

## Experimental evaluation of the contribution of adding a motion system to an EDS

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### INTRODUCTION

The use of flight simulators in pilot training campaigns has become a cheaper and safer alternative to the use of a real aircraft, as simulators will not cause any kind of human injury or vehicular damages. However, the degree of fidelity of the simulation is of the utmost importance for this application, thus it has become the subject of discussion in several studies.

It is understood as a flight simulator with a high degree of fidelity, all kind of simulators that are capable of providing motion cues that are sufficiently similar to those obtained during an actual flight, so much so that a human would be incapable of noticing any difference (Giordano et al., 2010). Many argue that the only way to obtain such a high quality of simulation is by using a motion platform, which makes the cost of this equipment the same order of magnitude of a real aircraft.

Several recent studies have contributed in this topic of discussion, the influence of the motion platform is still unclear (McCauley, 2006), (Proctor, Bauer and Lucario, 2007), (McDaniel, Scott and Browning, 1983). Bürki-cohen, Sparko and Bellman (2011) made a thorough review of the need of motion platforms in aircraft simulators while discusses the need of motion platforms in military helicopter simulators, but

The objective of this work is to analyze the contribution of adding a motion system to an EDS (Engineering Development System), yielding a flexible and reconfigurable simulator, available as soon as the official aerodynamic databank is made available. The advantage (if any) of creating an EDS with motion platform is that it brings to the aircraft development cycle, the opportunity of anticipating the knowledge acquired in the learning-by-using approach, by means of a simulation environment that resembles the behavior of the final product, especially in the early development phases.

The motion platform proposed in this paper is implemented using a COTS anthropomorphic 6-degree-of freedom (DOF) robot; a single pilot seat equipped with inceptors (e.g. sidestick, pedals and throttle controller) and a preliminary visual system. The main purpose of using an industrial robot instead of the conventional Stewart platform is to cause a substantial reduction in the final cost of the motion system, besides the fact that industrial robots have a larger workspace that facilitates the execution of some maneuvers.

To analyze the contribution of adding a motion system to an EDS an experimental procedure that compares flights performed by certified pilots is defined and implemented under two different situations, namely, flights with and without motion cue. For each situation, the pilots must perform a set of three high-gain maneuvers, aiming to evaluate the contribution of the motion system.

## **METHODS**

In this section it is described the development of the experimental procedure to evaluate the contribution of adding a motion system to an EDS. It is also presented the statistical model used to analyze the data from the tests.

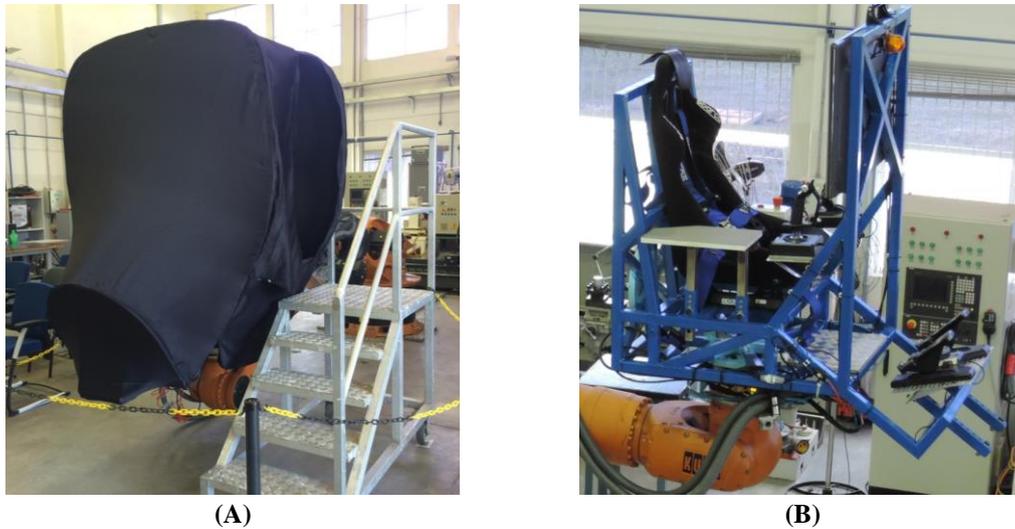
### **Participants**

Three experienced pilots were recruited as volunteers in this experimental procedure. Each of them performed three different maneuvers six times, half of them with motion and the rest of them, without. The testing procedure was sequential and the pilots were under normal conditions of stress.

### **Apparatus**

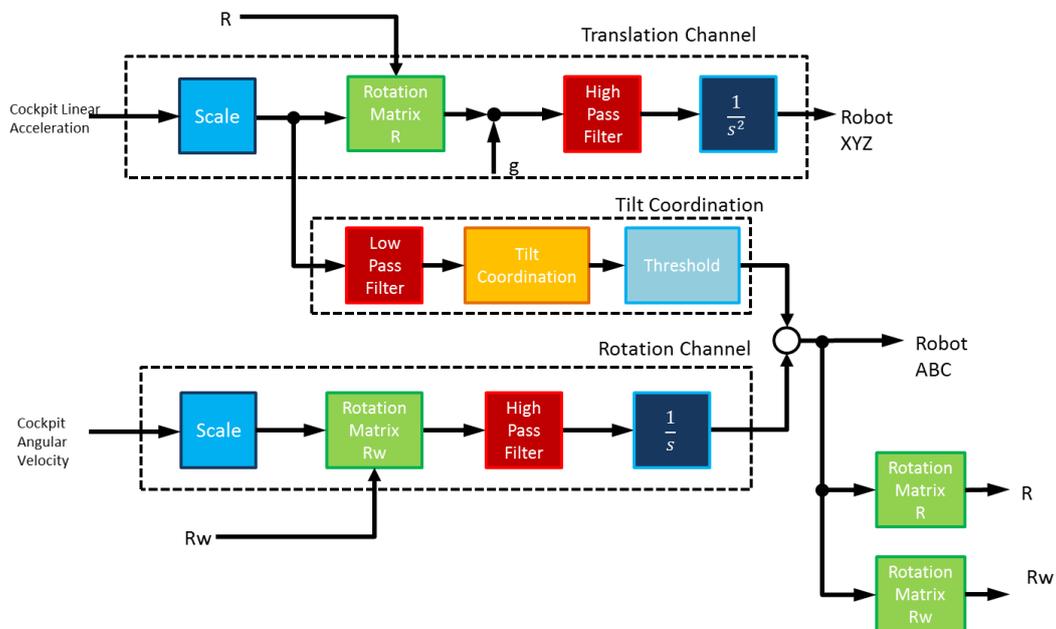
The simulator cockpit shown in Figure 1, consists of a metal frame covered by a sheet of isolating blackout to ensure the pilot does not recognize any external references. Fixed in it are inceptors, a seat and a conventional Full HD LCD TV 42", which consists of the only source of light that the pilot is able to see. The seat is an automobile bucket seat with

a five point safety-belt, the inceptors used are a Saitek™ X52 Pro Flight System (throttle + sidestick) and a Pro Flight Rudder Pedals without force feedback.



**Figure 1 – (A): Cockpit (B): The entire simulator system, cover off.**

For the motion platform, a COTS anthropomorphic 6-degree-of freedom (DOF) KUKA KR-500-2 robot is used. This robot has a payload of 500 kg and a maximum reach of 2826 mm. The motion control system was implemented using LabView™ and it consists of an implementation of the classical washout filter, original implemented by Grant, Reid and Lloyd (1995), as can be seen in Figure 2.



**Figure 2 – Classical washout filter**

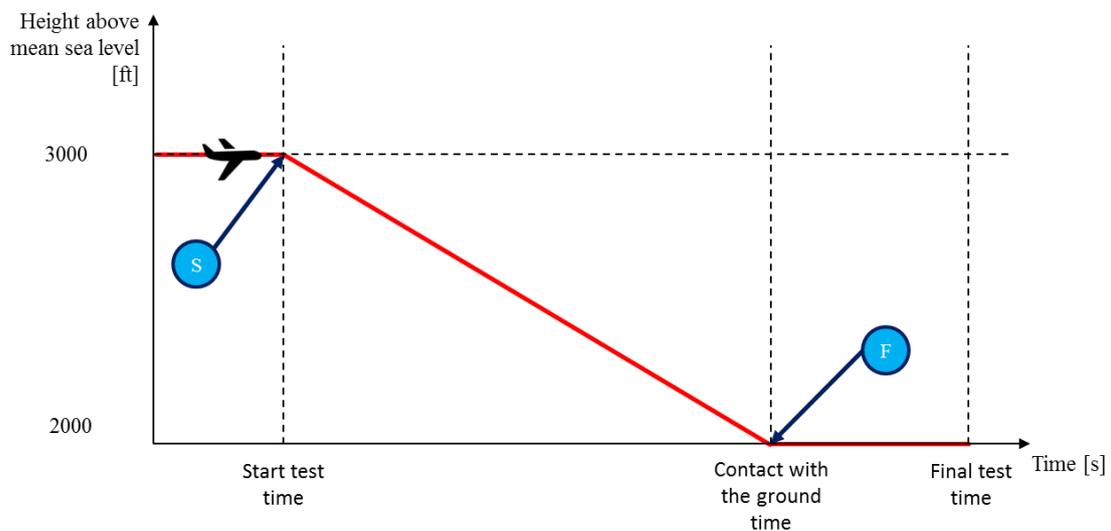
The airplane model used is an EMBRAER Phenom 300 and the visual system is rendered by XPlane 10™.

## Experiment procedure

The procedure is composed of three different flight plans based on high-gain maneuvers that are capable of provoking high degree of pilot compensation, namely: Landing, Offset Landing and Stall Recovery. These flight plans consider some results of Kallus, Tropper and Boucsein (2011) work and were defined with the help of some experienced pilots who integrate the team responsible for this work, and it is a continuation of the correlated work of Arjoni et al (2016).

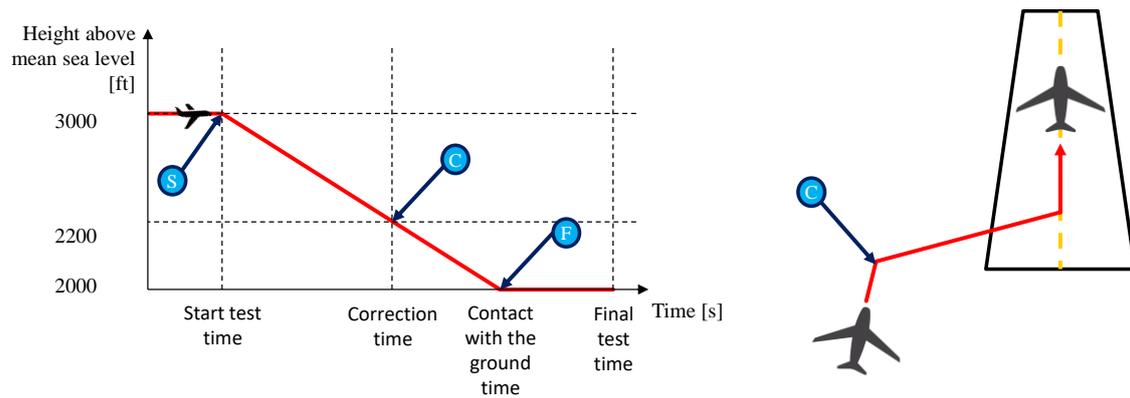
Each course is done under two conditions, with and without motion, and three repetitions were made. The entire testing procedure takes approximately one hour.

The Landing maneuver consists on landing the aircraft at the airport of São José dos Campos (SBSJ). The procedure starts at a height of 3000 ft above the mean sea level. The pilot must perform a full flap command and with help of PAPI (Precision Approach Path Indicator) lands the aircraft at a speed of about 105 knots. The procedure is over as soon as the aircraft comes to a complete stop as depicted in Figure 3.



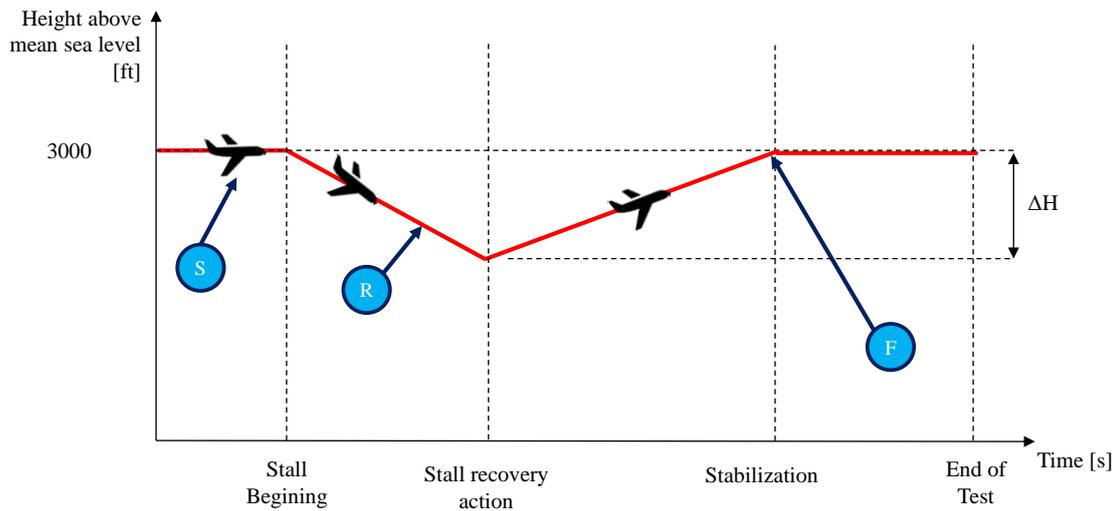
**Figure 3 – Landing procedure**

The Offset Landing maneuver also consists on landing the aircraft at the airport of São José dos Campos (SBSJ), the procedure starts with the aircraft at a height of 3000 ft above the mean sea level aligned in the left runway. At a height of 200 ft above the ground, the pilot must align with the middle runway and with the help of PAPI (Precision Approach Path Indicator) lands the aircraft with an approach speed of 105 knots. The test ends when the aircraft completely stops and must be done with a full flap command. Figure 4 is the representation of this procedure.



**Figure 4 – Landing procedure**

The Recovery from Stall maneuver starts with the aircraft at a height of 3000 ft above the mean sea level, the pilot must perform a full flap command and induce a stall condition by reducing throttle to 30%. After a stall warning, the pilot must recover the aircraft as fast as he can, while on full throttle, pitching down the aircraft and commanding flap to position 1. The objective is to maintain altitude loss to a minimum altitude. The test ends when the aircraft achieves the height of 3000 ft above the mean sea level again or be stable for more than 10 seconds. The procedure is represented in the Figure 5.



**Figure 5 – Recovery from Stall Procedure**

## Statistical Procedure and Analysis

The behavioural analysis of the flight is made offline and is based on the data collected during the experimental runs. For the landing and offset landing maneuvers the pilot's workload is collected, which consists of the integral of the sidestick position, in the recovery from stall maneuver, aside from the workload, the altitude lost during the procedure is also collected for precision analysis.

The pilots involved in the experiment are considered as a blocked parameter, so the variation originated from them can be extracted from the simulation mode, considered the main factor, with two levels: dynamic simulation and static simulation.

Equation (1) is an ANOVA model used to test the influence of the motion in the performance of the pilot. The significance of the experiment is 10%.

$$V_{ij} = \mu + M_i + \beta_j + e_{ij} \quad (1)$$

where:

$V_{ij}$ : Output value: Mean, Standard deviation, workload or efficiency;

$\mu$ : General output mean;

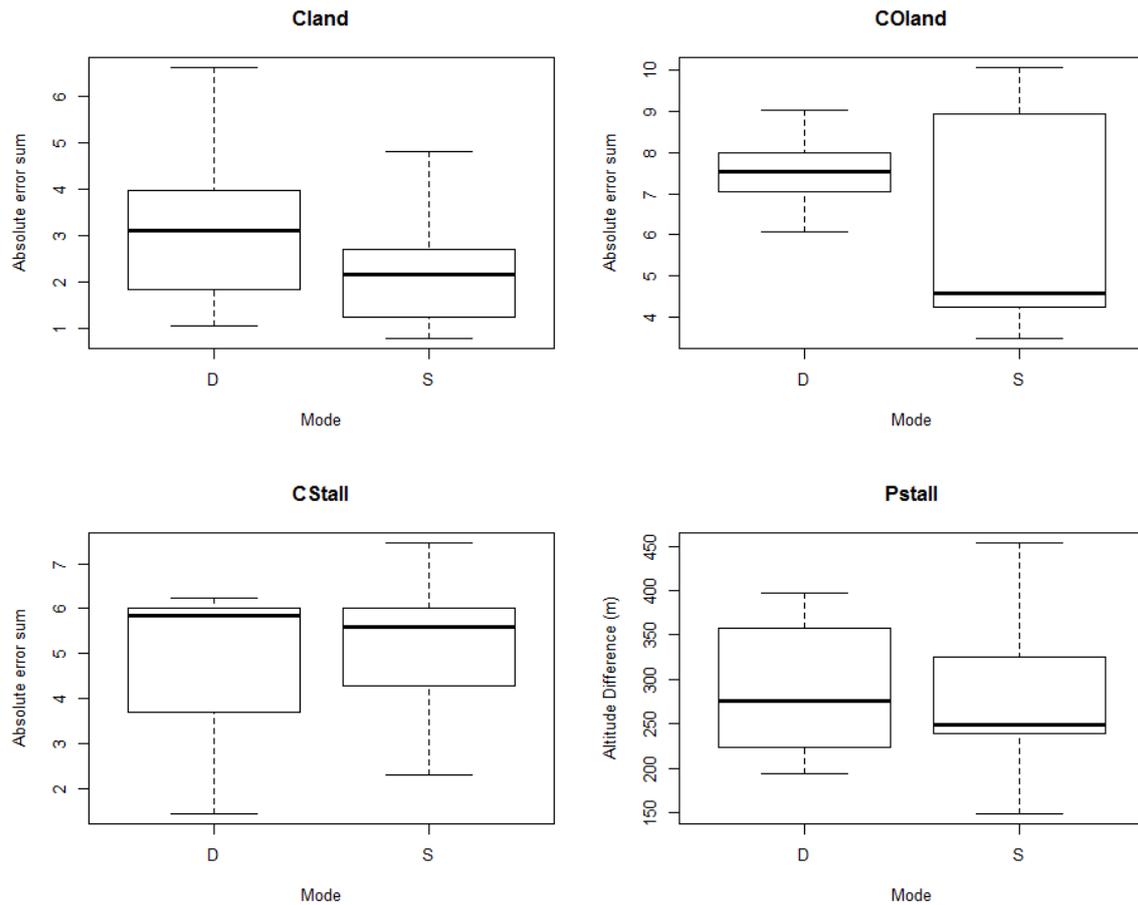
$M_i$ : Simulation mode variance;

$\beta_j$ : Pilot block variance;

$e_{ij}$ : Random error variance.

## RESULTS AND DISCUSSION

All the output variables collected during the test runs were subjected to an analysis of normality verification, to validate the ANOVA test (Montgomery, 2013). In the Landing, Offset Landing and Stall Recovery Workload maneuvers the data sets corresponding a normal distribution, although in the Stall Recovery Precision analysis it was necessary to exclude some detected outliers, which don't affected the validation of the test. The summary of the data collected during the test runs is represented by the boxplots displayed in the Figure 6; the boxes are represented by the letters S (Static) and D (Dynamic).



**Figure 6 – Boxplots from collected data**

Once proved the data normality, they were subjected to the ANOVA model presented in the previous session. Tables 1 to 4 resume the analysed variables involved in the experiment.

**Table 1 – ANOVA results of precision on stall recovery**

<b>Dstall - Precision on Stall Recovery</b>					
	<b>Df</b>	<b>Sum Sq</b>	<b>Mean Sq</b>	<b>F-Value</b>	<b>Pr (&gt;F)</b>
<b>M</b>	1	40	40	0,01	0,9205
<b>P</b>	2	55964	27982	7,28	
<b>Residuals</b>	14	53812	3844		

**Table 2 – ANOVA results of workload on stall recovery**

<b>Cstall – Stall Recovery Workload</b>					
	<b>Df</b>	<b>Sum Sq</b>	<b>Mean Sq</b>	<b>F-Value</b>	<b>Pr (&gt;F)</b>
<b>M</b>	1	0,89	0,886	1,555	0,238
<b>P</b>	2	38,64	19,322	33,89	
<b>Residuals</b>	11	6,27	0,57		

**Table 3 – ANOVA results of workload on offset landing**

<b>COland - Offset Landing Workload</b>					
	<b>Df</b>	<b>Sum Sq</b>	<b>Mean Sq</b>	<b>F-Value</b>	<b>Pr (&gt;F)</b>
<b>M</b>	1	9,73	9,726	3,857	0.0697
<b>P</b>	2	30,96	15,481	6,139	
<b>Residuals</b>	14	35,31	2,522		

**Table 4 – ANOVA results of workload on landing**

<b>Cland - Landing Workload</b>					
	<b>Df</b>	<b>Sum Sq</b>	<b>Mean Sq</b>	<b>F-Value</b>	<b>Pr (&gt;F)</b>
<b>M</b>	1	3,023	3,023	4,941	0.0432
<b>P</b>	2	31,12	15,561	25,43	
<b>Residuals</b>	14	8,566	0,612		

The analysis of data shows a significance of the motion platform addition in Landing and Offset Landing maneuvers. It can be notice a tendency of workload increasing when the motion cue is enabled.

The Stall Recovery analysis doesn't result in a significance of the motion platform addition, it can be addressed to a non-representative dynamic model of the aircraft in a stall condition. The simulation of the behavior in this situation can be considered as a challenge both for aeronautical and simulation development.

The sample size was sufficient to indicate a tendency of the motion significance, although a greater number of pilots would yield a more robust experiment.

## CONCLUSIONS

The current work focused on analyzing the contribution of adding a motion system to an EDS, and the conclusion is that there is a tendency of the relevance in the addition of motion, as can be seen in the section above. Even though there is not enough data to make a definitive claim, this work served as a way to highlight the best maneuvers to focus the studies on in the future as well as the ones that are simply not influenced by the motion at all.

Future works may include an extension of the testing procedures to generate a more reliable analysis, as well as including other maneuvers and the introduction of new dimensions to the simulation fidelity, such as implementing the avionics in the pilot's control panel and installing a control load system to the yoke.

## **ACKNOWLEDGES**

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