Aerospace technology Congress - FT 2019

Assessment of Pilot-Aircraft Interface as a Conceptual Design Tool

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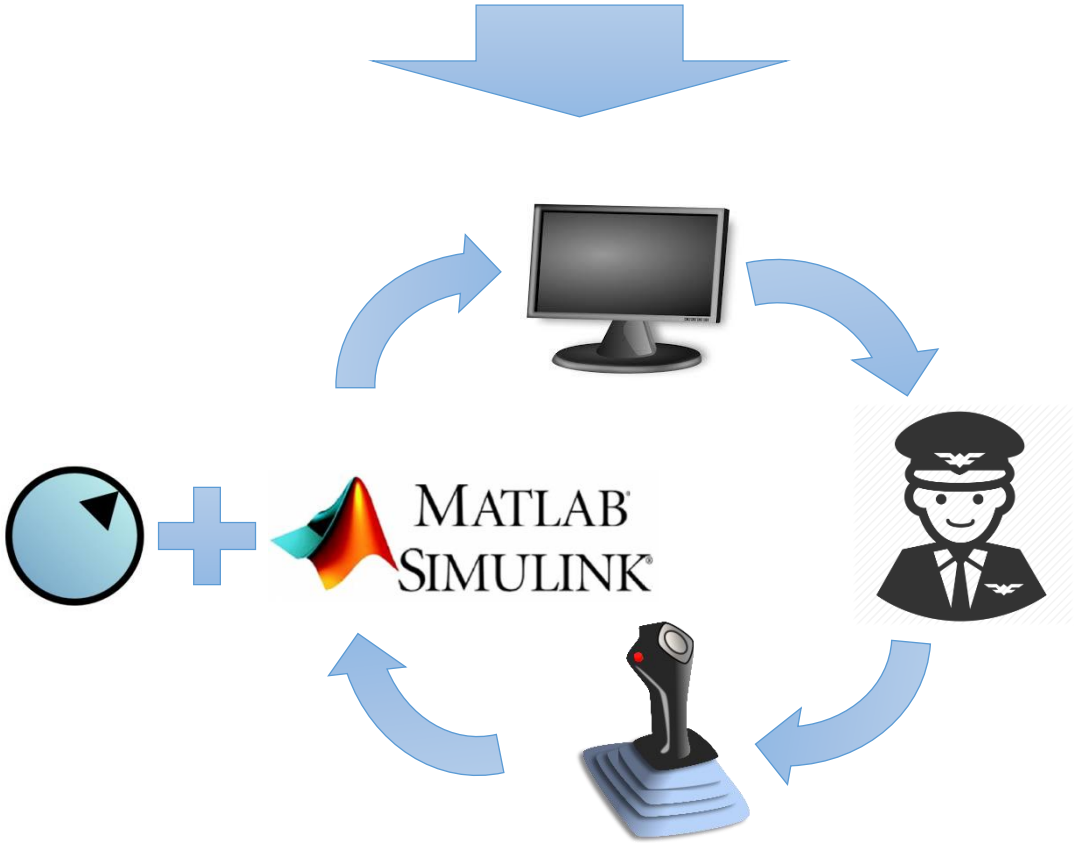
October 08, 2019

Where I come from…

- The city of São José dos Campos in Brazil

Contextualization

- Introduction of unstable aircraft configuration with dynamic trim canard



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EFFECTS OF TAILORED CONTROL SURFACE COMPLIANCE ON AIRCRAFT STABILITY AND CONTROL

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Keywords: pitch stabilization, canard, human in the loop simulation

Abstract

The aircraft design problem is an example of a highly integrated design, which calls for a multidisciplinary approach from the very beginning. With every generation of aircraft, it gets more difficult to make substantial improvements since so much have already been done to make aircraft as possible. Next generation civil aircraft needs to take every possibility to increase efficiency. One potential area of improvement is to reduce drag due to the requirement of positive stability. However, with the present state of the art it is difficult to get a system that can artificially stabilize an aircraft, certified. If this can be overcome, there are potential gains in drag, since all horizontal surfaces can be used for lift. Another advantage is that a wider range for center gravity can be allowed. In flight control the input signal to the aircraft are usually taken to be position of control surfaces. This is then translated to requirements on the actuation system, where the natural compliance of these systems is regarded, as something unwanted, when in fact it can also be used to tailor characteristics also at the aircraft level. This is relevant to both civil and military aircraft. The approach used here is to look at control surface actuators and different means to utilize also force control, possibly together with position control, and to introduce compliance in proper positions of the system. The pressure feedback is evaluated in a simulation environment using HOPSAN simulation package. Furthermore, an experiment is performed with the pilot in the loop to evaluate the different values of feedback gain. Statistical analysis of the results shows a significant influence of feedback level in the ability of the pilot to control the aircraft.

1 Introduction

Looking at future aircraft concept, one recurring concept is that of aft mounted prop fans. This is a problematic configuration from a center of gravity (CG) point of view, where a large portion of the weight is located aft. Therefore, the distance between wing and tail becomes short, resulting in considerable trim drag, unless a canard configuration is used. This is aggravated by the fact that the CG position is changing considerably between empty and fully loaded. One example of an aircraft using this three wing configuration is the Piaggio Avanti. However, in order to minimize drag the optimum lift distribution between the wing surfaces would result in an unstable configuration, Kendall [2].

Canard wing configuration is also common in military aircraft, pioneered in the Saab AJ37 Viggen in the sixties and subsequently in the Saab 39 Gripen, the Euorfighter Typhoon, the Dassault Rafale etc. Modern fighters are always are dynamically unstable and relay on an electronic control system for stabilization.

A hydraulic concept of a dynamic load trim actuator is shown in Fig. 1 as an example. It is essential that the solution is robust to ensure certification, e.g. implemented with passive control for civil aircraft. This system is nothing more than an adjustable spring, represented by the accumulator and thus need no active servo control.

1

Objective

- Understand pilot-aircraft interaction from early stages of design

How does performance vary among different pilots?

How is the pilot's behaviour and performance affected by HMI?

Can we obtain a pilot model for design optimization?

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EXPERIMENT

Performance analysis

Eye tracker analysis

Optimization of pilot model

Design of Experiment

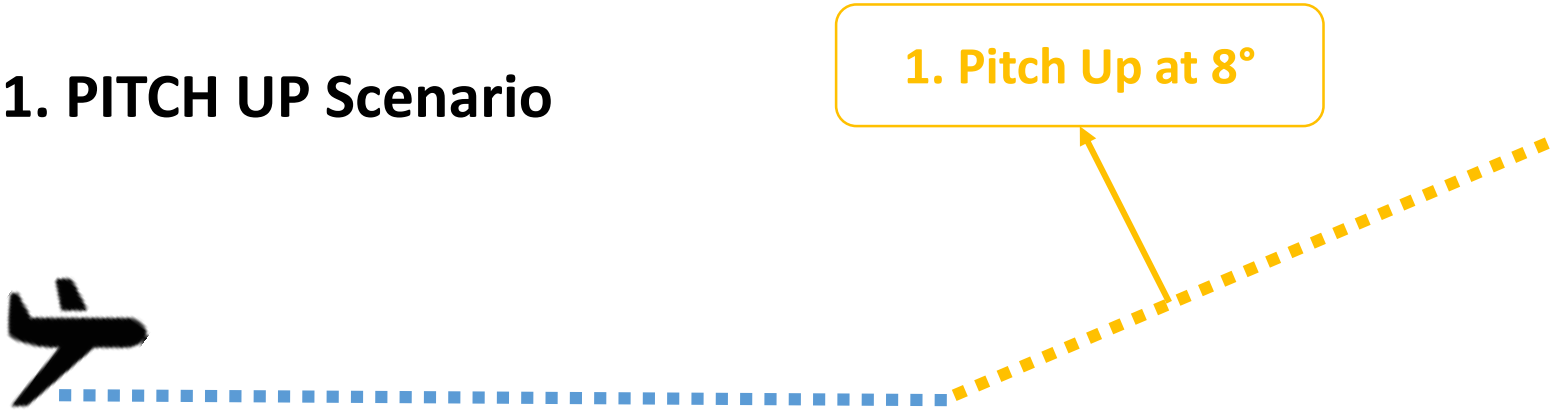
TASK: Track the pitch reference

- 4 Scenarios
  - Normal flight
  - Pitch up
  - Pitch down
  - Disturbance
- 2 HMI
  - Graphic
  - Numeric
- 2 Pilots
  - Pilot 1
  - Pilot 2

3 Repetitions → 48 Flights

Experiment Factors - Scenario

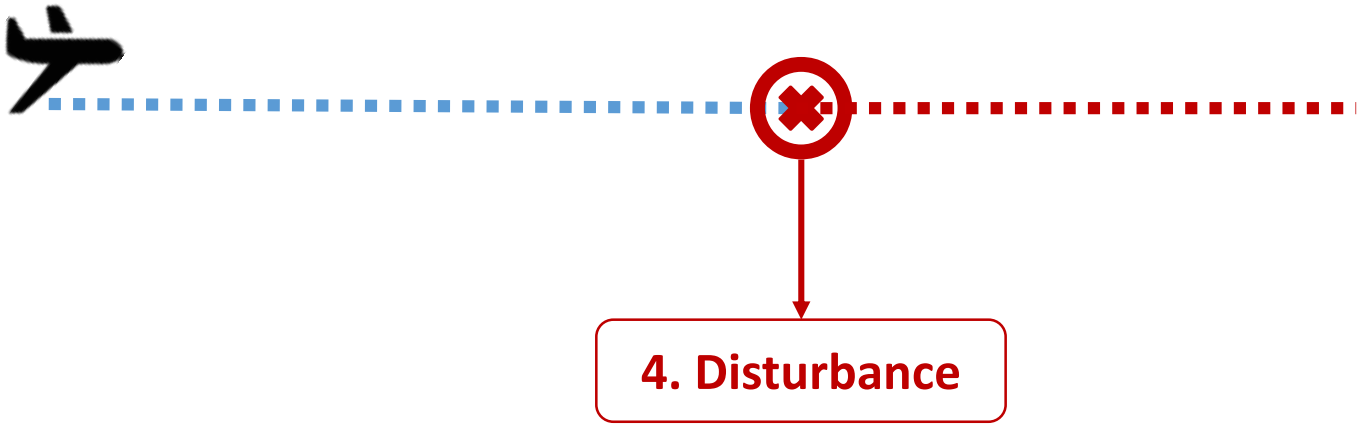
1. PITCH UP Scenario



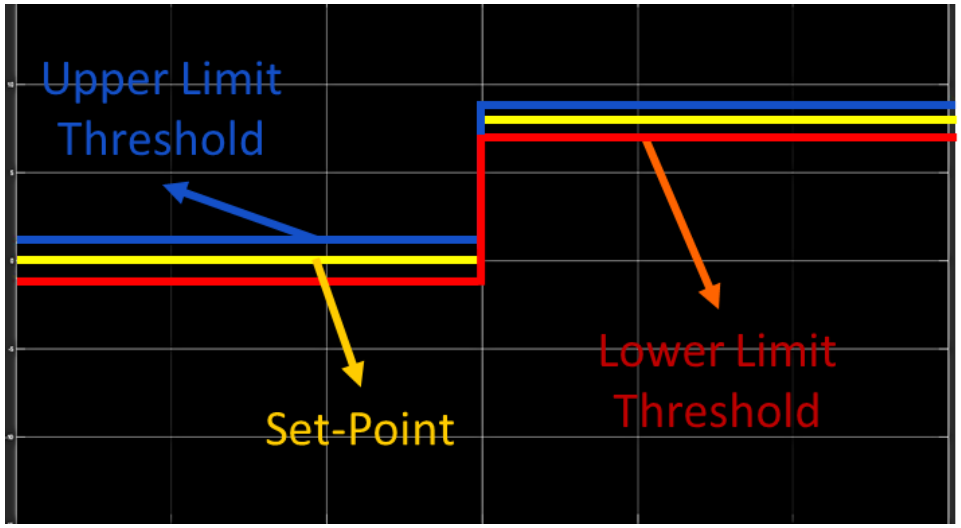
2. PITCH DOWN Scenario

3. NORMAL FLIGHT Scenario

4. DISTURBANCE Scenario



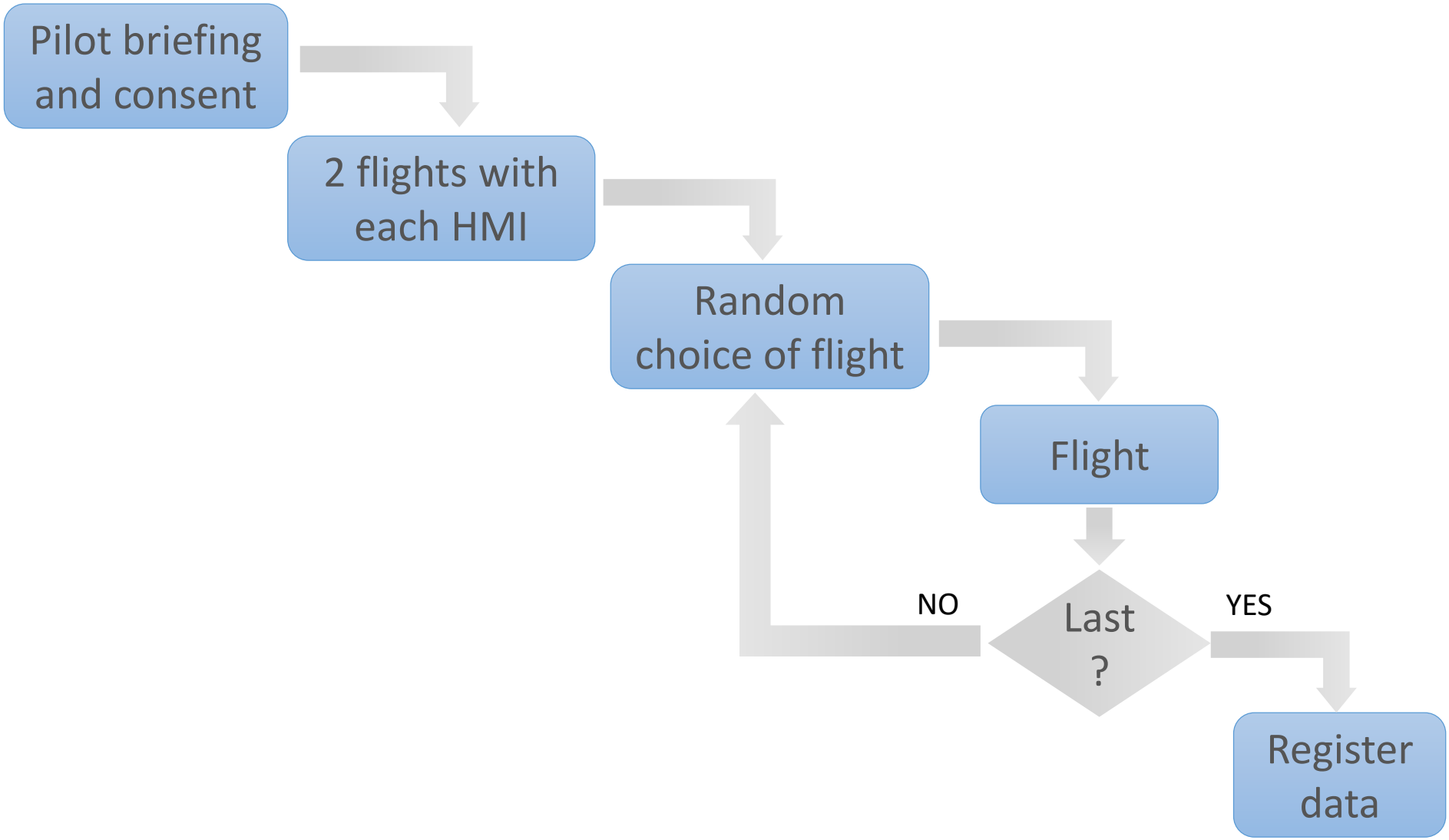
Experiment Factors - HMI



FLIGHTGEAR

MATLAB
SIMULINK

Experiment Procedure

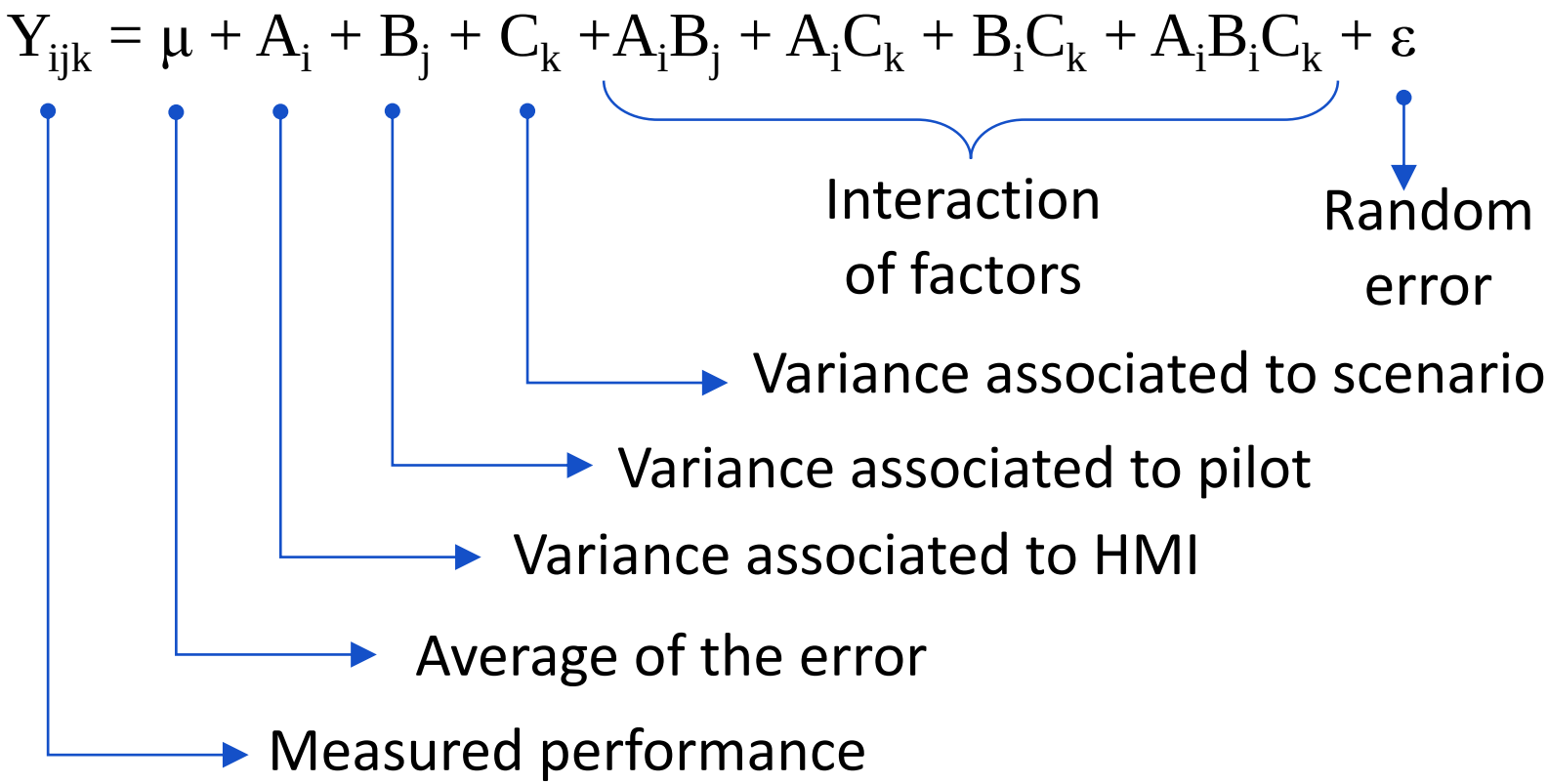


- Performance Metric:

$$Error = \frac{\sum(Pitch - SetPoint)^2}{Data\_length}$$

- ANOVA - Analysis of Variance:
  - Approach A - Single data set
  - Approach B - One data set per scenario

- ANOVA – Approach A: 1 data set

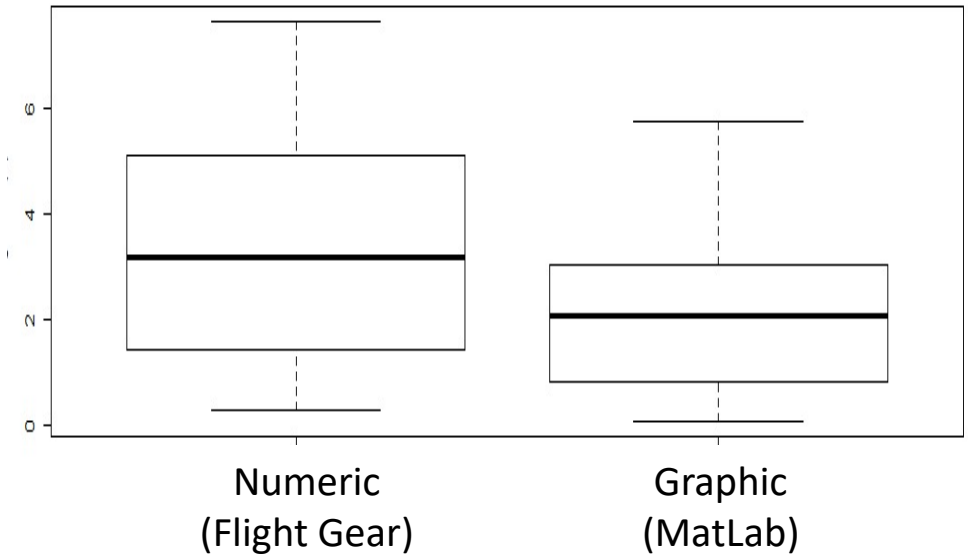


- ANOVA – Approach A: 1 data set

All Flights	
Interface Influence	0,000118
Flight Influence	1,1E-11
Pilot Influence	8,38E-05
Pilot x Interface	0,090645
Pilot x Flight	0,450191
Interface x Flight	0,045131
Interface x Flight x Pilot	0,881769
Outliers	#2, #18, #30

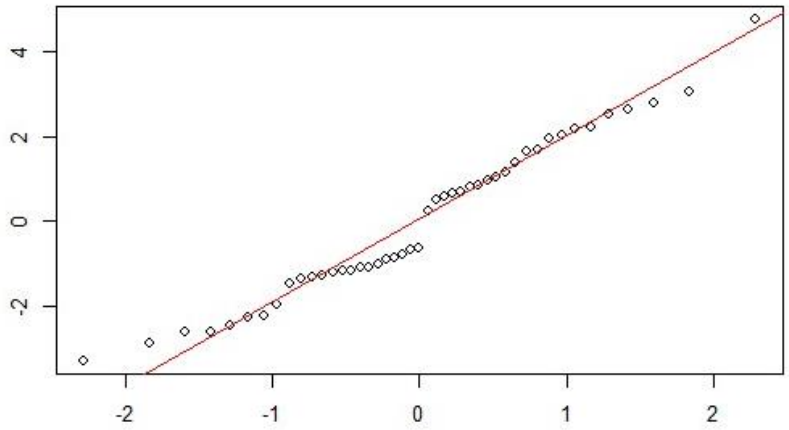
All three factors affect the mean error, i.e., the pilots performance.

Error *versus* Interface



- ANOVA – Approach A: 1 data set

Normal Q-Q Plot

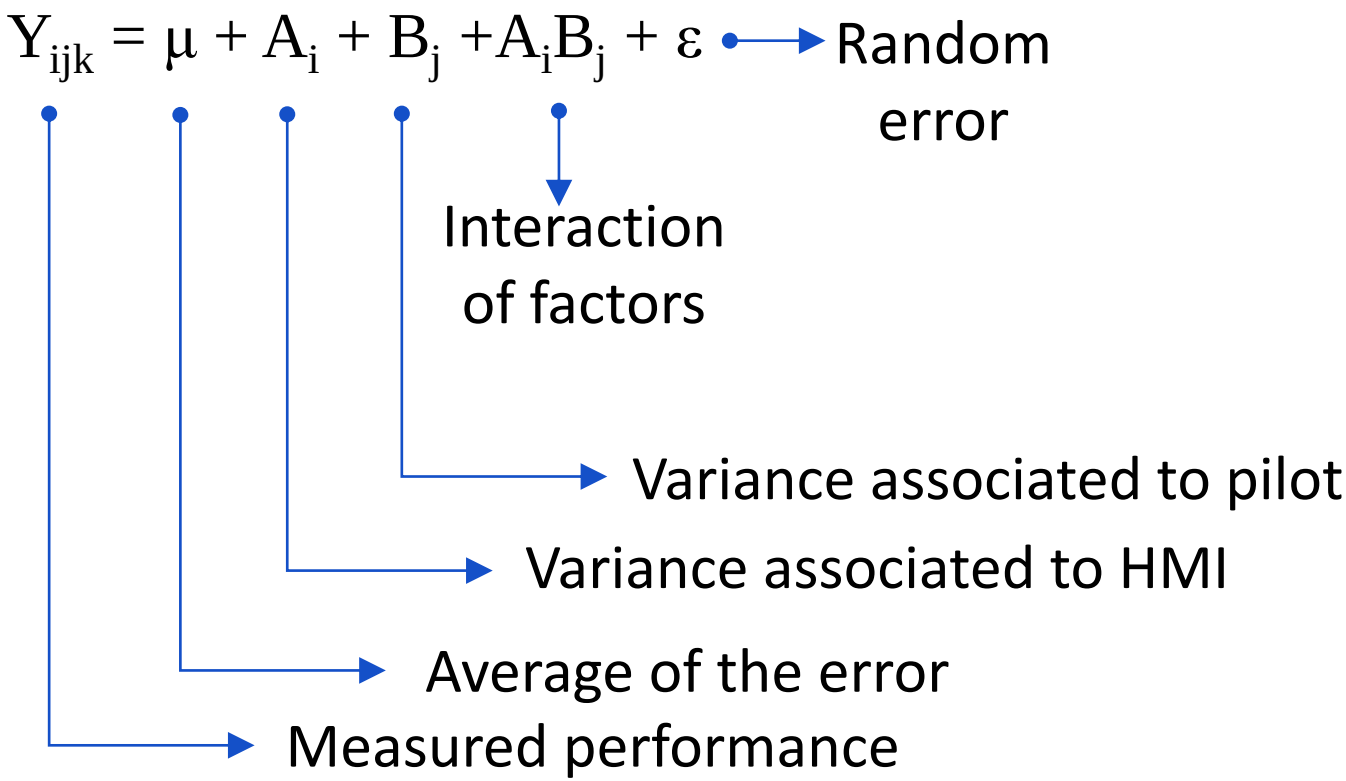


Data follows normal distribution

All Flights	
Shapiro-Wilk	0,05133
Bartlett for Pilot	0,7193
Bartlett for Flight	0,0043
Bartlett for Interface	0,1241

Variances are not homogenous

- ANOVA – Approach B: 4 datasets



- ANOVA – Approach B: 4 datasets

Stimulus	Interface Influence	Pilot Influence	Interaction influence	Outliers
Pitch-Up	0,0483	0,3347	0,4583	#2, #12
Pitch-Down	0,0313	0,0176	0,2748	
Normal	0,1672	0,0012	0,033	#6
Disturbance Flight	0,0149	0,1146	0,595	

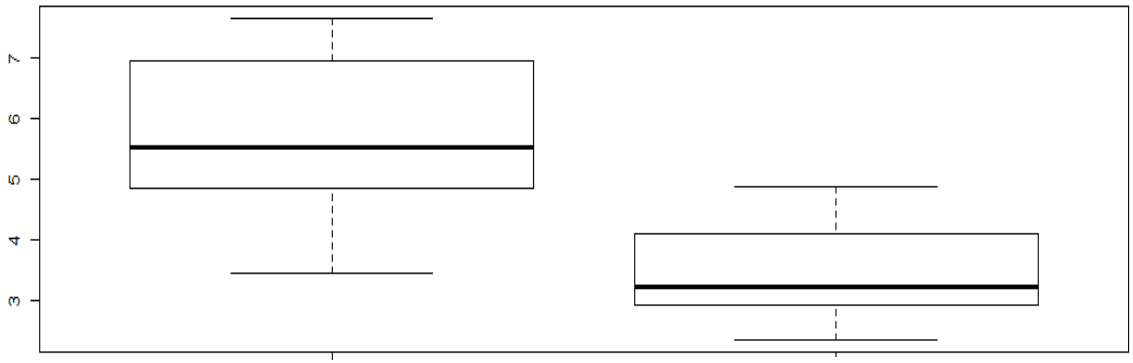
Interface is the most relevant factor

Stimulus	Shapiro-Wilk	Bartlett for Pilot	Bartlett for Interface
Pitch-Up	0,9495	0,2134	0,3454
Pitch-Down	0,128	0,8563	0,3942
Normal	0,516	0,0565	0,0799
Disturbance Flight	0,1679	0,6836	0,8444

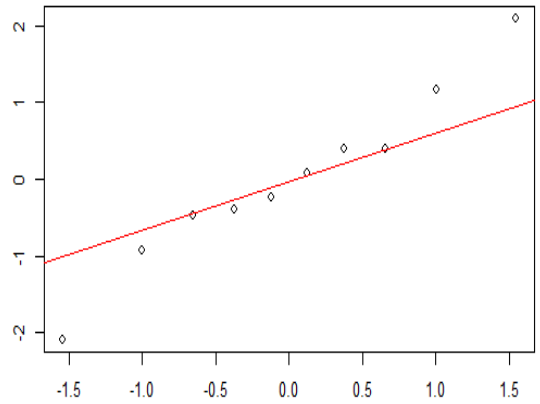
Data follow normal distribution and are homogenous

Performance Analysis

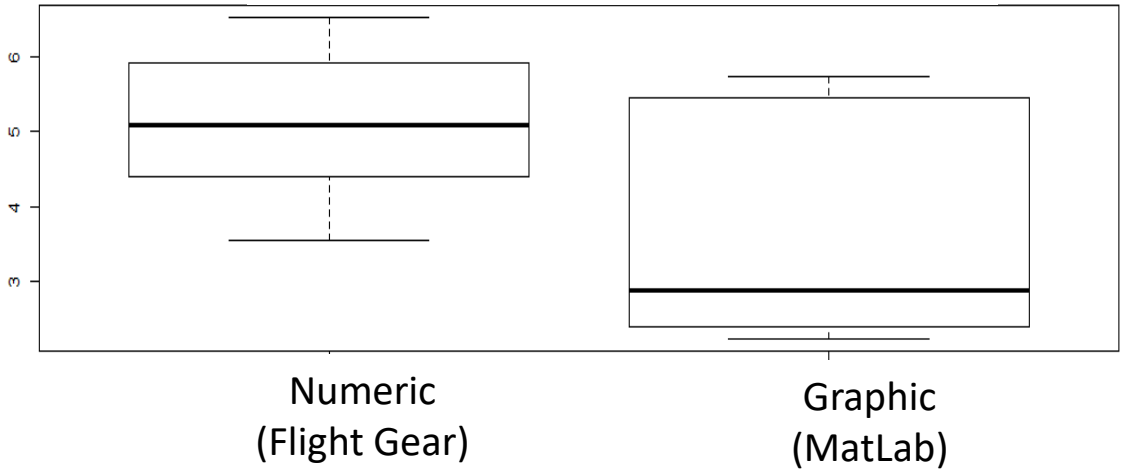
Error *versus* Interface – PITH UP



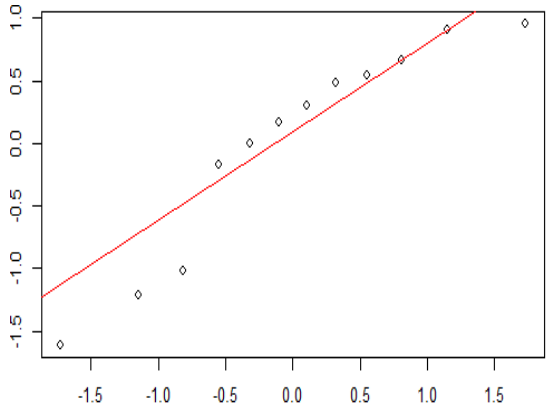
Normal Q-Q Plot



Error *versus* Interface – PITH DOWN

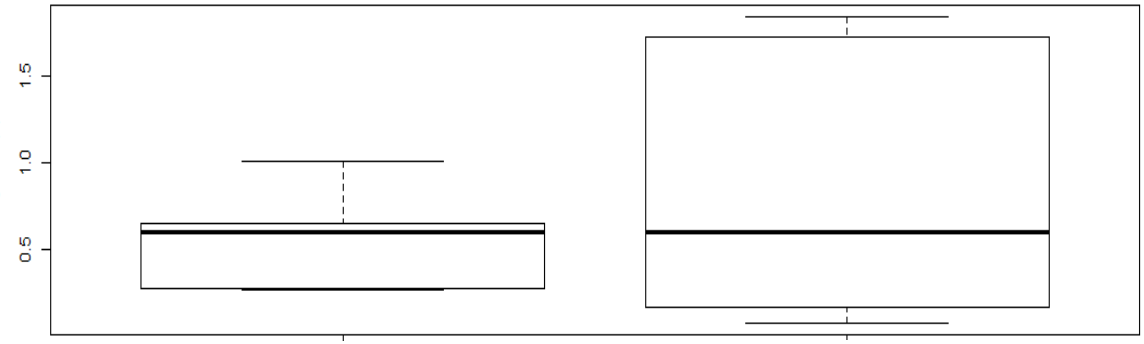


Normal Q-Q Plot



Performance Analysis

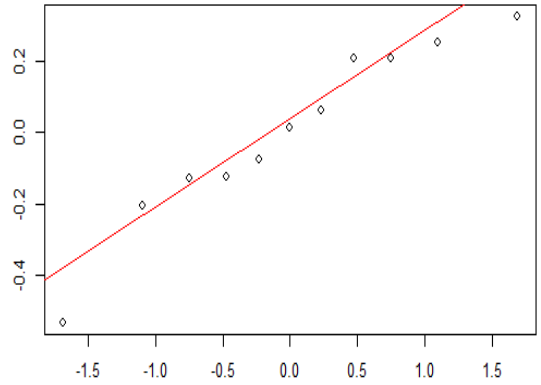
Error *versus* Interface – NORMAL



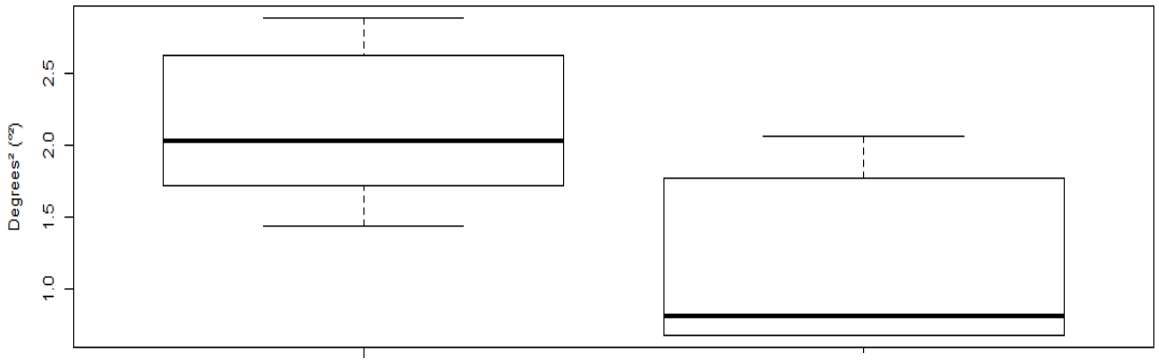
Numeric
(Flight Gear)

Graphic
(MatLab)

Normal Q-Q Plot



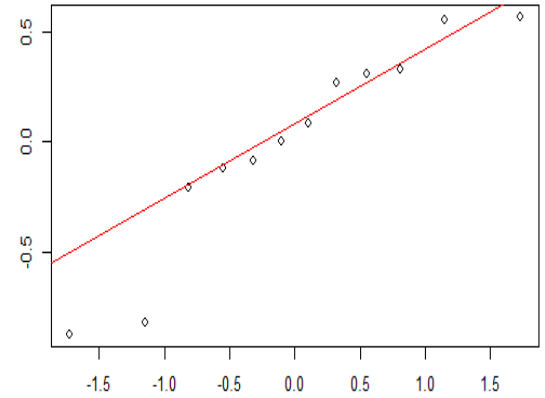
Error *versus* Interface – DISTURBANCE



Numeric
(Flight Gear)

Graphic
(MatLab)

Normal Q-Q Plot

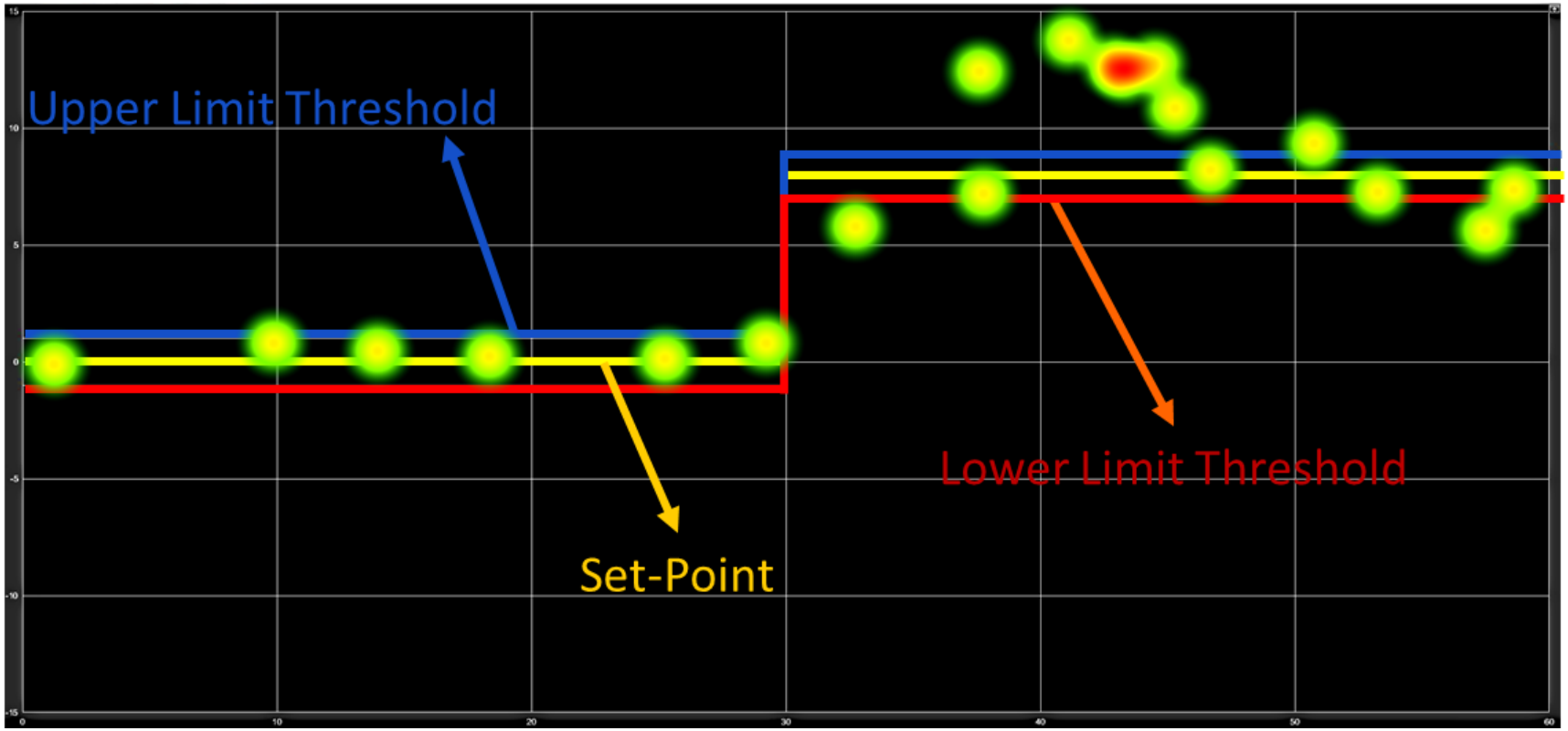


Eye-Tracker Analysis

- Heat map of attention – Numeric Interface

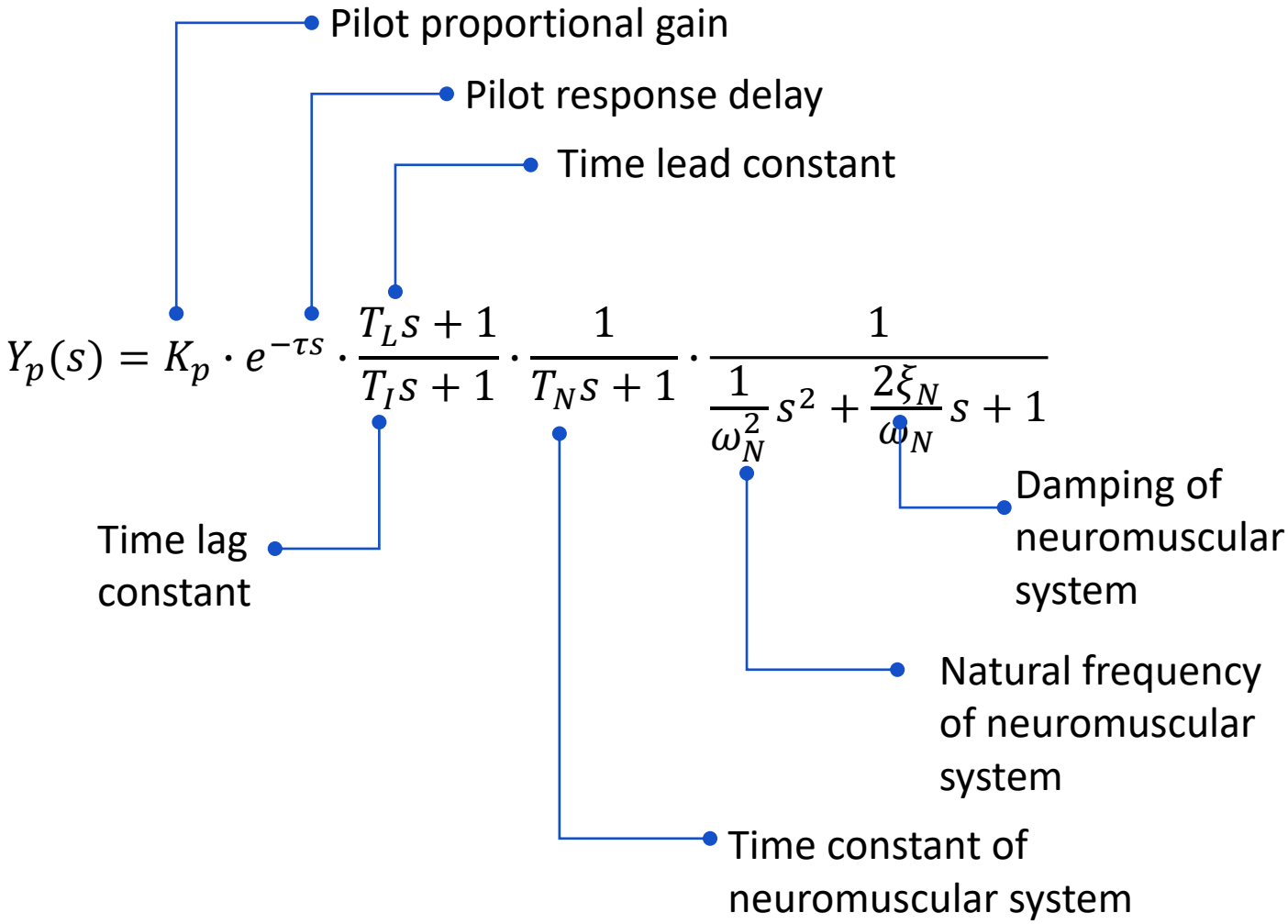
Eye-Tracker Analysis

- Heat map of attention – Graphic



Pilot Model

- Precision Model



- Precision Model

$$Y_p(s) = K_p \cdot e^{-\tau s} \cdot \frac{T_L s + 1}{T_I s + 1} \cdot \frac{1}{T_N s + 1} \cdot \frac{1}{\frac{1}{\omega_N^2} s^2 + \frac{2\xi_N}{\omega_N} s + 1}$$

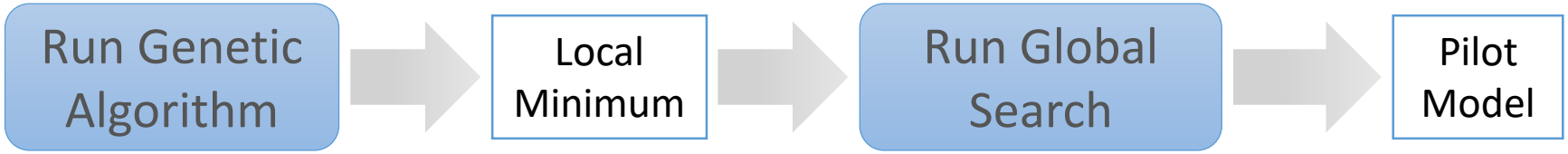
Adapt to rate or speed control ($T_L = T_I$)

$$Y_p(s) = K_p \cdot e^{-\tau s} \cdot \frac{1}{T_N s + 1} \cdot \frac{1}{\frac{1}{\omega_N^2} s^2 + \frac{2\xi_N}{\omega_N} s + 1}$$

Insert trim constant

$$Y_p(s) = K_p \cdot e^{-\tau s} \cdot \frac{1}{T_N s + 1} \cdot \frac{1}{\frac{1}{\omega_N^2} s^2 + \frac{2\xi_N}{\omega_N} s + 1} + C$$

Pilot Model Optimization



- Genetic Algorithm - limited range of parameters:
  - K_p: Range for pilot gain [0.0001; 1]
  - τ: Range for pilot delay [0.001; 1]
  - T_N: Range for time constant of neuromuscular system [0.001; 1]
  - ω_N: Undamped frequency for the neuromuscular system stabilized on 25
  - ξ_N: Damping ratio for the neuromuscular system Range [0.1; 1]
  - C: Trim Constant Range [-1; 1]

Pilot Model Optimization

- Cost function:
  - P_1: Inceptor rate factor (0.99)
  - P_2: Aircraft rate factor (0.01)
  - E_I: Inceptor error (real command minus modelled command)
  - E_A: Aircraft pitch error (real pitch minus modelled pitch)
  - n: Length of the dataset

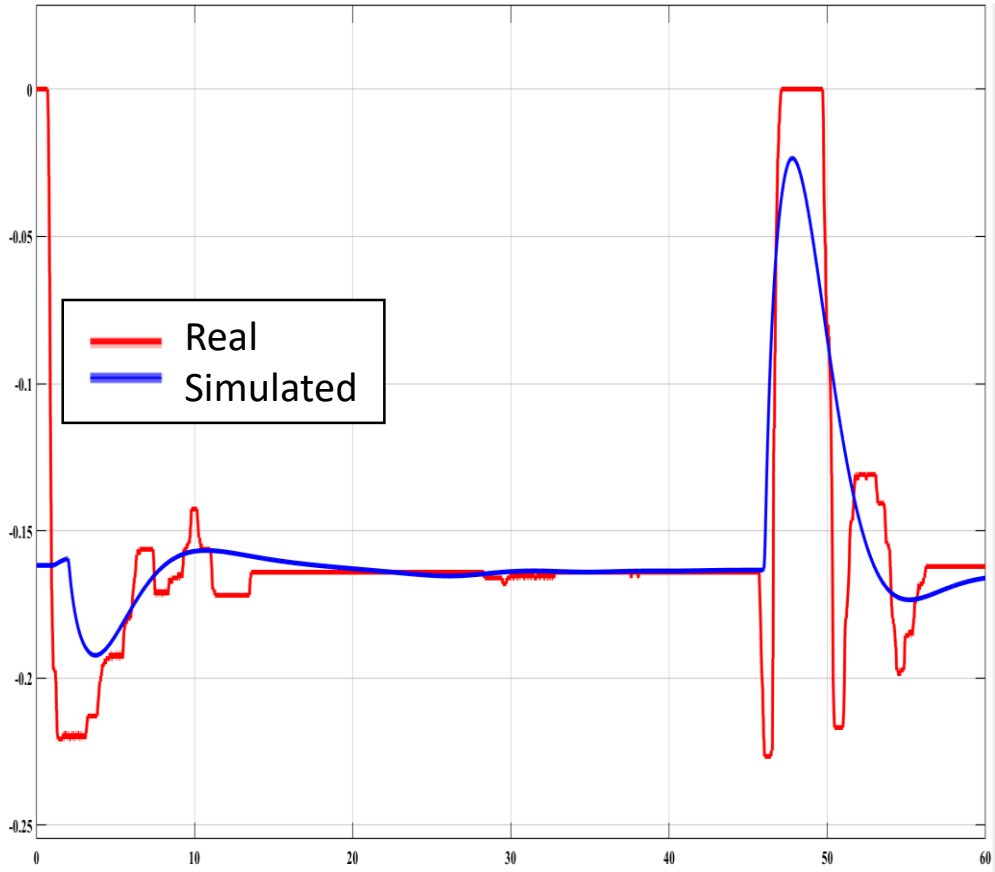
$$F = P_1 \cdot \sqrt{\frac{\sum {E_I}^2}{n}} + P_2 \cdot \sqrt{\frac{\sum {E_A}^2}{n}}$$

Pilot Model Optimization

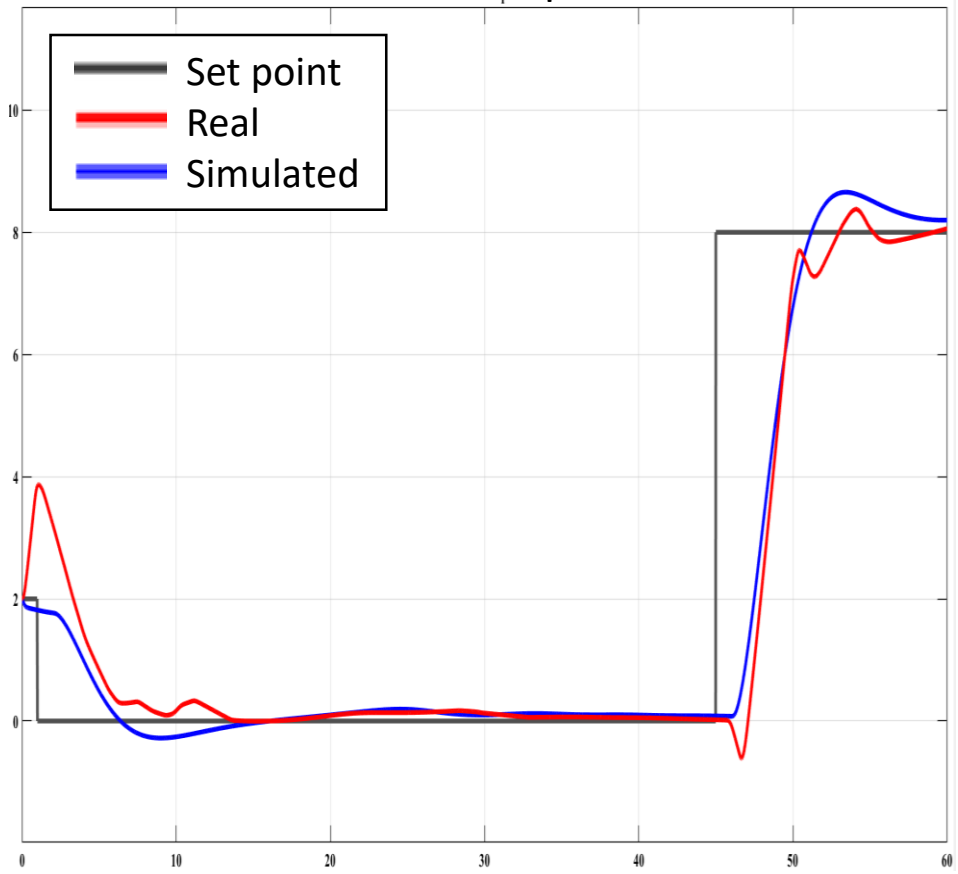
Model of Pilot 1

$$Y_p(s) = 0.0190 \cdot e^{-0.9923s} \cdot \frac{1}{0.5502s + 1} \cdot \frac{1}{\frac{1}{25^2}s^2 + \frac{2 \cdot 0.9279}{25}s + 1}$$

Inceptor Output



Aircraft Response

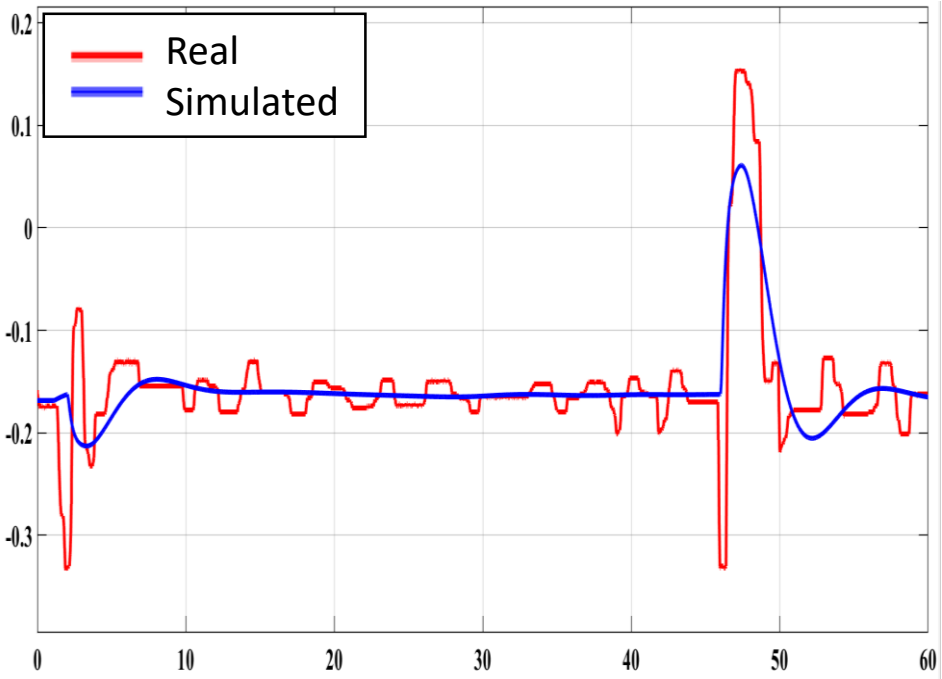


Pilot Model Optimization

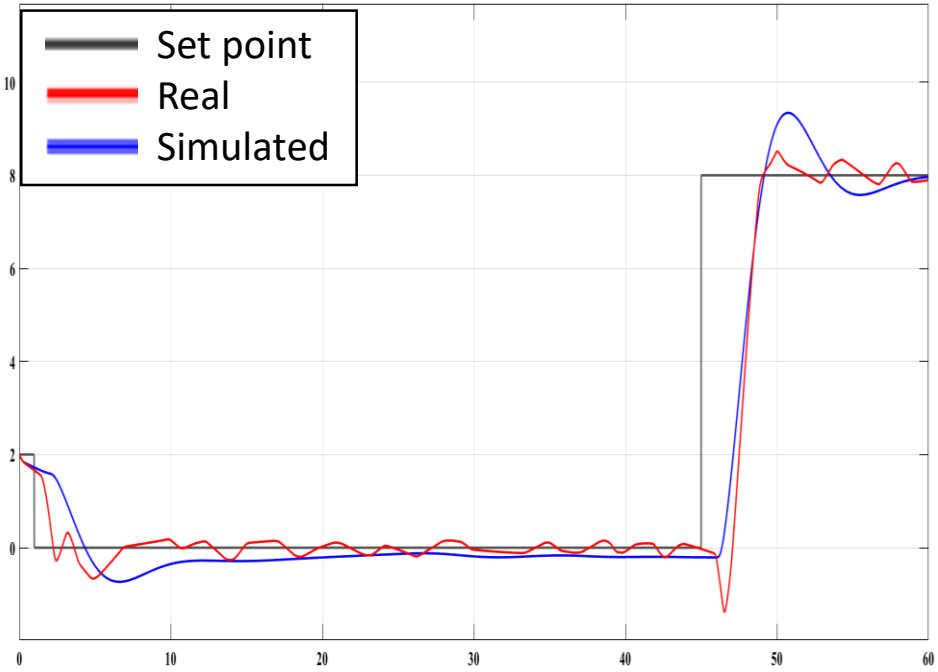
Model of Pilot 2

$$Y_p(s) = 0.0288 \cdot e^{-0.9957s} \cdot \frac{1}{0.3224s + 1} \cdot \frac{1}{\frac{1}{25^2}s^2 + \frac{2 \cdot 0.9448}{25}s + 1}$$

Inceptor Output



Aircraft Response



Conclusions and Next Steps

How does performance vary among different pilots?

How is the pilot's behaviour and performance affected by HMI?

Can we obtain a pilot model for design optimization?

Conclusions

Performance is affected by pilot, manoeuvre and HMI.

Different models for different pilots.

Future work

Extend experiment to a large pilot population.

Development of statistical pilot models.

Thank You

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