Experimental Evaluation of the Human Performance on a Robotic Flight Simulator Based on FOQA Parameters

Diego H. Arjoni , G. Rocha, R. Pereira, A. H. Moreira, R. M. Nicola ,W. R. de Oliveira, A. V. S. Silva, G. S. Natal, L. Silveira, E. Thomaz, E. Villani, L. G. Trabasso

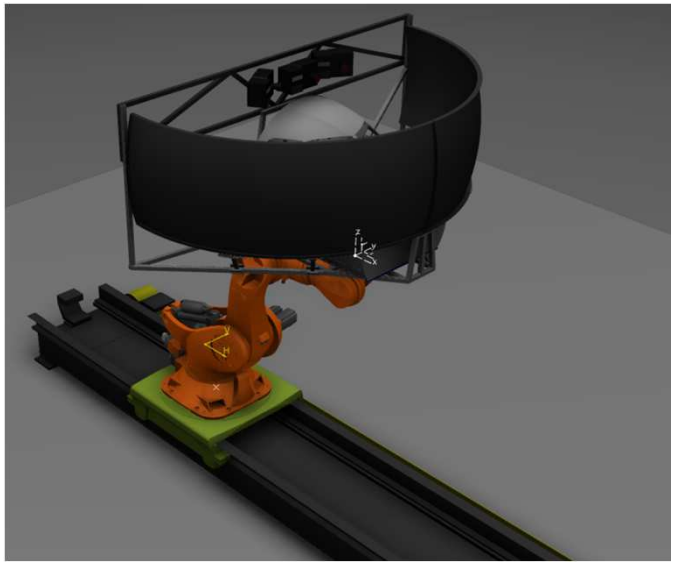
CENTRO DE COMPETÊNCIA EM MANUFATURA

ITA

- ITA – Aeronautics Institute of Technology
- Engineering school from Brazilian Air Force
- Located in the Brazilian aerospace cluster, in São José dos Campos

SIVOR Project

- Flight simulator based on industrial robot;
- Development tool available at early stages of aircraft lifecycle;
- Easily customized to different aircrafts;

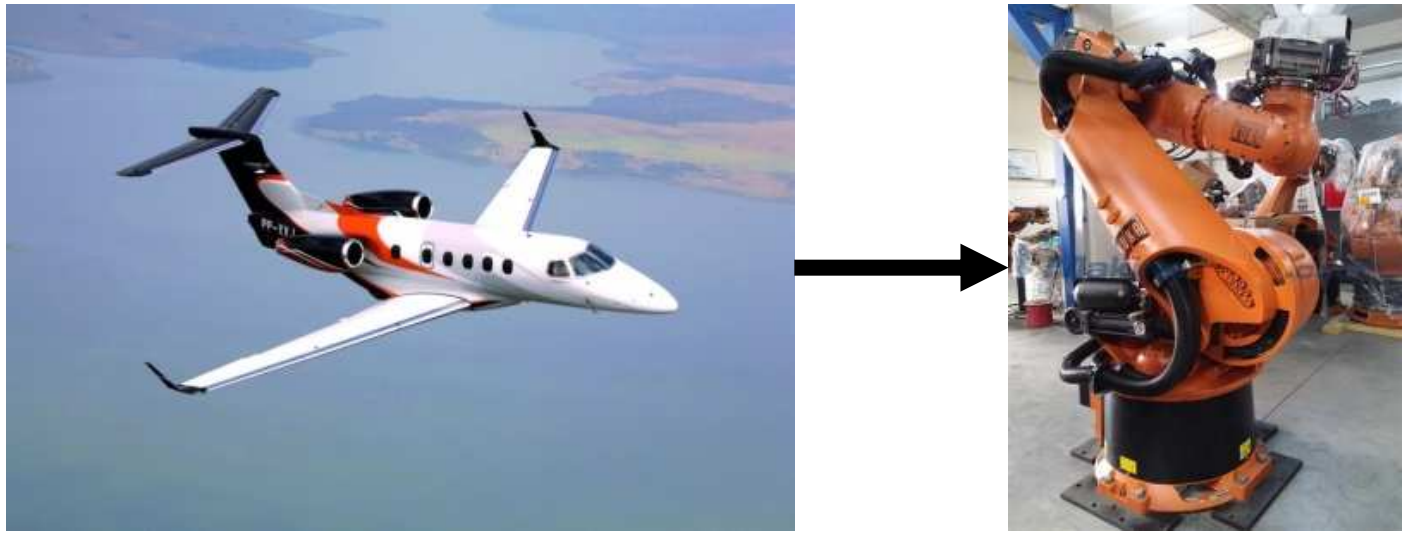


SIVOR under development
High degree of fidelity

SIVOR preliminary version

Washout Filter

- From the ‘infinite’ aircraft workspace to the finite robot envelope;
- Based on the human perceptions systems;



The Problem

Certification and evaluation of simulators are **subjective** to **pilots opinion**

Can we **measure** the influence of the flight simulator **motion** in the **pilot** behaviour?

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- Mathematical models of human systems
- Behavioural indicators

FOQA derived behavioural variables

Purpose

Can we use behavioural parameters derived from FOQA to quantify the influence of the motion cue of SIVOR?

- Definition of a set of metrics
- Experimental analysis

FOQA

- FOQA -> Flight Operational Quality Assurance
- FOQA events have a binary characteristic
- In a real flight of an airline the pilot must follow the imposed FOQA thresholds

Liftoff Speed High	An event to determine the relationship of the actual liftoff speed to V_2.	Air/Ground Switch, Gross Weight, CAS Air/Ground = Ground, CAS > V_2 + x knots for x seconds	V_2 is calculated based on Gross Weight.
Liftoff Speed Low	An event to determine the relationship of the actual liftoff speed to V_2.	Air/Ground Switch, Gross Weight, CAS Air Ground = Air, CAS < V_2 – x knots for x seconds	V_2 is calculated based on Gross Weight.
Pitch High at Takeoff	An event that measures pitch at takeoff in relation to the angle required to strike the tail of the aircraft.	Air/Ground Switch, Pitch Air/Ground = Ground, Pitch > x degrees	Limits are based on the angle required for the tail cone to contact the ground with struts compressed.
Takeoff Climb Speed High	An event to detect climb speed higher than desired during the Takeoff Phase of flight.	CAS, Gross Weight, HAT HAT > x feet, HAA < x feet, CAS > V_2 + x knots	Altitude ranges should be used to accommodate different desired climb speeds in those ranges. In certain ranges, the climb airspeed will be based on V_2.

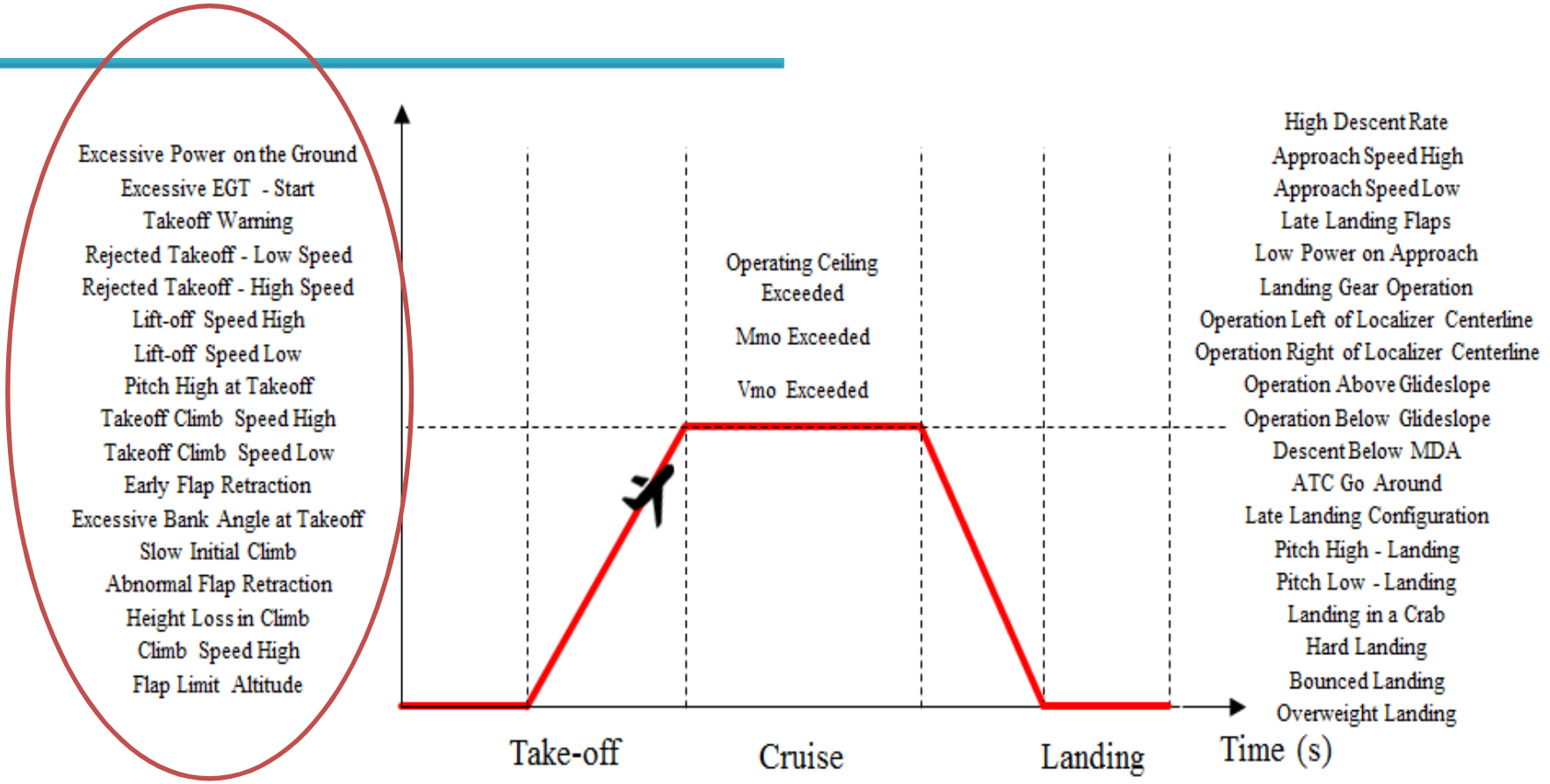
Metrics Definition

FOQA

FOQA derived manoeuvre

Is the **speed** affected by the simulator **motion**?

FOQA Events

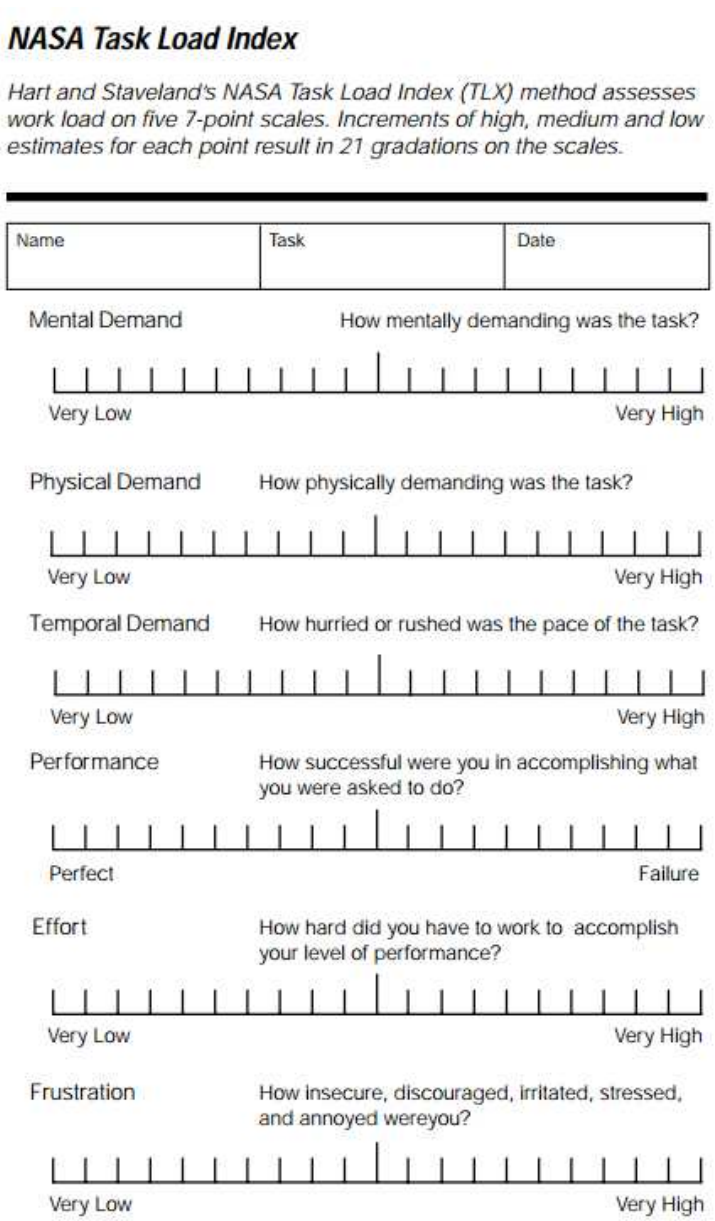


Focus of this work:

- Straight forward execution;
- Good interaction between pilot and aircraft.

Behavioural Parameters

- Behavioural parameters derived from NASA TLX (Task Load Index)



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

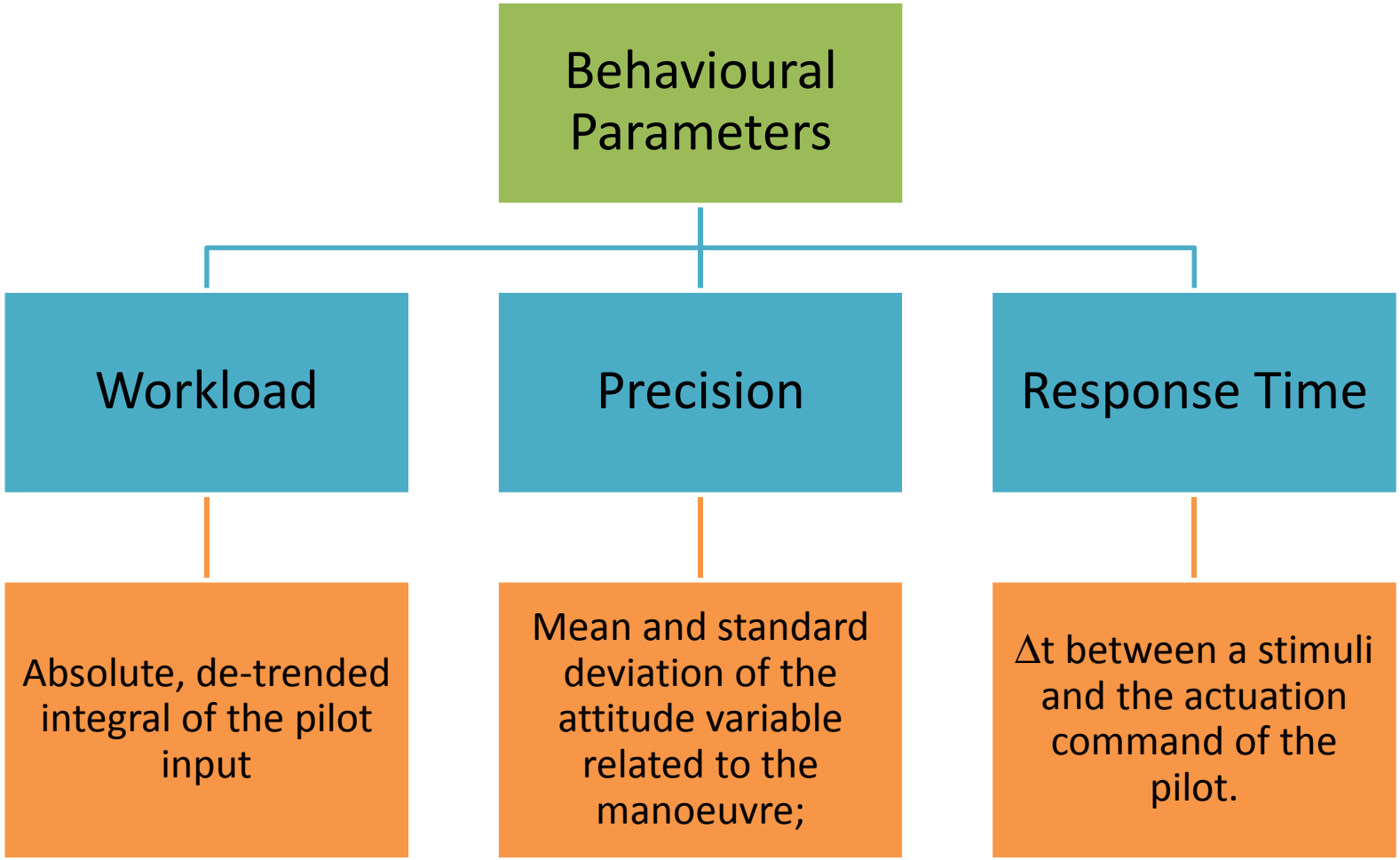
Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Behavioural Parameters



FOQA Events

- Analysis of the take-off FOQA events:
  - Can we associate it with our behavioural parameters?
  - Does it requires strong pilot-aircraft interface?

N	Event	Test Potential	N	Event	Test Potential
1	Excessive Power on the Ground	1	14	Turbulence - Flaps Extended	1
2	Excessive EGT – Start	1	15	Slow Initial Climb	0
3	Engine Overtemp	1	16	Abnormal Flap Retraction	1
4	Takeoff Warning	2	17	Height Loss in Climb	1
5	Rejected Takeoff - Low Speed	3	18	Climb Speed High	1
6	Rejected Takeoff - High Speed	3	19	Flap Limit Altitude	1
7	Lift-off Speed High	5	20	Turbulence - Flaps Up	2
8	Lift-off Speed Low	5	21	Holding/Excess Radar Vectoring	0
9	Pitch High at Takeoff	3	22	Landing Gear Down Speed Exceeded (Mach)	1
10	Takeoff Climb Speed High	3	23	Stick Shaker Operation	0
11	Takeoff Climb Speed Low	3	24	Engine Failure	0
12	Early Flap Retraction	2	25	TCAS Advisory	0
13	Excessive Bank Angle at Takeoff	5			

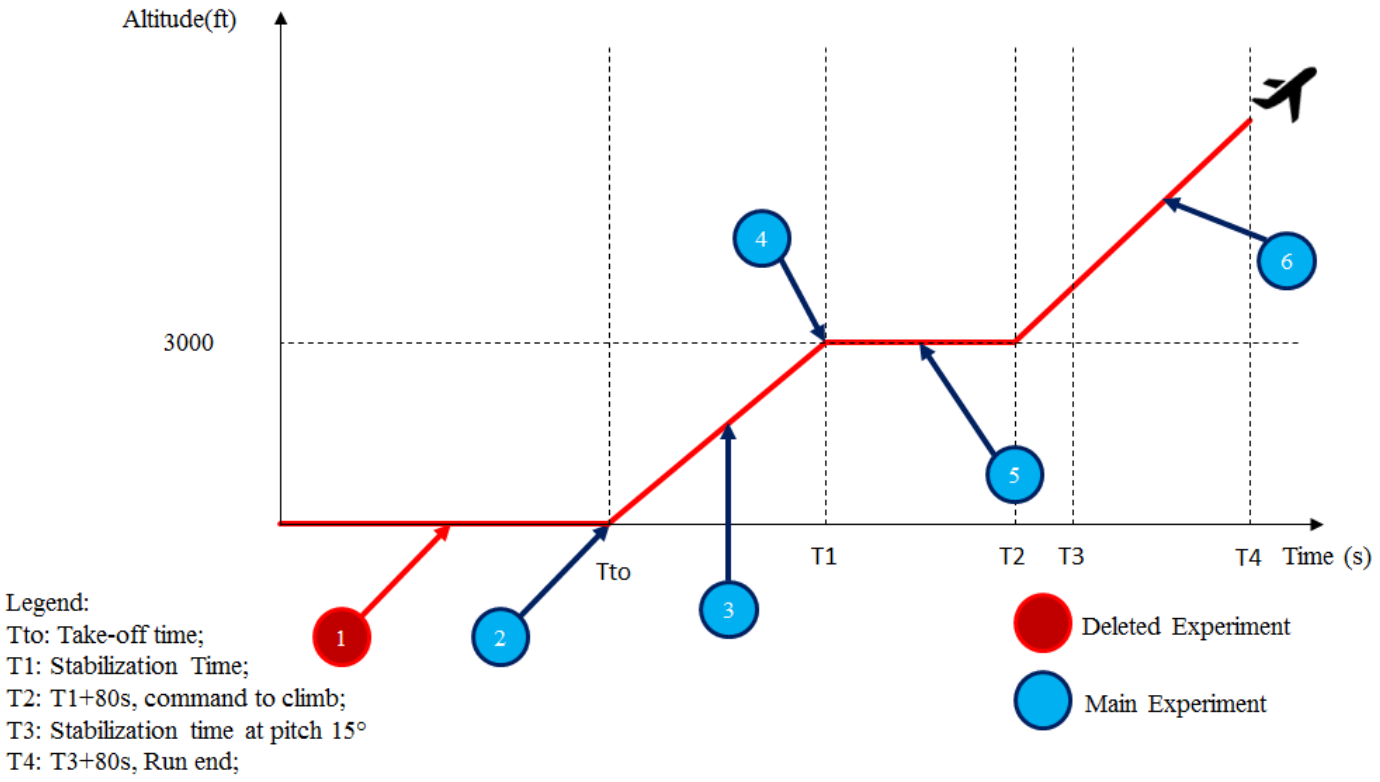
FOQA Events

Set of adapted FOQA events/manoeuvres

N	Event	Description	Workload	Precision	Response Time	FOQA
1	Reject Takeoff Speed	Verifies the response time and the workload to an engine failure at 100 knots	x		x	5,6
2	Lift Off Speed	Verifies the reaction time to lift off at 120 knots velocity			x	7,8
3	Takeoff Climb Speed	Verifies the workload and the precision in maintaining 140 knots at the initial climb, until the stabilization at 3000 ft altitude	x	x		10,11
4	Clean up Attitude	Verifies the sum of the response times in the accomplishment of the simultaneous tasks : flap retraction, landing gear retraction, power reduction to 60%, and altitude stabilization at 3000 ft.			x	4,12,19
5	Bank Angle Analysis	Precision and workload are measured during the maintenance of 0° of roll.	x	x		13,20
6	Climb Analysis	Precision and workload are measured to the maintenance of 15° pitch angle at 80% of throttle.	x	x		9,20

Manoeuvres

Experimental Take-off Path



Legend:
Tto: Take-off time;
T1: Stabilization Time;
T2: T1+80s, command to climb;
T3: Stabilization time at pitch 15°
T4: T3+80s, Run end;

Behavioural Variables

Event	*Variable Name*	*Behavioural Parameter*
Lift Off Speed	TR120	Response Time
Takeoff Climb Speed	MS	Precision: Mean
	VS	Precision: Standard Deviation
	CS	Workload
Clean up Attitude	TT	Response Time
Bank Angle Analysis	M_sA	Precision: Mean
	V_sA	Precision: Standard Deviation
	C_sA	Workload
Climb Analysis	M_sE	Precision: Mean
	V_sE	Precision: Standard Deviation
	C_sE	Workload

ANOVA

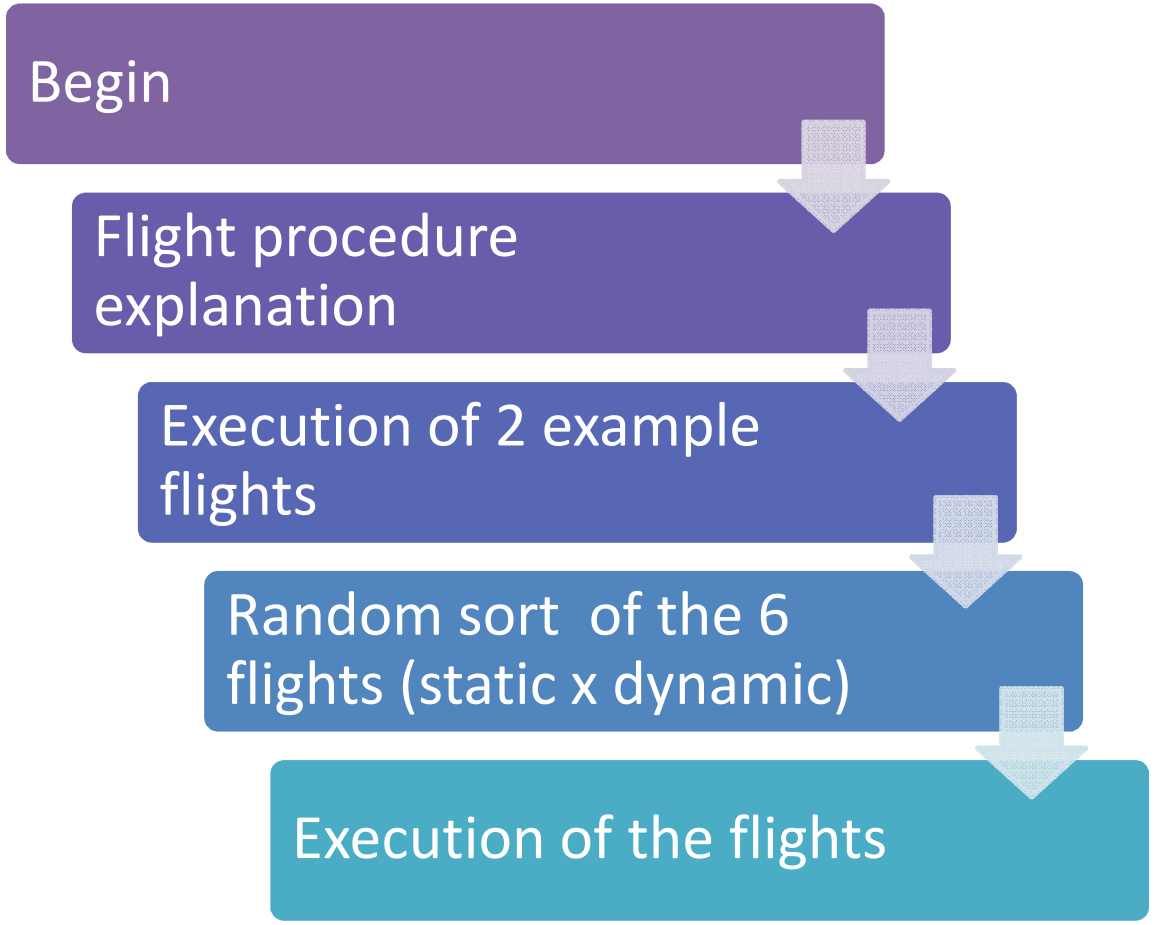
$$V_{ij} = \mu + M_i + \beta_j + e_{ij}$$

y_{ij}: Output value: mean, standard deviation, workload or response time;
μ: General output mean;
M_i: Simulation mode variance;
β_j: Pilot block variance;
ϵ_{ij}: random error

	Pilot			
Mode	1	2	...	N
Static	*	*	*	*
	*	*	*	*
	*	*	*	*
Dynamic	*	*	*	*
	*	*	*	*
	*	*	*	*

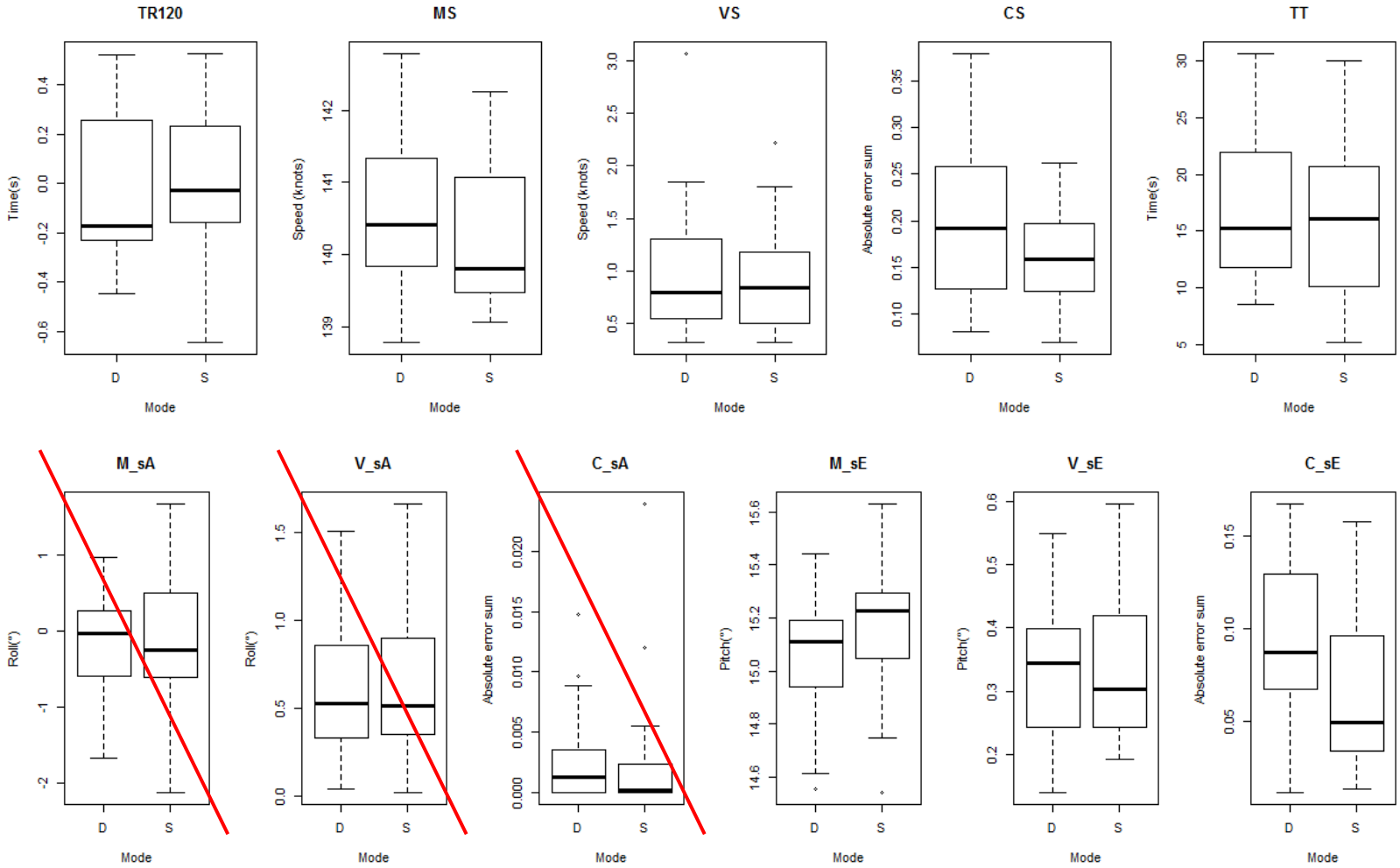
Number of pilots: 7;
Test Significance : 10%;

Experiment Procedure



Results and Discussion

Data Analysis



M_sA, V_sA and C_sA were excluded from the analysis due to a noticeable tendency in the C_sA sample, which affected the other two.

Data Analysis

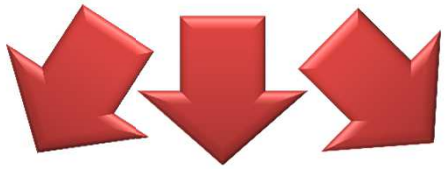
Variable	Residuals Df	P-Value	Significance	
TR120	32	0.535	Not Significant	
MS	33	0.171	Not Significant	
VS	33	0.547	Not Significant	
CS	33	0.005	Significant	Takeoff Climb Speed Workload
TT	30	0.311	Not Significant	
M_sA	-	-	Invalid	
V_sA	-	-	Invalid	
C_sA	-	-	Invalid	
M_sE	33	0.0201	Significant	Climb Analysis Precision: Mean
V_sE	33	0.8051	Not Significant	
C_sE	33	0.0088	Significant	Climb Analysis Workload

Data Analysis

- CS and C_sE significances:
  - Motion difficults the execution of the task, causing a workload increase
  - Workload variations due to CS and C_sE are small, once in absolute terms the total workloads are also small
- M_sE significance:
  - Increase of inclination perception
  - Pilot reaction to pitch stimuli changes
  - Workload and precision increases

Discussion

- Behavioural parameters derived from FOQA were not able to confirm that the motion has a significant effect on the human performance in all manoeuvres.



Motion is not always relevant

Behavioural parameters are not always sensible enough

Manoeuvres are not strong enough

Future Work

- New set of experiments:
  - Add disturbance cues to manoeuvres
  - Increase number of pilots
  - Increase cockpit realism

- Modelling of pilots' physical systems (vestibular system)

Thank you!

Questions?