Università degli Studi di Napoli “Federico II”

SCUOLA POLITECNICA E DELLE SCIENZE DI BASE

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

CORSO DI LAUREA IN INGEGNERIA AEROSPAZIALE

CLASSE DELLE LAUREE IN INGEGNERIA INDUSTRIALE (L-9)

Elaborato di laurea in

Flight tests for longitudinal static stability on a General aviation airplane

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ANNO ACCADEMICO 2022 – 2023

Chi ha provato il volo camminerà
Guardando il Cielo, perchè là è stato
E là vuole tornare
(Leonardo Da Vinci)

Abstract

The following thesis work aims to study and measure the longitudinal static stability of a general aviation aircraft. In the first chapter, the problem will first be framed from a theoretical point of view after the numerical examination of the equations describing the longitudinal static stability, as well as briefly illustrating the importance of flight tests in aeronautical experimentation. Subsequently, the methodology for analyzing the data collected after the experimental flight tests is presented.

The second chapter of this thesis work deals with the general characteristics of the aircraft used in the experimentation, with particular attention to the mass and balance limitations of the aircraft.

The third chapter deals with the experimental set up, the flight conductions methods and compliance with European air law and the data analysis in post processing which is carried out using a MATLAB script. The flight data reduction is conducted as described in chapter 1.

Sommario

Con il seguente lavoro di tesi ci si propone l'obbiettivo di studiare e misurare la stabilità statica longitudinale di un velivolo di aviazione generale. Nel primo capitolo il problema verrà dapprima inquadrato dal punto di vista teorico previa l'esamina numerica delle equazioni che descrivono la stabilità statica longitudinale, così come sarà brevemente illustrata l'importanza delle prove di volo nella sperimentazione aeronautica. Successivamente è esposta la metodologia di analisi dei dati raccolti a valle delle prove di volo.

Il secondo capitolo di questo lavoro di tesi tratta delle caratteristiche generali del velivolo utilizzato nella sperimentazione, con una attenzione particolare alle limitazioni di massa e bilanciamento del velivolo.

Nel terzo capitolo sono esposti il set up sperimentale, le modalità di conduzione sperimentali in conformità alla normativa europea e l'analisi dei dati che viene effettuata mediante uno script MATLAB così come descritto in precedenza nel primo capitolo.

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1. Introduction to longitudinal flight test

1.1 General information about flight test

Flight tests represent a crucial part in the aircraft certification program, in fact after all the ground work, static experiments and wind tunnel tests, the manufacturer can finally demonstrate that the airplane is able or not to perform its mission with planned performance in a certain safety range. Each test is planned and studied to collect parameters and data about all characteristic dimensions and measurement of the airplane. Of course, it is mandatory to place correctly all the inflight instrumentation which will record all the flight data.

Flight tests have a massive disadvantage, in fact they are particularly expensive. In order to perform an experimental flight it is necessary to calculate not only the flight cost but also what is directly connected with the airplane. In a flight test costs there are also the flight crews, the engineers, mechanics, ground operators, and ground specialists. This is the main reason why in a certification program a flight test is conducted almost at the end, not only because it requires already a valid type certificate and the built airplane but also because the industry must consider the cost against the effectiveness factor of a flight test.

1.2 Types of flight tests and flight planning

Ones the airplane is declared fit to fly by the authority, it is time to establish what kind of flight test we have to perform. Generally they can be classified by *operational* or *development*. The differences between them are the following:

- In operational flight test it is possible to archive the final aerodynamics data on the finite airplane and to study the inflight performance in order to satisfy the authority air law.
- Development tests come in whenever is not possible to observe a given issue at ground or to collect data for a research purpose.

Success or failure of a flight test is mainly connected to abilities of crews working on the project and coordination capacity of inflight and ground crews.

A good way of conducting a flight test is hence based on the mission planning that must be made on the ground with all the people involved in the test. In these long briefings it is important to answer two mainly questions:

- What are scope and targets of this flight?
- Which air laws have to be complied with?

Once these questions are properly answered, it is possible to organize flights modalities. An on-board must have for every flight deck conducting an experimental test are flight data cards. These documents are for flight crews (pilots and engineers) a fixed reference on flight conduction. In flight data card some important information are reported, like:

- Date of the test
- Aircraft type
- Airplane identification and serial number
- Purpose of flight
- Aircraft gross weight and center of gravity position
- Estimate times for takeoff and landing
- Flight configuration
- Flight techniques, test criteria, and maneuvers

The most important part of these flight data cards is that each of them must be frozen before the actual flight in a very long briefing by flight crews and ground flight test engineers. In the briefings not only the cards but also the airplane final configuration must be frozen and by so doing the airplane will be prepared for departure.

At the end of a first flight, both crews give a first interpretation of the acquired data and if they are considered satisfying for the test, the crews go for the other test or if it is necessary they proceed for repetition or configuration change until a satisfactory data acquisition or until the data prove that it is mandatory to change airplane configuration to not fail the tests. When the test is finally completed, results are analyzed in a post-flight briefing. When the data are properly collected the engineers analyze them and give an analytical interpretation to the experiments for a proper analysis.

1.3 Center of gravity theory and requirements

1.3.1 Introduction to weight and balance

A very crucial part in the ground work of a conventional flight test is to establish in a certain acceptable range where is located the center of gravity of the airplane. Not only where it is when the airplane is still on the ground but also how it shifts when the airplane is flying.

The reason why is important to calculate take off mass and the center of gravity is that airplane performance, stability, and control depend by these factors. Because of this, not only in flight test this matters but also in commercial, military, and general aviation operations an estimation of take-off mass and center of gravity is a European requirement for a safe flight.

Conventionally the best way to calculate the ramp mass of the airplane, already loaded of fuel, crews, and payload is on an automatic scale. This procedure is unfortunately impracticable for each flight for commercial operation because of equipment complexity and high cost of the procedure itself. In normal operations the empty weight is known, the fuel mass can be easily calculated by telelevers installed onboard in fuel tanks and for payload airlines do a baggage weighting on the ground and for passengers the operator assume a standard value of mass.

Thus, it is possible to have a mass summing up all the values. Center of gravity position is estimable in relation to mean aerodynamic cord, giving a datum reference, and assuming a proper distribution of the loaded mass (fuel and payload).

1.3.2 Empty weight determination

As previously stated, the empty weight is mandatory to estimate in both commercial flight operation and in general aviation airplanes. A fail to estimate these data means a bad estimation of airplane center of gravity and consequently a wrong inflight performance calculation. This is the reason why this data is so crucial not only for normal operation but also for flight testing.

For all airplanes, empty weight calculation must be done in a controlled area like an hangar where meteorology factors like wind, snow, and rain cannot afford the data collected.

In first assignment the airplane is not supposed to have usable fuel on board but only unusable fuel, oils, emergency equipment like oxygen masks, life vests, and the necessary engine fluids and toilet water.

For general aviation airplanes the regulation is considered pretty much the same, except for toilets water if not installed onboard.

Once the allowable mass on board in the empty weight is established, is necessary to put the airplane fully wings leveled and longitudinally leveled on the automatic scales.

The scales for general aviation airplane are usually three: the first one is placed under the nose wheel gear and the other two are placed under left and right primary wheels of landing gear. The empty mass is the sum of the values recorded by three scales.

A second step for the center of gravity is to choose a datum line or reference line and calculate the distance between this line and the mass distribution in the airplane.

The datum line depends by the builder but usually is the leading edge of root airfoil for rectangular wings. Otherwise for jets can be the nose or the nose cone for single engine propeller airplanes. The following expressions are used to estimate the center of gravity longitudinal position with respect to the datum line:

$$W_E = \sum_i W_i \qquad (1.1)$$

$$M_E = \sum_i M_i \qquad (1.2)$$

$$C.G._{ref} = \frac{M_E}{W_E} \qquad (1.3)$$

where:

- W_E is the empty mass
- W_i is a single mass
- M_E is total moment by datum line
- M_i is moment given by i-mass from datum line

1.3.3 Center of gravity by mean aerodynamic chord

Last step is to calculate the mean aerodynamic chord (m.a.c.) and define the longitudinal center of gravity position as fraction of m.a.c.

This came directly from the fact that the center of gravity is calculated from a generic datum that can be chosen at any point of the airplane.

With no further demonstration here follows the equation for the mean aerodynamic chord:

$$\bar{c} = \frac{2}{S}\int_0^{b/2} c^2(y)dy \qquad (1.4)$$

Where:

- *b/2*: half-wing span
- *y*: station along wing span
- *c*: chord length at station *y*
- *S*: wing planform area

The expression of m.a.c. can be simplified if the wing planform is single trapezoidal panel, with the taper ratio defined as tip chord divided by the root chord:

$$\lambda = \frac{C_{\text{tip}}}{C_{\text{root}}} \qquad (1.5)$$

$$\bar{c} = \frac{1+\lambda+\lambda^2}{1+\lambda} \qquad (1.6)$$

Once the mean aerodynamic chord is known, it is possible to calculate where is located its station from the assigned reference

$$X_{\text{m.a.c.}} = \frac{2}{S}\int_0^{b/2} x(y)c(y)dy \qquad (1.7)$$

where:

- *x* is the position of leading edge from reference
- *y* is the station along the wing span

and finally, the non-dimensional center of gravity position is:

$$\bar{X}_{CG} = \frac{X_{\text{cg,ref}} - X_{\text{m.a.c.}}}{\bar{c}} \qquad (1.8)$$

1.3.4 European air law requirements for flight testing

Here follows directly from EASA European regulation weighting limitations, tolerances and requirements on empty weight determinations.

CS 23.21 Proof of compliance

(a) Each requirement of this subpart must be met at each appropriate combination of weight and centre of gravity within the range of loading conditions for which certification is requested. This must be shown –

(1) By tests upon an aeroplane of the type for which certification is requested, or by calculations based on, and equal in accuracy to, the results of testing; and

(2) By systematic investigation of each probable combination of weight and centre of gravity, if compliance cannot be reasonably inferred from combinations investigated.

(b) The following general tolerances are allowed during flight testing. However, greater tolerances may be allowed in particular tests –

Item	*Tolerance*
Weight	+5%, –10%
Critical items affected by weight	+5%, –1%
C.G.	±7% total travel

Figure 1.1 EASA CS23.21 (European Aviation Safety Agency, Amendment 3 20 July 2012)

CS 23.29 Empty weight and corresponding centre of gravity

(a) The empty weight and corresponding centre of gravity must be determined by weighing the aeroplane with –

(1) Fixed ballast;

(2) Unusable fuel determined under CS 23.959; and

(3) Full operating fluids, including –

(i) Oil;

(ii) Hydraulic fluid; and

(iii) Other fluids required for normal operation of aeroplane systems, except potable water, lavatory precharge water, and water intended for injection in the engines.

(b) The condition of the aeroplane at the time of determining empty weight must be one that is well defined and can be easily repeated.

Figure 1.2 EASA CS23.29 (European Aviation Safety Agency, Amendment 3 20 July 2012)

1.4 Longitudinal static stability theory

1.4.1 Introduction to stability and control

When it is time to design and establish a certain level of stability and controllability, it is mandatory to carefully evaluate the mission that the airplane is supposed to perform. Generally in commercial airplanes for passenger comfort is preferable to have a large stability instead of high controllability requirements. The same cannot be accepted for military airplane, where a high level of controllability is mandatory for a success in a certain mission.

For a satisfying stability measurement it is necessary to indicate a certain reference axes system. The purpose of this work is to measure static longitudinal stability. Longitudinal motion is defined in the symmetry plane or about the lateral Y axis of a body axes reference system where:

- X axis is the longitudinal runs fore and aft in the aircraft and is located in plane symmetry, it is defined positive in flight direction
- Y axis is also called lateral axis, this is perpendicular to the plane of symmetry and positive to the right of airplane.
- Z axis or vertical axis is in the plane of symmetry and perpendicular both to X and Y and is defined positive in down direction

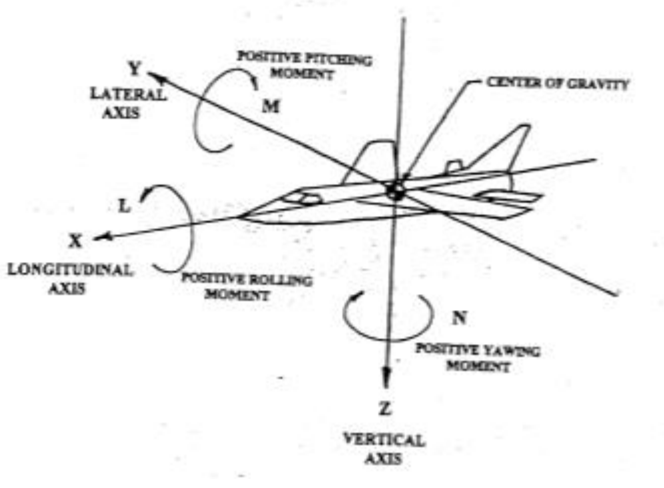


Figure 1.3 Body axis reference system

The stability of an airplane can be divided in static and dynamic. An airplane exhibits a positive static stability if, when displaced from a condition of equilibrium (in a fixed flight path), it has tendency to return to the initial equilibrium. If the airplane has a tendency to continue its movement when displaced from equilibrium condition, it exhibits a negative static stability (unstable). If the airplane exhibit neither a tendency to return neither a tendency to continue in its movement, it exhibits a neutral static stability. The equilibrium condition is called *trimmed condition.*

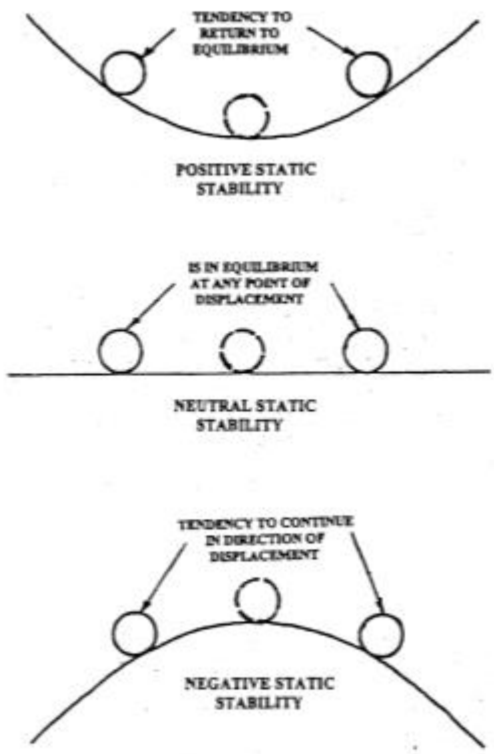


Figure 1.4 Static stability

Controllability can be as well defined as the attitude of airplane to respond to pilot input control movements. There is a relationship between stability and airplane controllability, not always this connection is totally clear in aviation community. Stability and controllability are the opposite of each other. If an airplane has a strong positive stability it will expose as well a massive difficulty to be controlled in flight. However, if the same airplane exposes high negative stability, its controllability will be poor as well, this because it will nor remain in any trimmed condition (equilibrium condition).

When it is necessary to deal with longitudinal motion it is supposed that everything happen in the plane of symmetry of the aircraft, or motion around Y axis. Only for small disturbances, longitudinal motion does not generate couples with motion around other axis. This is very important, because in static stability the motion can be considered bi-dimensional and consequently its analysis is simplified. In this work will be reported *non-maneuvering* tasks. They are so called because not so much maneuvering is required in these phases of flight and they are:

- Take-off
- Climb out
- Cruise
- Holdings
- Gliding path
- Descents
- Approaches
- Missed approach

Since the airplane will exhibit different levels of stability, depending if flight controls are fixed or free to move in airstream, in this work we case-study both of them. A further distinction will be done between *stick-free* and *stick-fixed* static stability.

1.4.2 Stick fixed static stability theory

With stick-fixed stability the pilot holds on the controls and does not leave the stabilator or equilibrator free to move in airstream. Whatever the motion on the control is, this is always caused by the pilot and not by free wind. In this kind of condition, the variation of pitching moments C_m about the aircraft's center of gravity with changing lift coefficient C_L is a function of the pitching moments of the individual components of the airplane for assigned lift coefficient. A quick examination to each component will be done and after that a sum up of all the contributions of moment with variation of lift coefficient and give a final analytical expression.

This first look is on the wing, it is mandatory to first examinate and calculate the wing aerodynamic center or the point where, on the wing cord, the pitching moment generated by the wing remains constant with changing of lift coefficient. Once this operation is done it is easy to see that if the center of gravity stays ahead of aerodynamic center (a.c.), the wing pitching moment will be a nose down (a stable restoration moment), in otherwise the moment will be pitch-up (an unstable non-restoration moment). This quick analysis can give a positive or a negative contribution to airplane longitudinal stability. In the worst case the contribution will be negative (unstable).

The fuselage is conventionally considered unstable because of its shape, and because of upwash and downwash of the wing action on the body itself. All these actions summed up give an unstable contribution by the fuselage with increase of lift coefficient.

Nacelles contribution is pretty much similar to the fuselage actions on the, hence they give unstable addition.

The effect of engine thrust very depends on where they are installed on the airplane and contribution depends also on engine's number on board. Because of this work the engine contribution to stability is given by a single engine piston installed in the airplane's nose, this means that source of thrust is given by propeller revolutions and the contributions can be considered unstable for each increase of power settings and stable for the opposite.

Last a close look to the horizontal tail, which can be considered the main flight component for stability and controllability in the longitudinal plane. The tail can produce a stabilizing pitching moment overcoming the unstable contribution of the other airplane's components. A very common use of volume tail coefficient is done in airplane's design to give an indication of how powerful the contribution of horizontal tail plane is and to compare several designs and configurations:

$$\overline{V_H} = \left(\frac{S_t}{S_W}\right)\left(\frac{l_t}{\bar{c}}\right) \qquad (1.9)$$

where:

- $\bar{V}_H$ is the tail volume coefficient
- S_t is the horizontal tail area
- S_W is the wing area
- l_t is the horizontal distance from the wing a.c. to tail a.c
- $\bar{c}$ is the wing mean aerodynamic chord

The equation that defines the slope of pitching moment curve for all the entire airplane in gliding flight is:

$$\frac{\mathrm{d}C_{m_{c,g.}}}{\mathrm{d}C_L} = \frac{X_a}{\bar{C}} + \left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{fus} + \left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{nac} - \left(\frac{a_t}{a_w}\right)\overline{V_H}\eta_t\left(1 - \frac{\mathrm{d}\varepsilon}{\mathrm{d}\alpha}\right) \qquad (1.10)$$

Where:

$\frac{X_a}{\bar{C}}$ = wing contribution and position of a.c. in relation to center of gravity.

a_t = lift curve slope of horizontal tail

a_w= lift curve slope of the wing

$\frac{\mathrm{d}\varepsilon}{\mathrm{d}\alpha}$ = downwash variation with angle of attach

$\eta_t = \frac{q_t}{q_\infty}$ is the tail efficiency factor, another index to have an indication of tail effectiveness, the index is given comparing the dynamic pressure seen by the tail with the asymptotic dynamic pressure. This index is generally smaller than one, this because the horizontal tail is located in the wing wake turbulence zone of severe downwash. The other large effect that the tail actually sees is that the angle of attack is different by the one seen by the wings and the reason of that are both the downwash effect and the incidence of tail and wings.

However a close look to the terms of equation (1.10) shows that all the indexes are fixed except for the wing term that can be easily shifted by moving the center of gravity, so it can change for every single flight. If we suppose to shift properly the center of gravity, we will probably reach a point where the equation (1.10) will be zero. The position of the center of gravity that give us this kind of result is called *stick-fixed neutral point* (N_o). When this point is determined (and it can be done within flight tests), it is possible to calculate the slope of the of the pitching moment with:

$$\frac{\mathrm{d}C_{m_{c,g.}}}{\mathrm{d}C_L} = \frac{X_{c.g.}}{\bar{C}} - N_O \qquad (1.11)$$

The distance between the center of gravity and the neutral point is called *stick-fixed static margin.*

The equation (1.11) once solved give us only one trim point (where $C_{mcg} = 0$), hence in order to fly trimmed at different C_L in steady leveled flight it is important to design the airplane in order to variate not the center of gravity in equation (1.10) but some other terms. Equation (1.10) is here rewritten in a different form:

$$C_{m_{\text{ces.}}} = C_{m_{\text{u.c.}}} + \frac{X_a}{\bar{C}} C_L + \left(C_{m_{\text{c.g.}}}\right)_{\text{fus}} + \left(C_{m_{\text{c.g.}}}\right)_{\text{nac}} - a_t \alpha_t \eta_t \overline{V_H} \quad (1.12)$$

- $C_{m_{\text{u.c.}}}$ is the wing pitching moment that can be changed using leading or trailing edge devices, but this is a method not conventionally used for maneuvering operations.
- $\frac{X_a}{\bar{C}}$ is the distance between the wing-body aerodynamic center and the aircraft center of gravity. This can be changed by shifting the c.g. position but there are physical limitations due to longitudinal stability and control, however the c.g. shifts during the flight for fuel consumption but again this is not a conventional maneuvering method.
- α_t Changing the angle of attack of airplane tail is considered a valid method for maneuvering purposes, it can be done with command line moving the entire horizontal tail (in this case we talk about *stabilator* command) or moving a part of it (in this case the talk about *elevator*).

Commercial jets use an elevator in combination with a movable stabilizer to enhance longitudinal control effectiveness on both maneuvering and trim.

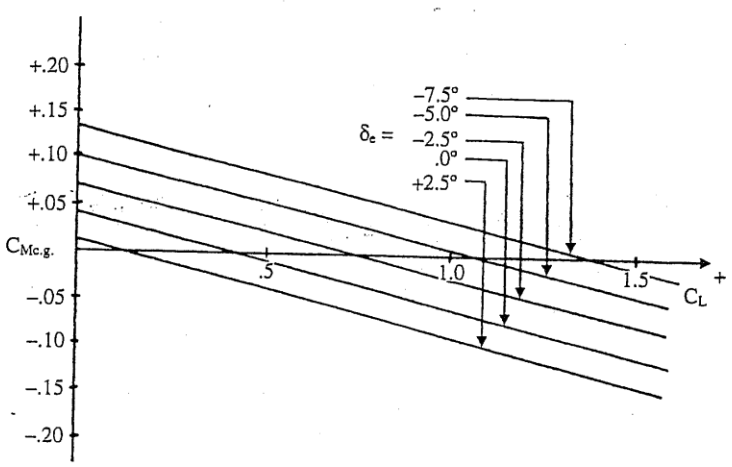


Figure 1.5 Cm c.g. vs Cl for different elevator angles.

Let’s now have look to the equation that solves the elevator or stabilator position for each lift coefficient. The expression is:

$$\delta_e = \delta_{e_{C_L=0}} - \frac{\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_X}{C_{m_{\delta_e}}} C_L \qquad (1.13)$$

Where:

- δ_e = elevator deflection
- $\delta_{e_{C_L=0}}$ = elevator deflection for zero lift coefficient
- $\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_X$ = slope of the pitching coefficient vs C_L curve
- $C_{m_{\delta_e}}$ = pitching moment coefficient by elevator deflection, also known as control power coefficient.

If the airplane has a stabilizer, the equation becomes:

$$C_{m_{\delta_e}} = -a_t \, \tau \, \eta_t \, \overline{V_H} \qquad (1.14)$$

τ = tail effectiveness factor, for stabilator is 1.0

The equation that will help us to calculate the stick-fixed neutral point by flight test is given by differentiating the equation (1.13) respect to C_L:

$$\frac{\mathrm{d}\delta_e}{\mathrm{d}C_L} = \frac{\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_X}{C_{m_{\delta_e}}} \qquad (1.15)$$

The reason why this equation is so important in flight tests is because when $\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_X$ becomes zero also the slope of elevator deflection vs lift coefficient does the same $\left(\frac{\mathrm{d}\delta_e}{\mathrm{d}C_L} = 0\right)$. This relationship between these two terms will help us to find the stick-fixed neutral point.

1.4.3 Stick free static stability theory

A very common inflight situation on longitudinal controls is when the airplane is flying in steady leveled flight and the pilot does not hold on the controls and likely the autopilot is non engaged. By so doing the controls are all free to move in the airstream floating in it. This kind of situation is called *stick-free longitudinal stability*. This situation holds only if the airplane has reversible control surfaces. Not all aircraft are equipped with these systems. Indeed a lot of them have hydraulics system installed onboard, supposed to move the flight controls commanded by a fly by wire system. This means that in a reversible flight control surface we can move the elevator with our hands, simulating the airstream flow, and see the movement on the control lines. Instead in a non-reversible system we may not be able to move the surface and see the result on the command line. A very good example of this situation is the newest Airbus fleet with its side-stick logic.

When we evaluate *stick-free longitudinal stability* we have to take into account the hinge moment coefficients given by the control surfaces. There are at least two terms: one due the angle of attack of horizontal tail without deflection of the control surface; the other due the elevator deflection when the horizontal tail is at zero angle of attack. An additional term may be present if the control surface is equipped with a trim tab.

The equation for the total elevator hinge moment is:

$$C_{h_e} = C_{h_0} + C_{h_{\alpha_t}}\alpha_t + C_{h_{\delta_e}}\delta_e + C_{h_{\delta_t}}\delta_t \quad (1.16)$$

Where:

- C_{h_e} = total elevator hinge moment coefficient
- C_{h_0} = elevator hinge moment due to camber line (zero if symmetric airfoil)
- $C_{h_{\delta_t}}$ = elevator hinge moment due to trim tab deflection
- δ_t = trim tab deflection

If the elevator is in equilibrium the total hinge moment is zero, this means that the *float* tendency is eliminated by the restoring tendency. If this condition occurs, in absence of a trim tab, the elevator floating angle is defined as:

$$\delta_{e_{\text{float}}} = -\frac{C_{h_{\alpha_t}}}{C_{h_{\delta_e}}} \quad (1.17)$$

When the elevator or stabilator is free to move in airstream, the angle given by equation (1.17) is negative since both terms are negative. This means that stability in this *stick-free* case is reduced. The full expression for this case is:

$$\left(\frac{\mathrm{d}C_{m_{c,g.}}}{\mathrm{d}C_L}\right)_{\text{free}} = \left(\frac{\mathrm{d}C_{m_{c,g.}}}{\mathrm{d}C_L}\right)_{\text{fixed}} + C_{m_{\delta_e}}\left(\frac{\mathrm{d}\delta_{e_{\text{float}}}}{\mathrm{d}C_L}\right) \qquad (1.18)$$

A close look to the equation (1.18) indicate that the longitudinal stability contains the term of *stick-fixed* case, hence also *stick-free* stability firmly depends from the center of gravity position. The position of center of gravity that gives the zero of equation (1.18) is called *stick-free neutral point.* Similarly, the distance between the neutral point and the center of gravity is called *stick-free longitudinal static margin*. The equation that gives us the *stick-free* longitudinal static stability foe each c.g. is:

$$\left(\frac{\mathrm{d}C_{m_{c,g.}}}{\mathrm{d}C_L}\right)_{\text{free}} = \frac{X_{c.g.}}{\bar{C}} - N_O' \qquad (1.19)$$

1.5 Flight tests data reduction methods for longitudinal static stability

The equations of longitudinal stability presented in the previous section present some practical issues: there are terms that cannot be easily measured in flight tests; also shifting the center of gravity up to the neutral point is not a safe way to operate the airplane. Conversely, a safer way to proceed for stick-fixed stability is to measure the elevator or stabilator position vs. the equivalent airspeed for several c.g. positions well ahead the expected neutral point. A very similar problem is related to the stick-free neutral point determination. By considering the expression for longitudinal control force, it can be shown that if $\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{\text{free}} = 0$ also the derivate of stick force vs equivalent airspeed is zero $\left(\frac{\mathrm{d}F_s}{\mathrm{d}V_e} = 0\right)$

$$\frac{\mathrm{d}F_s}{\mathrm{d}V_e} = 2K\frac{W}{S_W}\frac{C_{h_{\delta_e}}}{C_{m_{\delta_e}}}\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{free}\frac{V_e}{V_{e_{r-mm}}^2} \qquad (1.20)$$

Since also in this case it is not safe to fly the airplane with the center of gravity at the neutral point, it is preferable to take the data from the stick-fixed case and record also the pilot force on the control stick or on the yoke. The plot of stick force vs. calibrated airspeed must exhibit a stable slope as the regulations require. Equation (1.20) is not only a function of stability but also of trim. In order to exclude the dependence of the equation from trim we can divide the stick force by dynamic pressure q:

$$\frac{\mathrm{d}(F_s/q)}{\mathrm{d}C_L} = -A\frac{C_{h_{\delta_e}}}{C_{m_{\delta_e}}}\left(\frac{\mathrm{d}C_m}{\mathrm{d}C_L}\right)_{\text{free}} \qquad (1.21)$$

The equation (1.21) is function of stability only where:

- $A = -K\, S_e C_e$
- $K =$ control system gearing constant
- S_e = elevator area
- C_e = elevator m.a.c

Here are the different steps for the data reduction for static longitudinal stability:

1. Plot the data of elevator position vs calibrated airspeed for each flight at different c.g. and interpolate the data with a smooth curve.
2. From the curves obtained with step 1, plot the elevator position vs. lift coefficient, where C_L is calculated from the equation of lift for steady leveled flight. All the curves end in the same elevator position for $C_L = 0$.
3. Take the slopes $\frac{d\delta_e}{dC_L}$ at variations of C_L from each curve and plot vs. c.g. position. Interpolate the data with curves and extrapolate to zero. The result obtained is the c.g. position of the neutral point for single lift coefficient.
4. Final plot is the locus of neutral points X_N for each C_L vs. the lift coefficient C_L. Compare it with the most aft c.g. position allowed for airplane. That position is marked position since it is the most important neutral point.

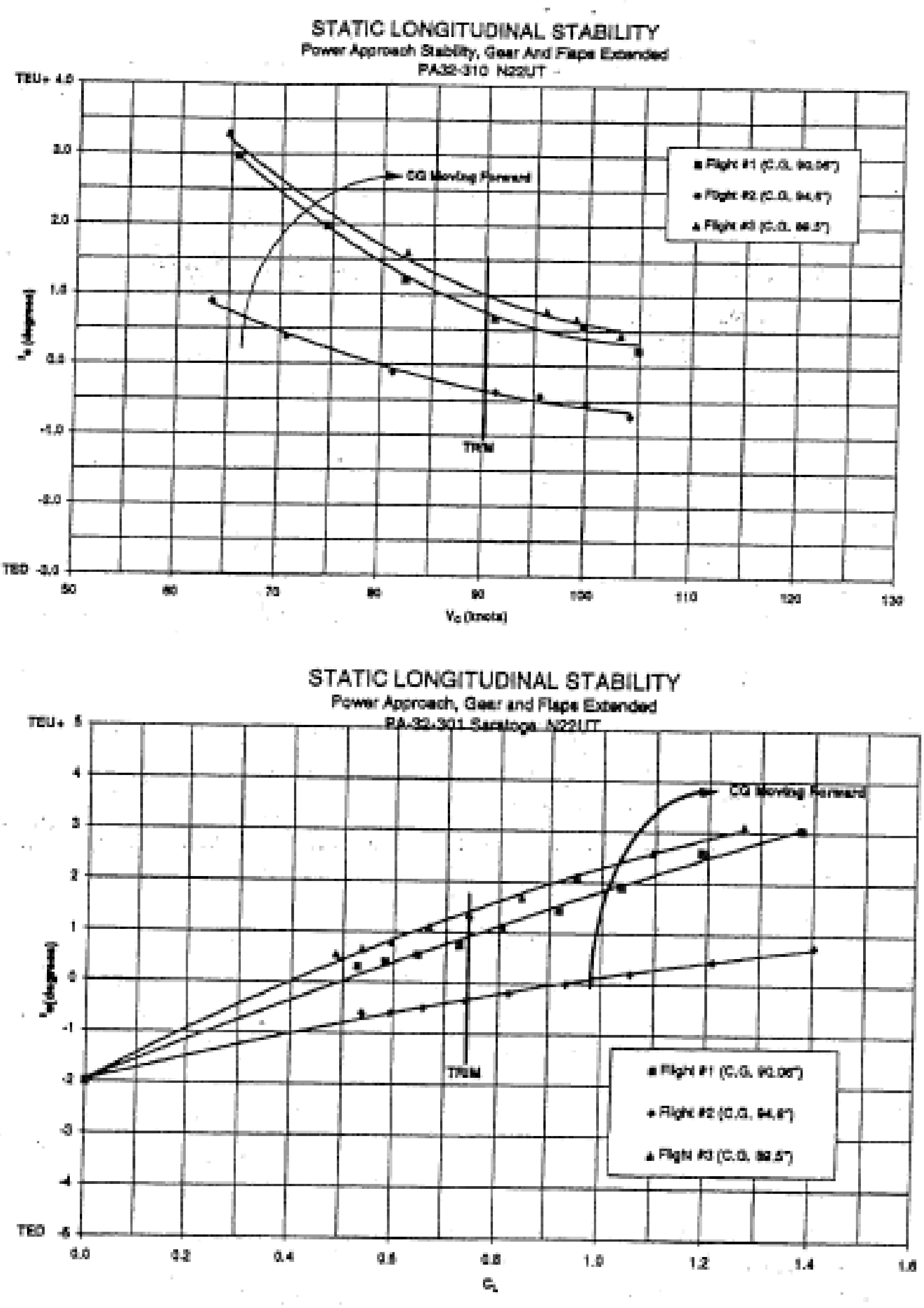
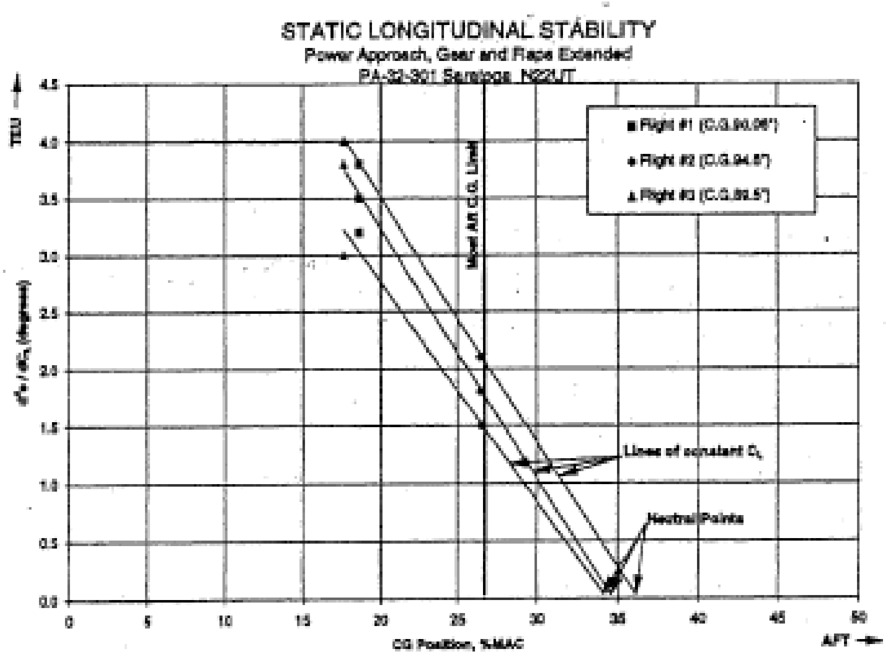


Figure 1.6 step 1 and 2 data reduction (Kimberlin, 2003)



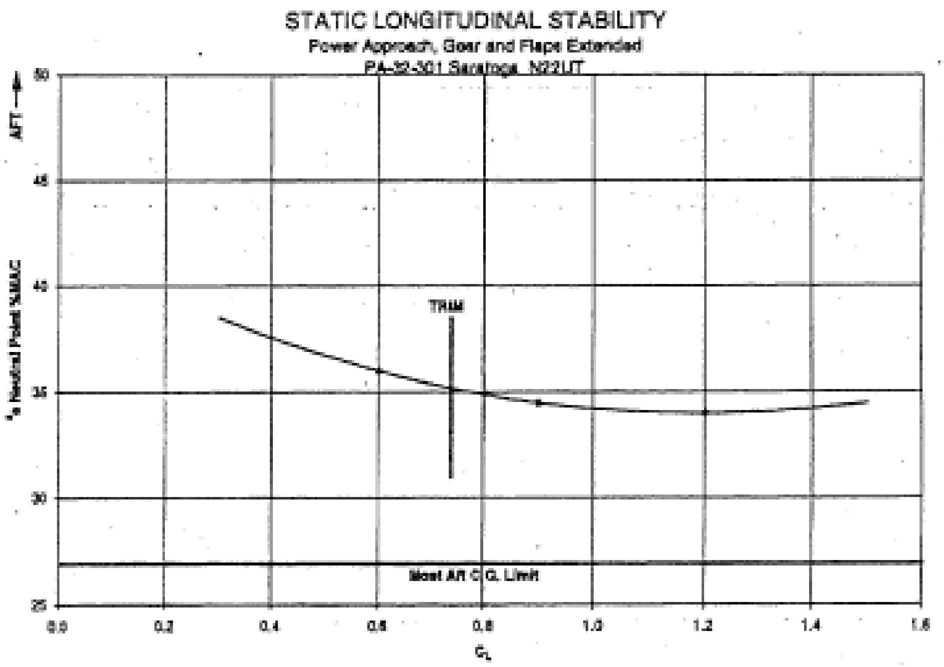
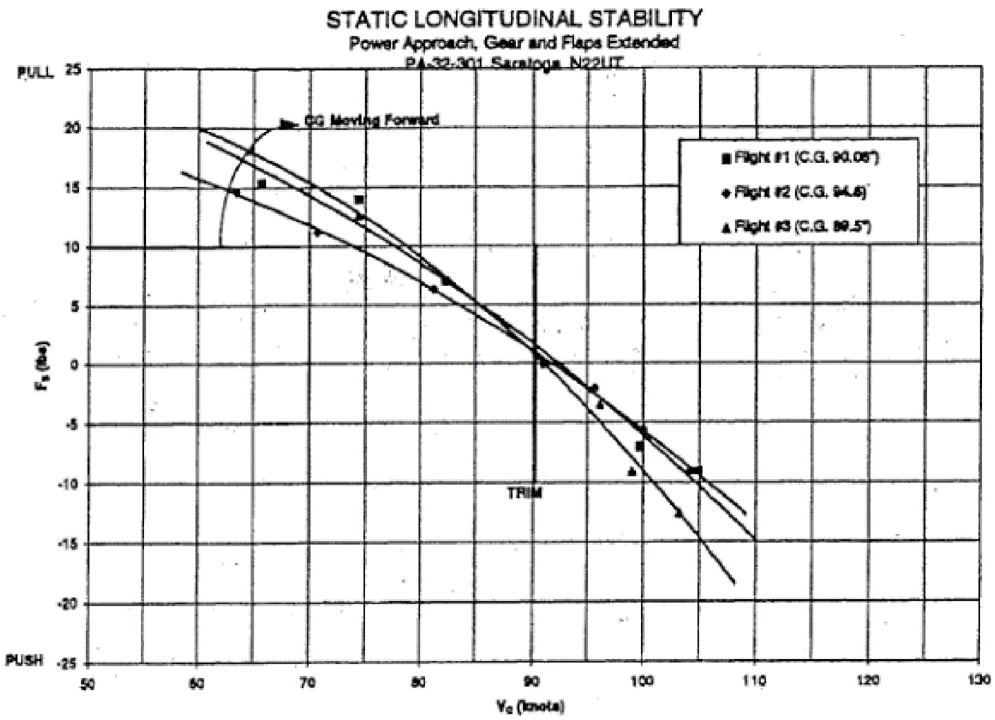


Figure 1.7 step 3 and 4 elevator data reduction (Kimberlin, 2003)

The second set of data collected are the ones related the stick force. The steps for data reduction are the following:

1. Plot elevator control force vs calibrated airspeed for each c.g. position tested and interpolate data through data.
2. Use increments of airspeed to obtain the elevator control force from previous plot using faired lines (and not the data points) and plot F_s/q vs. C_L for each c.g. position. The lines should cross at or near the trim C_L
3. For increments of C_L take slopes $d(F_s/q)/dC_L$ for each c.g. and plot slopes vs. c.g. Then extrapolate to zero slope. This is the control force neutral point for that C_L.
4. Final plot is the locus of neutral point vs. C_L. We marked the trim C_L, which is the most important one because it is the position where the pilot spent the most of his time, next to the trim position.



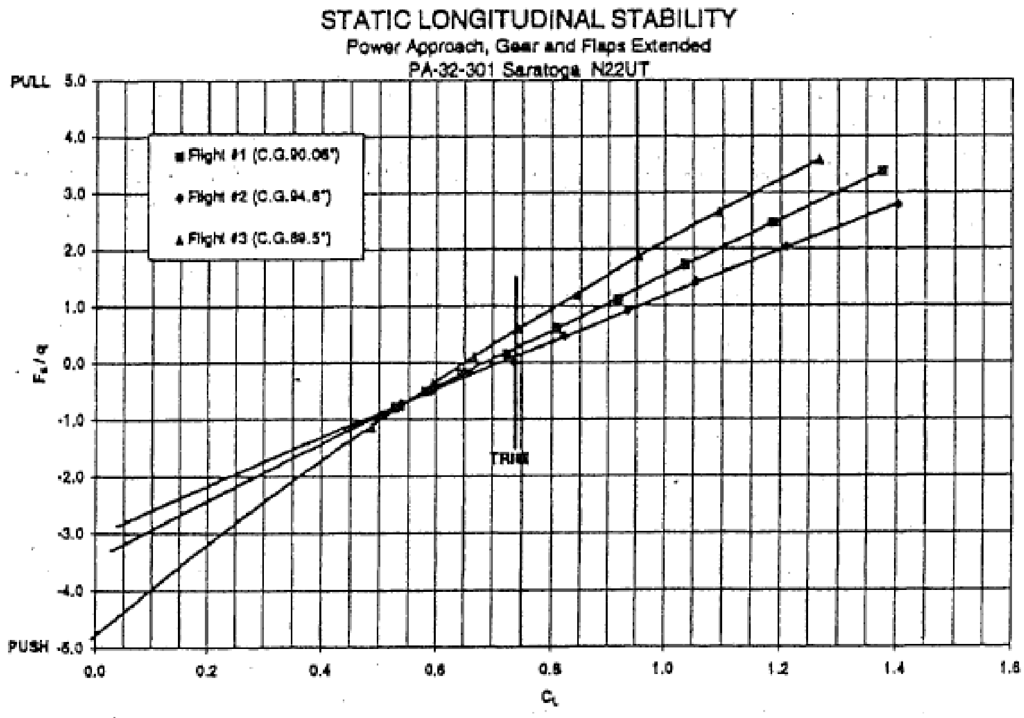
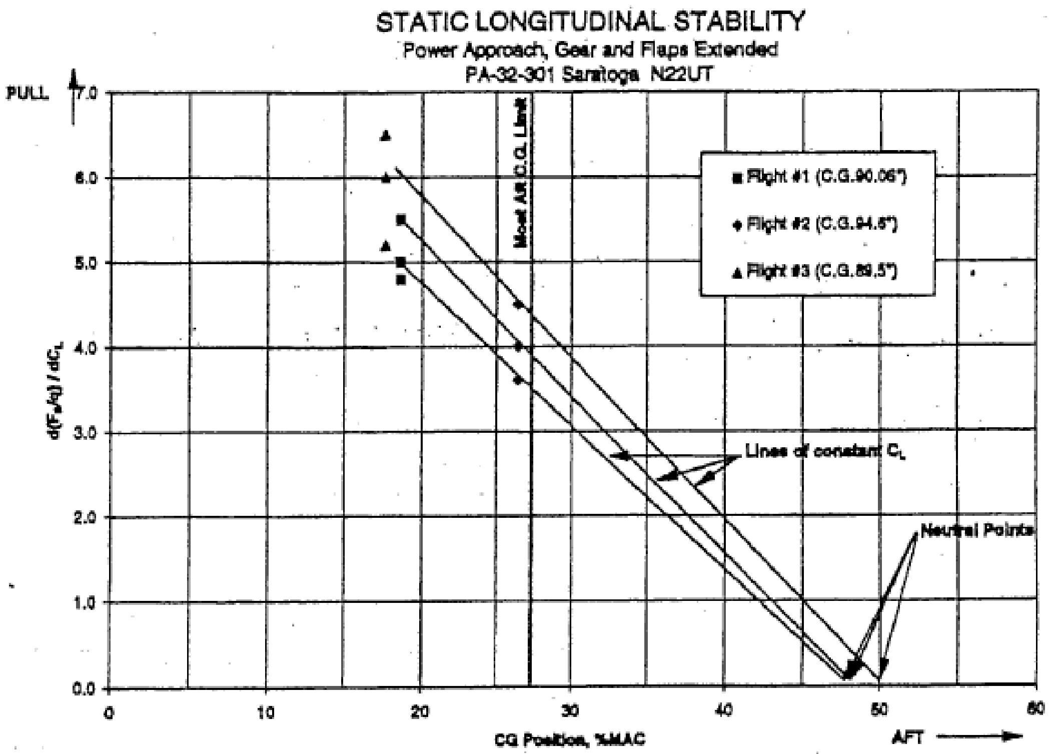


Figure 1.8 step 1 and 2 for control force data reduction (Kimberlin, 2003)



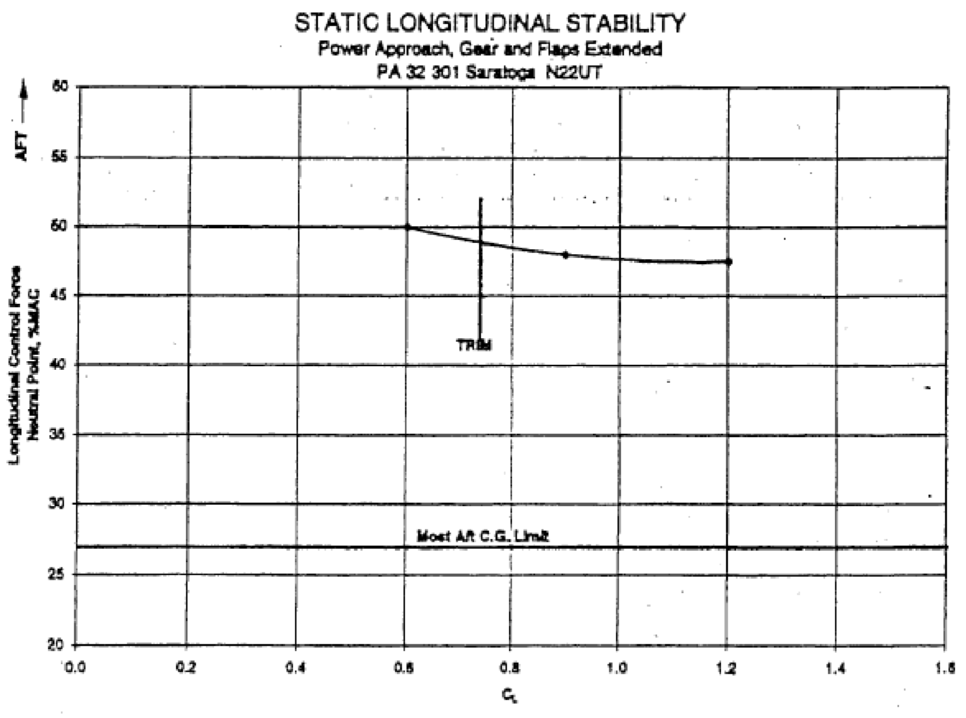


Figure 1.9 step 3 and step 4 control force data reduction (Kimberlin, 2003)

2. Partenavia P66-Charlie aircraft characteristics

The Partenavia P66C is a single engine general aviation airplane classified as Charlie category and configured as 4 seats airplane. The aircraft is usually used ad flight school type or as short range light general aviation airplane. Because of its incredible design, the airplane has high benefits in stability especially around longitudinal axes and that is the reason why this airplane was chosen for static stability measurements.

Here follows some information about airplane geometry and a close look to mass and balance that were used in flight tests.

2.1 General characteristics

- Engine: n.1 LYCOMING 0-320-H2AD
  hp/RPM 160/2700 take-off
  hp/RPM 160/2700 max continued power
- Propeller: n.1 HOFFMAN HO23C-186 140
- Fuel tanks: Left wing 90 Liters, Right Wing 90 Liters, usable fuel 162 Liters
- Control surfaces deflections: Ailerons up 28 ^{o} ± 2^{o} down 15^{o} ± 2^{o}
  Stabilator up 14 ^{o} ± 2^{o} down 8^{o} ± 2^{o}
  Rudder right 25 ^{o} ± 2^{o} left 25^{o} ± 2^{o}
- Flaps 15 ^{o} ± 2^{o} take-off
  35 ^{o} ± 2^{o} landing
- Load factor limitation +4.4 −1.76
- Maneuvering speed V_A = 118 K IAS
- Max take-off weight 990 kg
- Max landing weight 990 kg
- ***Center of gravity limitation***
  Max aft. 0.430 m from datum reference line (up to 990 kg)
  Max fwd. 0.300 m from datum reference line (from 800 kg to 990 kg)

- ***Geometry***:

  Wing span: 9.956 m

  Length: 7.240 m

  Height: 2.770 m

  Wing surface 13.400 m^2

Mean aerodynamic chord 1.360 m

- ***Stall Speeds***

CONFIGURAZIONE		0°	30°	60°
FLAPS RETRATTI	kt.	54	58	77
FLAPS 15° (DECOLLO)	Kt.	50	54	71
FLAPS 35°(ATTERR.)	Kt.	46	49	65

Figure 2.1 Stall speeds

- ***Performance***

- Max speed sea level 132 kTAS
- Cruise speed (75 % at 7000ft) 125 kTAS
- Cruise speed (65 % at 10500ft) 118 kTAS
- V_a (maneuvering speed) 118 kIAS
- V_{ne} (velocity never exceed) 177 kIAS
- V_{no} (max structural cruise speed) 121 kIAS
- V_F (max full flap speed) 83 kIAS
- V_x best climb rate see level 80 kIAS (990 kg full power 910 ft/min)
- V_y steep climb speed see level 70 kIAS (990 kg full power 800 ft/min 15^0 flap)
- Service ceiling 10000 ft
- Take-off distance 550 m (sea level)
- Take-off run 275 m (sea level)
- Landing distance 460 m (sea level)
- Landing run 190 m (sea level)
- V_y steep climb speed see level 70 kIAS (990kg full power 800 ft/min 15^0 flap)
- Service ceiling 10000 ft

- Three-view

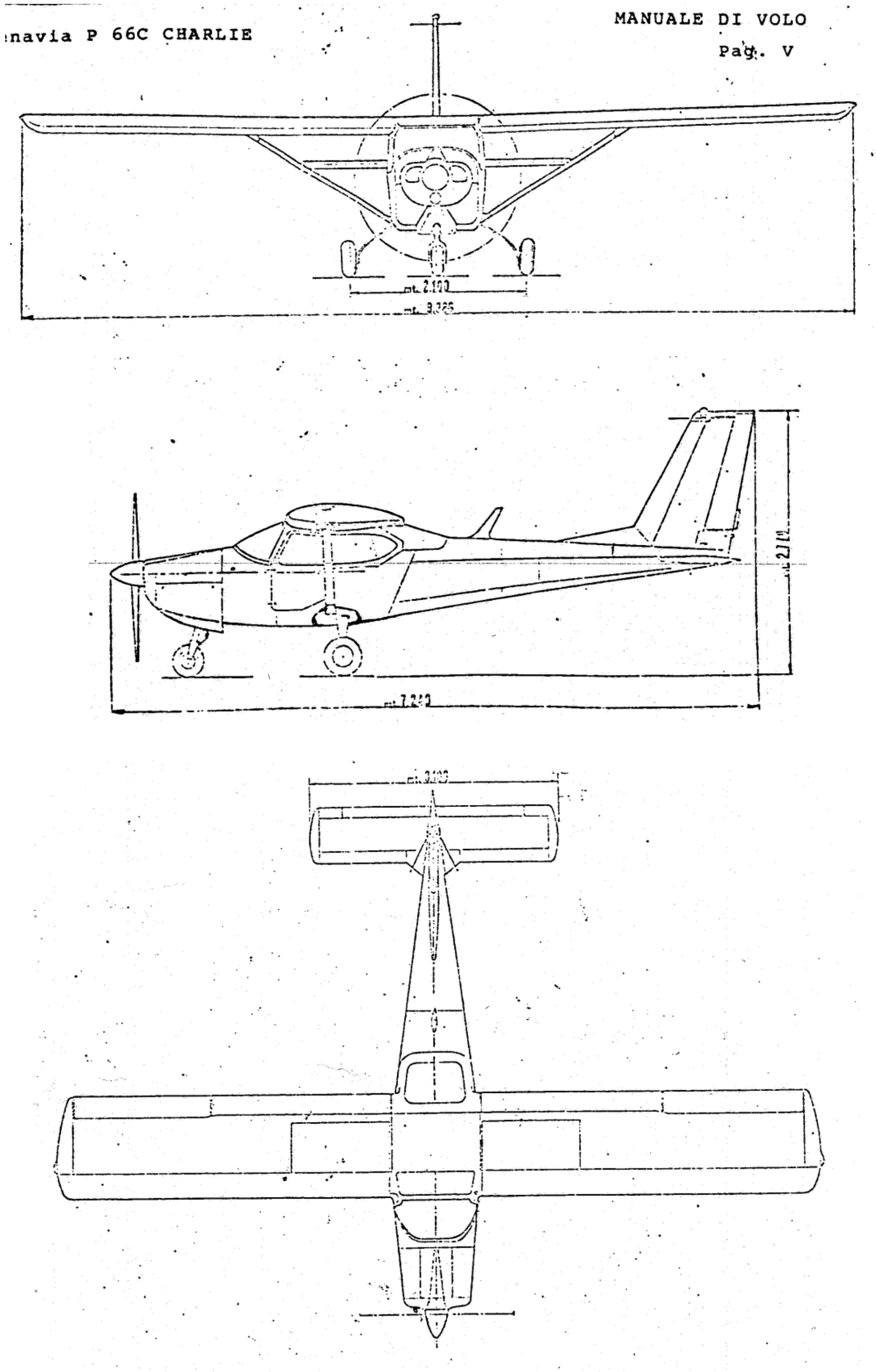


Figure 2.2 three view

Figure 2.3 P66C I-CRBO side view

Figure 2.4 P66C front panel view

2.2 Mass and balance limitations

Here is a closer look at mass and balance limitations of Partenavia P66C aircraft. All flight tests must be executed in the center of gravity excursion limitations, hence it is very important before every experimental flight to analyze the position of the center of gravity.

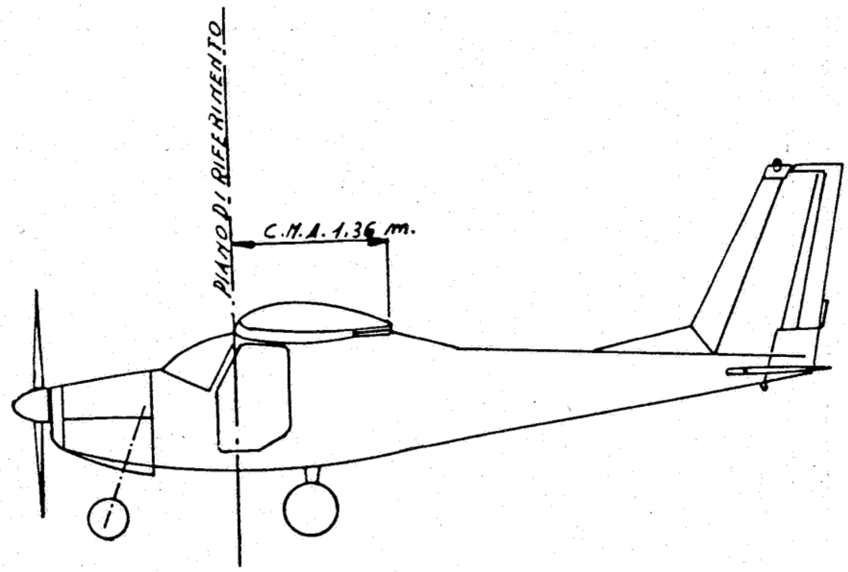
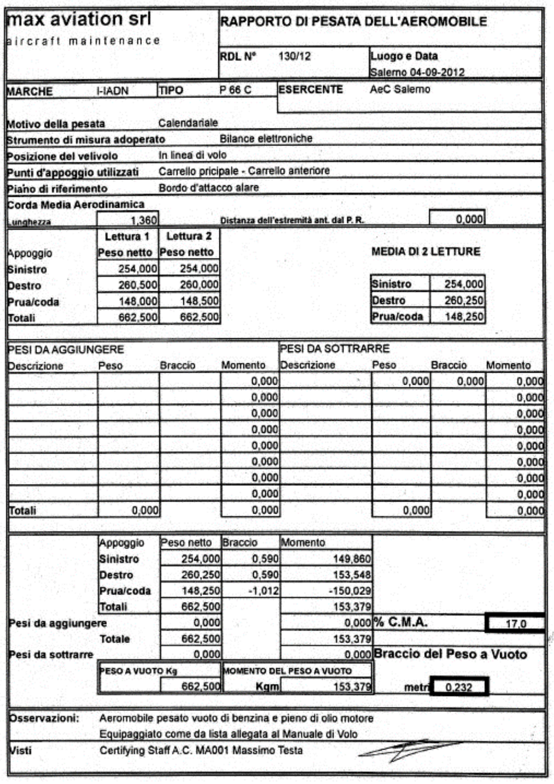


Figure 2.5 datum reference line

All the arms are measured from the reference line that Partenavia assigned from the leading edge. Here follows the weight sheet of the airplane, and the excursions limitations for center of gravity and momentum limitations vs. weight, where the procedure for the empty weight calculation is the same exposed in Chapter 1.

Of course the following steps are to calculate the weights of the instrumentations and both pilots mass, then to add the minimum take-off fuel and then to calculate the take-off weight, therefore the center of gravity for the flight tests.



max aviation srl
aircraft maintenance

RAPPORTO DI PESATA DELL'AEROMOBILE

RDL N° 130/12
Luogo e Data Salerno 04-09-2012

MARCHE	I-IADN	TIPO	P 66 C	ESERCENTE	AeC Salerno

Motivo della pesata	Calendariale
Strumento di misura adoperato	Bilance elettroniche
Posizione del velivolo	In linea di volo
Punti d'appoggio utilizzati	Carrello pricipale - Carrello anteriore
Piano di riferimento	Bordo d'attacco alare

Corda Media Aerodinamica
Lunghezza 1,360 Distanza dell'estremità ant. dal P. R. 0,000

Appoggio	Lettura 1 Peso netto	Lettura 2 Peso netto
Sinistro	254,000	254,000
Destro	260,500	260,000
Prua/coda	148,000	148,500
Totali	662,500	662,500

MEDIA DI 2 LETTURE

Sinistro	254,000
Destro	260,250
Prua/coda	148,250

PESI DA AGGIUNGERE				PESI DA SOTTRARRE			
Descrizione	Peso	Braccio	Momento	Descrizione	Peso	Braccio	Momento
			0,000		0,000	0,000	0,000
			0,000				0,000
			0,000				0,000
			0,000				0,000
			0,000				0,000
			0,000				0,000
			0,000				0,000
			0,000				0,000
Totali	0,000		0,000		0,000		0,000

	Appoggio	Peso netto	Braccio	Momento
	Sinistro	254,000	0,590	149,860
	Destro	260,250	0,590	153,548
	Prua/coda	148,250	-1,012	-150,029
	Totali	662,500		153,379
Pesi da aggiungere		0,000		0,000
	Totale	662,500		153,379
Pesi da sottrarre		0,000		0,000

% C.M.A. 17,0

PESO A VUOTO Kg 662,500
MOMENTO DEL PESO A VUOTO Kgm 153,379

Braccio del Peso a Vuoto metri 0,232

Osservazioni: Aeromobile pesato vuoto di benzina e pieno di olio motore
Equipaggiato come da lista allegata al Manuale di Volo

Visti Certifying Staff A.C. MA001 Massimo Testa

Figure 2.6 empty weight sheet

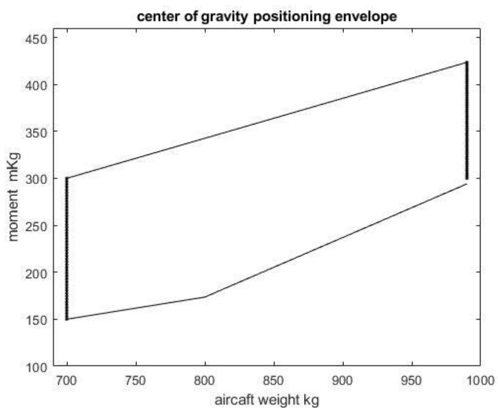


Figure 2.7 momentum limitations

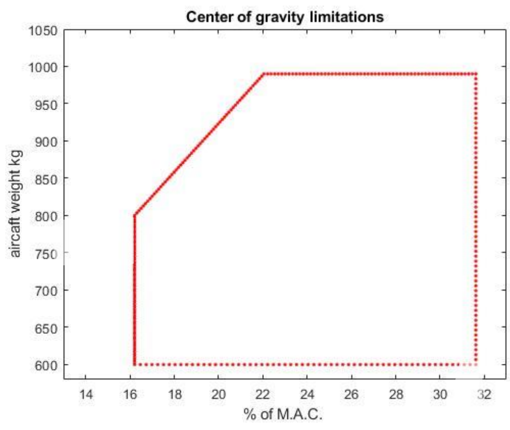


Figure 2.8 center of gravity limitations

3. Longitudinal flight tests

This chapter of the work deals with the experimental phase of this thesis. The first part is composed by experimental set-up, including instrumentation analysis and onboard placement, followed by flight execution and data reduction and analysis.

3.1 Experimental set-up and instrumentation

In order to measure the static longitudinal stability of a general aviation airplane, following the criteria given in chapter one, it is mandatory to measure simultaneously airplane airspeed, elevator or stabilator deflection, atmospherics data and pilot force on the yoke. All these measures require an instrument that must be properly placed on board without interference with all flight operations. The requirement is essential because if the instrumentation is not placed properly, the data can appear distorted from flight crew actions. Of course an accurate calibration is mandatory for good data extraction.

In the following instrumentation for the test and its onboard positioning are presented.

3.1.1 Potentiometers

In flight tests potentiometers are a must have for flight control surfaces deflections. Potentiometer literally means electric potential meter, indeed it is a electro-mechanic device equivalent to two-series resistors, where the sum of both resistors is constant but both relative values can change. In our flight tests, because we needed to evaluate only the stabilator deflection, we used one potentiometer installed directly on the command linkage for pitch control. Device’s calibration is done directly once the potentiometer is installed onboard.

Figure 3.1 Potentiometer

Figure 3.2 P66C command line

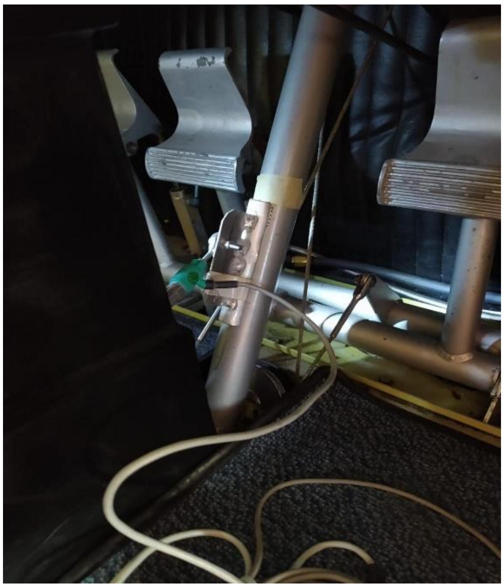


Figure 3.3 Potentiometer on command line

Since the potentiometer is a linear excuriosn instrument, also calibration curve is linear as well. To calibrate the potentiometer we used a digital level sensor placed on the stabilator. At several surface deflections we recorded the potentiometer signal and the level sensor indication. The process take plase from full pich-up deflection till full down deflection. Six positions were marked.

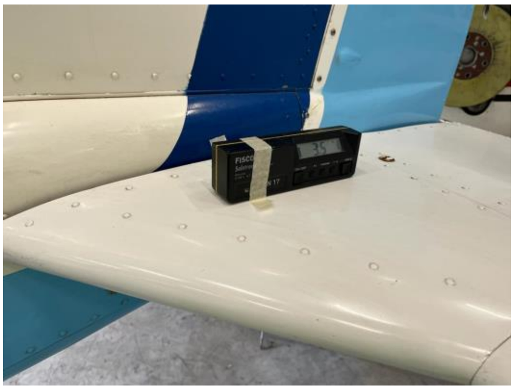


Figure 3.4 bubble sensor on stabilator

	True value	Raw value
1	5.70	5609
2	3.70	7412
3	−1.30	10752
4	−10.10	16420
5	−14.00	18655
6	−16.30	20115

Table 3.1 potentiometer calibration points

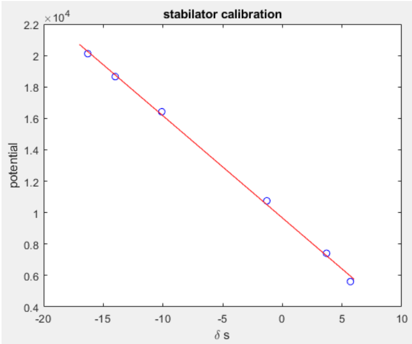


Figure 3.5 stabilator calibration

3.1.2 Load cells

These units are used to convert physical force to voltages using strain gauges. The applied force came directly from flight crew, conventionally the pilot flying, who applies the force on the control stick, the yoke or the rudder command. Because of load cells' shape, they are conventionally installed on an *ad hoc* made support, which was subsequentially applied on the control line. In these flight tests, we used one load cell applied on the yoke to measure the longitudinal force applied by the *maneuvering pilot*. Because of the bulky size of load cell plus support we decided to seat the *maneuvering test pilot* on the right and *off-maneuvering test pilot* on the left seat.

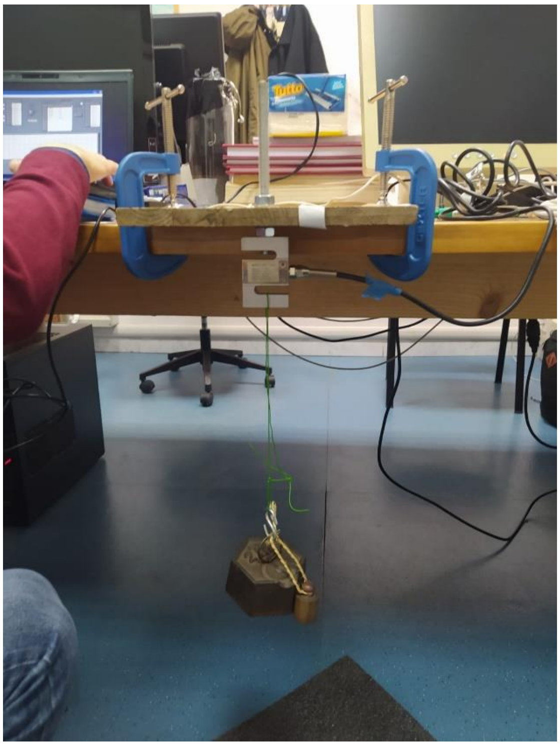


Figure 3.6 load cell calibration

Figure 3.7 load cell and support

3.1.3 Ballast

In order to execute the flight test at a certain center of gravity well ahead the actual neutral point and well inside the certification limits of P66, it was added up to 80 kg of ballast positioned in the cabin. The ballast is conventionally positioned outside the cabin under the tail to provide the largest mass offset. However, in these flight tests it was not possible to modify the airplane configuration, so it was decided to add extra weight instead of an outside installation.

The ballast was placed under the back seat, three units of 20 kilos each plus the battery used to give direct current to the instrumentation.

Figure 3.8 ballast

Figure 3.9 ballast and battery

3.1.4 Acquisition instrumentation

The acquisition instrumentation was positioned in the back seat of the airplane and safely locked with a pair of straps and correctly leveled with a wood support plate. The reason for that is not only for airplane safety but for the instrumentation that must work leveled and placed close to the center of gravity. The scope of acquisition instrumentation was to record the signals coming from the potentiometers, load cells, and GPS.

Figure 3.10 acquisition instrumentation

- ***Box Megaris*** - This is the main flight acquisition computer and it is the unit connected to the battery. The computer is responsible for data collecting during the flight. When data acquisition stops, the data are saved in a *.txt* file.
- ***Multichannel Box*** - It is the unit where the signals of potentiometers and load cell are connected, the box itself is connected to the main computer.
- ***Inertial Platform*** – The sensor installed is an AHRS – C400 type. This unit is responsible for airplane attitude recording. It has three sensors for angular velocity and three accelerometers. This can give a full indication for flight dynamic description. the three magnetometers are installed for the North magnetic orientation.

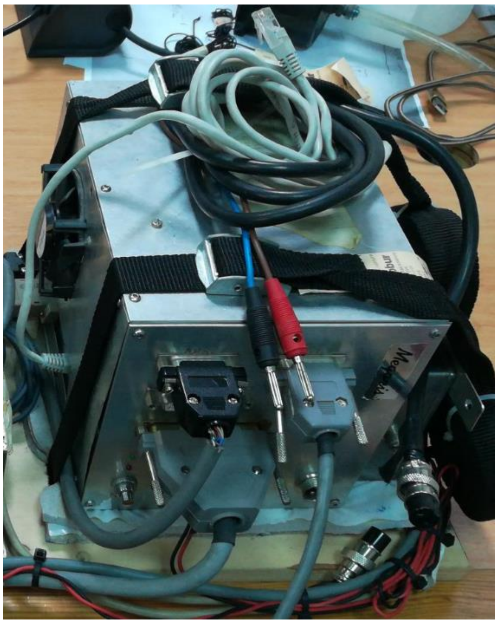


Figure 3.11 Box Megaris

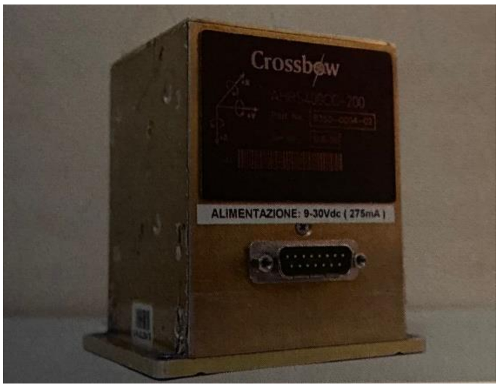


Figure 3.12 Inertial Platform

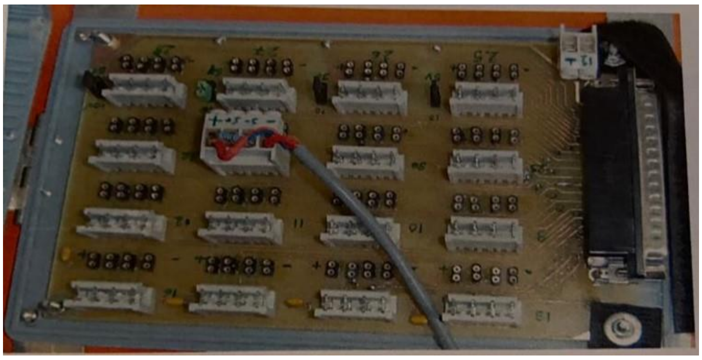


Figure 3.13 Multichannel Box

3.2 Flight test execution

Before every flight, especially in *non-standard* operations, it is mandatory to complete a series of pre-flight tasks like:

- Loadsheet (mass and balance paperwork)
- Pre-flight briefing (ground crew and flight crew)
- Pre-flight inspection before starting checklist

Only when tasks are adequately completed it is possible to proceed with the test. In the next subsections a closer look to each pre-flight task and the flight itself is given.

3.2.1 Loadsheet

Since for European requirement it is mandatory to fly within the limits of flight manual for mass and balance, and every *pilot in command* is supposed to demonstrate this via a loadsheet properly filed and stored onboard, the first task is the mass and balance evaluation.

A standard people scale for the instrumentation and pilots has been used.

	Masses (units in kg)	Distances from reference line (units in m)
Empty airplane mass	643.21	140.66
Captain	90	0.350
Copilot	74	0.450
Left station	4.4	1.005
Right station	5.3	1.005
Under seat Left	20	1.005
Under seat Right	20	1.005
Fuel	113.4	0.670

Table 3.2 masses and arms for flight test

Once the masses and respective arms of each external mass has been calculated, the next step is the calculation of estimated take-off mass and center of gravity position.

Take-off mass	970.31
Take-off Moment	331.39
Center of gravity (% m.a.c.)	25.11
Center of gravity (mm)	341.35

Table 3.3 Mass and balance data

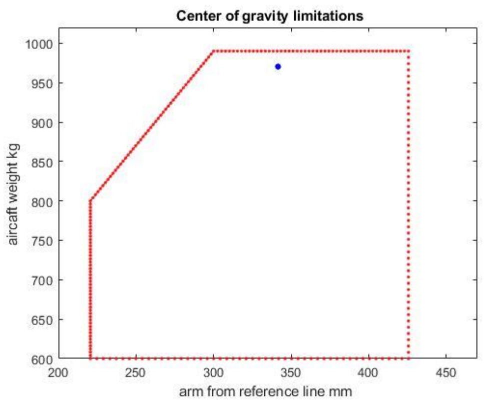


Figure 3.14 c.g. position from datum line

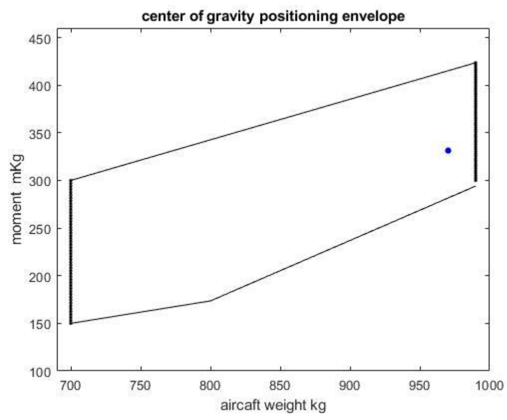


Figure 3.15 Weight vs moment

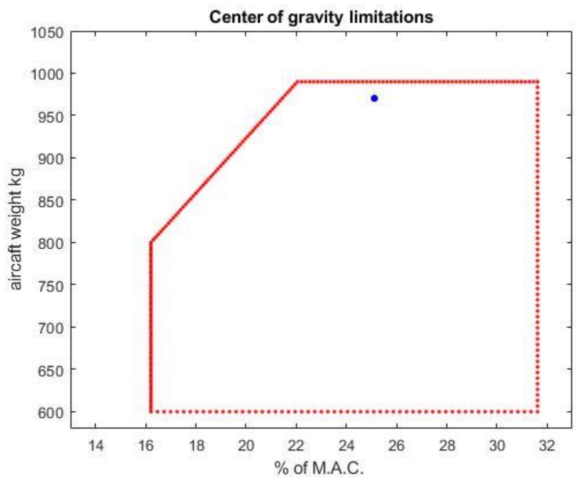


Figure 3.16 c.g. position in percentage of m.a.c.

After step one was verified, the loadsheet was signed in order to declare that the airplane was within the limits of its airworthiness certification.

3.2.2 Pre-flight briefing

The flight was conducted in the very busy airspace of *Naples international airport Capodichino Ugo Niutta* (ICAO code: LIRN), which means that coordination between both crews and airport control had to be perfect in order to be able to depart in time. In this briefing are discussed the items like the flight execution and airplane conduction to the maneuvering area, flight crew roles, ground crew roles, and longitudinal flight test execution.

- Flight crew roles

The flight crew was composed by Captain Vincenzo Dello Iacono seating on the left operating as *non-maneuvering test pilot*. He had the role to take-off the airplane and fly it to the maneuvering area. The copilot for this flight was the author of this thesis, operating as *maneuvering test pilot*. The author had the role to fly the airplane in the actual maneuver and was responsible for airplane configuration and speed changing during the execution.

- Ground crew roles

The ground crew was composed by professor Danilo Ciliberti, professor Pierluigi Della Vecchia, and laboratory technician Gennaro Zolfo. They had the role of calibrate the instrumentation and give a proper calibration before the installation. The potentiometer and the load cell were not easily installed in the aircraft. The load cell measuring pilot stick forces had to be attached to the yoke and, because of its large size, limited the movement of the maneuvering pilot. This is actually the reason why the ground crew had to modify the support several times for the *safe to go* call from the flight crew. Acquisition instrumentation was placed by ground crew on the back seats locked on a support and the calibration had to be done just before boarding and the acquisition of data started once the battery was attached, hence just a few seconds before boarding, data recording was started. Several checks of instrumentation and battery were done before the airplane was loaded and the configuration on the ground was fully *frozen* and both flight crew and ground crew were satisfied.

- Flight execution

In the Flight execution briefing was discussed the safety items for the standard part of flight: essentially taxi, take-off, climb-out, VFR navigation, and landing.

For take-off it was decided to operate a standard Flap 15 with a lift off speed of 65 KIAS. The climb-out was set at 70 KIAS with a gentle right turn pointing the exiting navigation waypoint *Naples Harbor*. Once the maneuvering area was reached, the captain had to switch over the controls to copilot responsible for the test.

- Longitudinal flight test execution

For the tests executions we refer to the air law requirement from EASA *Certification Specification* ***CS 23.171, CS 23.173(a b c) , CS 23.175(a b c)***. Going through the regulations, it is clear that it is not specified what level of stability is mandatory to demonstrate. Air laws requires only that the airplane must exhibit stability together with a sensitive variation of force on the control yoke. This last requirement is important because it means that the airspeed variation, with constant power applied, come together with control force variations.

Here follows the air law directly from EASA source:

EASA | ***Easy Access Rules for Normal, Utility, Aerobatic and Commuter Category Aeroplanes (CS-23) (Amendment 1)*** | *SUBPART B — FLIGHT STABILITY*

STABILITY

CS 23.171 General

ED Decision 2003/14/RM

The aeroplane must be longitudinally, directionally and laterally stable under CS 23.173 to 23.181. In addition, the aeroplane must show suitable stability and control “feel” (static stability) in any condition normally encountered in service, if flight tests show it is necessary for safe operation.

(a)

CS 23.173 Static longitudinal stability

ED Decision 2003/14/RM

Under the conditions specified in CS 23.175 and with the aeroplane trimmed as indicated, the characteristics of the elevator control forces and the friction within the control system must be as follows:

(a) A pull must be required to obtain and maintain speeds below the specified trim speed and a push required to obtain and maintain speeds above the specified trim speed. This must be shown at any speed that can be obtained, except that speeds requiring a control force in excess of 178 N (40 lbf) or speeds above the maximum allowable speed or below the minimum speed for steady unstalled flight, need not be considered.

(b) The airspeed must return to within the tolerances specified when the control force is slowly released at any speed within the speed range specified in sub-paragraph (a). The applicable tolerances are –

(1) For all aeroplanes, plus or minus 10% of the original trim airspeed; and in addition;

(2) For commuter category aeroplanes, plus or minus 7.5% of the original trim airspeed for the cruising conditions specified in CS 23.175(b).

(c) The stick force must vary with speed so that any substantial speed change results in a stick force clearly perceptible to the pilot.

(b)

CS 23.175 Demonstration of static longitudinal stability

ED Decision 2003/14/RM

Static longitudinal stability must be shown as follows:

(a) *Climb*. The stick force curve must have a stable slope, at speeds between 85% and 115% of the trim speed, with –

(1) Flaps retracted;

(2) Landing gear retracted;

(3) Maximum continuous power; and

(4) The aeroplane trimmed at the speed used in determining the climb performance required by CS 23.69(a).

(b) *Cruise*. With flaps and landing gear retracted and the aeroplane in trim with power for level flight at representative cruising speeds at high and low altitudes, including speeds up to V_{NO} or V_{MO}/M_{MO} as appropriate, except that the speed need not exceed V_H –

(1) For normal, utility and aerobatic category aeroplanes, the stick force curve must have a stable slope at all speeds within a range that is the greater of 15% of the trim speed plus the resulting free return speed range, or 74 km/h (40 knots) plus the resulting free return speed range, above and below the trim speed, except that the slope need not be stable–

(i) At speeds less than 1.3 V_{SI}; or

(ii) For aeroplanes with VNE established under CS 23.1505(a), at speeds greater than V_{NE}; or

(iii) For aeroplanes with V_{MO}/M_{MO} established under CS 23.1505(c), at speeds greater than V_{FC}/M_{FC}.

(2) For commuter category aeroplanes, the stick force curve must have a stable slope at all speeds within a range of 93 km/h (50 knots) plus the resulting free return speed range, above and below the trim speed, except that the slope need not be stable –

(i) At speeds less than 1.4 V_{SI}; or

(ii) At speeds greater than V_{FC}/M_{FC}; or

(iii) At speeds that require a stick force greater than 222 N (50 lbf).

(c) *Landing*. The stick force curve must have a stable slope at speeds between 1.1 V_{S1} and 1.8 V_{S1} with –

(1) Flaps in the landing position;

(2) Landing gear extended; and

(3) The aeroplane trimmed at –

(i) V_{REF}, or the minimum trim speed if higher, with power off; and

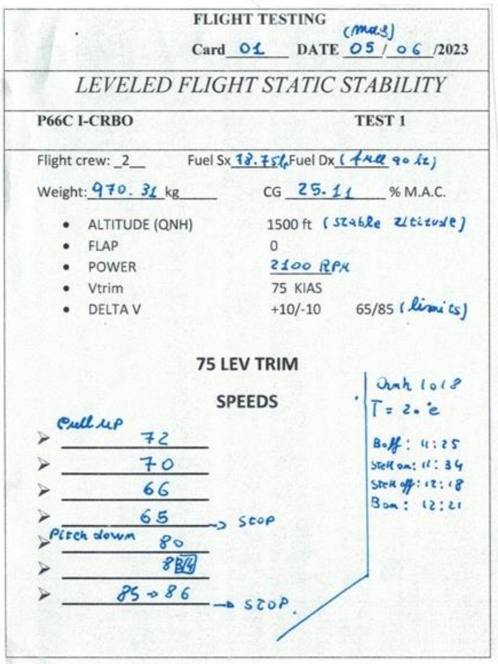
(ii) V_{REF} with enough power to maintain a 3° angle of descent.

(c)

Figure 3.17 (a) E.A.S.A. CS 23.171 (b) E.A.S.A. CS 23.173 (c) E.A.S.A. CS 23.175

(European Aviation Safety Agency, Amendment 3 20 July 2012)

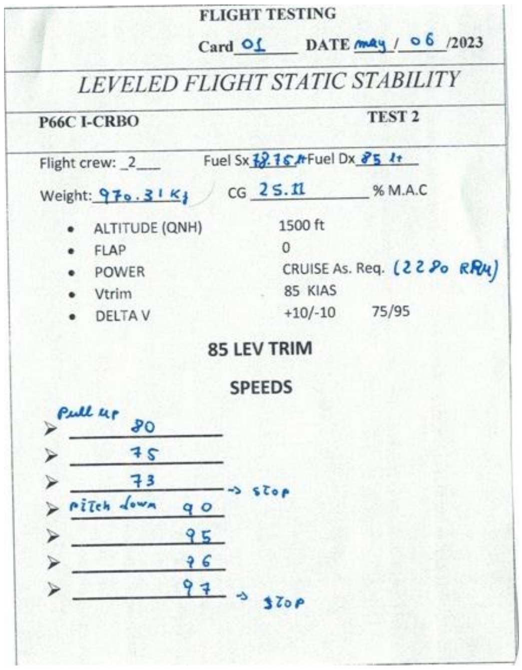
After a close look to air law requirements, flight crew and ground crew started to write down the flight testing data cards in order to freeze the criteria for the flight. Here follow the flight testing cards:


FLIGHT TESTING
Card 01 DATE 05 / 06 /2023 (may)
LEVELED FLIGHT STATIC STABILITY
P66C I-CRBO TEST 1
Flight crew: 2 Fuel Sx 18.75 lt Fuel Dx (full 90 lt)
Weight: 970.31 kg CG 25.11 % M.A.C.
- ALTITUDE (QNH) 1500 ft (stable altitude)
- FLAP 0
- POWER 2100 RPM
- Vtrim 75 KIAS
- DELTA V +10/-10 65/85 (limits)

75 LEV TRIM
SPEEDS
Pull up
- 72
- 70
- 66
- 65 → stop
- Pitch down 80
- 84
- 85 → 86 → stop

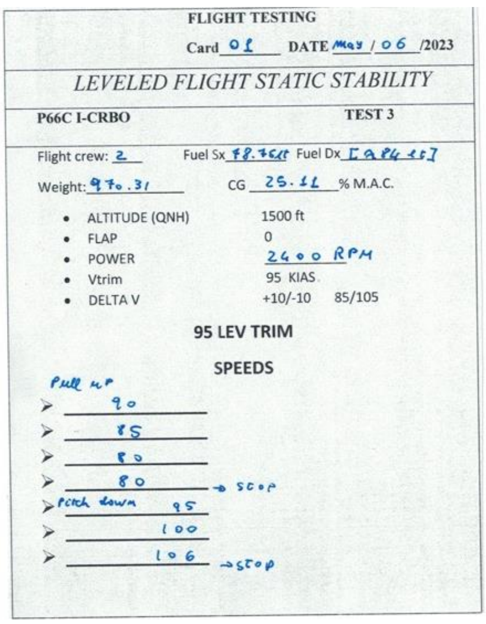
Qnh 1018
T = 20°
B off: 11:25
Stell on: 11:34
Stell off: 12:18
B on: 12:21

(a)


FLIGHT TESTING
Card 01 DATE may / 06 /2023
LEVELED FLIGHT STATIC STABILITY
P66C I-CRBO TEST 2
Flight crew: 2 Fuel Sx 18.75 lt Fuel Dx 85 lt
Weight: 970.31 Kg CG 25.11 % M.A.C
- ALTITUDE (QNH) 1500 ft
- FLAP 0
- POWER CRUISE As. Req. (2280 RPM)
- Vtrim 85 KIAS
- DELTA V +10/-10 75/95

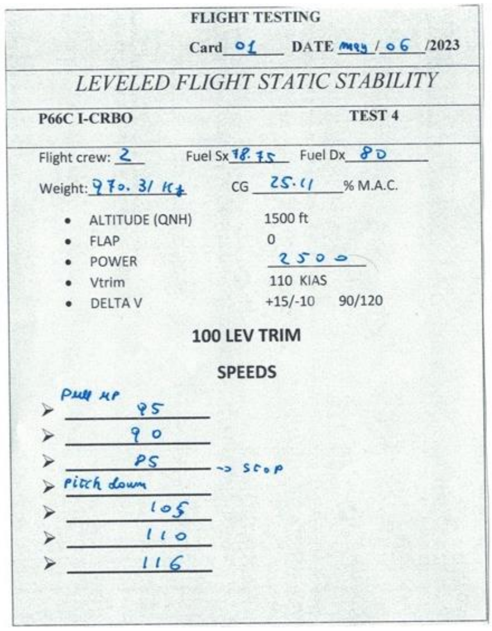
85 LEV TRIM
SPEEDS
Pull up
- 80
- 75
- 73 → stop
- Pitch down 90
- 95
- 96
- 97 → stop

(b)


FLIGHT TESTING
Card 01 DATE may / 06 /2023
LEVELED FLIGHT STATIC STABILITY
P66C I-CRBO TEST 3
Flight crew: 2 Fuel Sx 18.75 lt Fuel Dx [90 lt]
Weight: 970.31 CG 25.11 % M.A.C.
- ALTITUDE (QNH) 1500 ft
- FLAP 0
- POWER 2400 RPM
- Vtrim 95 KIAS
- DELTA V +10/-10 85/105

95 LEV TRIM
SPEEDS
Pull up
- 90
- 85
- 80
- 80 → stop
- Pitch down 95
- 100
- 106 → stop

(c)


FLIGHT TESTING
Card 01 DATE may / 06 /2023
LEVELED FLIGHT STATIC STABILITY
P66C I-CRBO TEST 4
Flight crew: 2 Fuel Sx 18.75 Fuel Dx 80
Weight: 970.31 Kg CG 25.11 % M.A.C.
- ALTITUDE (QNH) 1500 ft
- FLAP 0
- POWER 2500
- Vtrim 110 KIAS
- DELTA V +15/-10 90/120

100 LEV TRIM
SPEEDS
Pull up
- 95
- 90
- 85 → stop
- Pitch down
- 105
- 110
- 116

(d)

Figure 3.18 Flight testing cards at different initial airspeeds

(a) 75kts (b) 85kts (c) 95kts (d) 100kts

Following Air law ***CS 23.175 (b)*** in a steady leveled flight, in cruise phase, a gentle pull-up is required to slow down the airplane below the airspeed specified in flight testing card illustrated in ***Figure 3.14.*** As planned in briefings, flight test must follow a large range of speeds. In order to stay away from critical conditions the slower speed was set at 65 kts (Indicated airspeed), hence a 17% of margin on clean leveled stall speed, upper speed was put at the maneuvering airspeed V_A = 118 kts. For instrument reading facilities, on cards the max testing speed was set at 120 kts, but this value was never achieved.

Once in flight the maneuvering action was executed by copilot while the captain read the airspeeds, where the airplane was stable when the pull-up or pitch down were executed. The speeds were then written on cards in blue ink during flight.

3.3 Data reduction

This part of work deals with flight test data reduction and analysis. Data analysis start with the preliminary examination of time histories related to each test. Every time history will show stabilator deflection and stick force at the same time. In order to have a data visualization we used a MATLAB script which processed the data coming from acquisition instrumentation. The data come in a *.txt* file. Since the recording starts when the battery is connected to the instrumentation, an electrical signal of 5 Volts was manually given by a switch installed on the copilot yoke, to identify start and stop of each test. Here follows the time history for each test:

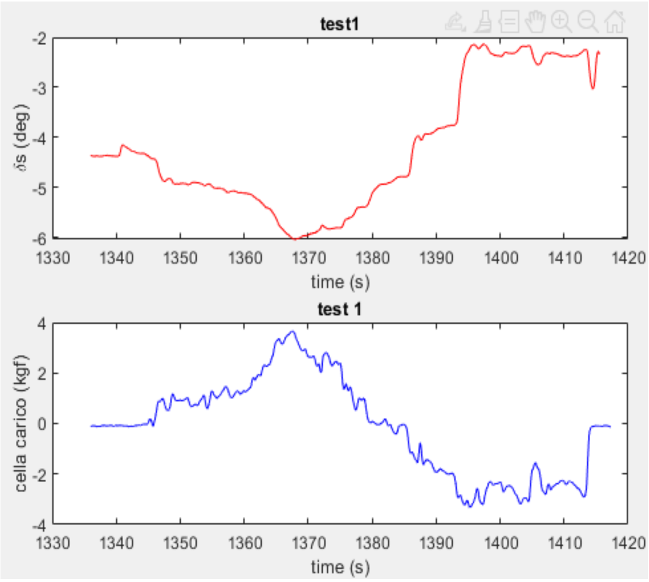


Figure 3.19 time history card (a) 75 kts

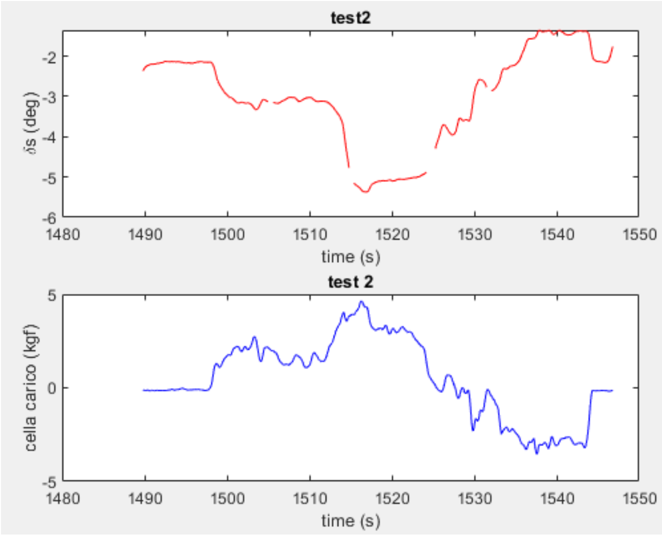


Figure 3.20 time history card (b) 85 kts

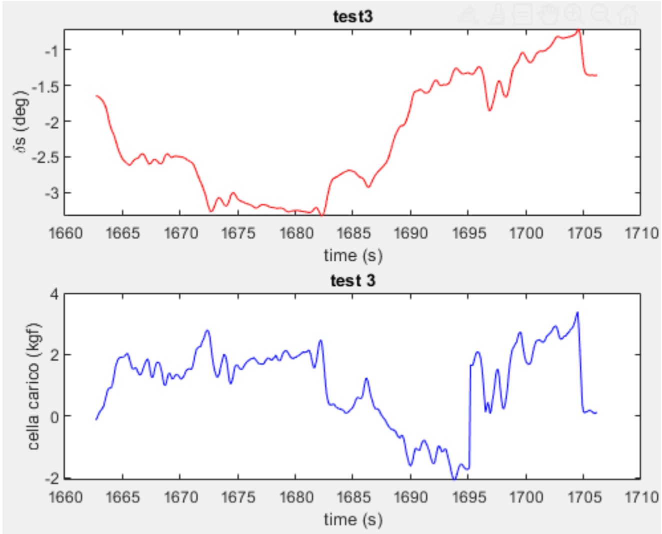


Figure 3.21 time history card (c) 95 kts

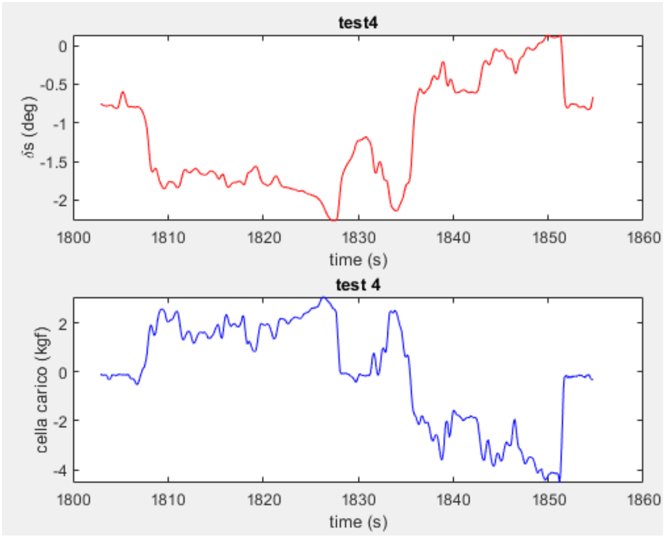


Figure 3.22 time history card (d) 100 kts

The preliminary analysis of time history shows what was discussed in the briefings. The stable plot of force applied vs stabilator position indicate that both load cell and potentiometer were recording coherently with maneuver execution. The second indication that the data are good to be processed is that when the speeds are lower the forces required to maintain steady leveled flight are much larger and at higher speeds also with a very gentle touch we were able to observe larger variations in speeds, and at the same time less deflection needed.

The next step for data is to find out for each test points at constant speed, force and stabilator deflection, then generating interpolation slopes for force and elevator deflection vs. speed for each test executed. Here follows the data extracted from time histories:

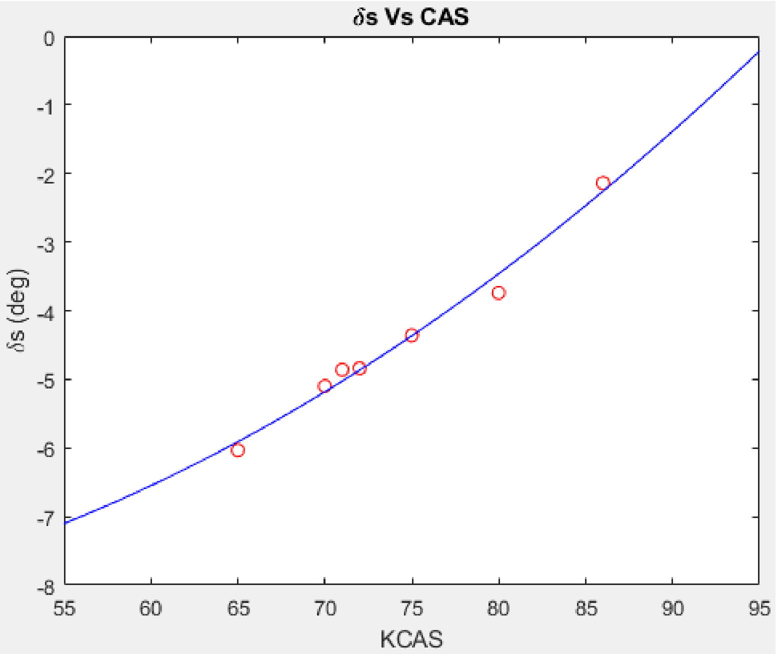


Figure 3.23 stabilator vs CAS card (a) 75 kts

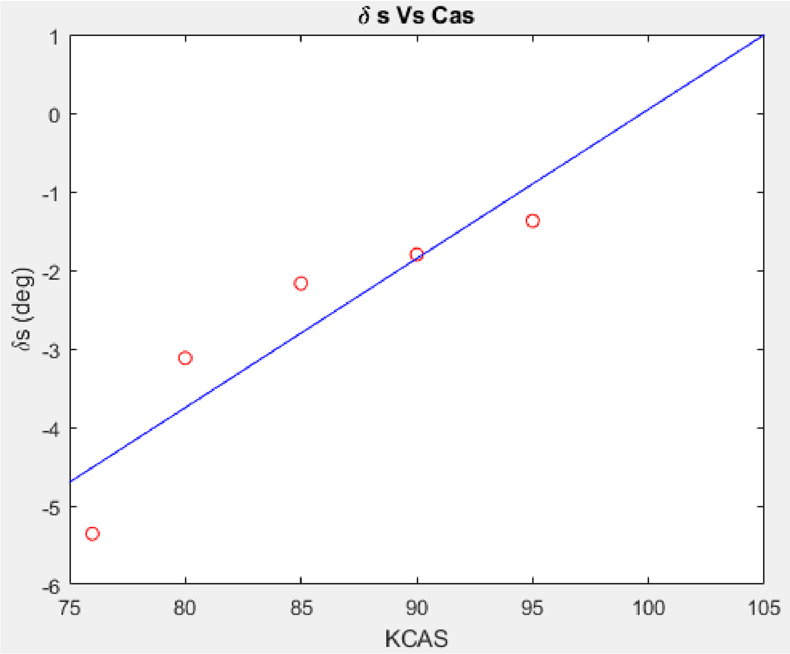


Figure 3.24 stabilator vs KCAS card (b) 85 kts

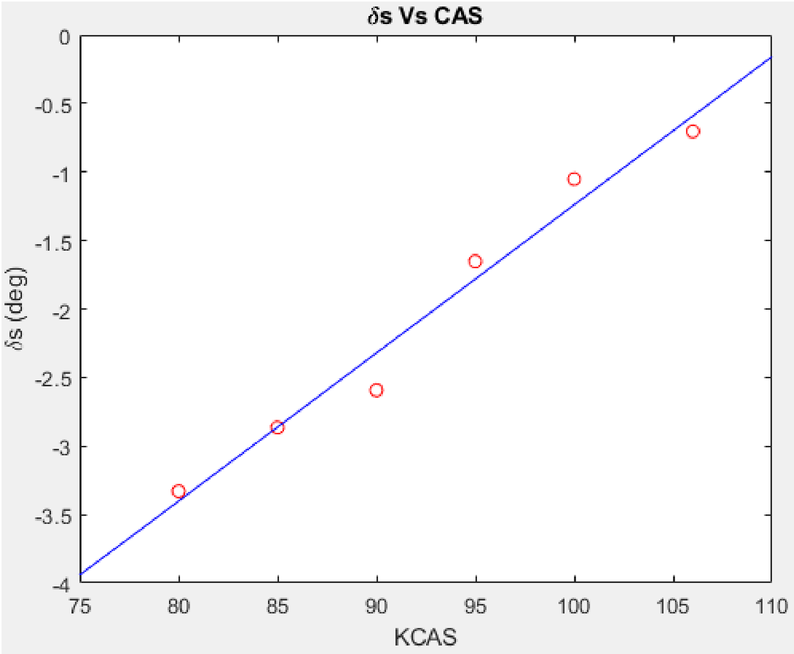


Figure 3.25 stabilator vs KCAS card (c) 95 kts

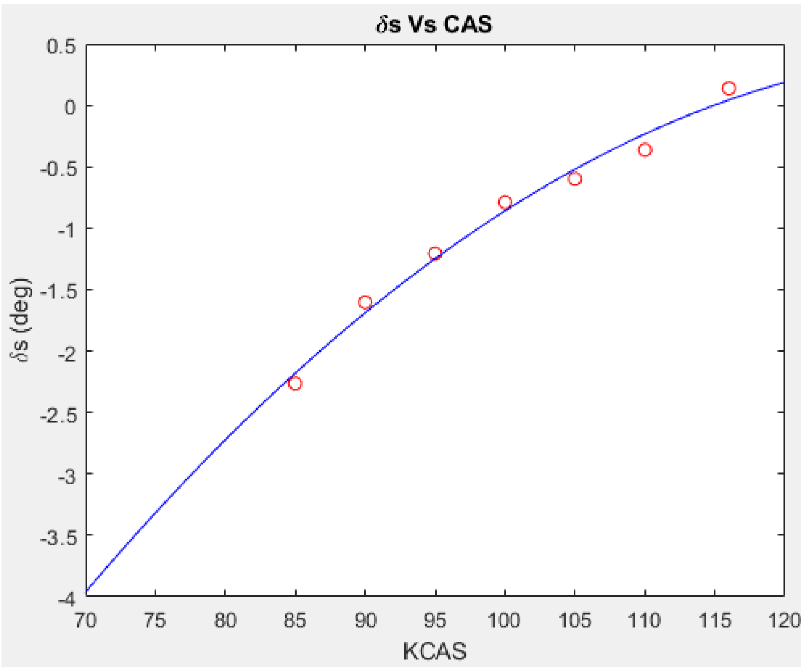


Figure 3.26 stabilator vs KCAS card (d) 100 kts

Next step is to calculate the control curve for stabilator variation vs. lift coefficient. In order to calculate the curve a data gathering was needed for all four tests in a single plot with relative interpolation curve, which must exhibit a stable slope.

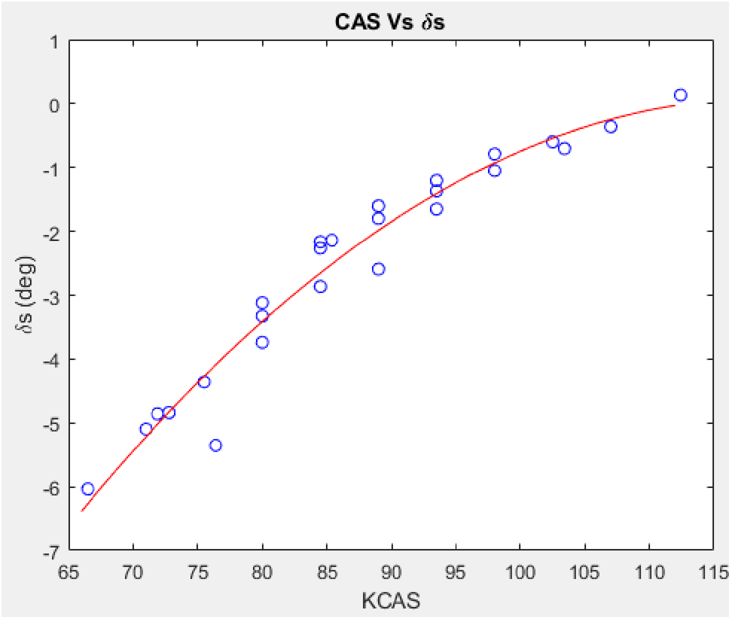


Figure 3.27 stabilator vs KCAS (all the cards, initial airspeed from 75 to 100 kts)

Each blue point on the plot is associated with a speed in knots, hence it was necessary to convert speed in meters per second and then use the lift equation for steady leveled flight in order to calculate the lift coefficient. Here follows the weather data for density calculation:

- P = 1018 hPa (QNH)
- T = 296.15 K (18°C)
- $\rho = P/(RT) = 1.2183\ kg/m^3$

Then a correction of the airspeed following the airspeed indicator calibration slope from the flight manual, since in the lift equation the true or equivalent airspeed must be used. Only after that it was possible to plot stabilator deflection vs. lift coefficient, and calculate the curve through the data.

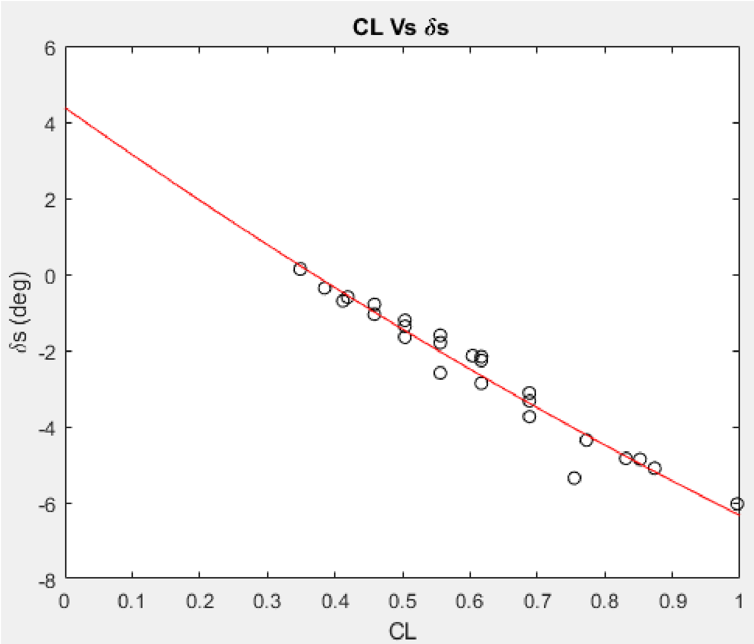


Figure 3.28 stabilator vs lift coefficient

From data exposed in ***Figure 3.28*** it is possible to calculate a valid estimation for fixed center of gravity, of stick-fixed static stability derivative. In order to give a proper estimate, the interpolating curve is supposed to be linear within the range of lift coefficient between 0.3 and 0.6 or wherever the collected data are closer. Here follows the derivative estimate:

$$\frac{\mathrm{d}\delta_e}{\mathrm{d}C_L} = -10.12 \quad deg \qquad (3.1)$$

Final step for data reduction is to examinate the control force data vs airspeed in order to verify the stick-free stability requirements.

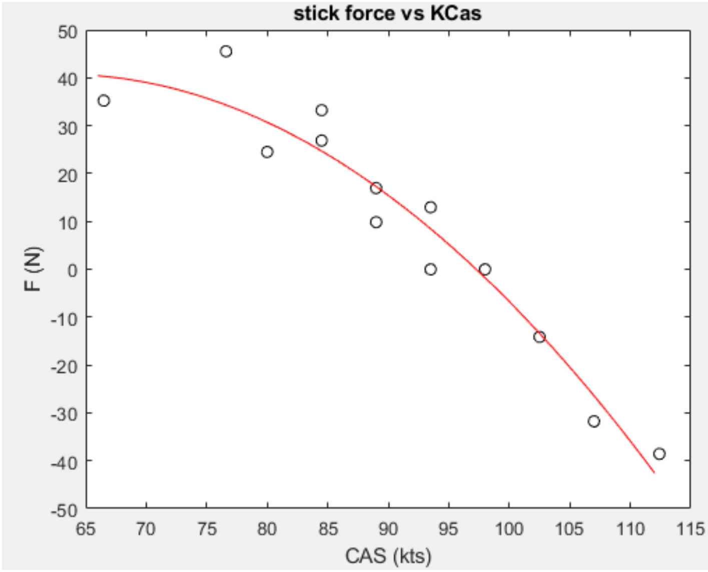


Figure 3.29 stick force vs KCAS all cards

From data extracted it was possible to generate the interpolating curve through the data. We can actually see that the slope is stable as required from air law, that is by increasing the airspeed a push force is needed and vice versa.

It is now necessary to give unique dependence of derivative $\frac{dF_s}{dV_S}$. We do that dividing stick force by dynamic pressure. By so doing $d(F_S/q)/dC_L$ become a function of stability only.

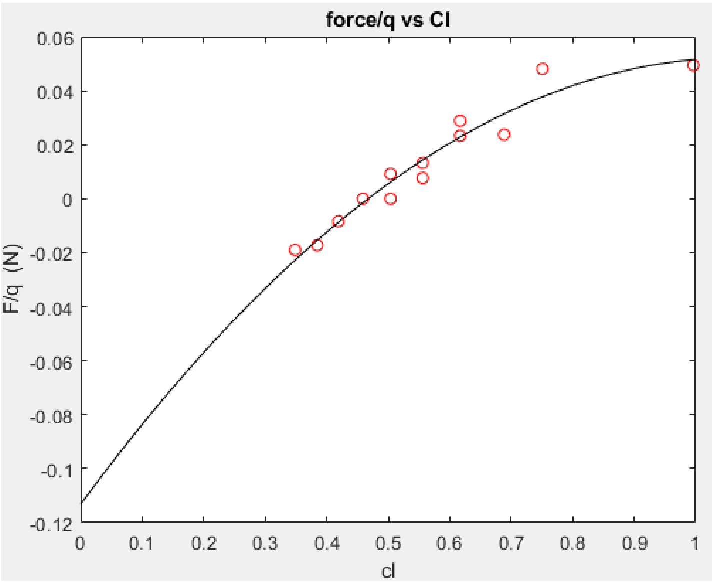


Figure 3.30 stick force vs C_L

Also in this case it is possible to calculate the stability derivative for stick-free longitudinal static stability. A proper estimate is given, choosing data from ***Figure 3.30,*** if the interpolating curve is supposed to be linear wherever the data are closer. The data used for this estimate are chosen in range of lift coefficient between 0.3 and 0.6. Here follows the derivative estimate:

$$\frac{\mathrm{d}(F_s/q)}{\mathrm{d}C_L} = 0.1477 \qquad (3.2)$$

4. Conclusions

This work had the scope to perform a series of flight tests in order to calculate the longitudinal static stability of a *Partenavia P66 Charlie* aircraft in both stick-fixed and stick-free conditions.

The flight tests conducted on the airplane indicated that:

- The instrumentation recorded all the flight test in all conditions planned in pre-flight briefings
- The maneuvers were performed exactly as the air law requires
- Starting from a steady leveled flight in a trim condition, in order to slow down the airplane from stability point, a positive force was needed and vice versa.
- Once the flight controls were released, the airplane exhibited tendency to return to the initial trim point.
- An increase of negative deflection of the longitudinal flight control surface was needed in order to fly a higher lift coefficient.
- Higher speeds required less control force on the yoke in order to move the flight control surface and to perceive attitude variation from the cockpit.
- All the data reported a stable positive slope of elevator deflection vs. airspeed.
- All the data reported a stable negative force of force required vs. airspeed.

All these information acquired, from data analyzed and from pilot feeling during the test, are a valid indication that the airplane exhibit a positive longitudinal static stability.

4.1 Limitations and future work

A limitation occurred in experimental phase of this work. A valid estimate of neutral point was not possible to achieve in this work. In order to extrapolate a valid position of neutral point it is necessary to fly the same test at different centers of gravity positions. A large shift of the latter between flights must be provided. In this experiment it was not possible to obtain an adequate displacement with just pilot seating or ballast repositioning. For this reason, the post-processing data analysis is limited. A future work on longitudinal static stability measurement for neutral point estimate could be implemented with an *EASA EC.748/2012 sub(d) form*, providing a valid modification of airplane, allowing the ballast to be positioned in the fuselage afterbody. This distant ballast location should provide a sufficient shift of the center of gravity, very close to the backward limit of the latter.

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