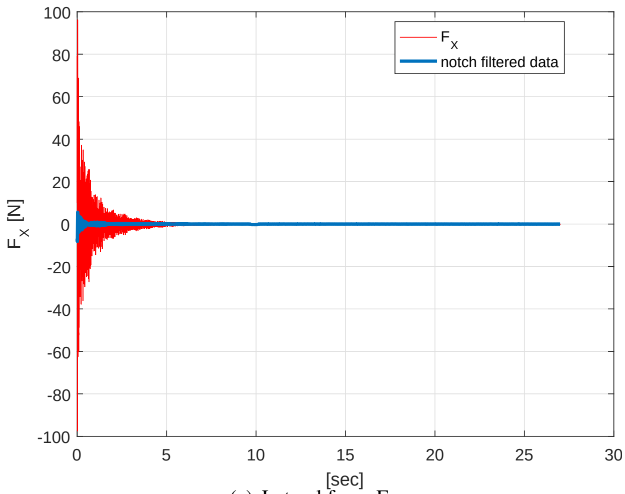
$$H_{Fy}(s) = \frac{Fy(s)}{\delta_{cmd}(s)} = \frac{-6173}{s^2 + 112.5s + 1843} \tag{2}$$

The Fig. 11 shows the measured data input data compared with simulated response of the actuation systems.

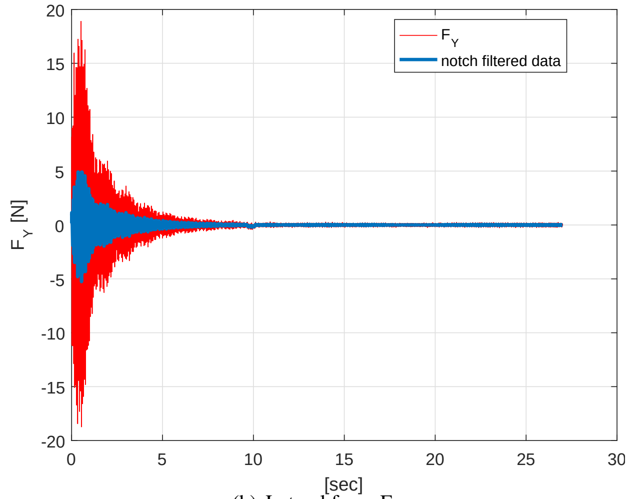
The simulated output of the actuation systems (lateral aerodynamic forces), compared with different experimental data (different from the ones used in identification) is shown in Fig. 12.

DOI: 10.13009/EUCASS2019-925

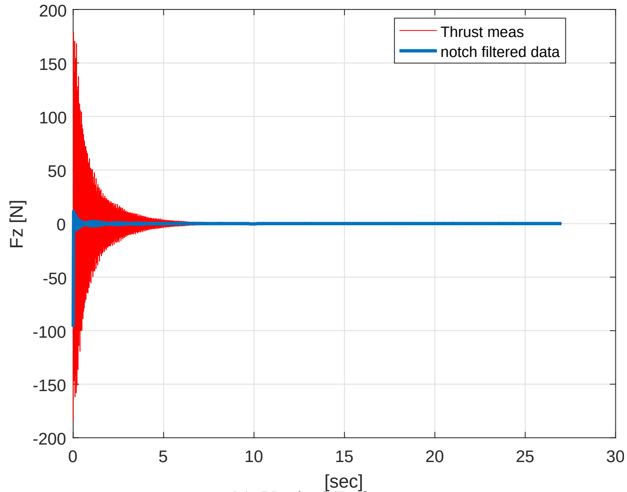





(a) Lateral force Fx

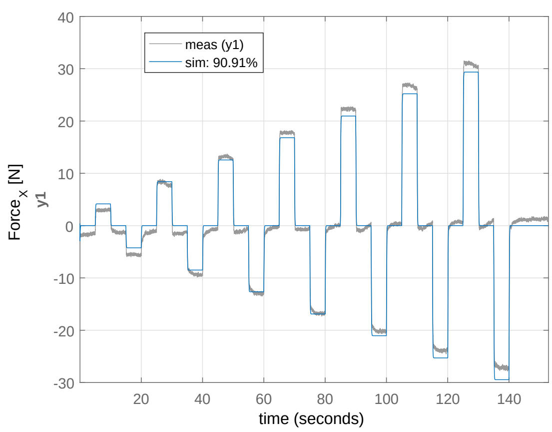



(b) Lateral force Fy

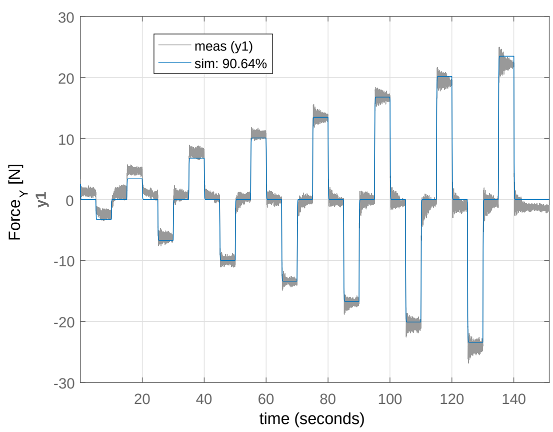



(c) Vertical Fz force

Figure 10: Raw and filtered (notch and low pass filters) experimental data.




(a) Vane X simulated response compared with input data

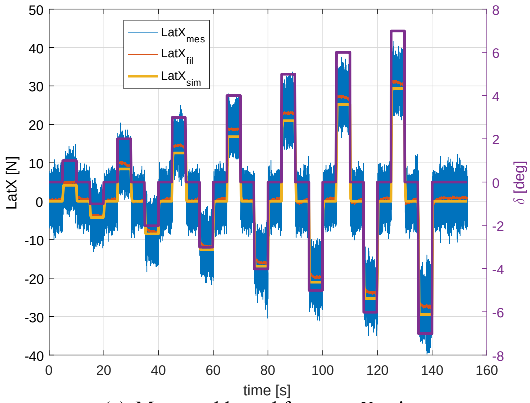



(b) Vane Y simulated response compared with input data

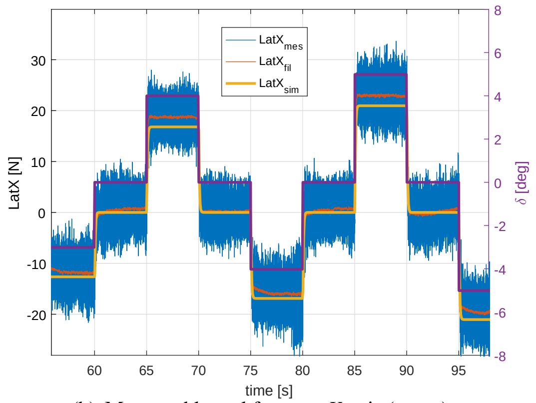
Figure 11: Vanes simulated response compared with input data to the identification function.

DOI: 10.13009/EUCASS2019-925

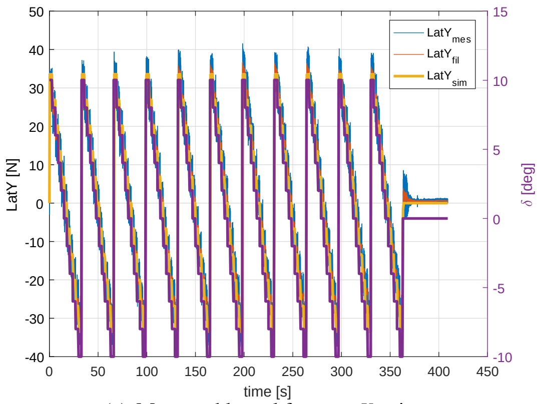




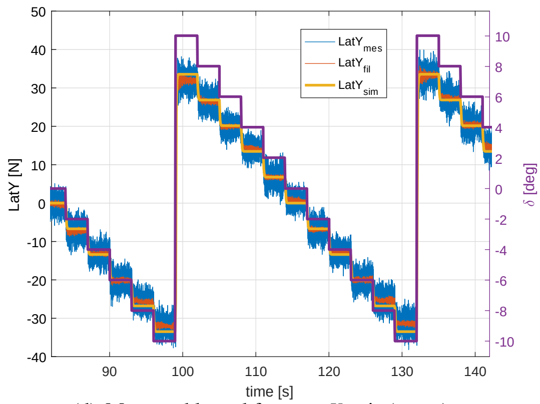

(a) Measured lateral force on $X$ axis




(b) Measured lateral force on $X$ axis (zoom)




(c) Measured lateral force on $Y$ axis




(d) Measured lateral force on $Y$ axis (zoom)

Figure 12: Simulation output compared with experimental data.

DOI: 10.13009/EUCASS2019-925



## 5. Conclusions

This paper presents the work that has been done under Demonstrator for Technologies Validation (DTV) activity that INCAS is in charge of. The design of the reusable testing platform based on a turbojet engine, the test bench and testing procedures are shown. The paper includes a brief presentation of the mechanical design of the VTVL vehicle, the internal structure, the landing gear, the vanes and the roll control system. For this system, an experimental setup has been designed and used for all the tests that were envisioned in the test plan. The purpose of these tests is to update the 6DOF Flight Simulator with the dynamics of each sub-system and make a step forward for the tethered flight test, which is expected to take place in a few months.

## 6. Acknowledgments

Considering the complexity of developing such a system, it is redundant to say that in order to obtain the desired results up until this phase, many more people had to be directly or indirectly involved in the high pace development phases. With this occasion, an acknowledgement is due to Samir Bennani (ESA TEC-SAG) for providing technical guideline throughout the entire development which helped in increasing implementation cycles as well as capabilities, in a fast manner. A special acknowledgement is due to the Romanian Space Agency for providing the necessary support in implementing this project from both technical and programmatic point of view, as well as maintaining such developments relevant on the strategic agenda. This project has received funding from ESA, with the support of the Romanian Space Agency.