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Department of Mechanical and Aerospace Engineering

Master Thesis in

Synthetic Data Package development for FNPT-type simulator

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Abstract

Dynamic simulation models are proving increasingly realistic and reliable, to the extent that they can accurately and faithfully simulate the dynamic behavior of their real-world counterparts, even when the latter are still in the design phase. With this purpose, they are often employed to support the design phase by testing solutions that exist only on paper, resulting in obvious time and resource savings. This thesis carried out in collaboration with TXT E-Tech, aims to investigate the use of a fixed-wing aircraft flight dynamics simulation model to create a "Data Package" for the validation and certification of a "Flight Navigation Procedures Trainer" (FNPT) simulator in accordance with EASA regulations.

According to the CS-FSTD(A) (Certification Specifications for Flight Simulator Training Device (Aircraft)), FNPT-type simulators are permitted to rely on data sources that are not directly tied to flight tests conducted on the specific aircraft or aircraft class being simulated. Consequently, this opens up new avenues for research into more accessible and economically feasible data sources.

The aircraft classes under consideration comprises the A320-200 and Boeing 737-800 series, examined through official documents and static analyses using Pacelab APD software. The goal is to extract relevant data for conducting simulator certification tests. Specifically, the study focused on Climb in all engine operating (AEO) and one engine inoperative (OEI) performances, engine acceleration/deceleration, column/wheel/pedal position vs forces, trim calibration, and alignment of cockpit throttle lever vs selected engine parameter.

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Nomenclature:

- AEO: All Engines Operating
- AFM: Aircraft Flight Manual
- AIM: Aeronautical Information Manual
- AMC: Acceptable Means of Compliance
- AIS: Aeronautical Information Services
- AOM: Aircraft Operating Manual
- ATM: Air Traffic Management
- BITD: Basic Instrument Training Device
- CAA: Civil Aviation Authority
- CAS: Calibrated Airspeed
- CL: Climb
- CS: Certification Specification
- CT&M: Correct trand and magnitude
- EASA: European Union Aviation Safety Agency
- EAS: Equivalent Airspeed
- ECAM: Electronic Centralized Aircraft Monitoring
- ENAC: Ente Nazionale dell'Aviazione Civile
- FAA: Federal Aviation Administration
- FADEC: Full Authority Digital Engine Control
- FCOM: Flight Crew Operating Manual
- FCTM: Flight Crew Training Manual
- FFT: Full Flight Trainer
- FNPT: Flight Navigation Procedure Trainer
- FSTD: Flight Simulation Training Device
- GA: Go Around
- GS: Ground Speed
- IAS: Indicated Airspeed

- IATA: International Air Transport Association
- ICAO: International Civil Aviation Organization
- IAE: International Aero Engines
- ISA: International Standard Atmosphere
- MCC: Multi-Crew Cooperation
- MCT: Maximum Continuous Thrust
- MTOW: Maximum Takeoff Weight
- OEI: One Engine Inoperative
- OAI: Outside Air Temperature
- PANS: Procedures for Air Navigation Services
- QTG: Qualification Test Guide
- QRH: Quick Reference Handbook
- REV: Reverse
- R/C: Rate of Climb
- SARPs: Standards and Recommended Practices
- SCC: Static Control Check
- SOP: Standard Operating Procedure
- TAS: True Airspeed
- TCDS: Type Certificate Data Sheet
- THS: Trim Horizontal Stabilizer
- TLA: Thrust Lever Angle
- TO: Takeoff
- VDR: Validation Data Roadmap
- VSD: Validation Source Data
- WAT: Weight-Altitude-Temperature

Chapter 1

Introduction to flight simulator

1.1 What is a flight simulator

Aircraft flight simulators are sophisticated devices designed to accurately replicate the behavior of an aircraft in flight, as well as the surrounding environment. This replication encompasses various factors, including the intricate equations governing flight dynamics, the response to flight control inputs, the integration of aircraft systems, and the influence of external elements such as air density, turbulence, wind shear, clouds, and precipitation. . ..
These simulators serve as invaluable tools for training, research, and development within the aviation industry, offering a controlled and immersive environment for pilots and engineers to enhance their skills and understanding of aviation principles.

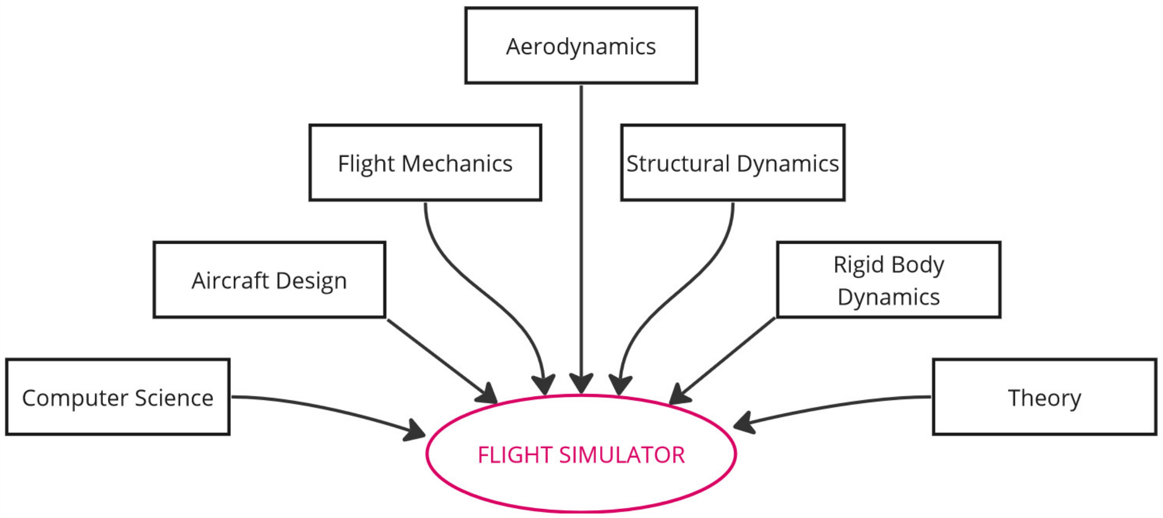


Figure 1.1: Flight simulator input

Flight simulation serves a multitude of purposes, encompassing vital areas such as flight training, aircraft design and development, and the exploration of aircraft characteristics and control handling qualities through research endeavors. The categorization of flight simulation can be delineated based on several parameters, facilitating a structured approach to its utilization and analysis within the aviation domain.

- When a flight simulator is mounted on the ground, which is the most common configuration, it is referred to as ground facilities. Alternatively, if the simulator is mounted on the same aircraft it aims to simulate, it is denoted as an in-flight simulator.

- A clear differentiation exists between simulation time and real-time within the context of flight simulation. When the simulation time precisely aligns with real-time, it is termed as an on-line simulator. Conversely, if there is a disparity between simulation time and real-time, it is categorized as an off-line simulator. Achieving synchronization between simulation time and real-time poses a significant challenge in ensuring certification standards.

- An on-line flight simulator offers diverse applications, serving purposes ranging from pilot and crew training to research endeavors and recreational gaming.

- Pilot and crew training cover a wide array of applications across distinct sectors, including commercial airline operations, military aviation, and industrial contexts. Each field has its own specific training needs to make sure pilots and crew are well-prepared for their roles.

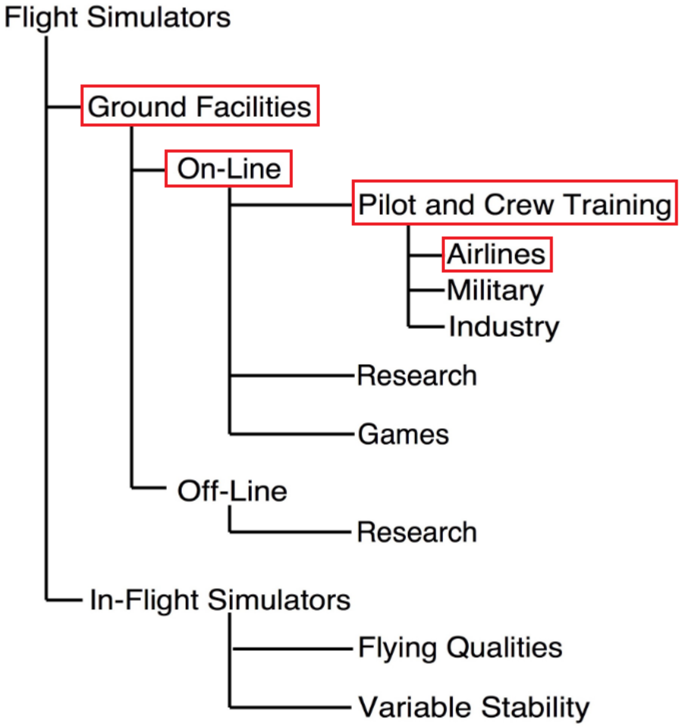


Figure 1.2: Flight simulator classification

This project emphasizes the development of an online simulator tailored for ground facilities, specifically designed to facilitate the training of pilots and crew members within the aviation sector.
The process of developing a flight simulators require standardization and regulations.

In the beginning there were no standards and each simulator manufacturer proposed what they believed was desirable for the airline's training needs.

In the early 1970's the simulator maintenance organisations of a small number of world airlines joined together to share the various problems which they were experiencing with both flights simulators and their respective manufacturers. The airlines later re-grouped (1973) under the supervision of IATA (International Air Transport Association) to form a specific technical committee.

In 1995, the ICAO (International Civil Aviation Organisation) manual was published as the manual of criteria for the qualification of flight simulators. Later, EASA (European Authorities for Aviation Safety) and FAA (Federal Aviation Administration) reviewed and modernised the Standards contained in the manual.

The current regulatory framework established by the EASA for ground facilities, online, pilot and crew training, and airline flight simulators is outlined in the Certification Specifications for Aeroplane or Helicopter Flight Simulation Training Devices (CS-FSTD (A or H)). These specifications delineate the certification requirements applicable to organizations operating Flight Simulation Training Devices (FSTD) and seeking initial qualification for such devices.

1.1.1 FSTD(A) classifications

The classification of simulators is contingent upon their complexity and their fidelity to the original aircraft or class of aircraft they aim to replicate. The EASA's CS-FSTD(A) document provides a comprehensive definition for each type of simulator. However, for the purpose of this discussion, brief descriptions of each type will be provided, with a particular focus on the simulator under analysis in this paper:

- **FFS** (*Full Flight Simulator*) - It is equipped with both visual and motion systems. FFSs are further classified into four levels, designated as Level A through D, with Level D representing the highest level of sophistication and imposing the most stringent requirements. Level D FFSs incorporate six degrees of motion and provide realistic cockpit sounds. Notably, FFSs are often tailored to specific aircraft types, enabling pilots to obtain a type-rating certification without the necessity of flying the actual aircraft.

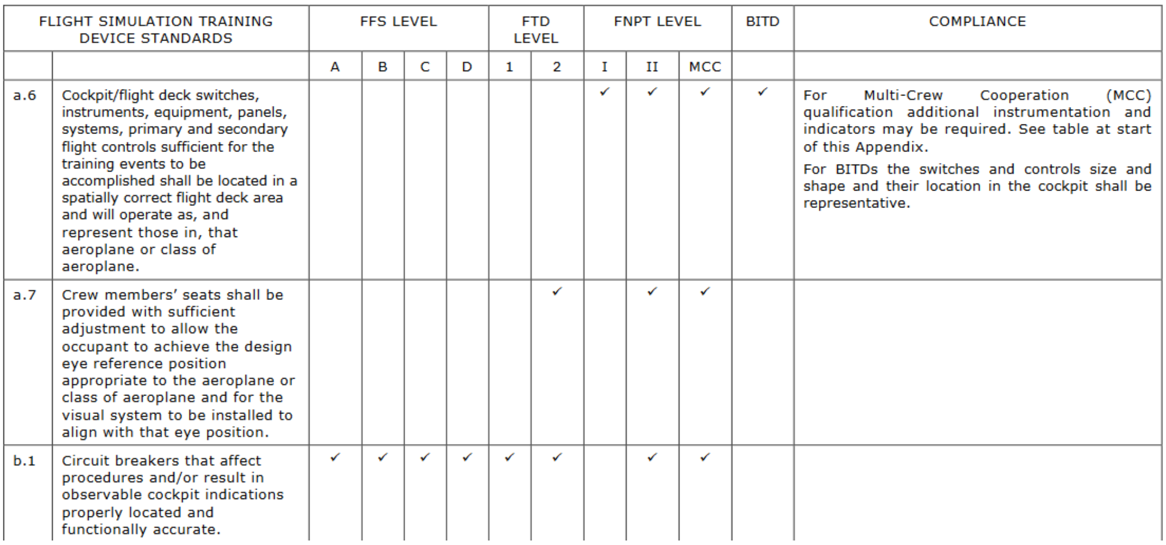
- **FTD** (*Flight Training Device*) - This devices are engineered to replicate particular aircraft configurations and may feature an enclosed cockpit, along with realistic visual references, contingent upon the qualification level of the FTD. While not all FTDs are equipped with motion capabilities, they are sufficiently advanced to deliver training conducive to the attainment of commercial and airline transport pilot certificates.

- **FNPT** (*Flight Navigation Procedural Training*) - This training device encompasses the flight deck or cockpit environment, complete with the requisite equipment and computer programs to simulate aircraft or a specific class of aeroplane during flight operations. It is in compliance with the minimum standards for a specific FNPT level of qualification. This category of simulator is classified into levels I and II, with an additional category specifically for helicopters known as MCC (Multi Crew Coordination training).

This paper focuses on an FNPT simulator at level II.

1.2 Certification process

Certification mandates not only the utilization of certified simulation software but also certified hardware, including cockpit and flight controls. These components are typically sourced from specialized companies.
This requirement stems from the fact that flight training systems can only receive certification as a comprehensive package, comprising both software and hardware elements. Various categories of flight simulators are approved for commercial pilot training, tailored to different training objectives. These categories span from fixed-base procedure trainers, which feature a generic cockpit, such as an FNPT simulator, to an FFS, which incorporate type-specific cockpits mounted on motion platforms to provide pilots with a realistic flight experience.
Responsibility for certification and training oversight falls under the purview of Civil Aviation Authorities (CAAs). The governing document guiding these processes is the CS-FSTD(A).
The CS-FSTD(A) document is structured into two distinct parts, referred to as books within its framework. The initial book is dedicated to providing comprehensive descriptions for each type of simulator to ensure clarity and prevent misunderstandings regarding their definitions.[3]



FLIGHT SIMULATION TRAINING DEVICE STANDARDS		FFS LEVEL				FTD LEVEL		FNPT LEVEL			BITD	COMPLIANCE
		A	B	C	D	1	2	I	II	MCC		
a.6	Cockpit/flight deck switches, instruments, equipment, panels, systems, primary and secondary flight controls sufficient for the training events to be accomplished shall be located in a spatially correct flight deck area and will operate as, and represent those in, that aeroplane or class of aeroplane.							✓	✓	✓	✓	For Multi-Crew Cooperation (MCC) qualification additional instrumentation and indicators may be required. See table at start of this Appendix. For BITDs the switches and controls size and shape and their location in the cockpit shall be representative.
a.7	Crew members' seats shall be provided with sufficient adjustment to allow the occupant to achieve the design eye reference position appropriate to the aeroplane or class of aeroplane and for the visual system to be installed to align with that eye position.						✓		✓	✓		
b.1	Circuit breakers that affect procedures and/or result in observable cockpit indications properly located and functionally accurate.	✓	✓	✓	✓	✓	✓		✓	✓		

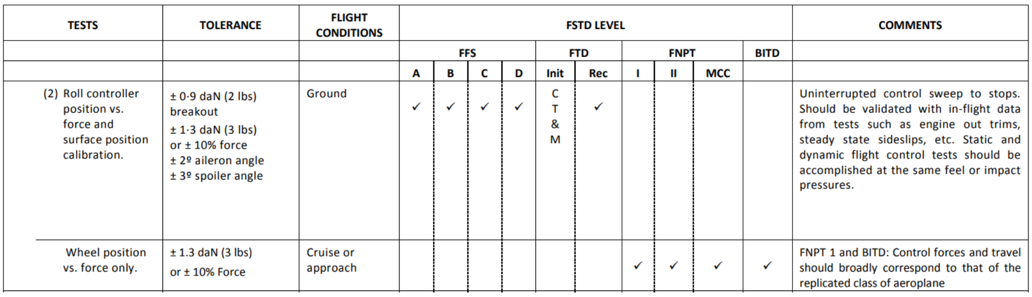
Figure 1.3: Flight simulation training device standards

The standards table for flight simulation training devices is structured into four primary categories: General, Motion, Visual, and Sound System.
The second book, entitled Acceptable Means of Compliance (AMC), outlines the criteria defining performance and documentation requirements for evaluating FSTDs utilized in the training, testing, and checking of flight crew members. These criteria and

compliance methods have been developed based on the extensive experience of competent authorities and industry stakeholders.
It can be simply divided into two testing tables:

- **Validation Tests** - It comprise a series of performance assessments aimed at comparing the simulator with the class of aircraft it seeks to simulate, while adhering to specific tolerances.
- **Function and Subjective Tests** - This series of tests is employed to assess the FSTD's capacity to perform consistently throughout a standard training duration and to confirm its proper functionality.

The validation tests contains the test name, associated tolerance, flight condition, and specifications regarding the type and level of flight simulator required to conduct the test. Additionally, brief comments are provided to assist the manufacturer in executing the test, particularly in cases where ambiguity may arise.



TESTS	TOLERANCE	FLIGHT CONDITIONS	FSTD LEVEL										COMMENTS
			FFS				FTD		FNPT			BITD	
			A	B	C	D	Init	Rec	I	II	MCC		
(2) Roll controller position vs. force and surface position calibration.	± 0·9 daN (2 lbs) breakout ± 1·3 daN (3 lbs) or ± 10% force ± 2º aileron angle ± 3º spoiler angle	Ground	✓	✓	✓	✓	C T & M	✓					Uninterrupted control sweep to stops. Should be validated with in-flight data from tests such as engine out trims, steady state sideslips, etc. Static and dynamic flight control tests should be accomplished at the same feel or impact pressures.
Wheel position vs. force only.	± 1.3 daN (3 lbs) or ± 10% Force	Cruise or approach							✓	✓	✓	✓	FNPT 1 and BITD: Control forces and travel should broadly correspond to that of the replicated class of aeroplane

Figure 1.4: Validation tests

Functions and subjective tests are distinct entities, each serving unique purposes, but their detailed comparison is beyond the scope of this paper. Below is an excerpt from the CS-FSTD(A) document illustrating its format:

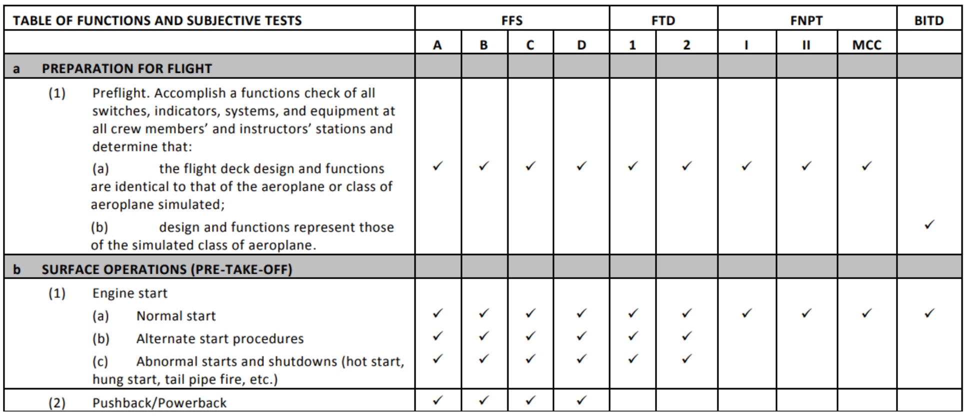


TABLE OF FUNCTIONS AND SUBJECTIVE TESTS	FFS				FTD		FNPT			BITD
	A	B	C	D	1	2	I	II	MCC	
a PREPARATION FOR FLIGHT										
(1) Preflight. Accomplish a functions check of all switches, indicators, systems, and equipment at all crew members' and instructors' stations and determine that:										
(a) the flight deck design and functions are identical to that of the aeroplane or class of aeroplane simulated;	✓	✓	✓	✓	✓	✓	✓	✓	✓	
(b) design and functions represent those of the simulated class of aeroplane.										✓
b SURFACE OPERATIONS (PRE-TAKE-OFF)										
(1) Engine start										
(a) Normal start	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(b) Alternate start procedures	✓	✓	✓	✓	✓	✓				
(c) Abnormal starts and shutdowns (hot start, hung start, tail pipe fire, etc.)	✓	✓	✓	✓	✓	✓				
(2) Pushback/Powerback	✓	✓	✓	✓						

Figure 1.5: Function and subjective tests

1.3 Data package

Focusing solely on the validation tests, it is imperative that each test is bench-marked against the aircraft or class of aircraft the flight simulator aims to replicate. Therefore, the results of every test conducted on the FNPT level II simulator must be compared with the characteristics of the actual aircraft, specifically the A320-200 and the B737-800 families in this case.

The collection of data representing these aircraft is referred to as a data package. The CS-FSTD(A) document provides concise descriptions for each flight simulator, outlining where this data can or cannot be obtained:

- For the initial qualification of FFSs and FTDs, validation flight test data from airplane manufacturers is preferred. However, data from alternative sources may be utilized, pending review and approval by the competent authority.
- For FNPTs and BITDs (Basic Instrument Training Devices) generic data packages may suffice; during an initial evaluation only correct trend and magnitude (CT&M) should be considered. The tolerances listed in the AMC are applicable for recurrent evaluations and should be applied to ensure the device remains at the standard initially qualified.

For FFSs and FTDs the recommended data package primarily consists of flight data, known for their reliability albeit their high cost. Conversely, BITDs and FNPTs entail a broader array of potential data sources. These may include flight test data, manufacturer's design data, information from the aircraft flight manual and maintenance manuals, results of approved or commonly accepted simulations or predictive models, recognised theoretical results, information from the public domain, subjective assessment of a qualified pilot or other sources as deemed necessary by the FSTD manufacturer to substantiate the proposed model ...

These suggestions underscore the flexibility in data selection, albeit accompanied by the challenge of identifying the appropriate data source and validating its reliability.

1.4 Methodology

Considering all the components required for assembling a comprehensive data package, it is essential to underscore the implementation of a structured procedure that ensures clarity and consistency throughout the development process.

1. First and foremost, it is imperative to extract the validation test table from the FNPT level II tests.
2. Consequently, extrapolating data and delineating its associated flight conditions will facilitate the identification of the requisite data sets.
3. Upon acquiring the dataset, the primary focus of this paper is to discern and compile all data sources designated as validated data sources (which will be defined further ahead).

4. From each validated data source, a set of data can be obtained.
5. Finally, establishing a link between each data point from the validation test table to the data from the validated data source leads to a well-defined data package.

Each data source's validity varies depending on its origin. For instance, information documented in the Certification Specification, under the direct oversight of EASA, is inherently validated due to the rigorous certification process it undergoes before publication. Conversely, information sourced from an anonymous blog post may lack verifiable reliability.

As a result, every gathered data source must undergo a validation process to be considered validated. However, due to time constraints within the scope of this thesis, only pre-validated data sources are utilized.

Each source comprises a list of information that may or may not correspond to the data outlined in the validation test table. Consequently, the final results will encompass a synthetic data package rather than a complete one, as not all identified sources within this thesis cover all the data points from the validation tests table.

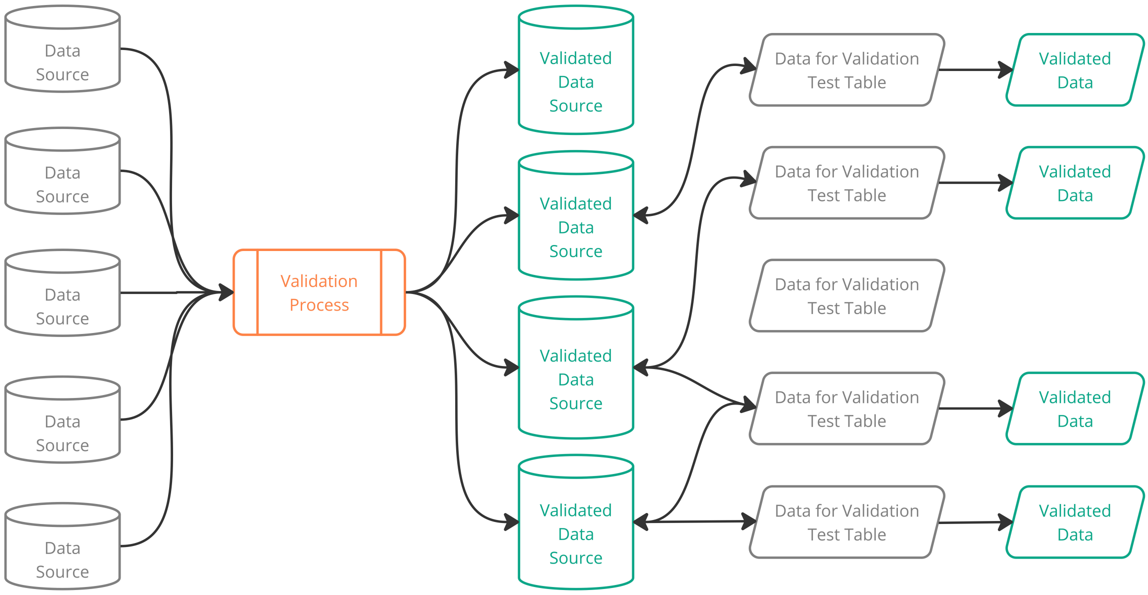


Figure 1.6: Data package creation process

Chapter 2

Validation test breakdown

he CS-FSTD(A) document features a validation test table outlining the FNPT level II. This paper aims to comprehensively analyze each test and the corresponding data necessary to assemble a dataset.
Subsequently, this dataset will be sought within the data sources detailed in the next chapter.

2.1 Qualification basis

In order to fully understand the validation test, a description about how this document is written and what are the expected results may be helpful.

2.1.1 Qualification Test Guide

The Qualification Test Guide (QTG) is the primary reference document used for evaluating an FSTD. It contains test results, statements of compliance and other information for the evaluator to assess if the FSTD meets the test criteria described in the AMC. This document contains a list of information, including:

- aeroplane model or class being simulated - A320-200 and B737-800.
- Statements of compliance (SOC) with certain requirements. SOCs should refer to sources of information and show compliance rationale to explain how the referenced material is used, applicable mathematical equations and parameter values, and conclusions reached.
- For each validation test a sub-list of information is defined, including:
  - References: these are the aeroplane data source documents including both the document number and the page or condition number;
  - Source data: copy of the validation data, clearly marked with the document, page number, issuing authority, and the test number and title.
  - comparison of results: an acceptable means of easily comparing FSTD test results with the validation data

2.1.2 Validation test

In this specific scenario, an initial evaluation for a FSTD entails a distinct procedure compared to recurrent qualification criteria. As previously mentioned, while each test delineates specific tolerances, these are included for completeness. However, for a FNPT, only correct trend and magnitude should be considered. Notably, for recurrent qualification criteria, which are not the focus of this thesis, the tolerance described pertains to the initial qualification criteria and not the validated data source.

Selecting a data source other than flight tests necessitates an explanation of its validity concerning the existing flight test information.

The validation test summary for an FNPT level II comprises performance, static and dynamic handling qualities, and visual system test categories.

Within each test category, data may be recorded as a series of snapshots or as a time history. The former represents an instant during a specific flight condition, while the latter introduces the time variable, potentially complicating the evaluation by introducing a dynamic factor.

This division allows for each data point to be unequivocally categorized based on these definitions.

2.2 Performance

Considering the guidelines for analyzing these tests, only the test name, flight condition, and comments will be taken into account. Regarding the tolerance column, only the relevant data will be extracted, and correct trend and magnitude (CT&M) will be considered.

2.2.1 Climb

TESTS	TOLERANCE	FLIGHT CONDITION	COMMENTS
(c) Climb			
(1) Normal climb all engines operating	± 3 kts airspeed ± 5% or ± 0·5 m/s (100 ft/min) R/C	Clean or specified climb configuration	Flight test data or aeroplane performance manual data may be used. Record at nominal climb speed and mid initial climb altitude. FSTD performance to be recorded over an interval of at least 300 m (1 000 ft). For FTDs may be a snapshot test.
(2) One engine inoperative second segment climb.	± 3 kts airspeed ± 5% or ± 0.5 m/s (100 ft/min) R/C but not less than applicable AFM values	2nd segment climb for FNPTs and BITDs gear up and take-off flaps	Flight test data or aeroplane performance manual data may be used. Record at nominal climb speed. FSTD performance to be recorded over an interval of at least 300m (1 000 ft). Test at WAT (weight, altitude, or temperature) limiting condition. For FTDs may be a snapshot test.

1(c)(1) - Nominal climb all engine operating

To ascertain the requisite data for this test, it is essential to comprehend the definition of "Nominal Climb." This term denotes the standard operational weight, configuration, speed, etc., for the climb segment. The configuration is specified in the Flight Condition column as a clean configuration, wherein external equipment is retracted to minimize drag and thereby maximize airspeed for a given power setting.

The data required can be identified in the 'tolerance' column as follows:

- Airspeed in knots
- Rate of climb (R/C) in feet per minute or meters per seconds.

The initial challenge identified here is the lack of specification regarding which airspeed is being considered. In aviation, various types of airspeed exist [9]:

- True Airspeed (TAS) refers to the speed of the aircraft relative to the atmosphere. It represents the aircraft's velocity relative to the air mass through which it is flying.
- Indicated Airspeed (IAS) signifies the speed of an aircraft as displayed on its Pitot-static airspeed indicator.
- Calibrated Airspeed (CAS) refers to the indicated airspeed corrected for instrument errors, position errors (resulting from incorrect pressure at the static port), and installation errors.
- Equivalent Airspeed (EAS) is defined as the airspeed at sea level in the International Standard Atmosphere, at which the dynamic pressure is equivalent to the dynamic pressure at True Airspeed (TAS) and the altitude at which the aircraft is flying.
- Ground Speed (GS) refers to the speed of the aircraft relative to the ground. It indicates the aircraft's velocity with respect to the Earth's surface.

The absence of specific information regarding the type of airspeed to use may be interpreted as providing a degree of freedom of choice in selecting the appropriate airspeed for the given context.

1(c)(2) - One engine inoperative second segment climb

A one engine inoperative (OEI) condition occurs when one engine fails on a multi-jet engine aircraft. This typically happens after surpassing the decision speed, requiring the aircraft to initiate a climb instead of aborting the takeoff. During this climb phase, once the rotational speed has been exceeded and the aircraft is at an altitude above 35 feet from the ground, it enters the second segment climb. In this segment, the aircraft ascends to an altitude of approximately 400 feet while maintaining a minimum airspeed of V2, which is defined as the minimum speed required in the event of an OEI condition during a second segment climb.

The data required for this phase are identical to those of the 1(c)(1) - Nominal climb with all engines operating, with the additional specification of the minimum rate of climb to maintain during this phase, as described in the Aircraft Flight Manual (AFM).

2.2.2 Climb performance dataset

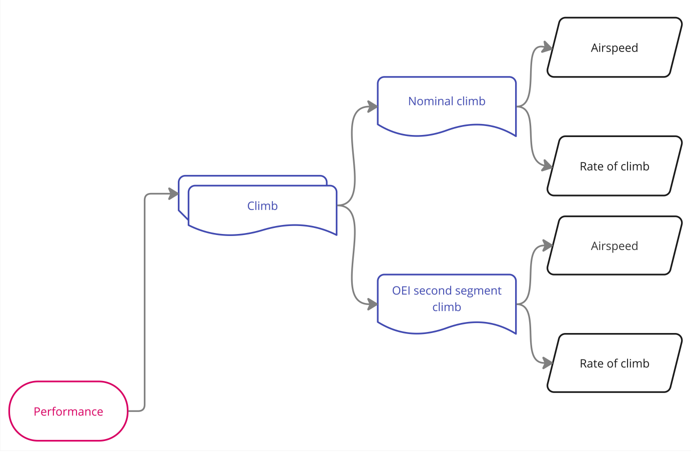


Figure 2.1: Performance climb test dataset

2.2.3 Engine

TESTS	TOLERANCE	FLIGHT CONDITION	COMMENTS
(e) ENGINES			
(1) Acceleration	± 10% T_i or ± 0·25s ± 10% T_t	Approach or landing	Ti = Total time from initial throttle movement until a 10% response of a critical engine parameter. Tt = Total time from initial throttle movement to 90% of go around power. Critical engine parameter should be a measure of power (N1, N2, EPR, etc.). Plot from flight idle to go around power for a rapid throttle movement. FTD, FNPT and BITD only: CT&M acceptable.
(2) Deceleration	± 10% T_i or ± 0·25s ± 10% T_t	Ground	Ti = Total time from initial throttle movement until a 10% response of a critical engine parameter. Tt = Total time from initial throttle movement to 90% decay of maximum take-off power. Plot from maximum take-off power to idle for a rapid throttle movement. FTD, FNPT and BITD only: CT&M acceptable.

1(f)(1) - Acceleration

During the landing phase, when engine power settings typically remain at idle, a rapid transition to go-around power settings, as described in the comments, can be employed

as a test performance for engine parameters.
The power settings for the A320-200 correspond to specific positions on the engine thrust lever, as illustrated in the figure extracted from [1], where REV represents reverse thrust, 0 indicates idle, CL signifies climb power settings, and $\frac{TO}{GA}$ denotes Take Off/Go Around power settings:

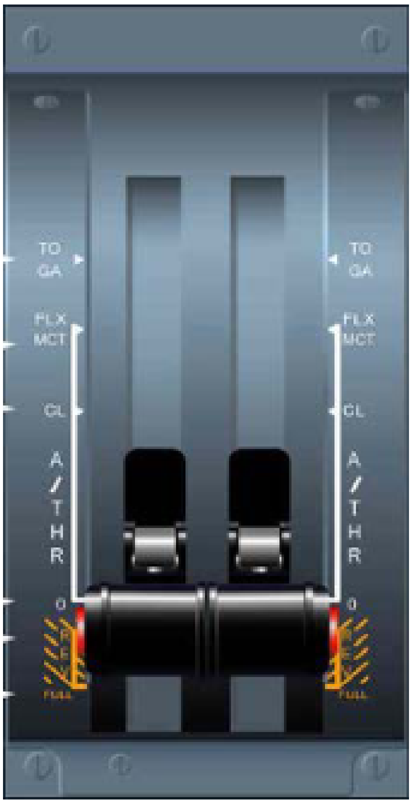


Figure 2.2: A320 thrust lever

This test aims to ascertain the total response time and the delay for a critical engine parameter. Therefore, the data required for this test includes the time taken for the transition as well as the critical engine parameter. This parameter may include throttle N1 or N2, Engine Pressure Ratio, etc..., as suggested.
The critical elements in this test is the meaning of "rapid transition" from one power setting to another, and which critical engine parameter take into account. This depends on which data source will be found.

1(f)(2) - Deceleration

The deceleration test corresponds to the exact same procedure conducted on the ground, involving an opposite command movement. Specifically, it entails transitioning from Take Off power settings to Idle power settings.
It is essential to specify that although Take Off Power and Go Around Power settings may correspond to the same indent on the thrust lever, the actual power settings are not identical. This distinction arises from the presence of an automatic power control system known as Full Authority Digital Engine Control (FADEC), which regulates the

engine parameters to achieve the desired conditions for each phase of flight. A general relation between Thrust and thrust lever is represented in the Flight Crew Operating Manual (FCOM) for the A320 aircraft[1]:

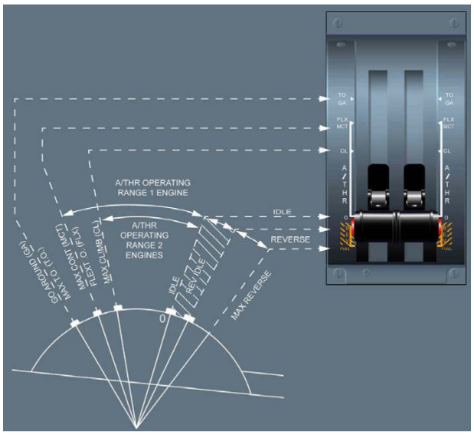


Figure 2.3: Relation between thrust lever and thrust rating

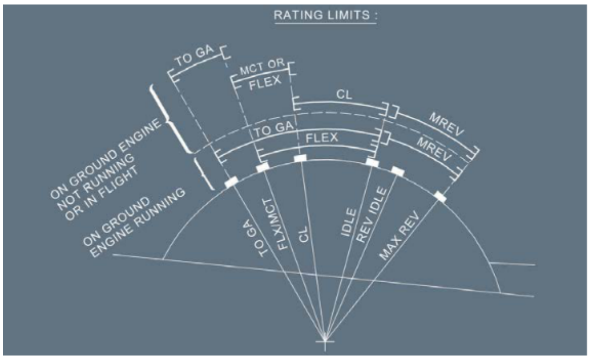


Figure 2.4: Thrust rating

Engine performance dataset

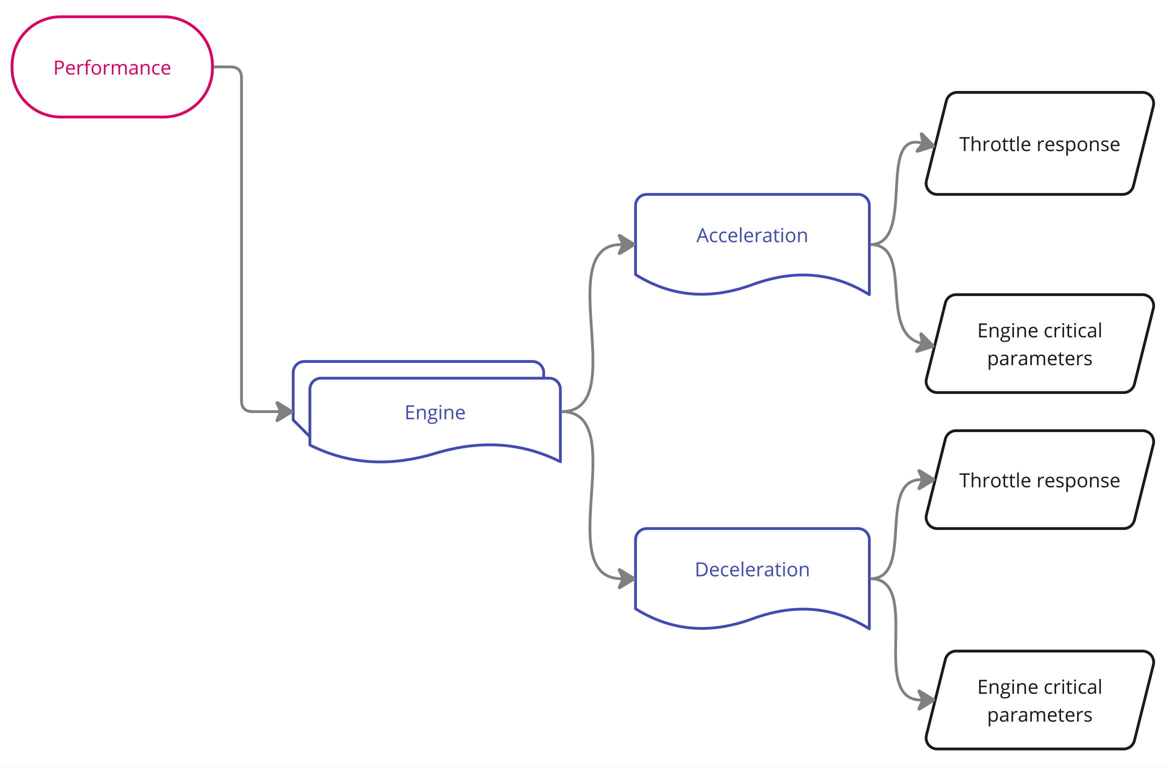


Figure 2.5: Performance engine test dataset

2.3 Handling qualities

Handling qualities are those characteristics of a flight vehicle that govern the ease and precision with which a pilot is able to perform a flying task[12].
The validation table is segmented into four distinct categories: Static control check (SCC), Dynamic control check, Longitudinal dynamic, Lateral - directional dynamic. The only category excluded from analysis is the dynamic control check, while the others necessitate a comprehensive examination.
Due to time constraints and lack of adequate instruments, the longitudinal and lateral-directional dynamic tests will not be included in the analysis.
All Static Control Check tests involving measurements of pitch, roll, and yaw controller position versus force or time should ideally be conducted directly at the control. Alternatively, the FSTD can be instrumented in a manner equivalent to the flight test aeroplane. The force and position data from this instrumentation should be directly recorded and matched to the aeroplane data.
It's worth noting that testing of position versus force may not be applicable if forces are solely generated by the use of aeroplane hardware in the FSTD.

TESTS	TOLERANCE	FLIGHT CONDITION	COMMENTS
(a) STATIC CONTROL CHECK			
(1) Pitch column position vs force only	± 2.2 daN (5 lbs) or ± 10% force	Cruise or approach	Uninterrupted control sweep to stops. Should be validated (where possible) with in-flight data from tests such as longitudinal static stability, stalls, etc. Static and dynamic flight control tests should be accomplished at the same feel or impact pressures.
(2) Roll wheel position vs force only	± 1.3 daN (3 lbs) or ± 10% Force	Cruise or approach	Uninterrupted control sweep to stops. Should be validated with in-flight data from tests such as engine out trims, steady state side-slips, etc. Static and dynamic flight control tests should be accomplished at the same feel or impact pressures.
(3) Rudder pedal position vs force only	± 2.2 daN (5 lbs) or ± 10% force	Cruise or approach	Uninterrupted control sweep to stops. Should be validated with in flight data from tests such as engine out trims, steady state side-slips, etc. Static and dynamic flight control tests should be accomplished at the same feel or impact pressures.
(6) Pitch trim indicator vs. surface position calibration	±1 of trim angle	Ground	Purpose of test is to compare flight simulator against design data or equivalent.
(8) Alignment of cockpit throttle lever vs. selected engine parameter.	± 5^{o} of TLA or ± 3% N1 or ± 0·03 EPR or ± 3% torque	Ground	Simultaneous recording for all engines. The tolerances apply against aeroplane data and between engines. For aeroplanes with throttle detents, all detents to be presented.

2.3.1 Position vs. force only

The initial three tests necessitate the measurement of force feedback exerted on the pilot during primary command movement.
The transition from mechanical control systems to fly-by-wire control systems underscored the need for implementing a system capable of providing tactile feedback to the pilot, thus ensuring awareness of the aircraft's state and the challenge associated with each flight maneuver.
These tests aim to ensure that the flight simulator adequately replicates these forces. Therefore, the required data for these tests include a plot depicting the force feedback alongside the command position, preferably without interruptions during the movement.
The challenges in this context revolve around two main aspects:

- The hardware employed to emulate the force feedback of the primary control systems, commonly referred to as aircraft Pitch, Roll, and Yaw controllers.

- The comprehensive understanding of the complete range and effects of these control commands.

The dataset comprises a total of six data points, each encompassing the command position and its corresponding force feedback.

2.3.2 Pitch trim indicator vs. surface position calibration

The process of trimming aerodynamic surfaces involves adjusting the angles of control surfaces to ensure the aircraft's stability. To execute this task, the aircraft is equipped with an onboard system known as the Trim Horizontal Stabilizer (THS), performed by the instrument called trim wheel.

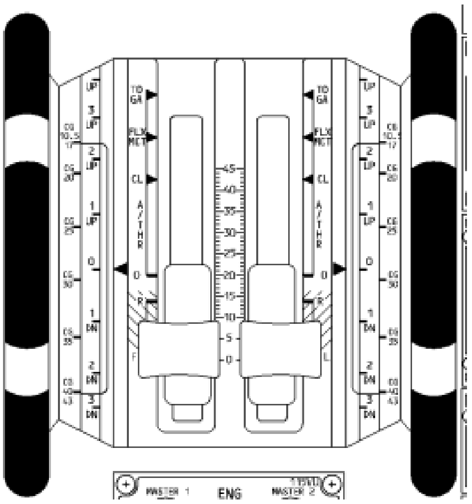


Figure 2.6: Trim wheel with thrust lever

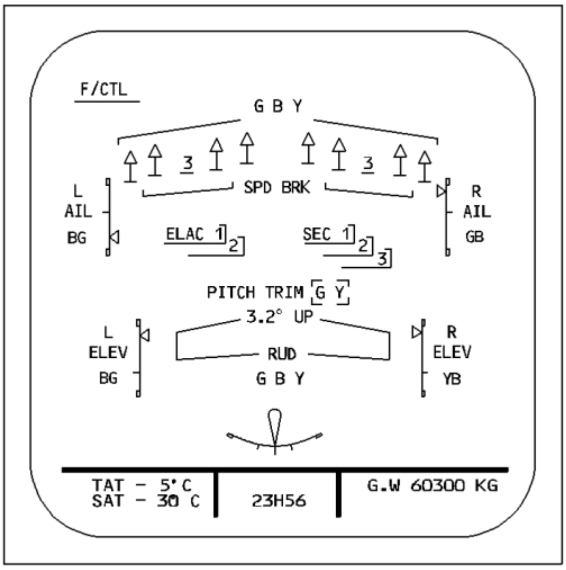


Figure 2.7: ECAM

Positioned adjacent to the throttle lever, this instrument facilitates adjustments to the stabilizers' angles, compensating for shifts in the center of gravity resulting from varying payload and fuel configurations throughout flight. Typically, the rotation of the trim wheel is automated by the onboard computer system, with manual adjustments being a rare occurrence. Once the desired angles are determined, commands are transmitted via fly-by-wire technology to the stabilizer, with the resulting angle displayed on the Electronic Centralized Aircraft Monitor (ECAM). The goal of the test is to validate that the deviation between the simulator-predicted position and the aircraft's designed position remains within a tolerance of less than 1 degree.
The data required for conducting this test includes the stabilizer angle of inclination and the position of the trim wheel.

2.3.3 Alignment of cockpit throttle lever vs. selected engine parameter

As outlined earlier, the simulated aircraft class is equipped with a throttle lever segmented into indentations. Each indentation corresponds to a distinct engine condition applicable across different flight phases:

- Idle Stop (0) - This condition entails the engine operating at its minimum RPM, tailored to the flight phase. This specification is necessary as Idle is employed both after startup and during descent prior to approach for landing. It's important to note that these two conditions do not require the engine to be in the same state.
- Climb
- MCT/FLX - Flexible Take Off or "FLEX" is the standard takeoff thrust setting used on Airbus aircraft, unless departing a contaminated (wet / icy) runway or if performance constraints (short runway or hot and high) exist, in which case TO/GA (full thrust) is used.
  "FLEX" takeoff settings use an assumed temperature thrust reduction to preserve engine wear and thereby prolong engine life.
  MCT (Maximum Continuous Thrust) is typically employed during cruise phase, aimed at setting the engine to a condition of maximum thrust sustainable for extended duration without unduly compromising engine life.
- TO/GA - As previously delineated, the selection of Take Off (TO) thrust settings is prescribed for operations on a contaminated runway. Conversely, under circumstances of performance constraints, such as during a landing abort, the Go Around (GA) thrust setting is opted for.
- Reverse Idle
- Reverse Max - Following a landing, it is customary to engage the reverse thrust max mode to expedite deceleration and reduce landing distances more effectively.

The aim of the test is to ascertain that upon selecting a specific engine mode among those previously outlined, the engine's performance closely mirrors that observed in

the aircraft class.
The test consequently necessitates arbitrarily selecting a performance characteristic of the engine and comparing it with the selected engine mode relative to the simulated aircraft class. For this reason, it is important to understand which characteristic to choose primarily based on the availability of data.

2.3.4 Handling qualities partial dataset

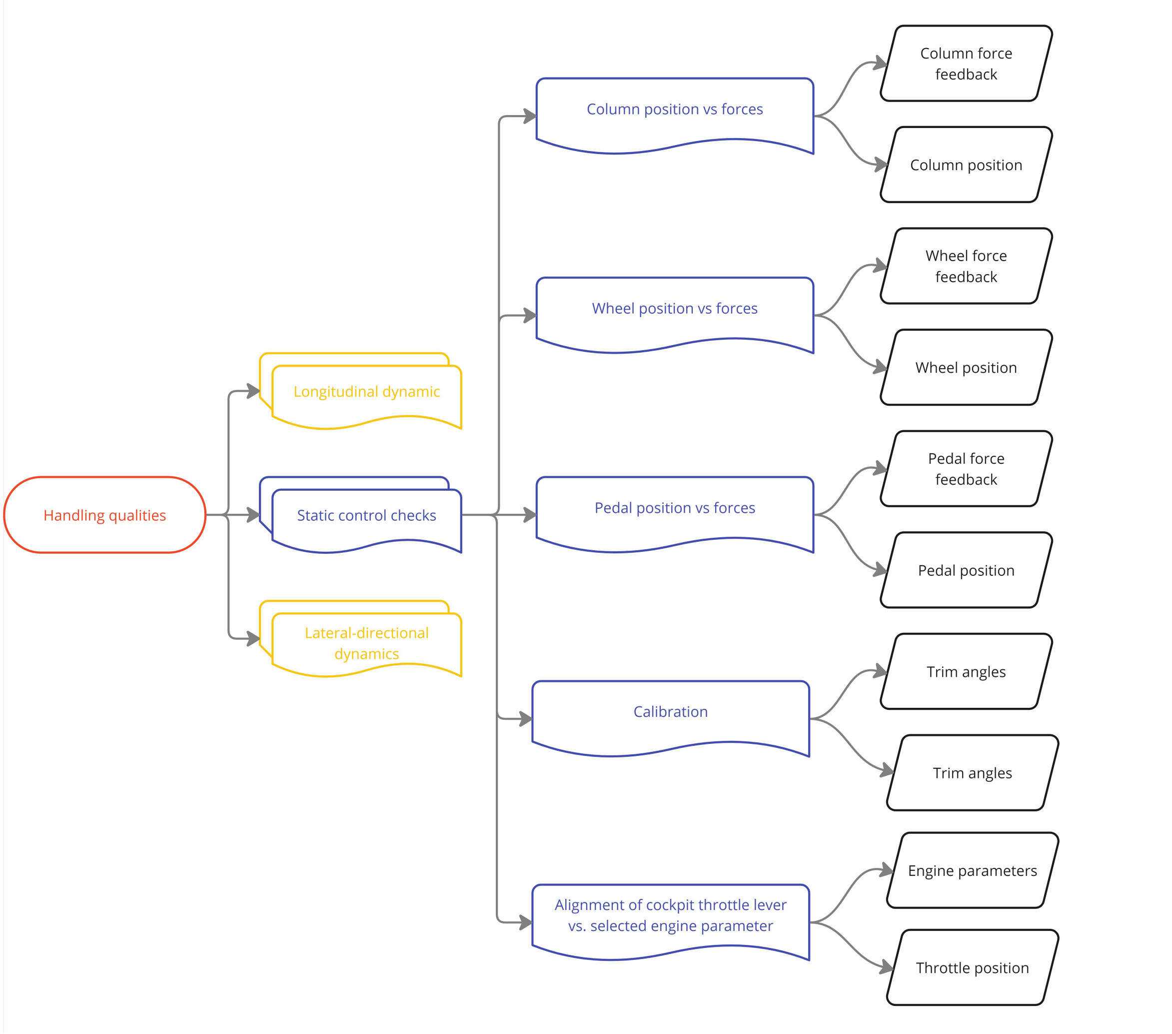


Figure 2.8: handling qualities static control check tests dataset

Chapter 3

Validation source data

As expressly stated in the Certification Specifications and Guidance Material for Simulator Data (CS-SIMD): "The Validation Source Data (VSD) serves to substantiate the objective qualification of airplane flight simulation training devices (FSTDs) aligned with pilot type rating training. It also encompasses provisional VSD to facilitate interim qualification, encompassing any supplementary features as requested by the applicant."[4].

After delineating the tests to be executed, an exhaustive analysis was undertaken to identify the potential sources from which to derive data for the creation of the package. Consequently, the approach commenced with consulting the most reliable sources possible, including nationally and internationally recognized organizations, as well as the aircraft manufacturers.

3.1 Validated source

The principal entities responsible for the certification of civil aircraft are the European Union Aviation Safety Agency (EASA) in Europe and the Federal Aviation Administration (FAA) in the United States.

Generally, each nation designates its own authority for certification; for instance, in Italy, this responsibility falls under the Ente Nazionale dell'Aviazione Civile (ENAC). Nevertheless, the focus often gravitates towards the aforementioned authoritative bodies.

Despite concerted efforts to standardize aircraft certification procedures, variations in regulations among nations can occur. Consequently, an international entity known as the International Civil Aviation Organization (ICAO) was established to provide guidelines and regulations, rather than mandatory rules, aimed at promoting uniformity in certification processes.

The primary aircraft manufacturers of reference are Boeing and Airbus, both of which rely on certification from both EASA and the FAA for their aircraft.

3.1.1 ICAO

The foremost step in identifying public sources for data acquisition involves thoroughly understanding the nature of data recorded for certification purposes.

This includes delineating how such data are recorded, verifying whether they undergo certification procedures, and ascertaining where they are defined within official documents and their certification status.

Annexes to the Convention on International Civil Aviation (ICAO) play a crucial role in shaping international aviation standards. These annexes contain the basic standards and recommended practices (SARPs) for various aspects of civil aviation. This encompasses guidelines on the appropriate methods and locations for storing technical and performance data pertaining to the aircraft.

In Annex 8, titled Airworthiness of Aircraft, it is recommended to specify the technical and performance data demonstrating that the aircraft has been certified according to CS-25. Consequently, it is advised to read the CS-25 in conjunction with the Aircraft Flight Manuals (AFM) and Flight Crew Operating Manuals (FCOM) for comprehensive understanding.

To facilitate this, ICAO offers other documents such as Doc 10066, officially known as Procedures for Air Navigation Services - Aeronautical Information Management (PANS-AIM), provides detailed requirements for the collection, management, and provision of aeronautical data and information.[7] It supports the transition from product-based Aeronautical Information Services (AIS) to data-centric AIM, enhancing safety and efficiency in air navigation.

Doc 7383 serves as a valuable resource for aeronautical information services. It facilitates efficient access to vital aeronautical information for planning and developing air operations. It's an essential tool for aviation professionals and ensures seamless communication across international boundaries.

3.1.2 EASA and FAA

The primary reference documents are the Certification Specifications, which outline the criteria for certifying specific aircraft, simulators, or components.

Another important document series are the Type Certificate Data Sheets (TCDS) that provide essential information about the certification of various aircraft, engines, propellers, and helicopters. These documents are crucial for understanding the technical specifications and performance characteristics of certified products.

The main documents this thesis rely on are:

- the CS-25 category, the Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes are delineated, encompassing the A320-200, the designated reference aircraft for the simulator.
- the CS-FSTD category, the Certification Specification and Acceptable Means of Compliance for Flight Simulator Training Device.
- the CS-SIMD category, the Certification Specifications and Guidance Material for Simulator Data.
- the TCDS category about A320-200 Aircraft and its engines, the CFM56 and the International Aero Engine (IAE) V2537.

The FAA offers analogous documentation, typically mirroring EASA's content with minor discrepancies. Consequently, FAA resources are only consulted if EASA fails to provide essential information necessary for assembling the Data Package.

3.1.3 Airbus and Boeing

In the wake of releasing a series of aircraft like the A320-200 or the B737-800, manufacturers provide a collection of manuals tailored for distinct purposes, including:

- Aircraft Flight Manual (AFM) is a crucial document associated with the Certificate of Airworthiness. It contains limitations within which the aircraft is considered airworthy. It also provides instructions and essential information for the flight crew members to safely operate the aircraft. It covers recommended operating techniques for normal, abnormal, and emergency situations. Additionally, it outlines the expected aircraft performance when operated according to these procedures.[11]
  It's a vital part of the aircraft inventory and must be carried on all flights unless the National Airworthiness Authority (NAA) accepts that the Operations Manual replicates relevant AFM information.

- The Flight Crew Operating Manual (FCOM) serves as a guideline for operators to develop their own Standard Operating Procedures (SOPs) in accordance with applicable requirements.
  It incorporates the aircraft manufacturer's guidance on how to use the systems on board the aircraft for enhanced operational safety and increased efficiency. Designed for a specific model, type of operation, and configuration, the FCOM ensures standardized procedures and practices.
  An FCOM is often structured in several volumes:
  - Operational Limitations: Covers limitations within which the aircraft is considered airworthy.
  - Normal and Supplementary Procedures: Provides instructions for various flight phases.
  - Dispatch Performance Data: Includes information related to aircraft performance.
  - Systems Information: Describes controls, indicators, and system functionality.
  - Quick Reference Handbook (QRH): Contains checklists for normal and non-normal procedures.
  - Flight Crew Training Manual (FCTM): Provides practical information on operating the aircraft

- the Aircraft Operating Manual (AOM) is a crucial document for safe and efficient flight operations. It provides procedures, instructions, and guidance for operational personnel during flight execution.
  It contains information beyond what's covered in the Aircraft Flight Manual (AFM), tailored specifically for conducting flights.

3.2 Other sources

Secondary sources, such as engineering software and websites, have been duly considered. These elements typically pose more complexity in validation and require in-depth analysis.

3.2.1 Skybrary and Eurocontrol

Skybrary, developed in partnership with Eurocontrol, is a reputable source of aviation safety knowledge. It serves as an electronic repository related to flight operations, air traffic management (ATM), and aviation safety in general.

It is considered a reliable source for aviation-related information as an online knowledge repository maintained by the Flight Safety Foundation. Skybrary provides valuable resources, including articles, case studies, and best practices related to aviation safety, procedures, and training.

On the other hand Eurocontrol, the European Organisation for the Safety of Air Navigation, is a reputable and authoritative organization in the field of aviation. It is an intergovernmental organization committed to delivering technical excellence and civil-military expertise across the entire spectrum of air traffic management. In summary, Eurocontrol is a reliable and influential organization that significantly impacts European aviation safety and efficiency.[6]

3.2.2 Turbotrans

he performance and technical specifications of the engine can be derived not only from Type Certificate Data Sheets (TCDS) but also extracted from engineering simulation software capable of approximating the engine's performance under specific conditions. Analyses must encompass both static and dynamic parameters to address the diverse range of tests mandated for simulator certification.

The company has identified an open-source engine analysis software named TURBOTRANS capable of meeting the data extraction requirements for the validation tests. Despite limited documentation, the program is well-defined.

The software in question is an open-source engine analysis tool designed to assess engine performance through comprehensive engineering simulations, encompassing control systems as well. Users have the flexibility to customize engine components, such as turbines and compressors, alongside control systems. Additionally, the software offers the capability to create personalized maps, along with pre-configured engine setups, systems, and predefined maps.

Despite being programmed in the somewhat dated Fortran IV language, the software architecture employs block diagrams and employs various solution methods tailored for different operational conditions, including transient and steady-state scenarios. Its user interface allows for intuitive creation, visually connecting blocks with arrows representing input and output data for easy monitoring.

The software yields results corresponding to critical engine performance metrics like N1, N2, N3, TIT, fuel flow, and thrust percentage. However, its usability is impeded by outdated documentation last revised in 1987[8], with only a single reference noted in the early 2000s and no available updates online.

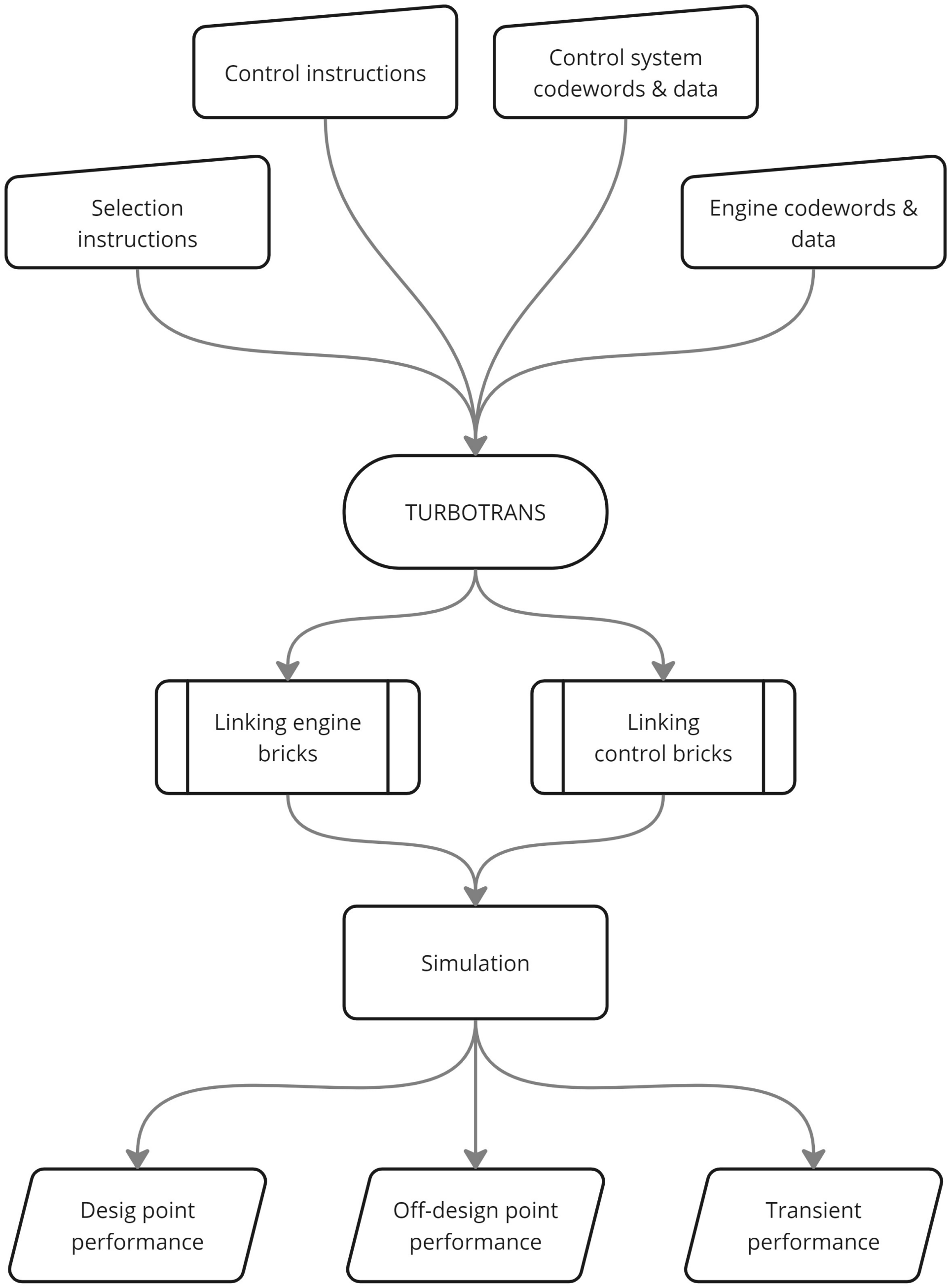


Figure 3.1: Turbotrans

Although more recent and validated alternatives exist, this software stands out for its accessibility and openness, enabling usage without licensing restrictions and facilitating direct code manipulation.

3.2.3 Pacelab APD

An alternative provided by the company itself is Pacelab APD, an advanced software platform specifically designed for aircraft preliminary design. Developed based on the PacelabSuite engineering software platform, Pacelab APD caters to aircraft and engine development units, primary suppliers, and research institutions.
Two key features provides:

- Ready-to-use propulsion and aircraft models to avoid starting from scratch.
- Extensible charts and reports, including payload range diagrams and flight envelope charts.

it is particularly notable for its inclusion of the A320-200 aircraft with both CFM56 and IAE 2537 engine variants. The software offers a diverse range of analysis capabilities to address various requirements:

- Aerodynamic Analysis
- Structural Analysis
- Weight and Balance Analysis
- Performance Analysis
- Propulsion System Analysis
- Mission Analysis
- Economic Analysis
- Environmental Impact Assessment

Its proficiency in conducting performance, propulsion, and mission analyses positions it as a suitable partial substitute for TURBOTRANS software. However, the absence of dynamic analysis capabilities to assess transient conditions may render it insufficient in certain cases, warranting the identification of an alternative solution.

3.3 Validation Data Roadmap

Once extracted from the validation tests are the procedures to be conducted, along with the necessary data for each test, and once the sources for acquiring the data to create the data package have been defined, the Validation Data Roadmap (VDR) comes into play. This document serves to precisely specify and document the sources utilized to procure each data point, as well as the corresponding test for which it was employed[4]. Its contents include:

- Scope Determination: Engineers assess the scope of VSD needed for simulator qualification.
- Substantiation: Justification for the chosen scope.

- Sources of Data: Identifying reliable sources for validation data.
- Process Overview: An overview of the validation process.
- Engineering Simulator/Simulation Validation Data: Specific data related to the simulator's engineering aspects

The creation of this document serves multiple purposes, which can be summarized into three main points:

- Quality Assurance: Ensures that simulators meet rigorous standards.
- Safety: Properly validated simulators enhance pilot training safety.
- Compliance: Aligns with regulatory requirements set by organizations like the European Union Aviation Safety Agency (EASA)

The thesis aims not to create a VDR but to incorporate its principles, constructing a data package that accurately defines the chosen sources and the rationale behind their selection for each test. This approach facilitates the partial development of the VDR through a thoroughly delineated preliminary process.

Chapter 4

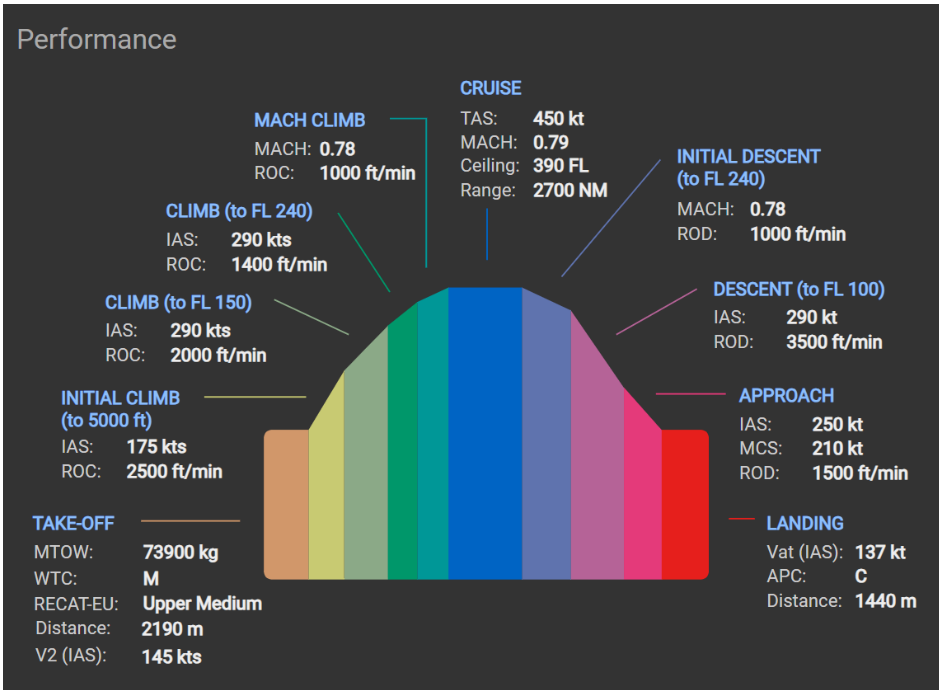
Source data validation

At this stage, all the necessary components are available to begin constructing the data package. The process involves taking each test individually and, drawing upon the company's expertise, the engineer's knowledge, and the guidelines outlined in ICAO - Annex 8, identifying the optimal source to attain the desired data point.

4.1 Performance

4.1.1 Nominal climb all engine operating

The test mandates evaluating the flight velocity and rate of climb over a duration ensuring the aircraft covers a minimum distance of 300 meters. In standard conditions, flight performance parameters are sourced from the Eurocontrol website.



Performance

TAKE-OFF
MTOW: 73900 kg
WTC: M
RECAT-EU: Upper Medium
Distance: 2190 m
V2 (IAS): 145 kts

INITIAL CLIMB (to 5000 ft)
IAS: 175 kts
ROC: 2500 ft/min

CLIMB (to FL 150)
IAS: 290 kts
ROC: 2000 ft/min

CLIMB (to FL 240)
IAS: 290 kts
ROC: 1400 ft/min

MACH CLIMB
MACH: 0.78
ROC: 1000 ft/min

CRUISE
TAS: 450 kt
MACH: 0.79
Ceiling: 390 FL
Range: 2700 NM

INITIAL DESCENT (to FL 240)
MACH: 0.78
ROD: 1000 ft/min

DESCENT (to FL 100)
IAS: 290 kt
ROD: 3500 ft/min

APPROACH
IAS: 250 kt
MCS: 210 kt
ROD: 1500 ft/min

LANDING
Vat (IAS): 137 kt
APC: C
Distance: 1440 m

Figure 4.1: A320-200 performance database

Eurocontrol's Aircraft Performance Database is a comprehensive resource that offers recognition and performance data for various aircraft types, including the A320-200. It covers details such as initial climb rates, cruise ceilings, approach speeds, and more[6]. Starting with the definition [5] of the aircraft as an A320-200 model with a Maximum Takeoff Weight (MTOW) of 73.9 tonnes, during the "Initial Climb" phase involving a climb of 5000 feet (approximately 1500 meters), ensuring a minimum distance covered of at least 300 meters, a rate of climb of 2500 feet per minute and an Indicated Airspeed (IAS) of 175 knots are identified. These values are considered valid as the test does not specify which definition of velocity to use.
At the end of the website it is specified that "All data presented is only indicative and should not be used operationally", indeed, this is not an issue since the simulator requires not real operational data but indicative data providing an order of magnitude and a trend.
The completion of the initial test was relatively straightforward due to its request for non-sensitive data, readily obtainable under standard flight conditions.

4.1.2 One Engine Inoperative Climb

During the climb phase in the event of an engine failure during takeoff, once the decision speed is surpassed, a takeoff must still be executed. The initial phase of this climb, following the rotation of the aircraft, is referred to as the Second Segment Climb.
s defined in the CS-25 [2], it begins when the landing gear is fully retracted after takeoff and it concludes at the higher of 400 feet or the specified acceleration altitude.

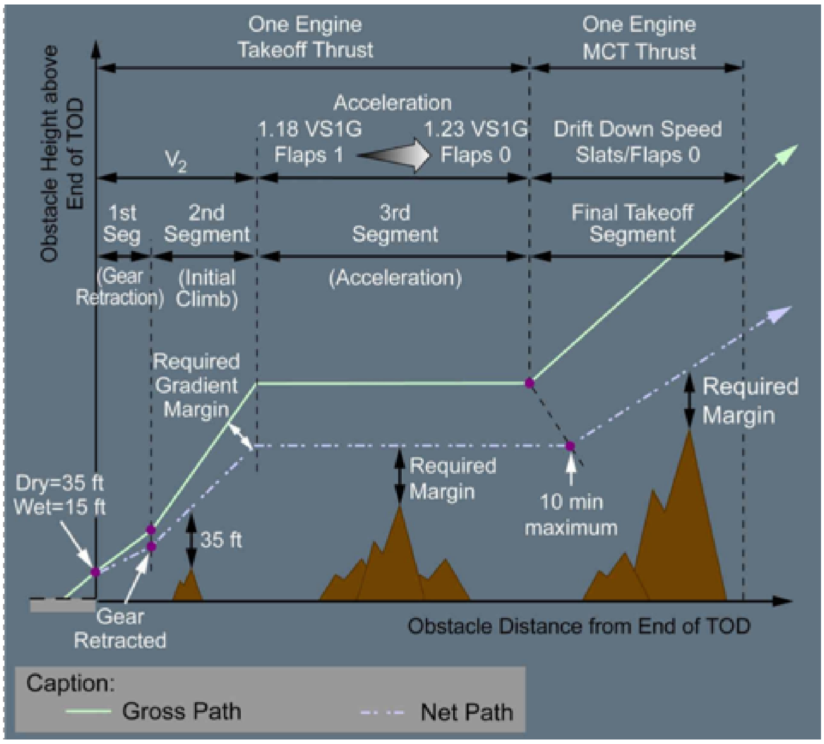
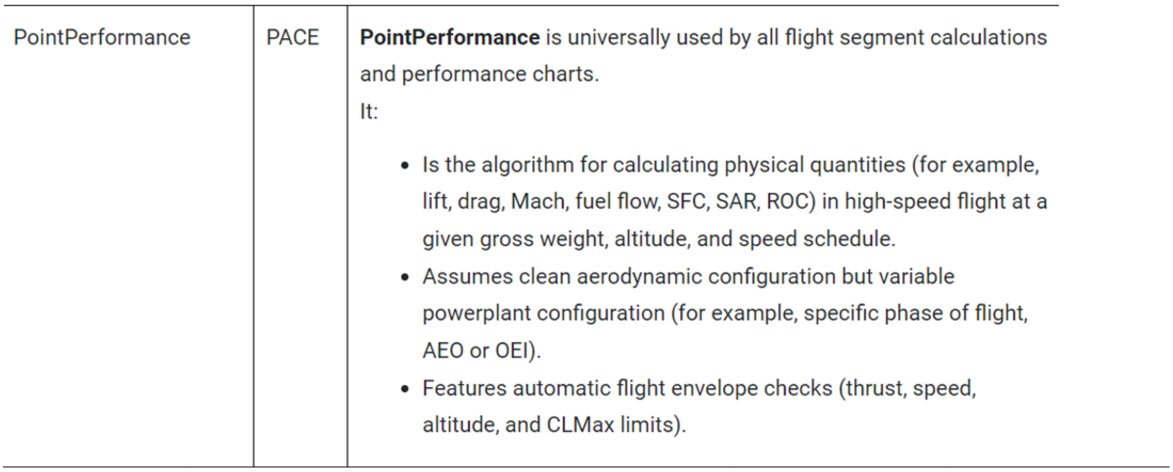


Figure 4.2: Climb path

According to CS-25 regulations and as reiterated in the Aircraft Flight Manual (AFM), during this phase, the minimum speed to be maintained is V2, defined as the minimum speed under one engine inoperative (OEI) conditions during the second segment climb. Additionally, for a twin-engine aircraft, a climb gradient of 2.4% is required.
The climb gradient is defined as the ration between the vertical speed and the ground speed.
An additional parameter is required for this test, called a WAT limited condition, or a Weight, Altitude, Temperature limited condition. One of those three parameters must be at its limited condition as defined in the "Operational Limit Condition" in the AFM.
Identifying the most appropriate data source for obtaining these parameters poses challenges. Initial analysis revealed no documents explicitly listing the flight speed and climb rate of an A320-200 or B737-800 under OEI conditions. Therefore, reliance was placed on the Pacelab APD software.
The software provides a type of analysis known as Point Performance [10], which is invaluable for evaluating the performance characteristics of the aircraft during specific mission phases. In this context, it is particularly beneficial for assessing the Second Segment Climb in OEI conditions.



PointPerformance	PACE	**PointPerformance** is universally used by all flight segment calculations and performance charts. It: • Is the algorithm for calculating physical quantities (for example, lift, drag, Mach, fuel flow, SFC, SAR, ROC) in high-speed flight at a given gross weight, altitude, and speed schedule. • Assumes clean aerodynamic configuration but variable powerplant configuration (for example, specific phase of flight, AEO or OEI). • Features automatic flight envelope checks (thrust, speed, altitude, and CLMax limits).

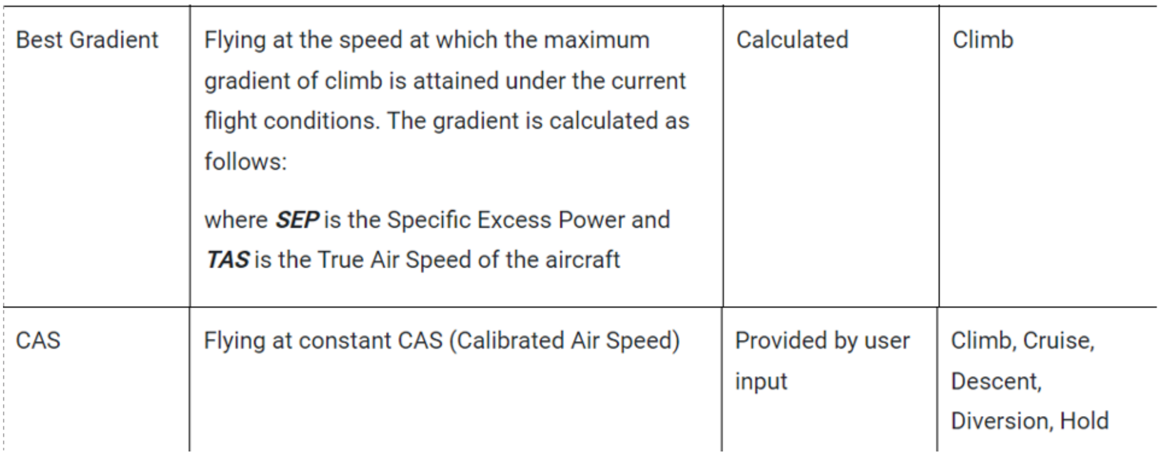
Figure 4.3: point performance definition

The software requires a set of input data, and following a performance analysis, it generates a document containing a series of output specifications.

- Altitude - as described in the AFM, an altitude of 400 feet is set as the target altitude
- Temperature profile - ISA Standard Day is perfect as the nominal temperature condition, with
- ISA deviation - 0 Kelvin degrees
- The mass is set at its limited condition as defined in the AFM

- The mode is One Engine Inoperative while the
- speed policy require a further analysis

The definition of Speed Policy is defined in the Pacelab documentation [10] as:



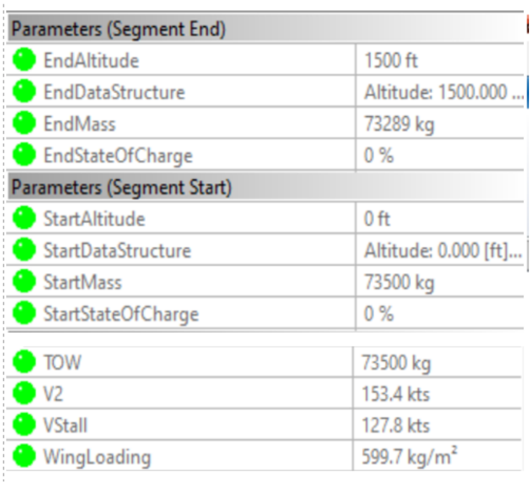
Best Gradient	Flying at the speed at which the maximum gradient of climb is attained under the current flight conditions. The gradient is calculated as follows: where ***SEP*** is the Specific Excess Power and ***TAS*** is the True Air Speed of the aircraft	Calculated	Climb
CAS	Flying at constant CAS (Calibrated Air Speed)	Provided by user input	Climb, Cruise, Descent, Diversion, Hold

Figure 4.4: point performance speed policy

The speed policy unfortunately doesn't consider the Indicated Air Speed as an option, therefore a further analysis between Calibrated Air Speed or Best Gradient speed policy has been conducted.

Despite the fact that Best Gradient aims to optimize the Rate of Climb, there is a challenge regarding the inability to control the climb speed, which may not be suitable for the simulated aircraft class. Therefore, the decision was made to utilize Calibrated Air Speed (CAS) and conduct two detailed analyses to determine the appropriate value.

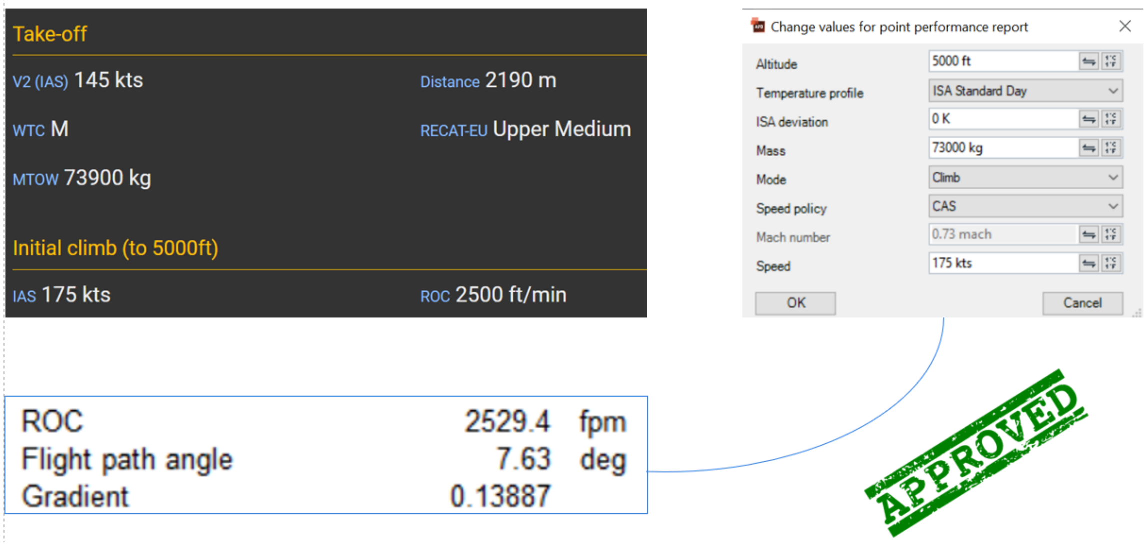
One analysis involved using the Aircraft Flight Manual (AFM) to verify the difference between CAS and Indicated Air Speed (IAS) at 400 feet altitude, equivalent approximately to ±1 knot. The other analysis utilized the V2 value indicated in the performance characteristics of the aircraft in the Pacelab APD software.



Parameters (Segment End)	
● EndAltitude	1500 ft
● EndDataStructure	Altitude: 1500.000 ...
● EndMass	73289 kg
● EndStateOfCharge	0 %
Parameters (Segment Start)	
● StartAltitude	0 ft
● StartDataStructure	Altitude: 0.000 [ft]...
● StartMass	73500 kg
● StartStateOfCharge	0 %
● TOW	73500 kg
● V2	153.4 kts
● VStall	127.8 kts
● WingLoading	599.7 kg/m²

Figure 4.5: A320 performance database from Pacelab APD

The final step involved validating the software. The decision was made to input the data from a nominal climb taken from the previous test and verify if the output Rate of Climb would be similar. The test concluded with a positive outcome.
The figure 4.6 represent the Eurocontrol performance database during Take-Off and Initial Climb, it contains all necessary data for performing a Nominal Climb on Pacelab APD, represented on its right; below both images, there are the results of the Pacelab APD test with a Rate of Climb of 2529 feet per minute, almost equal to the measured one on Eurocontrol



Take-off

V2 (IAS) 145 kts
Distance 2190 m
WTC M
RECAT-EU Upper Medium
MTOW 73900 kg

Initial climb (to 5000ft)

IAS 175 kts
ROC 2500 ft/min

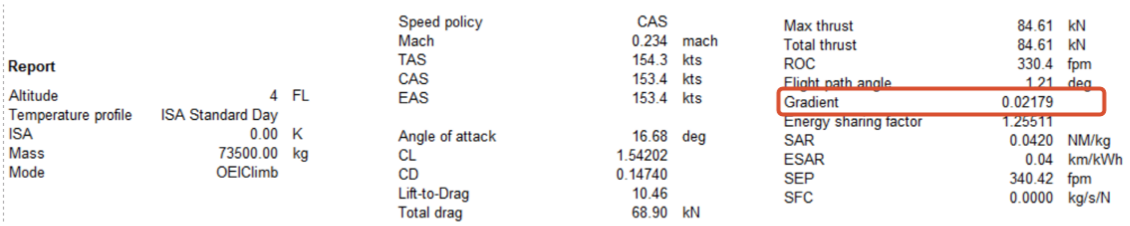
Change values for point performance report

Altitude: 5000 ft
Temperature profile: ISA Standard Day
ISA deviation: 0 K
Mass: 73000 kg
Mode: Climb
Speed policy: CAS
Mach number: 0.73 mach
Speed: 175 kts

```
ROC                  2529.4  fpm
Flight path angle      7.63  deg
Gradient            0.13887
```

Figure 4.6: Pacelab APD point performance validity test

In conclusion, the test was conducted by inputting the requisite data, with particular emphasis placed on observing the gradient rather than solely the rate of climb. The assessment aimed to ensure that the observed gradient surpassed the acceptable threshold of 2.4%.



```
                                           Speed policy          CAS        Max thrust              84.61  kN
                                           Mach                0.234 mach   Total thrust            84.61  kN
Report                                     TAS                 154.3 kts    ROC                     330.4  fpm
                                           CAS                 153.4 kts    Flight path angle        1.21  deg
Altitude                         4  FL     EAS                 153.4 kts    Gradient              0.02179
Temperature profile  ISA Standard Day                                       Energy sharing factor 1.25511
ISA                           0.00  K      Angle of attack     16.68 deg    SAR                    0.0420  NM/kg
Mass                      73500.00  kg     CL                1.54202        ESAR                     0.04  km/kWh
Mode                      OEIClimb         CD                0.14740        SEP                    340.42  fpm
                                           Lift-to-Drag        10.46        SFC                    0.0000  kg/s/N
                                           Total drag          68.90 kN
```

Figure 4.7: point performance report result

The results show a slight deviation from the accepted standard. However, with minor adjustments and corrections, a successful report is anticipated.

4.1.3 Acceleration and Deceleration

These types of tests demand performance evaluations under acceleration and deceleration conditions, which are inherently characterized by transients. Therefore, neither

official documents nor Pacelab APD software may be equipped to address them.
Despite that, starting from version 7.4 of Pacelab APD, a new feature has been introduced, capable of considering, albeit in a very limited manner, the phases of acceleration and deceleration of the aircraft.
Alternatively to using Flight Segment Performance, where acceleration from condition A to condition B can be studied, another method of analysis in Pacelab APD called ”studies” can be applied.
Both methods could prove valid under skilled hands, but to assess subsequent tests as well, this particular type of test was overlooked, leaving the task of resolving it to future endeavors.

4.2 Handling Qualities - Static Control Check

4.2.1 Force feedback vs position

This type of test necessitates understanding the relationship between the position of a control and the force it yields.
Firstly, this test is distinguished based on whether it involves mechanical control lines or fly-by-wire systems. In the latter case, characteristic of the A320-200, an artificial force feedback system is implemented to replicate the yoke force based on the maneuver difficulty and flight envelope.
Consequently, to access the data regarding control position and force feedback, it would be necessary to engage with the dedicated force feedback software.
Alternatively, one could reach out not to the aircraft manufacturer Airbus, but to the company responsible for implementing primary flight controls, such as Moog. Typically, these companies provide specifications related to the force feedback of the controls along with the hardware.
An even more relaxed alternative is the use of the force limits that pilots can endure, as defined by CS-25 regulations.
While the first method is dismissed a priori due to the nature of this data package, the second method has been minimally explored with limited results, primarily identifying helicopter components and inadequate force feedback values.
Therefore, the third method was pursued, justified by a workaround derived from common sense and experience. Specifically, under nominal conditions, ensuring a yoke force equivalent to half of the minimum limit prescribed in CS-25 regulations as the minimum force required for the pilot to move the control, and maximum force, indicating the maximum force the pilot can withstand following a control maneuver.
Depending on whether the control is defined by a wheel or a stick, the pilot’s effort is measured in Nm (Newton-meters) or N (Newtons); with Nm depending on the Wheel diameter.
As an example, here is what is expected the pilot to perceive during a full yoke deflection from a neutral position, both positively and negatively:

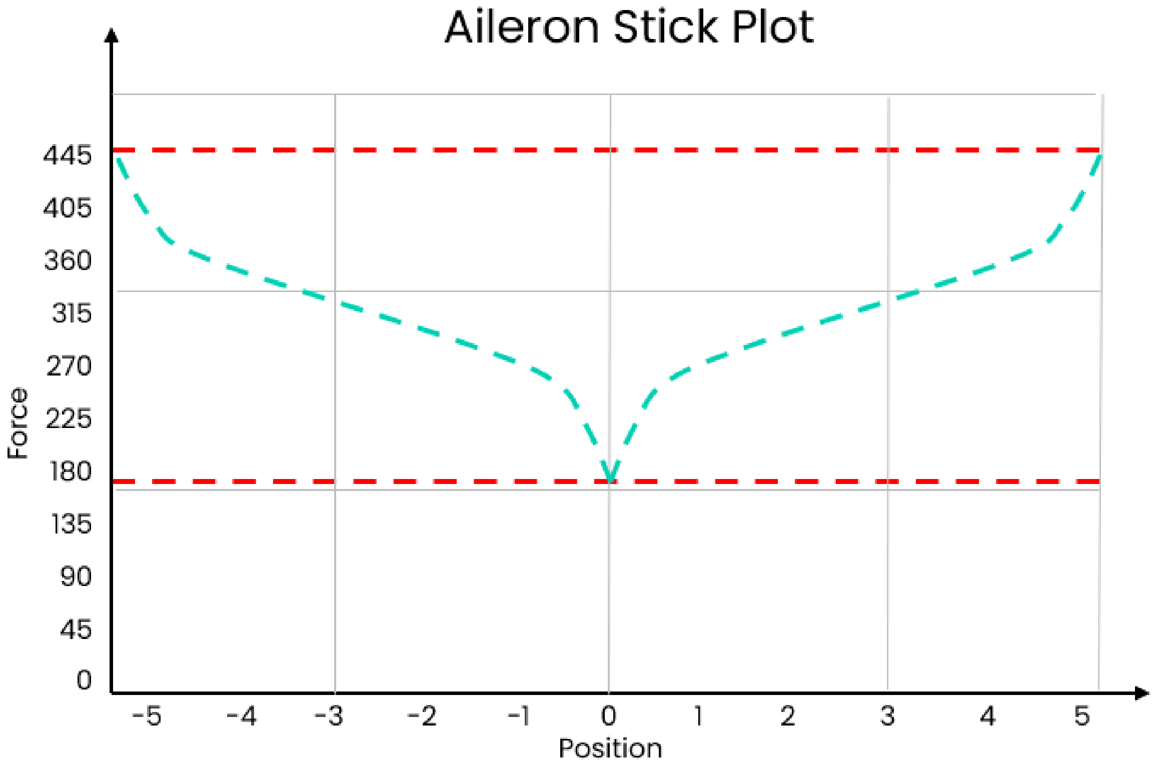


Figure 4.8: Force Feedback vs Command Position

4.2.2 Trims calibration

This test requires meticulous analysis of its execution methodology.

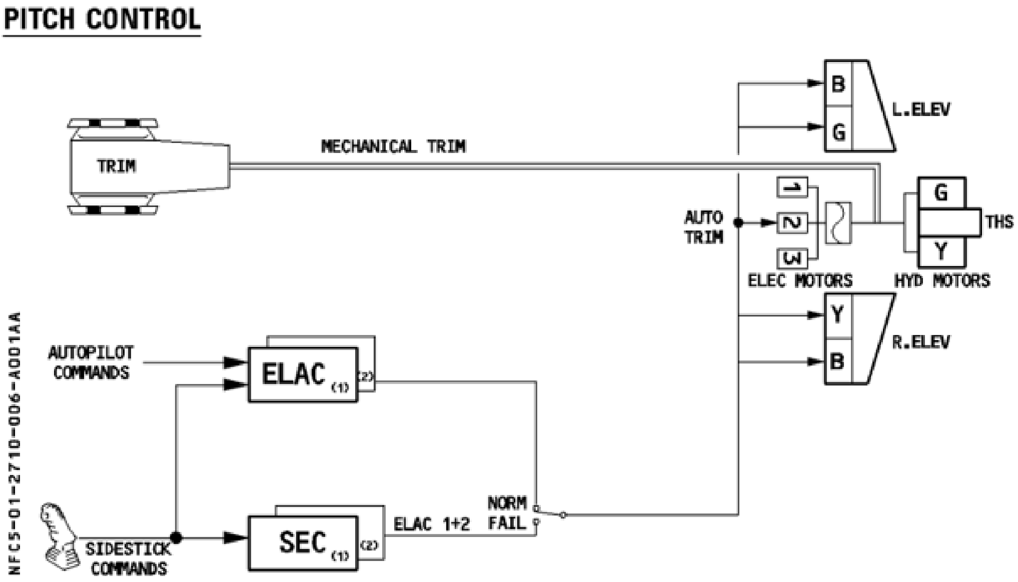


Figure 4.9: Pitch control scheme

It presupposes a thorough understanding of the Trim Horizontal Stabilizer (THS) operation and the capability to compare the simulated surface position with the expected real aircraft position.
However, this test poses a challenge due to the incomplete knowledge of THS specifications. Only partial information has been acquired, particularly regarding the total excursion of the trim wheel. Nonetheless, it is proposed to utilize this data to demonstrate a presumed linear behavior in the real aircraft and verify its replication in the simulator following a command.
The complete excursion ranges from 13.5 degrees nose up to 4 degrees nose down, with an electronic limit at 11 degrees nose up for safety reasons.
Through mechanical actuation, it is possible to bring the THS to its full travel limit.

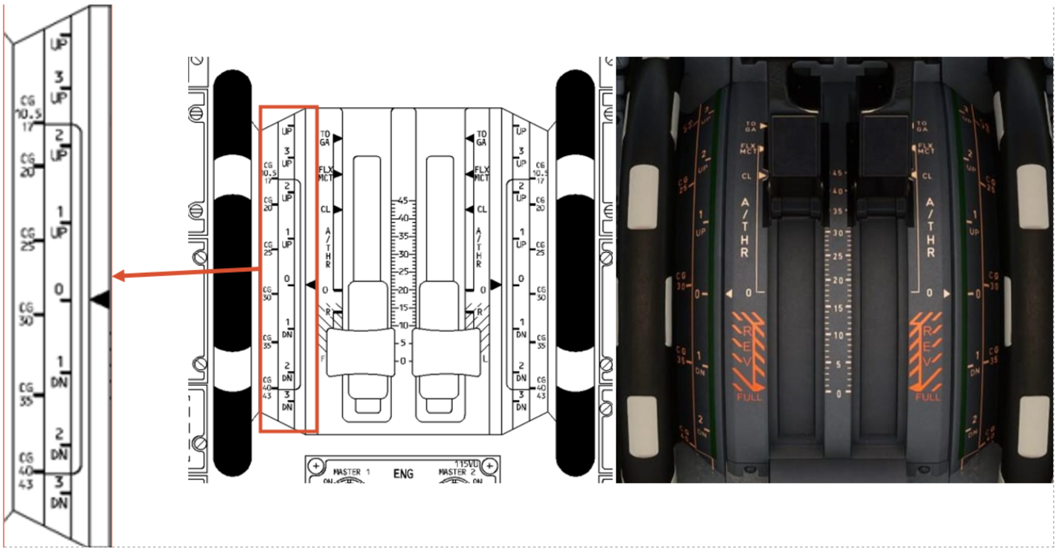


Figure 4.10: THS

With additional information, it would be possible to identify the center of gravity (CG) positions using the graphs provided in the Aircraft Flight Manual (AFM). Subsequently, these positions could be input into the THS to determine the stabilizer angles. The CG also has positioning limits on the ground and in flight. Through further analysis based on these limits, it would be feasible to determine the stabilizer angle.
However, it is assumed that there is a linear relationship between the command and the stabilizer angle in the simulator, with a sufficiently small deviation and a similar order of magnitude. Below is a generic representation of the expected result of a hypothetical test:

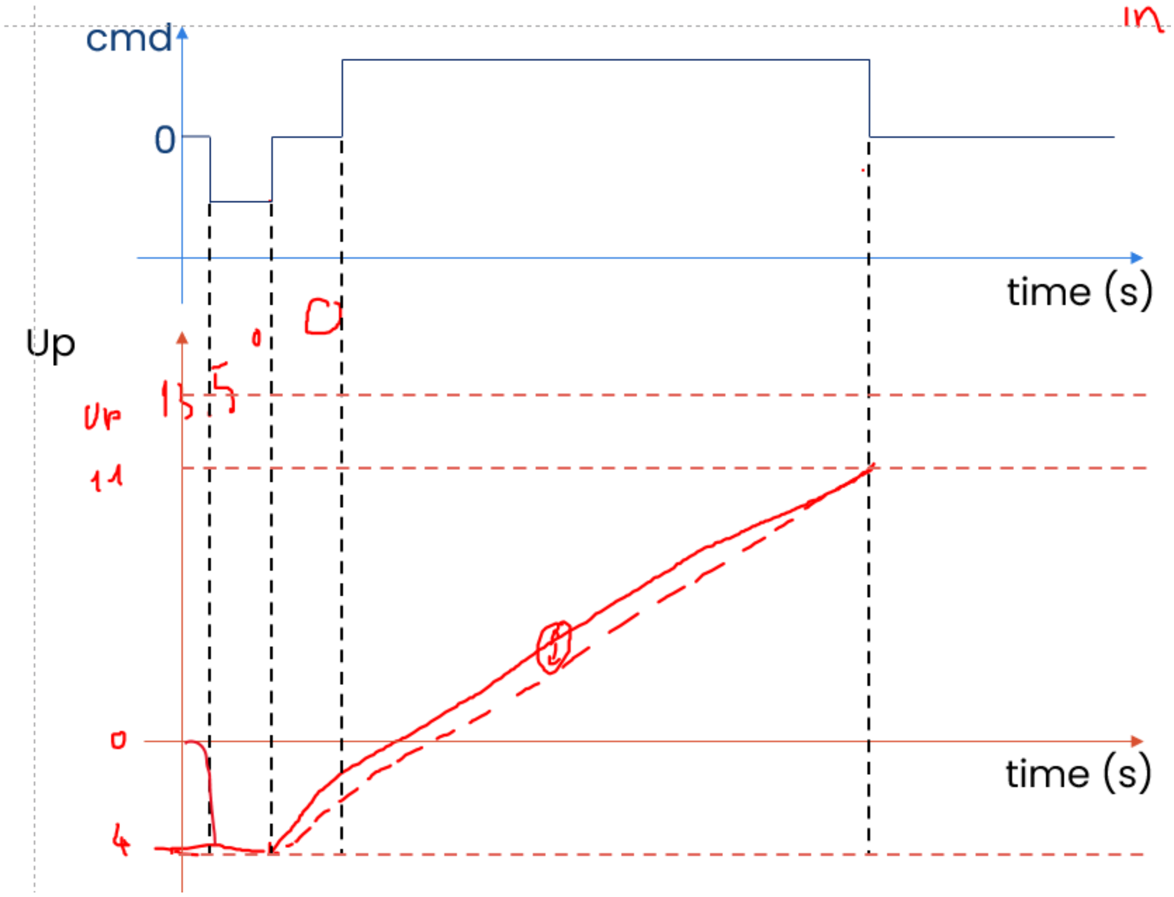


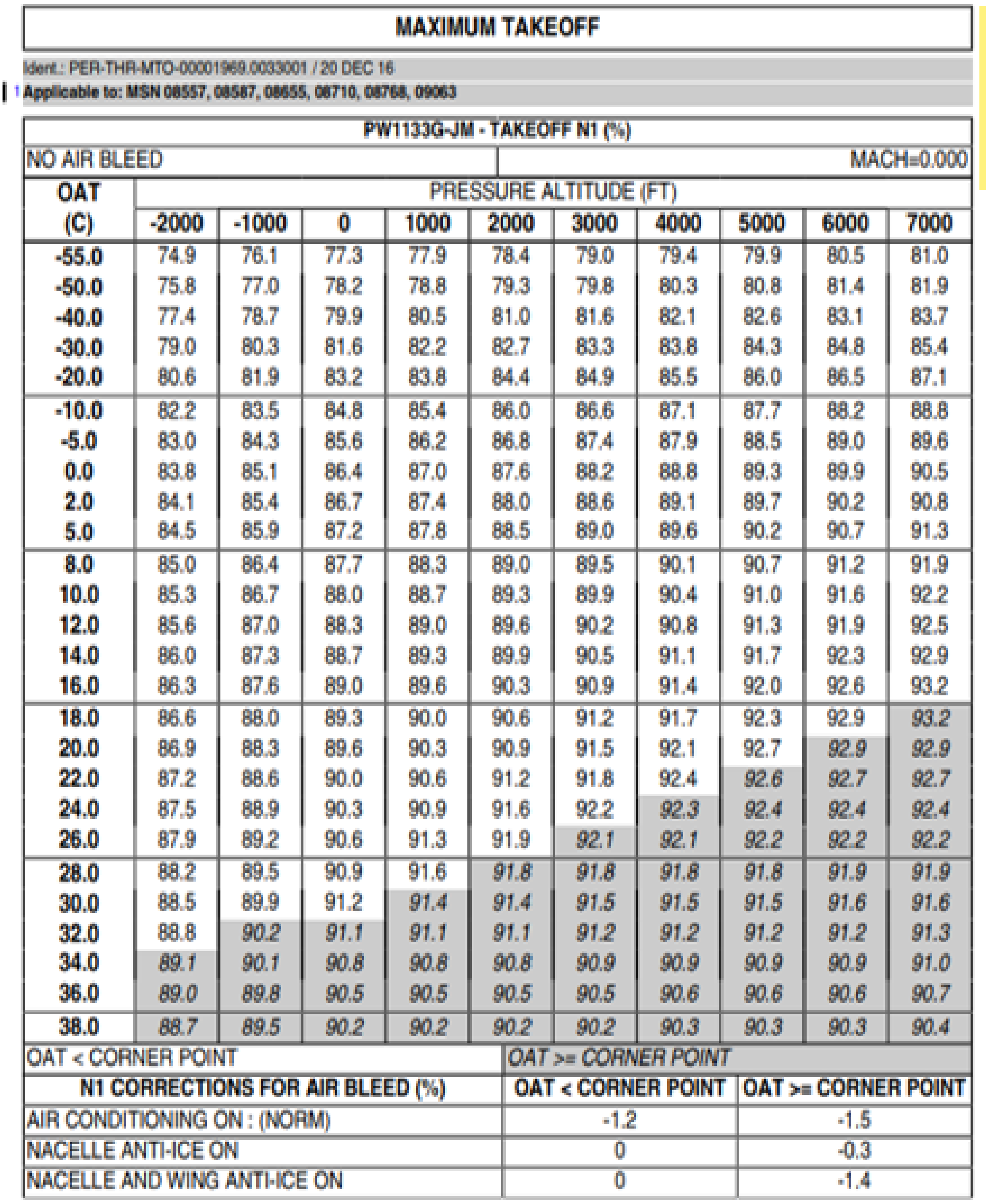
Figure 4.11: THS vs Command

4.2.3 Thrust alignment

The primary challenge in representing the engine characteristics based on throttle lever positions is that numerous parameters significantly influence performance, making it difficult to discern a clear relationship.
For instance, actions such as activating the air conditioning or anti-icing system actively alter engine parameters without necessarily changing the throttle lever position.
For this reason, it has been decided not to directly associate a specific throttle lever position with an indentation value. Instead, tables retrieved directly from the Aircraft Flight Manual (AFM) under the ”thrust ratings” section will be used.
Based on the

- Outside Air Temperature (OAT)
- Total Air Temperature (TAT),
- pressure altitude
- flight Mach number
- corrective factors such as air bleed

A unique value of N1, also known as throttle setting, can be identified. Below is an example of a table:



MAXIMUM TAKEOFF

Ident.: PER-THR-MTO-00001969.0033001 / 20 DEC 16

1 **Applicable to: MSN 08557, 08587, 08655, 08710, 08768, 09063**

PW1133G-JM - TAKEOFF N1 (%)

NO AIR BLEED — MACH=0.000

OAT	PRESSURE ALTITUDE (FT)									
(C)	**-2000**	**-1000**	**0**	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**
-55.0	74.9	76.1	77.3	77.9	78.4	79.0	79.4	79.9	80.5	81.0
-50.0	75.8	77.0	78.2	78.8	79.3	79.8	80.3	80.8	81.4	81.9
-40.0	77.4	78.7	79.9	80.5	81.0	81.6	82.1	82.6	83.1	83.7
-30.0	79.0	80.3	81.6	82.2	82.7	83.3	83.8	84.3	84.8	85.4
-20.0	80.6	81.9	83.2	83.8	84.4	84.9	85.5	86.0	86.5	87.1
-10.0	82.2	83.5	84.8	85.4	86.0	86.6	87.1	87.7	88.2	88.8
-5.0	83.0	84.3	85.6	86.2	86.8	87.4	87.9	88.5	89.0	89.6
0.0	83.8	85.1	86.4	87.0	87.6	88.2	88.8	89.3	89.9	90.5
2.0	84.1	85.4	86.7	87.4	88.0	88.6	89.1	89.7	90.2	90.8
5.0	84.5	85.9	87.2	87.8	88.5	89.0	89.6	90.2	90.7	91.3
8.0	85.0	86.4	87.7	88.3	89.0	89.5	90.1	90.7	91.2	91.9
10.0	85.3	86.7	88.0	88.7	89.3	89.9	90.4	91.0	91.6	92.2
12.0	85.6	87.0	88.3	89.0	89.6	90.2	90.8	91.3	91.9	92.5
14.0	86.0	87.3	88.7	89.3	89.9	90.5	91.1	91.7	92.3	92.9
16.0	86.3	87.6	89.0	89.6	90.3	90.9	91.4	92.0	92.6	93.2
18.0	86.6	88.0	89.3	90.0	90.6	91.2	91.7	92.3	92.9	*93.2*
20.0	86.9	88.3	89.6	90.3	90.9	91.5	92.1	92.7	*92.9*	*92.9*
22.0	87.2	88.6	90.0	90.6	91.2	91.8	92.4	*92.6*	*92.7*	*92.7*
24.0	87.5	88.9	90.3	90.9	91.6	92.2	*92.3*	*92.4*	*92.4*	*92.4*
26.0	87.9	89.2	90.6	91.3	91.9	*92.1*	*92.1*	*92.2*	*92.2*	*92.2*
28.0	88.2	89.5	90.9	91.6	*91.8*	*91.8*	*91.8*	*91.8*	*91.9*	*91.9*
30.0	88.5	89.9	91.2	*91.4*	*91.4*	*91.5*	*91.5*	*91.5*	*91.6*	*91.6*
32.0	88.8	*90.2*	*91.1*	*91.1*	*91.1*	*91.2*	*91.2*	*91.2*	*91.2*	*91.3*
34.0	*89.1*	*90.1*	*90.8*	*90.8*	*90.8*	*90.9*	*90.9*	*90.9*	*90.9*	*91.0*
36.0	*89.0*	*89.8*	*90.5*	*90.5*	*90.5*	*90.5*	*90.6*	*90.6*	*90.6*	*90.7*
38.0	*88.7*	*89.5*	*90.2*	*90.2*	*90.2*	*90.2*	*90.3*	*90.3*	*90.3*	*90.4*

OAT < CORNER POINT — *OAT >= CORNER POINT*

N1 CORRECTIONS FOR AIR BLEED (%)	**OAT < CORNER POINT**	**OAT >= CORNER POINT**
AIR CONDITIONING ON : (NORM)	-1.2	-1.5
NACELLE ANTI-ICE ON	0	-0.3
NACELLE AND WING ANTI-ICE ON	0	-1.4

Figure 4.12: Thrust ratings

Chapter 5

Final considerations

5.1 The reliability of the data package

The data package has been constructed taking into consideration the validity and accessibility of the sources; however, at times, it was necessary to leave room for interpretation in the descriptions of the tests and in resolving the data to be found. Therefore, the work actually requires an ability to verbally demonstrate the validity of the data, which may not always be validated explicitly.

5.2 Future Works

Almost all tests have more or less found their sources, including the CS-25, the AFM, Eurocontrol, and Pacelab APD. Sources, as defined in Annex 8, are often recycled and retrieved from various places, so the information obtained in the AFM, for example, is reproduced in the FCOM.

Therefore, a more careful and detailed analysis of the sources and tests can certainly lead to further reduction in the sources to draw from and, above all, obtain the most possible.

Some tests have performed better than others; for tests such as Acceleration and Deceleration, the issue is still unresolved.

Furthermore, Handling Qualities for Longitudinal and Lateral Dynamics have not been addressed at all, awaiting a more suitable source such as engineering flight simulators, or even the Visual System, which has not been considered at all given the workload.

In the future, it is expected to revisit these already analyzed tests and put them into a Validation Data Roadmap format and continue with the missing tests.

Chapter 6

Acknowledgements

The moment of gratitude was marked by hours spent staring at a blank screen while my mind traversed all the adventures and people I have encountered, who have helped me along this very challenging journey. Putting into words the feelings of gratitude I have towards so many people is difficult, and there wouldn't be enough words in this world to summarize what I have felt over these years.

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My journey began like the best of adventures, by chance. One February day, my best friend, the man who knows me better than I know myself, jokingly invited me to take an exam in Turin. This exam was the entrance exam for the Polytechnic University of Turin, of which I was unaware until a few seconds before.

I would like to thank him before anyone else for being by my side since middle school and for supporting me in every way, even unknowingly.

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During this journey, on one hand, friendship have blossomed, turned into love that then turned into friendship again, which have strengthened over the years. On the other hand, very old friendships have remained incredibly solid, and I want to thank them both from the bottom of my heart.

Last but not least, I would like to thank my supervisors who have been by my side every step of the way, demonstrating kindness, amiability, and availability.

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