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An Investigation into the Duty Cycle of Powered Flying Controls

Parts 1 and 2

by

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AN INVESTIGATION INTO THE DUTY CYCLE OF POWERED FLYING CONTROLS
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SUMMARY

An account is given of the development of instrumentation for a long term statistical study of the duty cycle of powered flying controls together with some data gathered so far from a cross-section of Service aircraft.

The primary purpose of this investigation was to rationalise the testing of powered flying control actuators. An examination of the results to date indicates that the actual usage of control actuators is less arduous in terms of total stroking distance and number of reversals, than the arbitrary Test Duty Cycle currently applied in prototype and flight clearance testing, as laid down by the Design Requirements of the Av.P.970.

The second purpose of the programme was to determine the horse power demand spectrum of existing powered flying controls, as characterised by the rate of control movement. The information yielded by this part of the investigation may well serve as a guide-line in stating the size and power requirement of future control designs. The present papers contain, apart from the detailed description of the recording equipment, summary data obtained from the ten aircraft types involved in the investigation, which passed the planned target of 1000 operational flying hours. The results confirm the suspected complexity of the case. A further analysis of the recorded data is indicated, before new rationalised design and test requirements are formulated.

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* Replaces RAE Technical Reports 69096 and 73065 - ARC 32257 and 34772.

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PART 1

1 INTRODUCTION

Av.P.970 Design Requirements, Chapter 207, section 11.1.2 and 3, postulate tests of endurance to be carried out on new powered flying controls actuators and installations. The designer is further referred to Leaflets 207/2 and 3 for guidance on the preparation of Test Declaration and Test Schedule. The aim of the complete test is to establish reliability of the actuator and the system, normally for 1000 flying hours, with periods between inspections of not less than 100 hours. It is naturally desirable although not always possible, to accelerate the test, in order to reduce the testing time. An acceleration factor of 5 has frequently been applied, so that 1000 flying hours were telescoped into 200 test hours. Section 3.2.4 admits, however, that "the length of the endurance test to establish this 1000 hours life cannot be laid down according to any fixed rule .... since it must depend on the relationship of the duty cycle to flying time, on the type of aeroplane for which the unit is intended and on the type of unit itself."

A further shortcoming of the Requirement is the fact, that the composition of the "duty cycle" in a new design is difficult to forecast, and so, in absence of any statistically founded guide-line, the design of the test is almost entirely arbitrary and at the discretion of the airframe and equipment designers.

Two extreme approaches are possible in the present circumstances: Either the test duty cycle may be adjusted so as to meet the 1000 hours endurance target, or it may be made severe enough to reveal the potentially weak points of the design. For obvious reasons the usual tendency has been towards the latter, resulting in a significant and costly reduction in the permitted life of the actuators, or else, in a lengthy and equally costly further development of the system to meet an endurance requirement based on a probably over-severe duty cycle.

One can, on the other hand, conceive of cases where the original role of an aircraft has been varied, and the original clearance based on the original duty cycle, may fail to afford cover for the new role.

Up to the present and as far as one can ascertain no systematic reasonably large scale investigation into the flying controls demands has been made. Apart from a number of 'single flight' recordings, hardly any information exists, on which to base the design of the duty cycle. Even a study conducted by the A.A.E.E.[1] was not sufficiently wide in scope to be generally applicable. It was with the objective of filling this gap that the investigation now in progress, and here reported on, was initiated.

The primary purpose of the programme of long term flight recording was to accumulate a significant volume of control demands data in a cross-section of aircraft types. These data would then be analysed in toto, providing a basis for classification of aircraft according to their control duty cycle, enabling the life testing of powered flying controls actuators to be rationalised.

In addition, the study was intended to furnish statistics of control power demand. Means of sensing and recording power was therefore required. Power being the product of force and rate, the plan was to sense force and rate by separate pick-offs performing simultaneous cross-multiplication to obtain the power history. The sensing of rate was comparatively easy to engineer, but as for the force sensing, all efforts to design an adequately sensitive, long-term-drift-free, universally applicable sensor have failed. In order to avoid delay in starting the programme the horse-power research was abandoned and it was accepted that recording the rate of control application would be a reasonable compromise. After all, it is largely the control rate which determines the size of metering valves, pipes, accumulators etc., and is thus an important factor in sizing the power system as a whole.

It has been long suspected that control designs often cater for unnecessarily high rates, resulting in serious growth factors (increase in structural weight occasioned by the equipment weight increase). It is, therefore, essential to keep the built-in horse power to a rational minimum, particularly as in high performance (high Mach number) aircraft the magnitude of idling losses (by-passing flow in an off-loaded pump, sump losses in variable delivery pumps, null leakage in spool valves etc.) increases absolutely with the size of the system. The consequence of such over-sizing is, further, poor utilisation of built-in power, overall inefficiency and generation of heat, all of which tends to make the equipment cooling problem more acute.

2 PROGRAMME OUTLINE

2.1 Size of sample

The statistically ideal sample should be large in number of specimens tested, that is to say as large a number as possible of aircraft of each type should be instrumented. In this way the effect of such variables as the operational role, climatic conditions, pilots' technique and temperament etc. would be encompassed. However, availability of aircraft, limitation on the numbers of recording equipment and general economic and practical Service considerations permitted only one aircraft of each type (with the exception of the Lightning) to be instrumented. Fortunately, at least in some of the types, in the course of their operational life the mode of utilisation is varied: land-based to carrier-based, bomber to tanker, troop-carrying to supply-dropping, operational to conversion training, moderate climate to artic or tropical, etc. and, consequently, the effect of such variations upon the nature of the duty cycle can be isolated.

2.2 Duration of test

The consideration of duration of recording and that of 2.1 are in the statistical sense complementary. Since the declared purpose of the exercise is to prove 1000 hours endurance of the PFC (powered flying control) installation and since, in most cases, only one aircraft of a given type was to carry the DCR (duty cycle recorder) equipment, it seemed not unreasonable that the duration of the test should be a minimum of 1000 hours flying. A number of other considerations enter the argument. If, for instance, the effect of seasonal weather variation, such as the amount of atmospheric turbulence throughout the year, were to be determined, then obviously, the absolute minimum of the test would be one year, but preferably two years to account for possible freak weather conditions. Having, however, regard to the average rate of utilisation of operational aircraft (Service), three years of flying must be allowed for, to realise the 1000 hours target. On the other hand, considering the large number of aircraft instrumented (12, carrying 30 recorders), a certain number of fatalities and hold-ups cannot be ruled out: one operational training aircraft carrying 3 recorders was grounded for 2 years for repairs and modifications following a landing accident. Another operational aircraft with 1 recorder aboard was lost in the North Sea in 1966, entailing a 30 months wait for a replacement. In extreme cases the duration of the test may have to be cut short, unless the records to date indicate an abnormal pattern of control behaviour or, unless the aircraft in question is one representing a distinctive group, not generally overlapping with other groups, such as, for instance one aircraft with supersonic capability vis-a-vis other subsonic aircraft. Incidentally, one type, the Valiant has been taken out of Service having completed only one third of the set 1000 hours recording target.

2.3 Limitation of the investigation, choice of recording method

One important stipulation regarding the proposed recorders was, that they must be capable of entirely automatic operation in Service aircraft for reasonably long periods, not requiring servicing or re-calibration by Service personnel. They were to present data in a simple form so that they could be easily read at regular intervals, say monthly, again without embarrassment to the Service.

When the requirement of the Duty Cycle Recorder was first formulated, it was appreciated that a multi-channel magnetic analogue record of various control demand parameters would be most useful, in that all the variables under observation retain their correct relation in time and can, therefore, be subsequently extracted and cross-processed as and when required. So, for instance, a spectrum of horse-power demand could be easily obtained from time analogue of control displacement alone (at a known ASI) as follows: The displacement record is differentiated, yielding control rate. At the same time, using the known hinge moment characteristic of the control surface, displacement is directly translated into actuator thrust. The product of thrust and rate is then computed continuously or at any desired instant of time.

By contrast, a counting method, although convenient for direct determination of statistical distribution of individual variables, suffers from one serious disadvantage, in that an event, having been counted, loses its identity in time and cannot be, therefore, related to any other event similarly counted. In addition, even individual events cannot be subsequently processed (differentiated or integrated), as is the case with analogue record. In general, therefore, when recording a complex event, counting methods will require more recording channels (and sensors) than corresponding analogue ones.

There was at the time of inception of the DCR project no long running multi-channel analogue recorder, tape or wire, commercially available, and it was clear that to design and develop suitable analogue equipment specially for the purpose of this investigation would seriously delay the programme. There was, however, an instrument in existence, developed in the Structures Dept., R.A.E., the Counting Accelerometer (Fatigue Meter), the electromechanical principle of which seemed capable of adaptation for the DCR purposes. There was, in addition, in Structures Dept. a substantial quantity of Type 54/56 electromechanical 4 digit counters surplus to requirement. It was, therefore thought expedient, in the circumstances, to adopt the counting method of recording with the view to expediting the programme and obtaining as quickly as possible some, albeit limited, interim information on the controls behaviour.

2.4 Scope of investigation

There are many factors which have a bearing upon control actuator wear and which thus determine the rate of incidence of faults and failures, inspection and overhaul periods and ultimately, the life of a unit, e.g. rate of displacement, loading, number of reversals, both of direction and pressure, rubbing distance etc. It is invidious to apportion the relative importance of these factors. There is evidence to suggest that potentially the weakest point in a conventional linear hydraulic actuator is its sealing mechanism. The design of most conventional seals is such that the elastomeric rings perform their sealing task by virtue of their deformation under pressure. A certain degree of extrusion of the elastomer into the running clearance of the assembly is unavoidable, the peak of the destructive shearing action occurring on reversal of the direction of stroking. In addition, the ordinary rubbing wear on the seal/piston rod face takes place. It is suggested, therefore, that the two most powerful factors effecting the endurance and working life of a hydraulic linear servo-actuator is the number of reversals and the integral of the stroking distance. The velocity of stroking, even at its maximum is too low materially to aggravate wear although, as argued earlier on, it does play an important role in determining the size, power, and overall efficiency of the control system. Following this reasoning it was decided to restrict the present experiment to counting the frequency of incidence of a number of predetermined levels of the actuator output displacement and rate.

Observation and experience indicate that, as far as the amplitude of the control movement is concerned, cruising and ordinary manoeuvring entails a control cycle consisting of a large number of small to medium amplitude movements, while take-off and landing (e.g. cross-wind) may demand smaller numbers of medium to large control excursions. To these one must add a relatively small, but not on the whole insignificant, number of mostly large control movements executed in the course of taxying, pre-flight checks, ground maintenance inspection and testing. Accordingly, one may wish to differentiate between such two conditions of control cycling, and to this end each recorder is virtually duplicated, enabling the two régimes to be recorded separately and identified, the switching-over being related to some aircraft function separating the two régimes, e.g. landing gear. Similarly, in an aircraft type with supersonic capability it may be desirable to separate the subsonic and the supersonic régimes. In that case, the change-over signal would be derived probably from the Mach meter.

The form of the recorder now begins emerging. Ram displacement will be recorded on counters set at five discrete levels on either side of the null point, which corresponds in most cases to the zero angle position of the control surface. Arising out of the design of the counter used, there exist two discrete voltage levels on either side of the nominal counting level: on rising signal voltage the nominal setting value has to be exceeded by a small amount before the coils are energised and the counter 'cocked', while on diminishing signal the voltage must drop somewhat below the nominal before the instrument counts and resets. The setting and the maintenance of these two levels is quite critical: closing the interval results in sensitivity to signal noise and possible instability (flutter) of the counter, while opening up the gap tends to increase the counting errors. This point will be discussed in detail later on.

As was surmised earlier, there should be a tendency of the large counts being those of the small amplitude movements (small corrections, autopilot and autostabilisation), large excursions being by comparison few. Since one of the major interests will be the computation of the total stroking distance, and since the very numerous small movements will probably add up to a figure of stroking distance significantly larger than the sum of relatively few large travels, better discrimination would seem more important at the low displacement levels, and, consequently, it was thought right to bunch the lower levels more closely together: an approximately exponential level distribution was aimed at, namely ±3%, ±6%, ±15%, ±40% and ±90% of full half amplitude from null point (it turns out, in the event, that the greatest contribution to the total stroking distance comes from the 20% level approximately).

As regards the recording of ram velocity, assuming again that there will be a numerical preponderance of small control movements and accepting also, that the rate-load characteristic of a hydraulic valve controlled actuator is nearer to being elliptical than linear and, consequently, the fact of the load opposing or following will have but marginal effect upon the rate, it would seem that the recorder need not be sign conscious, and so, keeping the general dimensions, shape and the total number of counters in both the displacement and velocity recorder units the same, ram velocity can now be counted on ten discrete levels, evenly spaced at 10% maximum rate intervals.

The equipment will count satisfactorily up to 5 cps which is quite adequate for the present application. The level setting accuracy is ±10% of the nominal value at any level.

3 DESCRIPTION OF THE DUTY CYCLE RECORDING EQUIPMENT

3.1 General

The DCR equipment to be described here was developed and manufactured by Messrs. Denis Ferranti Meters Ltd., to R.A.E. specifications. The design drawings and schedules are listed in the Master Reference Index MRI Z460D.

Fig.1 depicts schematically a complete recording system required to instrument one control axis, being composed of

One Sensing Unit	Spec. DFM Z/497
One Displacement Unit	Spec. DFM Z/495
One Velocity Unit	Spec. DFM Z/496
One Timing Unit	Spec. DFM Z/498

The Sensing Unit or Head generates electrical signals proportional to position and velocity of the actuator output, which are communicated to and processed by the Displacement and Velocity Units.

The Timing Unit records the control utilisation time. It, too, is duplicated and capable of recording separately the times of the two régimes referred to earlier.

All production units were subjected to normal Type Approval Tests according to requirements and recommendations of M.O.A. Specifications DTD 1085B, EL 1384 and Av.P.24.

3.2 Sensing unit

The construction of the Sensing Head is seen in Fig.2. It contains a dc tachogenerator which transmits to the Velocity Unit a signal proportional to the ram velocity, and an inductive position pick-off, which receives from the Displacement Unit an ac carrier and returns to the Displacement Unit the carrier modulated according to the ram position. These two transducers are driven through a gear train from a drum, onto which is wound a length of thin gauge flexible steel cable, the free end of which emerges from the Unit through a paxolin gate and is anchored to a suitable point of the moving output member of the actuator. Conversely, when the Sensing Unit is carried on the moving actuator body, the cable end would be anchored to the structure. The cable is kept taut, by the action of a coil spring, which applies torque to the drum equivalent to some 7 lb mean cable tension. Maximum extension of the cable out of the Sensing Head is $12\frac{1}{2}$ inches. In order that the mechanical and electrical range of the transducers is exploited as fully as possible, while the cable travel and number of revolutions of the drum varies with the actuator stroke from aircraft to aircraft, three sets of gear pairs of varying ratio are supplied (Fig.3). The cable is also provided with a quick-release AMP connector (see Figs.44 and 45), which facilitates the connection and disconnection of the Unit.

It would be clearly easier to drive the Sensing Head either from the pilot's controller or a point of the input circuit. There are two objections against such an arrangement: (a) the 7 lb cable load may conceivably interfere with the control feel; (b) in aircraft equipped with SAS, which by-passes the pilot's controller, large numbers of small corrective movements would not be counted. When the Sensing Head is, however, driven by the actuator output, every movement in excess of the first counting level setting is counted; the cable forces, including the 30 lb breaking pull of the cable, are quite insignificant vis-a-vis the verv large load capacity of the actuator output. The relatively low breaking strength of the cable is an insurance against destruction of the Sensing Unit in case of partial or complete seizure of the gears or the transducers.

3.3 Displacement Unit

Fig.4 shows the block diagram of the Displacement Unit, the circuit diagram of which is seen in Fig.6. In Figs.7 and 8, the covers have been removed to reveal the layouts of the counters and the wiring. The Unit is powered from a 22-29 volt dc source via a Zener stabiliser which supplies the various sub-circuits with 20 ± 0.1 volts.

A 1 kc relaxation oscillator generates a carrier for the ac position transducer in the Sensing Head, where it is amplitude modulated according to the output member position. The modulated carrier changes phase 180° as the transducer is rotated through its null position (corresponding to the control surface neutral, or trim position), and passes via a 10 kohm range control resistor (variable) through an isolating transformer and a non-linear amplifier, having an emitter-follower output, to a phase-sensitive demodulator, which also receives the carrier reference from the oscillator output transformer.

The demodulator has two outputs, each feeding one of the two level selector boards. Each level selector board carries five adjustable Schmitt trigger circuits. Thus, when the Sensing Head cable, following, the ram movement is retracted, the ac transducer is rotated in such a direction, that the demodulator/discriminator passes a negative-going signal to triggers 1 to 5. Ram movement in the opposite direction results in a negative-going signal being applied to triggers 6 to 10. In each group of five triggers the switching levels are set to a required level distribution by means of adjustable resistors. These ten-turn flat resistors of 1.5 kohm and 10 kohm determine the switching and reset levels in each trigger circuit. The Schmitt triggers connect the operating coils of two electro-magnetic counters to the negative rail. The free end of one of the coils of the two level counters will then be connected to the positive rail and cause the counter to operate, depending upon the position of the régime switch (see Fig.1). Thus, ten pre-set levels of position signal are counted on either of two sets of 10 counters each.

The nature of the régime switch varies with the installation requirements. It may take the form of an airspeed or Mach indicator switch, allowing of segregation of counts above and below a particular ASI or Mach number. In other cases the regime change-over is related to some mechanical function, such as operation of the undercarriage. The general denotation of the two régimes was chosen as 'Ground' and 'Flight'.

In Fig.7, the left hand column of counters contains levels 1 to 5, the second column levels 6 to 7 reading from bottom to top. Columns 3 and 4 correspond to columns 1 and 2 in the alternate régime. The counters are of the four-decade type except levels 1, 2, 6 and 7, which have five decades, to cater for the larger count numbers expected at the lower counting levels.

Test sockets SK3, SK4 and SK5 are provided for the adjustment of system gain and for calibration purposes. SK4 and SK5 stand normally at -2.2 volts with respect to SK3, with the transducer in the null position. With the transducer in its extreme position the range control resistor is adjusted to give -6 volts between SK3 and SK4 or SK5, depending on the direction of rotation from the null position.

A 1:1 isolating transformer permits the use of a center-earthed through-line suppressor system on the carrier lines at outlet PL2 (not shown in Fig.6). This was necessary in order to meet the radio interference standards for civil aircraft equipment.

3.4 Velocity unit

The general arrangement of the Velocity Unit is shown in block form in Fig.5, and the circuit diagram in Fig.9. In external shape and size this instrument is identical with the Displacement Unit as is evident in Fig.10. Electrically the two Units are also similar, except for certain circuit changes necessitated by the fact, that, unlike the Displacement Unit, the Velocity Unit receives from the Sensing Head and handles a dc signal (proportional to ram velocity).

The dc signal passes via a chopper circuit through an ac amplifier to a demodulator. Negative feedback across the amplifier is adjusted by a 2 kohm range control resistor. This is to ensure correct amplifier gain to suit the particular ram velocity range being measured, and can be checked on test sockets SK3 and SK4.

The demodulated signal is next passed on to 10 level selector switches (Schmitt triggers), having ON/OFF (COUNT/RESET) adjustment, each driving in turn one of a pair of counters, very much as in the case of the Displacement Unit.

The system is conscious only of the magnitude of the signal (the tacho output voltage) and not of its sign. Consequently, all the 10 level selector circuits can now be set to operate at progressively increasing signal levels from 0 to maximum, usually in 10% steps.

As in the Displacement Unit, while the majority of the counters are 4-decade ones, levels 1 to 4 have five decade capacity, to cater for the expected more numerous small rate demands.

3.5 Timing Unit

The Timing Unit is made up of two self-starting electrically driven escapement clocks, which count the hours of recording time in each of the two régimes. The R.A.E. made prototype appears in Fig.46.

4 AIRCRAFT INSTALLATION

4.1 Scope of application

Although, originally, it was intended to instrument a somewhat larger range of aircraft, both helicopter and fixed wing, it was found practical to restrict the investigation to the following types: Wessex, Hunter, Lightning, Buccaneer, Sea Vixen, Victor, Vulcan, Valiant, Comet 2 and VC10. In this way a comprehensive coverage of aircraft type, size, speed, role, utilization and climatic and geographical environmental effects is achieved. Of the above list, the Wessex, the Hunter, the Valiant, the Vulcan and the Comet 2 have reached or approached the target of 1000 hours recording time and are summarily reviewed in this Report. The Lightning, the Buccaneer, the Sea Vixen, the Victor and the VC10 will be reported on in due course. For reasons of economy, no civil airline aircraft have been covered by this survey. The Comet 2, operated by an R.A.E. Department, has been employed in a global role as a vehicle for equipment flight testing, but although nominally an airliner, it does not strictly represent the civil transport category. By contrast, the VC10, in global operation with the R.A.F. Transport Command, should fill the remaining gap in the investigation.

4.2 Data collection and recorder reliability

By arrangement with Technical Records Offices at Stations operating the DCR instrumented aircraft, readings of the recorders are taken and returned to the R.A.E. at approximately monthly intervals (Fig.11). This is intended primarily to indicate whether or not the installations are functioning correctly. Thus, while the instruments are under regular surveillance in the early stages, a trend in control demands is established in time, and any subsequent significant deviation from this trend is a signal for a check of the equipment. Such checks may occasionally result in the rejection, in whole or in part, of the data for the period concerned. A large proportion of failures has been found to be due to damage sustained by the Sensing Units in the course of servicing of the powered controls actuators.

One incident, which illustrates the usefulness of the monthly checks and the caution necessary in interpreting the readings, is worthwhile recording: examination of a particular data return showed abnormally high control demands in the 'Flight' régime. An inquiry at the Station revealed, that the aircraft flying controls had been exercised for some hours for setting-up purposes while the aircraft was jacked-up for a concurrent servicing of the undercarriage retraction system. Since, however, the régime switch-over was related to the undercarriage oleo leg extension, the control movements which should have been counted in the 'Ground' régime, were in fact recorded in the 'Flight' régime. Vastage of counting time occasioned by such errors was gradually eliminated with experience and cooperation of the Services.

Faults of electrical nature within the instruments manifest themselves quite distinctly by either complete absence of counts or by records grossly inconsistent with the established trends of the control channel in question.

Great care is also required in analysing data relating to controls trimmable within more than the usual range, e.g. aileron-flaps (Buccaneer) and multi-trim elevon (Vulcan II) which may operate about possibly widely separated null (trim) positions.

Troubles experienced with Timing Units were largely due to the fact that, the basic component used in this instrument, a self-starting electrically driven escapement clock, was actually an ex-engine hour counter. Many have been used previously, none had a known history. In addition, in certain installations the Timing Units were mounted in areas of high vibration level, resulting in abnormal wear and even fatigue failures in the mechanism and the attachment.

A number of modifications improved matters markedly. Nevertheless, the readings of the Timing Units are always checked against the entries in Form 700 or the Log Book.

The following table summarises faults which have occurred up to the end of 1967, followed by a brief account of the faults and their effect.

Aircraft	Number of units per a/c				Number of faults				Time in use months
	Displacement	Velocity	Sensing	Timing	Displacement	Velocity	Sensing	Timing	
Victor	3	3	3	1	2	2	4	4	40
Vulcan	3	3	3	1	3	3	1	0	31
Valiant	3	3	3	1	3	5	2	3	17
Wessex	4	4	4	1	0	0	000	0	41
Sea Vixen	3	3	3	1	0	0	3	1	18
Buccaneer	3	3	3	1	1	0	3	1	24
Hunter	2	2	2	1	2	3	2	0	45
Comet 2	3	3	3	1	0	0	1	0	26
TOTAL	24	24	24	8	11	13	16	9	

Fault	Effect
Sensing Unit	
In 14 cases the cable had come off the pulley (see section 3.2 and Figs.2 and 3) due to mis-handling. 4 cases of tachogenerator destruction following cable break.	No counts on Displacement or Velocity Units at all counting levels.
Displacement Unit	
Defective counters.	Low or no counts on corresponding levels.
Open circuit nickel resistor.	No counts.
Weak trigger action due to loss of gain in transistor.	Low count on effected level.
Oscillation of trigger circuit due to transistor drift.	Excessive count on effected level.
Flat trimming resistors, wear.	Calibration and gain setting impossible.
O.C.77 faulty. No trigger action.	No count on effected level.
Velocity Unit	
Defective counters.	No count on effected level.
Weak trigger.	Low count on effected level.
Oscillation of trigger.	Excessive counts.
Plessey plug-socket damaged.	Continued to operate normally.

Fault	Effect
Timing Unit	
Intermittent action attributed to wear.	Incorrect time reading.
Fatigue failure of balance wheel spindle.	No reading.

5 RECONSTRUCTION OF DUTY CYCLE FROM COUNTER RECORDS

5.1 Interpretation of displacement counts and computation of total stroking distance

Considering first control displacements on one side of neutral (trim) position (similar treatment may be applied to those on the other side), Fig.12a shows an arbitrarily chosen distribution of levels y of position demand 1 to 5, at which counters 1 to 5 will count and reset (in readiness for the next count). Let each counting level correspond to a ram stroke of y_N units of length relative to the neutral position, and let x_N be the interval between the counting and the reset levels, suffix N indicating the number of the level in question, increasing with the distance from neutral. Thus, the third counter will count, when the ram is displaced y_3 units from neutral, and will not count on that level again, until it had been re-set, when the ram re-passes (towards neutral) through position $y_3 - x_3$. Let, further, the count appearing on the Nth level counter be n_N. Suppose, at the end of a recording period, the counts n_1 to n_5 recorded on counters 1 to 5 are 5, 4, 3, 2 and 1 respectively. Fig.12a shows a number of possible alternative duty cycles, which would fit the given count pattern. Case 1 is rather improbable, but is a possible reconstruction of the given n_N distribution resulting in the minimum total stroking distance. Comparative analogue recordings of control demands carried out by other investigators, as well as results obtained from a pen recorder installed in the R.A.E. Comet 2 and flown simultaneously with the DCR over a period of several hours suggest, that a 'normal' or 'average' demand will consist of discrete excursions out from and back to the neutral (trim) position. Cases II, III and IV show such reconstructions. Case IV would give maximum total stroking distance, since in each excursion the ram has passed beyond the nominal counting level to a position only just short of the next higher level. An improbable case. Equally unlikely is Case II, where it has been assumed that the ram has moved exactly to the counting level. Case III appears to be the most likely control cycle reconstruction to fit the given set of counts n_N. This reconstruction provides the probable mean duty cycle, with the peaks of the individual excursions falling half way between values y_N and y_{N+1}. It is likely that over a reasonably long recording period, the computation of the total stroking distance, based on the latter assumptions, will yield an answer of the right order.

Having regard to the mode of operation of the recorder, it is, further, necessary to define the true meaning of the counts n_N. When the control is displaced to a position corresponding to y_N, the system had necessarily passed through all the lesser positions y_{N-1}, y_{N-2} ... y_1, all the lower level counters having recorded the passage. Thus, when reconstructing the duty cycle, the actual number of discrete excursions to level y_N is calculated from the expression

$$\bar{n}_N = n_N - n_{N+1} \quad .$$

The total stroking distance, therefore, for a given set of counts n_N (remembering that the Displacement Unit contains ±5 levels) will be computed as follows:-

$$S = 2(\bar{n}_5\bar{y}_5 + \bar{n}_4\bar{y}_4 + \bar{n}_3\bar{y}_3 + \bar{n}_2\bar{y}_2 + \bar{n}_1\bar{y}_1)$$

where $\bar{y}_N = \dfrac{y_N + y_{N+1}}{2}$, and $\bar{n}_N = n_N - n_{N+1}$

or, more generally, for M counting levels

$$S = 2\sum_{N=1}^{N=M} (n_N - n_{N+1})\frac{y_N + y_{N+1}}{2} = 2\sum_{N=1}^{N=M} \bar{n}_N\bar{y}_N =$$

$$= \sum_{N=1}^{N=M} (n_N - n_{N+1})\,(y_N + y_{N+1}) \quad .$$

In Fig.12b such a reconstruction is shown for a case, where $n_5 = 1$, $n_4 = 3$, $n_3 = 6$, $n_2 = 8$, $n_1 = 6$ and $y_1 = 1$, $y_2 = 2$, $y_3 = 5$, $y_4 = 13$, $y_5 = 30$ and y_6(limit of stroke, not counted) = 33 units. Using the above expression for the total stroking distance

$$S = \sum_{N=1}^{N=6} (n_N - n_{N+1})(y_N + y_{N+1}) =$$

$$= (1-0)(30+33) + (3-1)(13+30) + (6-3)(5+13) + (8-6)(2+5) + (6-8)(1+2) =$$

$$= \underline{211 \text{ units}} \ .$$

5.2 Probability of error in counting small amplitude oscillations

Small amplitude oscillations of the controls about a position other than neutral may occur, as shown in Fig.12c, and these may or may not be recorded. Consequently, the total stroking distance calculated from the recorded level counts, using the formulae of section 5.1, may be more or less in error, compared with reality. The analysis is at its simplest and will be confined to the first counting level y_1, but the argument is clearly valid anywhere within the counting range of the instrument.

Altogether, six typical instances of small amplitude oscillations are considered. The first four are of amplitude smaller than the interval y_1, and indeed $y_1 - x_1$, but somewhat greater than x_1, the last two are smaller in amplitude than x_1. Their position relative to level y_1 varies from instance to instance. For a given x_1, it is seen, that only instance II would produce counts, since only in this instance does the amplitude of the small oscillation encompass the interval x_1. The formula for S would interpret the record of instance II as a cycle of amplitude $(y_1 + y_2)/2$ and so result in a relatively small over-estimate of the actual total stroked distance. None of the remaining five instances would have been registered by the counters. Thus, considerable errors between reality and the computed value of S may arise. Clearly therefore, for relatively large count-reset interval x_1, the probability of error in the undesirable sense, i.e. underestimate of the total stroking distance, is high. If, however, the interval x_1 were reduced to, say, $x_1/2$, it is seen, that counts would now be obtained in instances I, II and VI and the probability of error would be significantly reduced. Instances III, IV and V will, of course, never register, however small x_1 may be. This is inherent in the method of counting of events in finite intervals. The errors may be, possibly, offset by the application of a suitable factor, determined from a judicious consideration of the overall count pattern.

In practice the minimum magnitude of x_N is determined by the drift in the triggering circuit. If x_N was set very small in the initial calibration, time and environment changes may well cause further narrowing of the interval, or even a cross-over, giving rise to instability, flutter, of the Schmitt trigger circuits, resulting in very large counts being registered, with the controls actually stationary. Experience has shown the smallest values of x_N to be of the order of 1% of maximum travel.

5.3 Interpretation of velocity counts

Although there is, no doubt, a good deal to be read into the velocity level count patterns, it is proposed, in this part of the Report, to regard the counts as simply indicative of how frequently a certain control rate has been demanded and realised. The Final Report will attempt to interpret the velocity records in terms of horsepower, as mentioned in the introduction.

Figs.28 to 42 show the velocity distribution in the five aircraft so far completed. One fact, already emerging from the plots, is that, with the exception of the Vulcan inboard elevon, Fig.36, the aircraft are endowed with more than generous maximum control rate, of which, in most cases, barely 50% is utilised in flight.

6 PRESENTATION OF RESULTS

6.1 General

By the beginning of 1968, four installations had realised their recording target: Hunter, Comet 2, Vulcan II and Wessex. The Valiant had been withdrawn from Service in 1965, but it, too, had by then accumulated a significant volume of DCR data (337 flying hours) and is, therefore, included in this review.

In Figs.13 to 27, the Displacement Duty Cycle reconstruction is presented in histogram form. The counting level distribution $\bar{y}_N$ (see section 5.1) is plotted along the horizontal axis as a percentage of maximum design stroke, with the actual stroke in inches indicated at each discrete level. The counts at these levels have been processed to give $\bar{n}_N$, the number of strokes per hour in the 'Flight' régime, and are shown as the white-column ordinates accompanied by the appropriate numerical value of $\bar{n}_N$. As regards the 'Ground' régime, although this has been both counted (n'_N) and timed (T') separately, and is therefore capable of yielding a 'Ground' Duty cycle, such a presentation it was felt, has little practical significance in itself, and it has been, therefore, decided to present, rather, combined level counts ($n_N + n'_N$) related to the flying time T. $\bar{\bar{n}}_N$ is the symbol for these combined stroke counts per hour, which appear as the banded-column ordinates at the discrete counting levels, again accompanied by their appropriate numerical values. This 'Ground'-corrected duty cycle distribution has, indeed, a practical significance in determining the wear life of a control system, since, clearly, the seals and all the rubbing components of an actuator wear at much the same rate whether on the ground or in flight, yet, the life of the equipment is mostly specified in terms of airframe flying hours and it seems, therefore, that the presentation of $\bar{\bar{n}}_N$ (based on flying time T) is logical and justified. However, the recorded fact, that a good deal of controls exercising is taking place with the aircraft on or near the ground is of interest and the values of T and T' for the various aircraft are quoted under the respective headings in the table 6.3.

The quantities $\bar{n}_N$ and $\bar{\bar{n}}_N$ together with $\bar{y}_N$ were used to compute the total stroking distances $\bar{S}$ and $\bar{\bar{S}}$ (see section 5.1).

A somewhat different problem is presented by the Wessex. Here the 'Ground' régime includes ground use, hovering and forward flight up to 80 kn ASI, and, in fact, the ratio of T'/T is reversed, the aircraft spending about 4 times as much of active control time in the 'Ground' régime than it does in the 'Flight' régime. It was thought, therefore, appropriate to examine independently the 'Ground' and the 'Flight' duty cycle patterns, based on T' and T respectively, as well as the 'Combined' case, based on combined counts $(n_N + n'_N)$ and combined time $(T + T')$. Correspondingly the histograms consist at each discreet counting level of three ordinates: white column for the 'Flight' case (above 80 kn ASI), black column for the 'Ground' case (below 80 kn ASI) and banded column for the 'Combined' (total) case.

The total stroking distance realised in P.F.C. actuator type testing was calculated in each case from data extracted from relevant manufacturers' Test Declarations and Test Reports. Invariably the tests were designed to demonstrate 1000 flying hours endurance of the P.F.C. installations, hence, dividing the total test stroking distance by 1000, the test stroking distance per hour flying was obtained to which the symbol Σ was assigned. The ratio $\Sigma/\bar{S}$ has the significance of a Reserve Factor and indicates the degree of severity of the Type Test vis-a-vis actual usage. With the one exception of the Wessex yaw axis, the ratios $\Sigma/\bar{S}$ in the aircraft so far analysed are large or very large, ranging from 2.5 to 53.0!

6.2 Individual aircraft DCR results and relevant data

6.2.1 Hunter

Type FR10, No. XJ694, carried a 2-axis DCR installation between July 1963 to September 1967, being based most of that time on R.A.F. Gütersloh and taking part in NATO exercises. Total recording 'Flight' time 847 hours, 'Ground' time 184 hours. Régime change-over was effected by an undercarriage up-lock switch. The type testing followed the schedules laid down for Hunter Mk.6: elevator, Fairey Aviation document T.T.S. No. 3926, Issue 1, 8.12.58; aileron, T.T.S. No. 3928.FC, Issue 1, 2.4.59. This aircraft has no autopilot nor SAS and, indeed, the displacement demand distribution, Figs.13 and 14 is typical of a manually controlled aircraft. The elevator distribution indicates a shift of neutral (trim) position towards elevator "down". Ratio $\Sigma/\bar{S} = 57.4/10.566 = 5.4$, $\Sigma/\bar{\bar{S}} = 57.4/13.758 = 4.2$. The aileron counts distribution is symmetrical, consistent with the aircraft symmetry in roll. A possible explanation for the values of $\bar{n}_1$ being smaller than $\bar{n}_2$ may be, that the aircraft does not respond readily to aileron demands of the order of 0.060 inch, the pilot using, intuitively, somewhat coarser rolling control. Ratios $\Sigma/\bar{S} = 96{,}0/18.153 = 5.3$ and $\Sigma/\bar{\bar{S}} = 96.0/20.004 = 4.80$.

6.2.2 Valiant

Bomber, No. WZ367. Figs.15, 16, and 17. This aircraft carried a Timing Unit of early design which gave a great deal of trouble and, consequently, all calculations are based on log book flying time. The DCR accumulated 337 'Flight' counting hours on aileron and rudder and 270 hours on the elevator, when the aircraft was withdrawn from Service in 1965. An ASI switch set at 120 kn was used to effect the régime change-over. While carrying DCR equipment, between May 1963 and October 1964, the aircraft was based in the United Kingdom. Data relating to the P.F.C. type tests were extracted from the following documents: aileron (Boulton Paul type P.108) test Report No. 3085, March 1954; elevator and rudder (type P.107) test Report No. 3084, April 1954. The Valiant was equipped with an autopilot and a yaw damper, which probably accounts for relatively large counts on levels 1 and 2. The distribution is symmetrical in the aileron and elevator, while that of the rudder suggests a small shift of trim to starboard. This is rather consistent with observations made on an early experimental DCR installation in an R.A.E. based Valiant, which showed a similar rudder trim shift, traced to the inability of setting accurately the throttle controls. The R.A.E. Valiant, in fact, flew with 2 degrees of rudder most of the time. Ratios Σ/S are following: aileron $\Sigma/\bar{S} = 490.0/31.656 = 15.5$,

$\Sigma/\bar{\bar{S}} = 490.0/32.429 = 15.0$; elevator $\Sigma/\bar{S} = 384.0/29.273 = 13.0$, $\Sigma/\bar{\bar{S}} = 384.0/34.168 = 11.3$; rudder $\Sigma/\bar{S} = 355.0/7.328 = 48.5!$, $\Sigma/\bar{\bar{S}} = 355.0/11.349 = 31.3!$

6.2.3 Comet 2

No.XN453. Figs.18, 19 and 20. The aircraft was based at R.A.E. Farnborough and its role was extremely varied, comprising long range flying (Greenland, U.S.A., Canada, West Indies, Nairobi, Far East, Australia) as well as low altitude flying in the U.K., formation flying with other aircraft and local circuit training flights. A detailed analysis of this vast range will be attempted in Part II of this Report. Total 'Flight' counting times are: aileron and rudder 1530 hours, elevator 1472 hours, accumulated between September 1963 and September 1967. A switch was fitted to the undercarriage oleo-leg to operate the régime change-over at unstick speed. Information on the type testing of the Lockheed Precision Products PFC actuators was obtained from the following documents: aileron, Test Schedule No. Air 103790; elevator, Test Schedule Air 100778; rudder Test Schedule Air 100782 (first issues 1957-8). The presence of a 3-axis autopilot and the multifarious utilisation of the aircraft renders the interpretation of the count distribution somewhat problematic. Ratios Σ/S for aileron: $\Sigma/\bar{S} = 81.0/12.193 = 6.6$, $\Sigma/\bar{\bar{S}} = 81.0/20.744 = 3.9$; elevator $\Sigma/\bar{S} = 81.0/3.16 = 25.5$, $\Sigma/\bar{\bar{S}} = 81.0/7.32 = 11.0$; rudder $\Sigma/\bar{S} = 81.0/1.53 = 53.0!$, $\Sigma/\bar{\bar{S}} = 81.0/5.21 = 15.5$. Aileron appears to be the dominant control.

6.2.4 Vulcan MK.II

Bomber. Figs.21, 22 and 23. Two successive aircraft were instrumented: No. XJ824, January 1964 to February 1965, and No. XH559, May 1965 to November 1966, the transfer of the DCR equipment being necessitated by the introduction of Mod. 1102, which interfered with the original layout of the DCR in XJ824. The aircraft was used in operational role based on U.K. The elevon control system possesses certain unusual features. There are inboard and outboard elevons, receiving common pilot's and autopilot input signals, but due to a difference in the input linkage gearing, the inboard elevon has larger travel than the outboard one. Only the inboard elevon is provided with SAS. Accordingly, the inboard and outboard elevon movements were monitored by separate DCR's. Another unusual control feature is the existence of more than one elevon trim position associated with various areas of the flight envelope. The extension of the undercarriage oleo-leg on take-off provided signal for the régime changeover at unstick speed. The P.F.C. actuators of Boulton Paul manufacture have been Type Tested to specifications contained in the following documents: Inboard elevon Type P132, Technical Report 3512/2; outboard elevon Type P135, Technical Report 3515/11; rudder Type P138, Technical Report 3512/2. The above mentioned multi-trim feature renders the interpretation of the elevon count distribution difficult. Particularly in the inboard elevon, which accepts all signals, including SAS, one may be surprised at the absence of large counts on level 1. It is possible that the SAS amplitude demand is smaller than the setting of the first level (3.5% full stroke) resulting in the SAS cycle failing to register. While it is not denied that this constitutes an error in the count of control reversals, as far as the total stroking distance S is concerned, one can see from all the other aircraft records, that the main contribution to S is derived from the medium amplitude levels, around 25% maximum stroke, and, consequently, the omission of the small level counts entails an error of less than significant order. The rudder displacement counts distribution is again indicative of the first counting level having been set too coarse for the autopilot demand. Ratios Σ/S are following: inboard elevon $\Sigma/\bar{S} = 290.0/18.576 = 15.5$, $\Sigma/\bar{\bar{S}} = 290.0/22.116 = 13.0$; outboard elevon $\Sigma/\bar{S} = 164.0/10.026 = 16.5$, $\Sigma/\bar{\bar{S}} = 164.0/12.225 = 13.5$; rudder $\Sigma/\bar{S} = 286.0/17.776 = 16.0$, $\Sigma/\bar{\bar{S}} = 286.0/29.850 = 9.5$.

6.2.5 Wessex

Mk.HASI, No. XP153. Figs.24, 25, 26 and 27. This helicopter was used in operational training role in the U.K. The régime change-over signal was derived from an ASI switch at 80 kn forward speed. Between August 1963 and January 1967 the DCR equipment, whose record of serviceability was excellent, accumulated the following recording times: port and starboard lateral and fore and aft main servos the Total (Combined) time 1684 hours, of which 469 hours was spent in 'Flight' régime, and 1215 hours in 'Ground' régime. The figures for the yaw channel were 1641, 459 and 1182 respectively. The documentation of the type tests is found in the following Westland Aircraft Publications: the main rotor actuators Type WS 16-65-20003, Technical Report G479 (December 1959), the tail rotor actuator Type WS 16-65-61614/1, Technical Report G480 (October 1959). This aircraft is equipped with autopilot and SAS on all axes, altogether a rather complex system with cross coupling between channels (e.g. a proportion of the collective pitch control demand is diverted to the tail rotor actuator to compensate for the variation of the main rotor torque). Contrary to the expected unpredictability of helicopter trim range, the count distribution on all four channels is remarkably symmetrical. In the absence of any previous statistical data on the probable stroking level distribution, and in consultation with the designers, the counting levels have been spaced in regular intervals of 20% maximum stroke, first level being set at 10%. In the event, this has proved to be too coarse a setting to register small demands, probably quite numerous, from the autopilot and SAS of the order of a few per cent of maximum stroke. But, if the argument developed on that subject for the Vulcan above is accepted, no significant error in respect of the total stroking distance S has been committed. The ratios of the Type Test to actual stroking distances, related to the Total (Combined 'Flight' and 'Ground') stroking distance S, are: port lateral $\Sigma/S = 104.5/28.98 = 3.6$, starboard lateral $\Sigma/S = 104.5/27.3 = 3.8$, fore and aft $\Sigma/S = 104.5/15.042 = 6.9$. It should be mentioned, that, since the DCR counts the output movements of the actuators, clearly, in the case of the helicopter, it is impossible to isolate the collective pitch demands, these being concealed within the counts of output displacements of the other main rotor control axes.

While in all cases so far examined the Type Test total stroking distance Σ far exceeded the realised stroking distance S, that is to say, the actuators carry large, or very large reserve factors, the Wessex yaw channel is the only outstanding exception. Its ratios Σ/S are of the order of 0.5. However, as far as information to date goes, it seems that the tail rotor actuator failure rate is not unusual.

6.3 Summary of results

Aircraft	Control axis	Recording time		Stroking distance				Reserve factor		
		'Flight' T hours	'Ground' T' hours	Type test Σ ft/hour	'Flight' $\bar{S}$ ft/hour	Combined $\bar{\bar{S}}$ ft/hour	'Total' S_{Total} ft/hour	'Flight' $\Sigma/\bar{S}$	Combined $\Sigma/\bar{\bar{S}}$	'Total' Σ/S_{Total}
Hunter	Aileron	847	184	96.0	18.153	20.004	-	5.3	4.8	-
	Elevator	847	184	57.4	10.566	13.758	-	5.4	4.2	-
Valiant	Aileron	337	-	490.0	31.656	32.429	-	15.5	15.0	-
	Elevator	270	-	384.0	29.274	34.168	-	13.0	11.3	-
	Rudder	337	-	355.0	7.328	11.349	-	48.5	31.3	-
Comet 2	Aileron	1530	413	81.0	12.193	20.744	-	6.6	3.9	-
	Elevator	1472	403	81.0	3.160	7.320	-	25.5	11.0	-
	Rudder	1530	413	81.0	1.530	5.210	-	53.0	15.5	-
Vulcan II	Aileron	1223	311	290.0	18.576	22.116	-	15.5	13.0	-
	Elevator	1223	311	164.0	10.026	12.225	-	16.5	13.5	-
	Rudder	1223	311	286.0	17.776	29.850	-	16.0	9.5	-
Wessex	Port lateral	469	1215	104.5	43.933	23.136	28.885	2.5	4.5	3.6
	Stbd lateral	469	1215	104.5	41.737	21.720	27.300	2.5	4.8	3.8
	Fore & aft	469	1215	104.5	14.634	15.366	15.042	7.0	6.8	6.9
	Yaw	469	1182	31.30	76.072	61.772	69.894	0.41	0.51	0.45

Acknowledgments

The author wishes to acknowledge the contributions of Mr. T.J. Jenkins, who, prior to his leaving the Department in 1965, was in a large measure responsible for monitoring the design and production of the DCR equipment and its installation in all but the latest aircraft, and of Mr. M.S. White, responsible for servicing the DCR installations and all collection and handling of the recorded data.

REFERENCE

No.	Author	Title, etc
1	-	'Note on the number of PFC movements measured in flight.' A&AEE Report A&AEE/Tech/169 (1959)

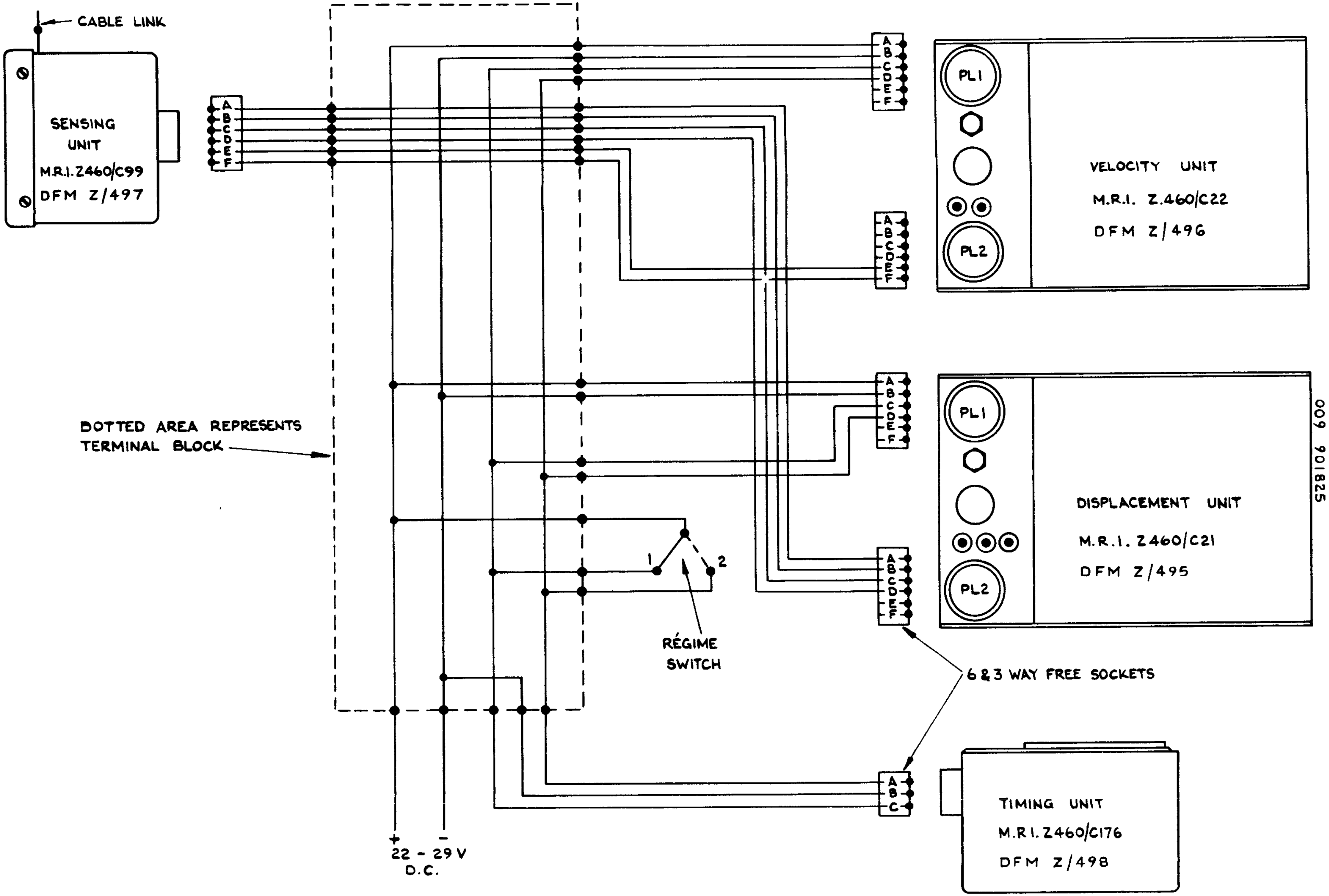

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FIG.1 COMPLETE RECORDING SYSTEM FOR 1 CONTROL AXIS

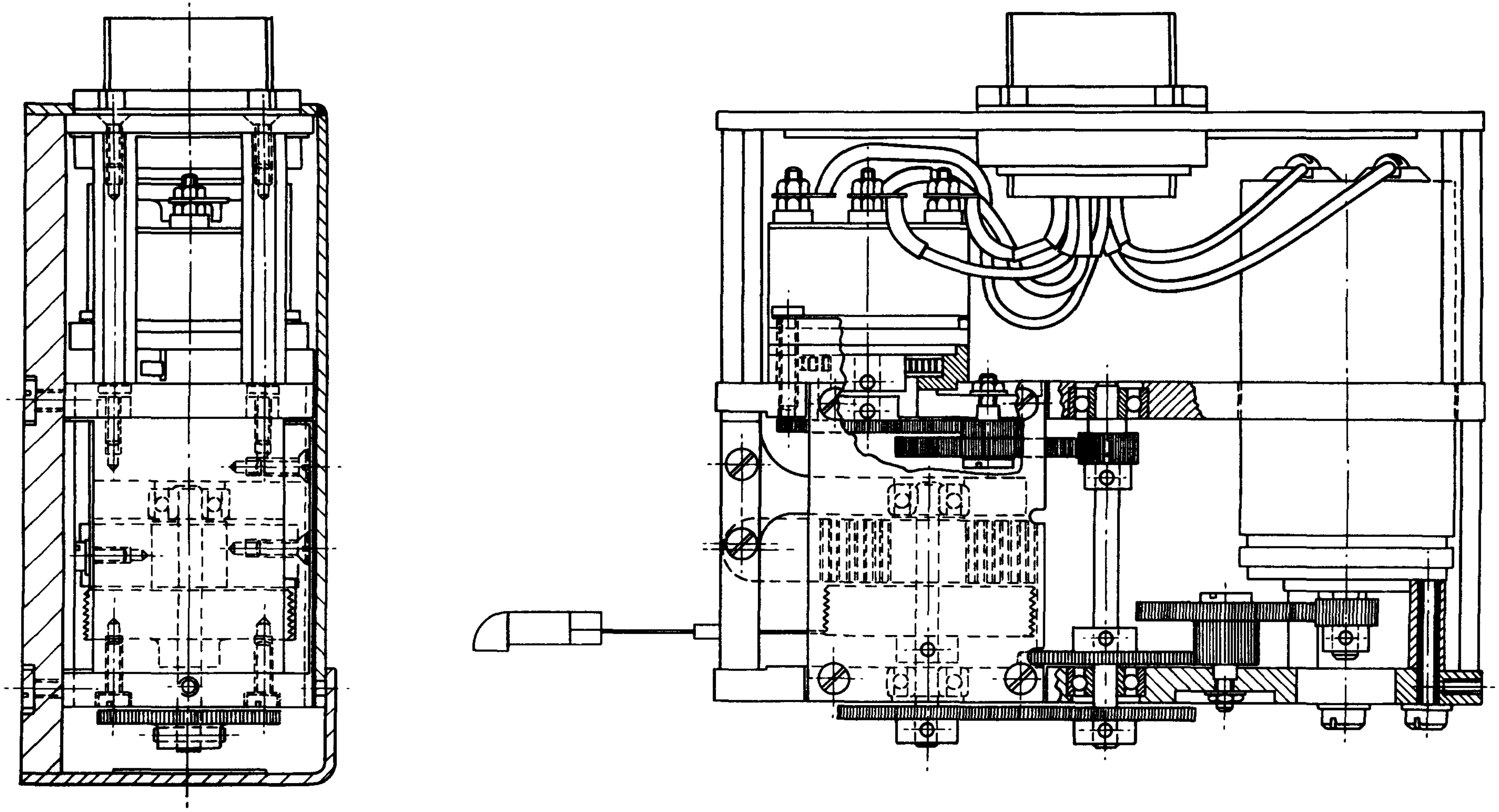
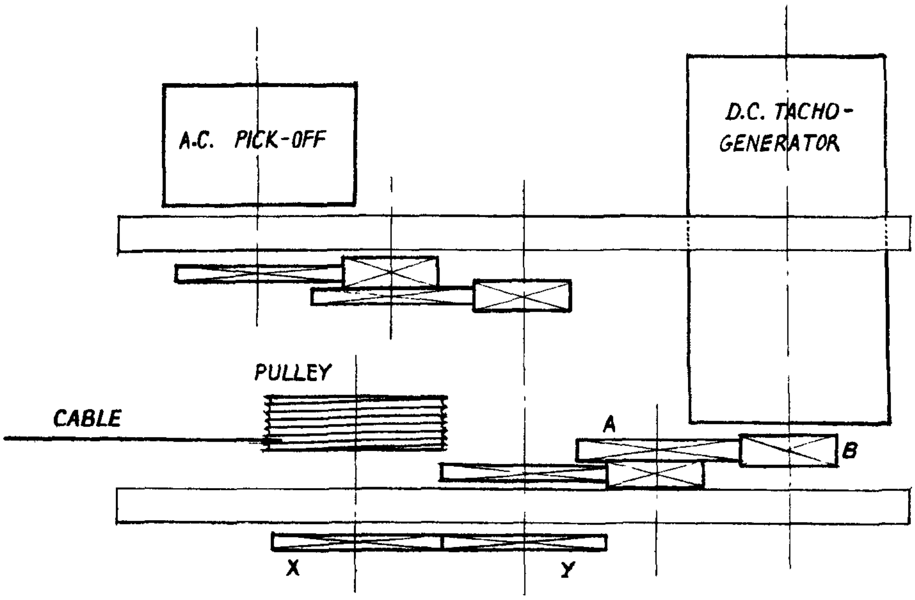


FIG. 2 SENSING HEAD



CHANGE WHEEL RATIO X : Y	DISPLACEMENT RANGE INCHES		VELOCITY RANGE INCHES / SEC.	
	ACTUATOR STROKE	90% ACTUATOR STROKE	CHANGE WHEELS A : B 103 : 30	CHANGE WHEELS A : B 71 : 62
66 : 132	12·5 – 6·25	11·25 – 5·625	30 – 4	90 – 12
99 : 99	6·25 – 3·125	5·625 – 2·812	15 – 2	45 – 6
132 : 66	3·125 – 1·562	2·812 – 1·406	7·5 – 1	22·5 – 3

TO REMOVE WHEELS X & Y WITHDRAW SEL-LOK SPRING PINS.

TO REMOVE WHEELS A & B FIRST REMOVE TACHO, WITHDRAW SEL-LOK SPRING PIN, REMOVE NUT & UNSCREW SPINDLE ON WHEEL A.

Fig.3 Sensing head change wheel range table

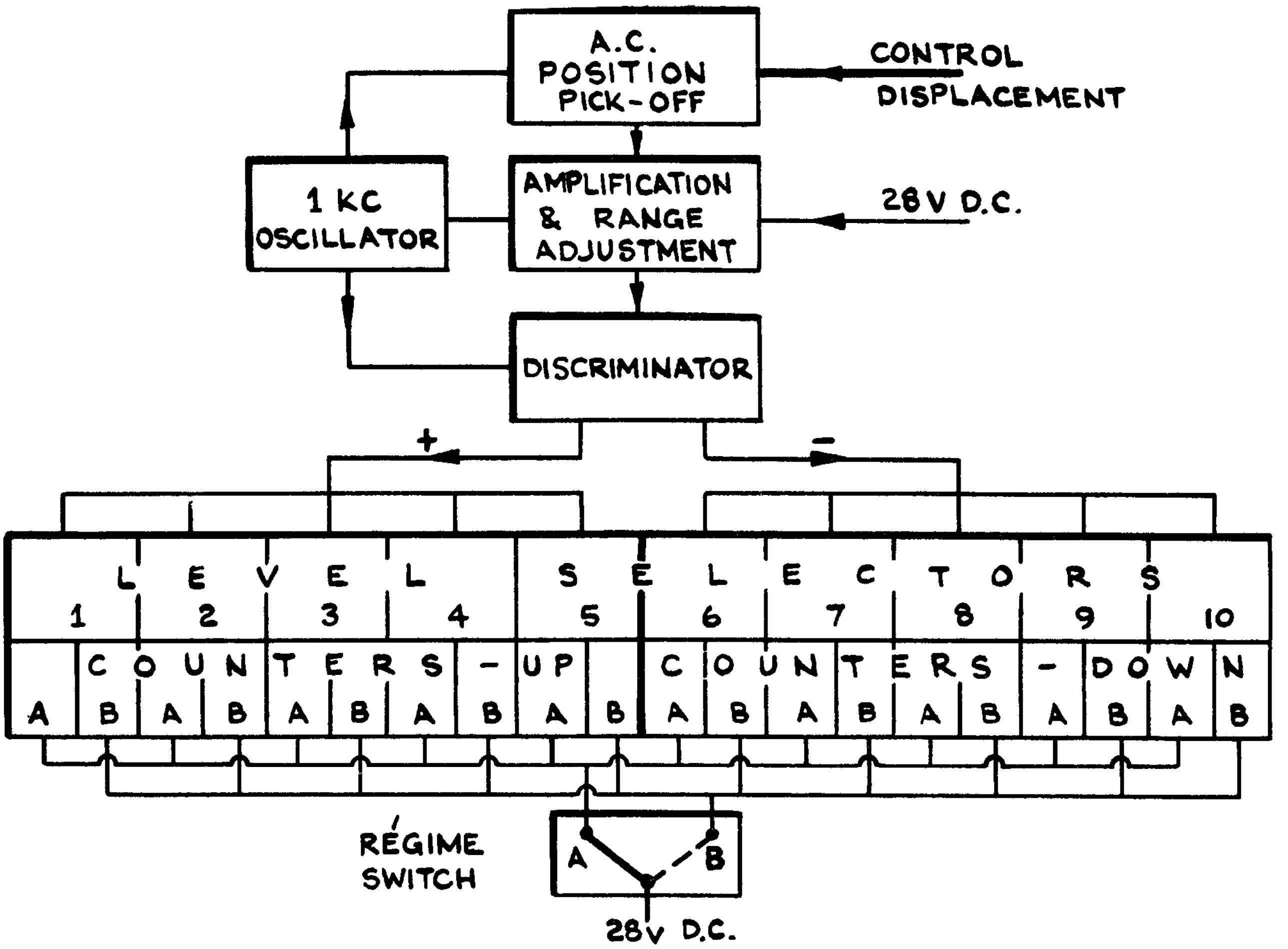


FIG.4 DISPLACEMENT CIRCUIT BLOCK DIAGRAM

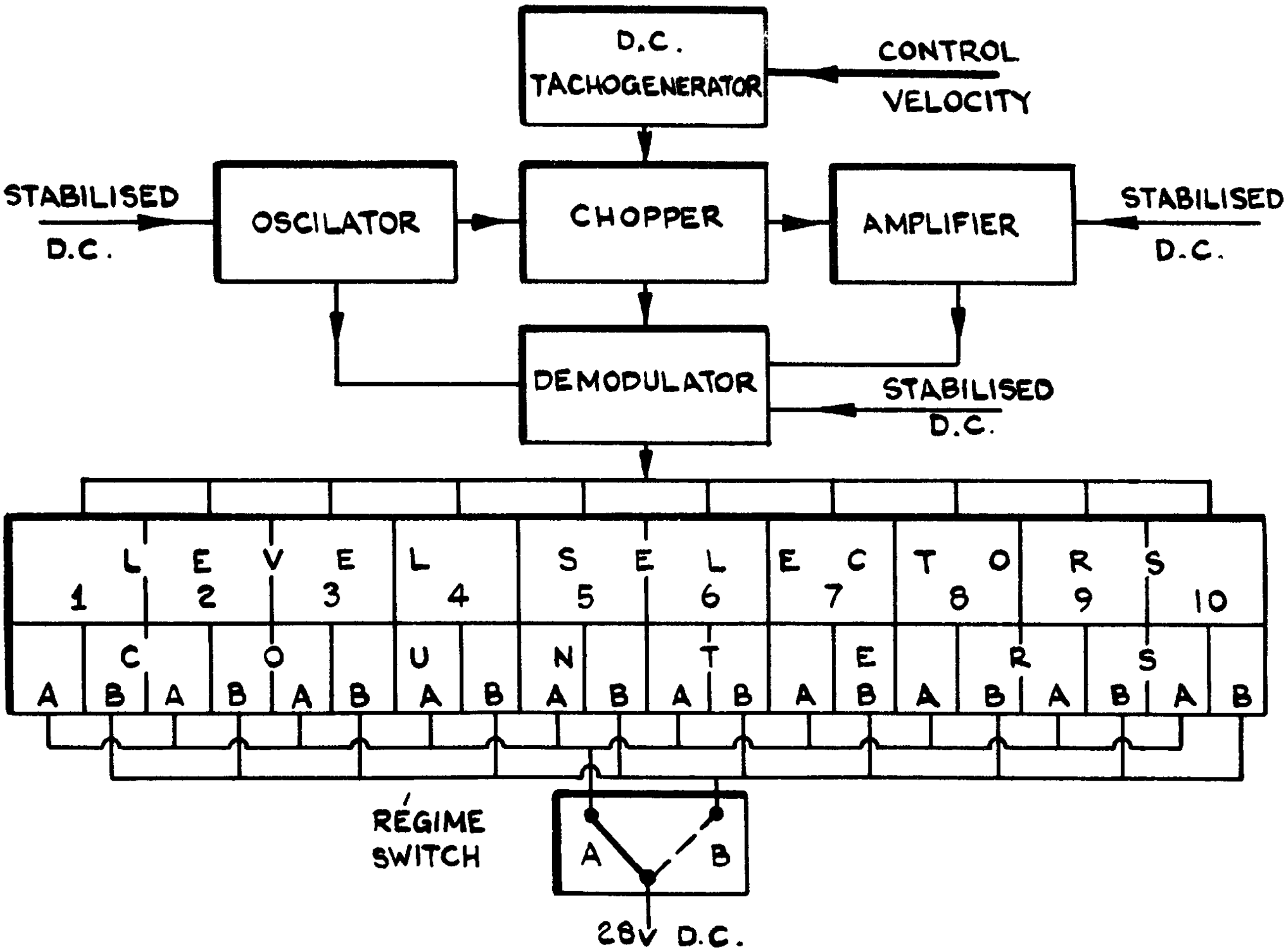
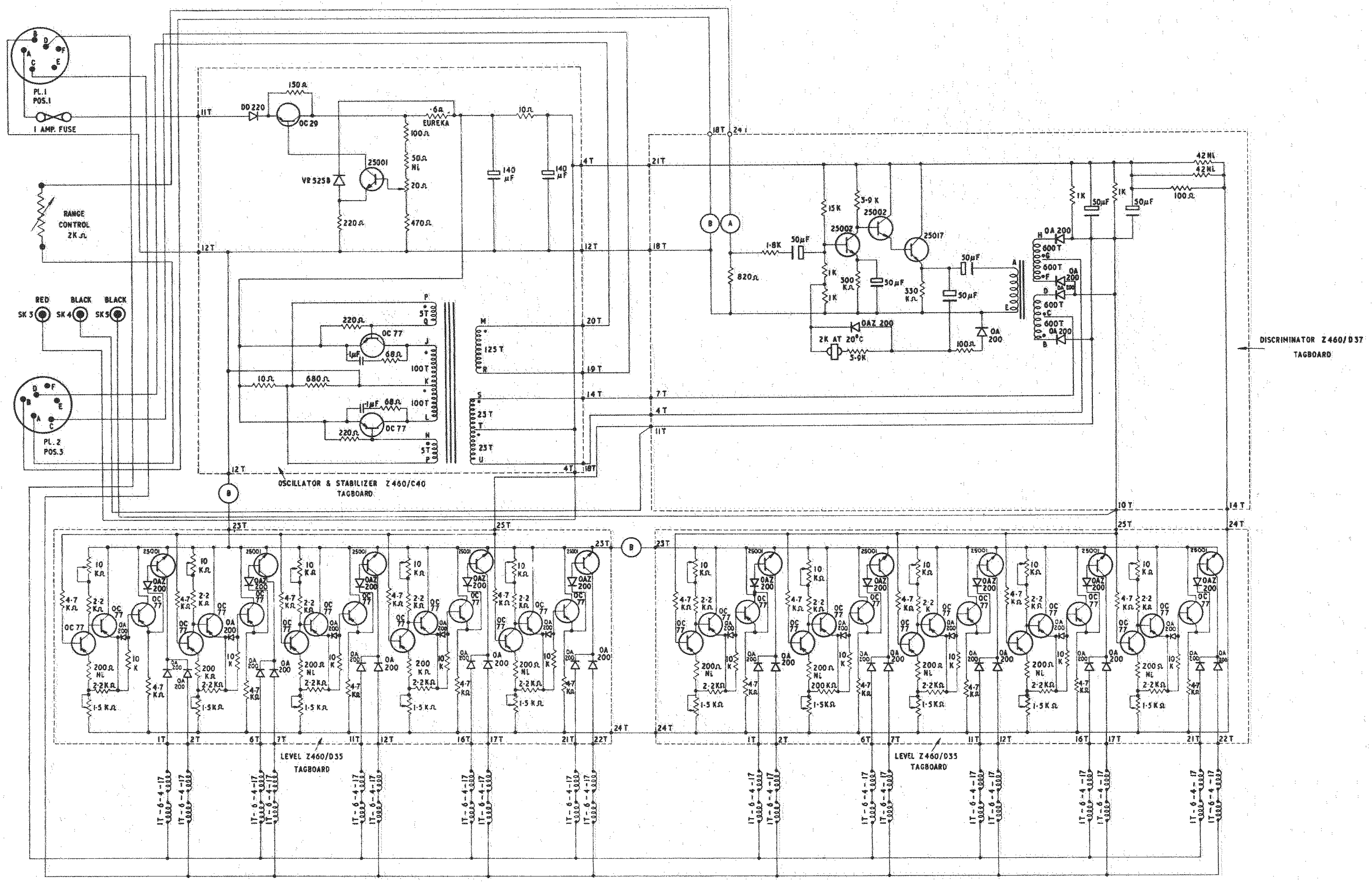
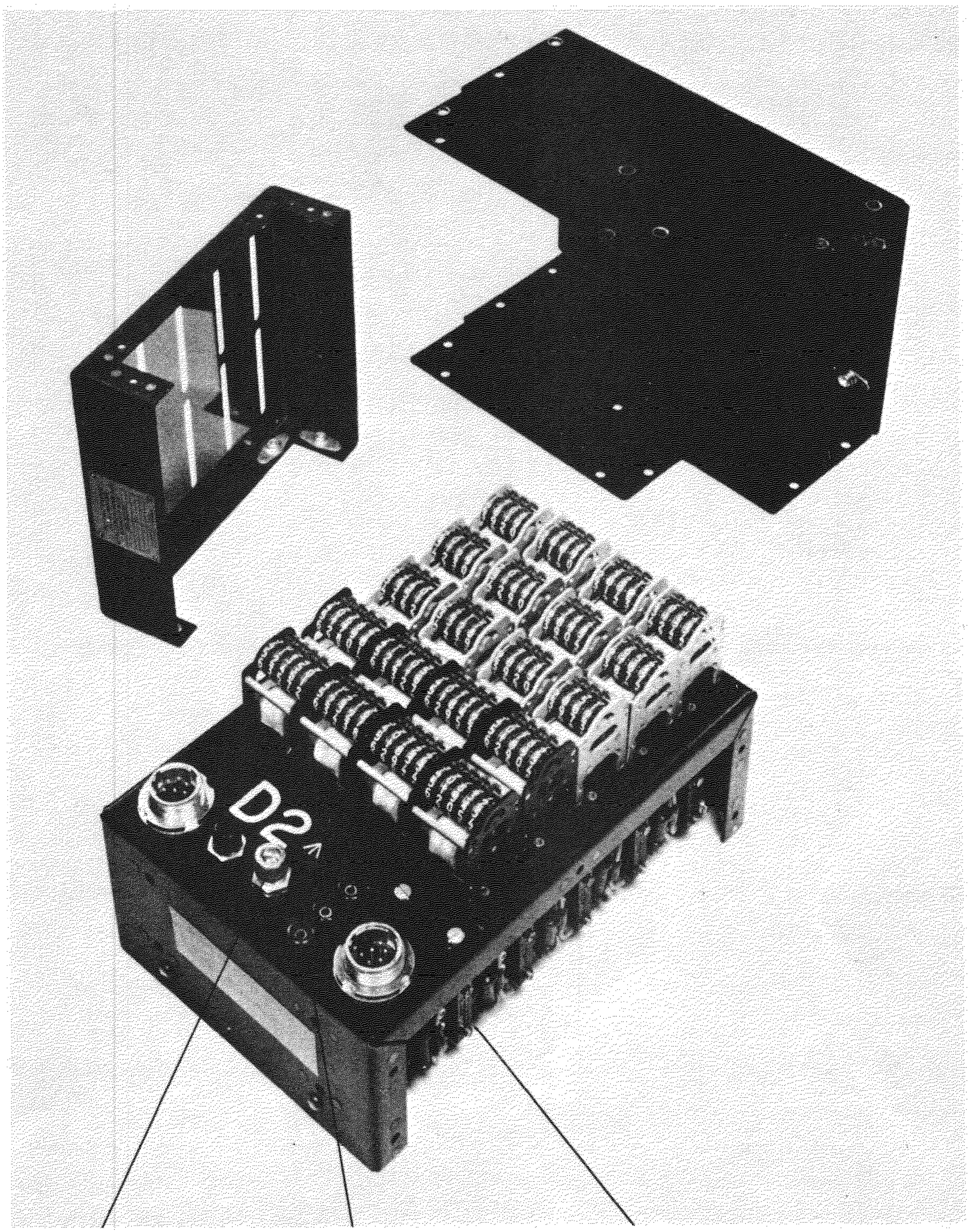


FIG.5 VELOCITY CIRCUIT BLOCK DIAGRAM



SEE Z 460/D26 FOR WIRING DIAGRAM

FIG.6 DISPLACEMENT UNIT, CIRCUIT DIAGRAM



Range control

Test sockets

Level adjusting potentiometer

Fig.7 Displacement unit,counter layout

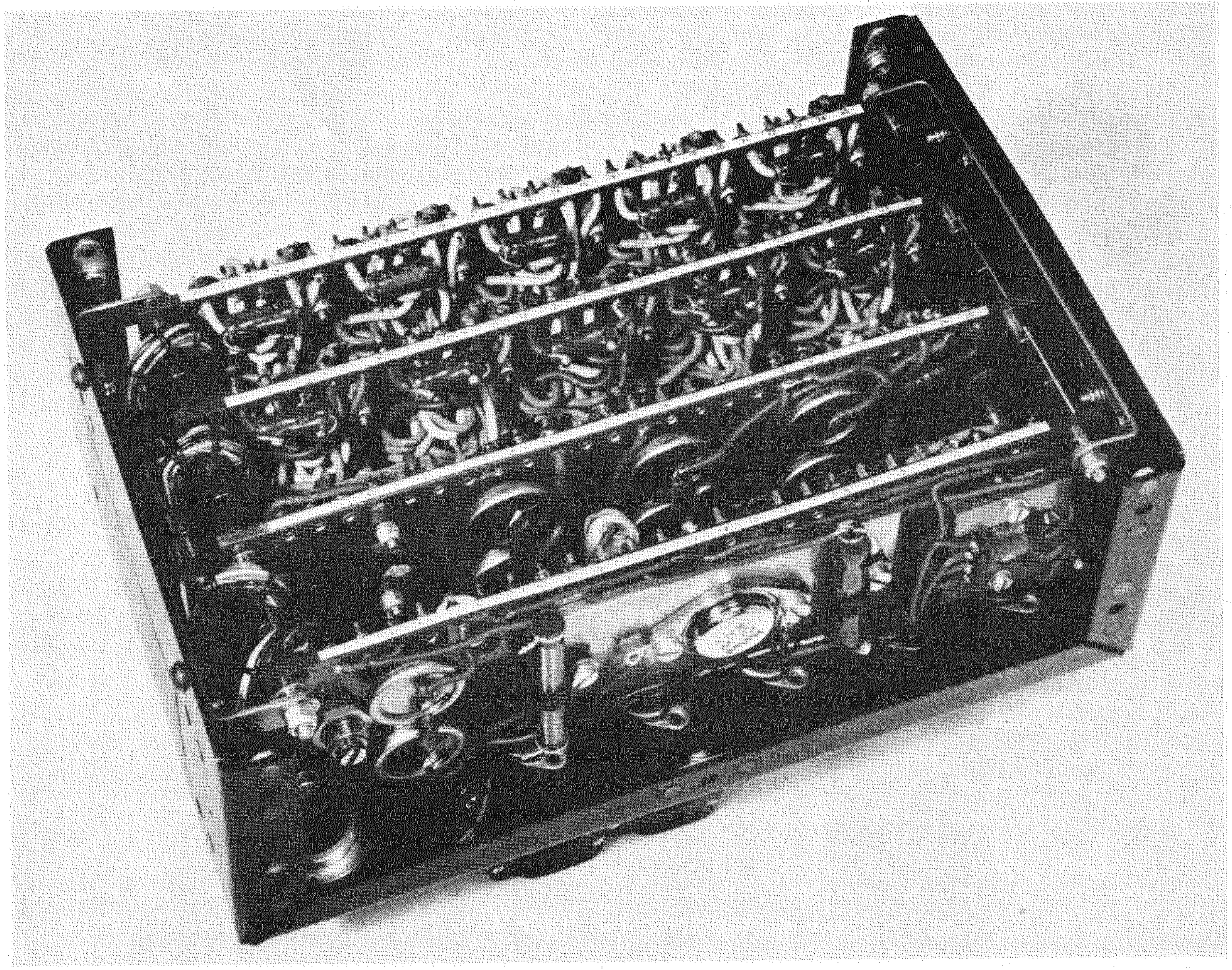


Fig.8 Displacement unit,wiring layout

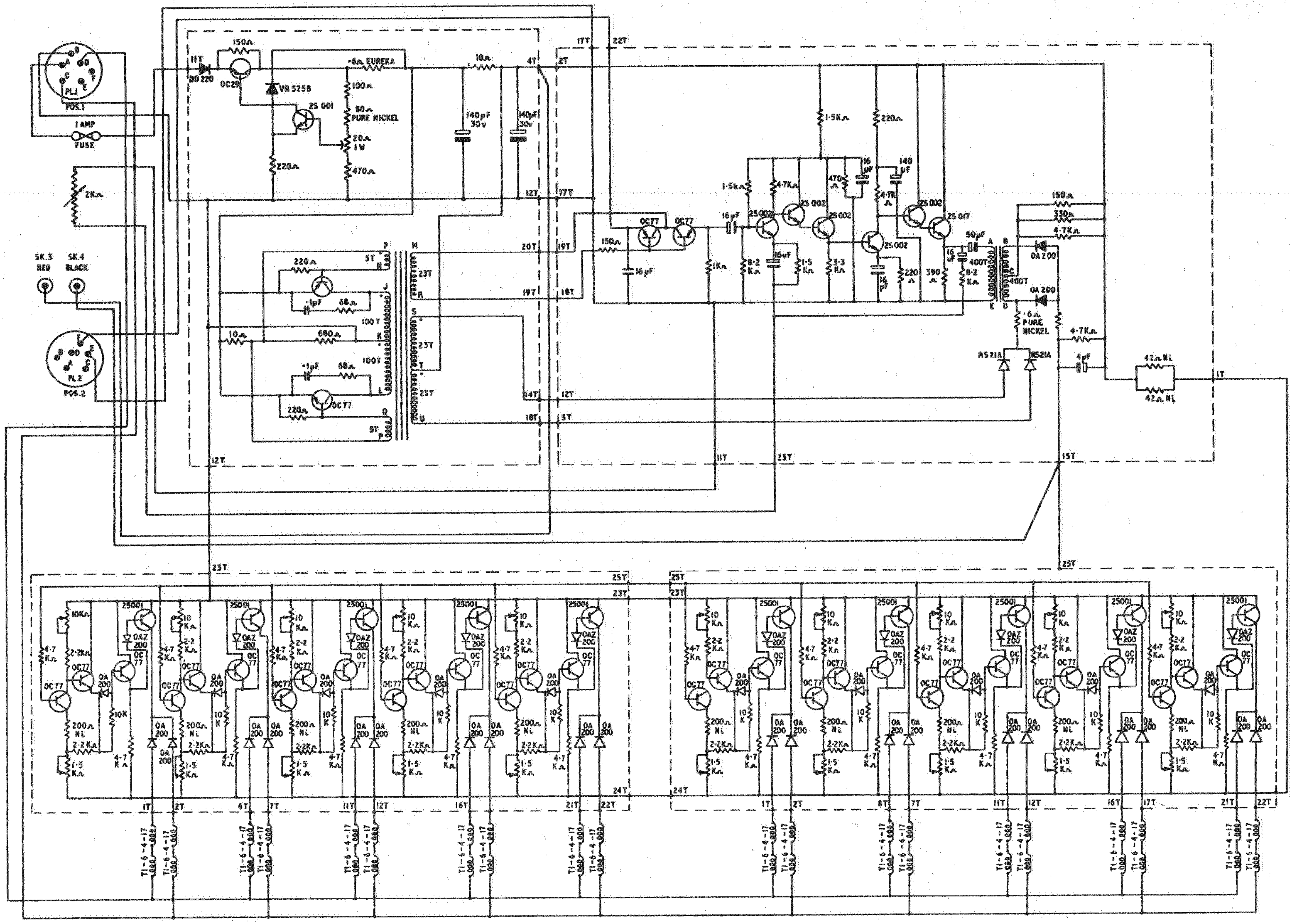
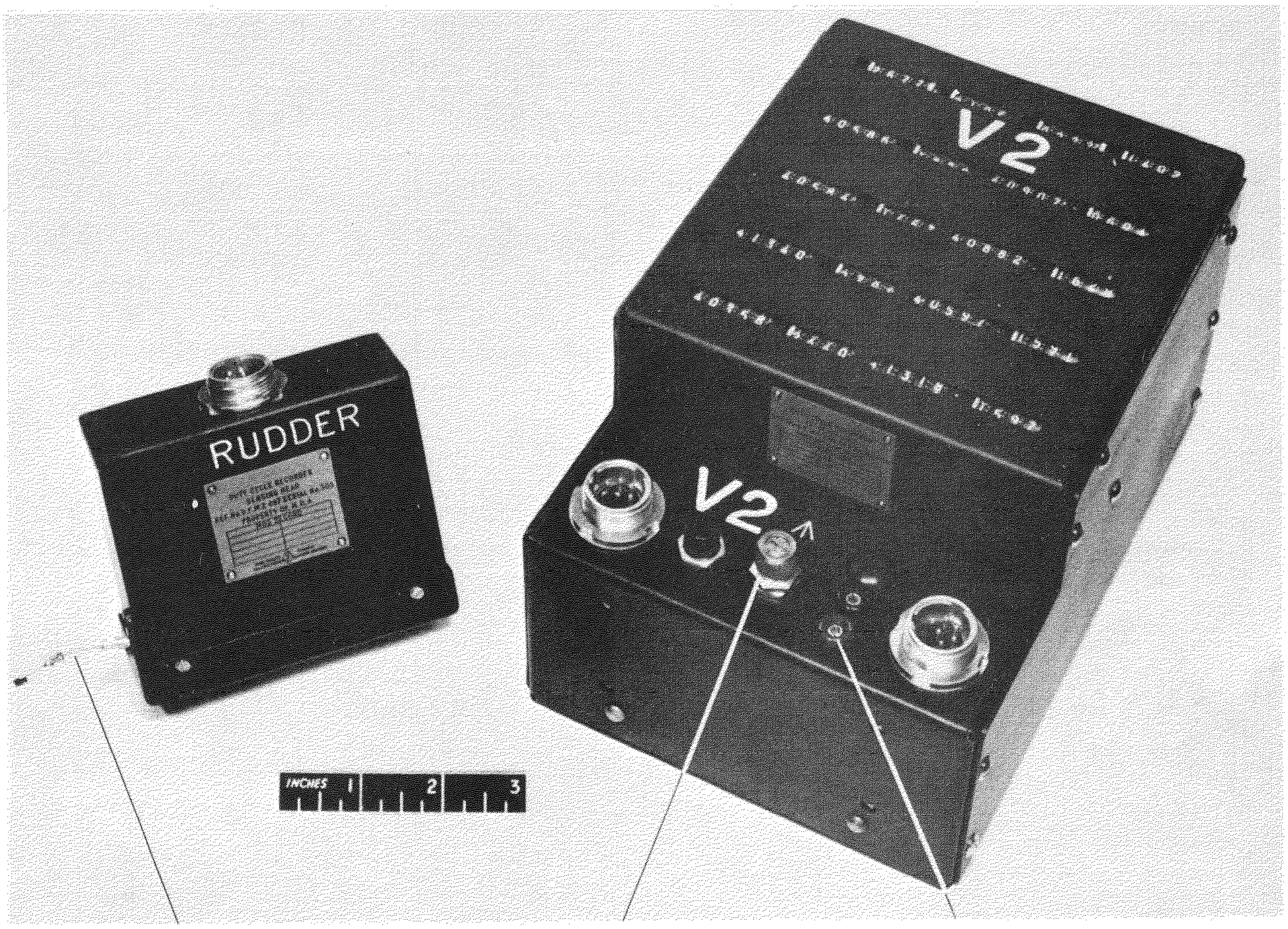


FIG.9 VELOCITY UNIT, CIRCUIT DIAGRAM

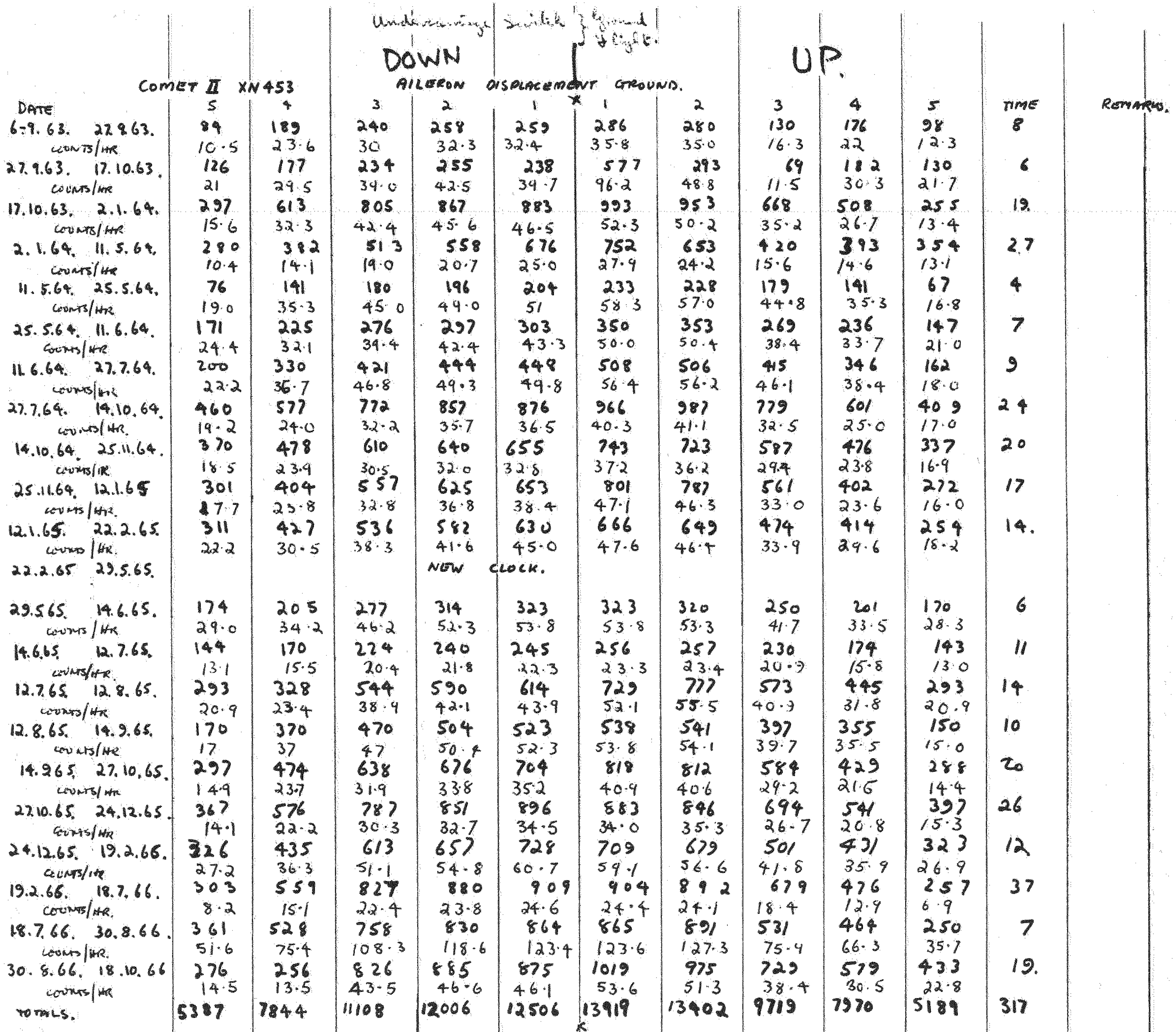


Operating cable

Range control

Test sockets

Fig.10 Velocity unit and sensing head



COMET II XN453

Undercarriage Switch } Ground & Flight.

AILERON DISPLACEMENT GROUND.

DATE	DOWN 5	4	3	2	1	UP. 1	2	3	4	5	TIME	REMARKS.
6.9.63. 22.9.63.	84	189	240	258	259	286	280	130	176	98	8	
COUNTS/HR	10.5	23.6	30	32.3	32.4	35.8	35.0	16.3	22	12.3		
27.9.63. 17.10.63.	126	177	234	255	238	577	293	69	182	130	6	
COUNTS/HR	21	29.5	39.0	42.5	39.7	96.2	48.8	11.5	30.3	21.7		
17.10.63. 2.1.64.	297	613	805	867	883	993	953	668	508	255	19.	
COUNTS/HR	15.6	32.3	42.4	45.6	46.5	52.3	50.2	35.2	26.7	13.4		
2.1.64. 11.5.64.	280	382	513	558	676	752	653	420	393	354	27	
COUNTS/HR	10.4	14.1	19.0	20.7	25.0	27.9	24.2	15.6	14.6	13.1		
11.5.64. 25.5.64.	76	141	180	196	204	233	228	179	141	67	4	
COUNTS/HR	19.0	35.3	45.0	49.0	51	58.3	57.0	44.8	35.3	16.8		
25.5.64. 11.6.64.	171	225	276	297	303	350	353	269	236	147	7	
COUNTS/HR	24.4	32.1	39.4	42.4	43.3	50.0	50.4	38.4	33.7	21.0		
11.6.64. 27.7.64.	200	330	421	444	448	508	506	415	346	162	9	
COUNTS/HR	22.2	36.7	46.8	49.3	49.8	56.4	56.2	46.1	38.4	18.0		
27.7.64. 14.10.64.	460	577	772	857	876	966	987	779	601	409	24	
COUNTS/HR.	19.2	24.0	32.2	35.7	36.5	40.3	41.1	32.5	25.0	17.0		
14.10.64. 25.11.64.	370	478	610	640	655	743	723	587	476	337	20	
COUNTS/HR	18.5	23.9	30.5	32.0	32.8	37.2	36.2	29.4	23.8	16.9		
25.11.64. 12.1.65	301	404	557	625	653	801	787	561	402	272	17	
COUNTS/HR.	17.7	23.8	32.8	36.8	38.4	47.1	46.3	33.0	23.6	16.0		
12.1.65. 22.2.65.	311	427	536	582	630	666	649	474	414	254	14.	
COUNTS/HR.	22.2	30.5	38.3	41.6	45.0	47.6	46.4	33.9	29.6	18.2		
22.2.65 29.5.65.				NEW	CLOCK.							
29.5.65. 14.6.65.	174	205	277	314	323	323	320	250	201	170	6	
COUNTS/HR	29.0	34.2	46.2	52.3	53.8	53.8	53.3	41.7	33.5	28.3		
14.6.65. 12.7.65.	144	170	224	240	245	256	257	230	174	143	11	
COUNTS/HR.	13.1	15.5	20.4	21.8	22.3	23.3	23.4	20.9	15.8	13.0		
12.7.65. 12.8.65.	293	328	544	590	614	729	777	573	445	293	14	
COUNTS/HR	20.9	23.4	38.9	42.1	43.9	52.1	55.5	40.9	31.8	20.9		
12.8.65. 14.9.65.	170	370	470	504	523	538	541	397	355	150	10	
COUNTS/HR	17	37	47	50.4	52.3	53.8	54.1	39.7	35.5	15.0		
14.9.65. 27.10.65.	297	474	638	676	704	818	812	584	429	288	20	
COUNTS/HR	14.9	23.7	31.9	33.8	35.2	40.9	40.6	29.2	21.6	14.4		
27.10.65. 24.12.65.	367	576	787	851	896	883	846	694	541	397	26	
COUNTS/HR	14.1	22.2	30.3	32.7	34.5	34.0	35.3	26.7	20.8	15.3		
24.12.65. 19.2.66.	326	435	613	657	728	709	679	501	431	323	12	
COUNTS/HR	27.2	36.3	51.1	54.8	60.7	59.1	56.6	41.8	35.9	26.9		
19.2.66. 18.7.66.	303	559	827	880	909	904	892	679	476	257	37	
COUNTS/HR.	8.2	15.1	22.4	23.8	24.6	24.4	24.1	18.4	12.9	6.9		
18.7.66. 30.8.66.	361	528	758	830	864	865	891	531	464	250	7	
COUNTS/HR.	51.6	75.4	108.3	118.6	123.4	123.6	127.3	75.4	66.3	35.7		
30.8.66. 18.10.66	276	256	826	885	875	1019	975	729	579	433	19.	
COUNTS/HR	14.5	13.5	43.5	46.6	46.1	53.6	51.3	38.4	30.5	22.8		
TOTALS.	5387	7844	11108	12006	12506	13919	13402	9719	7970	5189	317	

Fig.11 Specimen record sheet

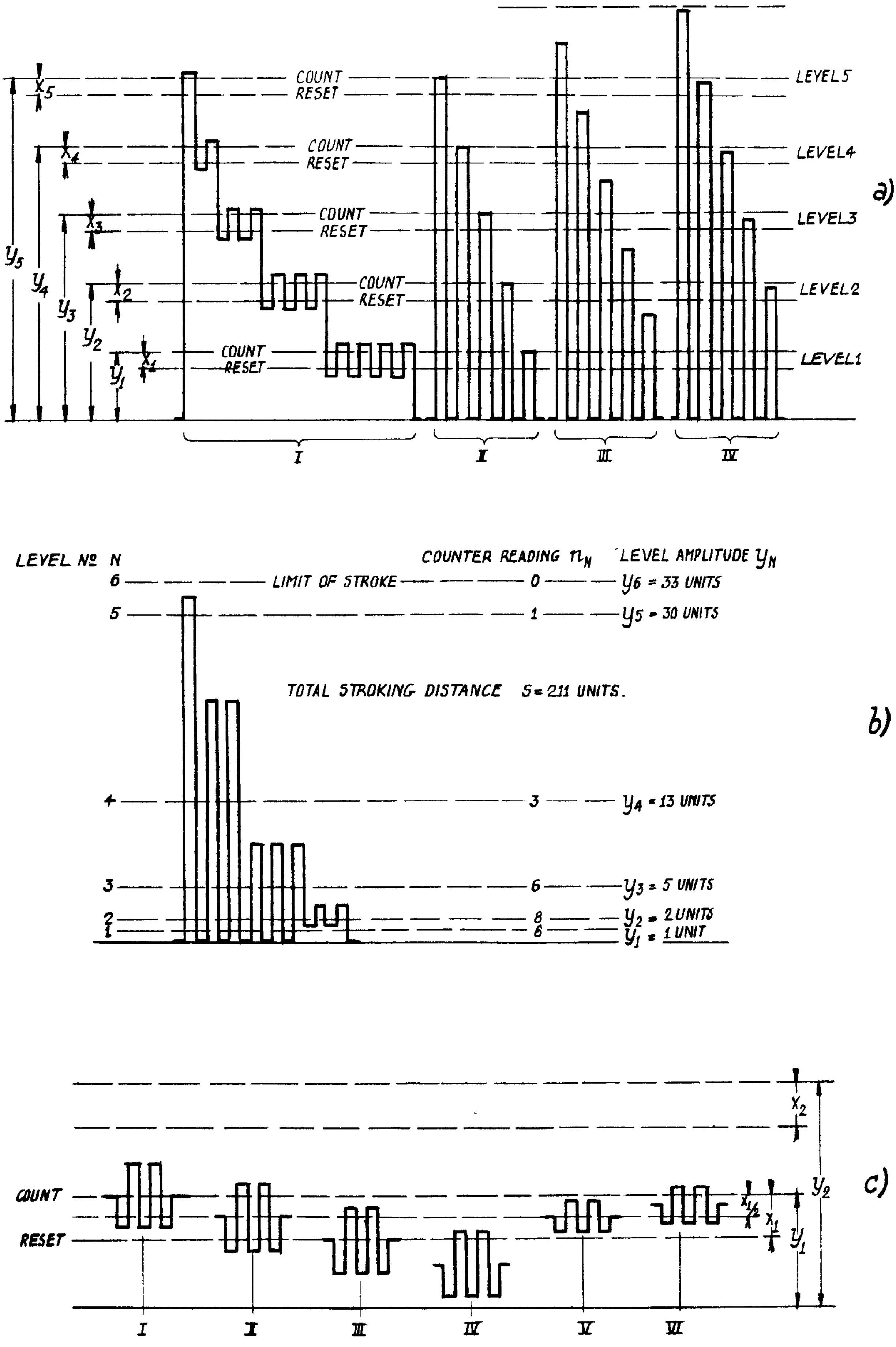


Fig.12 Reconstruction of duty cycle

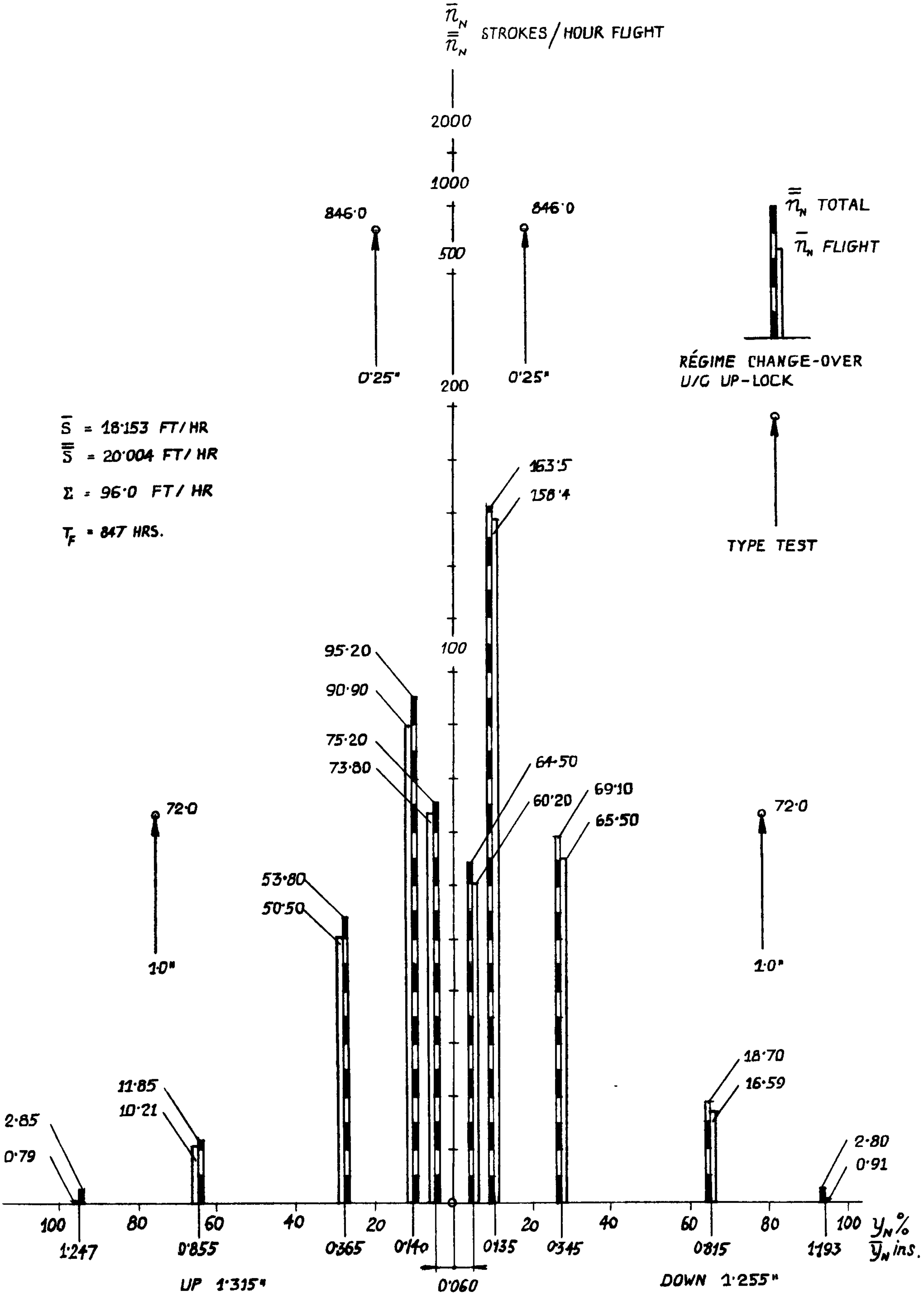


Fig.13 Hunter,aileron displacement

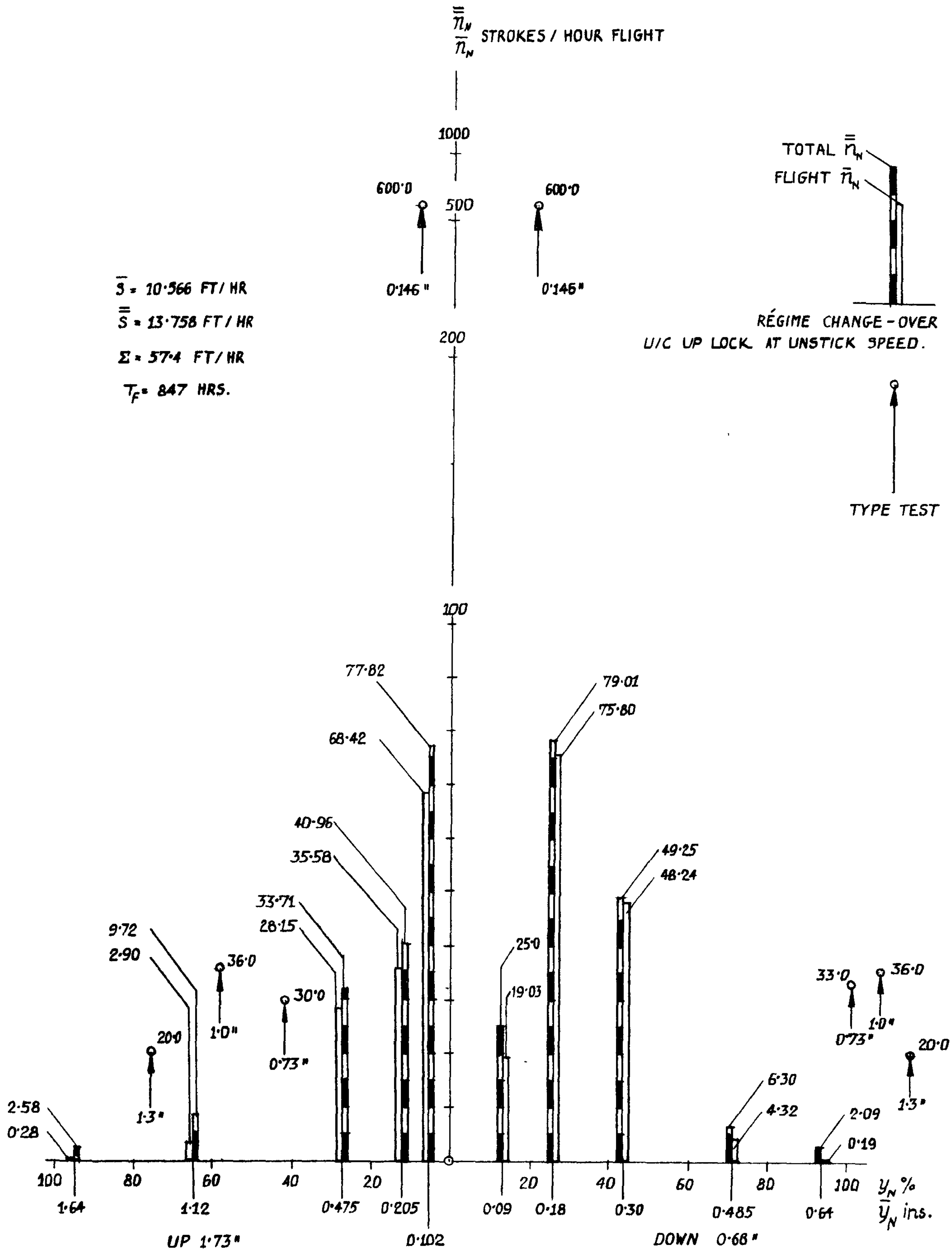


Fig.14 Hunter,elevator displacement

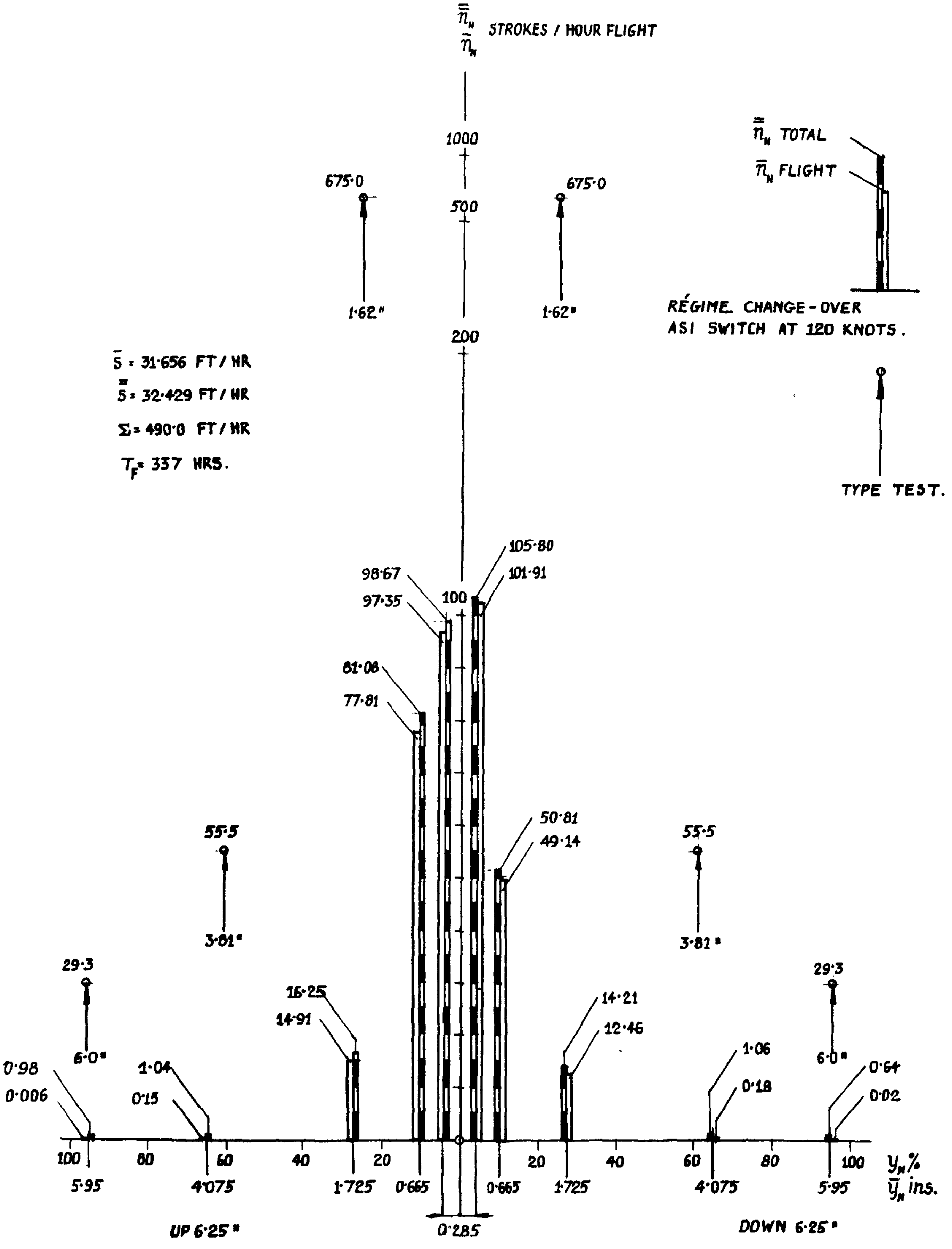
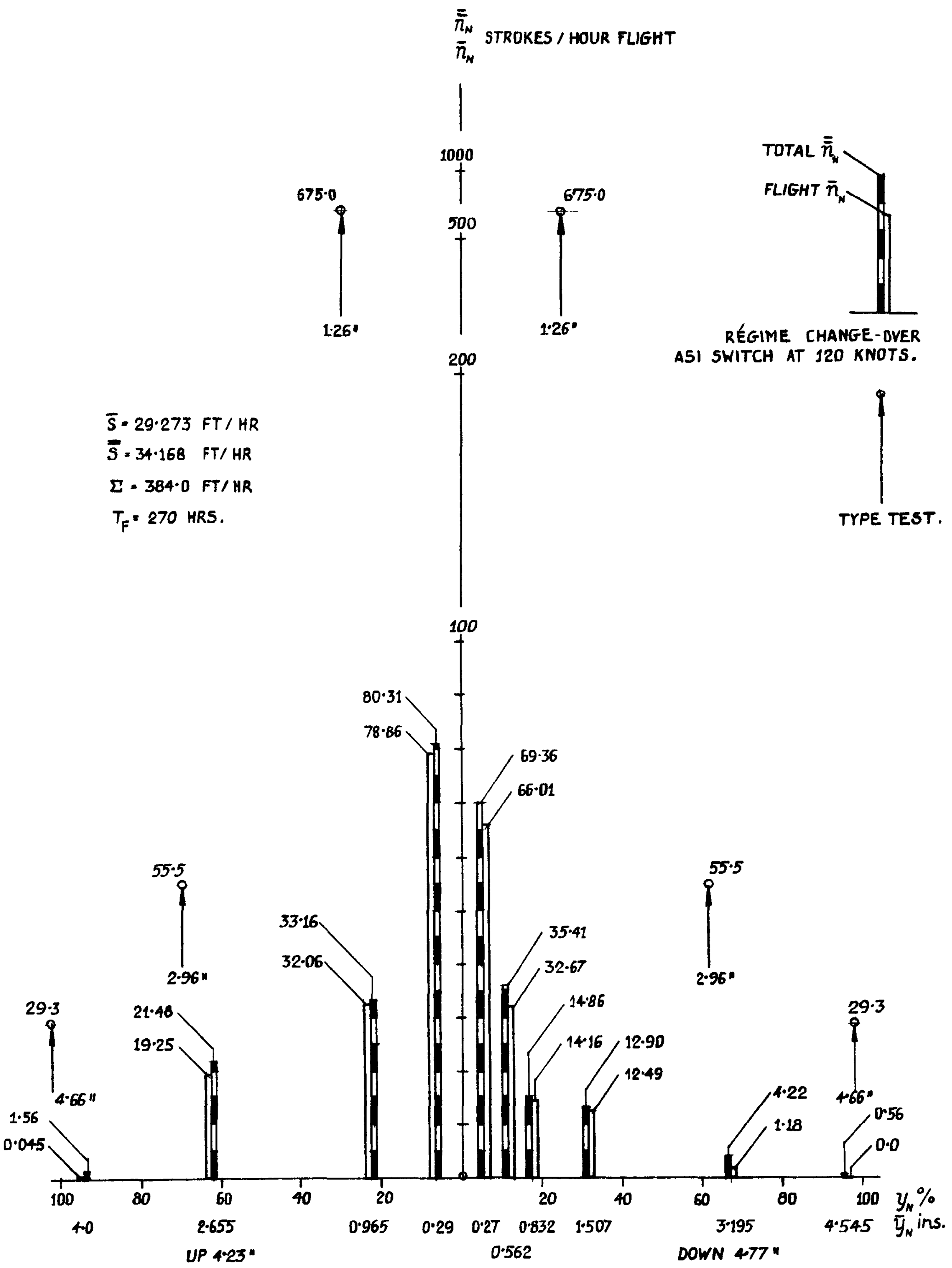


Fig.15 Valiant,aileron displacement



NEG.NO.C5904

Fig.16 Valiant,elevator displacement

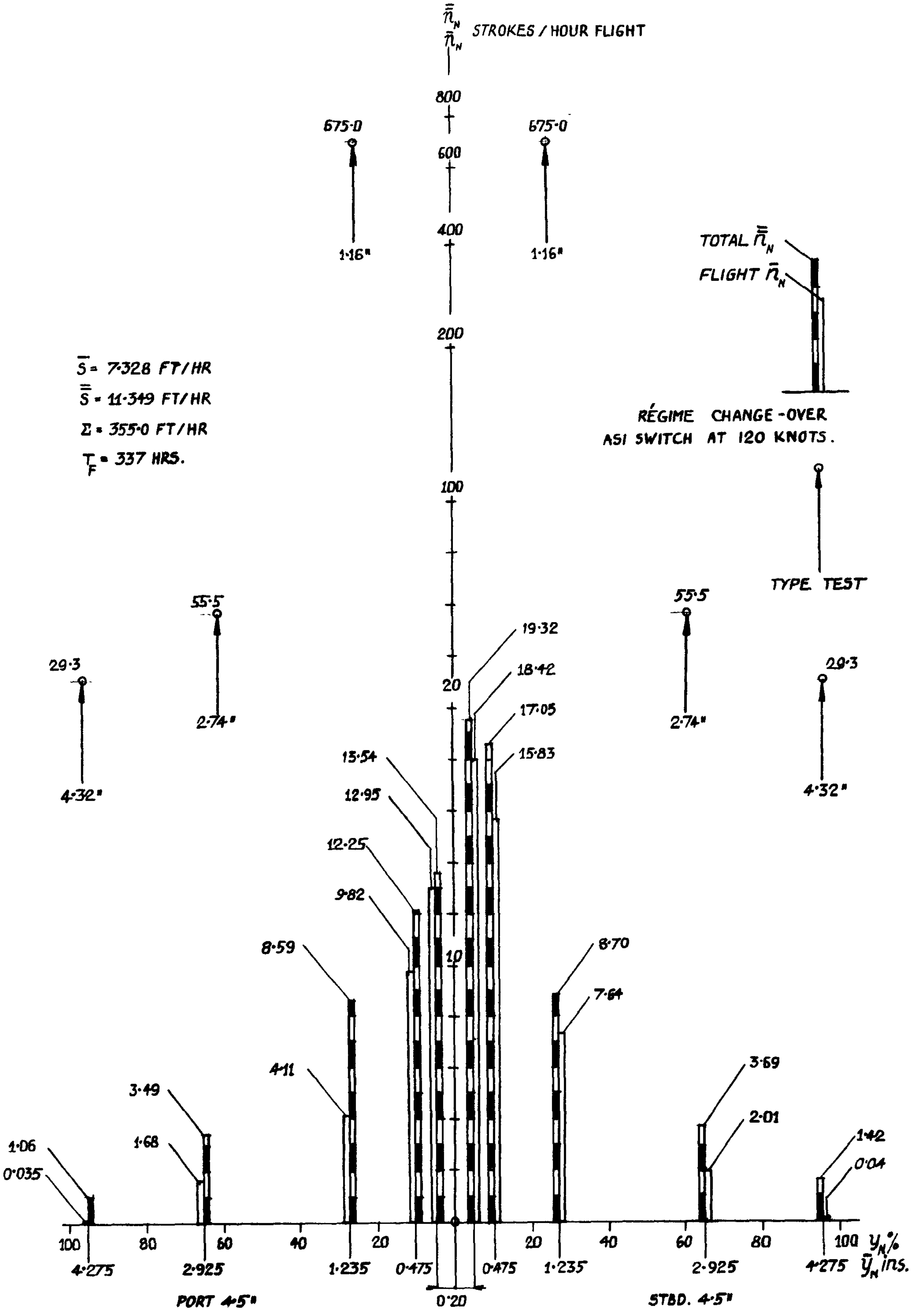


Fig.17 Valiant,rudder displacement

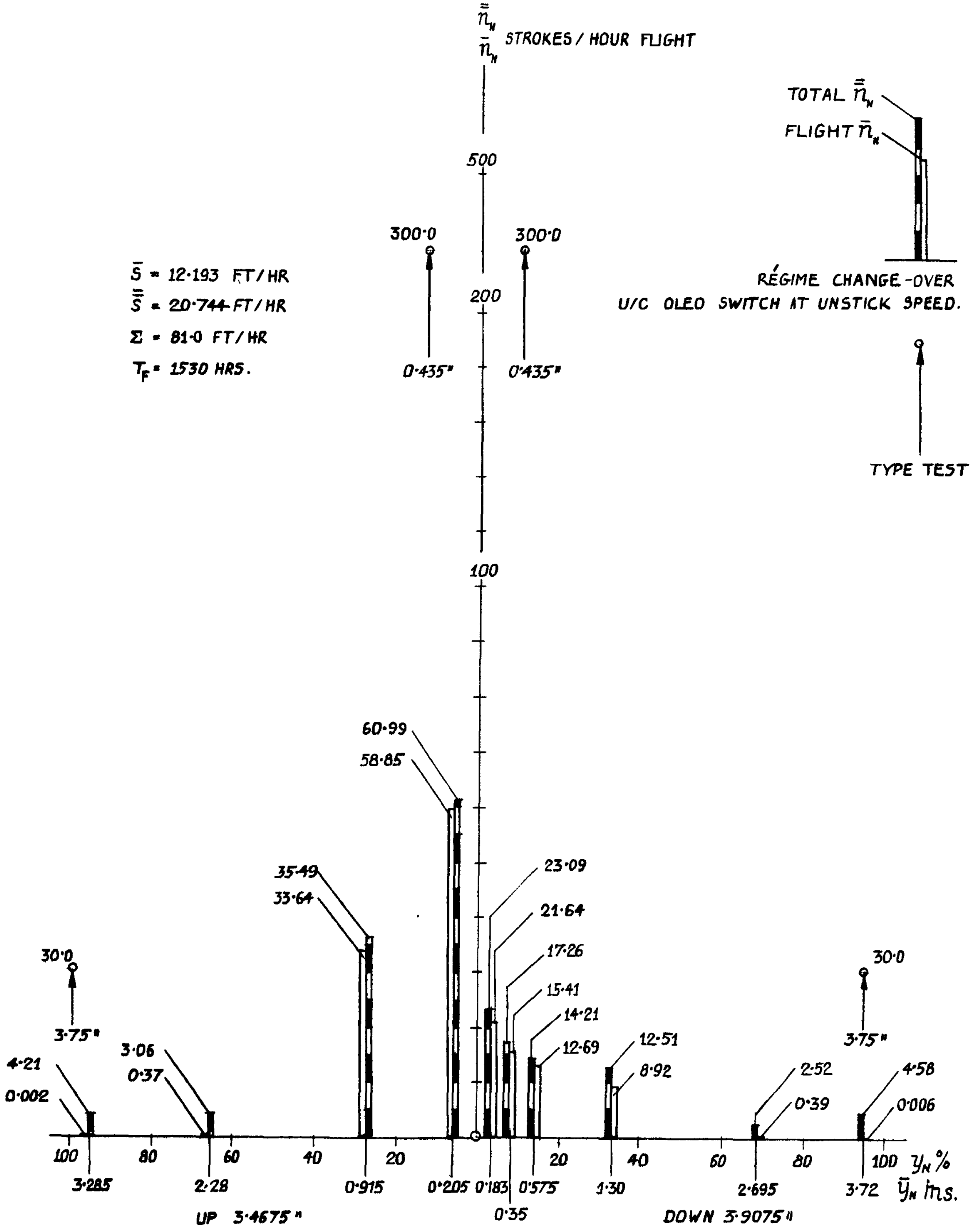


Fig.18 Comet 2,aileron displacement

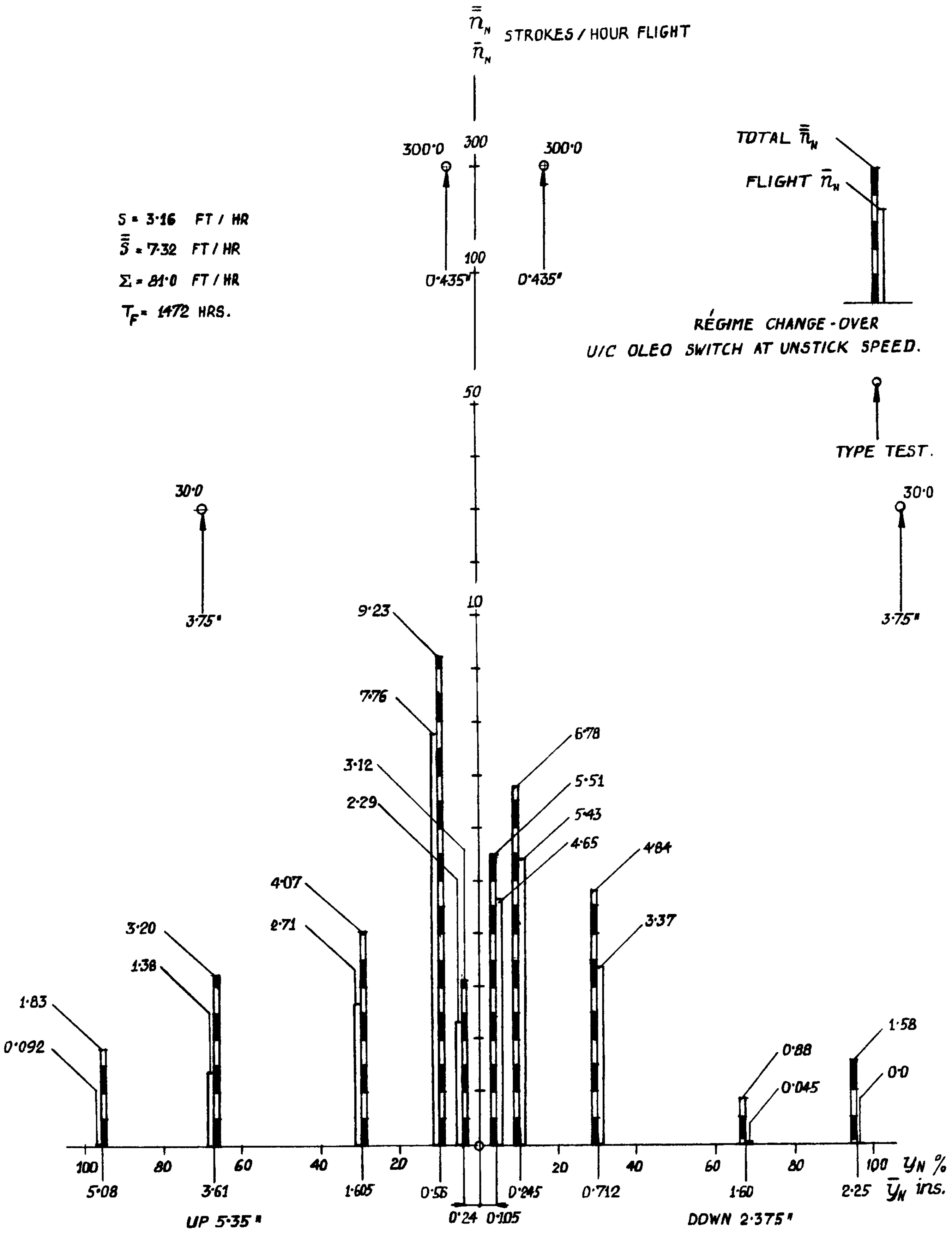


Fig.19 Comet 2,elevator displacement

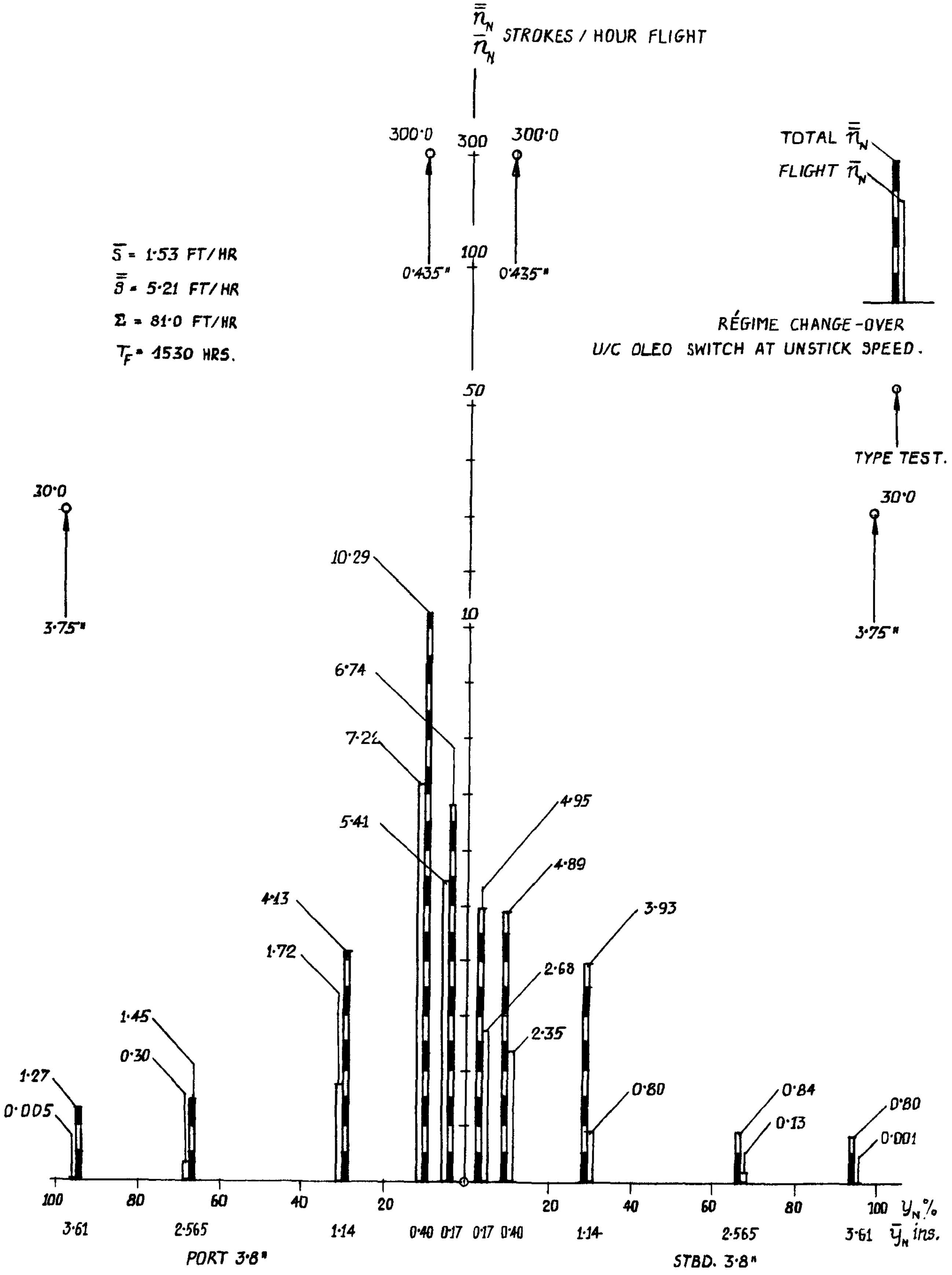


Fig.20 Comet 2,rudder displacement

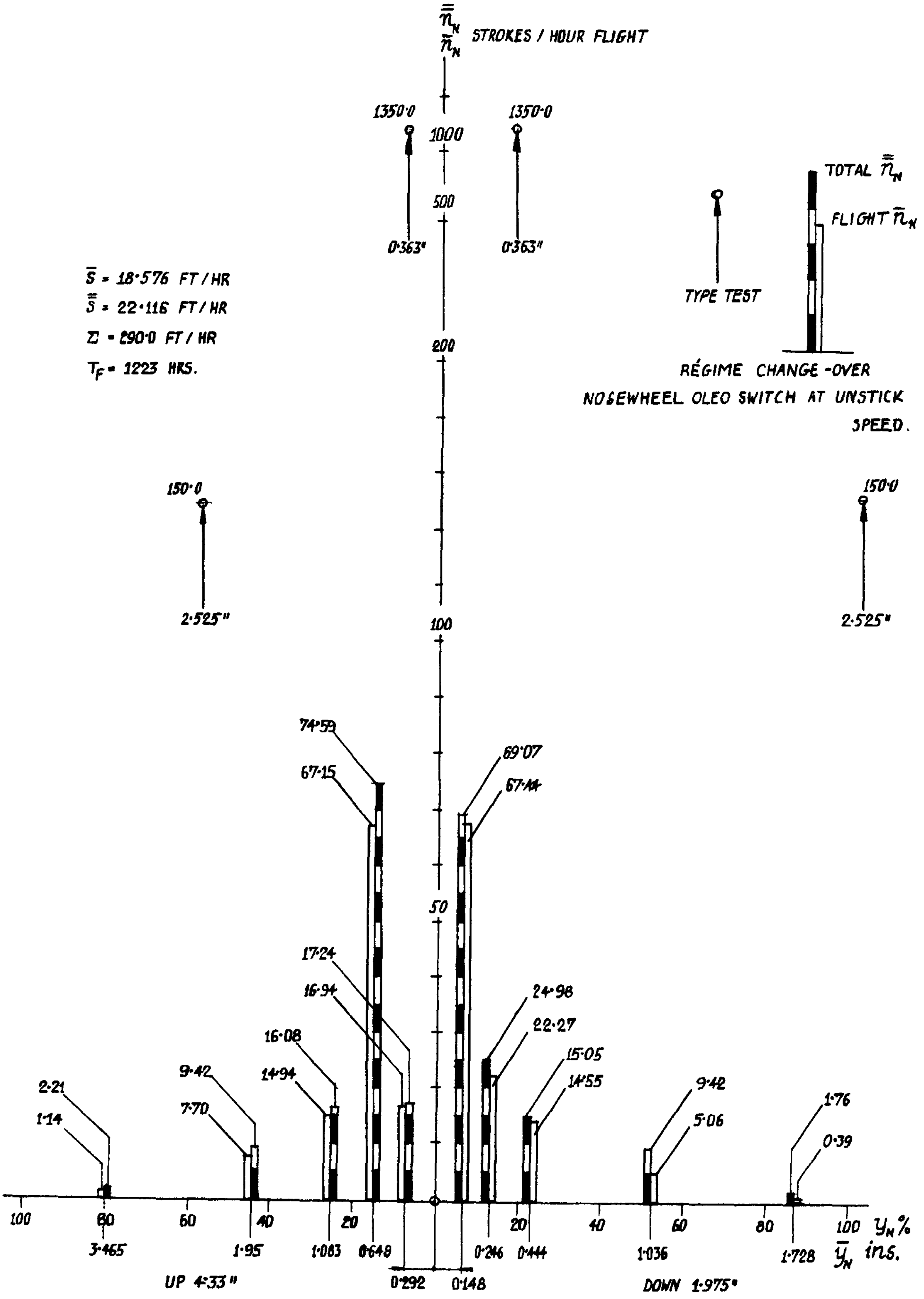


Fig.21 Vulcan 2, inboard elevon displacement

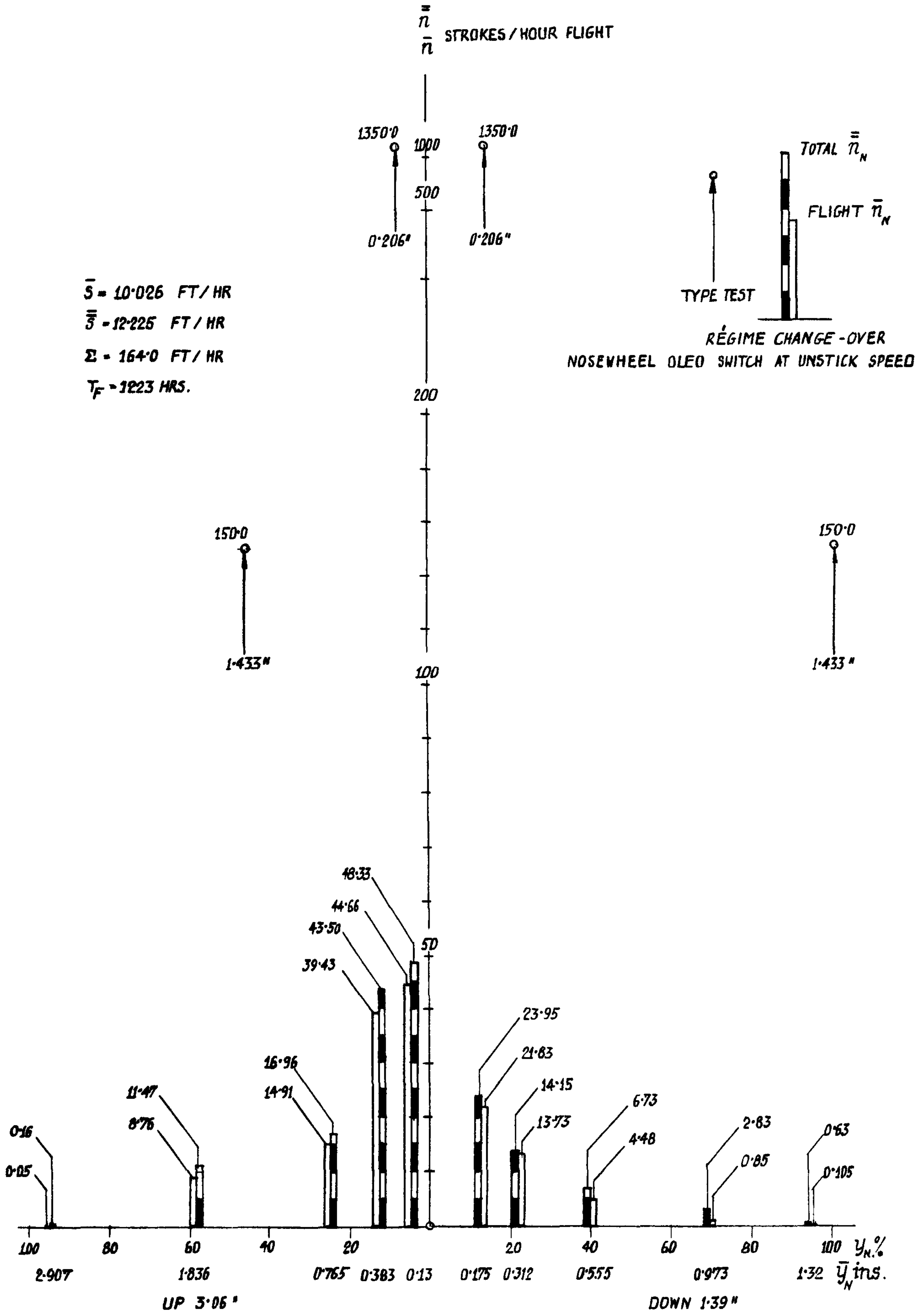


Fig.22 Vulcan 2,outboard elevon displacement

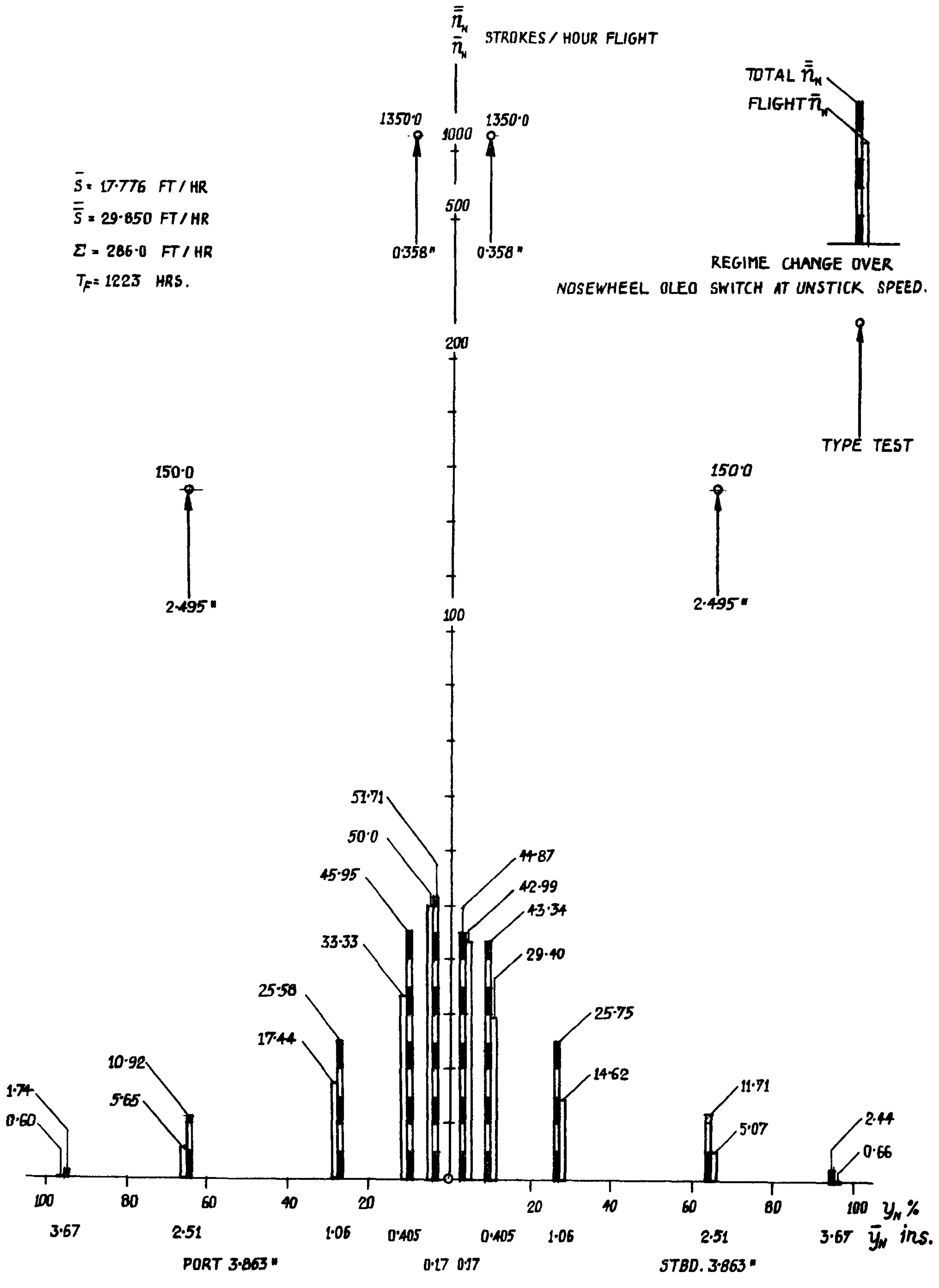


Fig.23 Vulcan 2,rudder displacement

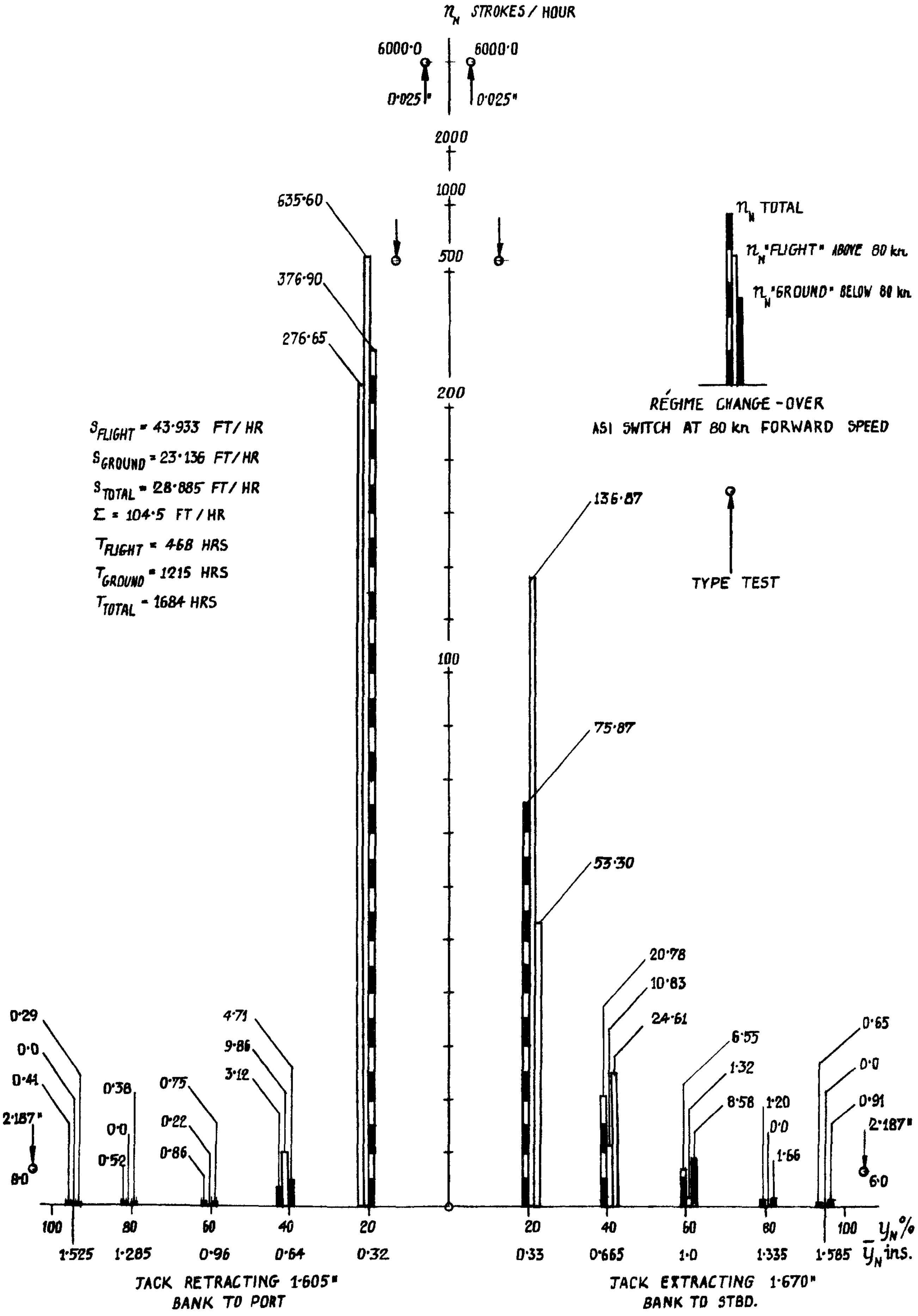


Fig.24 Wessex,port lateral displacement

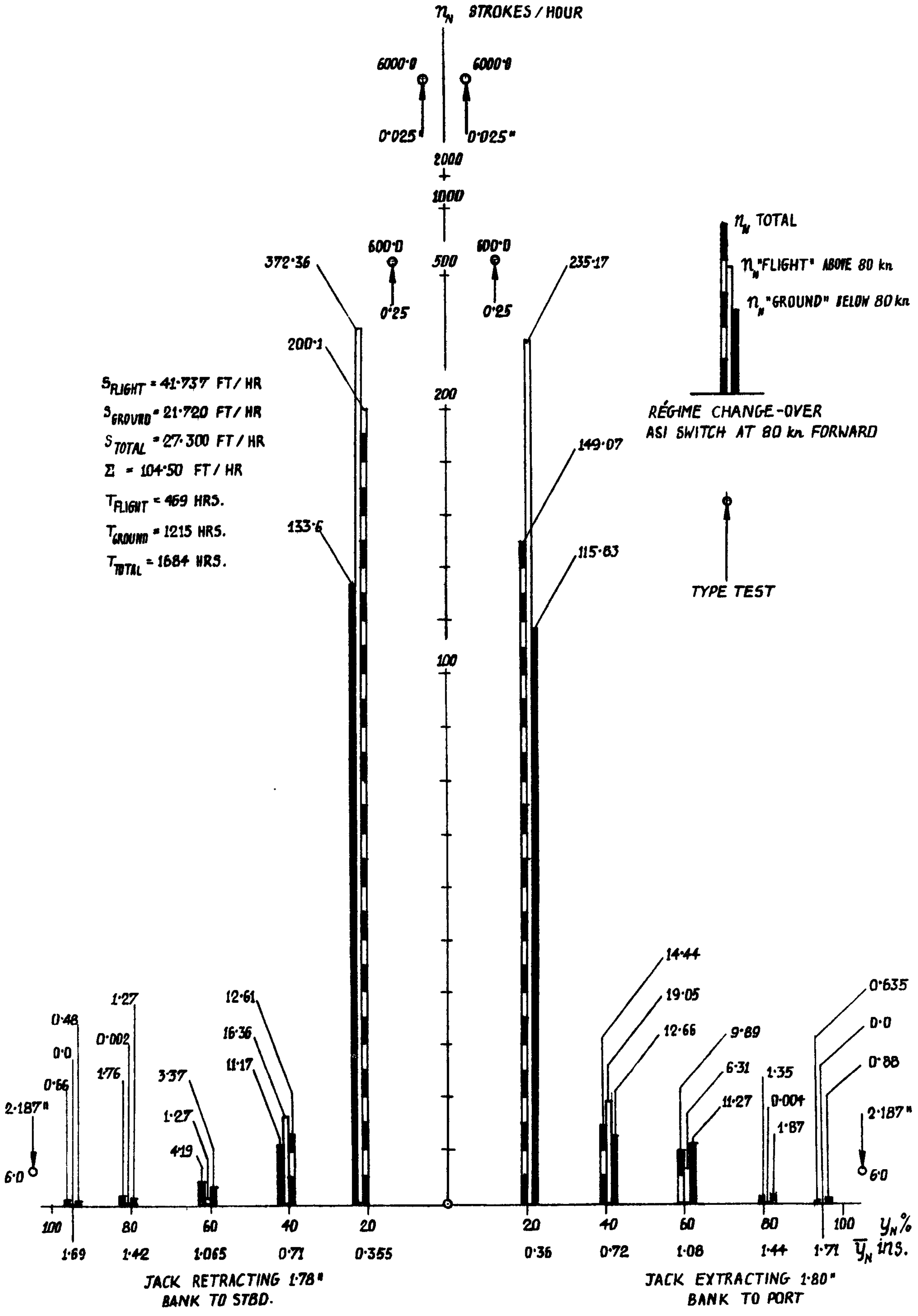


Fig.25 Wessex, stbd lateral displacement

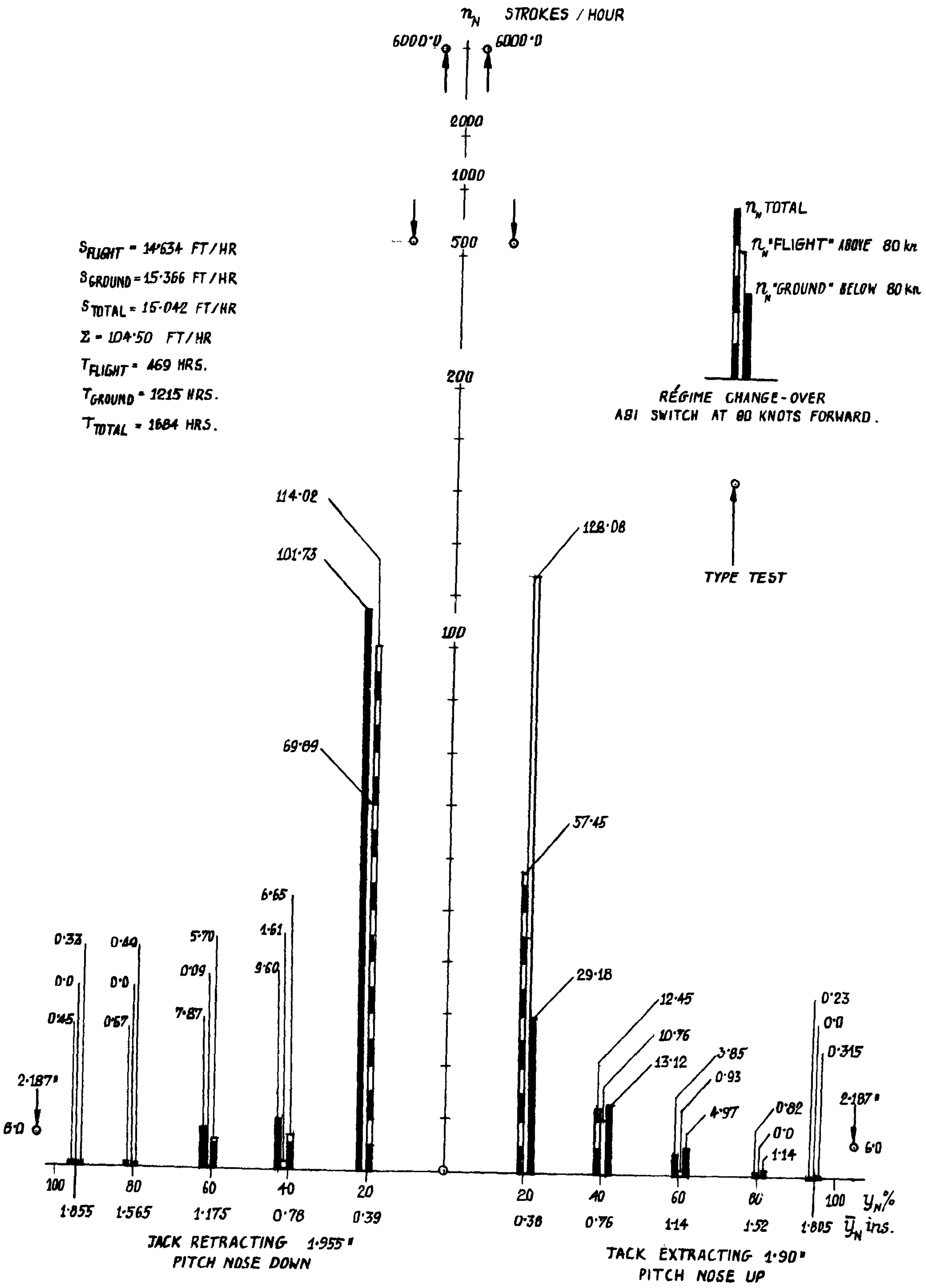


Fig.26 Wessex,fore and aft displacement

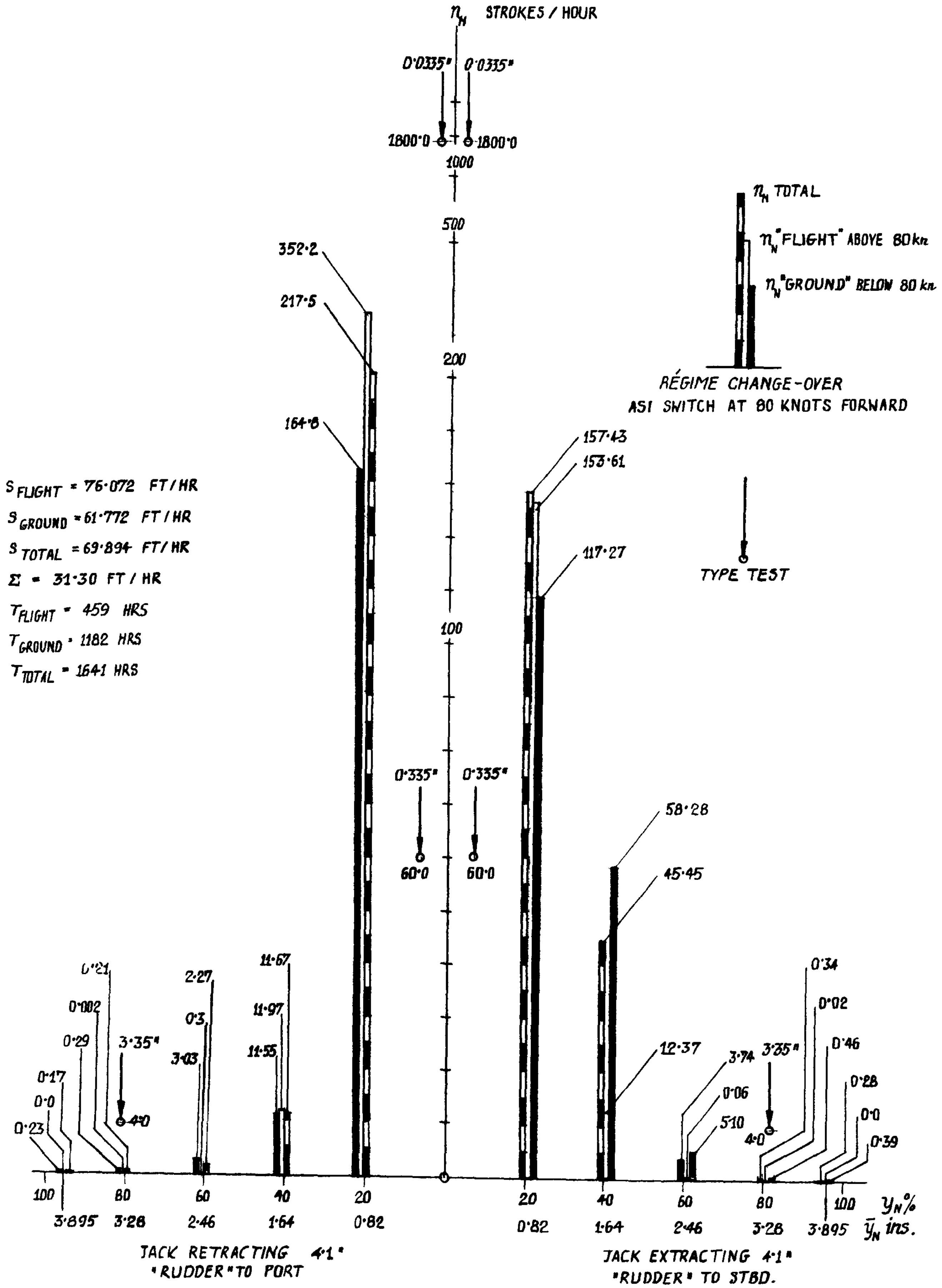


Fig.27 Wessex,yaw displacement

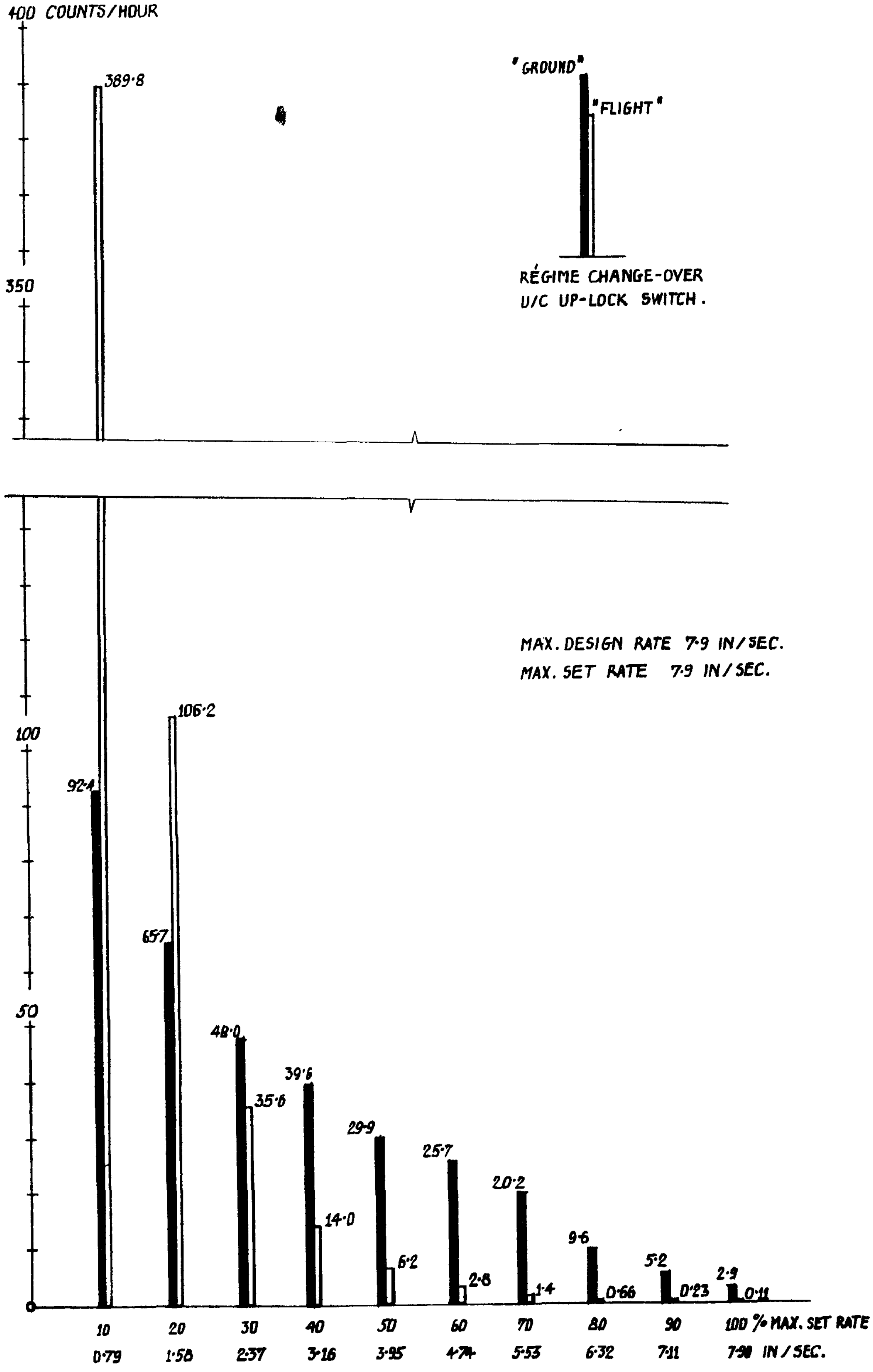


Fig.28 Hunter,aileron rate

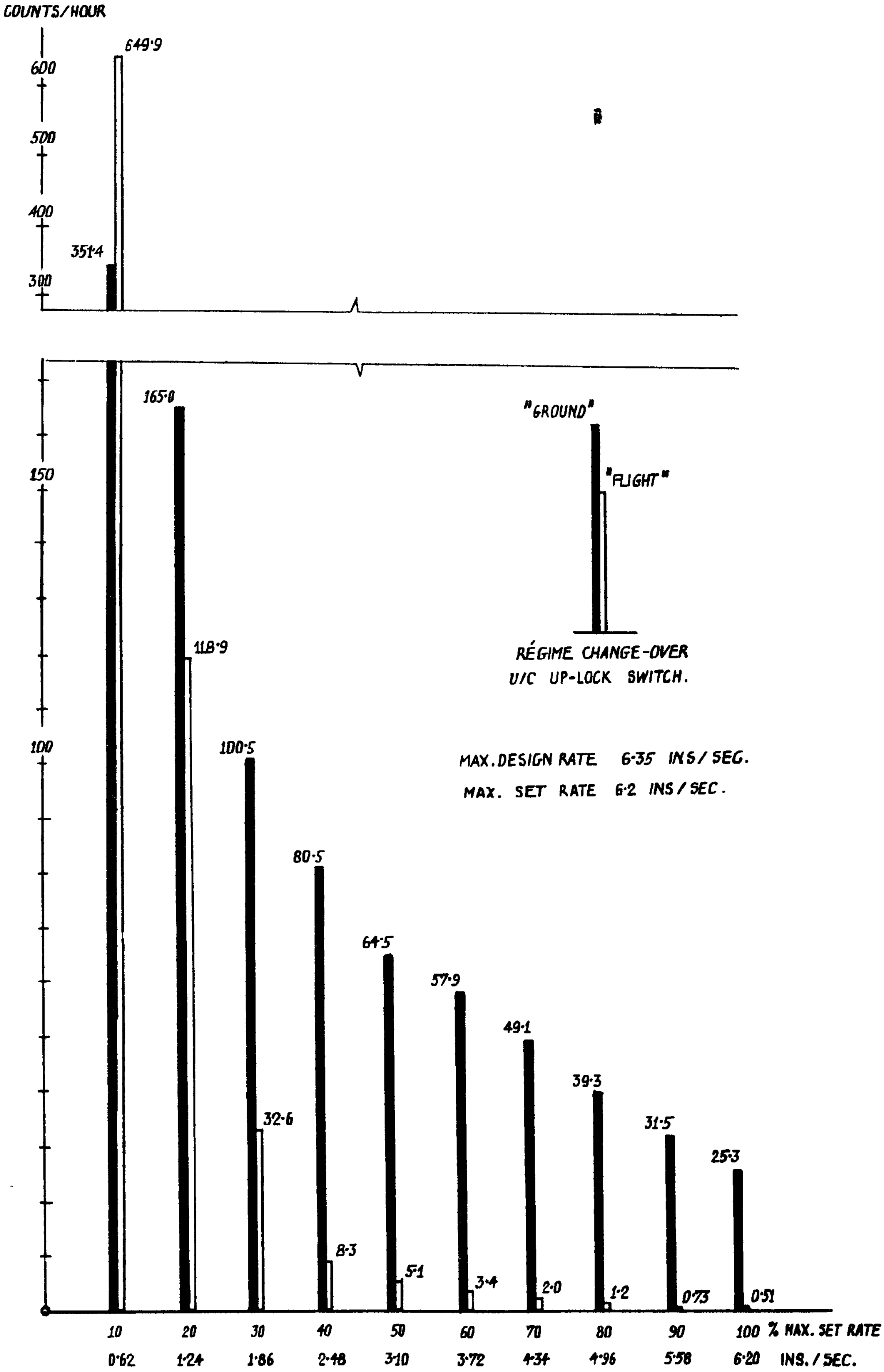


Fig.29 Hunter,elevator rate

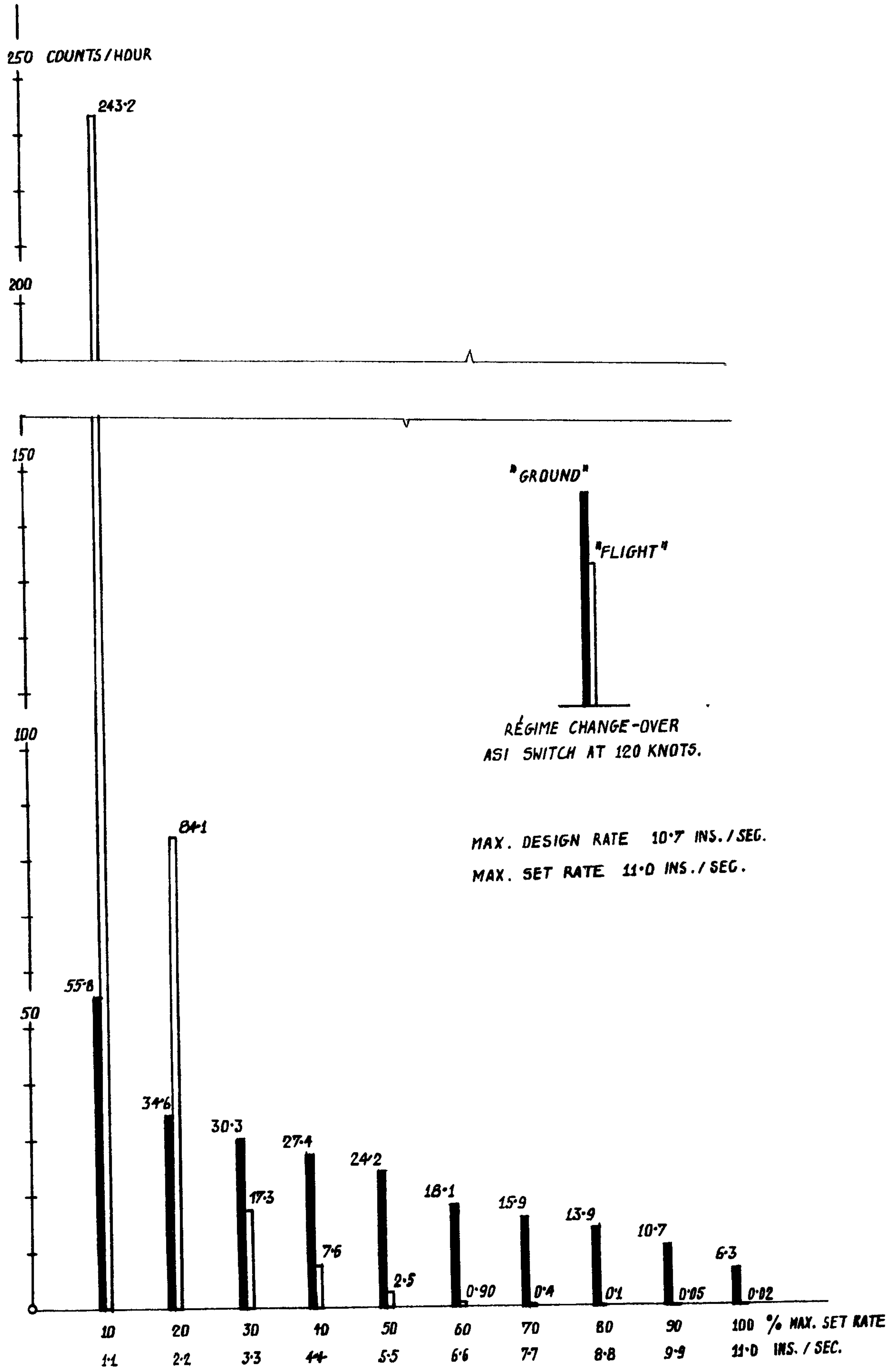


Fig.30 Valiant,aileron rate

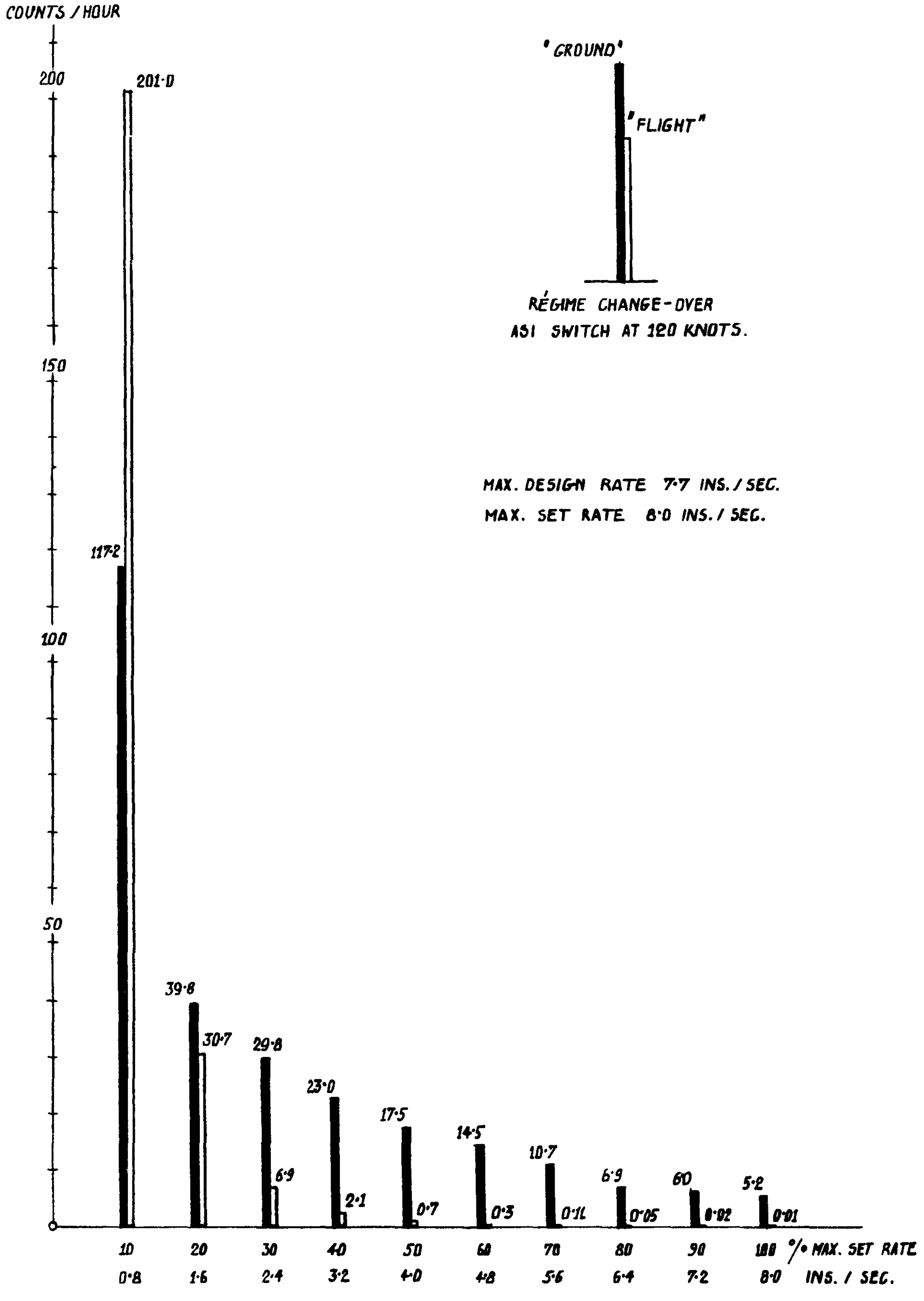


Fig.31 Valiant,elevator rate

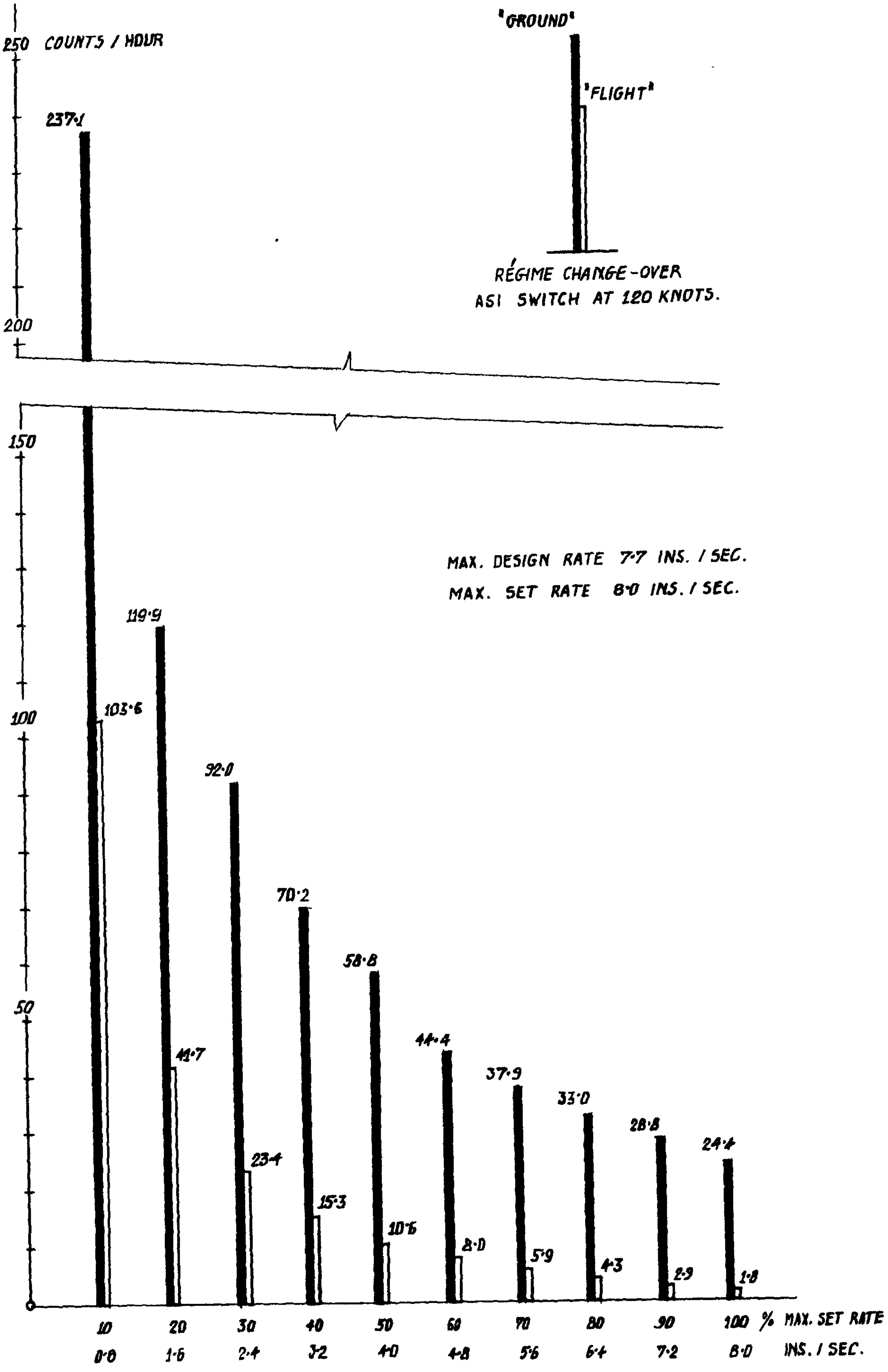


Fig.32 Valiant,rudder rate

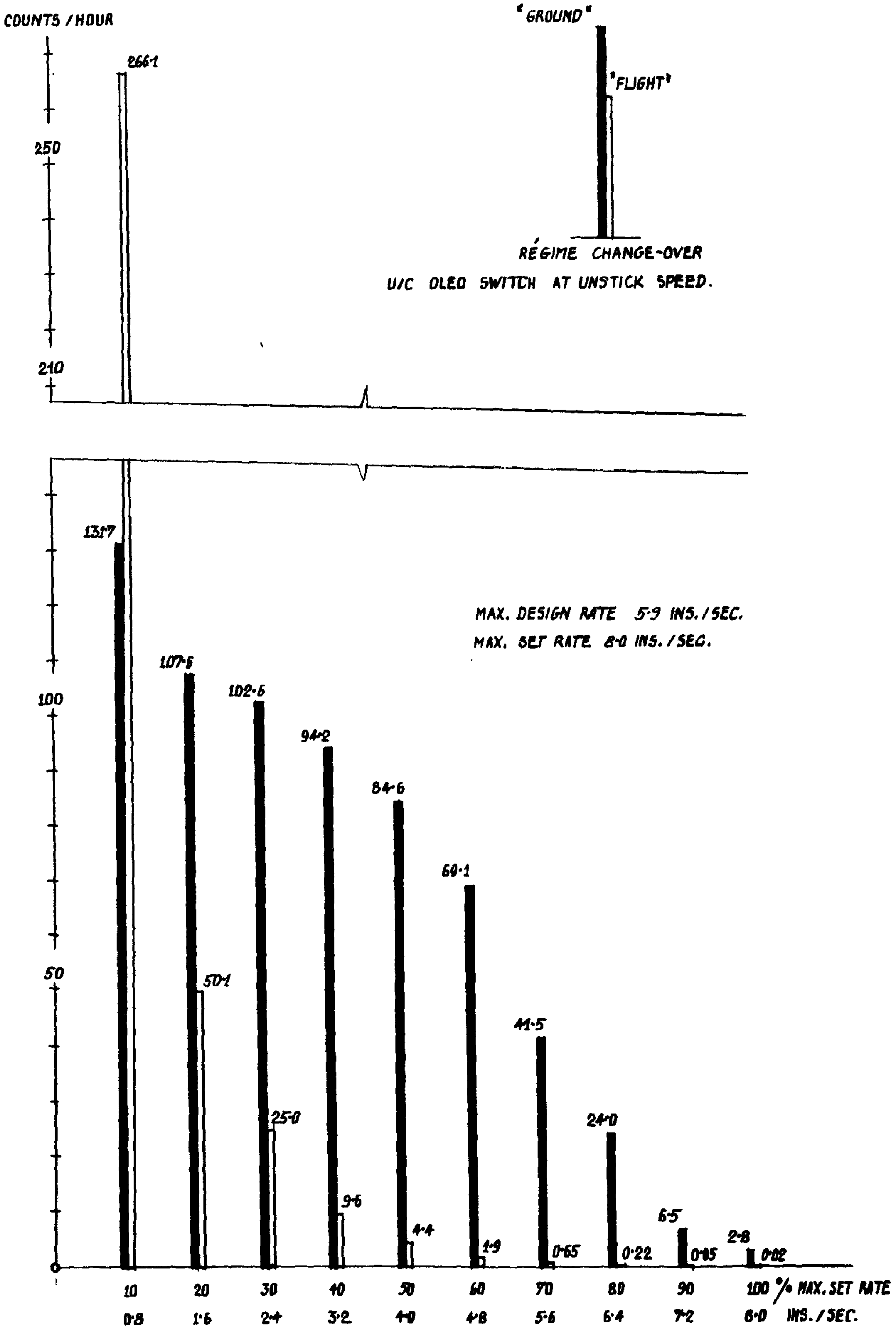
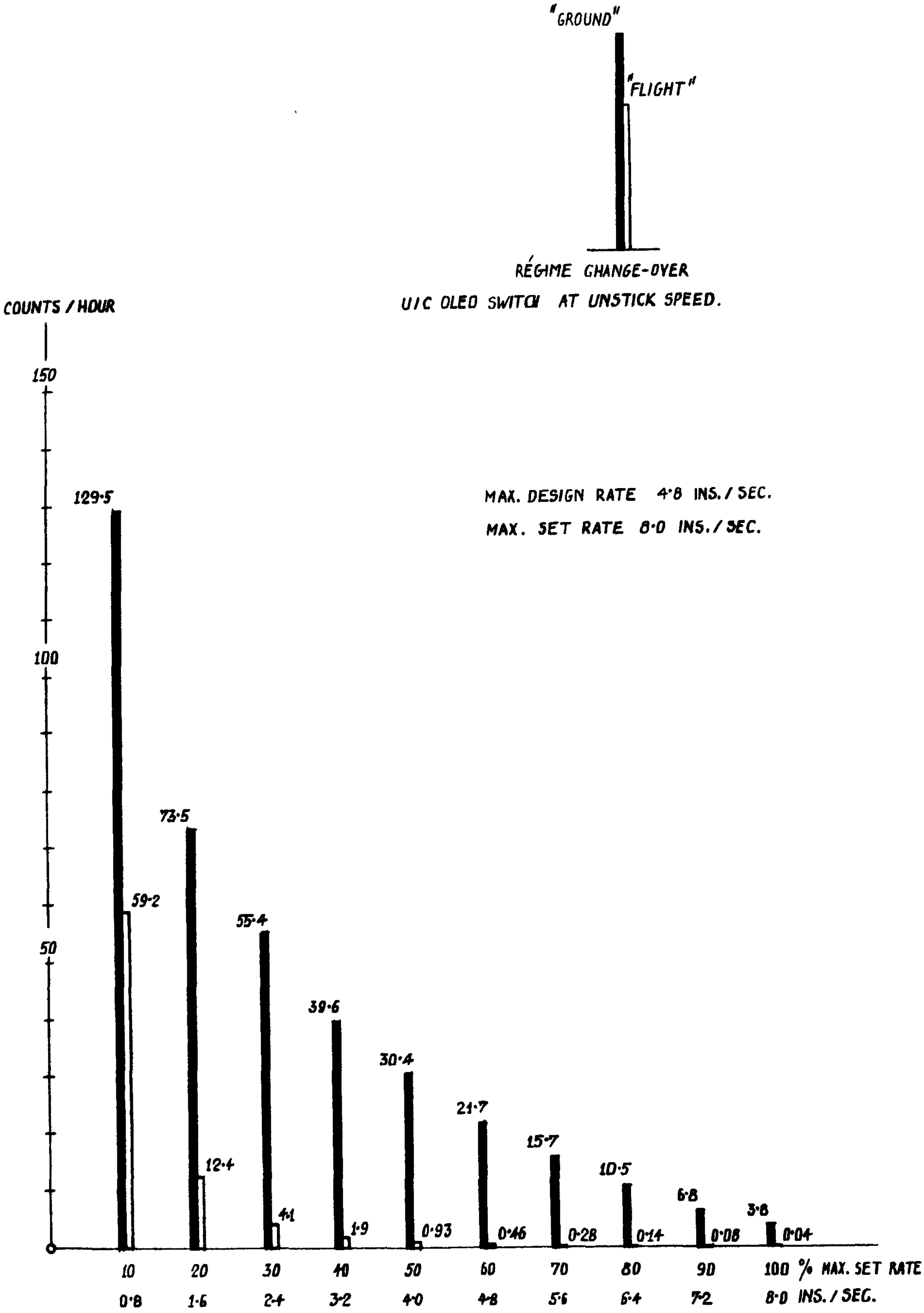


Fig.33 Comet 2,aileron rate



MAX. DESIGN RATE 4·8 INS./SEC.

MAX. SET RATE 8·0 INS./SEC.

Fig.34 Comet 2,elevator rate

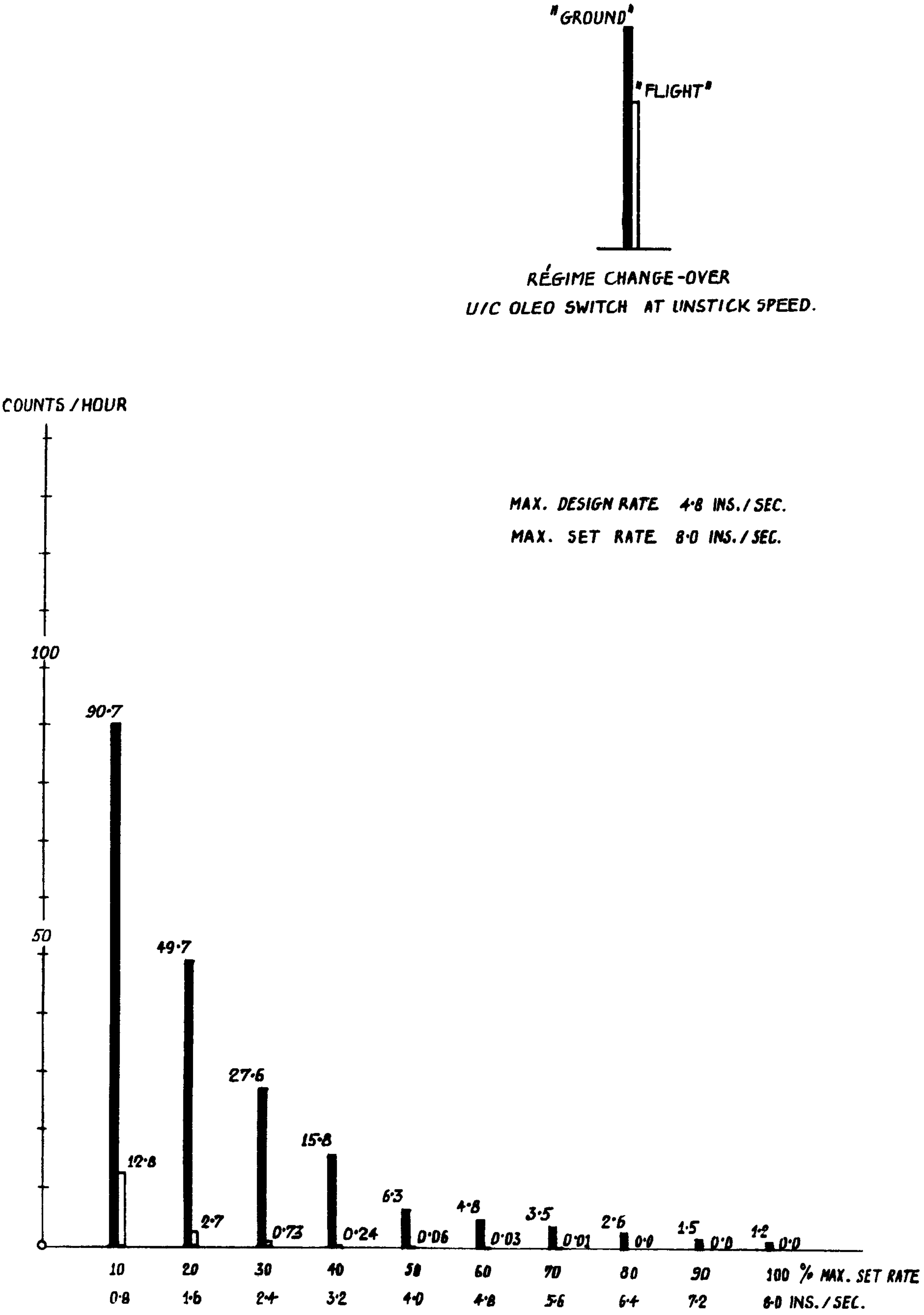
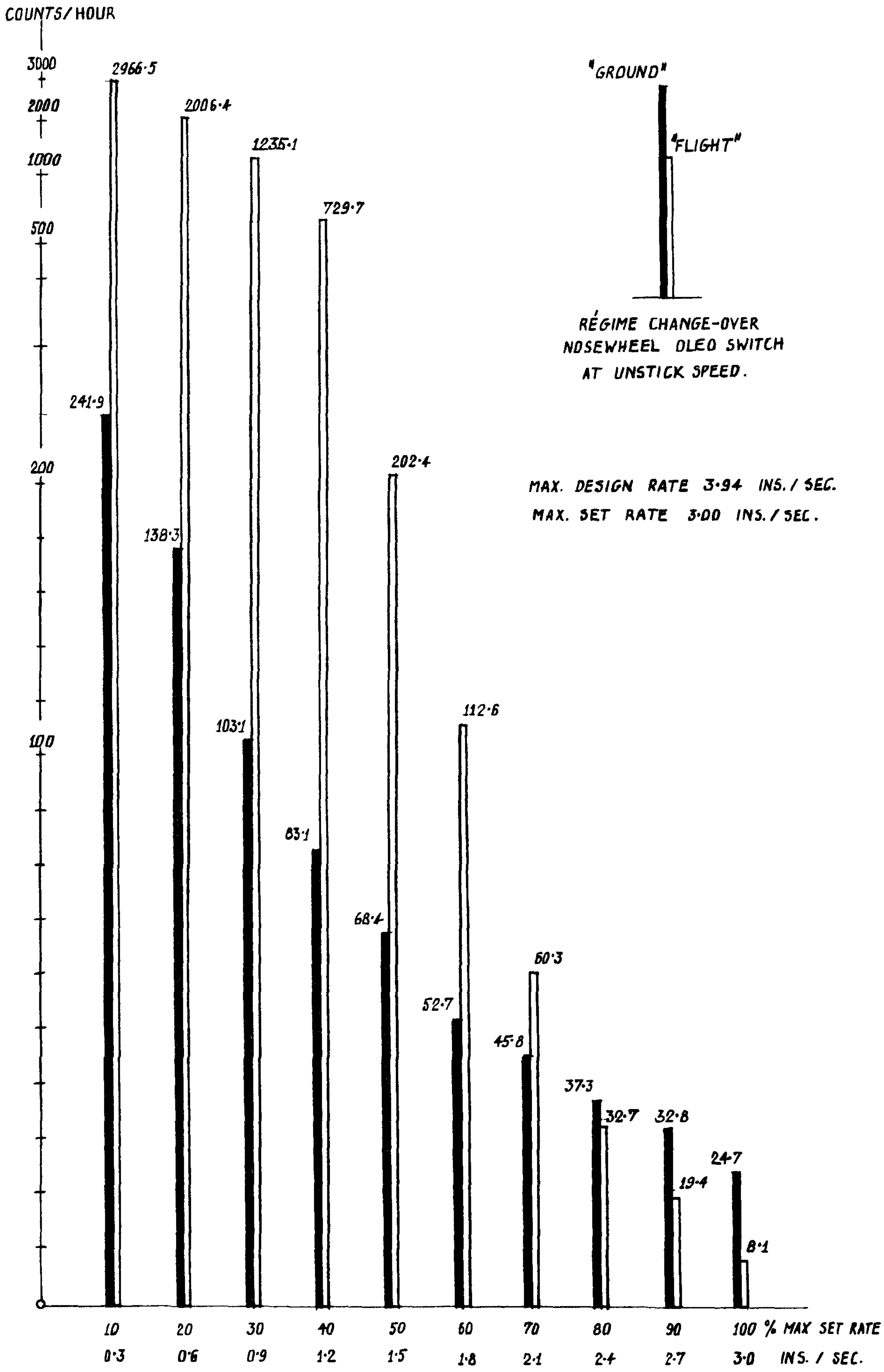


Fig.35 Comet 2,rudder rate



RÉGIME CHANGE-OVER
NOSEWHEEL OLEO SWITCH
AT UNSTICK SPEED.

MAX. DESIGN RATE 3·94 INS. / SEC.
MAX. SET RATE 3·00 INS. / SEC.

Fig.36 Vulcan 2,inboard elevon rate

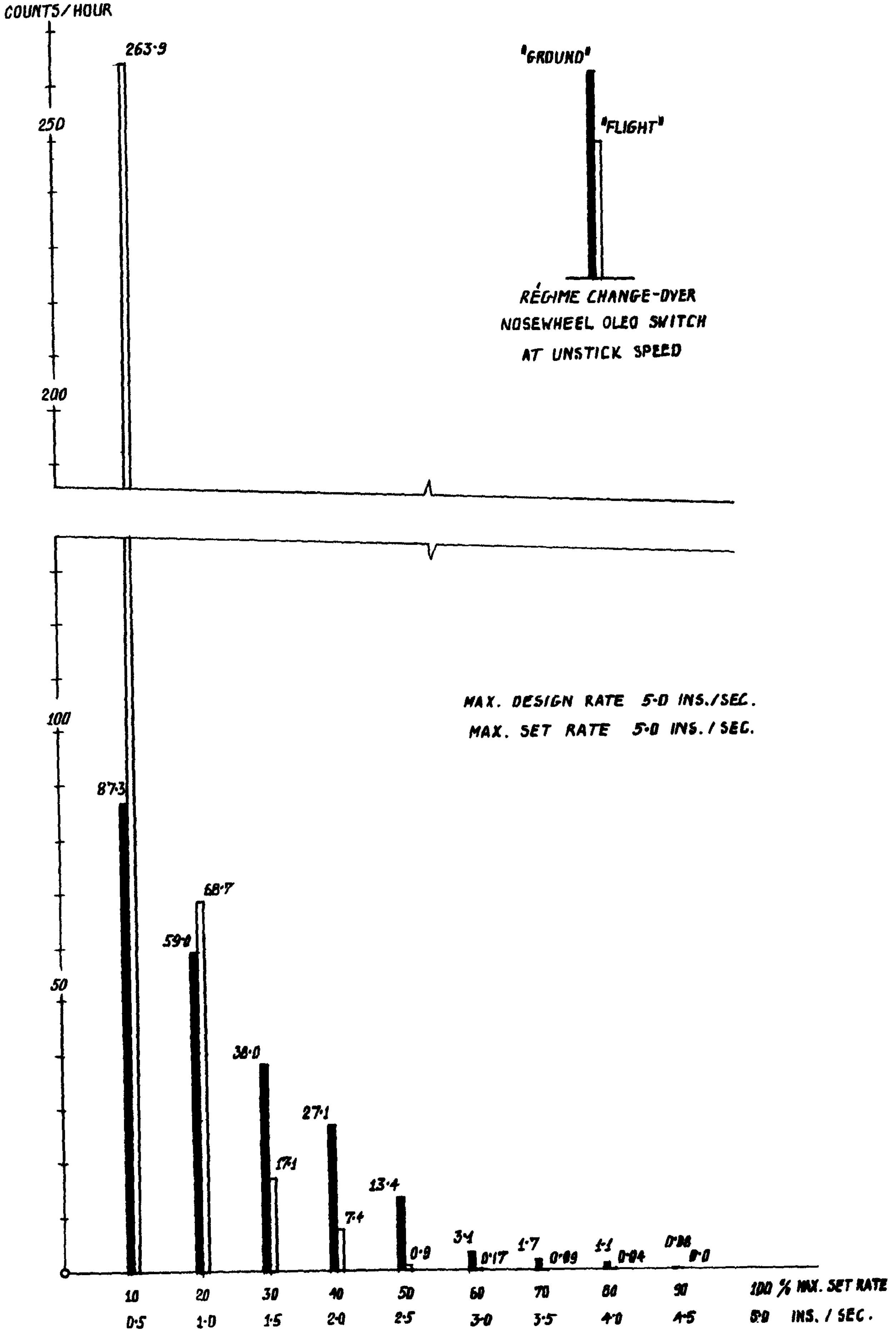


Fig.37 Vulcan 2,outboard elevon rate

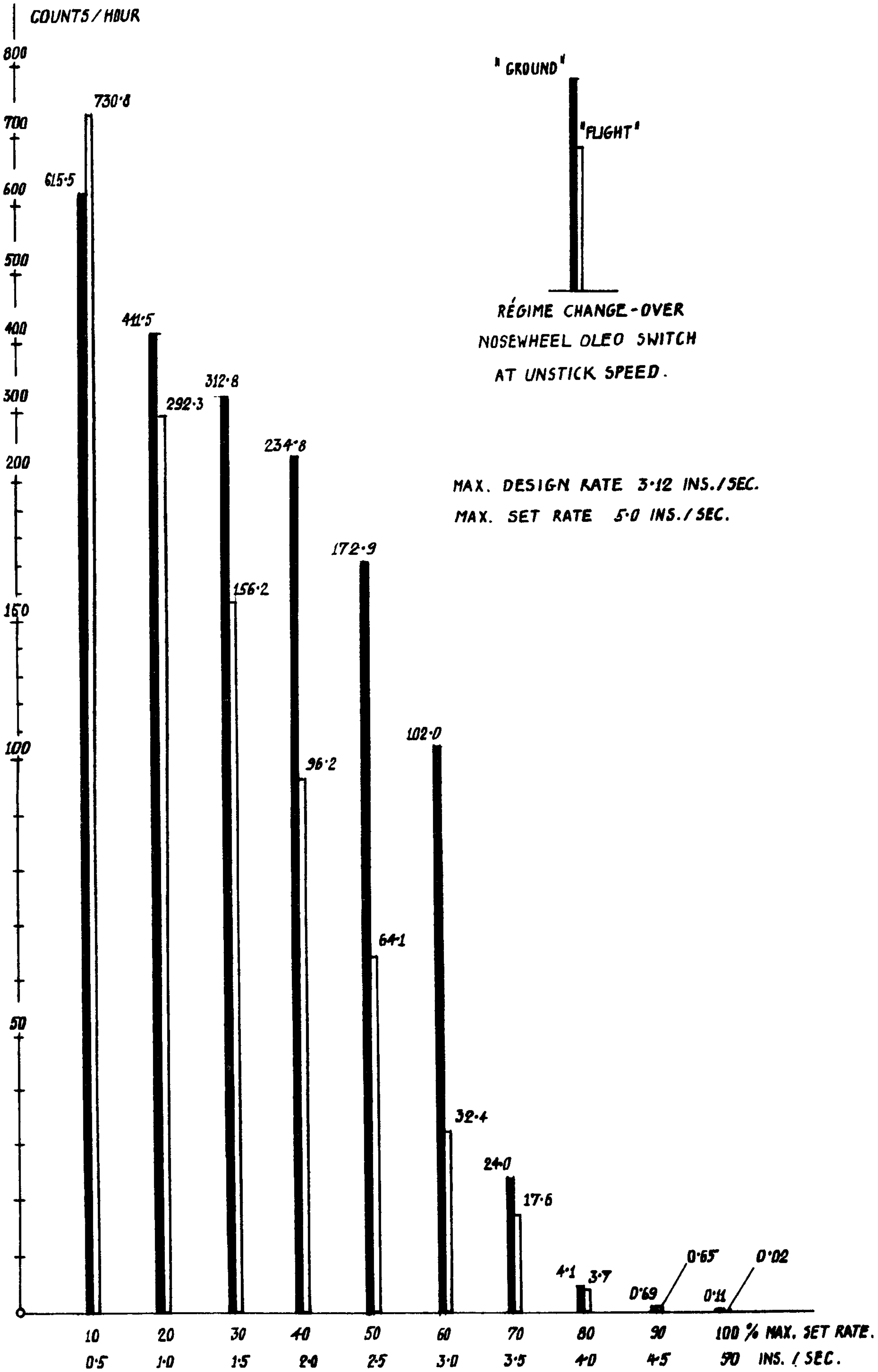


Fig.38 Vulcan 2,rudder rate

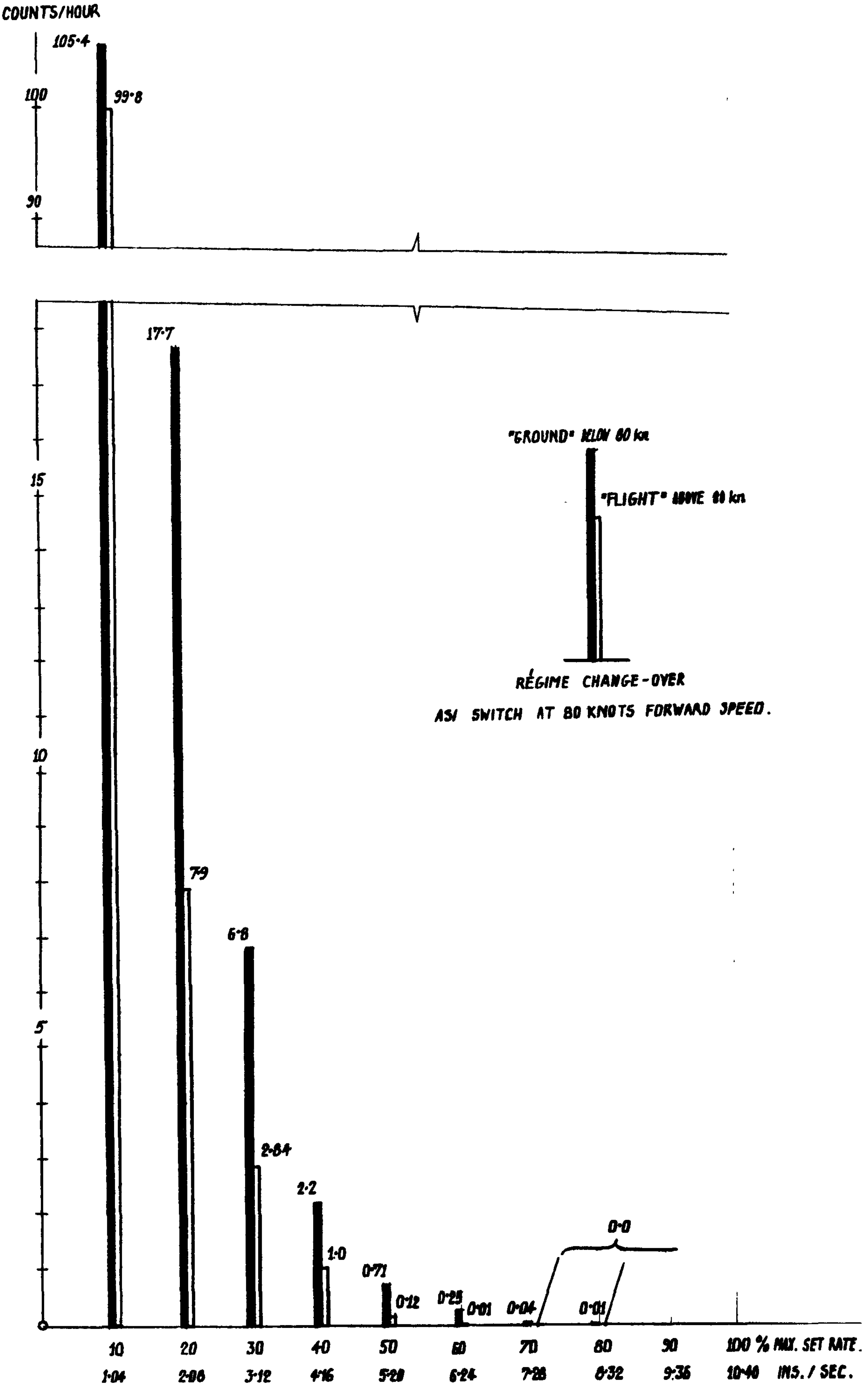


Fig.39 Wessex,port lateral rate

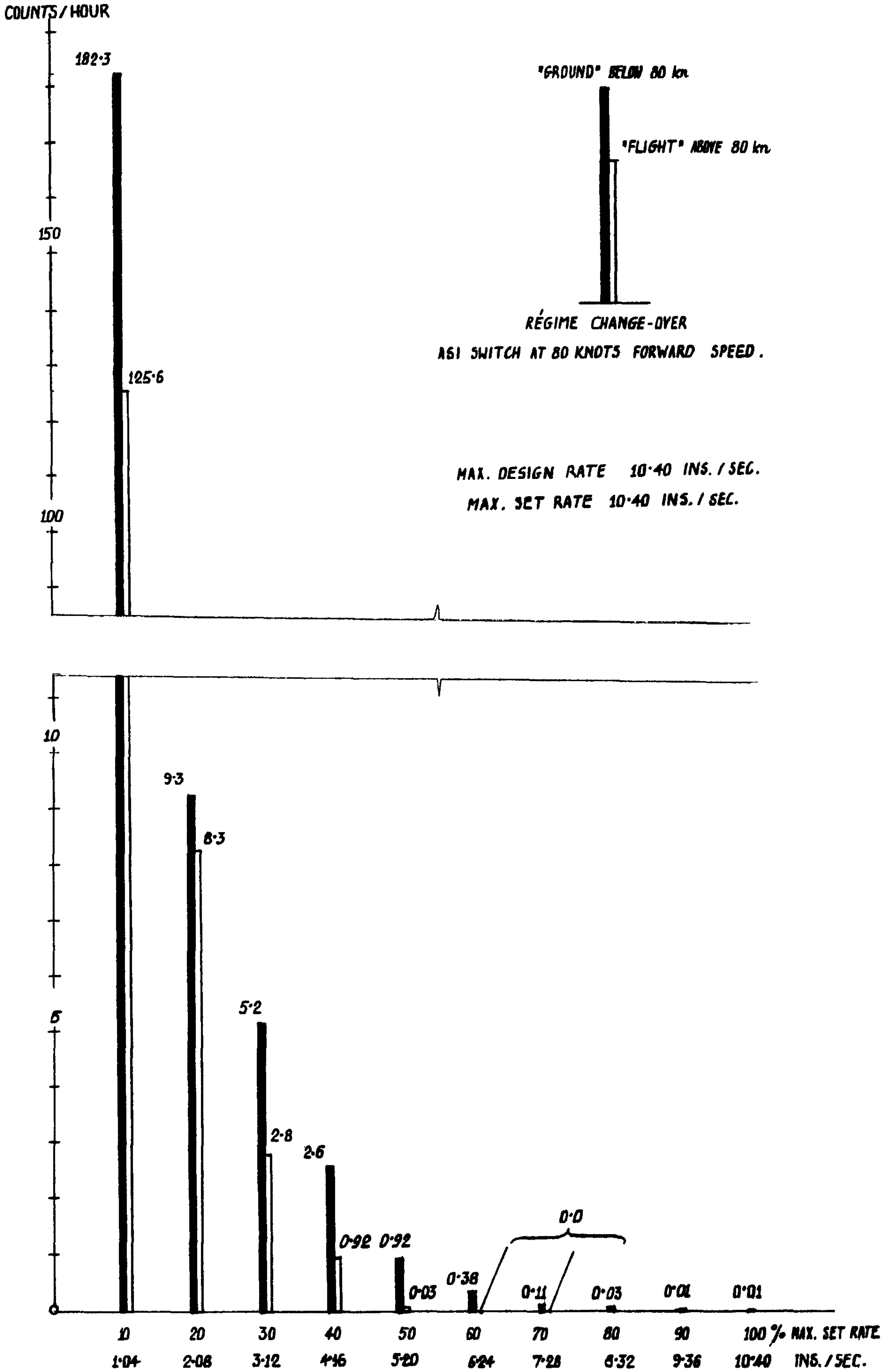


Fig.40 Wessex, stbd lateral rate

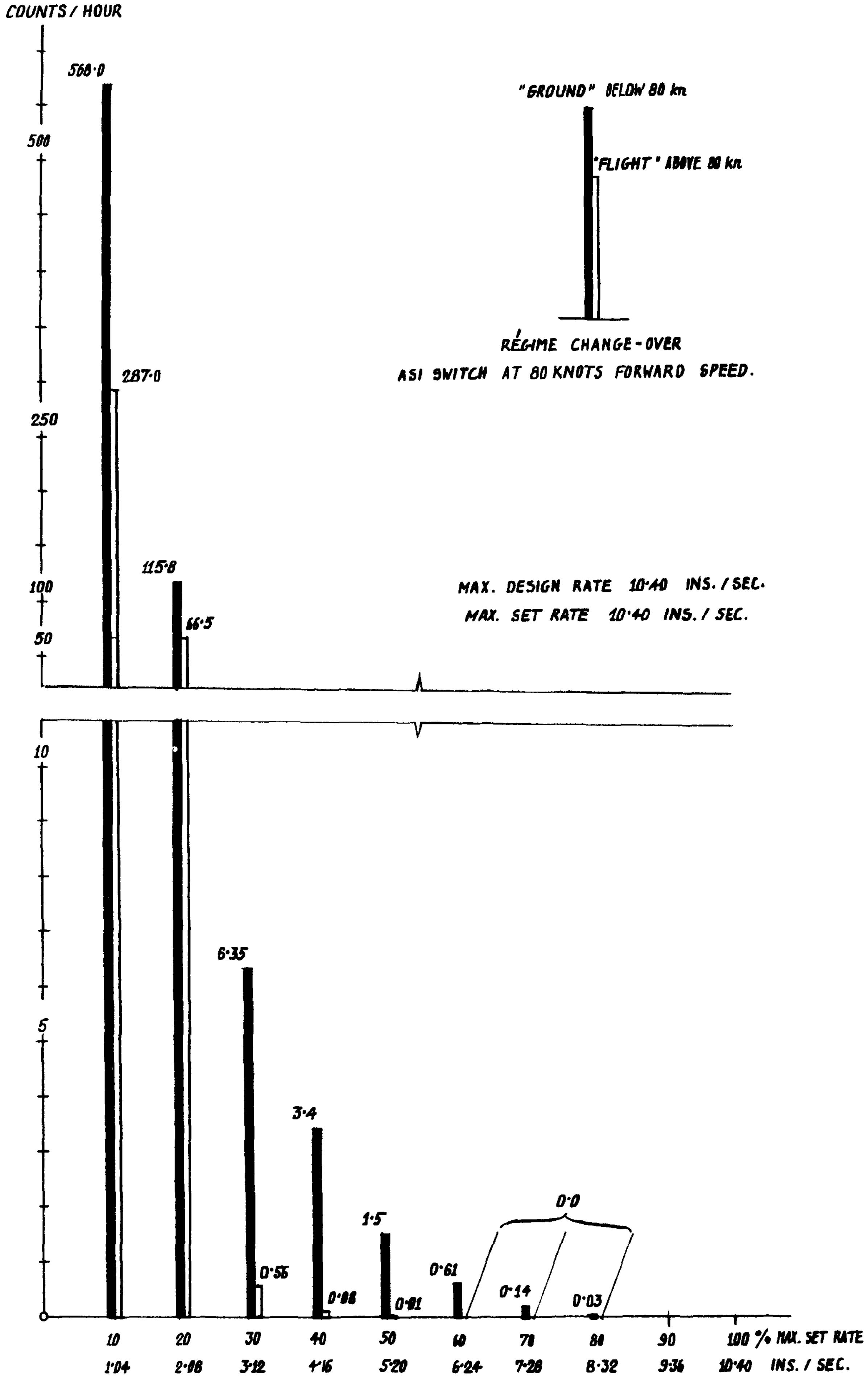


Fig.41 Wessex,fore and aft rate

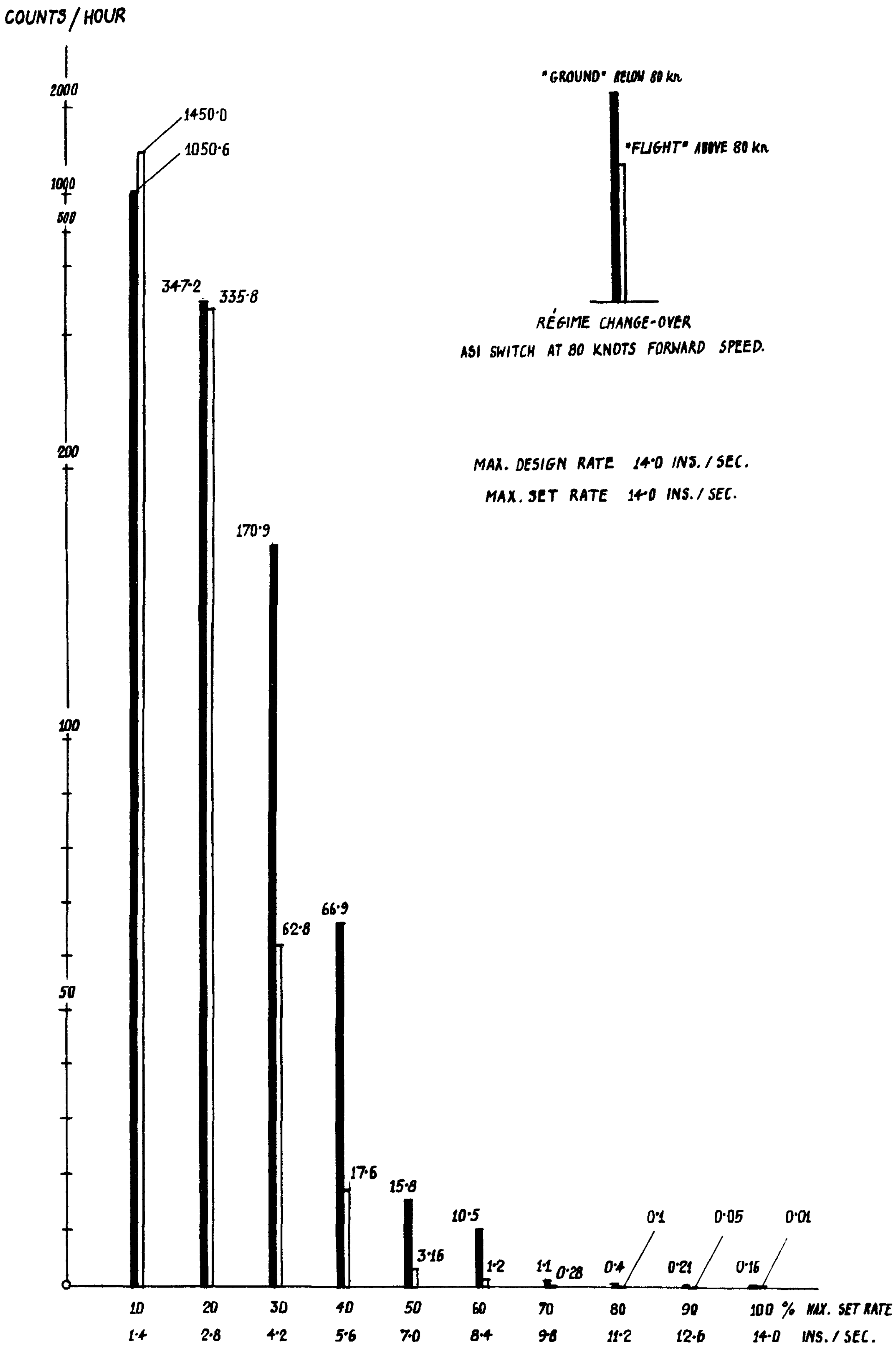
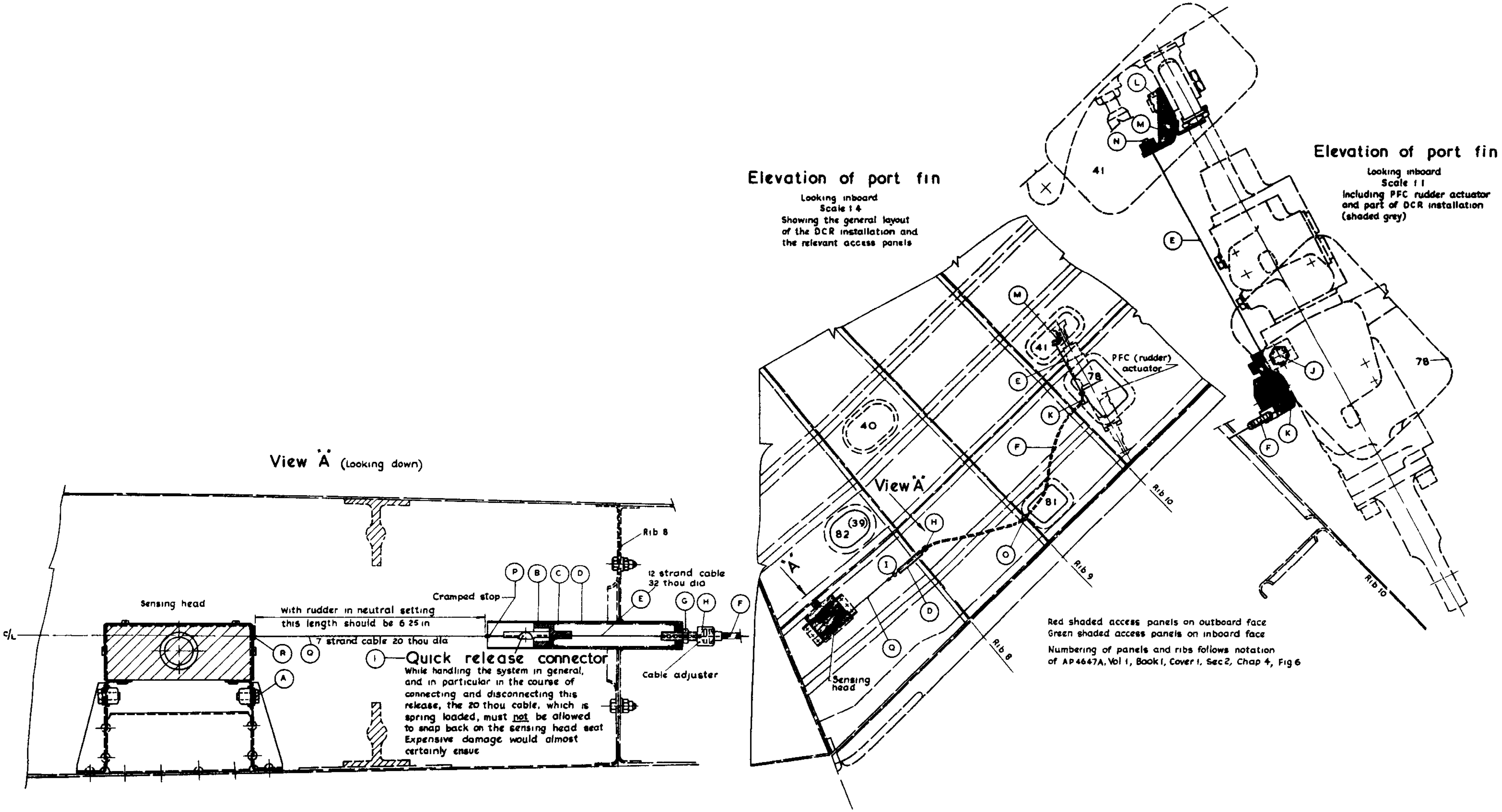


Fig.42 Wessex,yaw rate



View A (Looking down)

Quick release connector
While handling the system in general, and in particular in the course of connecting and disconnecting this release, the 20 thou cable, which is spring loaded, must not be allowed to snap back on the sensing head seat Expensive damage would almost certainly ensue

Elevation of port fin
Looking inboard
Scale 1 4
Showing the general layout of the DCR installation and the relevant access panels

Elevation of port fin
Looking inboard
Scale 1 1
Including PFC rudder actuator and part of DCR installation (shaded grey)

Red shaded access panels on outboard face
Green shaded access panels on inboard face
Numbering of panels and ribs follows notation of AP4647A, Vol 1, Book 1, Cover 1, Sec 2, Chap 4, Fig 6

Fig 43 Typical sensing head installation instructions

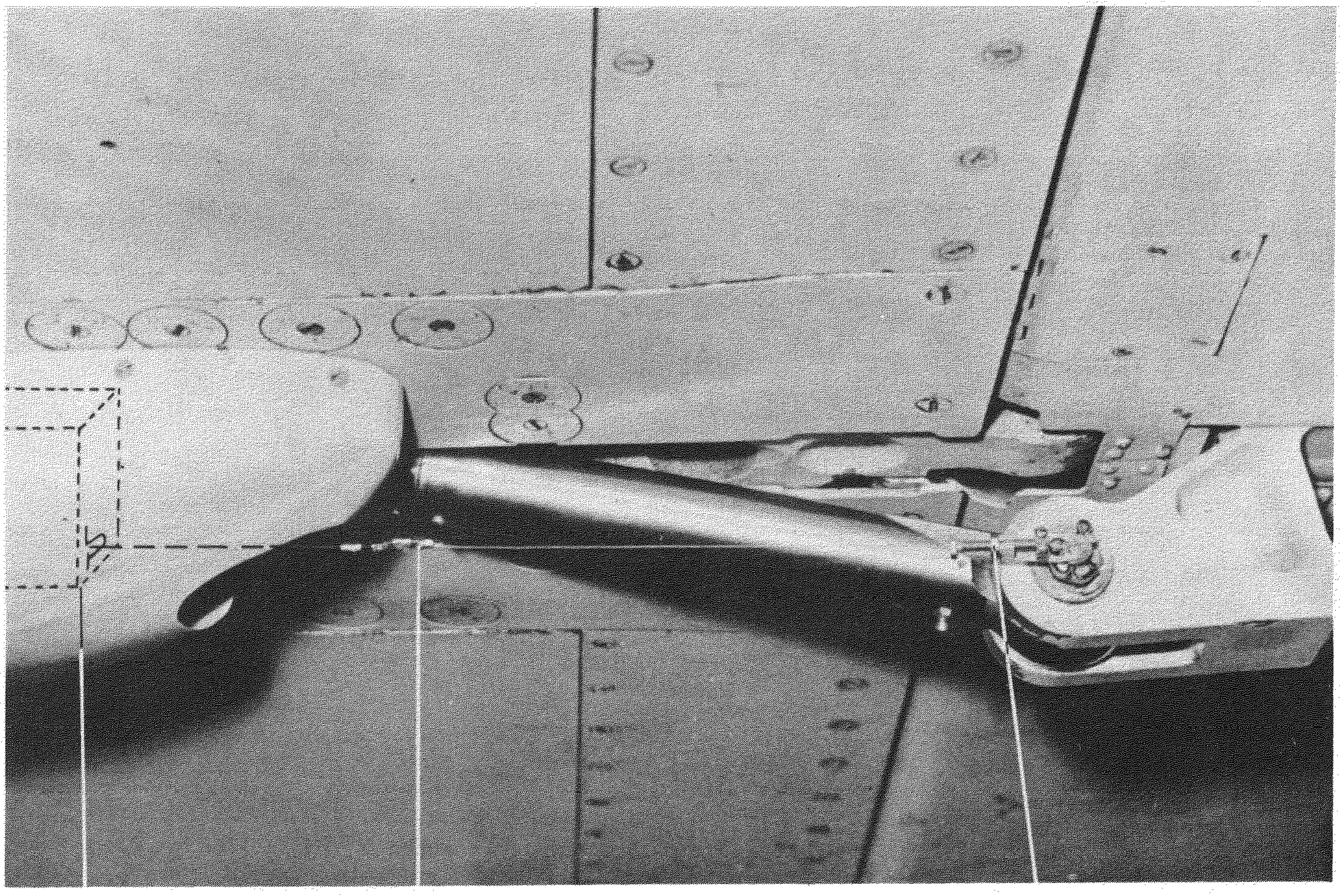


Fig.44 Aileron sensing head installation

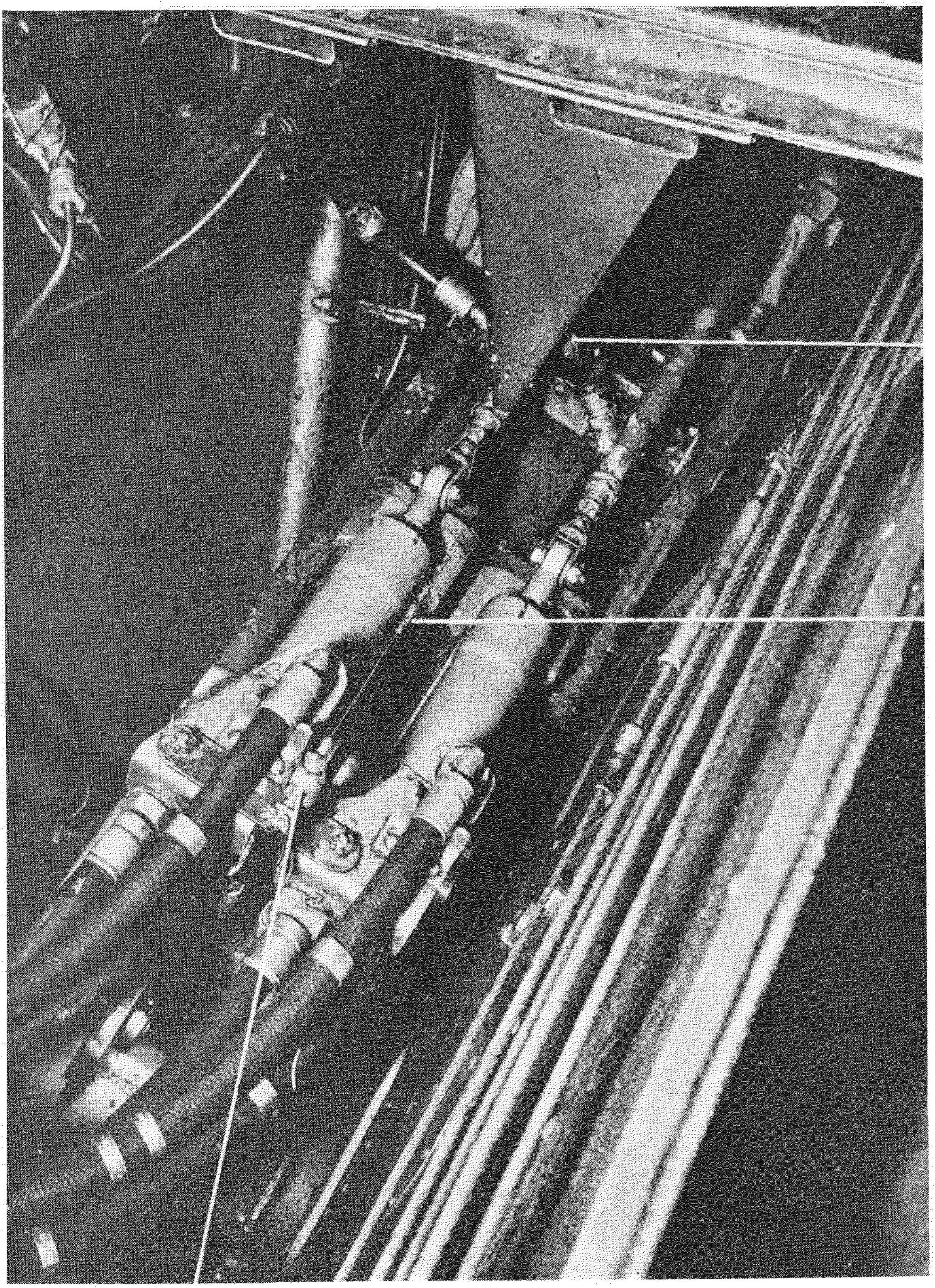


Fig.45 Sensing head installation (Comet 2, aileron)

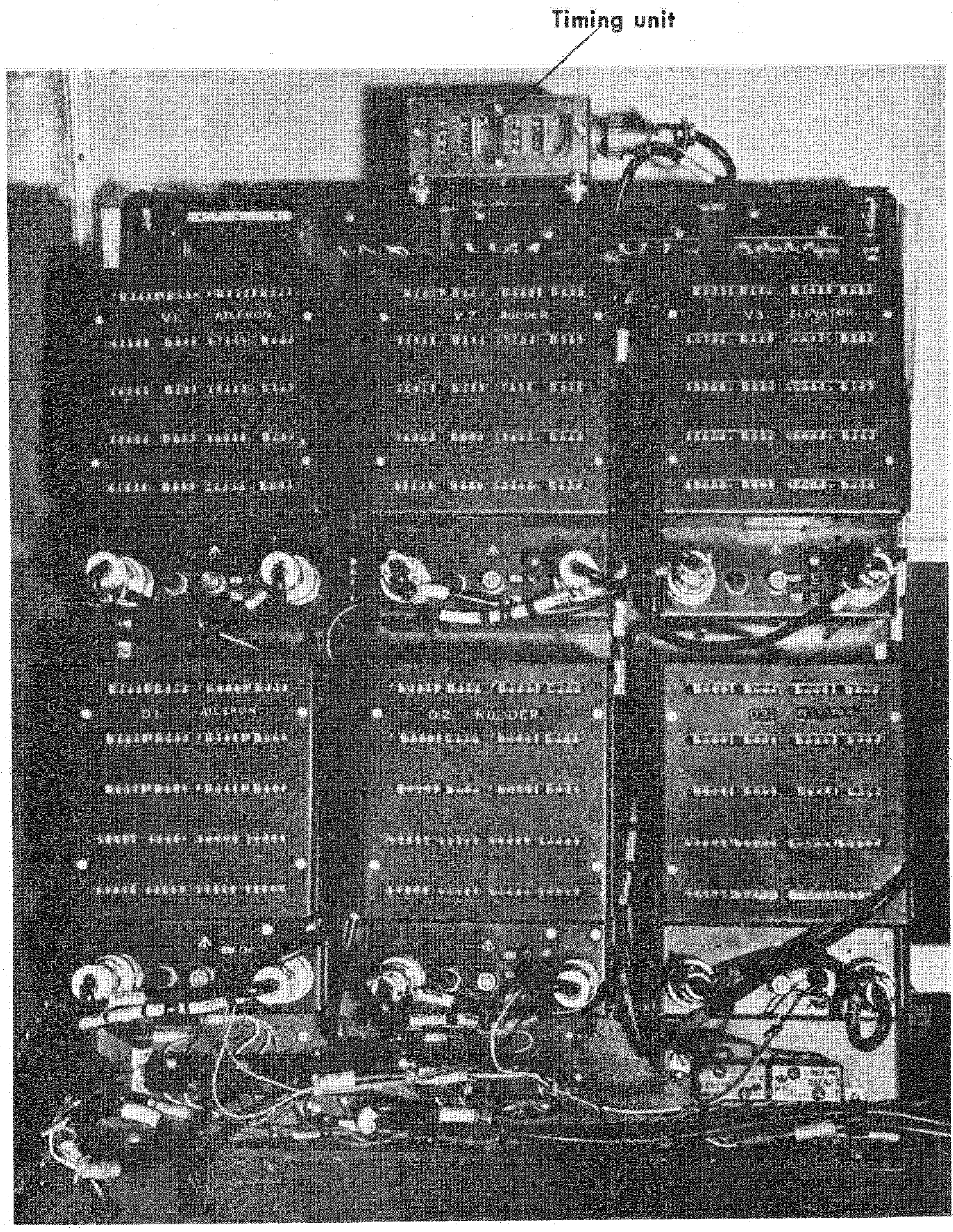


Fig.46 Recorder installation (Comet 2)

PART 2

1 INTRODUCTION

To the aircraft of the first group including the Hunter, the Valiant, the Comet 2, the Vulcan and the Wessex, reported on in Part 1 of Technical Report 69096, a second group of aircraft instrumented for duty cycle recording has now been added encompassing the Sea Vixen, the Victor, the VC 10, the Buccaneer and the Lightning. Both the background reasoning and the engineering of the experiment is common to both groups, and the reader is invited to study Part 1 before proceeding with the present Report.

2 INDIVIDUAL AIRCRAFT DCR RESULTS AND RELEVANT DATA

2.1 Sea Vixen (Figs.1-3 and 16-18)

Aircraft XN 699 operated in Mk.1 role from the Ark Royal between January 1965 and September 1966, and, after conversion to Mk.2, was flown as a trainer from RNAS Yeovilton between October 1967 and August 1970. Régime change-over (flight/ground) was effected by the undercarriage up-lock switch. Total 'flight' recording time of the aileron and the tailplane was 880 hours and that of the rudder 440 hours. The 'ground' recording amounted to 349 and 278 hours respectively. The flying control actuators were HM Hobson type 157 (aileron), 194 (tailplane) and 190 (rudder), and the respective documents laying down the type test procedures were numbers TD 2821/2, TD 3759 and TD 2692/2. An auto-pilot and autostabiliser were fitted and the distribution of the control displacement counts is not inconsistent with the behaviour of an autostabilised aeroplane. There are small asymmetries of displacement distribution in all three axes, indicating a marginal out-of-trim of the aircraft. The noticeably low reading of the first level 'down' in the aileron (Fig.1) is difficult to explain. Ratios Σ/S (reserve factors) are as follows: Aileron $\Sigma/\bar{S} = 17.002/10.464 = 1.62$, $\Sigma/\bar{\bar{S}} = 17.002/18.231 = 0.92$; Tailplane $\Sigma/\bar{S} = 29.34/33.715 = 0.87$, $\Sigma/\bar{\bar{S}} = 29.34/73.247 = 0.40$; Rudder $\Sigma/\bar{S} = 8.06/1.257 = 6.4$, $\Sigma/\bar{\bar{S}} = 8.06/6.299 = 1.30$. Assuming that the type test documentation was complete and correctly interpreted, the reserve factors in this aircraft powered controls were somewhat less than adequate. There is, however no evidence of excessive rate of failure in practice and the inherent reliability of the system must be assessed as good.

2.2 Victor B 1A (Figs.4-6 and 19-21)

Bomber, XH 591, flew with the duty cycle recorder between February 1963 and June 1966 at RAF Honnington, except for about 6 months during 1965, when it was operated in Singapore, RAF Tengah. The régime change-over was activated by an ASI switch set at 104 knots, so that the 'flight' régime encompassed the important parts of both the take-off and the landing phases. Total 'flight' recorded times were 1177 hours for the elevator, 966 hours for the aileron and 983 hours for the rudder. Corresponding 'ground' times were 480, 364 and 447 hours. The control surfaces of the Victor were powered by HM Hobson actuators type 147 (elevator), type 148 (aileron) and type 149 (rudder). Type testing followed the schedules laid down in HM Hobson document TD 5019. The aircraft was fitted with an auto-pilot as well as a yaw damper, and one would, therefore, expect to see in the displacement distribution a distinct prevalence of small control movements. In the Victor facts do not exactly follow this expectation. One finds in the elevator displacement (Fig.5), for instance, that application of 50% of full control movement is still relatively frequent. Another phenomenon, previously observed in the Hunter, is apparent here in the pitch (Fig.5) and roll (Fig.4) axes, namely that the smallest counting level displacements of 4.5% are distinctly less frequent than the next larger ones of 10.5%. It may well be, that this is due to the lack of effectiveness of the controls at small control surface angles, resulting in the pilot or the auto-pilot having to apply rather coarser control in order to obtain desired response. The frequency of rudder application (Fig.6) is an order of magnitude higher than in the other two axes (Figs.4 and 5), consistent with the presence of the yaw damper. There is a little asymmetry in the rudder displacement distribution, suggesting a state of directional out-of-trim. From the elevator displacement graph (Fig.5) it is also evident that 80% of actuator full travel is regularly demanded (1.48 times per hour flight), with little in hand in emergency. Reserve factors Σ/S are as follows: 'flight' aileron $\Sigma/\bar{S} = 61.83/22.054 = 2.7$, elevator $\Sigma/\bar{S} = 50.99/10.917 = 4.7$, and rudder $\Sigma/\bar{S} = 74.8/12.081 = 6.2$. The corresponding 'total' figures are: aileron $\Sigma/\bar{\bar{S}} = 61.83/27.434 = 2.3$, elevator $\Sigma/\bar{\bar{S}} = 50.99/14.301 = 3.6$ and rudder $\Sigma/\bar{\bar{S}} = 74.8/15.714 = 4.8$. Regarding the control rate distribution (Figs.19, 20, 21) it appears that the realised rates are actually somewhat in excess of the 'design' values but the demand seems to be reasonably satisfied by the rates provided.

2.3 VC 10 type C, Mk.1 (Figs.7-9 and 22-24)

Aircraft XV 107 was operated, with the DCR instrumentation, world-wide by the Air Support Command, based on RAF Brize Norton, between May 1969 and August 1970. The régime change-over was related to the operation of a switch mounted on the undercarriage oleo-leg. Consequently the 'flight' régime encompasses the whole flight from unstick to touch-down. The DCR 'flight' recording times were with the aileron and the elevator 1094 hours, with the rudder 1257 hours. The corresponding 'ground' times were 244 and 263 hours. The control surface actuators were made by Messrs. Boulton & Paul, types 147, 148 and 149, and type tested in accordance with a B & P document LTR 3543/112. The aircraft was provided with a 3-axes autopilot as well as with a yaw damper. Apart from a little asymmetry (out-of-trim) in the region of small displacement from a nominal zero position and indication of control ineffectiveness at small control surface angles (elevator only, Fig.8), the control displacement distribution exhibits no unfavourable features. The presence of a yaw damper is again evident in the rudder distribution (Fig.9). Judging by the relatively high frequency of small aileron control movements, roll appears to be the most labile axis. The control movement provided seems to meet the overall demand adequately. The reserve factors Σ/S are in the 'flight' régime $\Sigma/\bar{S} = 36.5/13.385 = 2.7$ (aileron), $\Sigma/\bar{S} = 36.5/1.714 = 21.3$ (elevator) and $\Sigma/\bar{S} = 36.5/3.044 = 12.1$ (rudder). Corresponding 'total' factors are: aileron $\Sigma/\bar{\bar{S}} = 36.5/14.595 = 2.5$, elevator $\Sigma/\bar{\bar{S}} = 36.5/3.770 = 9.7$ and rudder $\Sigma/\bar{\bar{S}} = 36.5/6.022 = 6.1$. Testing of the rudder and particularly the elevator is thus seen to have been heavily factored. The picture of the rate demand distribution in the elevator (Fig.23) and the rudder (Fig.24) is satisfactory. The aileron control (Fig.22), however, appears to be somewhat underrated, maximum design rate being demanded 36.8 times per hour flight.

2.4 Buccaneer, S.2 (Figs.10-12 and 25-27)

The DCR installation in this aircraft had a rather chequered history. Aircraft XN 928 was first instrumented, but was written off in a heavy landing after only some 5 hours of recording. The recorder was next fitted to XN 925, which, in fact never flew. Lot of time was lost before the third aircraft XT 276 was instrumented. This aircraft then operated from RNAS Lossiemouth and between May 1968 and July 1970, although not reaching the target of 1000 flying hours, did nevertheless clock up meaningful recording times, thus: in 'flight' régime 237 hours (aileron), 449 hours (tailplane) and 383 hours (rudder), the respective 'ground' times being 172, 287 and 287 hours. The régime change-over was set at 195 knots (ASI switch), a figure well in excess of the unstick and touch-down speeds. Consequently, the 'flight' régime counts depict actual flying including high speed manoeuvring, while the take-off and landing would be reflected in the 'ground' régime record, together with the actual ground usage. The aileron, tailplane and rudder actuators were Boulton & Paul types P146, P147 and P148, and the type testing followed schedules specified in the Firm's documents TR 3528/49, TR 3529/34 and TR 3530/26. Both an automatic pilot and an auto-stabiliser (3-axes) were provided. Special feature of this aircraft is that the ailerons are used either in the differential mode (roll motivators), or/and as lift augmentors (both up, both down). This clearly influences the control displacement distribution, both in the roll (Fig.10) and pitch (Fig.11) senses: there exists a distinct shift of control position datum. The aileron displacement (Fig.10) is quite adequate. In the case of the tail-plane (Fig.11), however, also having regard to the high régime change-over speed mentioned earlier, there appears to be little, if any, reserve of tailplane movement, 89-90% of total tailplane travel being demanded about twice per hour flight. The rudder displacement distribution is normal (Fig.12). The reserve factors are in the 'flight' régime: aileron $\Sigma/\bar{S}$ = 465.7/26.990 = 17.3, tailplane $\Sigma/\bar{S}$ = 981.8/14.593 = 67.4, and rudder $\Sigma/\bar{S}$ = 361.5/1.112 = 322.0! The corresponding 'total' figures are: aileron $\Sigma/\bar{\bar{S}}$ = 465.7/31.990 = 14.6, tailplane $\Sigma/\bar{\bar{S}}$ = 981.8/29.170 = 33.7 and rudder $\Sigma/\bar{\bar{S}}$ = 361.5/28.371 = 12.6. Clearly the severity of testing was out of all proportion. As for control rate, the rudder (Fig.27) appears quite adequate, tailplane (Fig.26) is borderline in respect of 'ground' régime, which, it should be remembered, comprises the landing, while the aileron (Fig.25) is clearly underrated.

2.5 Lightning Mk.5 (Figs.13-15 and 28-30)

Like in the Buccaneer, the DCR installation in the Lightning was plagued by ill fortunes. The aircraft having very high density of equipment installation, it was not possible to carry all three axes of the DCR in one aircraft. Three aircraft were, therefore, instrumented. XS 453 carrying the aileron recorder was, unfortunately, lost in the North Sea after only 3 hours flying. Another aircraft was then instrumented for aileron recording, but, because of numerous modifications it had to undergo, it, too, did not fly by the time the DCR programme was terminated. The other two aircraft, XS 454 (rudder) and XS 455 (tailplane), operating from RAF Coltishall, although not attaining the 1000 flying hours target, clocked up, nevertheless, between August 1965 and September 1970, meaningful 'flight' times of 438 hours (tailplane) and 392 hours (rudder). The corresponding 'ground' recording times were 6, 725 and 672 hours. The Lightning being capable of sustained supersonic flight, an opportunity existed to examine the control duty cycle at elevated speeds. At 250 knots ASI, M = 0.74 is realised at the altitude of 35000 feet, and M = 1.0 at 50000 feet. The régime change-over was, therefore, coupled to the ASI switch set at 250 knots. All flying below the 250 knots mark, including the take-off and landing manoeuvres is thus covered by the 'ground' régime recording. The aircraft was equipped with a 3-axes auto-pilot and auto-stabiliser. The control actuators were of HM Hobson design types 203 (aileron), 150 (rudder) and 337 (tailplane) and the type testing followed schedules laid down in English Electric documents EB 2.08.742, 741 and 3550 respectively. The control surface displacement distribution is on the whole indicative of reasonably effective and harmonised controls, with only a few points worth comment. There is a little out-of-trim in roll (Fig.13), but it is surprising to see as much as 65% of full aileron movement being demanded 3 times per hour in high speed flight (Fig.13). This may well be a freak result, considering that the aileron displacement figures were computed from only less than 10 hours of flying total, although the same phenomenon is observed, to a lesser degree, in the tailplane (Fig.14). The rudder appears to be the most powerful control (Fig.15), displacement beyond 20% full stroke being hardly every demanded in the 'flight' régime. The ratios Σ/S were in 'flight': aileron $\Sigma/\bar{S} = 21.8/1.913 = 11.4$, tailplane $\Sigma/\bar{S} = 43.2/9.975 = 4.3$, and rudder $\Sigma/\bar{S} = 25.94/2.093 = 12.4$. The respective 'total' figures were: aileron $\Sigma/\bar{\bar{S}} = 21.8/8.041 = 2.7$, tailplane $\Sigma/\bar{\bar{S}} = 43.2/49.734 = 0.9$ and rudder $\Sigma/\bar{\bar{S}} = 25.94/13.702 = 1.9$. The type testing thus appears realistic except for the tailplane, which is marginal. As far as control rates are concerned, only the tailplane (Fig.29) is seen to utilise the rate provided, the aileron (Fig.28) and the rudder (Fig.30) are overrated.

3 SUMMARY OF RESULTS

Aircraft	Régime change-over	Control axis	Recording time		Stroking distance			Reserve factor	
			'Flight' T hours	'Ground' T' hours	Type test Σ ft/hour	'Flight' $\bar{S}$ ft/hour	'Total' $\bar{\bar{S}}$ ft/hour	'Flight' $\Sigma/\bar{S}$	'Total' $\Sigma/\bar{\bar{S}}$
Sea Vixen	U/C up-look	Aileron	880	349	17.002	10.464	18.231	1.62	0.92
		Tailplane	880	349	29.34	33.715	73.247	0.87	0.40
		Rudder	440	278	8.06	1.257	6.299	6.4	1.30
Victor	ASI switch 104 kn	Aileron	1177	480	61.83	22.054	27.434	2.7	2.3
		Elevator	966	364	50.99	10.917	14.301	4.7	3.6
		Rudder	983	447	74.8	12.081	15.714	6.2	4.8
VC 10	U/C oleo-leg	Aileron	1094	244	36.5	13.385	14.595	2.7	2.5
		Elevator	1094	244	36.5	1.714	3.770	21.3	9.7
		Rudder	1257	263	36.5	3.044	6.022	12.1	6.1
Buccaneer	ASI switch 195 kn	Aileron	237	172	465.7	26.990	31.990	17.3	14.6
		Tailplane	449	287	981.8	14.593	29.170	67.4	33.7
		Rudder	383	287	361.5	1.112	28.371	322.0	12.8
Lightning	ASI switch 250 kn	Aileron	3	6	21.8	1.913	8.041	11.4	2.7
		Tailplane	438	725	43.2	9.975	44.734	4.3	0.9
		Rudder	392	672	25.94	2.093	13.702	12.4	1.9

4 DISCUSSION

The purpose of the duty cycle recording programme was discussed in Part 1 of the Report in detail. It will be recalled that the purpose was twofold: (a) to establish a rational basis for the type testing of flying control actuators, and (b) to provide a design guide in respect of size, power and performance of new control systems projects. It has been suggested that the life of an actuator is determined essentially not by the incidence of mechanical or structural failures, but rather by the rate of wear of its rubbing components and the resulting internal and external leakage of hydraulic fluid, as well as the resulting degradation of dynamic performance of the system. Particular attention was focussed on the valve assembly and the high pressure sealing mechanisms. Initially (1949) the minimum life of an actuator was specified as 1000 flying hours. (Development of seals raised this figure in recent years to 3000 hours or even more.) In absence of any real evidence as to the composition of the actual flight duty cycle, the testing has been conducted to an arbitrarily agreed duty cycle, and it was long suspected, that this was unduly severe. The present statistical investigation confirmed that suspicion in all but a few instances. For a number of reasons, stated in Part 1, the functioning of the control actuators was observed under two régimes, 'flight' and 'ground'. The readings of the counting recorders were processed, as described in Part 1, and plotted as 'flight' and 'total' distributions ('total' meaning the added stroking in 'flight' and 'ground' régimes), both related to 'flight' times (strokes per hour 'flight'). In the simplest case the régime change-over would coincide with the unstick and touch-down phases of a flight. Since during these two phases relatively large movement of controls is known to be demanded, the 'flight' distribution would be a suitable criterion of adequacy of the controls in respect of both displacement and rate. Such a régime change-over signal is best derived from a switch activated by the extension or compression of the undercarriage oleo-leg. (Comet, Vulcan, VC 10). Similarly, the change-over may be effected by an ASI switch set to operate at a speed slightly below that of unstick/touch-down (Victor). In all the other cases,where régime change-over was related to either the undercarriage up-lock (Hunter, Sea Vixen), or to the ASI switch set higher than the unstick/touch-down speed (Valiant, Buccaneer), a significant number of flight control movements will be recorded within the 'ground' régime. As a result, adequacy of control cannot be reliably judged from the 'flight' distribution. Neither is the 'total' distribution suitable for this purpose, since the 'ground' régime will almost certainly contain significant counts of large amplitude stroking occurring during taxiing or possibly, in course of maintenance and ground testing. The choice of this method of régime change-over was dictated by the availability in the aircraft of that particular type of switch, as well as high cost of installation of a preferred means of ground/flight sensing. The Lightning was a special case, in that it was attempted to determine the nature of control duty cycle associated with elevated flight speeds, including $M > 1.0$.

The 'flight' and 'ground' régime counts were added and divided by 'flight' time to yield the 'total' distribution. The integral of stroking at all counting levels provided the 'total' stroking distance $\bar{\bar{S}}$ in feet per hour 'flight', which, compared with the total type test stroking distance Σ, also in feet per hour 'flight', gives the 'total' reserve factor. This factor is then a measure of adequacy of testing of a control actuator. As a matter of interest the ratio $\Sigma/\bar{S}$, the 'flight' reserve factor, was also computed and tabulated. This tends to give some very large reserve factors, without, however, a practical significance.

5 CONCLUSIONS AND RECOMMENDATIONS

It has been envisaged to analyse in Part 2 the findings on completion of the Programme in order to extract certain interesting facts, such as the possible variation of the duty cycle pattern with the circumstances of the particular aircraft utilisation. So, for instance, the RAE Comet II was flown both locally on experimental work and long distance communication; the Lightning was instrumented to distinguish between high and low speed flight; the Victor flew both in the temperate climate of the UK and in condition of low altitude high turbulence tropical climate in the Far East, and the Sea Vixen was operated both from the deck of a carrier and, as a trainer, from solid runways. In many cases, unfortunately, this interesting effect was largely masked by other variables, such as seasonal weather variation, variation of pilots' techniques, as well as by the fact, that a particular aircraft did not remain in one particular operation condition for a significant length of recording time. It was pointed out in Part 1 that a counting method does not allow of an event to be accurately located in time. Although an arrangement existed between the RAE and the RAF and the Navy to render returns of the counts in monthly periods (this being primarily designed to save recording time in case of failures of the recording system), the time correlation with the entries in the form 700, the Log Book, was found extremely difficult. In consequence, the plan to carry out the above-mentioned finer analysis of individual distributions was abandoned. Another obstacle to establishing a control cycle pattern in existing aircraft to be used in anticipating future control system demands is the unpredictability of control effectiveness and the variation, from type to type, of manoeuvre coordination.

In the light of the foregoing, the problem of classifying aircraft in terms of control duty cycle is a complex one, requiring further study of the great wealth of data provided by the recording programme and collected in this Report, before new rationalised design and test requirements are formulated.

Acknowledgments

The author wishes to acknowledge the contribution of Mr. S.M. White, who coordinated the installation of the CDR in some of the aircraft dealt with in this Report, as well as being responsible for the servicing of the installations and collecting and processing the recorded data.

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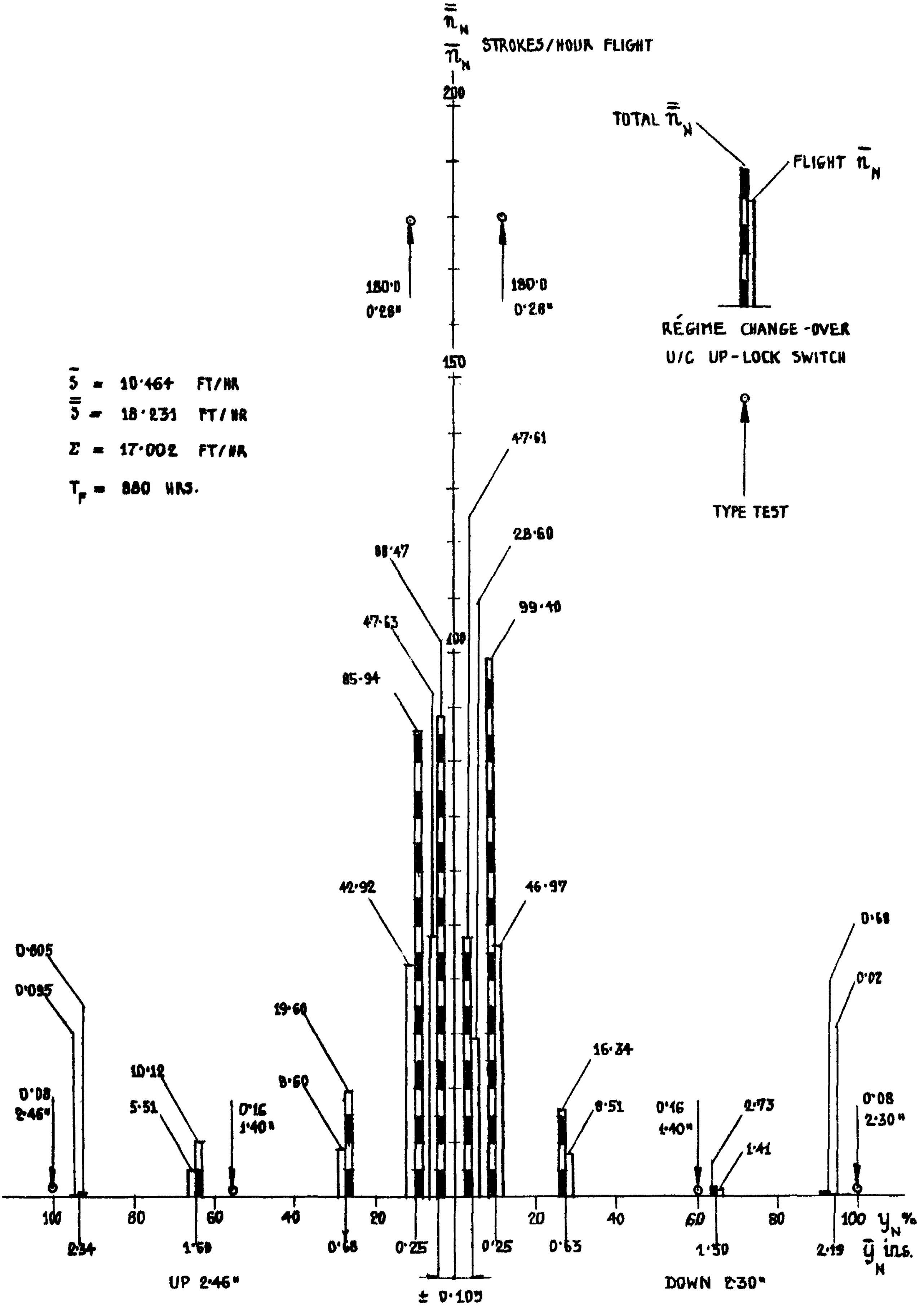


Fig.1 Seavixen, aileron displacement

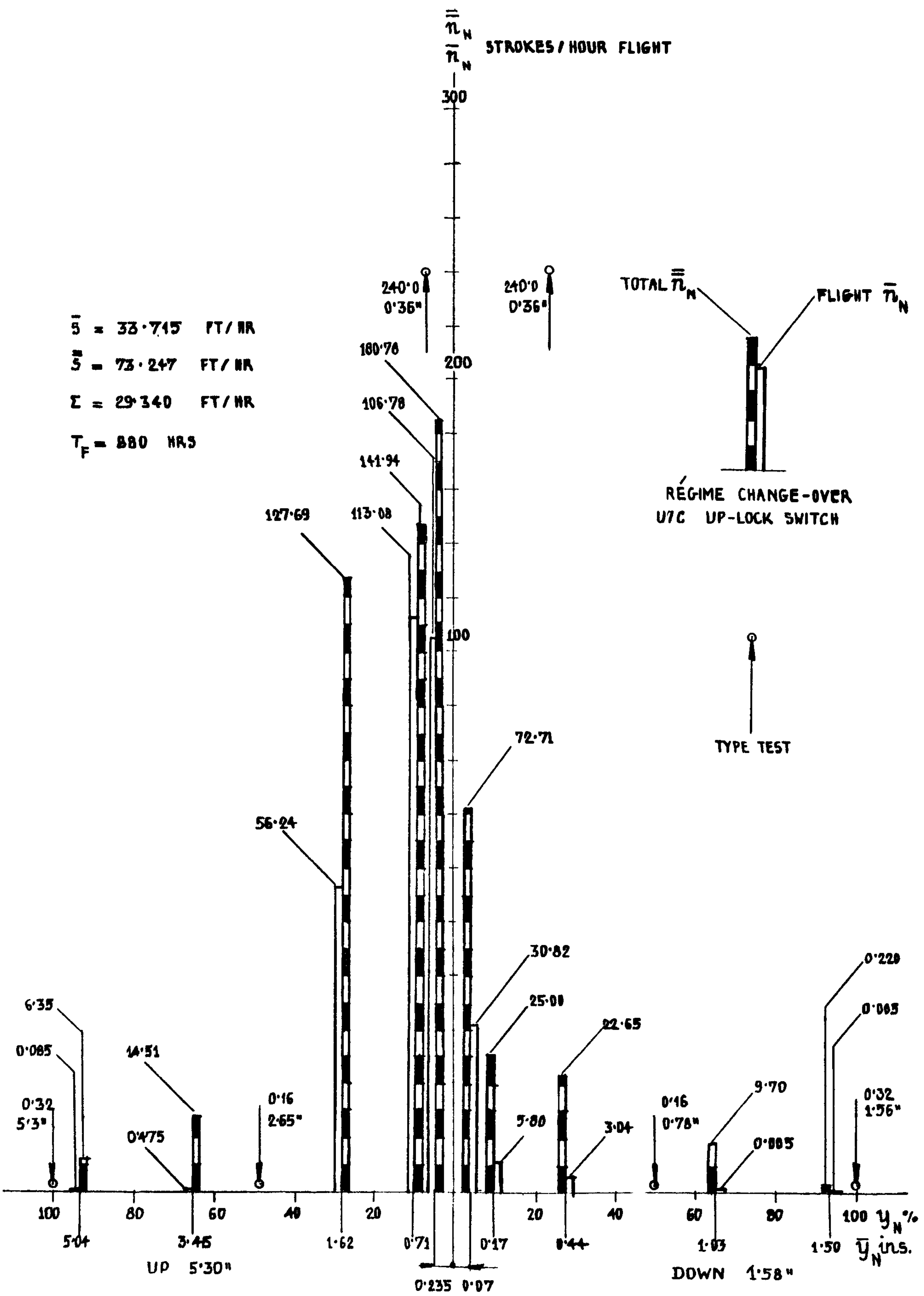


Fig.2 Seavixen, tailplane displacement

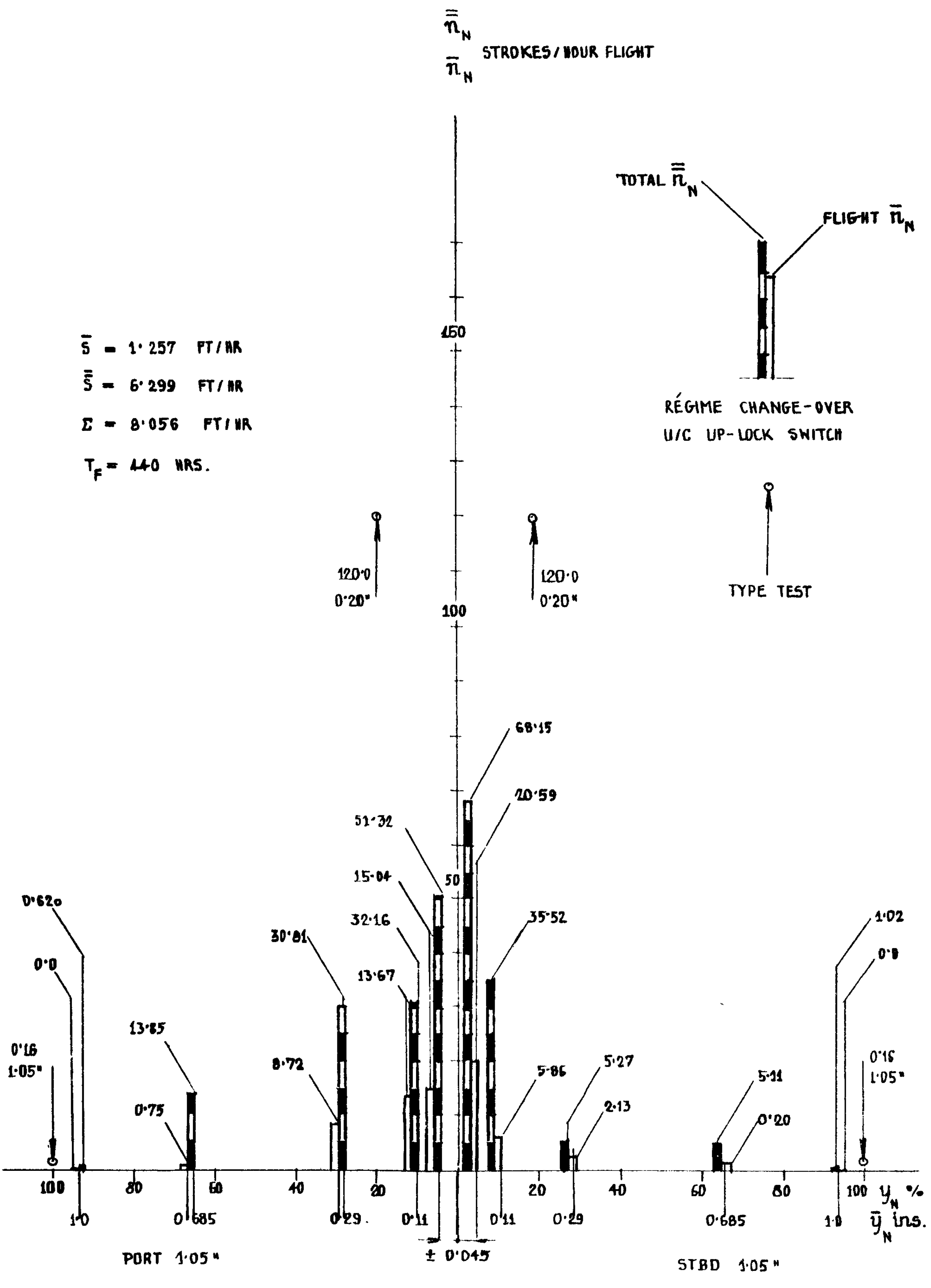


Fig.3 Seavixen, rudder displacement

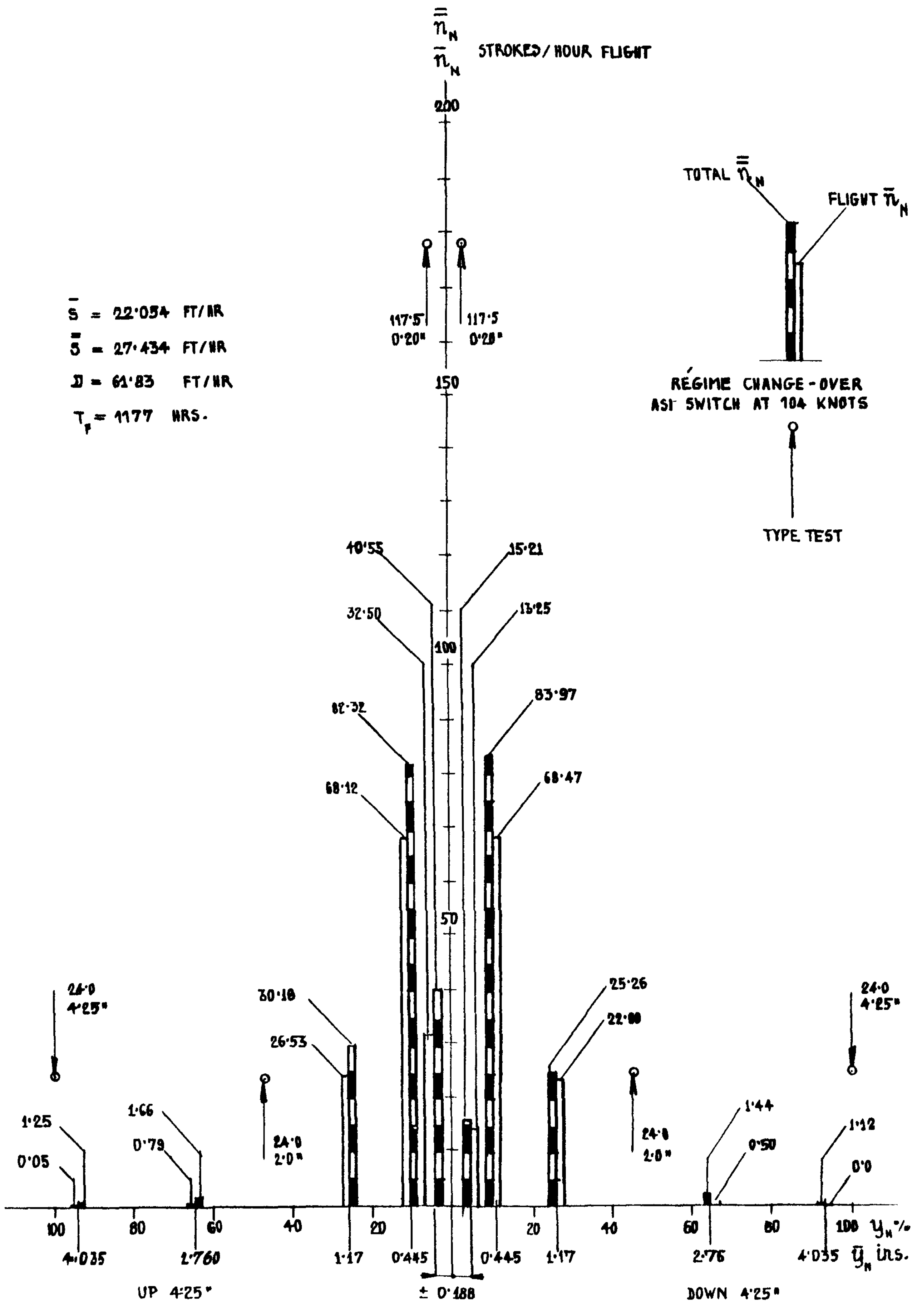


Fig.4 Victor, aileron displacement

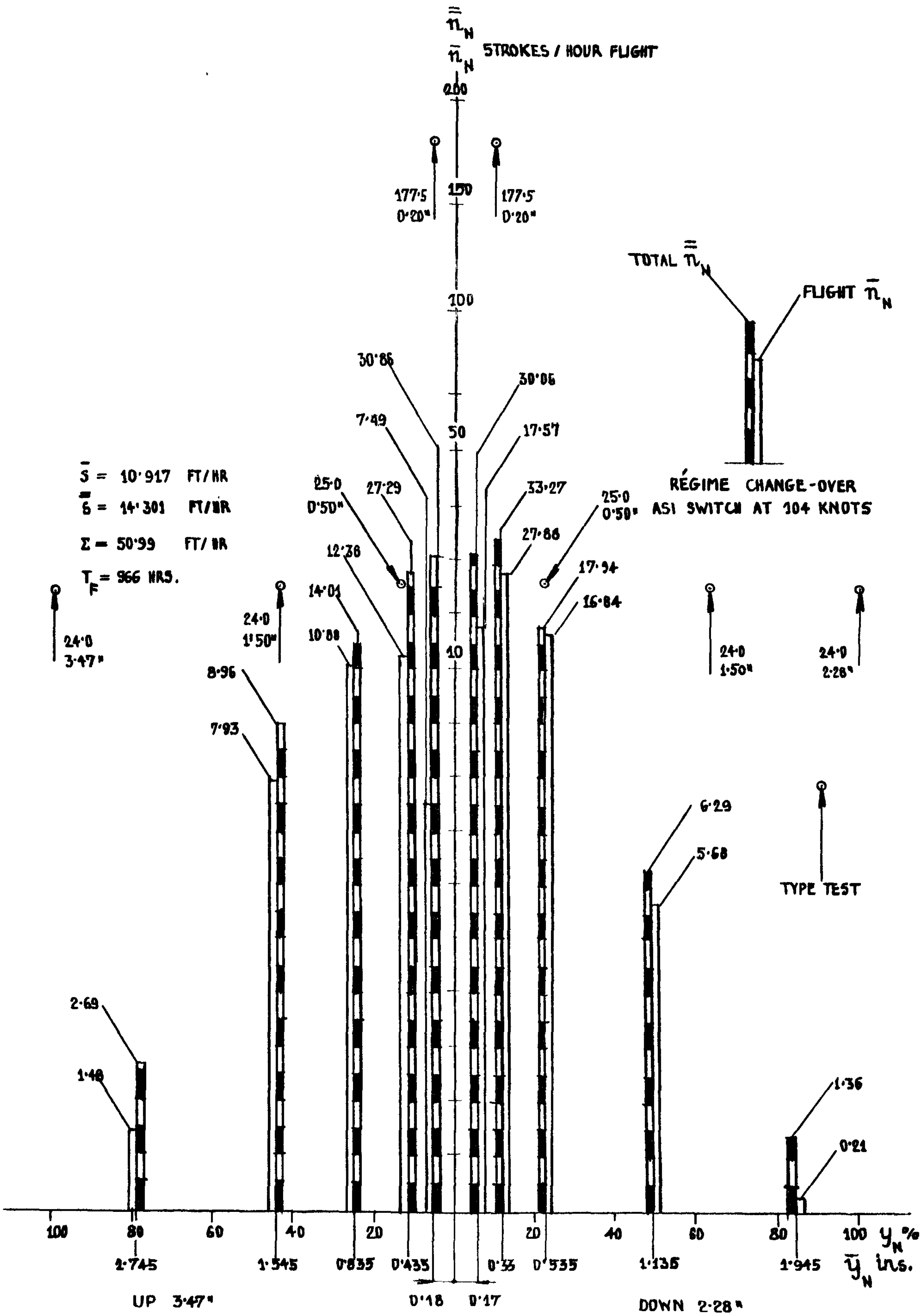


Fig.5 Victor, elevator displacement

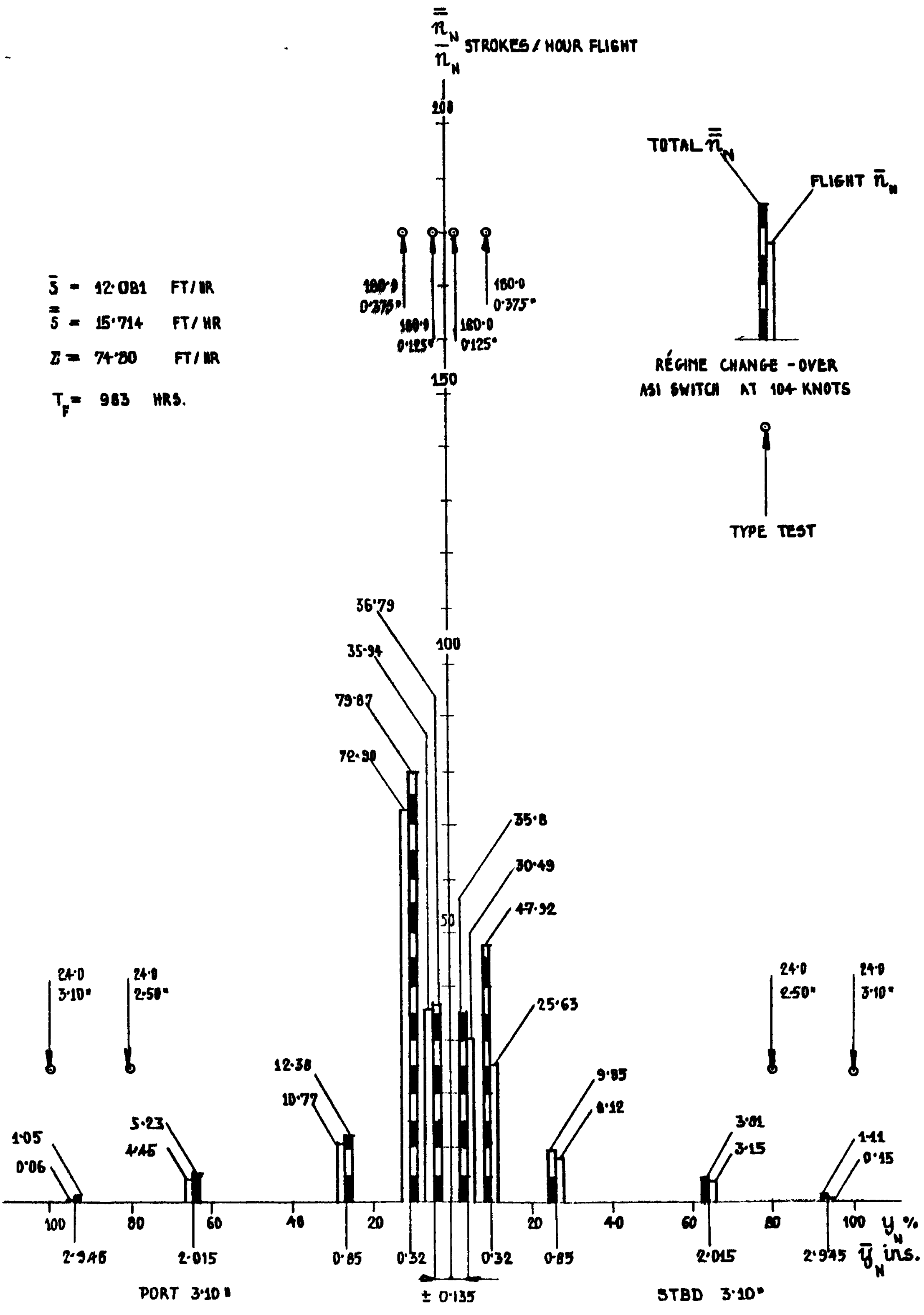


Fig.6 Victor, rudder displacement

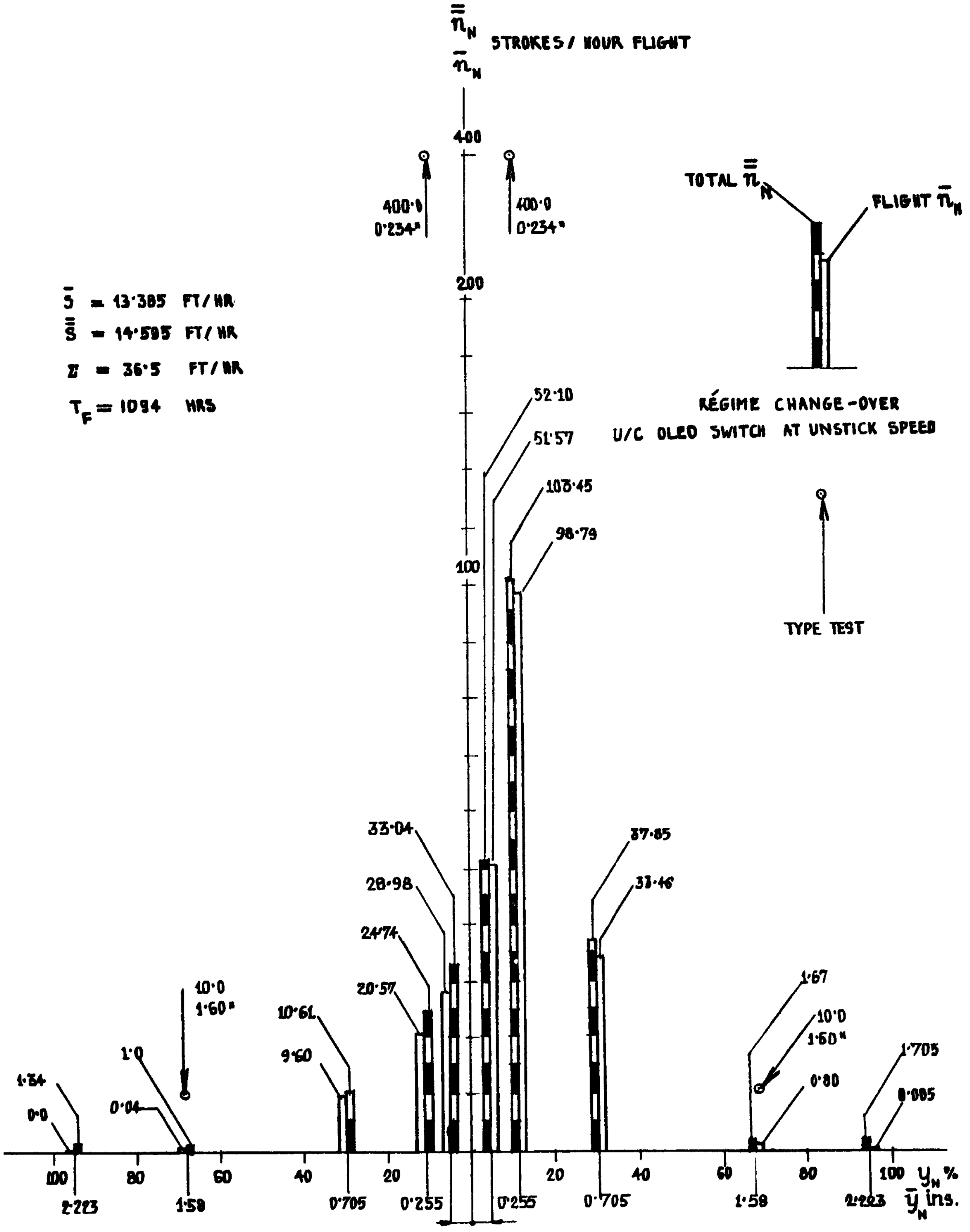


Fig.7 VC 10, aileron displacement

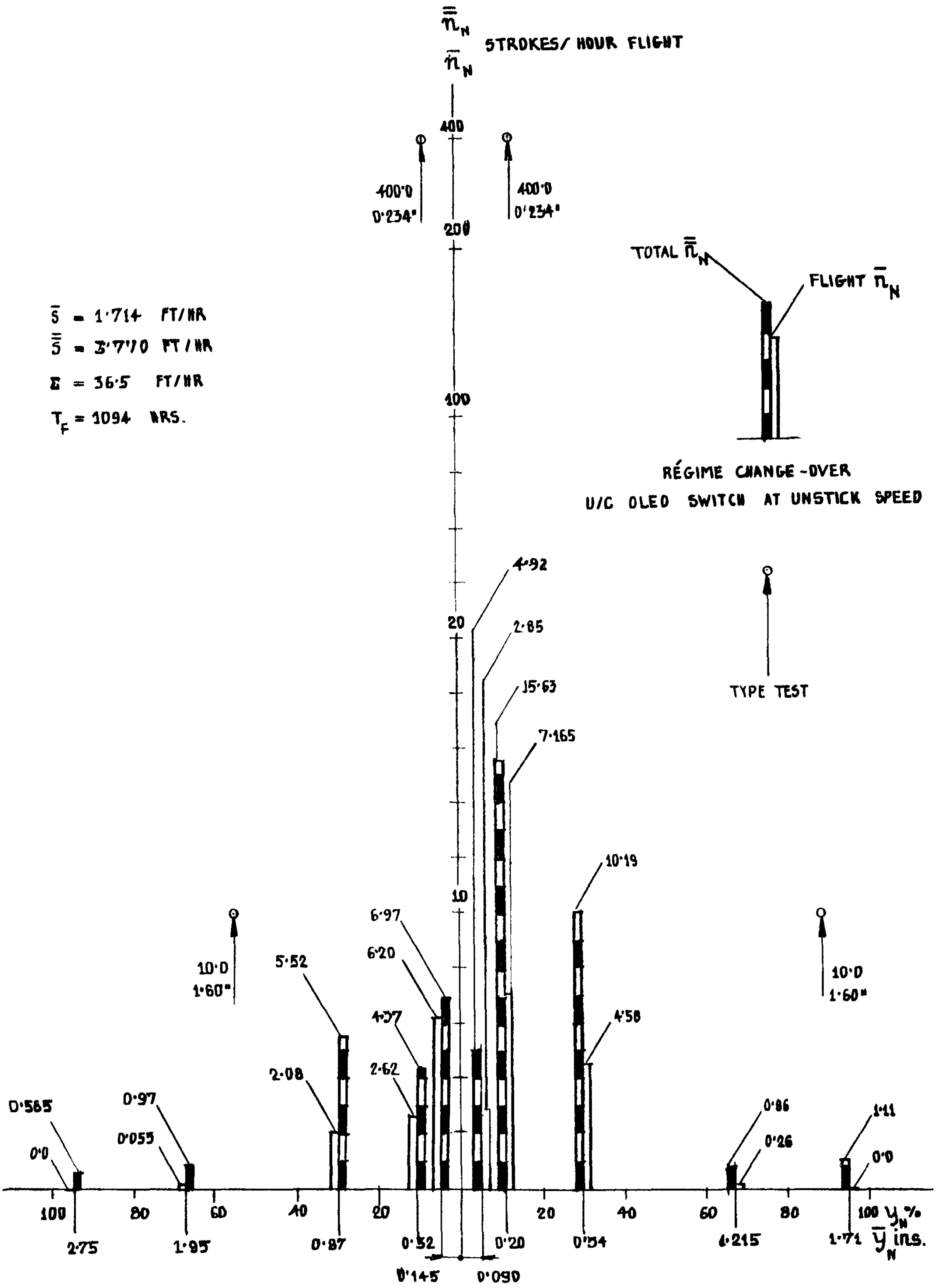


Fig.8 VC10, elevator displacement

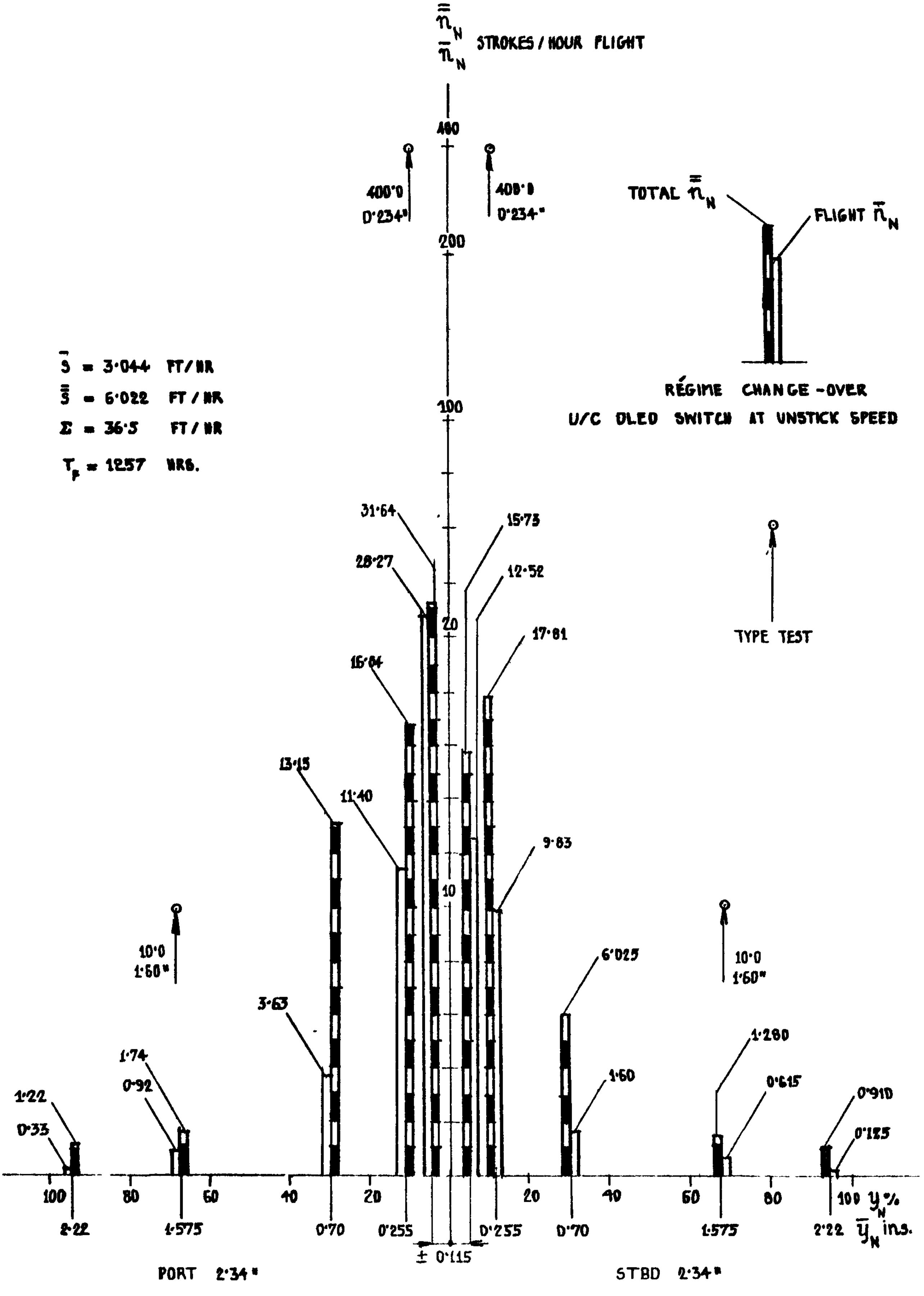


Fig.9 VC10, rudder displacement

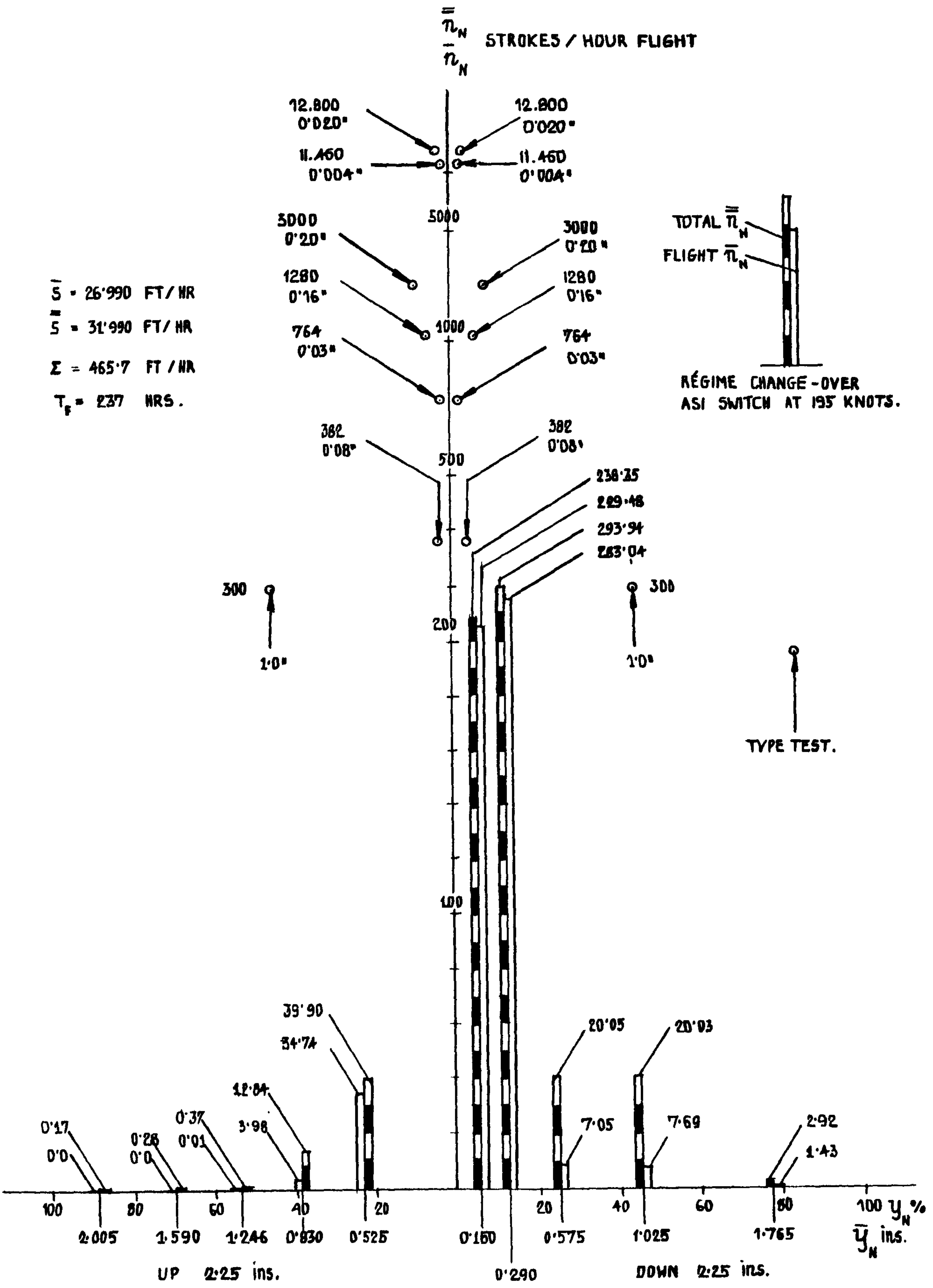


Fig.10 Buccaneer, aileron displacement

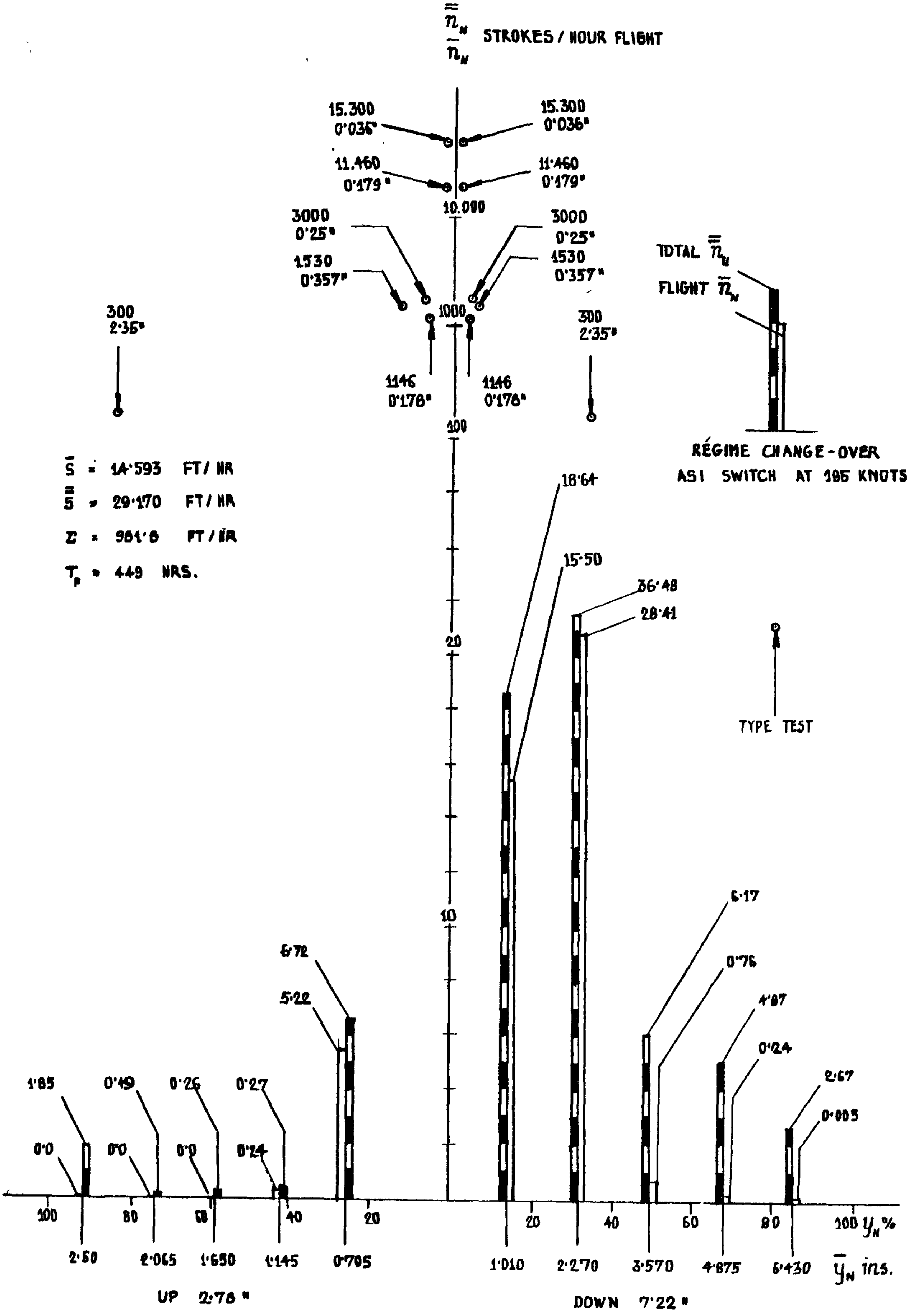


Fig.11 Buccaneer, tailplane displacement

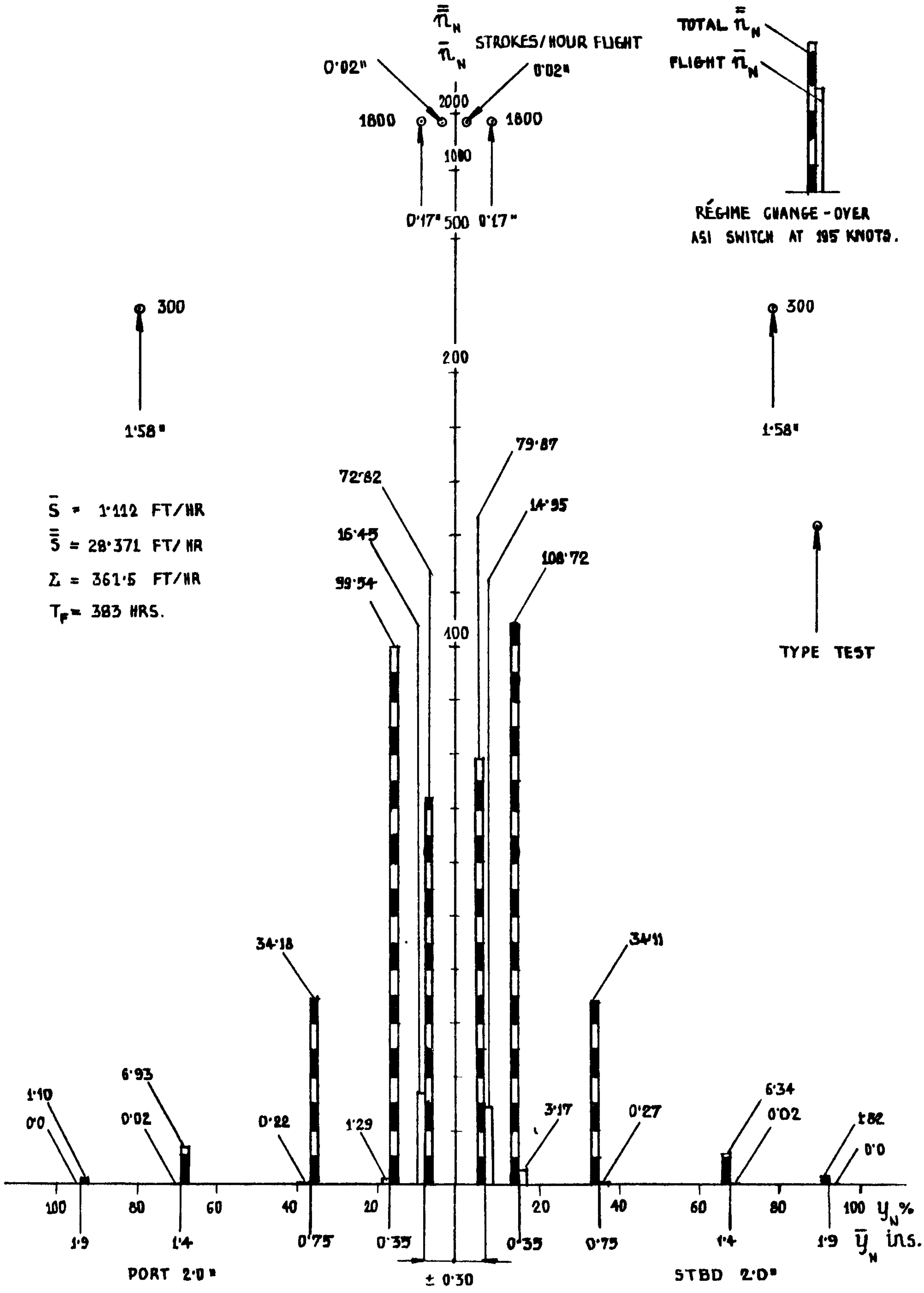


Fig.12 Buccaneer, rudder displacement

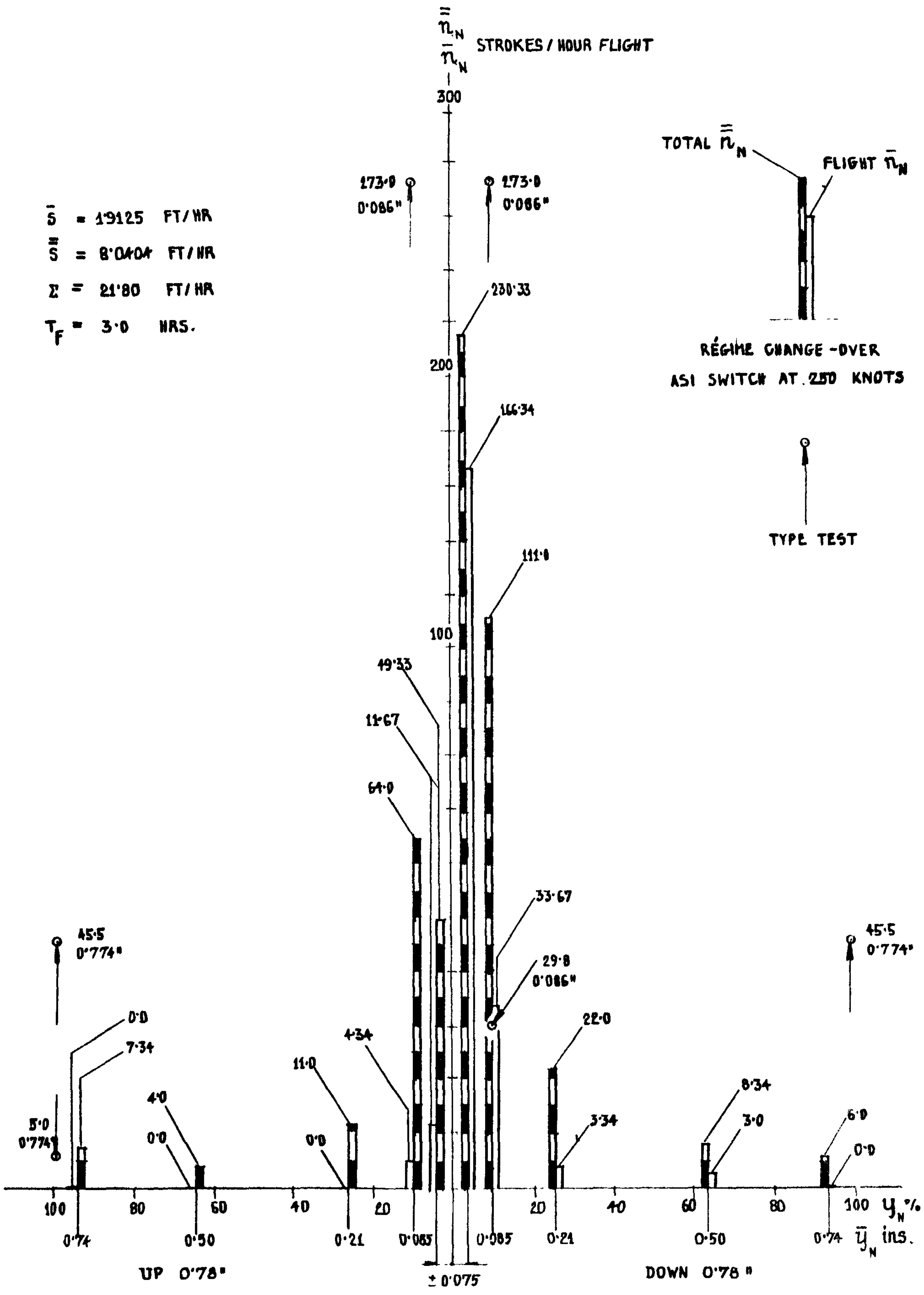


Fig.13 Lightning, aileron displacement

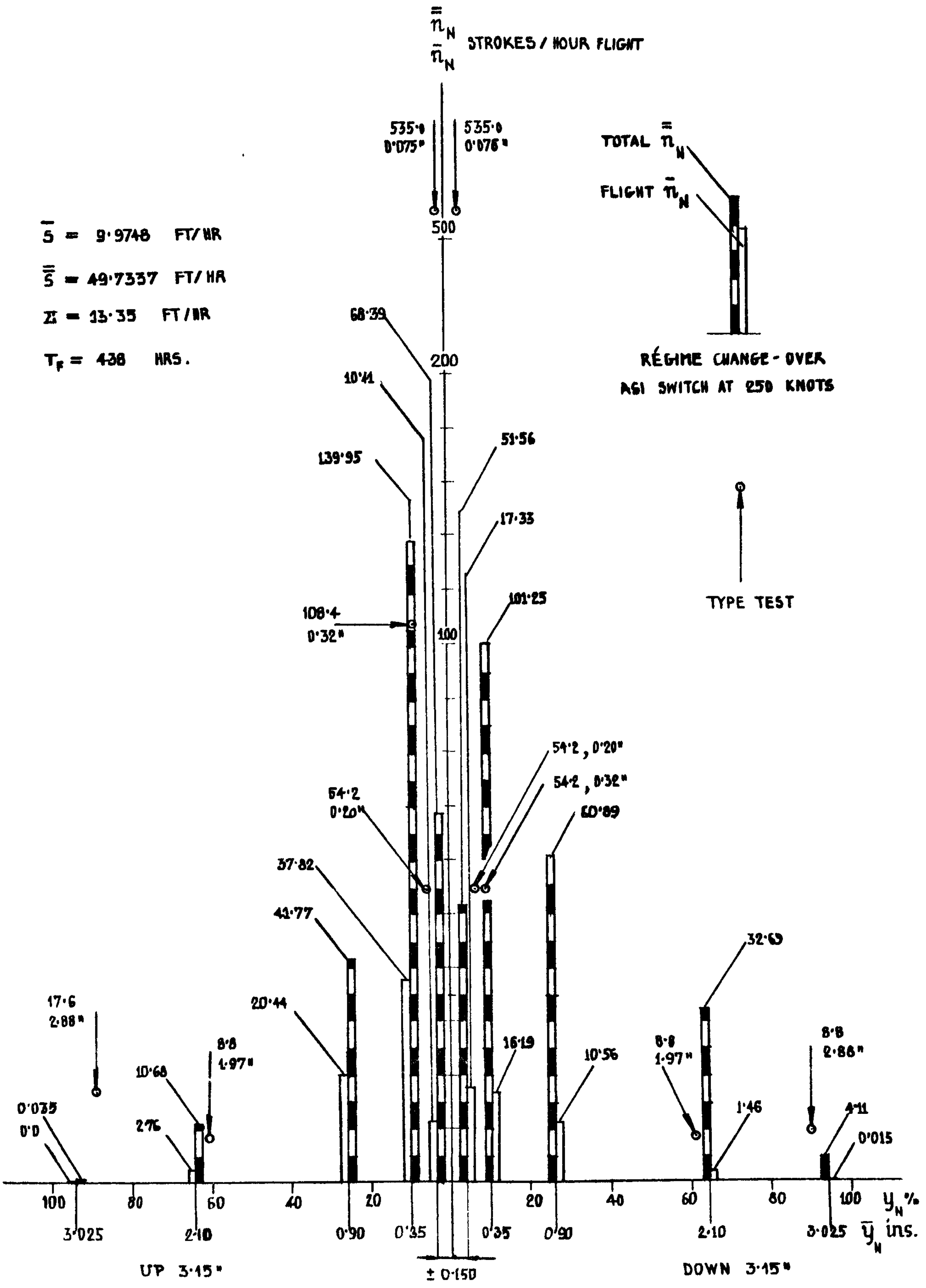


Fig.14 Lightning tailplane displacement

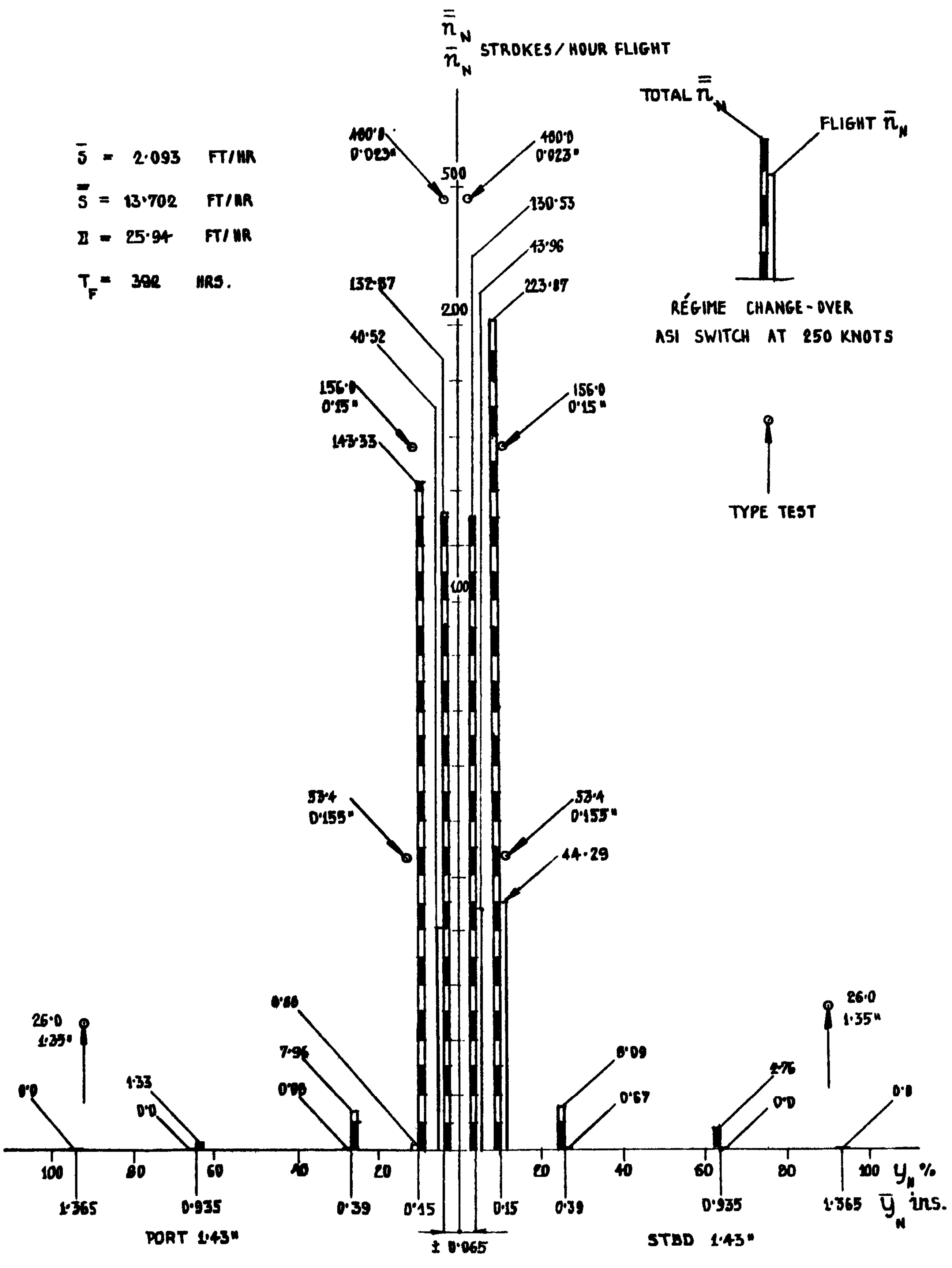


Fig.15 Lightning, rudder displacement

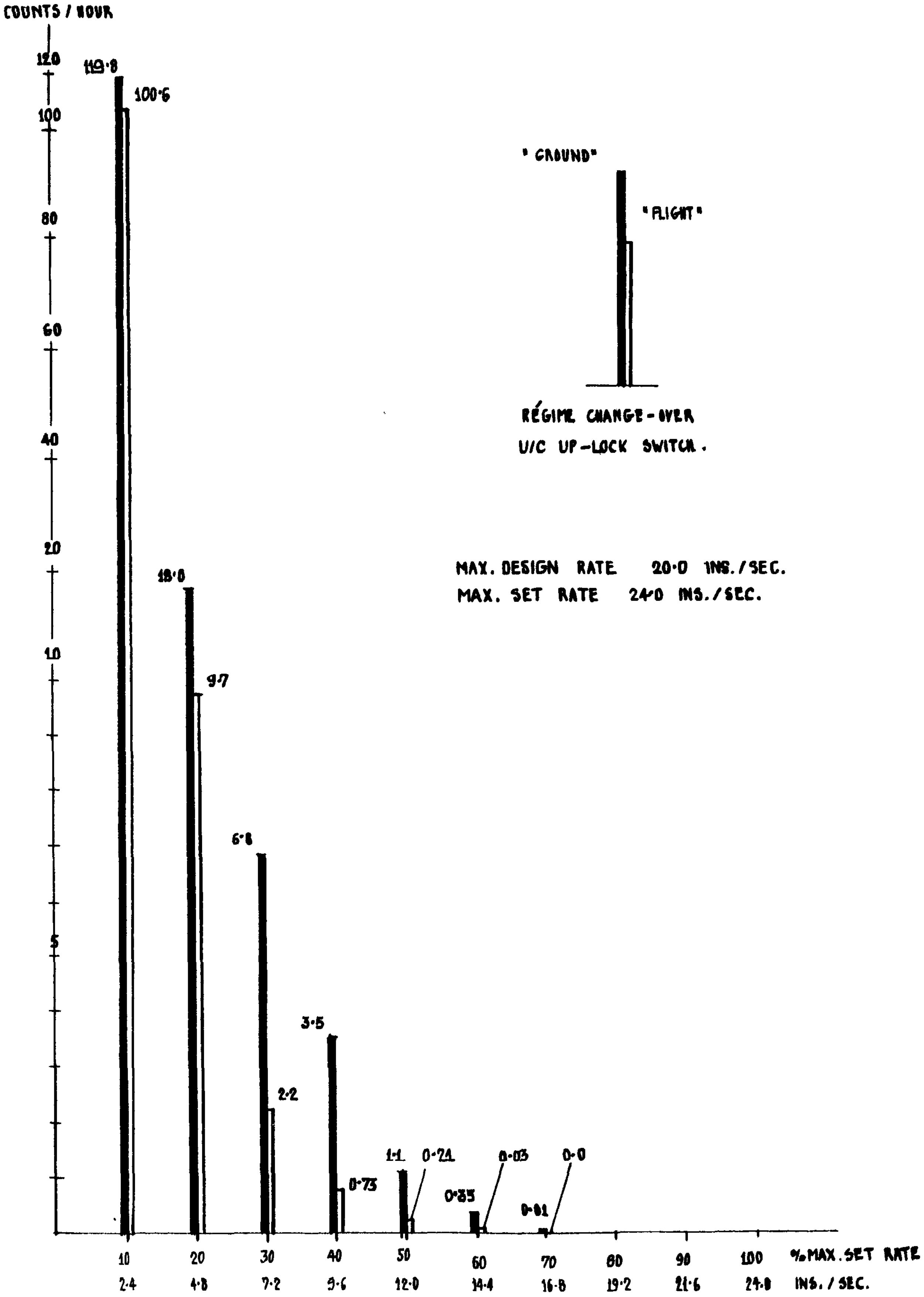


Fig.16 Seavixen, aileron rate

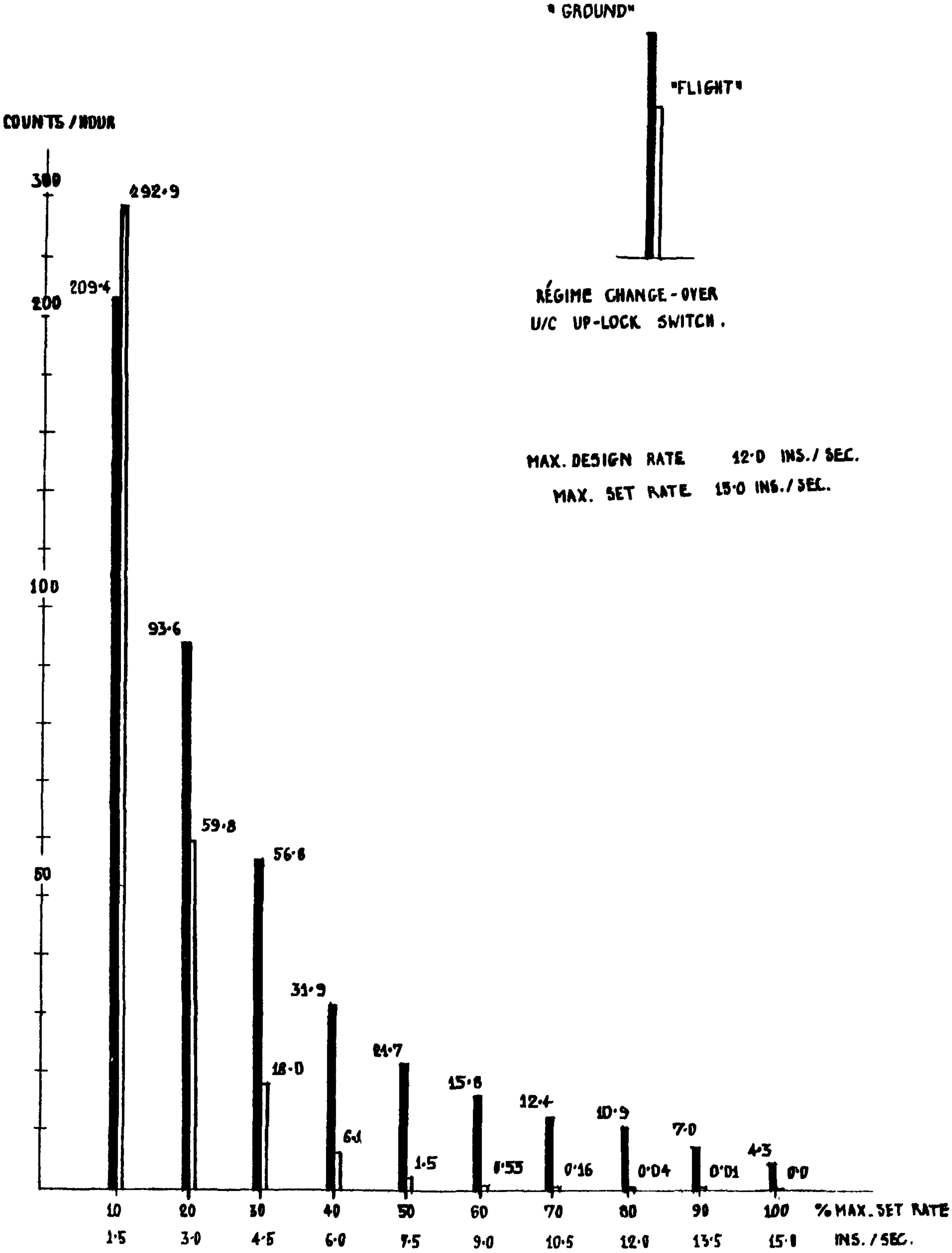


Fig.17 Seavixen, tailplane rate

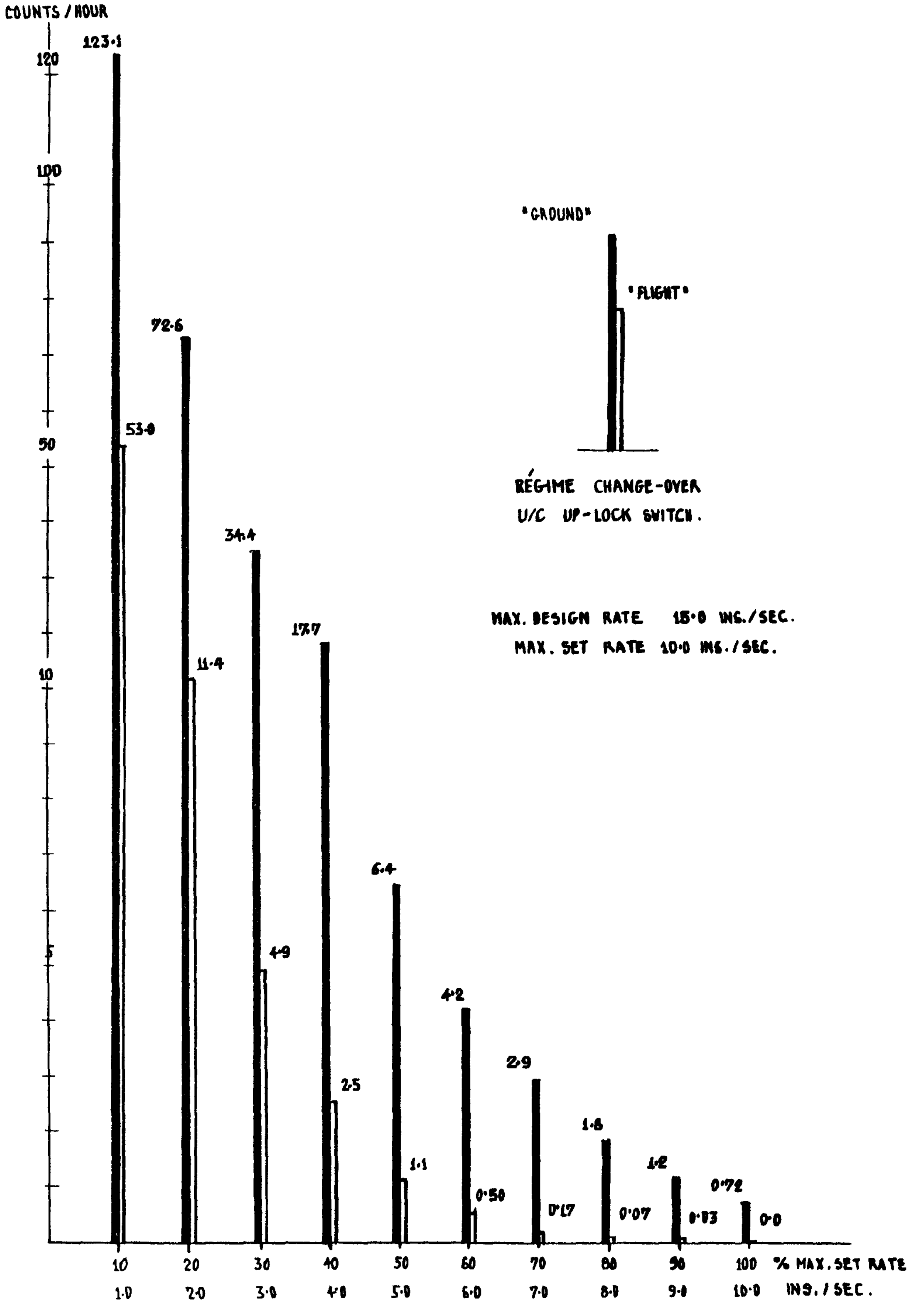


Fig. 18 Seavixen, rudder rate

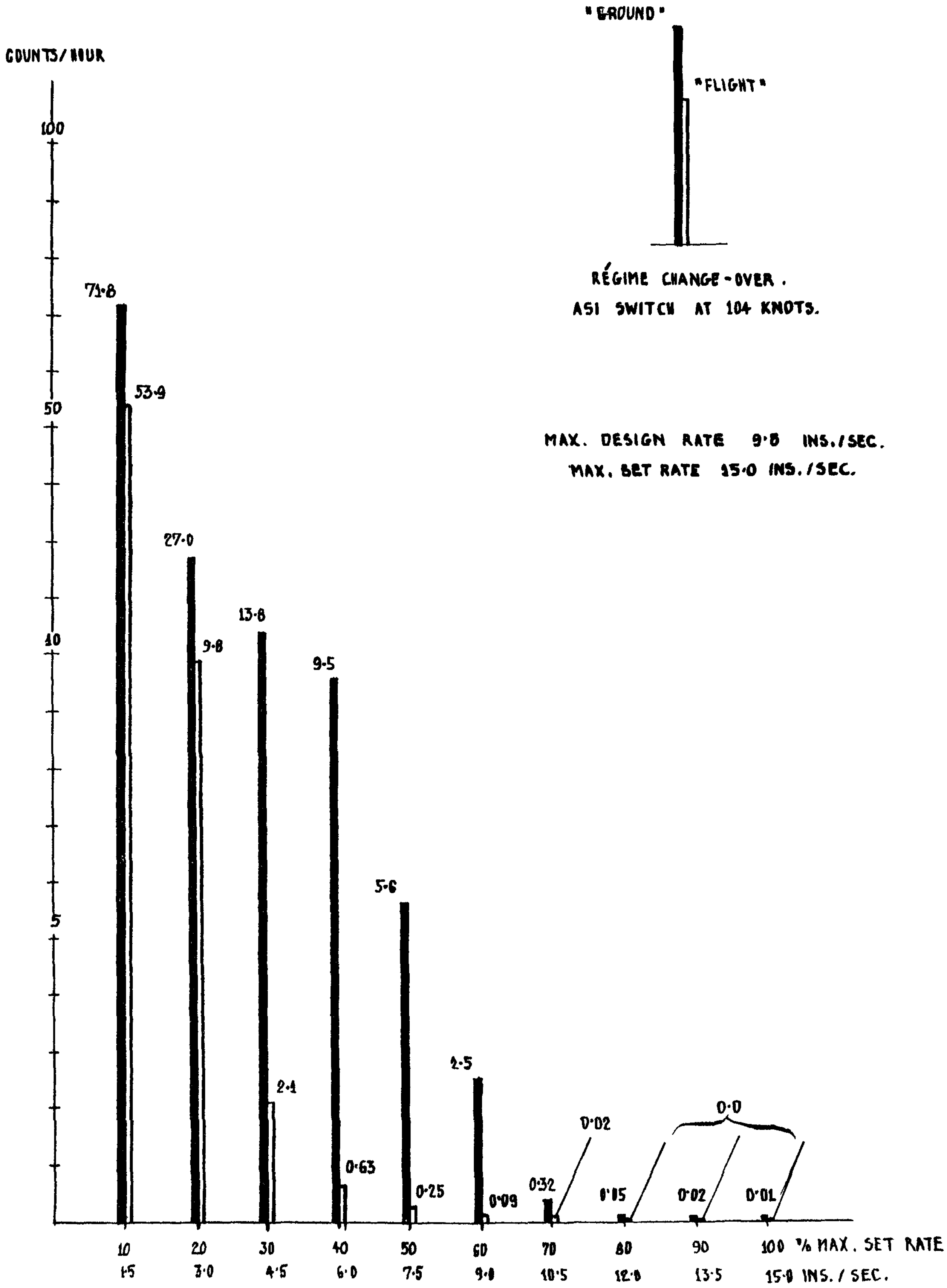


Fig.19 Victor, aileron rate

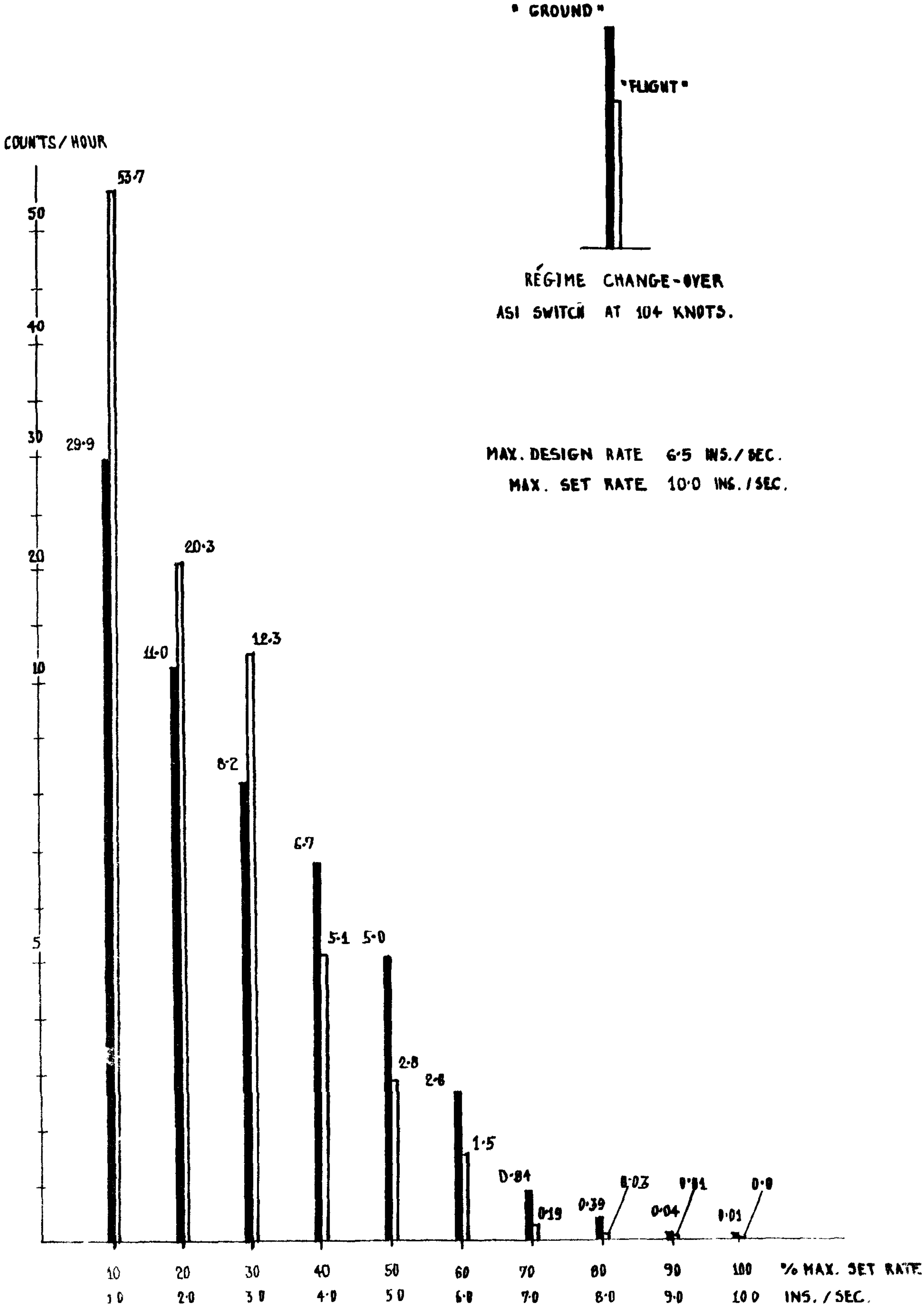


Fig.20 Victor, elevator rate

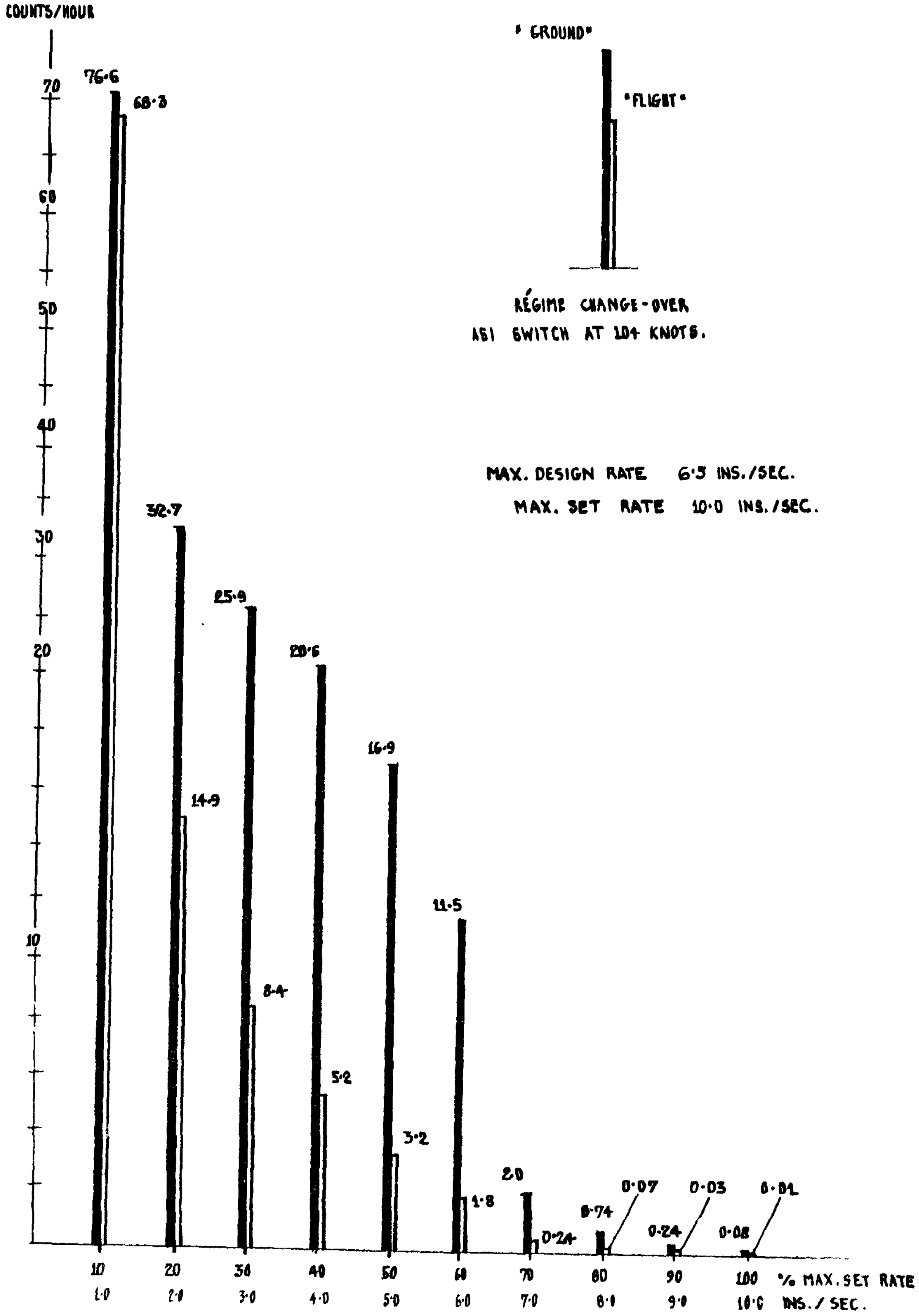
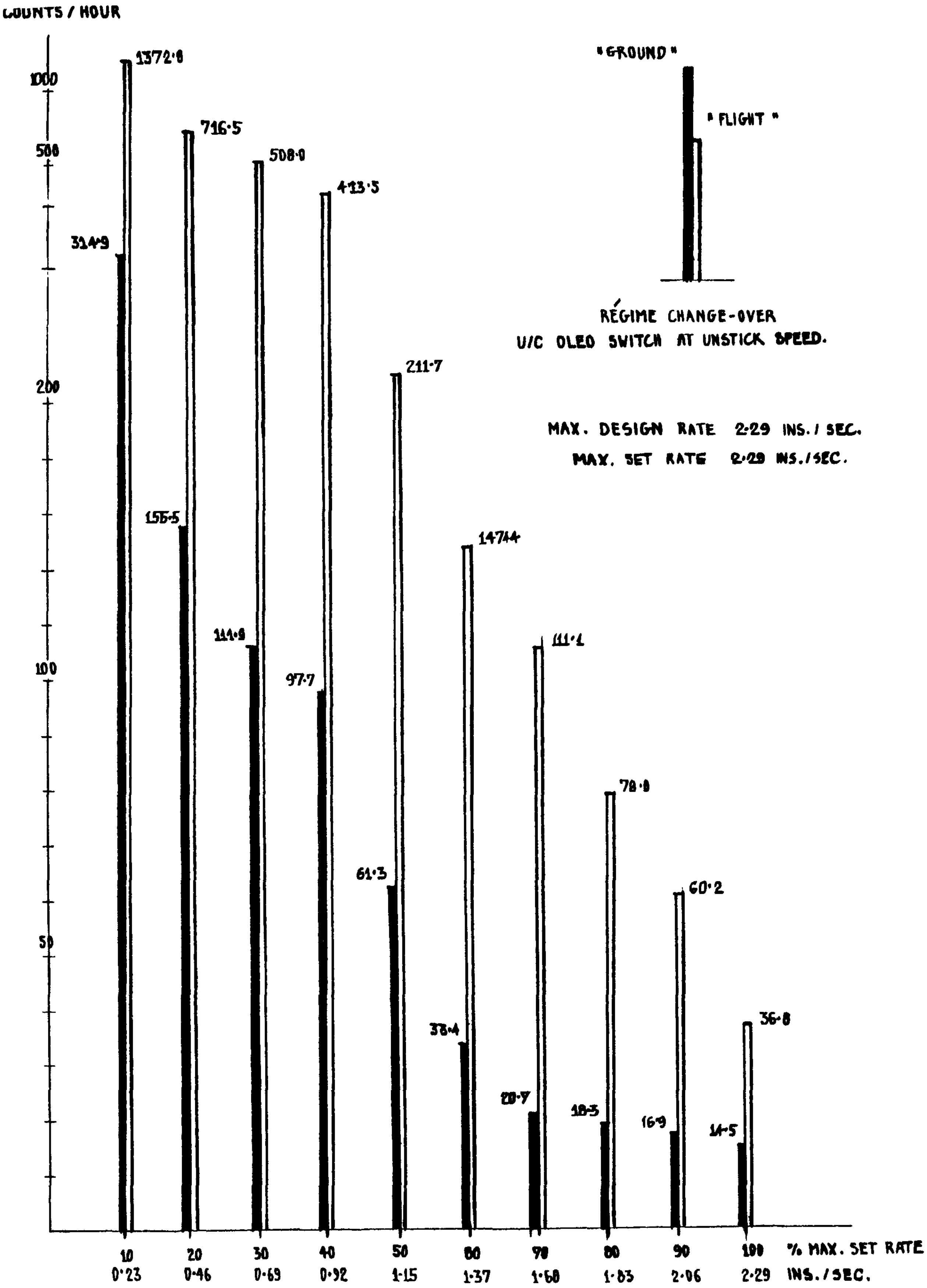


Fig.21 Victor, rudder rate



RÉGIME CHANGE-OVER
U/C OLEO SWITCH AT UNSTICK SPEED.

MAX. DESIGN RATE 2·29 INS./SEC.
MAX. SET RATE 2·29 INS./SEC.

Fig.22 VC10, aileron rate

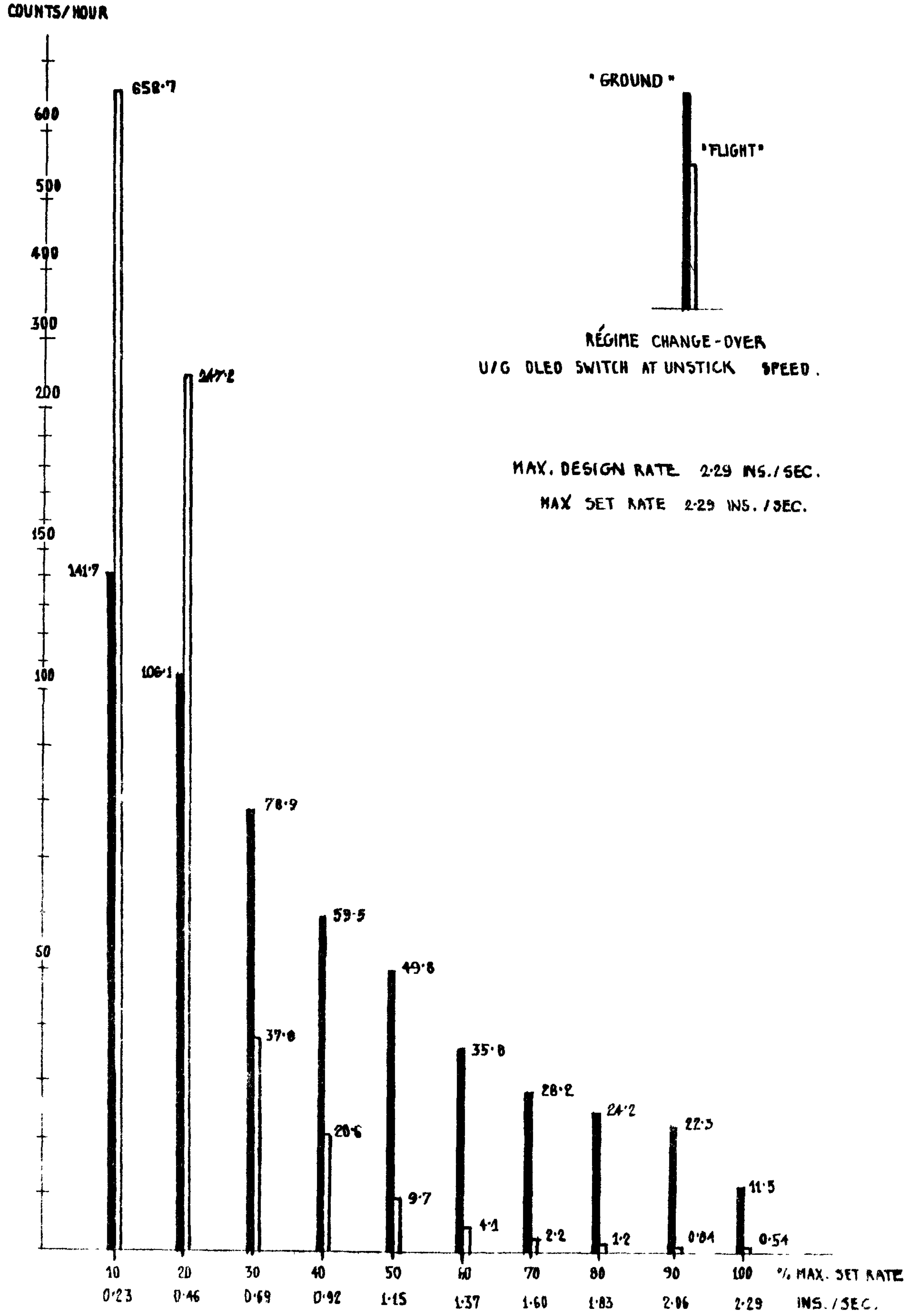


Fig.23 VC 10, elevator rate

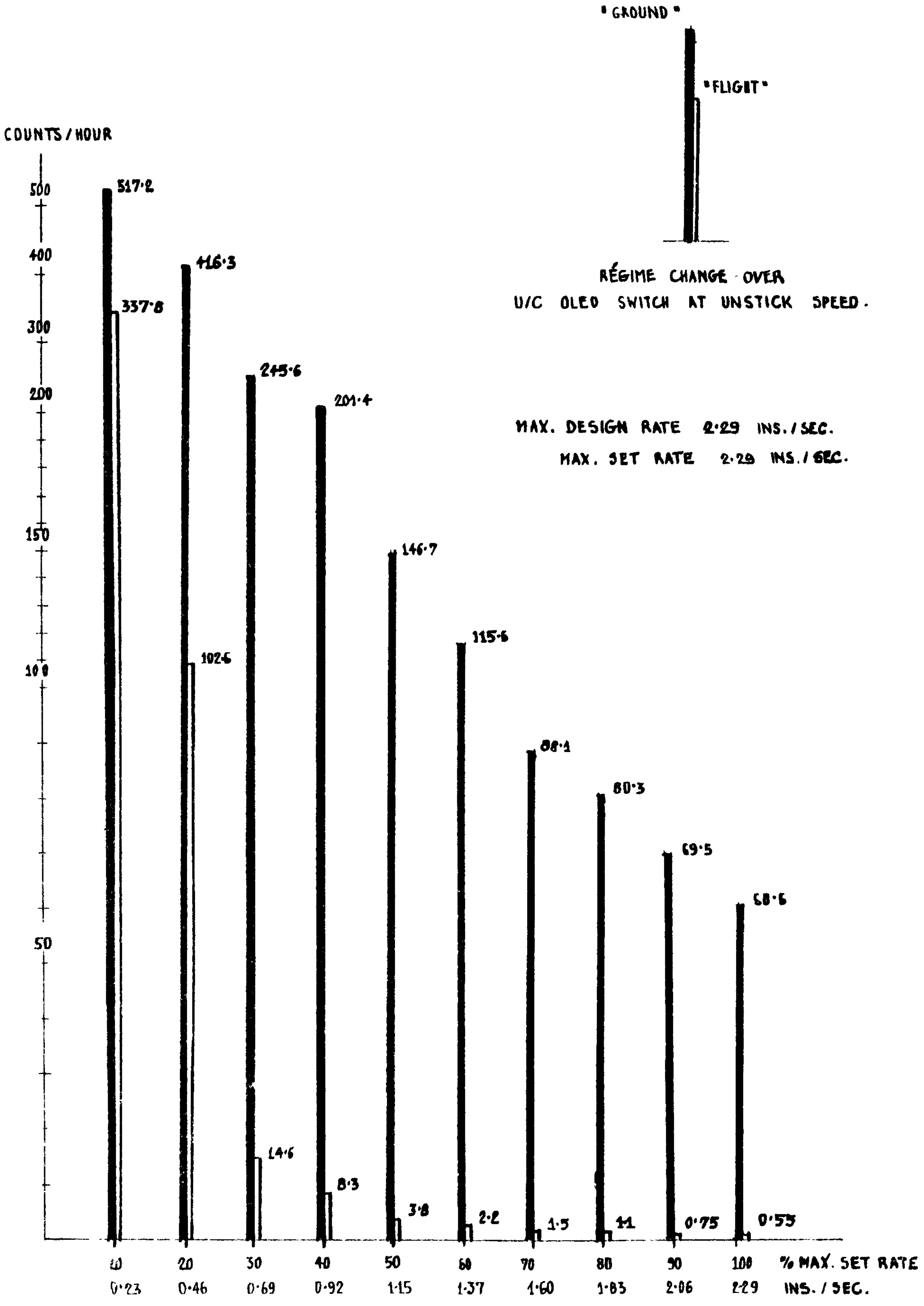


Fig.24 VC10, rudder rate

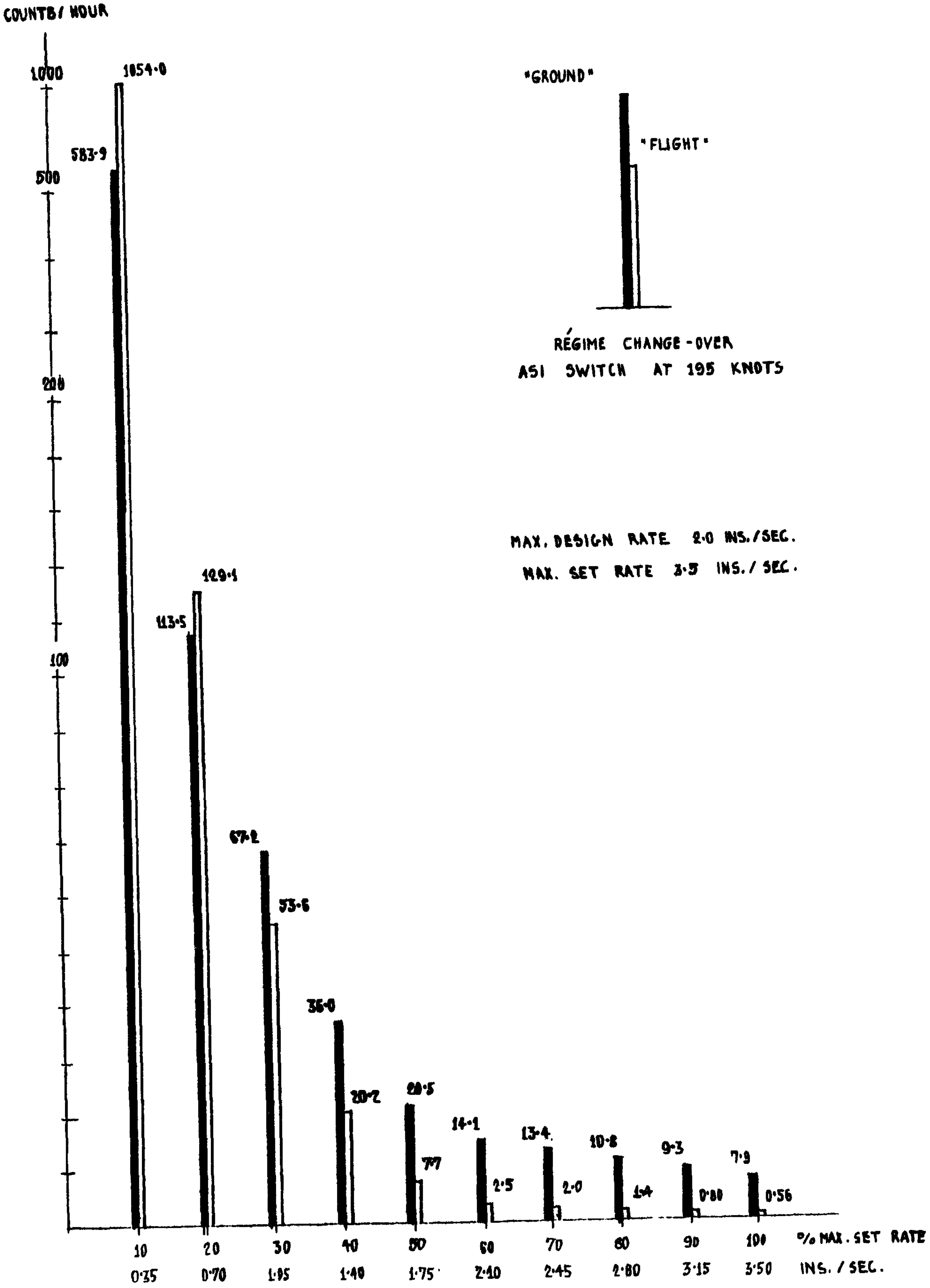


Fig.25 Buccaneer, aileron rate

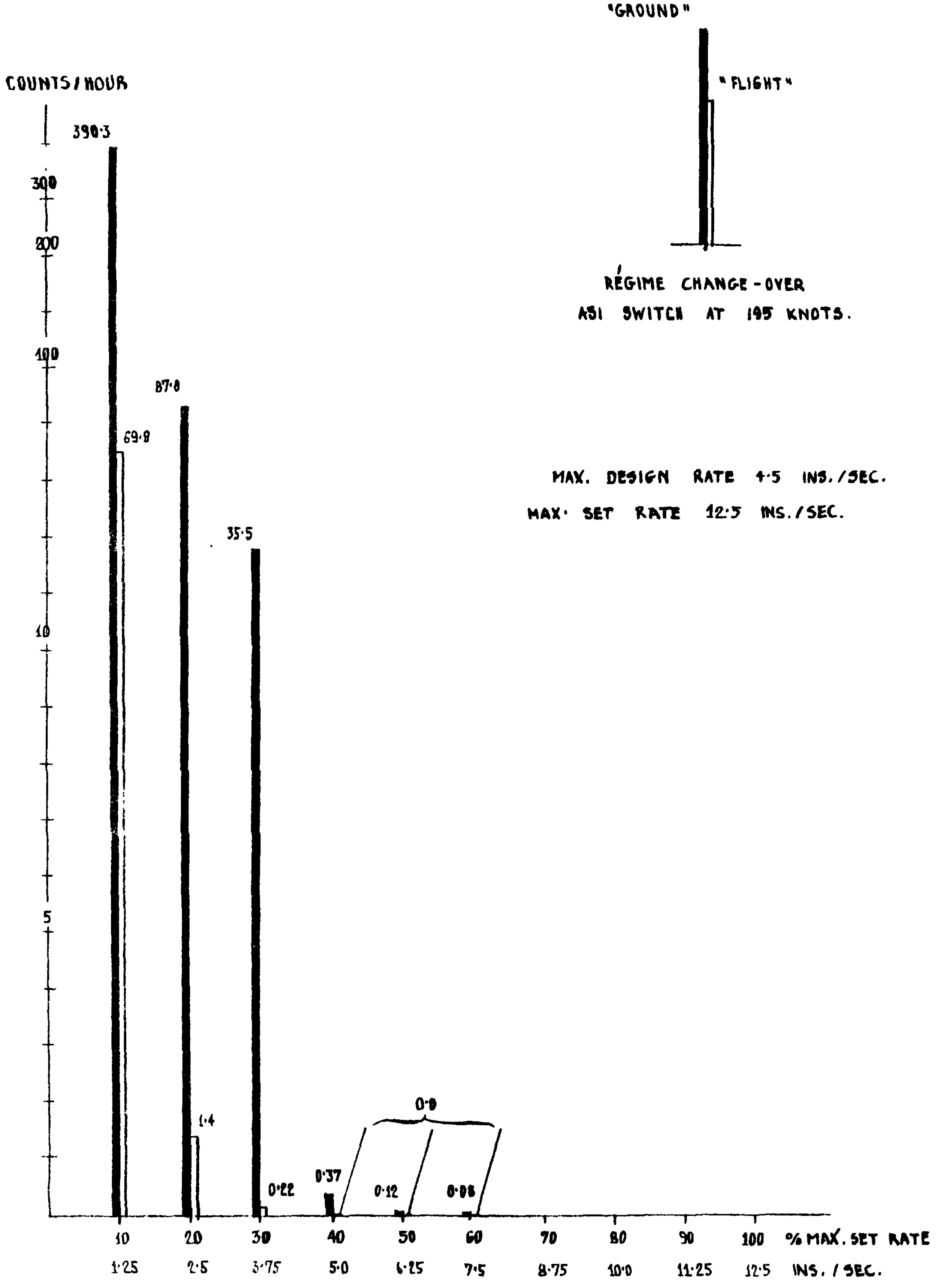


Fig.26 Buccaneer, tailplane rate

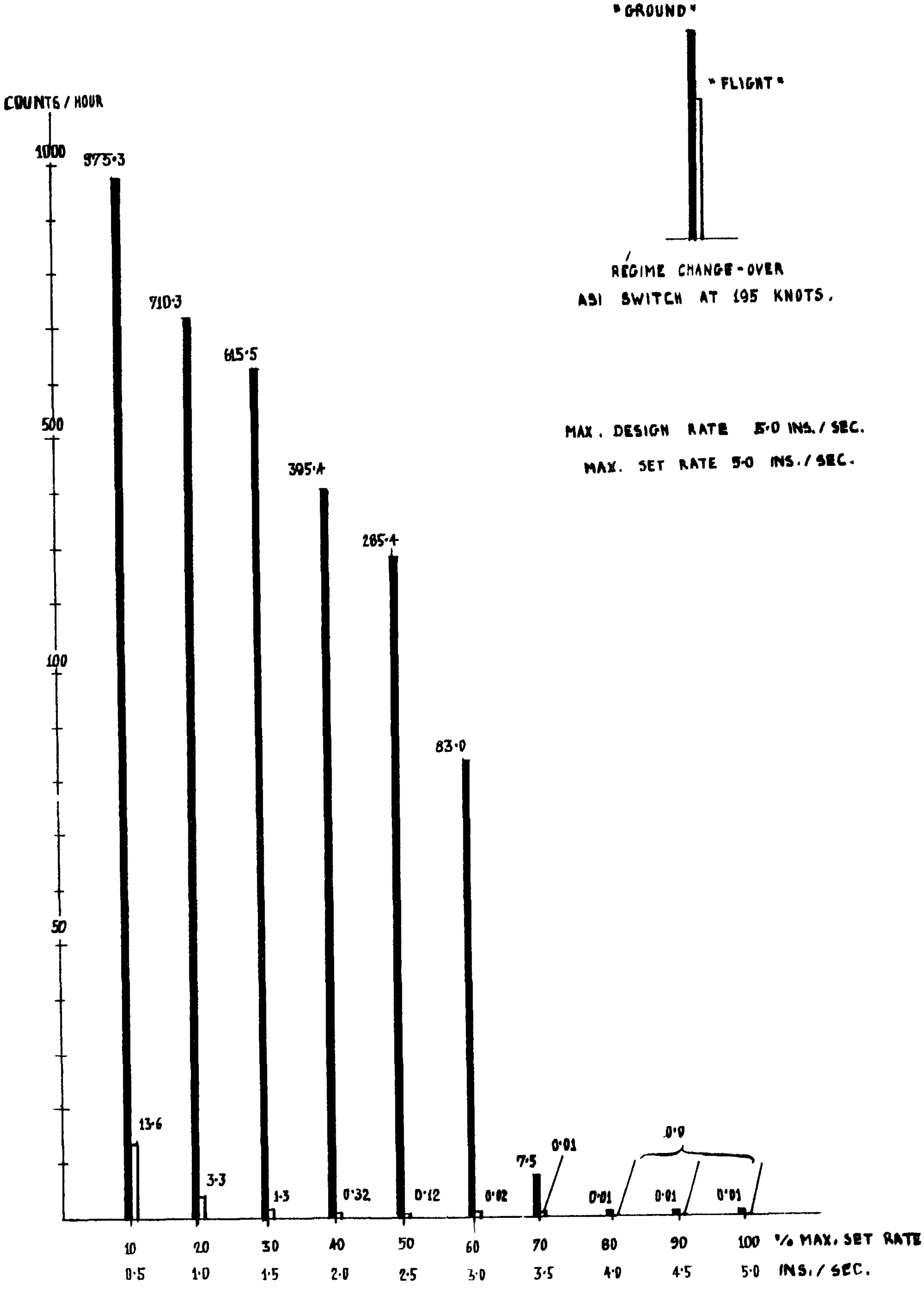


Fig.27 Buccaneer, rudder rate

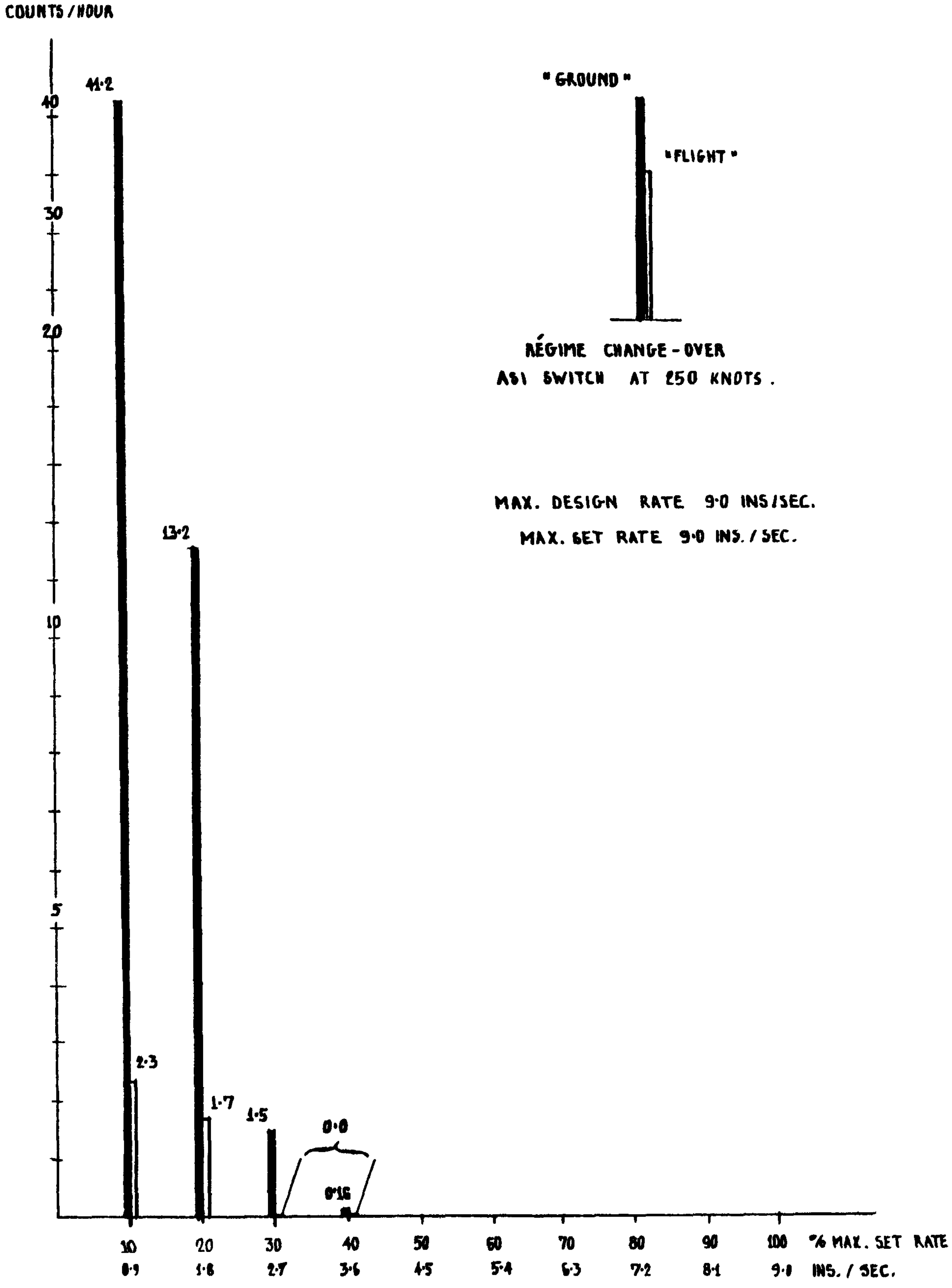


Fig.28 Lightning, aileron rate

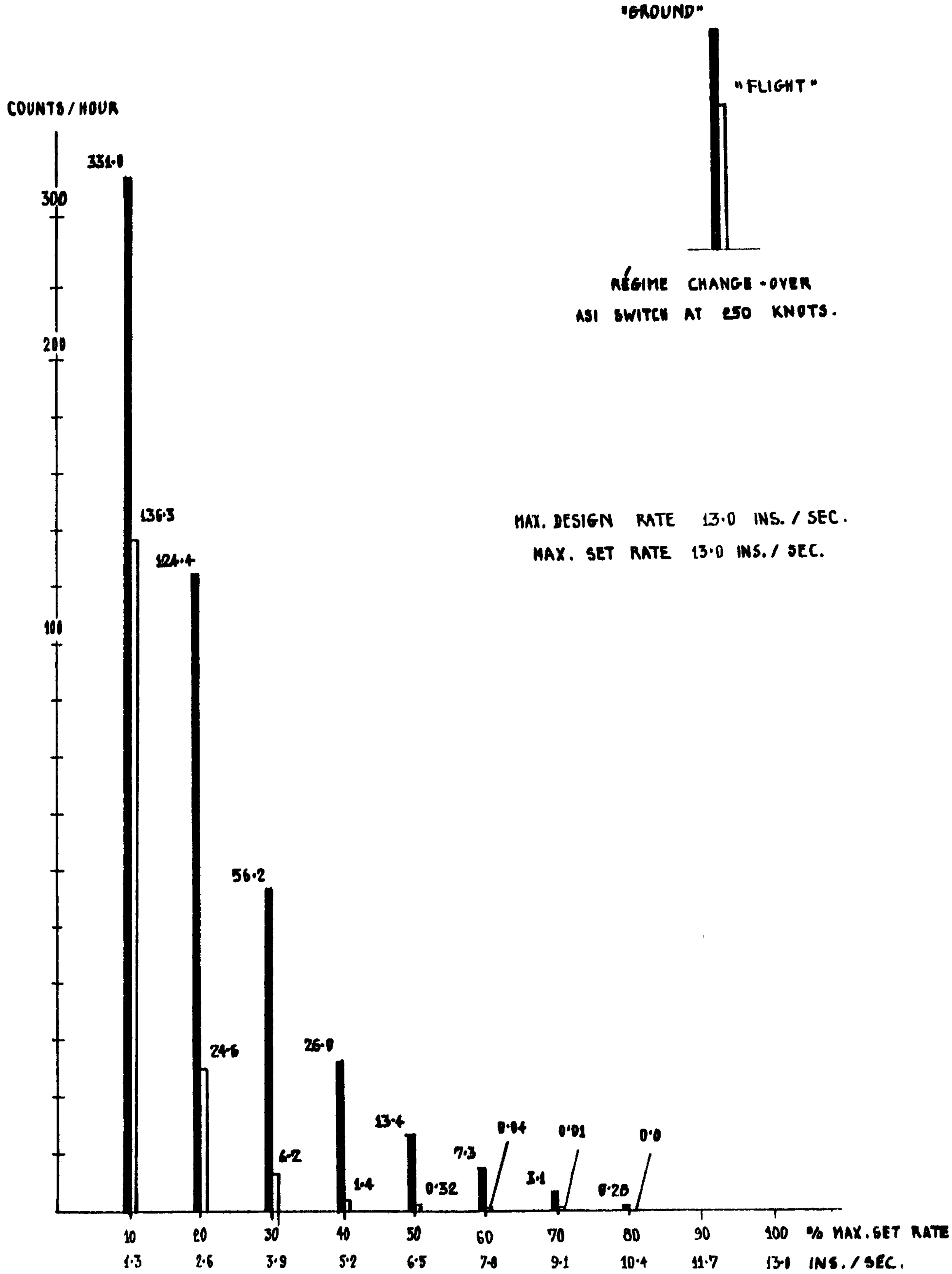


Fig.29 Lightning, tailplane rate

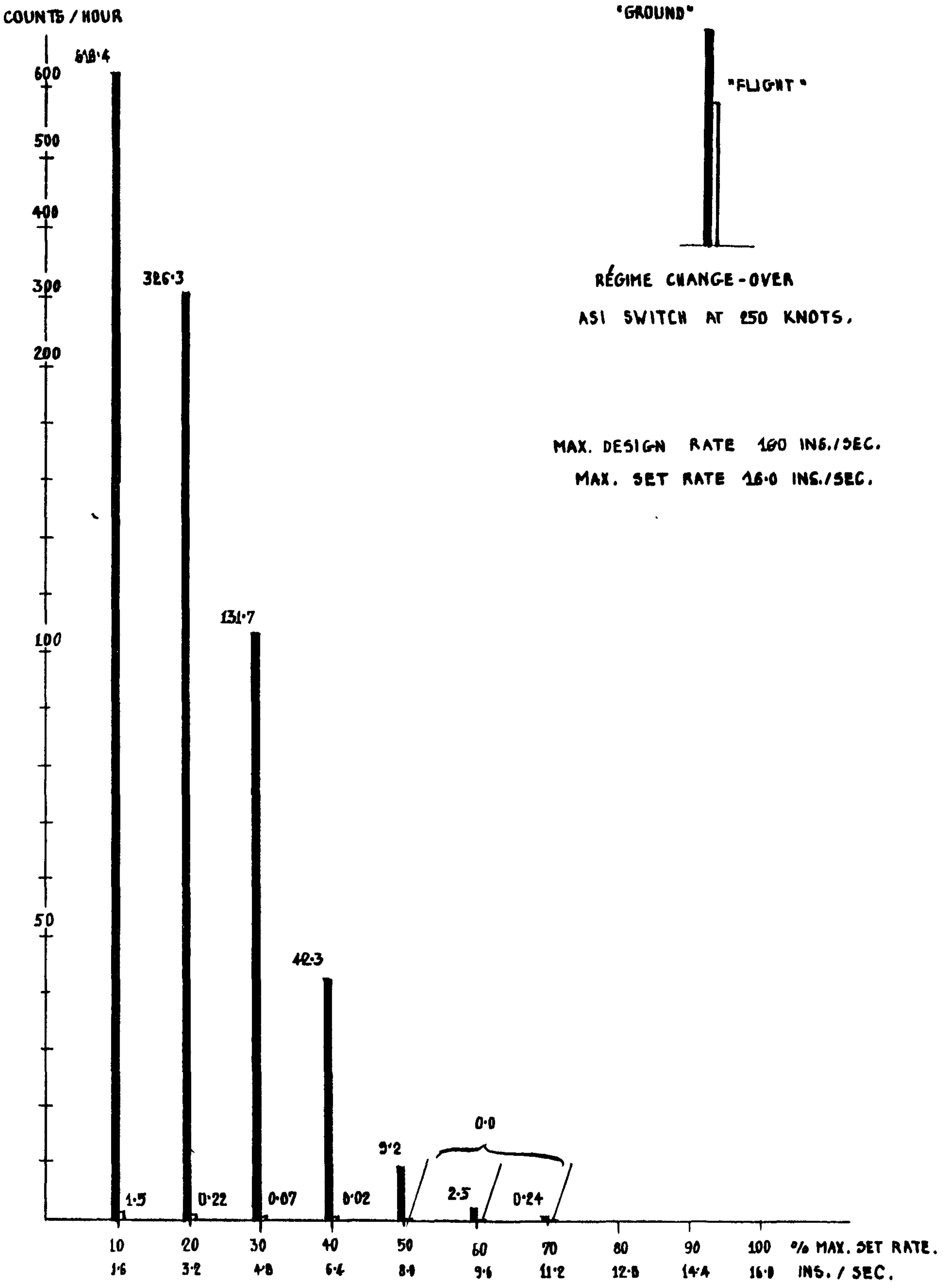


Fig.30 Lightning, rudder rate

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