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METHODS OF TESTING AT CONSTANT ATTITUDE

(Polar, and longitudinal characteristics)

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FOREWORD

The purpose of ICAO Circulars is to distribute information bearing upon the progress of ICAO's work more widely than would be possible for the ordinary series of documents.

The present circular publishes a national study describing a method of flight testing developed to obtain directly certain data such as the value of $\frac{D}{W}$, the ratio of the drag to the weight of an aeroplane. This quantity is of fundamental importance in the new method of prescribing performance standards for aeroplanes that is now being studied by ICAO.

The report reproduced in this circular records work done in France. It was presented to ICAO by the Government of France so that it might be published for the information of all concerned.

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INTRODUCTION

In 1946 the Service technique aéronautique (Aeronautical Technical Service) requested the Flight Test Centre (C.E.V.) to study the problem of determining in flight the polar of an airframe by a method faster than the conventional method of stabilizations.

In July 1947 the C.E.V. produced a solution to this problem by proposing the method of accelerated and decelerated descents at constant attitude. This method, used for a long time on test aeroplanes, has now been sufficiently perfected to be applied to prototype aeroplanes, not only to determine the polar of the airframe, substantially equivalent to that of an aeroplane with, for example, propellers feathered, but also when it is wished to measure performance rapidly and reliably in different conditions of power.

This report comprises a description of the essential aspects of the method and a summary of the means to be used to measure the various parameters.

It has been illustrated by means of a few results of tests selected from the many flight tests performed to refine methods of piloting, of measurement and of calculation, to train pilots and engineers or research personnel, or to refine prototypes.

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CHAPTER I. - MANOEUVRES AT CONSTANT ATTITUDE

1.0. - CONVENTIONAL METHODS AND THE C.E.V. 1947 METHOD

The conventional methods used in the measurement of flight characteristics and performances are based on the essential concept of stabilization. The experimenters endeavour to maintain constant for a certain period of time the greatest possible number of parameters, and particularly the airspeed. In still air, the results obtained can be highly satisfactory since generally they closely correspond with actual operational conditions. In this manner, measurement of a vertical speed by achieving stabilization and recording altitude and time is direct and accurate.

But such tests take time. It is frequently difficult for the pilot to achieve a stabilization by reference to the instruments on the panel of the aeroplane, and the operation must be repeated as many times as there are points to be measured. The tests present, moreover, the disadvantage of assuming that there are no vertical movements of the atmosphere throughout the test area. This is an obvious disadvantage when measuring the low vertical speeds obtained with one engine inoperative, and it is also known that in the more usual case of level flight close to minimum power, true airspeed itself varies considerably depending upon the vertical component of the wind. Moreover, checking that the air is still required delicate measurements, which are generally impossible due to lack of facilities or methods.

German manufacturers, having realized the advantage of measuring the polar in-flight on aeroplanes with all propellers feathered, endeavoured during the last war to develop a rapid method which would have reduced the prohibitive high cost of conventional tests. The method of "Decelerated level flight" enabled them to achieve certain results, but it was only due to the virtuosity of the pilots handling the tests that an acceptable degree of accuracy was attained. In fact, to be good, the method would have required measuring instruments of such completeness, speed and accuracy as to permit making measurements during any type of manoeuvre.

The C. E. V. 1947 method is based on the use of the longitudinal attitude as the essential parameter. The pilot is no longer instructed to maintain constant speed or level flight but to maintain a certain attitude using a gonio-sight mounted with a vernier scale graduated to a twentieth of a degree. The cross-hairs of this sight — similar to the simple instruments used prior to the war on fighter aeroplanes — should be lined up with the apparent horizon, and the pilot has little more to do than to ensure correct sighting while glancing at the yaw meter which should preferably be placed near the sighting instrument.

This piloting technique is comparatively easy, and attains such accuracy that use of the gonio-sight has been extended to tests in which conventional methods are still applied. Furthermore, pilots have always been in the habit of making use of guide marks or simply of spots on the windscreen to achieve good stabilization. Manoeuvres while maintaining constant attitudes during acceleration or deceleration are short and progress very smoothly. Finally, the parameters selected for measurement are such as to permit complete discounting of the vertical movements of the atmosphere.

At this stage, however, attention should be drawn to two points to which we will return later. The first is the requirement for good visibility. The fact that the results are not affected by vertical movements of the atmosphere permits, in principle, the staging of tests in almost any weather with moderate turbulence. On the other hand, since by its very nature the gonio-sight requires good visibility to make the test possible, and since this condition is unfortunately infrequent at low altitudes, it has been found necessary to develop a gyroscopic device with a view to overcoming this drawback.

The second point concerns another requirement for proper use of the measurements viz. accurate calibration of the measuring equipment. While this new method is accurate and rapid, it requires experienced technicians who must be trained for the task, recording instruments of a high standard of accuracy, plus complete and versatile laboratories. Furthermore, it requires careful investigation of errors, their causes and their remedies.

This price to be paid for a modern method should not be regretted. Not only is the operation highly advantageous on the whole, since to do in one flight what used to require five has incalculable consequences on the costs of testing a prototype and particularly on the future of the whole series, but also these exigencies provide the certainty of increasing the true technical potential constituted by teams of trained specialists, which in itself offers a guarantee of future progress.

1.1. - DESCENT AND DECELERATION AT CONSTANT ATTITUDE

Before describing the principles that underlie the actual tests, and enumerating the means now adopted for the measurement of the various parameters, we will begin by defining the characteristics which, in the new method, are of particular interest to pilots, in other words, by a description of the various phases of the selected manoeuvres: dive at constant attitude, deceleration at constant attitude, and pseudo-stabilizations.

Let us take for example a twin-engine 5-ton aeroplane of the NC 702 class. It is proposed to determine the polar of such a craft with both propellers feathered. It is under this condition that for aeroplanes with conventional type powerplants the polar of an airframe without propellers can be most closely approximated. The total drag of the propellers of an NC 702 is only about eight per cent of the minimum airframe drag, and the results of wind tunnel tests on model propellers are adequate to provide the correction to be applied from one polar to the other.

The pilot's briefing covers the following points: Configuration: landing gear retracted, flaps retracted, mass M_o = 5000 kg, centre of gravity at 27%:

a) engines idling, propellers at coarse pitch stop: find the diving attitude A_1 at which the indicated airspeed reaches a limit of 350 km/h;

b) engines idling, propellers at coarse pitch stop: find the smallest attitude of deceleration A_2 that could lead to a stall;

c) engines stopped, propellers feathered: dive at constant attitude A_1 from 4000 metres to 2500 metres, then decelerate at attitude A_2.

Attitude A_1 is determined by diving with throttle at climb position and propeller under the control of the governor until the speed of 350 km/h is attained, and then by throttling down and increasing the angle of dive so as to maintain that speed: the gonio-sight setting is then A_1, it being understood that the speed obtained at that attitude with propellers feathered will be increased by about five per cent. This is specified when establishing the test instructions.

Attitude A_2 is obtained with engines throttled down, propellers at coarse pitch, by progressively adjusting the gonio-sight so as to raise the nose of the aeroplane slowly until the moment when the stalling speed warning appears. Generally, the power delivered by the powerplants is sufficiently low for this attitude to coincide with a progressive stall with propellers feathered.

These two tests are obviously unnecessary in the case of an aeroplane for which data is already available as a result of previous flight tests. A graph showing the attitudes corresponding to stabilization speeds (figure 1 is an example) provides an adequate approximation notwithstanding day-to-day variations of the height of the apparent horizon.

The pilot having determined the A_1 and A_2 settings then performs the following manoeuvre (Figure 2): after having reached a speed 50 per cent above the stalling speed and having feathered the propellers, he zooms up and when approaching the stalling speed eases the controls so as to obtain a rate of pitch that is sufficiently rapid to ensure that the speed does not decrease too sharply on commencement of the negative level out — and sufficiently slow so as to permit the gonio-sight, previously set to attitude A_1 to be lined up with the horizon accurately and without oscillation. Depending upon the aeroplane's characteristics it may or may not be possible thus to bring the indicated airspeed substantially below the stalling speed — 20 per cent below in the case of the NC 702: the kinematic acceleration produced by the curvature of the path causes a reduction of the apparent weight, and the load factor may decrease to 0.5.

Finally, during the last phase of the pitching, the speed increases and, when the gonio-sight is lined up with the horizon and the load factor returns largely to the value of unity, the speed has already slightly exceeded the stalling speed at weitht M_0g.

Here beings the first of the two parts of the manoeuvre that will be analyzed for calculation of the polar during descent at constant attitude. The pilot maintains the gonio-sight on the horizon and flies at a constant heading, without sideslip, keeping his aim trained on the same sector of the apparent horizon, maintaining the cross-hairs horizontal and keeping an eye on the sideslip indicator. When the assigned minimum altitude is reached - 2500 metres - the pilot or an assistant adjusts the gonio-sight to A_2, and the aeroplane is pulled up as abruptly as possible, i.e. at the limit load factor which has been decided on by the crew for reasons of safety, considerations of mechanical and physiological resistance (a load factor of 2 in the present example), so that the attitude assumes its new A_2 value.

The second important part of the manoeuvre — deceleration at constant attitude — is handled in the same manner: at constant attitude and heading, the aeroplane follows a slightly curved path, decreasing speed until the moment when one of the signs characterizing the stall or minimum steady flight speed appears.

The total duration of the manoeuvre is about three minutes and the polar is determined twice. The accuracy of the measurements is particularly good when incidences are small in the first part of the manoeuvre, and for high incidences in the deceleration.

1.2. - PSEUDO-STABILIZATION

Measurement of the polar of an airframe is an indirect measurement of its performance. It will be seen below that exactly the same is true of an aeroplane with its powerplants in operation, and that the rapid and accurate measurement of the "generalized" polar may with advantage replace conventional tests.

The manoeuvre to be effected is then the same in principle: with the NC 702 at cruising or reduced power it is even easier; however, it requires an automatic variable pitch propeller and a manifold control.

In cases of powerplants without automatic manifold control, or of an aeroplane requiring careful piloting, for example because one of the powerplants is inoperative, or again when it is necessary to operate at very low atmospheric levels to bring out excess power or simply to test near-to-ground performance, it becomes necessary to sub-divide the polar, and use is made of a series of accelerations and decelerations, each one covering a reduced range of speeds. We have given these manoeuvres the name of pseudo-stabilizations because they are in effect stabilizations interrupted at the very moment of reaching that stabilization.

The operations to be carried out by the pilot are as follows: stabilize flight approximately with the powerplant conditions appropriate to a low speed near stalling and adjust the gonio-sight to the horizon (A_1). Then set ($A_1 - 2^o$) and rapidly bring the attitude to its new value. Wait until all parameters are almost stabilized, if necessary manipulating the powerplant controls to maintain the characteristics specified in the briefing instructions, for example r.p.m. or manifold pressure. Assistance by the co-pilot or engineer is usually necessary. Once stabilization appears to have been reached, set ($A_1 - 4^o$) and effect another acceleration at constant attitude; and so on until reaching the maximum speed required. The inverse operation is then carried out, though generally with greater variations in attitude, and concluding with a deceleration at attitude ($A_1 + 2^o$) or ($A_1 + 3^o$) which leads to stalling.

These pseudo-stabilizations should generally be divided into two or three groups, a climb or descent being interposed to return to the mean altitude specified in the briefing instructions. Each pseudo-stabilization lasts one minute and the total manoeuvre required about 10 minutes. A prolonged pseudo-stabilization results in a stabilization and provides a check of the value of the incidence: the repetition of these checks makes it possible to draw up statistics and to eliminate the scattered points caused by updrafts.

Figure 3 represents a series of pseudo-stabilizations accomplished by a single deceleration. It will be noted that by imposing an oscillation on the attitude between one pseudo-stabilization and the next, the time necessary to arrive at stabilization is reduced.

1.3. - THE FUNCTION OF THE GONIO-SIGHT - APPLICATION TO LONGITUDINAL STATIC CHARACTERISTICS

It will be seen that the gonio-sight is the piloting instrument on which these methods are based. A brief description of it is given in the chapter on measurements, while this chapter is devoted to its function.

The stabilization of the longitudinal attitude affords a dual advantage. Firstly, alignment on the horizon with a calibrated sight provides a fairly accurate knowledge of one parameter; although this is redundant because of the other measurements, it has nevertheless been found useful. In the second place, the longitudinal attitude responds almost without lag to operation of the elevator control, as compared to the lag in speed; the piloting process thus becoming easier and very accurate. Unfortunately there is the drawback of fatigue caused by prolonged sighting: this, however, is reduced by suitable tinting of the gonio-sight and goggles.

The resulting ease of piloting extends to conventional tests. The best method of stabilizing speed is by determining the appropriate attitude, and then by maintaining that attitude. Moreover, the longitudinal attitude is a parameter that varies fairly rapidly with the conditions of flight. Its variation is the sum of the variations of the incidence and the angle of the flight path which, in normal conditions of flight, are in the same direction for a given engine power. Similarly, the operation of most automatic pilots is based on this parameter.

However, the manoeuvres selected for determination of performance are of interest in another field. They apply directly to the rapid measurement of a part of the flight characteristics relative to elevator and trimming controls and stability criteria. If, during a manoeuvre at constant attitude, the pilot leaves the trimming tabs in a set position, the hinge moment and the force on the controls are the same as for the stabilized conditions, because the absence of angular acceleration means that there is no resultant pitch moment, and the absence of a rate of pitch means that there is no additional induced speed on the tail surface. During the manoeuvres for determining the polar, the recording of displacements and forces on the control column or control gear provides displacement and force curves as functions of speed. This further reduces the costs of flight tests.

At the end of the following chapter there will be found, together with some examples of polars, results of measurements of longitudinal characteristics showing that results obtained in manoeuvres and in stabilized tests are identical.

It should be noted also that safety is increased in high speed tests when these may be carried out with the help of a gonio-sight. The pilot, in choosing a given attitude, sets himself a specific speed limit, with the guarantee that the slightest positive variation of that attitude will produce a reduction in speed; thus he is assured of a regular progression in the tests.

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CHAPTER II. - UTILIZATION OF RECORDINGS

2.0. - DEFINITION OF PARAMETERS - NOTATION AND CONVENTIONS

While the principle of calculation of the polar using recordings made during the manoeuvres described above is extremely simple, it is necessary to define clearly the notation and conventions used.

First of all, it should be noted that the system of units used by the C.E.V. since 1 January 1949 is the kilogramme-mass system (M.K.S.A.) in which the units of force and pressure are the "millisthène" and "millipièze". Instead of the millipieze, the practical unit of pressure adopted by the C.E.V. is the millibar, an international unit. In certain equations a factor of 100 may then be introduced without difficulty.

As to the conventions, almost all are shown in the basic figure 4, which relates to the case of substantially symmetrical flight. The tests are carried out at almost constant headings and with small sideslip. The nose of the aeroplane is directed leftwards and positive angles are measured clockwise. The flight path is relative to an ambient air mass assumed to be in uniform movement; the reference axes OZ and OH are respectively parallel to the vertical of the place flown over, and to the normal thereto in the flight plane, both in relation to the ambient air.

The other essential axes are the following, each pair being respectively perpendicular (Figure 4).

Axes L and V - aeroplane's longitudinal and vertical references: positive directions forward and towards the pilot's head, respectively;

Axes T and N - axes related to the speed along the flight path, coinciding with the tangent and with the principal normal respectively.

The span axis E (not represented) is directed towards the left of the pilot. Direction $O\Gamma$ is that of the resultant acceleration of the aeroplane $\vec{\Gamma}$, whose components are Γ_N and Γ_T on the axes relative to the path, or Γ_V and Γ_L on the axes of the aeroplane.

Angles are represented by the following symbols:

Θ: path angle, positive in climb;

i and j: incidence and sideslip defined as angles between two planes;

i_1 and j_1: incidence and sideslip defined as angles of the velocity with the reference planes of the aeroplane.

In the present case, i and i_1 are practically identical because j is small. The sideslip is positive when the velocity vector of the aeroplane is to the left of the longitudinal axis.

A: longitudinal attitude, positive when nose up, i.e. the angle of the longitudinal axis in relation to the horizontal plane.

A': lateral attitude, positive in a right turn, right wing low, i.e. angle of the transverse axis in relation to the horizontal plane.

B: heading, i.e. the angle formed by North and the horizontal projection of the longitudinal axis computed in the direction of the heading from 0 to 360 degrees or 400 grades (?).

Π: angle of the apparent vertical $O\Gamma$ in relation to the extended vertical axis of the aeroplane (Greek capital letter pi).

In addition here are some of the symbols used for the parameters characterizing the aeroplane and its powerplants:

α : (with various indices) deflection of ailerons, positive on making a right turn; or deflection of flaps, positive for a downward deflection.

β: deflection of the elevators, positive when the elevators are lowered.

γ : deflection of elevator tab, positive when the tab is lowered.

δ : deflection of the rudder, positive on a right turn.

S: reference surface (main aerofoil including the section within the fuselage).

M: total mass at the moment of the test (in kilogrammes-mass).

Mg: weight in "millisthènes" or newtons (g substantially equal to 9.81 m. s^{-2}).

The ambient atmosphere is characterized by:

ρ: density of the air.

$\sigma = \frac{\rho}{\rho_0}$: specific gravity in relation to standard atmosphere at MSL.

θ : external centigrade temperature (absolute temperature $T = \theta + 273^{\circ}$).

c: velocity of sound: $c = 20.1\sqrt{T}$ m/s;

at ground level in standard atmosphere: c_o = 340 m/s = 1220 km/h.

The following are the various speeds usually considered:

VI (IAS): indicated airspeed or instrumental speed - reading of the airspeed indicator without correction.

VC (CAS): calibrated airspeed - the reading of an ideal indicator connected to a perfect airspeed head (pilot and static) and calibrated on the ground by St-Venant's Law.

V (TAS): true airspeed = speed of the aeroplane relative to the air or relative to the ground at zero wind.

M: Mach number M = V/c. (When there is a possibility of confusion with mass, Mach is spelt out).

EV (EAS): equivalent airspeed $EV = V\sqrt{\sigma}$

The dynamic pressures appropriate to the speeds VI, VC and EV are:

Δ p: gross dynamic pressure

$p_i - p_s$: calibrated dynamic pressure

q: conventional dynamic pressure; by definition, $q = \frac{\rho V^2}{2}$

The above pressures are in the following ratios:

$$p_i - p_s = q\left(1 + \frac{M^2}{4} + \frac{M^4}{40} + \ldots\right) = \frac{\rho_o}{2}(VC)^2\left(1 + \frac{M_o^2}{4} + \frac{M_o^4}{40} + \ldots\right) \text{with}$$

$$M_o = \frac{V}{c_o}$$

$EV = 46\sqrt{q}$ (q in millibars and EV in km/h) $= 12.8\sqrt{q}$ (EV in m/s).

Vertical speed is represented by v, positive in climb, and expressed in metres per second.

The principal symbols for powerplants are:

N: rotational speed in revolutions per minute

T: thrust (in millisthènes)

C: torque (in milli-mètresthènes)

P'4 or Pa: pressure at the vent situated on the induction manifold, as defined by the manufacturer and approved by the National Authorities.

2.1. - DEFINITION OF THE POLAR

To complete this introduction, EIFFEL's definition of the polar curve should be recalled. It is the curve, graduated according to incidence, representing the relation between the lift and drag coefficients.

While originally polars were used only for an aerofoil or of a non-powered airframe, the same method of representation is applied here to the complete aeroplane, in which lift is affected by the slipstream and the normal component of the propeller thrust, and drag is affected by the tangential component of the thrust. Due to the special importance of the ratio between lift and incidence, the appropriate curve is generally substituted for the graduation of the polar in incidence.

In other words, any point of a flight at constant attitude — i.e. without speeds induced by angular motion — will make it possible to plot a point of the polar. The figure formed by the two axes and the radius vector joining this point to the point of origin of the axes is the reduction to scale 1/Sq of the figure formed by the normal and tangent to the path and the resultant of aerodynamic forces and thrust. The same angle (π+ i), which is of course the angle of the apparent vertical and the normal to the path (Figure 4), is found on both figures.

As theoretical research on the one hand, and experience on the other, prove that this point of the polar does not vary, regardless of whether the speed is stabilized or not within broad limits, it has been possible to base these methods of measurement on a standard manoeuvre.

Nevertheless, there is an essential difference between the results obtained in wind tunnels and in flight. In wind tunnels the polar is obtained at variable incidence and constant speed, therefore at constant Reynolds and Mach numbers, and a series of curves is obtained at uniform speed covering, at least in principle, all combinations of incidence and Mach numbers. The appearance of the curves is shown by the dotted line curves in Figure 5.

On the contrary, in the case of in-flight measurements, the basic relation between dynamic pressure, weight and lift coefficient shows that, at a given altitude and weight, there is only one curve cutting across the various wind tunnel curves — the full black curve in Figure 5. For flight investigation of the field outside that curve, it is necessary either to alter the apparent weight — which is possible only within narrow limits, since the load cannot be changed substantially and since load factors remain small in manoeuvres at constant attitude — or preferably to change the altitude, which modifies the ratio between dynamic pressure and Mach number.

Finally, the symbols adopted for the values affecting the determination of the polar are the following:

F: resultant of the aerodynamic force and thrust vectors.

F_N and F_T: projections of F on the principal normal and the tangent to the path.

F_V and F_L: projections of F on the vertical and longitudinal axes of the aeroplane.

C_N and C_T: lift and drag coefficients as measured in flight.

$F_N = 100\ C_N\ S.q$ (q in millibars, S in square metres, F in millisthènes.)

$F_T = 100\ C_T\ S.q.$

The symbols C_z and C_x are reserved for coefficients related to certain parts of the aeroplane; thus, they are used for the aeroplane without propellers.

2.2. - PRINCIPLE OF CALCULATION OF THE POLAR

The analysis of the records obtained in flight during one of the manoeuvres previously described is simple in principle, and it is the principle only that is set out below. It is quite obvious that the calculation of each one of the parameters recorded, from the position of the corresponding point on the photographic film, depending upon the setting of the recorder and the various calibrations, requires in itself two thirds of the time devoted by the analysis staff to a flight. However, readers of this report are familiar with these calculations.

C_N is calculated from the definition formula in which F_N is replaced by its value deduced from the general Dynamics Law:

$$F_N = M \Gamma_N$$

There are two methods of calculating Γ_N: either to calculate the normal acceleration due to the curvature of the path, from the plotting of the path, or from the derivative of the path angle equal to the derivative of the incidence if the attitude is constant, thus:

$$\Gamma_N = \gamma_N + g \cos \Theta$$

or record the acceleration component along the vertical reference of the aeroplane (normal accelerometer), thus:

$$\Gamma_N = \Gamma_V \frac{\cos (\pi + i)}{\cos \pi};$$

this ratio is obtained by projecting Γ on axes N and V.

C_N is therefore calculated from one of two equations:

$$C_N = \frac{M}{S} \frac{1}{q} (\gamma_N + g \cos \Theta) = \frac{M}{S} \frac{1}{q} \Gamma_V \frac{\cos (\pi + i)}{\cos \pi}$$

The drag coefficient is deduced from the lift coefficient by the ratio:

$$\frac{C_T}{C_N} = \tan (\pi + i)$$

from the equivalence of the angles $\widehat{F_N O F} = \widehat{N O \Gamma} = \pi + i$

$$\frac{C_T}{C_N} = \frac{F_T}{F_N} = \tan \widehat{F_N O F} = \tan (\pi + i)$$

If there are no means available to measure the incidence, a ratio based on other angles may be used:

$$\frac{C_T}{C_N} = \tan (\Delta\pi - \Theta)$$

In particular when the flight is stabilized $\Delta\pi$ cancels out, returning to the classic ratio

$$\frac{C_T}{C_N} = -\tan \Theta$$

We should like to emphasize incidentally one of the original features of this C.E.V. method of determining performance, namely, the simplicity of the basic instrument used in our endeavours to find new methods. This instrument, the H.B. pendular gauge-level, provides the accurate data on which the previous calculations are based. It is capable of measuring angle π to approximately a twentieth of a degree, and is highly reliable and accurate in operation. The angle recorded (pendular angle π, measured from a recorder datum) possesses a notable quality as may be seen by the ratio:

$$\frac{C_T}{C_N} = \tan (\pi + i)$$

in which C_T C_N and i, and therefore π, in no way depend on the attitude but on the point of the polar corresponding to the flight case. During a steep dive or pull-up, on a given aeroplane, under the same powerplant conditions and apparent weight, one finds exactly the same pendular angle when the incidence returns to the same value, i.e. for approximately the same indicated airspeed if the path is not too curved*.

This angle is also the angle indicated by the clinometer on the aeroplane panel and the previous remark shows under a new form the sense in which the pilot should interpret the readings; in particular, the clinometer indicates longitudinal attitude only at a constant speed.

* The condition of same apparent weight does not apply when the propellers are feathered, except, however, when compressibility is an appreciable factor.

2.3. - CALCULATION OF VERTICAL SPEED

It may not be desired to have all performances condensed in the form of a polar, but rather the usual curve of the vertical speed as a function of the aerodynamic speed. In this case it is possible to calculate directly, from parameters recorded in manoeuvres when the aerodynamic speed is V, the value v which would be the vertical speed if the aeroplane were in stabilized flight at the same speed V and in still air. This may be written thus:

$$v = - V \sin \arctan \frac{C_T}{C_N} = - V \sin (\pi + i)$$

and the vertical speed v^* recorded during the manoeuvre corresponds with the equation:

$$v^* = V \sin (A - i) + v_w.$$

and depends essentially on the attitude A selected for the gonio-sight setting and on the vertical component of the wind v_w.

The two equations evidently are identical only during stabilized flight in still air. A substantial advantage of the measurement of v from incidence and the pendular angle (or the attitude in stabilized flight), lies in the fact that the definition of the incidence includes the speed relative to the ambient air mass. As the measurements are made in relation to references parallel to the absolute axes and moving with the ambient air, the performances obtained are independent of vertical movements of the atmosphere. This advantage is common to all methods measuring the flight path angle by determining the incidence and the attitude, and not by barographic records, by flight paths observed from the ground, by variometer readings or by radiosondes.

2.4. - EXAMPLES OF POLARS

To illustrate this description of the principles of measurement of the polar in flight, some results obtained on Y, an 18-ton twin-engine aeroplane, and Z, a 6-ton four-engine seaplane, are reproduced.

Figure 7, for Y, give two partial sets of curves (C_N, i) and (C_N, C_T), the second of which is covered by a number of converging straight lines representing the various path gradients tan θ , and by a set of curves originating from the origin, being the loci of points of equal vertical speed represented by the equation:

$$C^2_T = 0,063 \frac{S}{M} C^3_N v^2 \sigma$$

This set is deformed when the wing-loading $\frac{M}{S}$ varies, while the Θ set remains unaltered. Moreover a scale — likewise a function of the wing-loading — provides the equivalent airspeed corresponding to C_N according to the equations:

$$Mg = 100\ C_N\ Sq \quad \text{and} \quad EV = 46 \sqrt{q}$$

Let us take for example point a situated on curve 2, characterizing the climb configuration with cowl flaps closed. It defines stabilized conditions of flight: the equivalent airspeed is 192 km/h, the equivalent vertical speed is + 2.7 m/s and the path gradient +0.05 ($\Theta = +2.8^\circ$).

By using the set (C_N, i) we see that $i = +8.8^\circ$, which enables us to find the longitudinal attitude:

$$A = \Theta + i = 11.6^\circ$$

which should be indicated by the gonio-sight, the artificial horizon and the clinometer.

If the flight is not stabilized, the clinometer will still give the same reading, while the gonio-sight and the artificial horizon will not.

We have supplemented the above sets of curves with an example of a curve (v, EV) for this same aeroplane Y, obtained by the polar method, on which we have superimposed points obtained experimentally by the conventional method of stabilizations under favourable meteorological conditions (Figure 6).

We have also included measurements taken a few months previously on two Martinet's. These tests were made on two laboratory aeroplanes (NC 701-2P No. 136 and NC 702 No. 282), for the purpose of developing methods and instruments of measurement, familiarizing pilots with manoeuvres at constant attitude, and preparing elements for appraisal of accuracy.

In particular, about one hundred manoeuvres at constant attitude were carried out in a period of eighteen months, with the configuration: flaps and landing gear retracted and propellers feathered. The scatter observed for these two aeroplanes remained small, the polars being displaced due to the presence of important external equipment on the 136, such as a tripod strut extending approximately two metres above the fuselage. Moreover, wind tunnel tests conducted by Mr. Monnin at the SNCAC (Société nationale de Constructions aéronautiques du Centre) on a specially equipped model of a Martinet have shown that the same results (0.004) are obtained by both methods for the increase of the drag coefficient. Figure 9 shows an example of a record of a manoeuvre at constant attitudes and the polar of NC 702 drawn through experimental points plotted in the course of seven tests made at different times over a period of four months.

The scatter of results obtained with powerplants in operation becomes greater when power control is inadequate. In any event, however, the scatter remains smaller than that observed in direct texts, which are much less frequent in view of their high cost.

2.5.- EXAMPLES OF LONGITUDINAL CHARACTERISTICS

As has been stated, manoeuvres at constant attitude provide an excellent method for rapid and accurate measurement of static longitudinal characteristics.

It was essential to check experimentally that the results obtained during these manoeuvres were identical with those provided by stabilizations. This check was made on a Martinet with recording of forces by three different procedures: dynamometers attached to the controls, dynamometers attached to the control gear and strain gauges (with amplifiers) attached to certain components of the transmission system.

The variation between the points obtained in acceleration, deceleration or stabilization did not in extreme cases exceed ± 3% of the speed corresponding to the same force or to the same indicated position, and was due almost entirely to static lags. These variations are hardly perceptible if the incidence recorder is used, as incidence circuits generally do not have any noticeable lag and it is only caused by imperfections of the control gear or measuring instruments.

Figure 10 provides an example of records of stresses in the elevator control system of a *Martinet* following paths at constant attitude. The static lag is particularly great due to the presence, in the same circuit, of four HB recorders and two complete instrument panels. This lag is proportional to the rate of variation of the static pressure and corresponds, in the 25 m/s dive in Figure 10 to an over-reading of indicated speed of about 10 km/h. The curve segments to be analyzed refer to the value g of Γ_V. This value is substantially maintained only during flight paths at constant attitude.

Figure 11 represents the analysis of another test on a *Martinet* in which the two paths, acceleration and deceleration, at constant attitude, have been followed by stabilizations under the same conditions (powerplants and tab). It will be noted that the results agree perfectly. The analysis was made using incidence recording. This agreement of results, moreover, is found in the case of many other variables and justifies application to a number of measurements of those standard manoeuvres, which may be termed broadly "motions of translation", e.g. pressure distribution.

The tests made by Mr. Girard of the SNCASO (Société nationale de Constructions aéronautiques du Sud-Ouest) on type 161 and 95 aeroplanes have also afforded a comparison between results obtained by stabilization and those obtained by manoeuvres. The reaction curves obtained coincide perfectly, to such a degree that minor deflections in the curves due to the passage of the flaps in the wake of the fixed plane are found in both instances. The forces at the elevator control have been recorded using a strain gauge dynamometer and a *Société Delord* ratio-meter receiver. An interesting and original measurement was made at the time of these tests. It consisted in the determination of the lift of the tail surface by measuring the bending stress of the fixed plane using resistance strain gauges. It would be useful if these tests were repeated on aeroplanes, the structure of which permits this measurement, particularly those equipped with an adjustable fin.

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CHAPTER III. - THE MEASUREMENT OF VARIOUS PARAMETERS

3.0. - GENERAL

Irrespective of the choice of methods of experiment and calculation, the value of a test is predicated upon the precision of the instruments of measurement, and in turn this precision is dependent on the conditions of use, among which the professional value of the human element takes a high place.

The C.E.V. methods of measurement are based essentially on the use of the Hussenot-Beaudoin (H.B.) multiple recorder. In the specific case of the measurement of the polar in flight the following parameters are measured. While only some are necessary, the others serve to improve the accuracy of results or to provide means for checking them.

Ambient air: pressure and temperature.

Configuration of the aeroplane: weight and centre of gravity position, position of flaps and tabs, characteristics of the powerplant.

Flight Path: altitude, speed and path gradient.

Accelerations: pendular angle and normal acceleration.

Orientation of the aeroplane: longitudinal attitude, incidence and sideslip.

Time is the fundamental variable of all records and is indicated in the abcissae.

In view of the fact that manoeuvres at constant attitude are particularly well suited for measurement of longitudinal static characteristics, the position of the elevator control surface and the force at the control or control system are usually added to the above parameters.

In the following paragraphs, a review is made of the various instruments used in 1948 to record the parameters, and the order of magnitude of the precision is considered.

3.1. - AMBIENT AIR

The ambient air is suitably defined when pressure, temperature and humidity are known. Pressure is recorded by the multiple reflector Jaeger barograph, an important accessory of the HB recorder. Neglecting lag and static errors of the airspeed head — which, moreover, may be corrected with ease and accuracy — ambient pressure is recorded to approximately one fifth of a millibar. The order of magnitude of light-spot deviations is derived from the following figures: the light-spots of five reflectors, all marked "baro dur" (i.e. small scale barograph), successively cover, across the 89 millimetre wide sensitized strip, a pressure-altitude range of 3000 metres; a second group of five reflectors mounted on a shaft turning ten times faster, each covering a range of about 300 metres. The 1500-metre range thus covered by the "open-scale" barograph may be selected at will to provide coverage within the useful altitude range. A sample recording is shown in Figure 12.

Ambient temperature is transmitted electrically by an electrical resistance bulb with double shield, by means of which the total temperature (i.e. ambient + adiabatic heating) is recorded to within approximately half a degree. This bulb, with an outer diameter of 20 mm is illustrated in Figure 13. It contains a platinum resistance, coiled on mica, of 100 ohms at zero degree. It is shielded against all radiation. The two corrections to be applied to the θ_1 measurements given, are correction for lag $\Delta_2 \theta$ and correction for heating - $\Delta_1 \theta$:

$$\theta = \theta_1 + \Delta_2 \theta - \Delta_1 \theta$$

The correction for lag, which is small enough, is given approximately by the ratio:

$$\Delta_2 \theta = \frac{3000}{V} \frac{d\theta}{dt}$$

where V is the true airspeed in kilometres per hour. At 200 km/h with a temperature gradient of 7 degrees per 1000 metres and a vertical speed of 10 metres per second, the correction is 1 degree. Rapidity of response of this bulb has been sacrificed to a certain extent in favour of sturdiness.

The value of heating, which has been practically made equal to the adiabatic heating, is

$$\Delta_1 \theta = 3.85 \ V^2 \ 10^{-5}$$

or 2° at 230 km/h, 10° at 500 km/h. Research is being carried out for speeds beyond 500 km/h.

Since it would have been unrealistic to try to develop a bulb giving the exact ambient temperature it was found far more satisfactory to ensure definite and accurate corrections. Moreover, the degree of adiabatic heating and the accuracy obtained by our instruments should provide an acceptable measurement of high speeds in an atmosphere simultaneously investigated by a slow aeroplane. The location of this bulb is selected by applying the same rules as for a total pressure head.

The electrical instruments used with the thermometric bulb are either a direct-reading industrial meter or an oscillograph for recording purposes and a milliampmeter for readings, used with a C.E.V. junction box of the D.60 or D.62 type (Figure 14) and which should have a measurement range of 0.8 m A.

Humidity is generally neglected for temperature below 10 degrees. For temperature above 10 degrees the values provided at ground level by conventional instruments are used, as well as results of meteorological soundings. Humidity is determined to within approximately 0.1.

3.2.- THE CONFIGURATION OF THE AEROPLANE AND THE POWERPLANTS

The weight and center of gravity position of the aeroplane are obtained by measurements on the ground and simple ballast corrections. The degree of accuracy is of the order of one thousandth.

The position of the landing gear and the various flaps is generally noted; it is sufficient to indicate this by means of special marks on the recording strip, and for this purpose signals are available to the pilot and experimental staff. On the other hand the positions of the tabs and particularly of the controls deserve to be recorded continuously. The most common transmission device consists of several simple or multiple potentiometers with varying rates of reduction and types of transmission mechanisms; these potentiometers record on one of the electrical receivers of the H. B. recorder.

The potentiometers (Delord) are wound on 100, 250 and 350 degrees. Total resistance is between 600 and 1000 ohms. The electrical receivers are:

- The S.F.I.M. type E. 10 potentiometric receiver in which a mobile frame drives a slide contact on a fine wound resistance (Figure 15).

The Beaudoin frame oscillograph connected to a D.65 junction box which provides simultaneous reading on a repeater. The oscillograph is mounted on an extension of the recorder, the "rear frame", which may consist of three frames (Figure 16).

The degree of precision obtained in the recording of data transmitted by potentiometer is respectively ± 0.7% and ± 0.4% of the measurement range. However, the degree of precision with which, for example, the displacement of a control is measured, may be brought to one thousandth by making the 360-degree potentiometer revolve several times, and by paying special attention to the transmission mechanism. The time of response at 10% output of the E. 10 recorder is of the order of 0.2 second; it varies between 0.05 and 0.01 second for the oscillographs.

In certain cases, the potentiometer does not have the requisite mechanical strength, or does not provide adequate flexibility of operation. Use may then be made of the mutual inductance Beaudoin goniograph with a D. 54 junction box fed by a transformer providing 800 or 1000 cycle alternating current (Figure 16). The total deflection of the receiver, milliampmeter or oscillograph at a range of measurement of 0.5 m A, is obtained by a movement of the rotor of 4 or 20 degrees, depending upon the position of the sensitivity selector.

Many of the powerplant characteristics are maintained constant during the determination of each polar, e.g. induction manifold pressure and r.p.m. These characteristics are generally read and noted. The others are derived from specific powerplant tests. Nevertheless, standard aeroplane recorder equipment provides for recording of rotational speeds by means of an impulse counter and recording of manifold pressure by differential capsule (reference to static pressure, and automatic pressure distributor) giving greater accuracy than the aeroplane instruments. In certain specific cases, a continuous record of rotational speed is useful. This is made using a Faure-Hermann alternator and an oscillograph, with a rectifier and filter junction box. Figure 17 shows a sample recording of engine speed.

In this manner the records of flight polars are frequently most complete, without however going to the point of overloading the strips with cylinder-head and line temperatures, which are, moreover, of little interest if the power varies.

Powerplant control, however, is never thoroughly accurate unless torque is recorded continuously at the same time as rotational speed. Unfortunately the French engine manufacturers have shown but little interest in this problem, which is one that requires to be considered from the very first stages of the design. Taking advantage of the suitable construction of the Renault-Argus 12 S 00 engine, the C. E. V. has developed an electric torquemeter which measures by goniograph the displacements of the stationary gear of the reduction system. Since its development this instrument has operated satisfactorily during forty hours of flight, giving a degree of accuracy of ± 1.5% of the range of measurement. A recording is shown in Figure 18.

3.3. - THE FLIGHT PATH

The flight path characteristics necessary for calculating the polar are the conventional dynamic pressure and, in certain cases, the gradient.

The conventional dynamic pressure q is derived from St. Venant's law of calibrated dynamic pressure $(p_i - p_s)$, itself calculated from the gross dynamic pressure Δp after correction for lag and pressure-head calibration.

The lag, affecting almost exclusively the static pressure circuit, is approximately proportional to the vertical speed expressed in pressure variation and it depends on the size of the vents and of the tubing and the volume of the instruments. A complex system is required to obtain a coefficient of 0.5 i.e. a lag of 0.5 millibar for a rate of variation of the static pressure of 1 mb/s caused by a vertical speed of 10 metres per second at 2000 metres. This lag corresponds to a static vent composed of two perforations, 2 mm in diameter, a connection 20 mm long and 2 mm in diameter, a pipe 10 metres long and 4 mm in diameter, and lastly a volume of 3 litres. It is possible to make the resultant lag on Δp negligible by adding a suitably chosen parasite volume in the pitot pressure circuit.

The pressure head is calibrated to determine the corrections for imperfect shape and positioning. The method of representation used by the C. E. V. consists of a curve in Hussenot co-ordinates (example in Figure 19 - Dornier

335 No. 2). The layout adopted has the following advantages: it gives the results directly taking into account compressibility effects (St. Venant's law) in terms of altitude, and it applies equally to the calibration of a pressure head by reference to a base point (direct measurement of true airspeed) and to the "method of the tower" (measurement of static error). (See C.E.V. Report No. 40/SM).

In the first case, each point of the pressure head calibration curve is determined by the Δp recorded on board and by the speed as measured by flying over the base; thus point P has the following co-ordinates:

Δp = 100 mb, and EV = $V\sqrt{\sigma}$ = 483 km/h

In the second case each point is defined by the value of Δp and by the static head error dps, which is the difference between the static pressure recorded on board and that which would have been obtained if the static head were perfect. This value is obtained by direct measurement of the altitude of the aeroplane, usually by a photographic method. Thus point P, is defined by Δp = 100 mb and p' p'' = dps = 15 mb

This "method of the tower" is extremely accurate for speeds in excess of 200 km/h. It assumes that the pitot head has been suitably installed.

Whichever method is used, the calibration obtained is only applicable for a given weight, as in fact, the aerodynamic field around the pressure head depends on the incidence. This observation becomes most important when the pressure head calibration is very oblique and when manoeuvres with high wing loadings are to be analyzed. Correction for weight through the effect of incidence involves a simple calculation which only requires a knowledge of the apparent weight, i.e. the lift coefficient.

The crossed co-ordinates pressure-head calibration curve is used as follows for the equivalent airspeed at altitude: suppose the following were recorded Δp = 150 (point Q) at Zp = 7,200 m, i.e. p_s = 400 mb; it is necessary to go from Q to Q' and thence to Q":

EV = 566 km/h

The true airspeed is then obtained multiplying EV by the square root of the inverse of the specific gravity at 7,200 m at the time of the test.

To calculate the lift and drag coefficients, start from Δp (point Q) as measured, thence to point Q' which would have been given by a perfect pressure head, and thence to point Q": EV is read and the conventional dynamic pressure q is given by the equation:

$$EV = 46 \sqrt{q}$$

The total error in the measurement of q is of the order of $\pm$ 1.2%.

We will mention briefly the conventional precautions to be taken in the installation of pitot and static pressure heads.

For Mach numbers below 0.7, the pitot head is advantageously separated from the static head and placed above or below the fuselage or wing in order to take advantage of a local field which varies little in direction and which remains approximately parallel to the skin a few centimetres away. For higher Mach numbers, it is often necessary to place the head well forward in zones of light over-pressure. The head itself is a sharp-edged open section cylindrical tube. Impact pressure is picked up to within approximately 0.002 $(p_i - p_s)$ up to local incidences approaching $\pm$ 20 degrees at a low M, or about $\pm$ 15° up to M = 1. The head is set parallel to the bisector of the extreme local flows. In this fashion an excellent pitot head pressure, as required for the proper application of the tower method, will be obtained without difficulty.

The problem of the static head is different. It is not necessary for it to be accurate to the same degree as the pitot head, as its deficiencies may be corrected with great accuracy when the corrections are calculated by the tower method at high speeds.

The static head, however, must be reliable*. In other words a given static head error should always correspond to given conditions of flight, or, to be correct, the same static head error should exist when Δp returns to a given value, if dynamic pressure alone is taken into account among the external factors affecting static head errors. This is easily obtainable when

* A distinction has to be made between aeroplane flight instruments and the testing instruments. In the case of the former, excessive corrections are to be avoided while in the latter everything should be subordinated to reliability.

M is small, by using fuselage heads or rigid pressure heads of standard design, subject to the proviso mentioned earlier that incidence and not dynamic pressure is the true active variable. On occurrence of a shock wave affecting the aerodynamic field around the static head, the influence of the Mach number is substantial, and there is a danger of a movement of the shock wave because of a variation of the state of the surface, sideslip, or other variables which are inactive when M is small. However, at constant incidence, on a single static head, or a Prantdl type pressure head, installed well forwards, hardly any variation of the static head error is observed before M reaches 0.8. At greater Mach numbers it is necessary to use calibrations combining the effects of incidence and Mach number. These calibrations require the application of the generalized tower method, with the "tower-aeroplane".

By placing the static head in a zone of slight over-pressure, the onset of local sonic phenomena is delayed. One disadvantage of such a head, which is felt when the pilot is flying at low altitude, but which disappears on analysis of the records, arises out of altimeter error; for instance, a pressure head providing an indicated airspeed too low by 2%, as produced by a local over-pressure of 0.04 $(p_i - p_s)$, would, on flying close to the ground at 900 km/h, make the altimeter under-read by 150 metres.

We know then the magnitude of the speed. The second parameter defining path is the angle Θ. The angle is only really required for one of the two methods of measurement of the polar, that which is used only when the records are incomplete. Nevertheless, it will be seen below that it is necessary to determine this angle for the incidence calibrations.

The path angle in relation to axes related to the ground and moving laterally with the horizontal component of the wind is given by the equation:

$$\sin \Theta = \frac{v}{V}$$

v being derived from the barograph record giving the static pressure variation dp observed during the time interval dt:

$$v = \frac{dp}{0.12 \sigma \, dt}$$

(v in metres per second, dp in millibars and dt in seconds).

If a degree of accuracy of ± 0.1 degree is desired at about 200 km/h, it is necessary to stabilize horizontal and vertical speeds for a period of one minute. Time is furnished by the time recorder with a degree of accuracy of 0.5% over one minute, including an instrument error of approximately 0.2% due to temperature and voltage variations.

As has been seen, the path angle in relation to the axes referred to the ambient air is given by the equation $\theta = A - i$ and a degree of accuracy to $\pm$ 0.1 degree may be obtained.

The difference between the vertical speeds calculated by both methods for the same instant gives the measure of the vertical movement of the atmosphere. With a slow aeroplane or a glider, the degree of accuracy of this measurement may be brought to + 0.1 m/s.

3.4. - ACCELERATIONS

There are two types of acceleration: linear and angular accelerations. The second are of no interest to us in manoeuvres at constant attitude and moreover, are scarcely measured directly.

Linear accelerations are, the components of resultant acceleration; most of the time, resultant acceleration remains close to the acceleration of gravity and in any case does not materially deviate from the vertical reference of the aeroplane and the normal to the path. The two components of interest in substantially symmetrical flight are tangential acceleration and acceleration normal-to-the-path. As they can scarcely be measured directly, they are measured along the aeroplane's axes. Generally it is not necessary to specify the point of the aeroplane at which the measurement is made, since, the instantaneous centre of rotation is seldom situated near the aeroplane (tail-spin, and rapid manoeuvres, vibrations).

The acceleration along the aeroplane's vertical axis, commonly known as normal acceleration, which hardly differs from the component normal to the path, is detected with an HB or S.F.I.M. mechanical-optical accelerograph which is placed in the recorder instead of a capsule or on the "stirrup" (record in Figure 20). Sensitivity is controlled according to the problem being studied, and ranges from one to eight millimetres per metre per second per second. For the flight measurement of the polar a range of + 5 to + 20 m/s^2 is chosen (or + 0.5 g to + 2 g). Then Γ_v is measured to 0.1 m/s^2 approximately, i.e. one hundredth.

Since this degree of absolute precision, however, is insufficient in the measurement of tangential acceleration, the indirect method is used, consisting of measuring the value of normal acceleration and, secondly, the direction of the resultant acceleration (or rather its component in the plane of symmetry) using an HB pendular level gauge previously referred to, as shown in Figure 21. This instrument measures angle π within a twentieth of a degree, and has a measurement range of 18 degrees (a rear frame with two levels provides 36 degrees) and a time of response at 10% of a quarter of a second at the critical damping usually adopted.

Finally, in order to have a complete analysis of the motion of the aeroplane, we still have to measure its orientation, which is defined, firstly in relation to the fixed axes by the longitudinal and lateral attitudes and the yaw, and on the other hand in relation to the axes linked with the speed, by the incidence and sideslip. When measuring the flying qualities, one must add also the rates of pitch, roll and yaw, as detected by gyrometers.

Excluding stabilized flight conditions for which the obvious instrument of measurement is the pendular level gauge, the graduations of the scale of the gonio-sight will show the longitudinal attitude, provided the horizon has been previously calibrated in stabilized flight measuring its apparent height by means of the gonio-sight and the pendular level gauge. Of course the setting of the sight in relation to the aeroplane's axis should be carefully determined. In order to do this, the gonio-sight and a theodolite are respectively sighted on each other and simultaneous readings are made of the angle of elevation of the theodolite, and the attitude of the aeroplane by means of an artillery level. It would be most interesting if the horizon sighting were completed by cine-gun photographs, but unfortunately certain difficulties exist due to the poor visibility of the Paris area.

We will now briefly describe the C.E.V. gonio-sight as shown in Figure 22 at the usual position in the cockpit. It is an S.F.O.M. type 80 clear sight mounted on a micrometer drum, the axis of which is parallel to the span of the aeroplane. The drum is rotated by a worm and a knurled knob. The graduations of the drum show the angle of rotation, and the divisions of the knurled knob show tenths. Suitably adjusted readings to a twentieth of a degree may be obtained, i.e., the degree of accuracy of the sight itself under the most favourable conditions.

It is useful to supplement the recordings with the readings of an axis-free gyroscope, or in other words, an artificial horizon with the pendulum vanes disconnected during manoeuvres: this provides an excellent check on the quality of the piloting technique. The C.E.V. mainly uses Anschutz-S.F.I.M.

gyroscopes with potentiometer transmission and electric erection system (Figure 23) giving a degree of accuracy of a quarter degree with an electric quotientmeter receiver. A sample recording is given in Figure 9.

With respect to the lateral attitude, recorded for example with a gyroscope of similar type, and to the yaw as given by a potentiometer directional gyroscope or any gyroscope installed in accordance with the same principles, it may be stated that their measurement is of little interest in the tests that we have been considering.

3.5. - THE ORIENTATION OF THE AEROPLANE

Incidence and yaw may be measured by means of vanes, directional pressure-heads or vents located on the surface of the aeroplane. The C.E.V., after three years of extensive tests, recommends the last method whenever the design and structure of the aeroplane permit. Moreover, the method may be applied also, after wind tunnel calibration, to the local incidence of a tail surface. The leading edge of the wing can be used for incidence measurement excepting stalls, but the best results are obtained with a well-streamlined fuselage nose. Four-pressure vents of about two millimeters diameter provide incidence and yaw measurements with adequate sensitivity and reliability resulting from the rigidity of the system. For example, in the case of the twin-engine NC 702 the quotient of the pressure difference between two-paired perforations, divided by dynamic pressure, varies by 0.09 per degree. The vents are placed on the nose of the fuselage along a parallel circle, selected in such a manner that the angle formed by the vertex of the tangent cone is approximately 90 degrees. Using a differential capsule in which the two reflectors cover the whole of the ±15 millibar recording strip, the sensitivity is 15 millimeters per degree in the region of 250 km/h. Photograph No. 24 illustrates some vents of this type, outlined by circles. The nose of the aeroplane is not encumbered by any equipment, so as to avoid disturbance of the airflow. A sample recording is shown in Figure 9.

Whenever this method is not practicable, directional heads of any type should be used. The C.E.V. uses cylindrical heads with a streamlined tip, perforated as in the case of the vents in the nose of the fuselage. Here again, the degree of accuracy may be held to a twentieth of a degree. Reliability depends on the rigidity of the mounting. Finally, as an accuracy of one degree is usually adequate for the measurement of yaw, it is convenient to use a mere vane, with transmission by means of a potentiometer.

Little mention has yet been made of calibrations, which are of fundamental importance. While research on the operational characteristics of measuring instruments is in many cases an arduous subject, investigations have been conducted in this field by the G.R.A. (Groupement français pour le Développement des Recherches aéronautiques) and the C.E.V. However, methods of testing recording manometers, barographs, pendular level gauges, gyroscopes, transmitters etc. are sufficiently well-known to require no elaboration. On the other hand calibration of vents for measurement of incidence and of yaw deserves a brief mention in view of the fact that there is less experience with these than in the calibration of airspeed pitot-static heads.

Incidence calibrations should be accurate, as it is the most important angle in the aerodynamic study of the aeroplane and its variations are relatively small; these calibrations must also be numerous because the aerodynamic field is affected by each change of configuration. Each calibration point is obtained, at rates carefully stabilized by means of the gonio-sight, by the simultaneous measurement of the attitude (using a pendular level gauge), and of the path gradient (using an open-scale barograph). Weather conditions should be carefully selected in order to avoid all vertical motions of the ambient air, and the operation should be conducted as often as possible in level flight. Moreover it is far easier to obtain an accurate incidence calibration than a curve of vertical speeds determined by means of the conventional method. Particularly, by comparing with this calibration all check points obtained throughout the tests, for example at the time of stabilizations in calm air, the engineer is assured of greater reliability than that which may be given by the conventional methods for curves of vertical speeds where cross-checking is very difficult. Figure 25 provides an example of the calibration for the fuselage nose vents of aeroplane Y.

The instruments for measuring sideslip are calibrated by maintaining a specified true track and fixing the heading of the aeroplane using the gonio-sight. To maintain the track while sighting the same direction, with the gonio-sight set at three and six degrees, it is necessary to cause the aircraft to sideslip by crossing the controls. The wind effect is compensated for by making return flights. However, in most cases, approximate calibrations derived from the records provided by pressure-heads or vanes may be acceptable.

Finally, let us note some applications which are made possible by the remarkable reliability of the vents in the nose of the fuselage: the C.E.V./Incidence/Sideslip/Weight and Center of Gravity position Panel, and the C.E.V. stall warning device.

Most of these instruments are based on the fact that, if an angle of incidence is registered by two vents with nil pressure differential, a mere manometer connected to these vents provides a reading (zero) that will correspond to that incidence, regardless of dynamic pressure, which is proportional to the apparent weight.

The C.E.V. instrument panel (Figure 26) is connected to the three pairs of vents shown in Figure 24. The panel comprises the following instruments:

- A sideslip indicator, in which the readings are more rapid and accurate than with the ball type; these readings alone remain accurate in an asymmetrical flight with part of the powerplants inoperative;

- Two incidence indicators in which the readings correspond to a cruising incidence and to an incidence close to stalling;

- A manometer registering dynamic pressure with a scale graduated in weight; the reading is taken in stabilized flight at the incidence given by the "cruising" incidence indicator, at a given powerplant rate.

- An elevator control or tab position indicator graduated in center of gravity position points. The reading of this instrument is valid at the same time as the weight indicator.

The stall warning device (Figure 27) is composed essentially of a capsule connected to two vents giving a zero pressure differential at the incidence which is selected as a little smaller than the stalling incidence. This capsule closes a circuit and sets off an acoustic or other signal. To prevent this device from operating when the aircraft is stationary or taxying, another capsule generally cuts off the circuit at speeds below half the landing speed.

3.6. - STRESSES

To conclude, the instruments used for continuous recording of stresses will be briefly mentioned. With these instruments the longitudinal static characteristics may be measured during the standard manoeuvres adopted for performance tests, to say nothing of the many applications that cannot be properly considered without recording, such as response to changes of configuration, particularly investigation of the minimum control speed — a sample recording is given in Figure 29 — measurement of stresses per g, flight characteristics at stalling speed or at high speeds, etc.

Because of the desirability of avoiding substantial modifications to the pilot's cockpit, the C. E. V. has given a high priority to the improvement of standard size control-gear dynamometers (length 100 mm, outer diameter 75 mm) with electric transmission, i. e. by S. F. I. M. potentiometer, Beaudoin mutual inductance, and SEXTA strain-gauge. Figure 28 shows one of these instruments connected to the control gear of a Martinet.

Likewise, a control column dynamometer with potentiometric transmission has been developed, employing the same elements as in the instrument used since 1947 by the C. E. V. for direct-reading measurements. This dynamometer may be fitted either with a dial micrometer or with the new S. F. I. M. potentiometric detector (Figure 30).

Used in conjunction with a good receiver, all these instruments provide a degree of accuracy of ±2% of the range of measurement.

CONCLUSION

The flights of a prototype aeroplane under test are few and costly. Consequently it is necessary to extract the maximum benefit from each flight, in other words, to increase the efficiency of tests. Already the various HUSSENOT recorders, ranging from the well-known A. 11 model to the midget A. 20, produced in 1948 (Figure 31), have considerably reduced the flying-time necessary for conventional tests and have greatly improved the degree of accuracy of results.

A new step towards improved efficiency and accuracy arises from the use of standard manoeuvres and gonio-sighting, and from the application of methods ensuring, for example, freedom from the effects of vertical motions of the air. These means serve to supplement conventional tests, which obviously cannot be entirely eliminated. It is still absolutely necessary to check the handling qualities of an aeroplane and its powerplants under conditions of operation which alone make it possible to check parameters, such as temperature, which require a long time to become stabilized. Also, it is occasionally useful to take direct readings for a specific performance if it is desired to know the order of magnitude immediately.

So far, these new methods have only been applied to a few prototypes and, naturally, some improvements may be expected.

Moreover, it is increasingly apparent that the applications of the measuring instruments developed by the C.E.V. are many and varied, and it is to be foreseen, provided adequate manufacturing facilities are made available, that they will come into early use in many branches of the industry and scientific research, both in France and abroad. There is little doubt that, in the narrower field of the aeronautical industry, the improvement of flight testing methods plays an essential part in the rapid development of modern aeroplanes.

Bretigny, 2 June 1949.

Chief, Research Section
J. Idrac
Assistant Technical Director

Chief, Methods Department
F. Hussenot
Director of the C.E.V.

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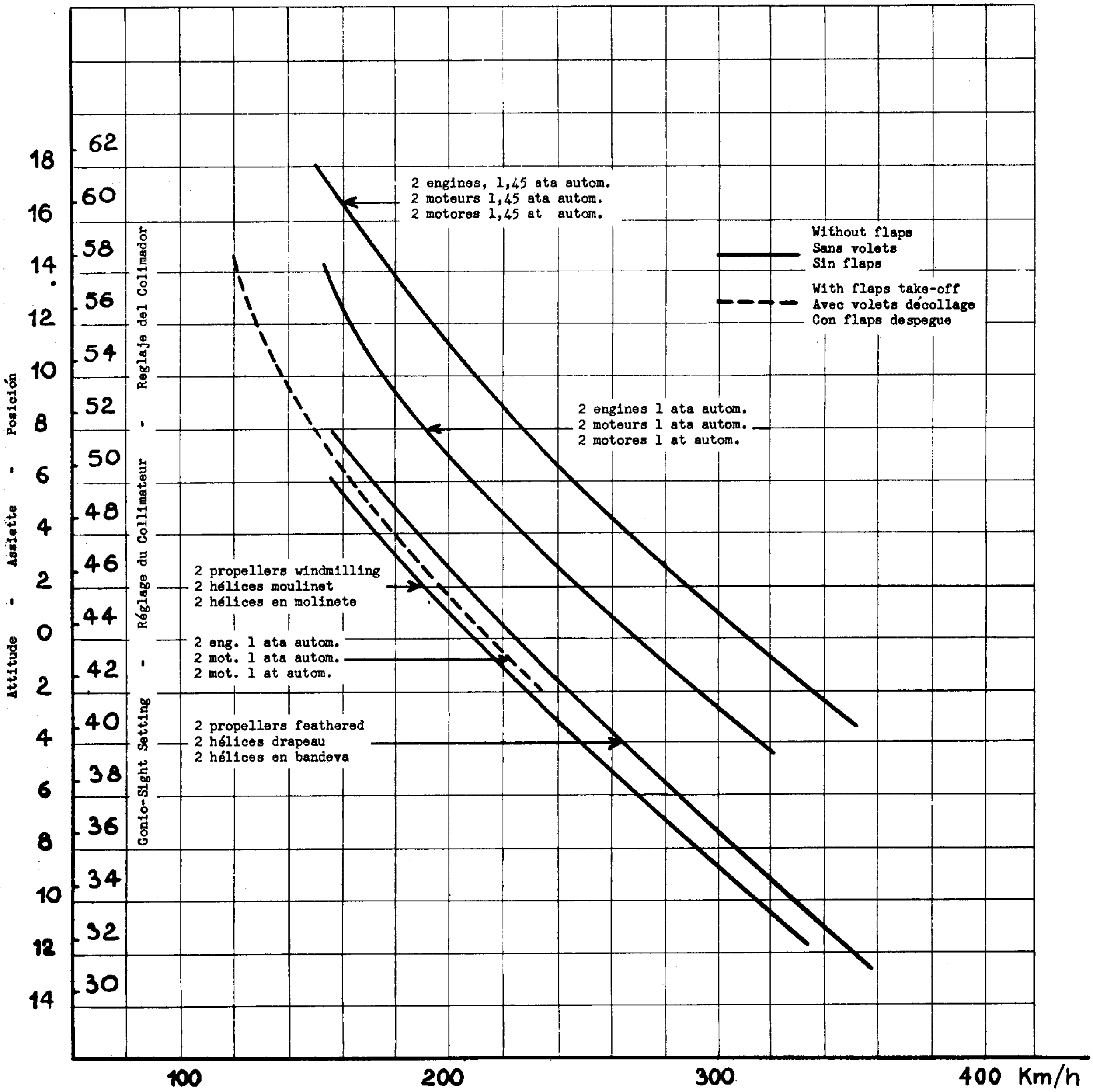


Fig. 1.- NC 702 No. 282 Sets of attitude curves in function of indicated airspeed in stabilized flight

NC 702 n° 282 Réseau des courbes des assiettes en fonction des vitesses indiquées en vol stabilisé

NC 702 Núm. 282 Red de curvas del ángulo de posición en función de las velocidades indicadas en vuelo estabilizado

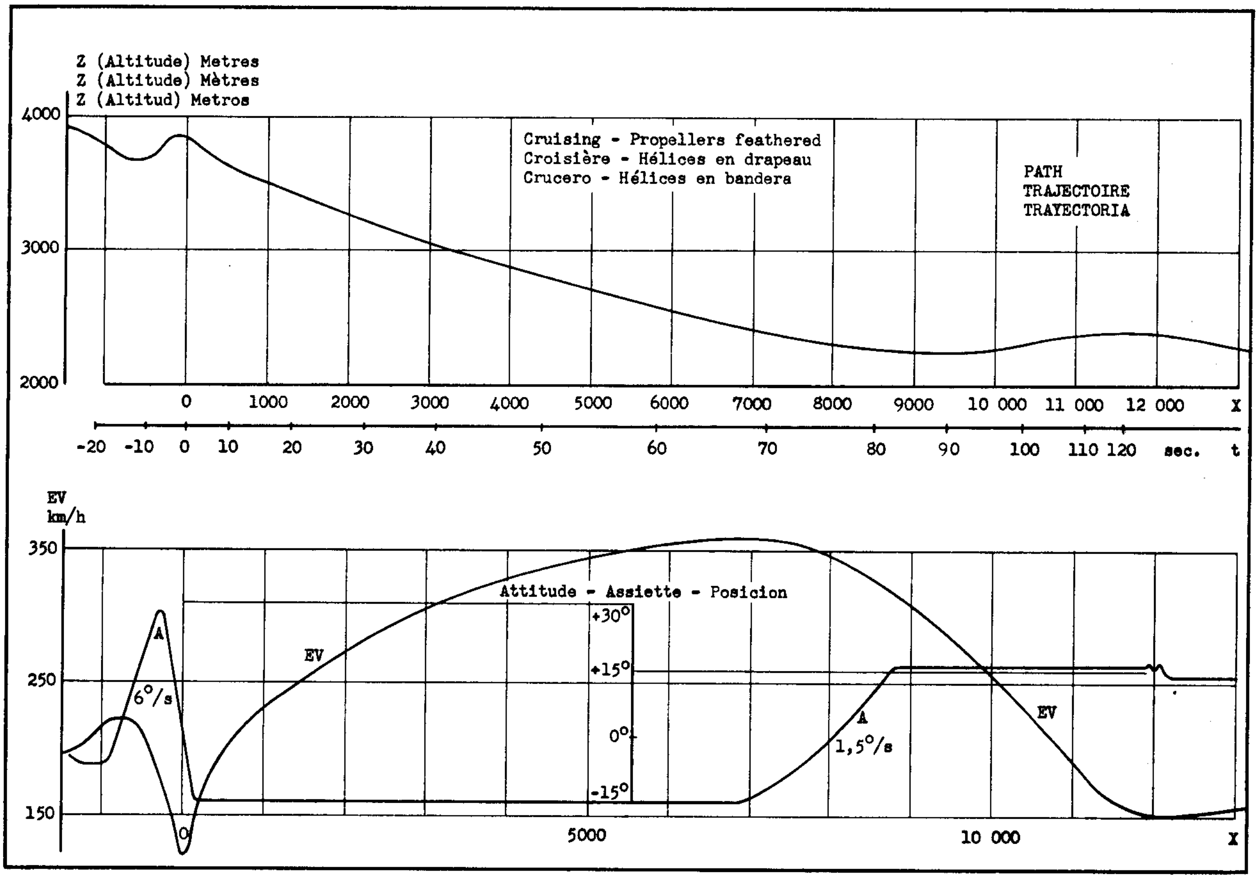


Fig. 2.- Manoeuvre at constant attitude for determination of the flight polar
Evolution à assiettes constantes pour la détermination de la polaire en vol
Maniobra con ángulo de posición constante para la determinación de la polar en vuelo

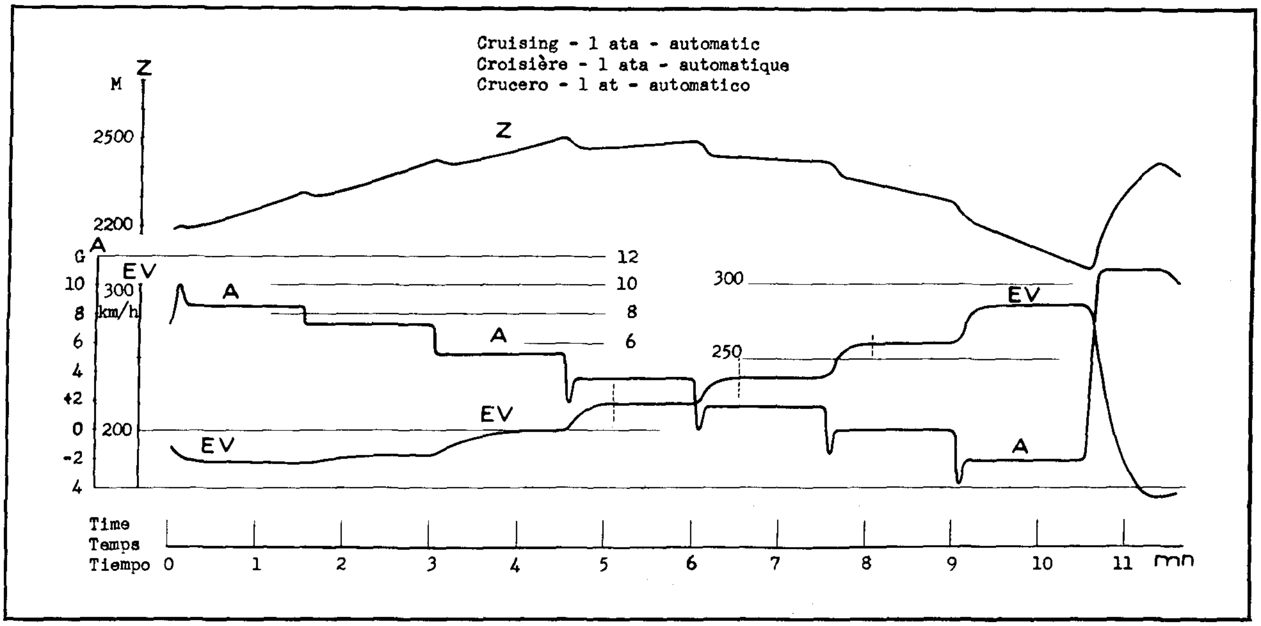


Fig. 3. - Pseudo-stabilizations and deceleration at constant attitudes
Pseudo-stabilisations et décélération à assiettes constantes
Seudoestabilizaciones y vuelo retardado con posiciones constantes

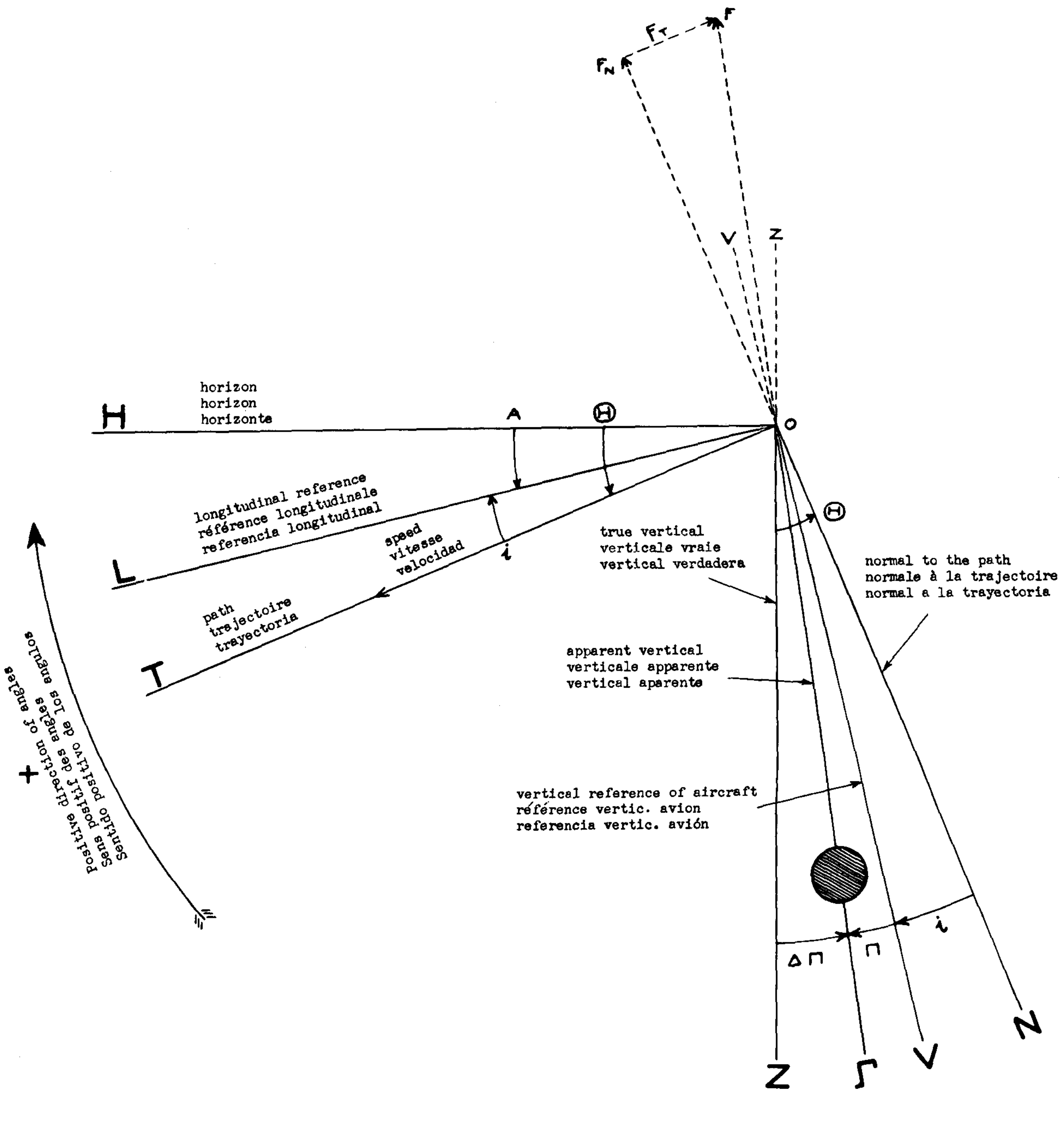


Fig. 4. - *The essential angles in substantially symmetrical flight*
Les angles essentiels dans le vol sensiblement symétrique
Angulos esenciales en el vuelo sensiblemente simétrico

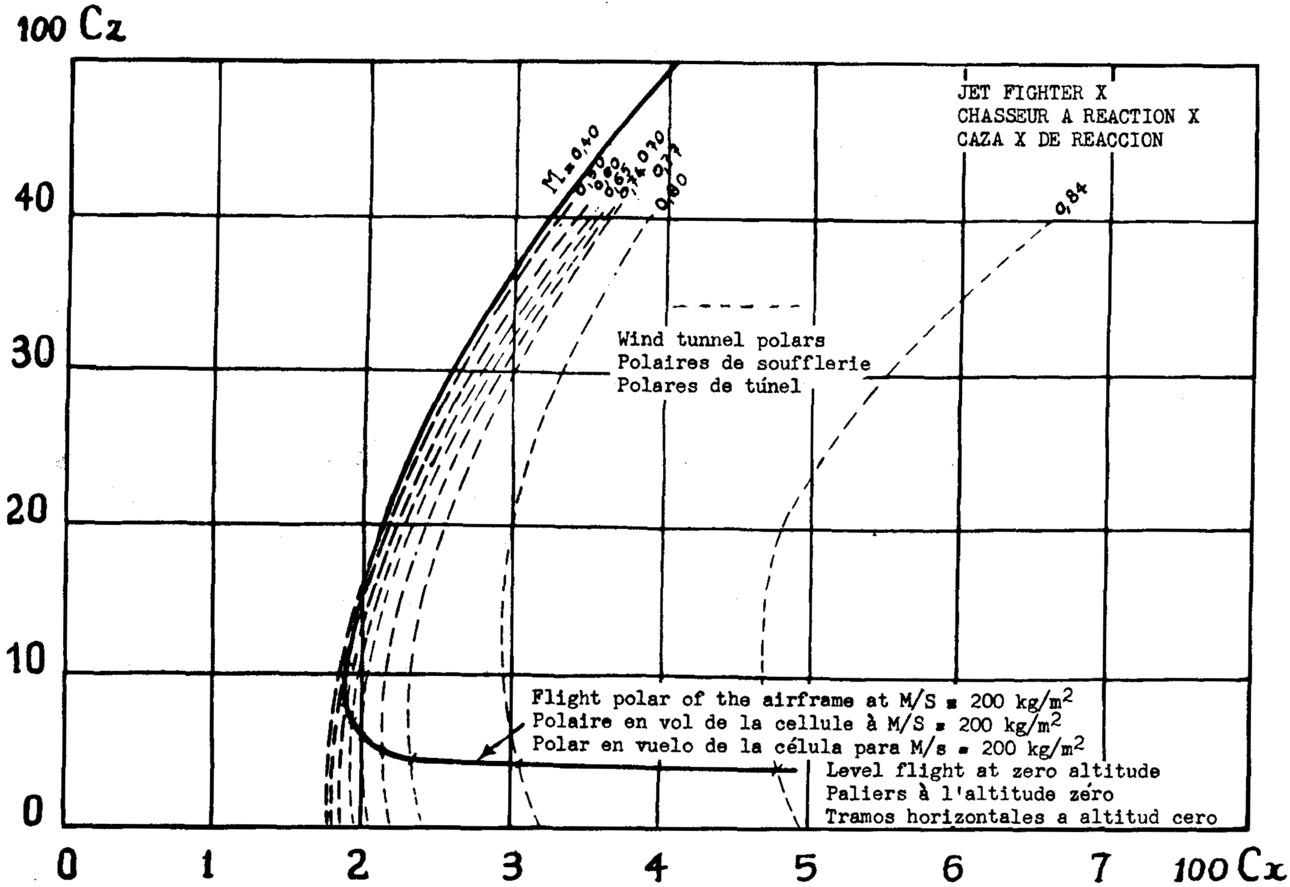


Fig. 5.- Wind tunnel polars and flight polar at zero altitude
Polaires de soufflerie et polaire en vol à altitude zéro
Polares de túnel aerodinámico y polar en vuelo a altitud cero

Y 18-Ton Twin-Engine Aeroplane
Bimoteur Y de 18 tonnes
Bimotor y de 18 toneladas

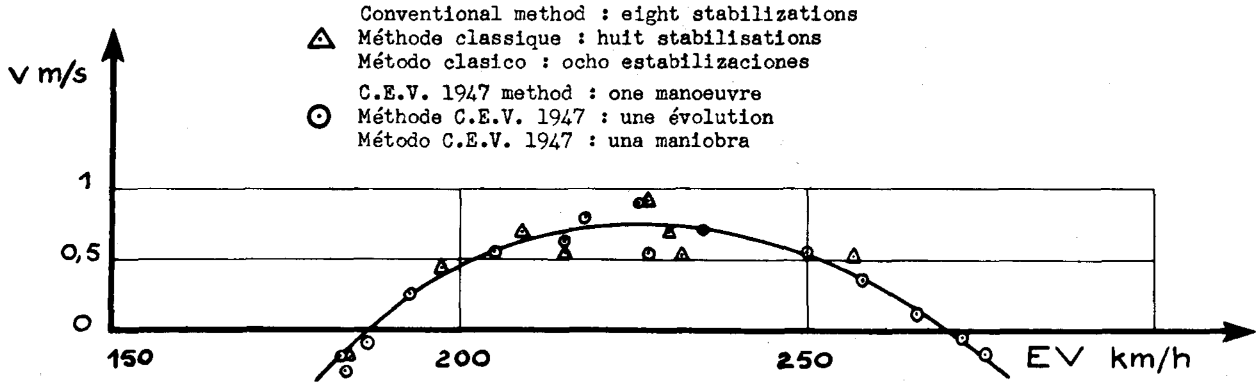
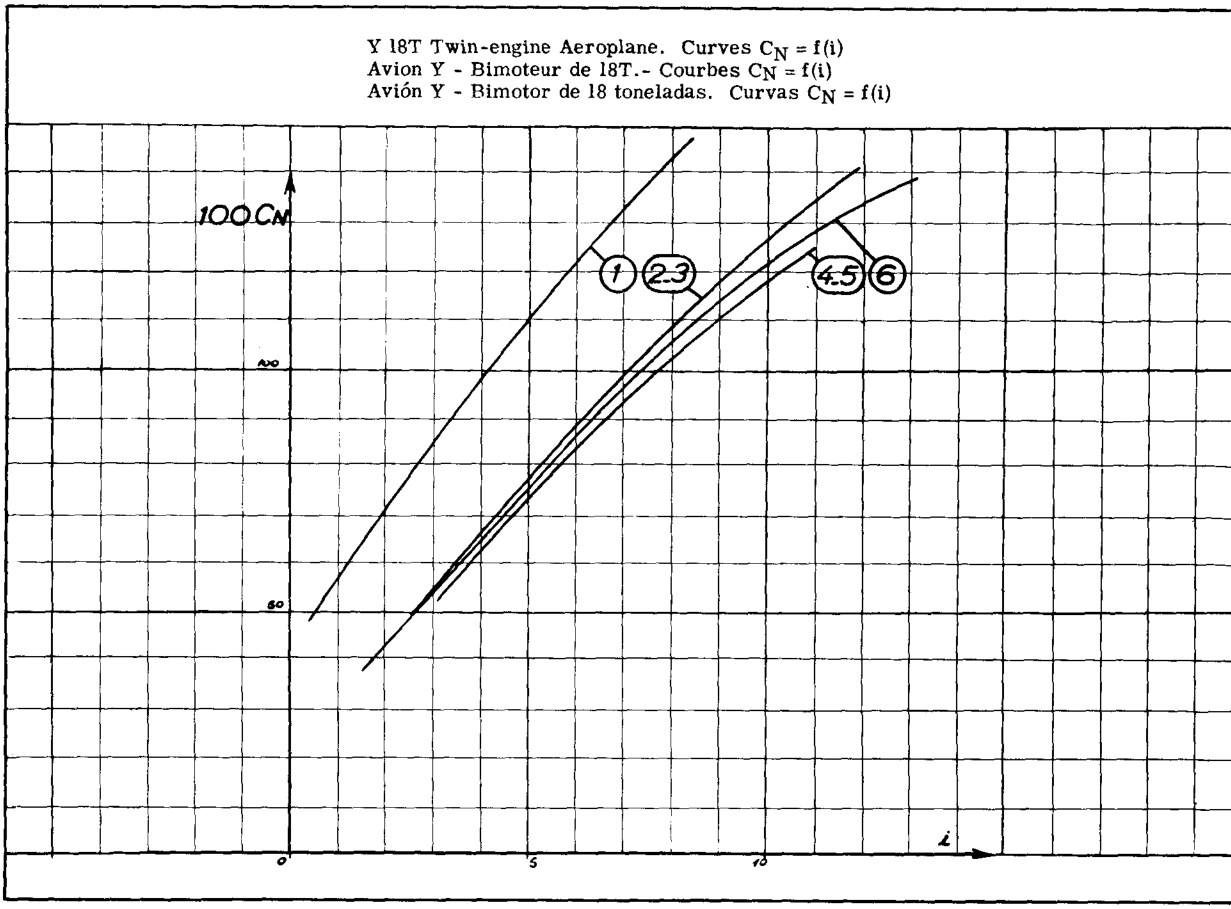


Fig. 6.- Vertical speeds at Z= 1500 m with one engine feathered (January 1949)
Vitesses verticales à Z = 1500 m. avec un moteur en drapeau (Janvier 1949)
Velocidades verticales a Z = 1500 metros con un motor parado y hélice en bandera (Enero de 1949)



(1) Engines at nominal rating - Landing gear retracted - Flaps 8°
(1) Moteurs régime nominal - Train rentré - Volets 8°
(1) Motores régimen nominal - Tren replegado - Flaps 8°

(2,3) Engines at climbing power - Landing gear retracted - Flaps 0°
(2,3) Moteurs régime de montée - Train rentré - Volets 0°
(2,3) Motores régimen de subida - Tren replegado - Flaps 0°

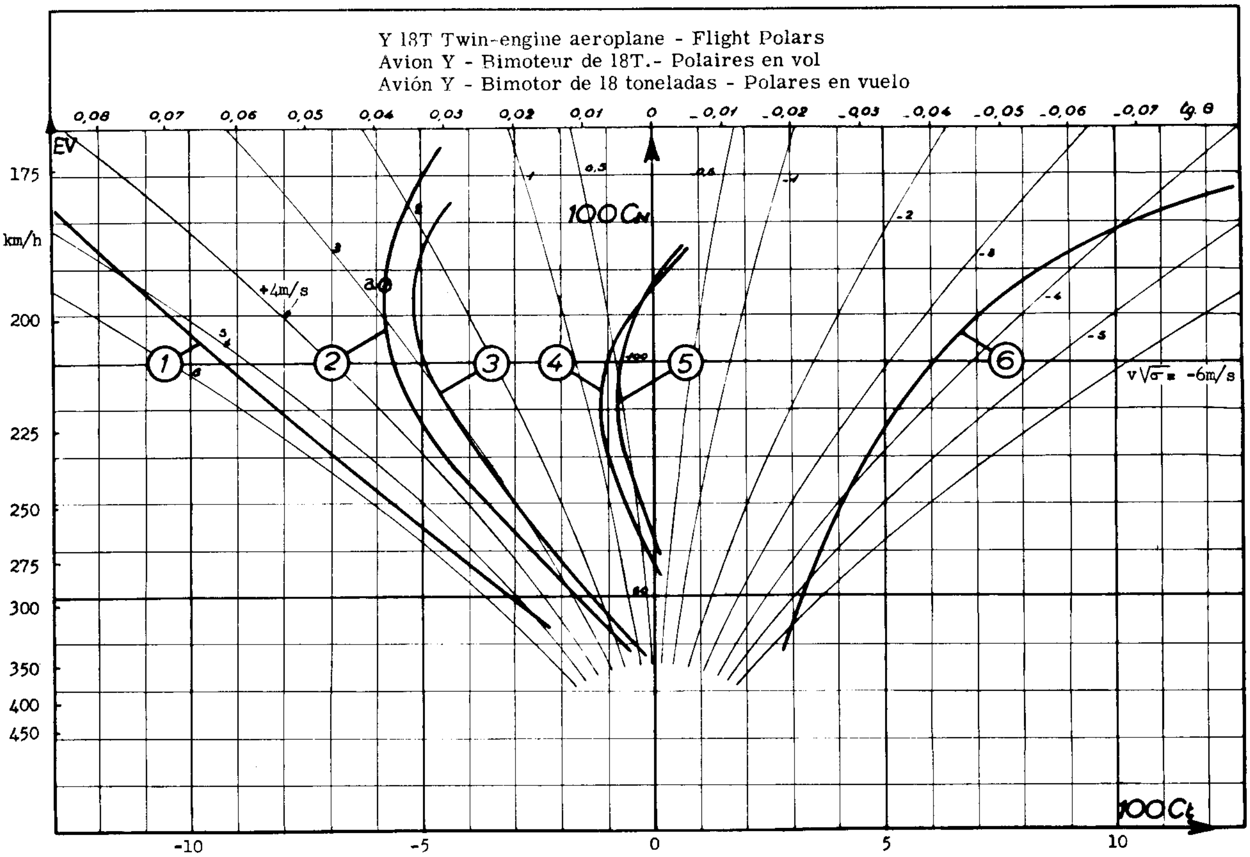
(4,5) Port engine inoperative - Landing gear retracted - (Nominal) - Flaps 0° - ailerons 0°
(4,5) Moteur gauche stoppé - Train rentré - (Nominal) - Volets 0° - ailerons 0°
(4,5) Motor izquierdo parado - Tren replegado - (Nominal) - Flaps 0° - alerones 0°

(6) Both engines inoperative - Propellers feathered. Landing gear retracted. Flaps 0° - Ailerons 0°
(6) 2 moteurs stoppés - Hélices en drapeau. Train rentré. Volets 0° - Ailerons 0°
(6) 2 motores parados - Hélices en bandera. Tren replegado. Flaps 0° - Alerones 0°

Wing loading: 210 kg/m²
Charge unitaire: 210 kg/m²
Carga unitaria: 210 kg/m²

Mean altitude: 1500 m.
Altitude moyenne: 1500 m.
Altitud media: 1500 m.

Fig. 7A.- Some polars of an 18-ton twin-engine aeroplane
Quelques polaires d'un bimoteur de dix-huit tonnes
Algunas polares de un bimotor de dieciocho toneladas



(1) Engines at nominal rating - Landing gear retracted; flaps 8° - Cowl flaps open.
(1) Moteurs régime nominal - Train rentré; volets 8° - Volets de capots ouverts.
(1) Motores régimen nominal - Tren replegado; flaps 8° - Aletas capo abiertas.

Wing loading: 210 kg/m²
Charge unitaire: 210 kg/m²
Carga unitaria: 210 kg/m²

Mean altitude: 1500 m.
Altitude moyenne: 1500 m.
Altitud media: 1500 m.

(2) Engines at climbing power - Landing gear retracted; flaps 0° - Cowl flaps closed.
(2) Moteurs régime de montée - Train rentré; volets 0° - Volets de capots fermés.
(2) Motores régimen de subida - Tren replegado; flaps 0° - Aletas capo cerradas.

(3) Engines at climbing power - Landing gear retracted; flaps 0° - Cowl flaps open.
(3) Moteurs régime de montée - Train rentré; volets 0° - Volets de capots ouverts.
(3) Motores régimen de subida - Tren replegado; flaps 0° - Aletas capo abiertas.

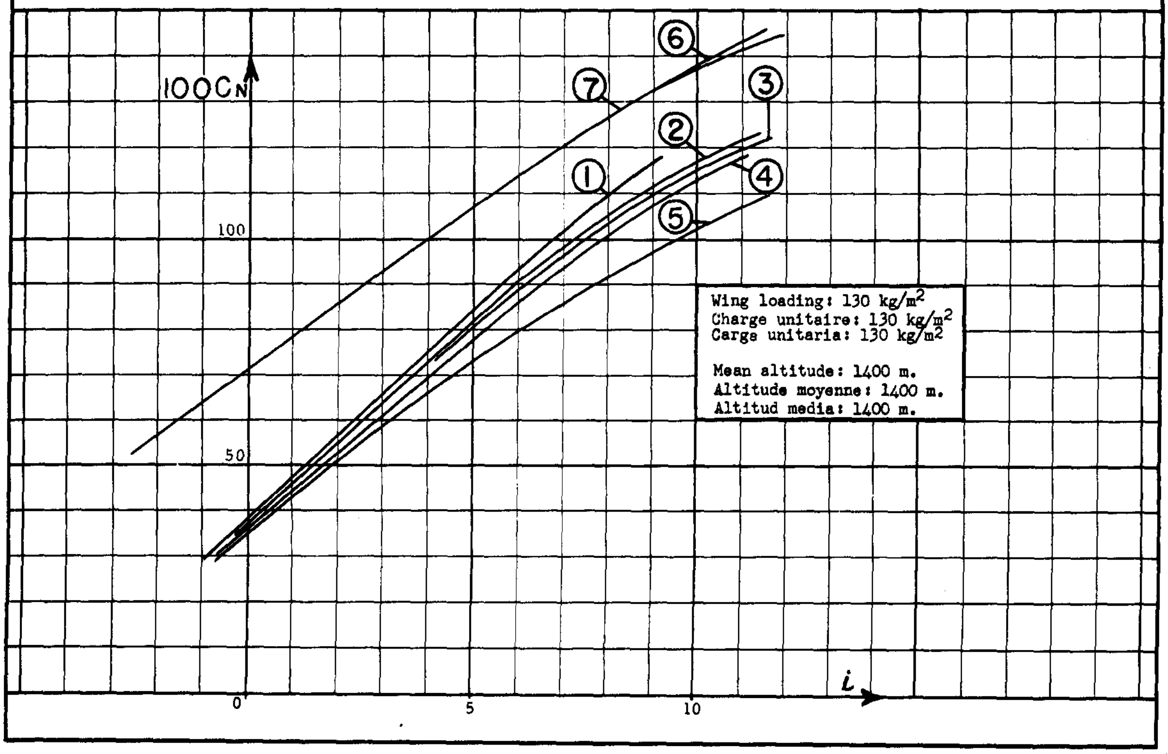
(4) Port engine inoperative - Landing gear retracted - Right engine: cowl flaps closed - Flaps 0° - Ailerons 0° - (Nominal)
(4) Moteur gauche stoppé - Train rentré - Moteur droit: volets de capots fermés - Volets 0° - Ailerons 0° - (Nominal)
(4) Motor izquierdo parado - Tren replegado - Motor derecho: aletas capo cerradas - Flaps 0° - Alerones 0° - (Nominal)

(5) Port engine inoperative - Landing gear retracted - Right engine: cowl flaps open - Flaps 0° - Ailerons 0° - (Nominal)
(5) Moteur gauche stoppé - Train rentré - Moteur droit: volets de capots ouverts - Volets 0° - Ailerons 0° - (Nominal)
(5) Motor izquierdo parado - Tren replegado - Motor derecho: aletas capo abiertas - Flaps 0° - Alerones 0° - (Nominal)

(6) Both engines inoperative. Propellers feathered - Landing gear retracted - Flaps 0° - Ailerons 0° - cowl flaps and radiator shutters closed.
(6) 2 moteurs stoppés. Hélices en drapeau - Train rentré - Volets 0° - Ailerons 0° - Volets de capots et de radiateurs fermés.
(6) 2 motores parados - Hélices en bandera - Tren replegado - Flaps 0° - Alerones 0° - Aletas capo y de radiador cerradas.

Fig. 7B.- Some polars of an 18-ton twin-engine aeroplane
Quelques polaires d'un bimoteur de dix-huit tonnes
Algunas polares de un bimotor de dieciocho toneladas

Z - 6T four-engine Seaplane - Curves $C_N = f(i)$
Avion Z - Quadrimoteur de 6T. - Courbes $C_N = f(i)$
Avión Z - Cuatrimotor de 6 toneladas - Curvas $C_N = f(i)$



(1) Cruising configuration - engines nominal rating.
(1) Configuration croisière - moteurs régime nominal.
(1) Configuración crucero - motores régimen nómina.

(2) Cruising configuration - engines max. cruising power 85 Pz.
(2) Configuration croisière - moteurs régime croisière max. 85 Pz.
(2) Configuración crucero - motores régimen crucero máx. 85 Pz.

(3) Cruising configuration - engines cruising power 81 Pz.
(3) Configuration croisière - moteurs régime croisière 81 Pz.
(3) Configuración crucero - motores régimen crucero 81 Pz.

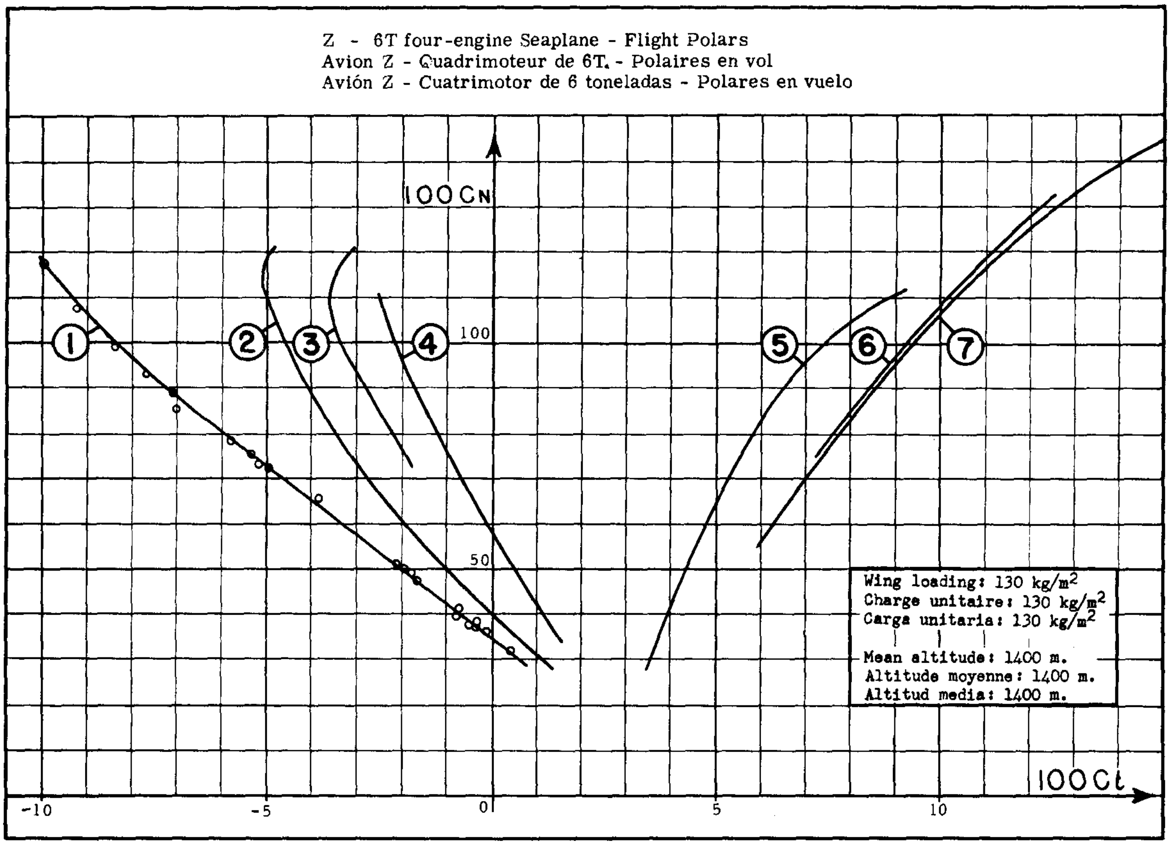
(4) Cruising configuration - engines min. cruising power 75 Pz.
(4) Configuration croisière - moteurs régime croisière min. 75 Pz.
(4) Configuración crucero - motores al régimen crucero min. 75 Pz.

(5) Cruising conf. - 4 engines inoperative - Propellers feathered.
(5) Conf. croisière - 4 moteurs stoppés - Hélices en drapeau.
(5) Conf. crucero - 4 motores parados - Hélices en bandera.

(6) Approach conf. - 4 engines inoperative - Propellers feathered.
(6) Conf. approche - 4 moteurs stoppés - Hélices en drapeau.
(6) Conf. aproximación - 4 motores parados - Hélices en bandera.

(7) Take-off conf. - 4 engines inoperative - Propellers feathered.
(7) Conf. décollage - 4 moteurs stoppés - Hélices en drapeau.
(7) Conf. despegue - 4 motores parados - Hélices en bandera.

Fig. 8A.- Some polars of a six-ton four-engine seaplane
Quelques polaires d'un hydravion quadrimoteur de six tonnes
Algunas polares de un hidroavión cuatrimotor de seis toneladas



(1) Cruising config. - engines nominal rating
(1) Config. croisière - moteurs régime nominal
(1) Config. crucero - motores régimen nominal

(2) Cruising config. - engines max. cruising power 85 Pz.
(2) Config. croisière - moteurs régime croisière max. 85 Pz.
(2) Config. crucero - motores régimen crucero max. 85 Pz.

(3) Cruising config. - engines cruising power 81 Pz.
(3) Config. croisière - moteurs régime croisière 81 Pz.
(3) Config. crucero - motores régimen crucero 81 Pz.

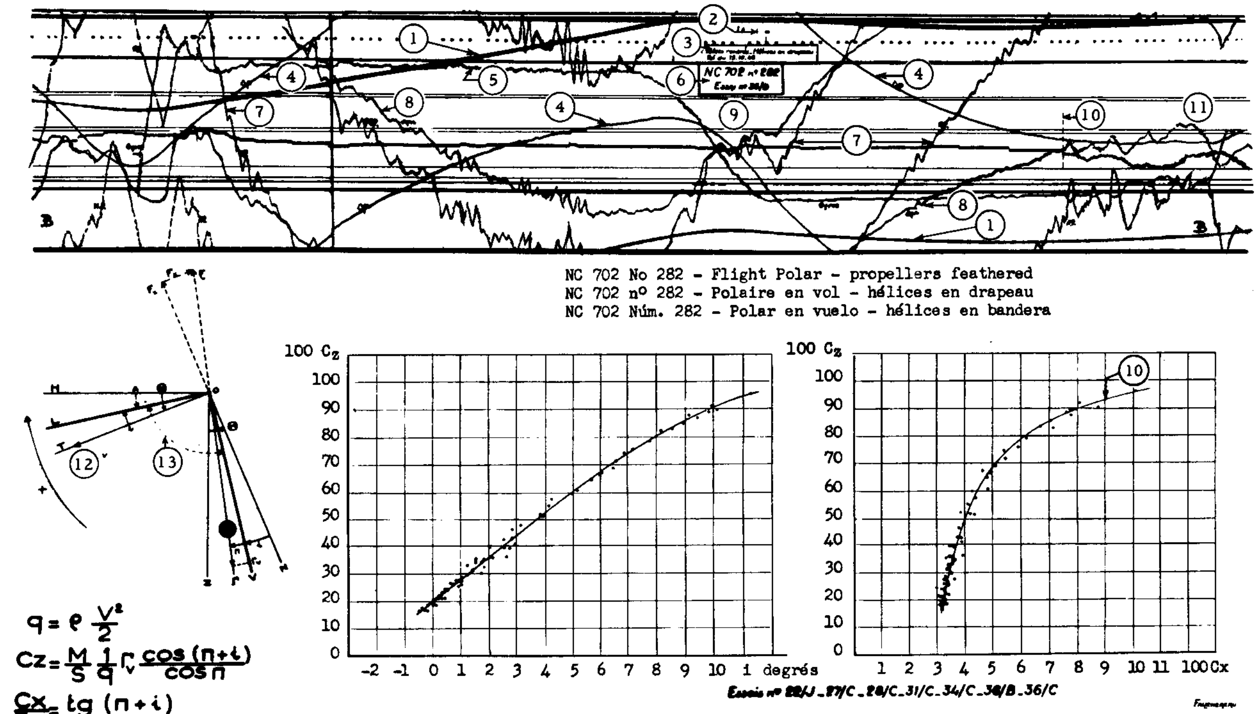
(4) Cruising config. - engines min. cruising power 75 Pz.
(4) Config. croisière - moteurs régime croisière min. 75 Pz.
(4) Config. crucero - motores régimen crucero min. 75 Pz.

(5) Cruising config. - 4 engines inoperative - Propellers feathered
(5) Config. croisière - 4 moteurs stoppés - Hélices en drapeau
(5) Config. crucero - 4 motores parados - Hélices en bandera

(6) Approach config. - 4 engines inoperative - Propellers feathered.
(6) Config. approche - 4 moteurs stoppés - Hélices en drapeau.
(6) Config. aproximacion - 4 motores parados - Hélices en bandera.

(7) Take-off config. - 4 engines inoperative - Propellers feathered.
(7) Config. décollage - 4 moteurs stoppés - Hélices en drapeau.
(7) Config. despegue - 4 motores parados - Hélices en bandera.

Fig. 8B.- Some polars of a six-ton four-engine seaplane
Quelques polaires d'un hydravion quadrimoteur de six tonnes
Algunas polares de un hidroavión cuatrimotor de seis toneladas



(1) Static pressure
(1) Pression statique
(1) Presión estática

(2) Time
(2) Temps
(2) Tiempo

(3) Landing gear retracted. Propellers feathered. Flight of 19.10.48
(3) Train et volets rentrés. Hélices en drapeau. Vol du 19.10.48
(3) Tren replegado. Hélices en bandera. Vuelo del 19.10.48

(4) Dynamic pressure
(4) Pression dynamique
(4) Presión dinámica

(5) Longitudinal attitude gyroscope
(5) Gyroscope d'assiette longitudinale
(5) Giroscopo de posición longitudinal

(6) NC 702 No. 282 Test No. 36/B
(6) NC 702 n° 282 Essai n° 36/B
(6) NC 702 Núm. 282 Ensayo Núm. 36/B

(7) Pendular level
(7) Niveau pendulaire
(7) Nivel pendular

(8) Incidence
(8) Incidence
(8) Incidencia

(9) Weather slightly bumpy
(9) Temps légèrement agité
(9) Tiempo algo agitado

(10) Onset of buffeting
(10) Début du buffeting
(10) Comienza el buffeting

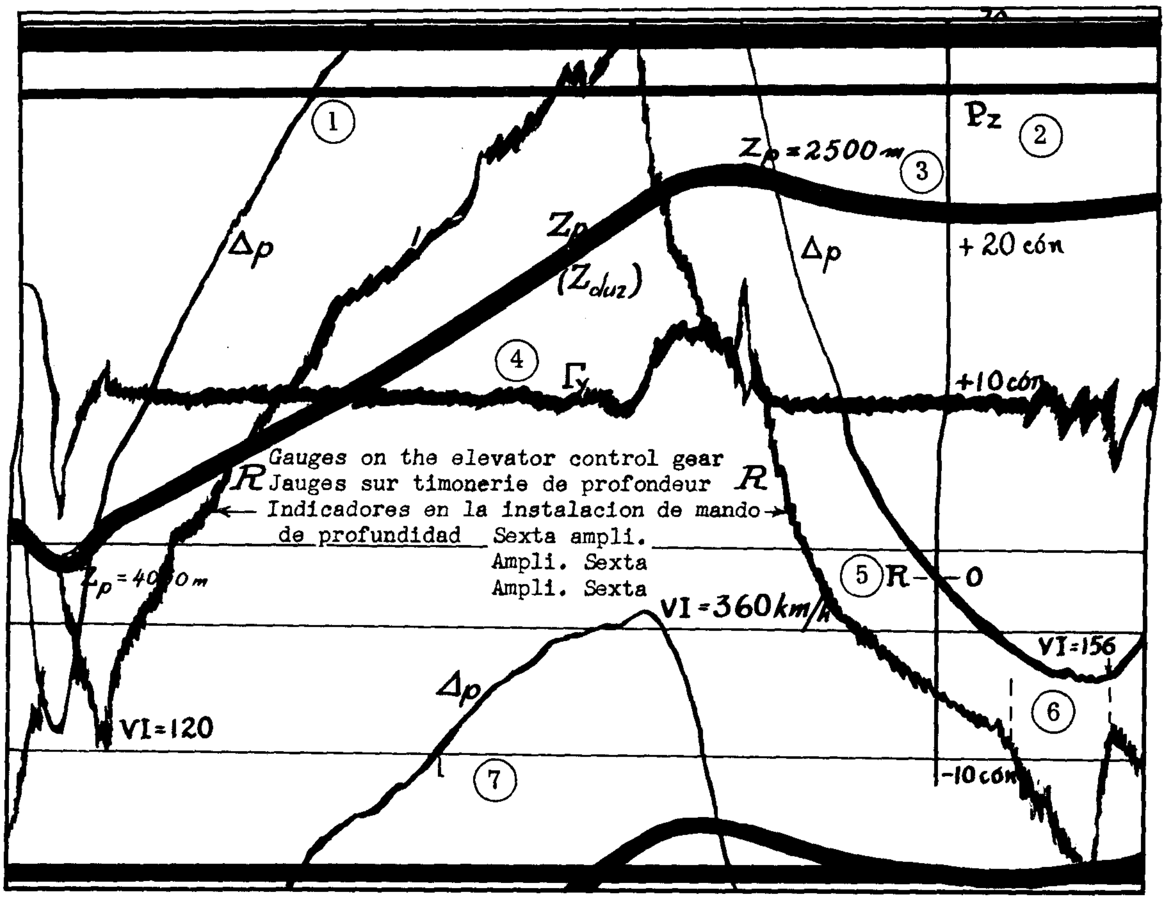
(11) Balance extreme forward - no stalling
(11) Centrage extrême avant - pas de décrochage
(11) Centrado mas avanzado - no hay perdida

(12) Speed v
(12) Vitesse v
(12) Velocidad v

(13) References of the aeroplane
(13) Références de l'avion
(13) Referencias del avión

Fig. 9. - Example of recording and scatter for a flight polar with propellers feathered
Exemple d'enregistrement et de dispersion pour une polaire en vol avec les hélices en drapeau
Ejemplo de gráfica de registrador y de dispersión para polar en vuelo con hélices en bandera

Test Nos 22/J-27/C-28/C-31/C-34/C-36/B-36/C
Essais nos 22/J-27/C-28/C-31/C-34/C-36/B-36/C
Ensayos Núms. 22/J-27/C-28/C-31/C-34/C-36/B-36/C



(1) Paths at constant attitudes acceleration and deceleration
(1) Trajectoires à assiettes constantes accélération et décélération
(1) Trajectorias con posicion constante aceleracion y retardo

(2) Pz brought to controls
(2) Pz ramené au manche
(2) Pz referido a la palanca

(3) Force at the controls
(3) Effort au manche
(3) Esfuerzo en la palanca

(4) Normal acceleration
(4) Accélération normale
(4) Aceleracion normal

(5) Scale R -- 0
(5) Echelle R -- 0
(5) Escala R -- 0

(6) Buffeting
(6) Buffeting
(6) Buffeting

(7) Static lag during dive
(7) Retard de statique en cours de piqué
(7) Retardo de estatica en el picado

Fig. 10. - Example of recording of stresses in the control gear of a MARTINET
Exemple d'enregistrement d'une contrainte dans la timonerie d'un MARTINET
Ejemplo de gráfica de registrador de esfuerzos en la instalación de mandos de un MARTINET

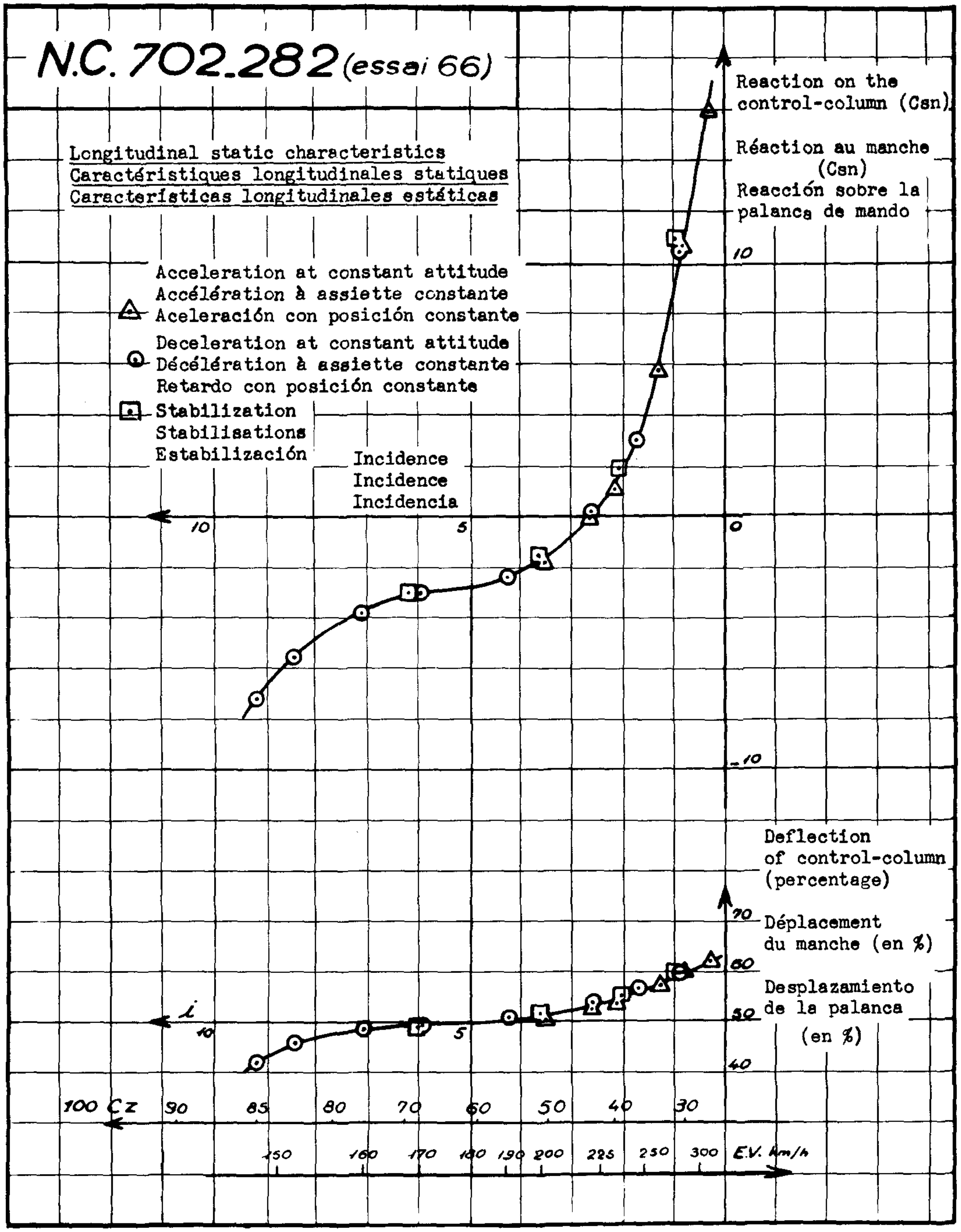


Fig. 11.- Example of checking the validity of measurements at unstabilized rates
Exemple de vérification de la validité des mesures en régimes non stabilisés
Ejemplo de verificación de la validez de las medidas en regímenes no estabilizados

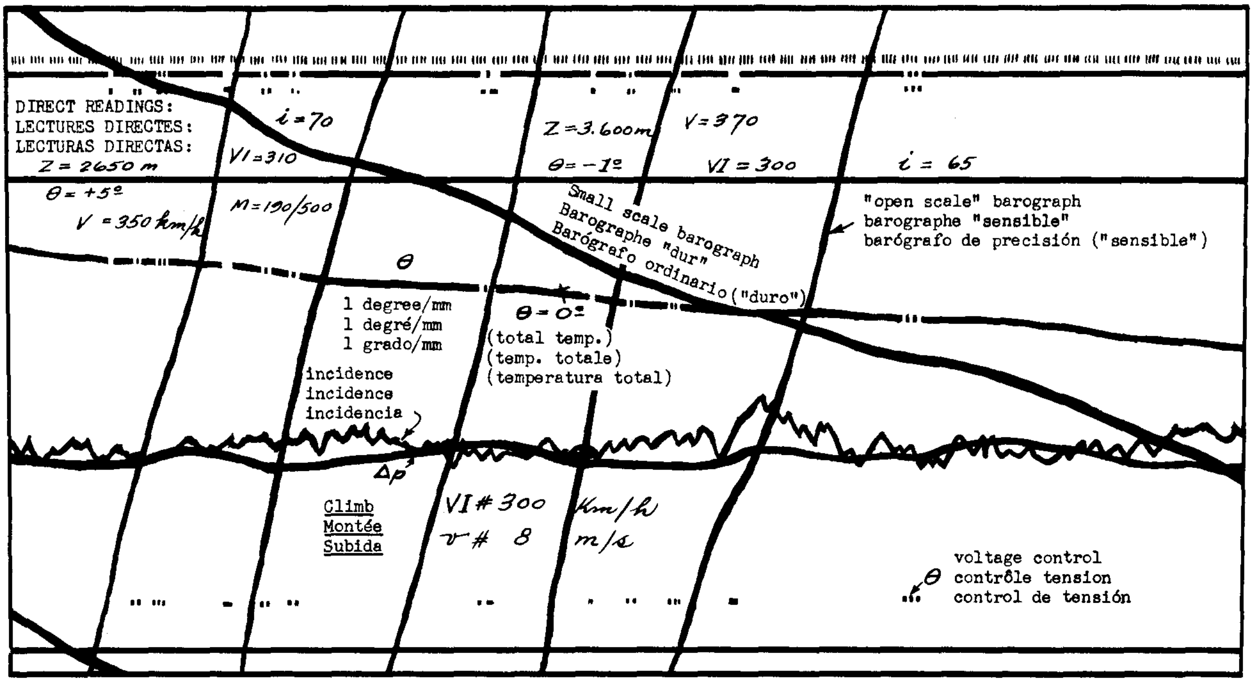
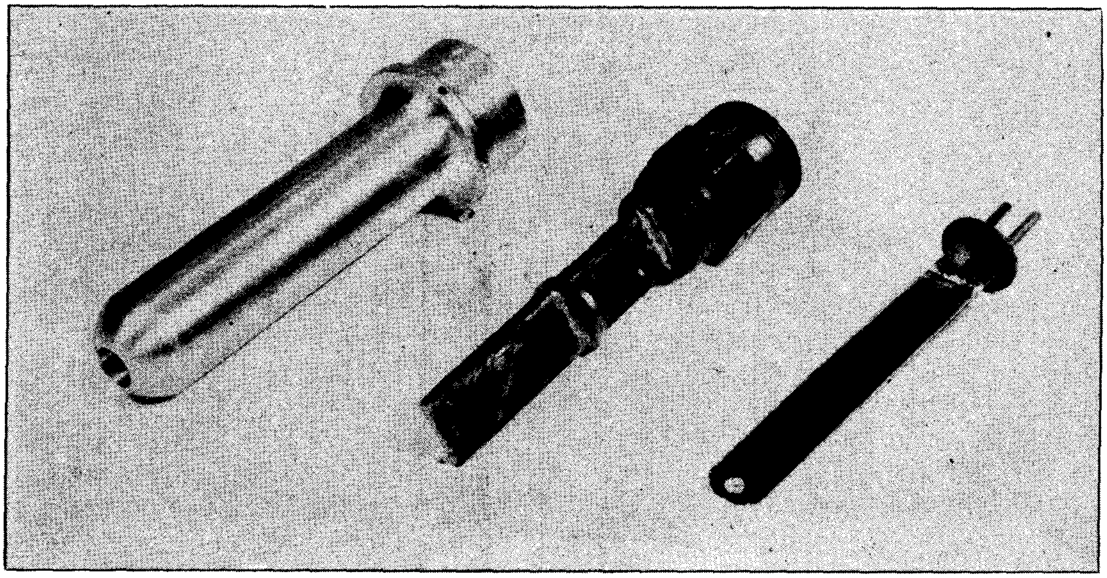
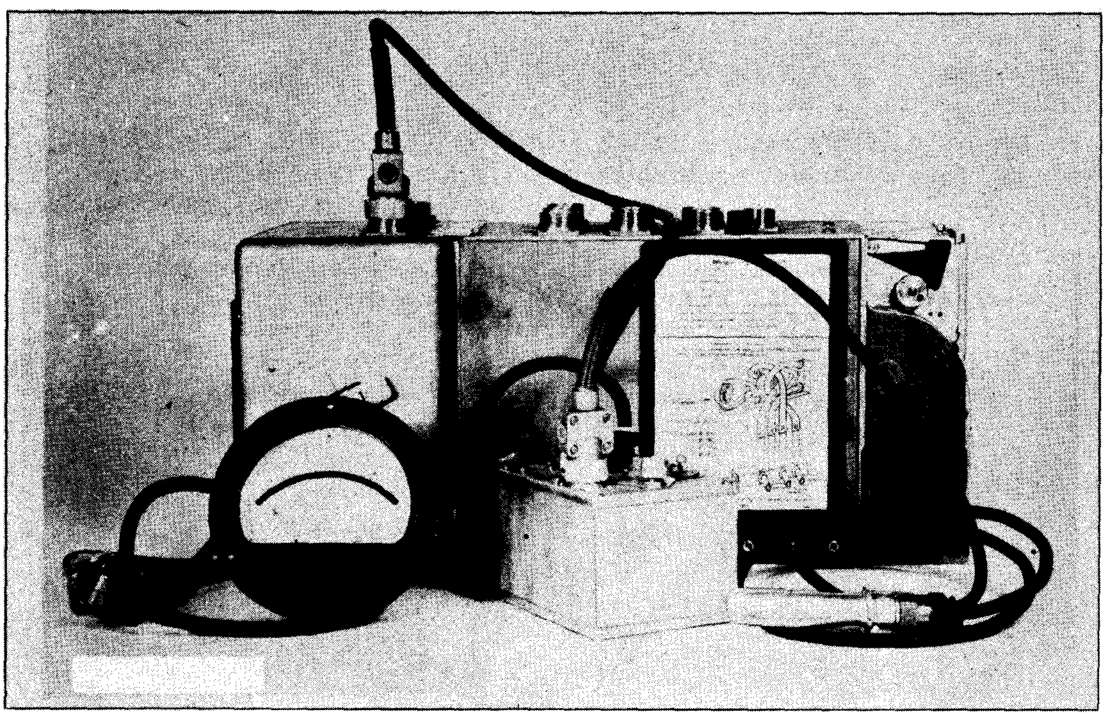


Fig. 12. - Example of recording of pressure-altitude and total temperature
Exemple d'enregistrement de l'altitude-pression et de la température totale
Ejemplo de gráfica de registradores de la altitud-presión y de la temperatura total



C.E.V. total temperature bulb - dismantled
Fig. 13 - Sonde de température totale C.E.V. démontée
Sonda de temperatura total C.E.V., desmontada



Simultaneous recording and direct reading of temperature
Fig. 14 - Enregistrement et lecture directe simultanés de la température
Registro y lectura directa, simultáneos, de la temperatura

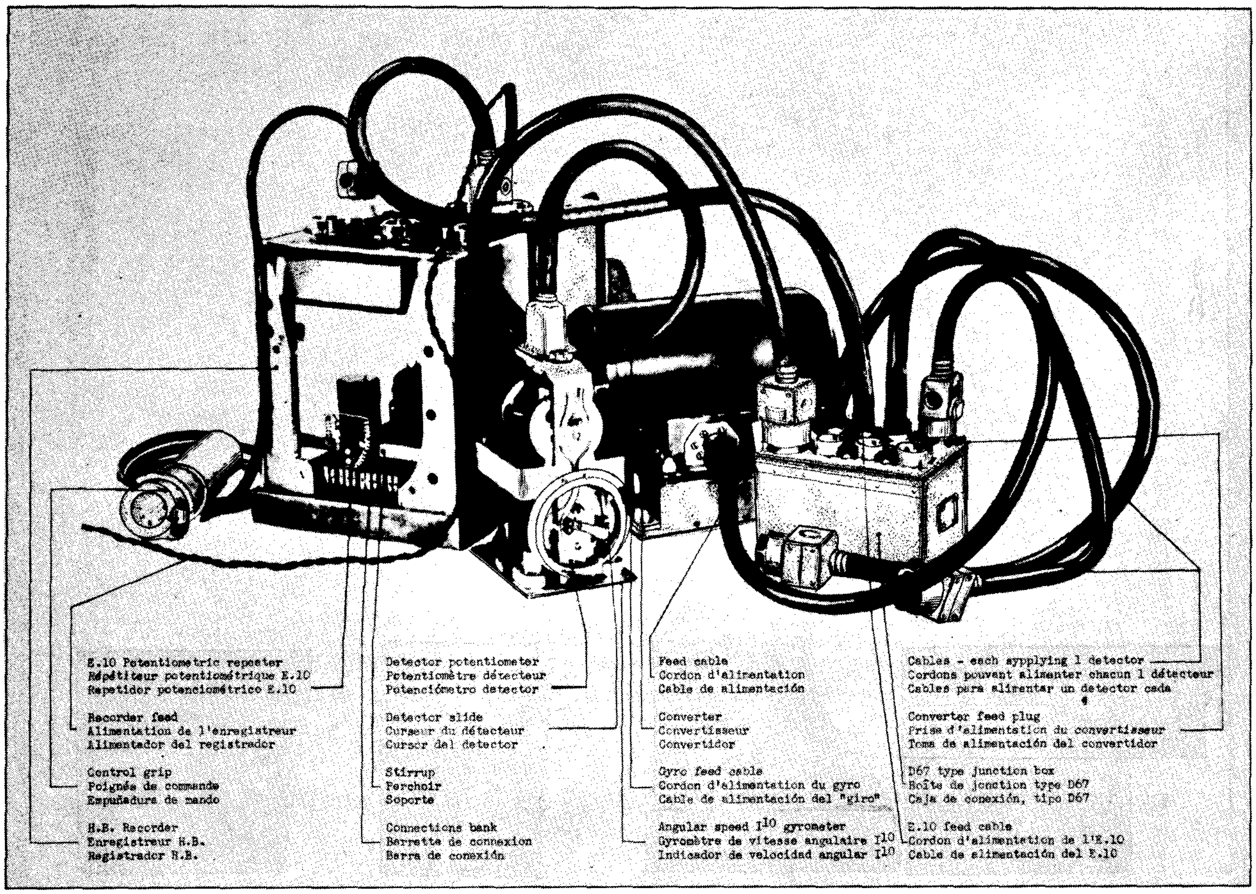
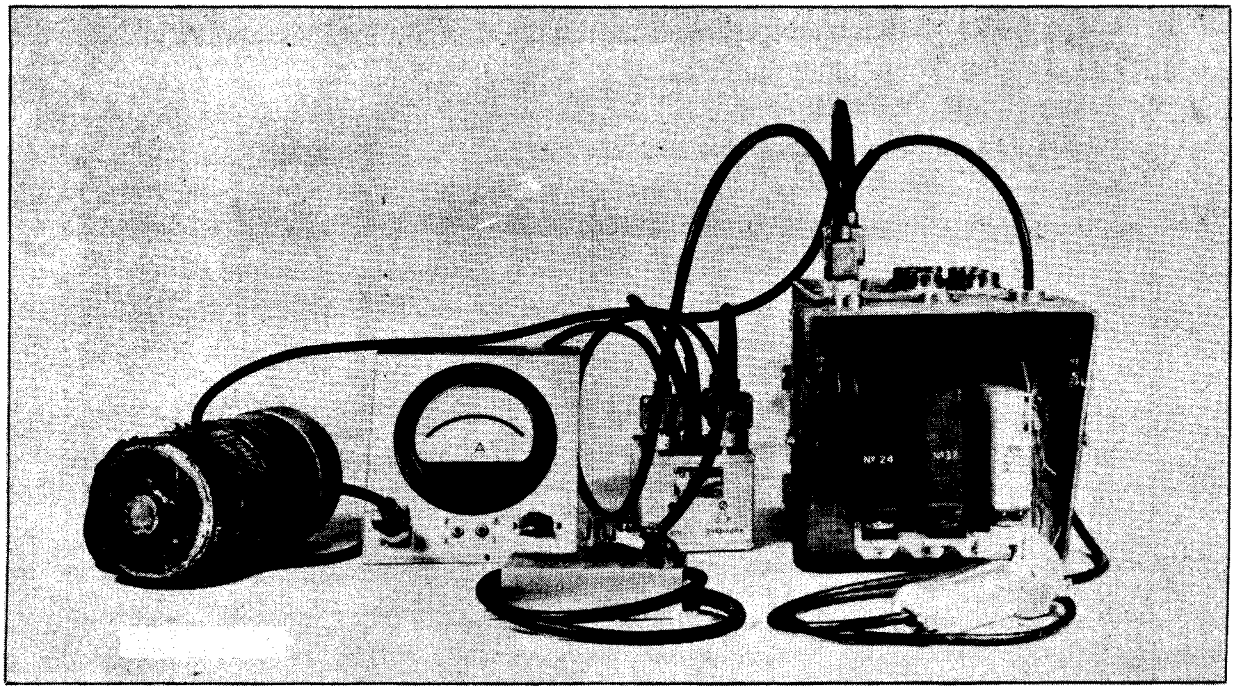


Fig. 15. - Installation for recording angular speeds. Note the type E.10 SFIM recorder receiver on its stirrup

Installation pour l'enregistrement des vitesses angulaires. Noter le récepteur inscripteur SFIM type E.10 sur son perchoir

Instalación registradora de velocidades angulares. Obsérvese el receptor inscriptor SFIM tipo E.10 en su soporte



BEAUDOUIN Goniograph equipped for recording and reading torque on a RENAULT 12.S.00 engine - Note the three E.22 oscillographs in the HB rear frame.

Fig. 16 - Goniographe BEAUDOUIN équipé pour l'enregistrement et la lecture du couple sur moteur RENAULT 12.S.00 - Noter les trois oscillographes E.22 dans le cadre arrière HB.

Goniógrafo BEAUDOUIN, equipado para lectura y registro del par sobre motor RENAULT 12.S.00 - Obsérvense los tres oscilógrafor E.22 en el cuadro posterior HB.

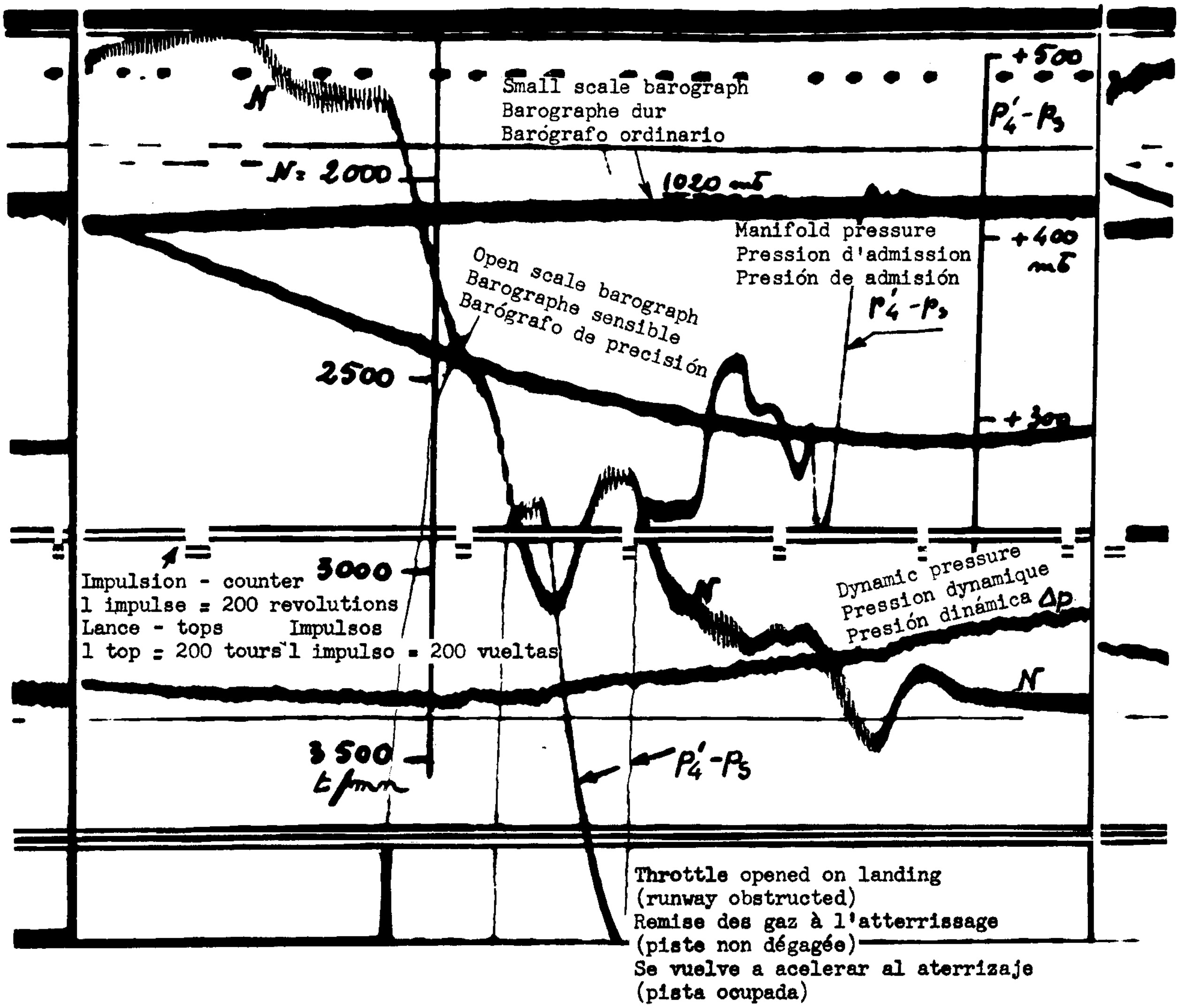
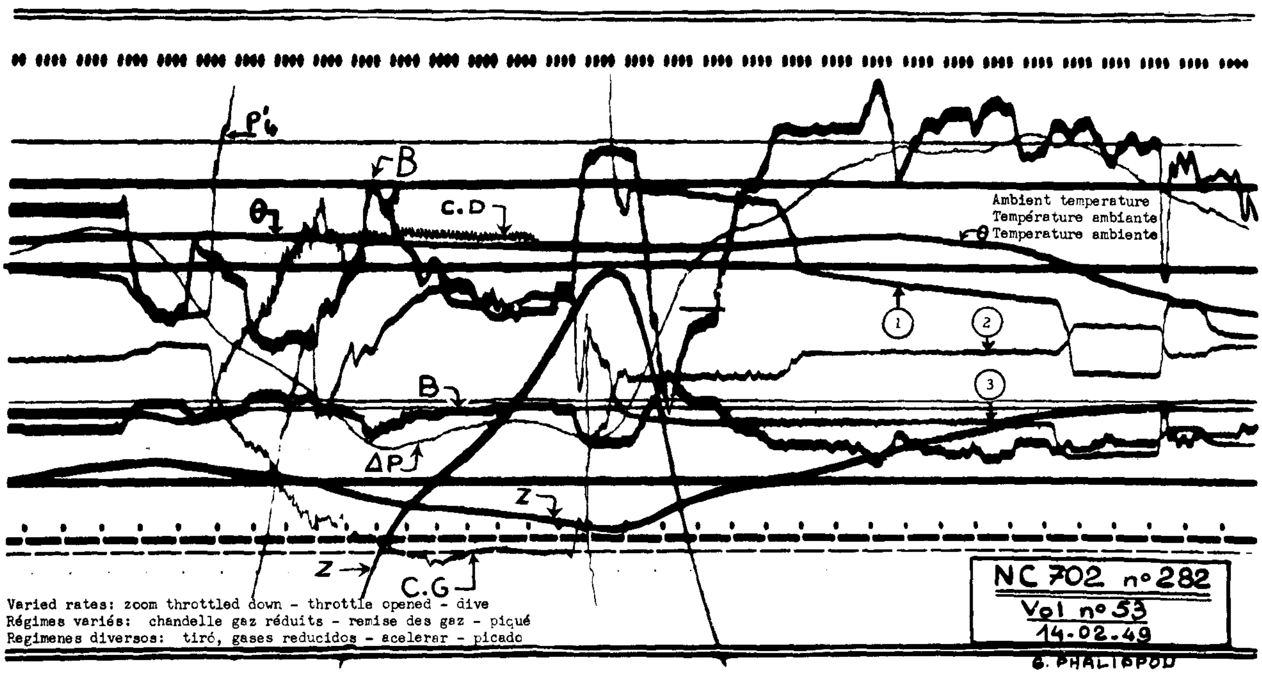


Fig. 17.- Recording of a rotational speed
Enregistrement d'une vitesse de rotation
Gráfica de un registrador de la velocidad de rotación



(1) Pa port engine
(1) Pa moteur gauche
(1) Pa, motor izquierdo

(2) Port engine torque
(2) Couple M. gauche
(2) Por del motor izquierdo

(3) Starboard engine torque
(3) Couple M. droit
(3) Par del motor derecho

Fig. 18. - Recording of engine torque on Renault 12.S.00
Enregistrement du couple-moteur sur Renault 12.S.00
Gráfica de un registrador del par motor en un Renault 12.S.00

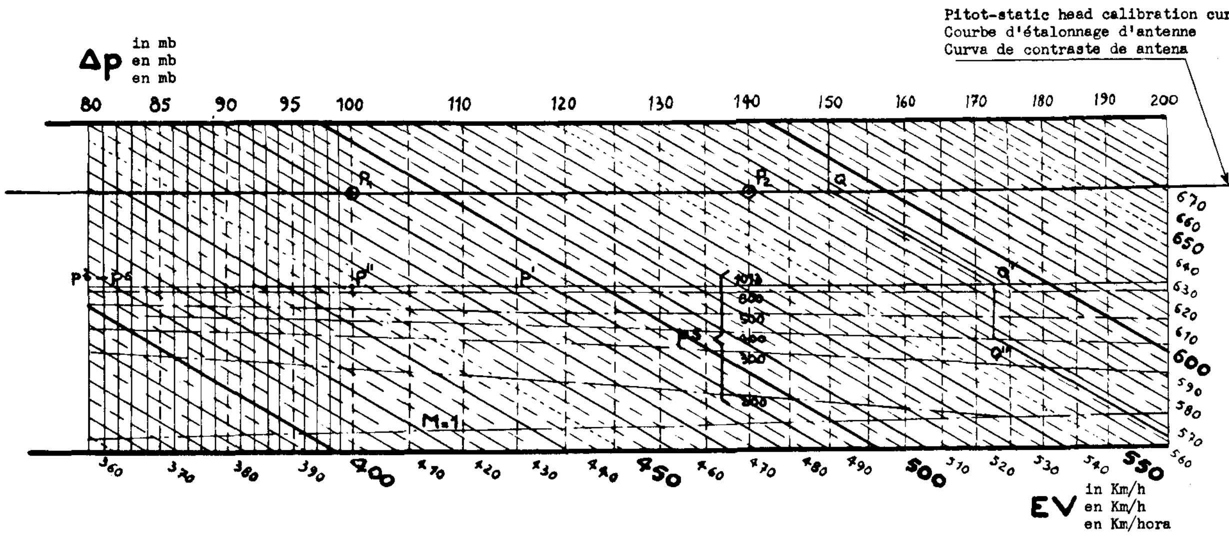


Fig. 19.- Airspeed pitot-static head calibration
Etalonnage d'antenne anémométrique
Contraste de antena anemométrica

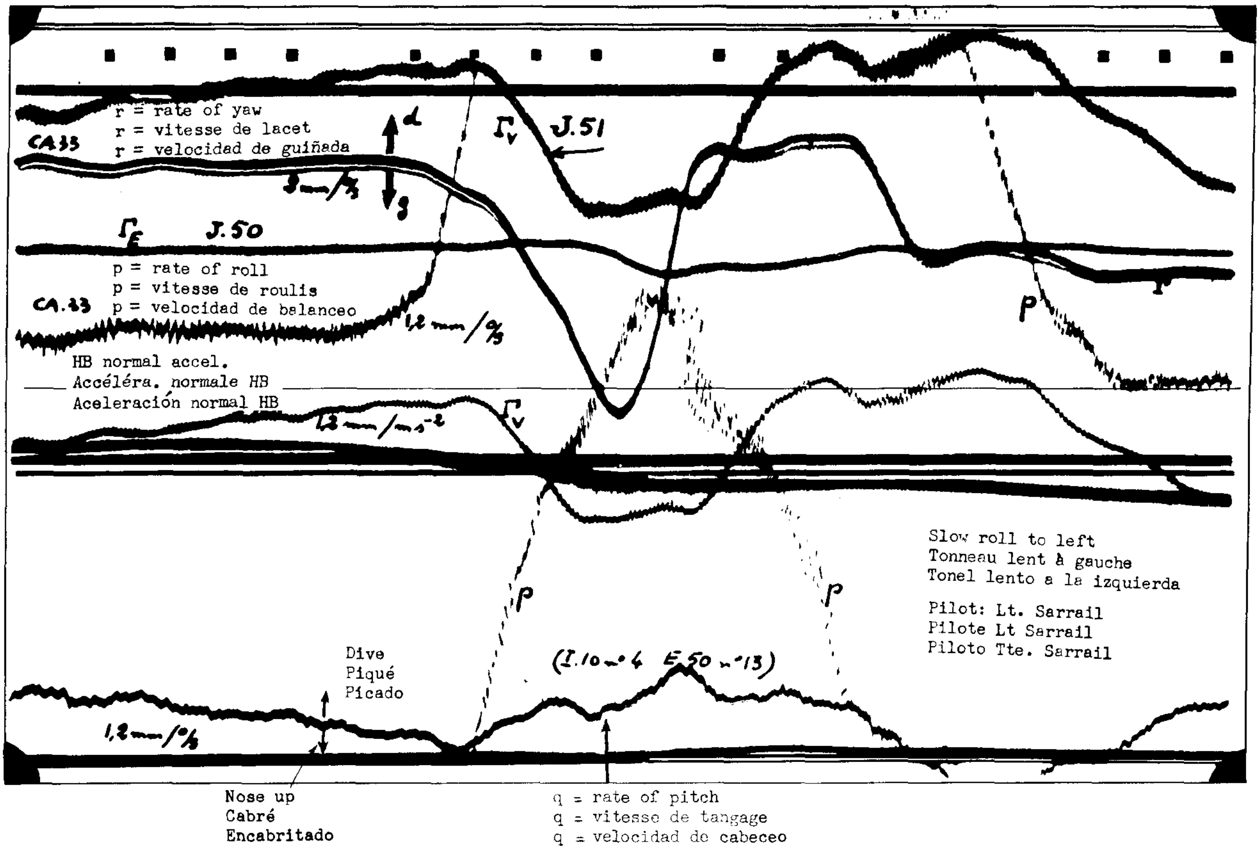
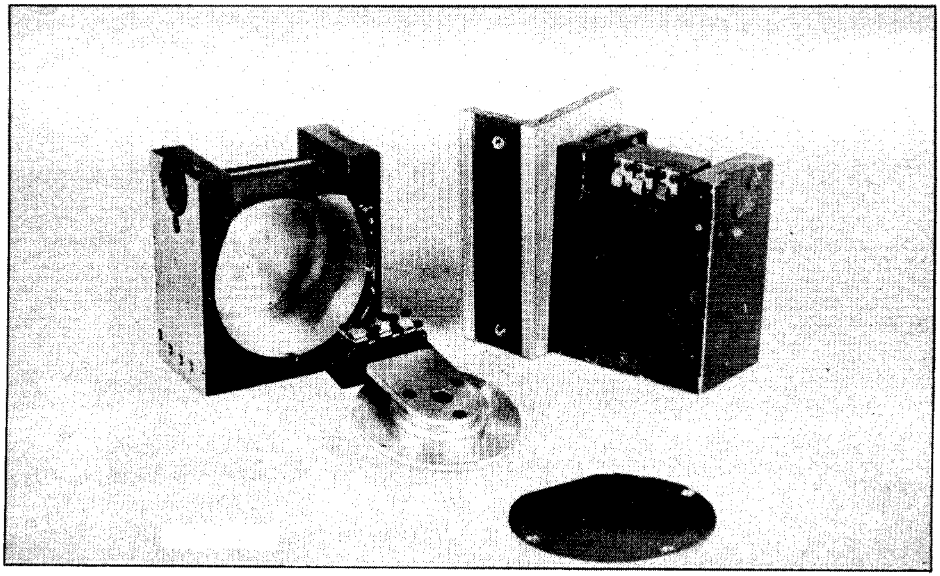
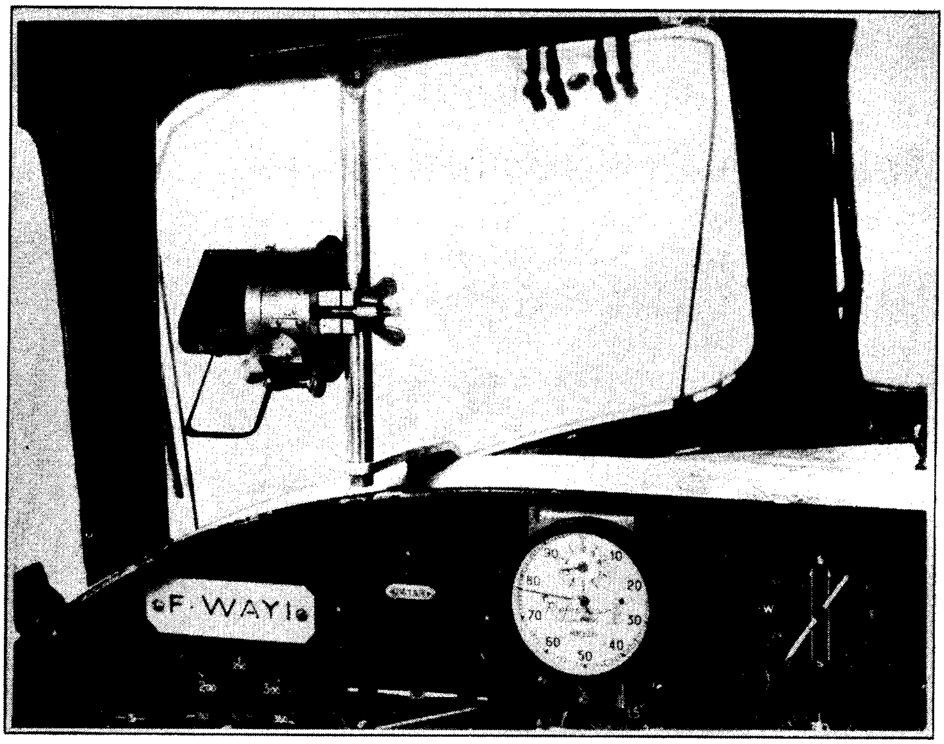


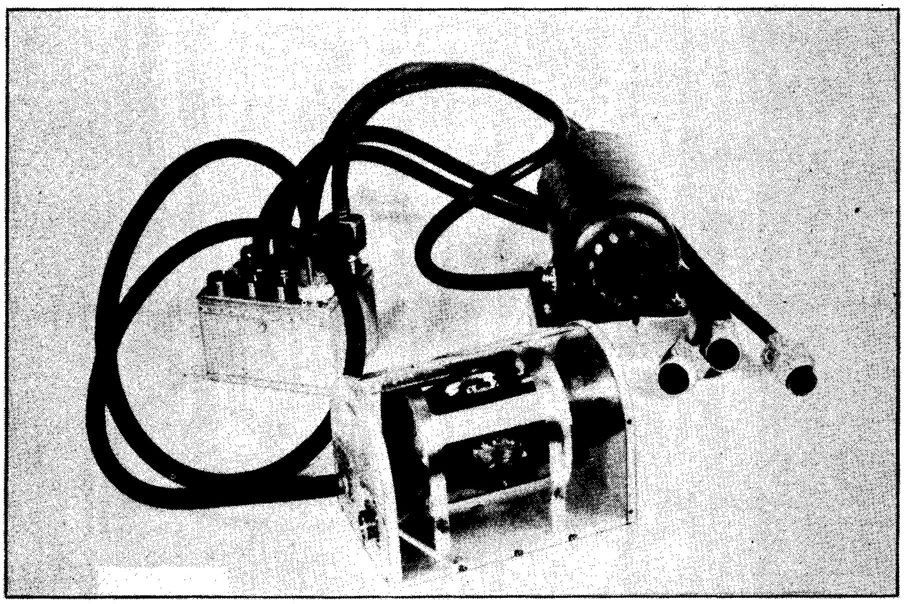
Fig. 20.- Mechanical-optical accelerograph recording
Enregistrements d'accélérographes mécano-optiques
Gráfica de acelerógrafos mecano-ópticos



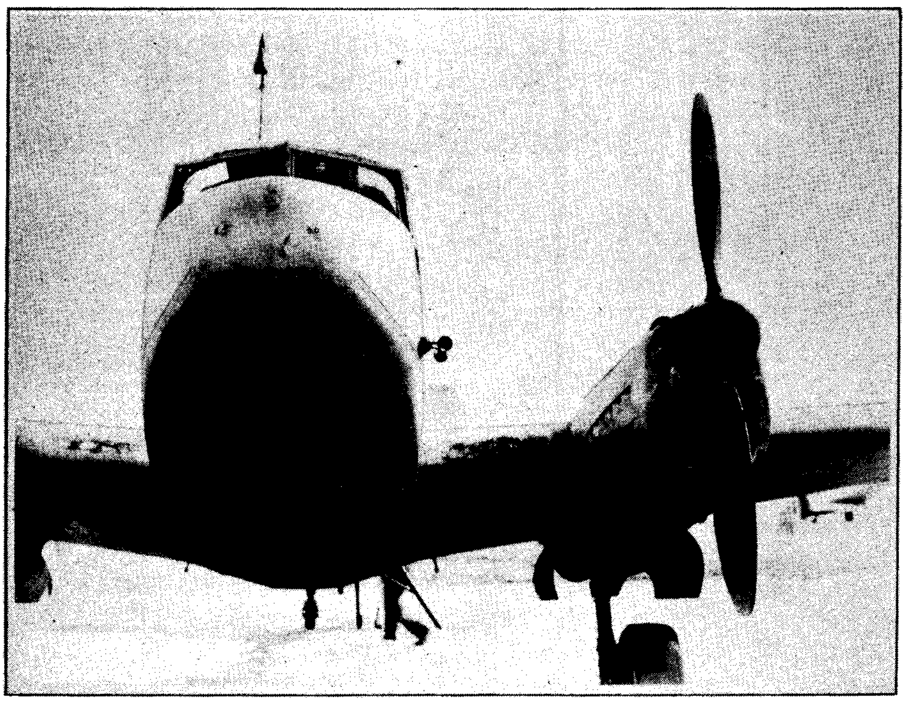
The H.B. pendular level gauge
<u>Fig. 21</u> - Le niveau pendulaire H.B.
Nivel pendular H.B.



The C.E.V. S.F.O.M. Gonio-sight
<u>Fig. 22</u> - Le collimateur S.F.O.M.-C.E.V.
Colimador S.F.O.M.-C.E.V.



Attitude Gyroscope
Fig. 23 - Gyroscope d'assiette
Gyróscopo de posición



Incidence vents on the nose of a fuselage
Fig. 24 - Prises d'incidence sur le nez du fuselage
Tomas de incidencia en la proa del fuselaje

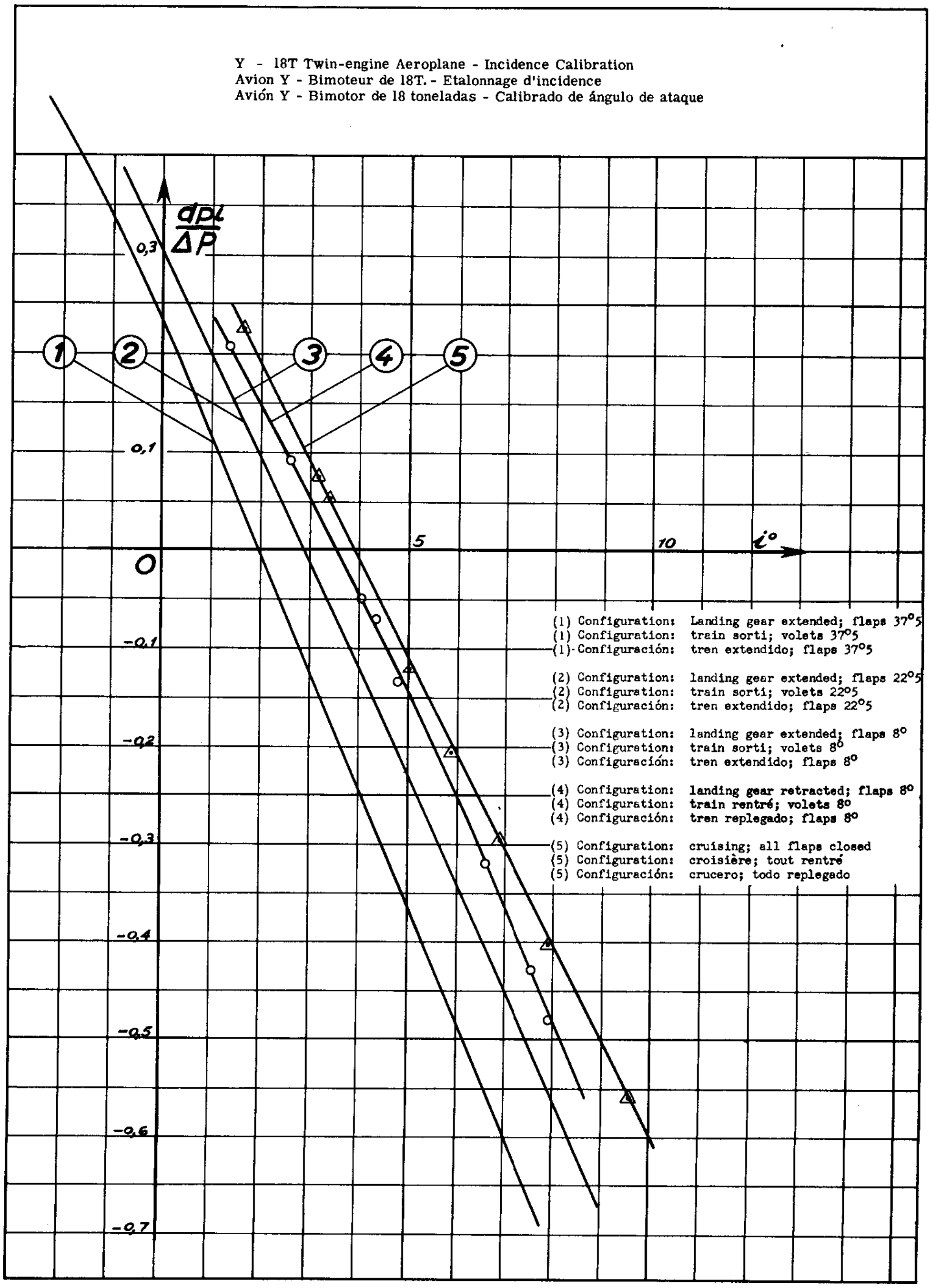
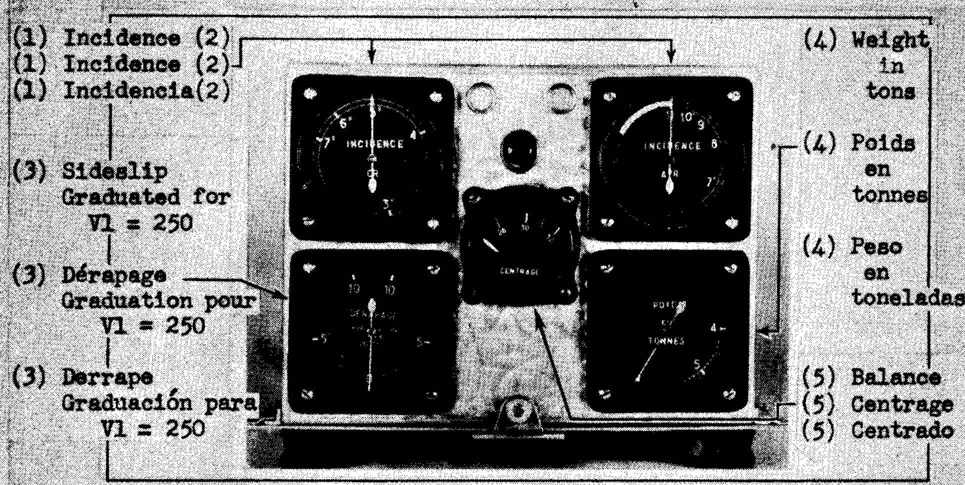
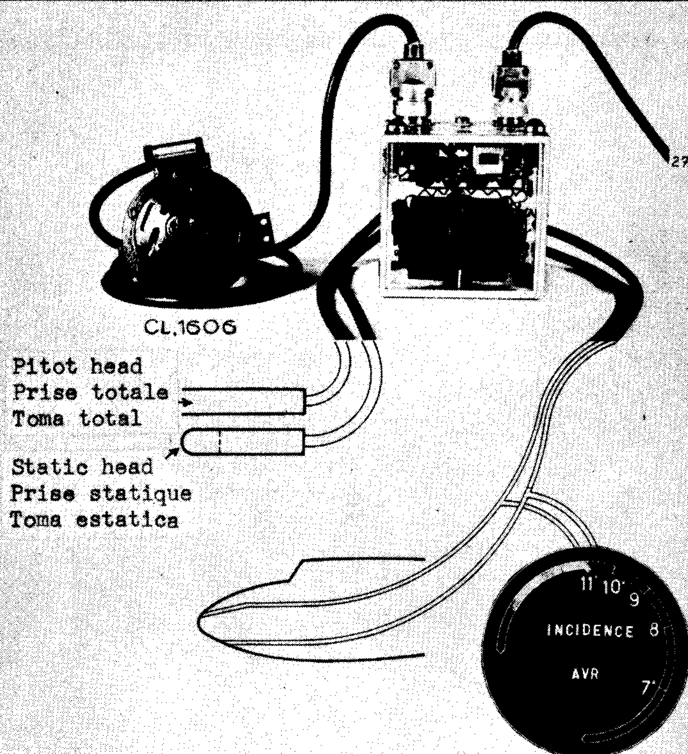


Fig. 25.- Example of incidence calibration
Exemple d'étalonnages d'incidence
Ejemplo de contraste de la incidencia



C.E.V. Panel
Fig. 26 - Tableau C.E.V.
Tablero C.E.V.



Stall Warner
Fig. 27 - Avertisseur de décrochage
Indicador de pérdida

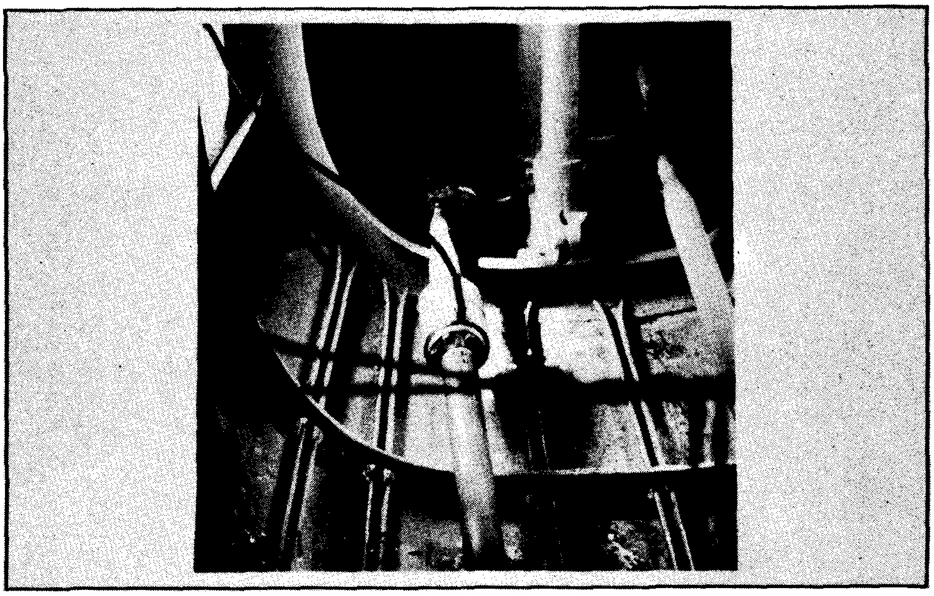


Fig. 28. - Control-gear dynamometer
Dynamomètre de timonerie
Dinamómetro de instalación de mandos

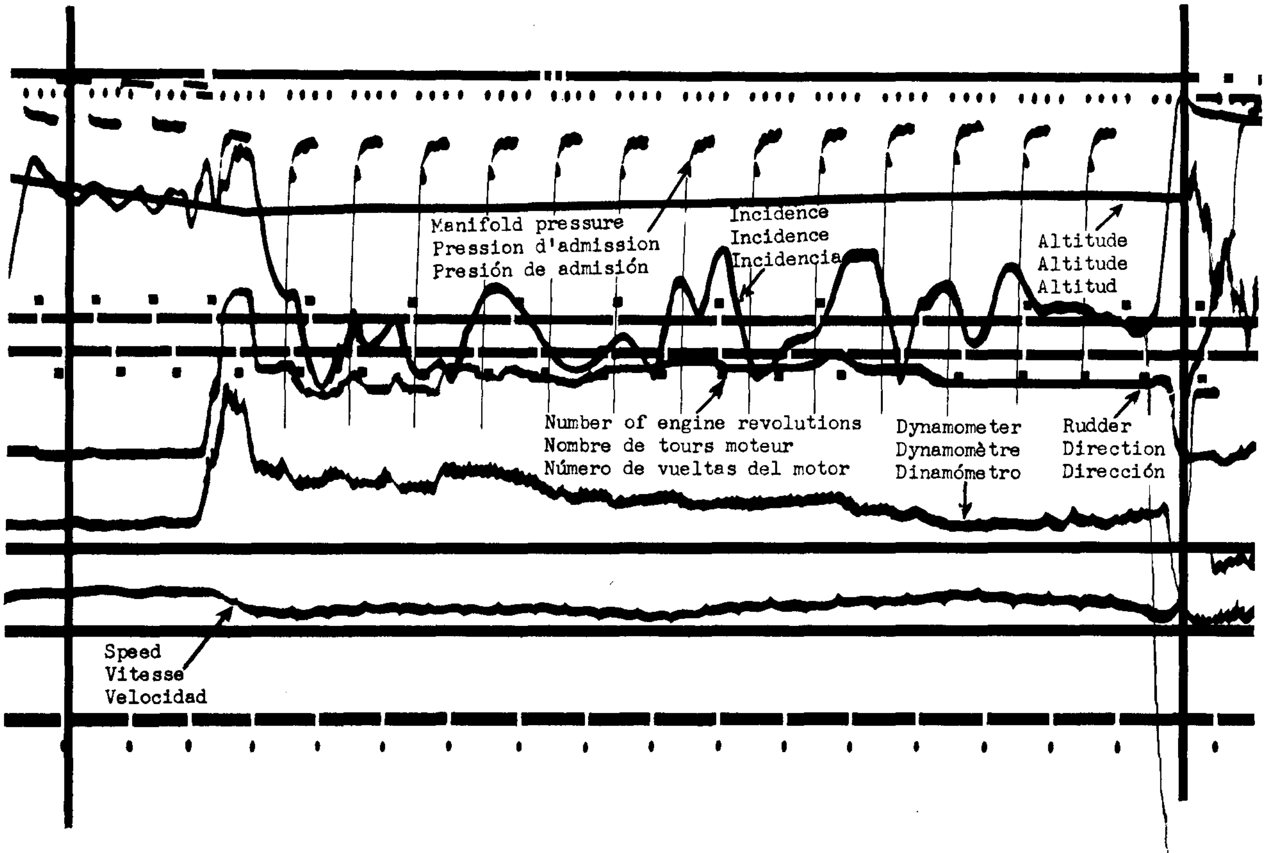
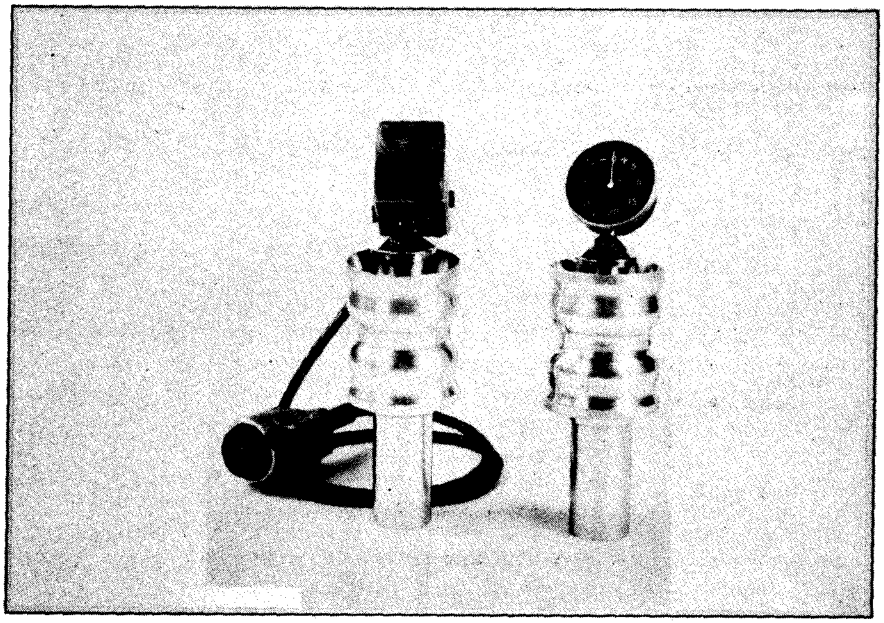
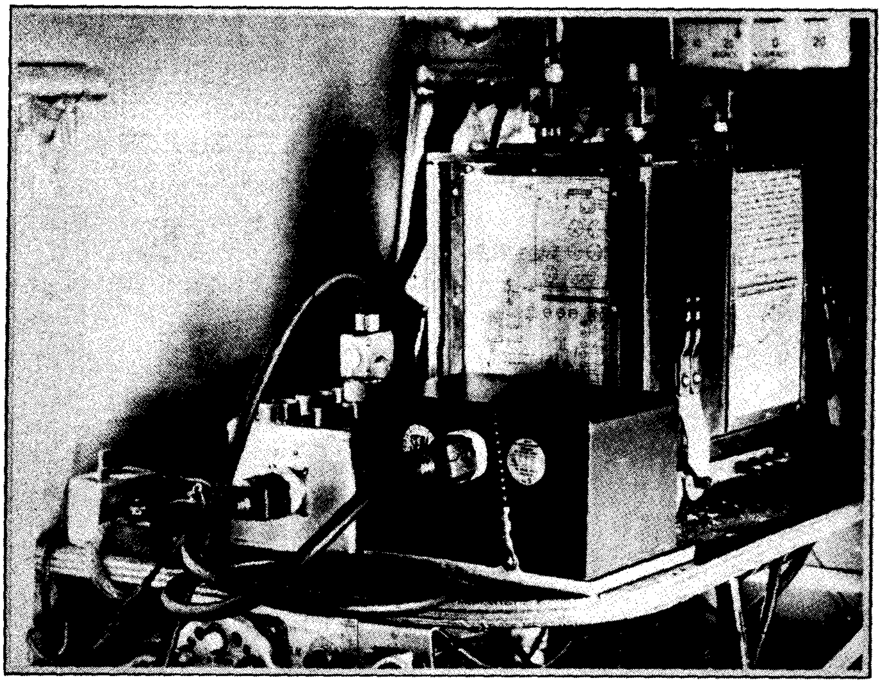


Fig. 29.- Recording with rudder control gear dynamometer
Enregistrement avec dynamomètre de timonerie de direction
Gráfica obtenida con dinamómetro de instalación de mando de dirección



C.E.V. Control-column dynamometers
Fig. 30 - Poignées dynamométriques C.E.V.
Empunaduras dinamométricas C.E.V.



A.11 and A.20 Recorders
Fig. 31 - Enregistreurs A.11 et A.20
Registradores A.11 y A.20