P/AERO DATA/89

ARROW 1

COMPLIANCE WITH REQUIREMENTS OF U.S.A.F. MIL. SPEC. F-8785.
HANDLING QUALITIES OF PILOTED AIRPLANES.

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AVRO AIRCRAFT

P/AERO DATA/89

ARROW 1

Compliance with Requirements of U.S.A.F. Mil. Spec. F-8785.
Handling qualities of piloted airplanes.

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INTRODUCTION

This report describes Arrow handling and stability characteristics as required in para. 3.3.2 of "Model Specification for Supersonic Aircraft Type CF-105 Mk. 1 AAMS - 105/1" Dated December 1956. Issue 1 and subsequent.

To facilitate reading, the USAF Military Specification F-8785," Flying qualities of piloted Airplanes" has been rewritten with paragraphs having a small left hand margin, and our comments have been written after each requirement with paragraphs having a wider margin.

The findings in this report are based on theoretical predictions from the results of model tests and simulator studies. The following test facilities were employed:-

N.A.E.	6 x 10 feet	Low Speed Wind Tunnel
	16 x 30 inch	Supersonic Wind Tunnel
	15 feet	Spin Tunnel
C.A.L.	3 x 4 feet	Transonic Wind Tunnel
	10 x 12 feet	Subsonic Wind Tunnel
	8 x 8 feet	Transonic Wind Tunnel
N.A.C.A. (Langley)	4 x 4 feet	Unitary Wind Tunnel
	4 x 4 feet	Supersonic Wind Tunnel

Avro Free Flight Model Testing.

Avro Arrow Flight Simulator.

U.S.A.F. MILITARY SPECIFICATION MIL-F-8785 (ASG)

SECTION U

FLYING QUALITIES OF PILOTED AIRPLANES

NUMERICAL INDEX

NUMERICAL INDEX (Continued)

NUMERICAL INDEX (Continued)

LIST OF FIGURES

NOTE: At altitudes of 50,000 and 60,000 feet the graphs given in figures 3, 6, 12, 38, and 39 apply strictly to the Arrow 2, for which the ailerons are automatically deflected 4 degrees up at these altitudes. However, the general conclusions deduced from these graphs will also apply to the Arrow 1.

DETAILED ANALYSIS OF THE FLYING QUALITIES OF THE AVRO ARROW 1

AS REQUIRED BY THE UNITED STATES MILITARY SPECIFICATION MIL-F-8785 (ASG) SECTION U.

1. SCOPE

1.1 Scope:

This specification contains the requirements for the flying qualities of U.S. military piloted airplanes.

1.2 Application:

The flying qualities for all airplanes proposed or contracted for shall be in accordance with the provisions of this specification, unless specific deviations are authorized by the procuring activity. Additional special requirements for stability and control may be specified by the procuring activity.

1.3 Classification:

For purpose of this specification, airplanes shall be divided into the following classes:

Class I - Primary trainer, observation, and other light airplanes specifically designated by the procuring activity.

Class II - Horizontal bomber, cargo, transport, glider, patrol, antisubmarine, early warning, mine-layer, heavy attack, and trainers for class II airplanes.

Class III - Fighter, interceptor, general purpose attack, and trainers for class III airplanes.

An airplane not listed specifically among these class designations shall be considered to be in that class which includes airplanes of the most similar type. When peculiarities of intended mission or configuration so dictate, an airplane of one class may be required by the procuring activity to meet selected requirements ordinarily specified for airplanes of another class.

The Arrow 1 is in class III.

1.3.1 Land- or carrier -based designation: - The letter-L following a class designation identifies an airplane as land-based, carrier-based airplanes are similarly identified by the letter -C. When no such differentiation is made in a requirement, the requirement shall apply to both land-based and carrier based airplanes.

The Arrow 1 is a land based aircraft, designation L.

2. APPLICABLE DOCUMENTS

2.1 Not applicable to this specification.

3. REQUIREMENTS

3.1 General

3.1.1 Airplane loadings:- Unless otherwise stated, the airplane weight for a specified c.g. (center of gravity) position shall be that corresponding to the normal service loading in which the specified c.g. is obtained. Similarly, normal service loading conditions shall govern the location of the c.g. for a specified weight. When not specified, loadings shall be optional.

In order to facilitate calculations in the early design stage, an arbitrary but realistic centre of gravity and weight combination has been chosen for the Arrow 1 as 47,000 lb for the centre of gravity at 31% of mean aerodynamic chord for most of the calculations. In addition in some cases data are presented for c.g. positions at $.28\bar{c}$, $.29\bar{c}$ and for weight cf 56,000 lb.

3.1.2 Altitudes:- Unless otherwise stated, the requirements shall apply at all altitudes at which the airplane might be operated in each of the specified configurations. In general, compliance with this stipulation may be determined by investigation of three significant altitudes consistent with the airplane mission requirements. Unless otherwise established between the procuring activity and the contractor, these altitudes shall be defined as follows:

(a) Low altitude: For design purposes, low altitude shall be sea level.

(b) High altitude: An altitude not lower than 80 percent of the service ceiling.

(c) Medium altitude: Approximately 50 percent of high altitude, or 40,000 feet, whichever is lower. (Medium altitude need be investigated only when the service ceiling is 40,000 feet or higher).

The high and medium altitude conditions may be excluded in consideration of configurations L, PA, WO, and TO.

3.1.2 Altitudes: (Continued)

The majority of design calculations for the Arrow 1 have been made at intervals of 10,000 feet from Sea level to 60,000 feet which exceeds the demands of the specification.

In order that this report shall not become too bulky, in general only the results of investigations at sea level, 30,000 feet and 60,000 feet will be presented herein.

3.1.3 Operational flight envelope:- For the three altitudes defined in paragraph 3.1.2 and for combat ceiling, Mach-number-normal acceleration envelopes for several significant airplane loading conditions shall be specified in the contract or otherwise established by agreement between the procuring activity and the contractor. Both positive and negative normal accelerations are to be included. These envelopes shall serve to define the boundaries within which the airplane is expected to be operational and within which the requirements of this specification therefore apply. Within these boundaries there shall be no objectionable buffet, trim or stability changes, or other irregularities which might detract from the effectiveness of the airplane in executing its intended mission. The operational flight envelope shall show cut-off points representing the highest Mach numbers at which the airplane is to be considered operational. These maximums shall be based on considerations of pull-out recovery (reaching level flight at 2,000 feet above sea level), as well as attainable speeds. In the requirements of this specification, a curve of such cut-off speeds plotted against altitude is referred to as the maximum operational speed envelope. If necesssary for adequate definition of this envelope, maximum speed points for various intermediate altitudes shall be included.

Three typical flight envelopes are given as figs. 1, 2 and 3. Note that the maximum Mach number is the structural limit Mach Number rather than the maximum obtainable Mach number from thrust available considerations.

3.1.3.1 The operational flight envelopes for an airplane intended solely for missions at supersonic speeds need not include the transonic speed range, provided that satisfactory transition through the transonic speed range is assured.

The Arrow 1 is intended to cruise in both the transonic and supersonic range, so the flight envelopes include the transonic range.

3.1.4 Maximum permissible speed envelope:- A V_D (or M_D) altitude envelope shall be established in addition to the envelopes specified in paragraph 3.1.3. This maximum permissible speed envelope shall be derived from consideration of dives entered at V_H. Unless limited by structural considerations, this envelope shall define, at each altitude, the maximum speed from which a recovery can be made which will result in level flight at an altitude of not less than 2,000 feet above sea level without encountering intolerable buffet, loss of control, uncontrollable trim changes, or other dangerous airplane behavior during the entire dive or pullout. In establishing this maximum permissible speed, the pullout shall be governed by the requirements of paragraph 3.3.16.1.

This envelope is not required for the Arrow 1 as the maximum horizontal flight Mach number is restricted by structural considerations. Maximum speeds in level flight for Arrow 1 are shown on fig. (24).

3.1.4.1 The development of any dangerous flight conditions associated with the dive or pull-out in paragraph 3.1.4 shall be sufficiently gradual, in order that the pilot is amply warned.

(a) Normal mode:

There are no dangerous conditions associated with a dive or pull-out providing it is within the flight envelope.

(b) Emergency mode:

Inertia coupling effects may be significant during an extreme pull-out. These effects should however be gradual.

3.1.5 External Stores:- In preparation of the flight envelopes discussed in paragraph 3.1.3 and 3.1.4, external stores which are not normally droppable in flight, or which are intended to be carried during the primary mission, shall be considered as integral elements of the airplane configuration. When such stores contain expendable loads the requirements shall, unless otherwise stated, apply throughout the range of store loadings. For other significant store installations, revisions to the flight envelopes and deviations from the flying qualities requirements shall be established by agreement between the procuring activity and the contractor in accordance with the mission requirements of the airplane with such stores installed. In establishing these agreements, consideration of reasonable single malfunctions, such as failure of release mechanism or failure of fuel feed, as well as normal initial asymmetric store installations, shall be included.

The Arrow 1 has no external stores.

3.1.6 Effects of armament provisions:- Operation of bomb bay doors, armament pods, or other movable protuberances, shall not cause objectionable buffet, trim changes or other characteristics which impair the tactical effectiveness of the airplane under any flight condition in which operation of such devices may be required in the conduct of the airplane mission.

3.1.6 Effects of armament provisions (Continued)

The requirements of the last paragraph on page 4 , need to be verified by flight test, particularly to investigate whether there will be objectionable buffet, which is difficult to predict. When the aircraft automatic control system is fully operational, the damping system will nulify any trim changes that would otherwise occur on lowering the missiles. From wind tunnel tests with three missiles, it is estimated that, for the aircraft on emergency control system, the trim change due to lowering four missiles would be as quoted in the table.

Mach No.	Altitude	Sea Level	20,000 ft.	40,000 ft.	60,000 ft.
.95	Change in Normal Accelera-tion	-1.5g	- .5g	- .1g	0
1.20		-	- .7g	- .6g	-.5g

3.1.7 Release of stores:- The release of any stores intended to be released during normal operation of the airplane shall not result in dangerous or seriously objectionable flight conditions.

The Arrow 1 has no external stores.

The Arrow 2 has only one releasable store at the present time; the fuselage drop tank. The release of dynamically scale models have been observed in the N.A.E. wind tunnel, simulating tank full and empty cases, and the effect of Mach number and altitude. Results show that the store drops cleanly and does not foul the fuselage.

3.1.8 Deceleration devices:- Unless specifically exempted by the procuring activity, all class II and class III airplanes shall be capable of deceleration dive-speed limitation, and constant-speed, glide-path control, to a degree which will be stated in the contract or otherwise agreed to by procuring activity.

These capabilities need not be provided by auxiliary devices, such as speed brakes, if other design features or provisions can be utilized to produce the desired characteristics. The term "deceleration device," as employed in this specification, shall apply to whatever brake, flap, or other feature is used to provide the desired incremental drag effect.

The Arrow 1 is equipped with an under-fuselage dive brake, intended primarily for deceleration and dive speed control. The characteristics of this brake are shown in Figures 4 and 5. It can be seen (Fig. 4) that the deceleration obtained is approximately a linear function of Mach No. at a given altitude, the maximum being about .35 'g' at M = 2.0 at heights of 30,000 and 40,000 feet. In the normal mode the change in

3.1.8 Deceleration devices (Continued)

normal acceleration due to dive brake extension will be negligible at all speeds. It will appear as a transient of short duration which should not require manual retrimming.

In the emergency mode the change in normal acceleration (Fig. 5) which accompanies this deceleration is reasonable, being always positive and reaching a maximum value of about 1.8 'g' at 40,000 ft. At subsonic speeds, the change in normal acceleration due to dive brake operation is much less. If it were desired to use the speed brake as a speed control on the approach, there would be a maximum change of +0.3 'g' in normal acceleration for a maximum deceleration of 0.1 'g'.

3.1.9 Configurations:- For purposes of this specification, the basic airplane configurations shall be as described herein. Items of configuration not specified, such as cockpit enclosure, cowl flaps, oil cooler flaps, gun turrets, blast tube covers, or bomb bay doors shall be in their normal settings for the particular configuration.

Configuration CR:	Cruise:	Power for level flight at trim speed (See table II), flaps in cruise position, gear up.
Configuration D :	Dive:	25-percent normal rated power or minimum operable power, whichever is the greater, flaps and gear up (unless normally used as speed brakes), speed brake extended.
Configuration G :	Glide:	Power off, unless otherwise specified: gear and flaps up.
Configuration L :	Landing:	Power off, gear down, flaps or other high lift device at landing setting.
Configuration P :	Power on, clean:	Normal rated power, flaps and gear up.
Configuration CO:	Combat:	Augmented power, airplane in combat configuration.
Configuration PA:	Power Approach:	Gear down, flaps, other high lift device, canopy, and approach brake in normal approach position: power for level flight at 1.15 V_{S_L} or normal approach speed, whichever is lower.

3.1.9 Configurations:- (Continued)

Configuration WO: Wave off: Gear down, flaps or other high lift device in landing position, take-off power.

Configuration TO: Take-off: Gear down, flaps or other high lift device at take-off setting, take-off power, including assist or augmentation used in normal take-off.

3.2 Mechanical characteristics of control systems

3.2.1 Control friction and breakout force:- Longitudinal, lateral, and directional controls shall exhibit positive centering in flight at any normal trim setting. Although absolute centering is not required, the degree of centering shall be such that the combined effects of centering, breakout force, stability, and force gradient do not produce objectionable flight characteristics, or permit large departures from trim conditions with controls free. Control-system friction in all airplanes shall be as low as possible, and breakout forces, including friction, feel, preload, etc, shall not exceed the values given in table I. These values refer to the pilot control force required to start movement of the control surface, and apply in flight at all attainable conditions of trimmed airspeed, altitude, temperature, and control deflection.

TABLE I

Maximum allowable stick breakout forces (including friction) pounds.

Control	Classes I, IIC and III
Elevator	3
Aileron	2
Rudder	7

In the Arrow 1, the stick is self centering in all control modes, since in the automatic mode the parallel servo will always return to its central position if the stick-input signal falls to zero, while in the emergency manual mode, the feel system spring will ensure the return of the stick to its trimmed position.

3.2.1 Control friction and breakout force:- (Continued)

The breakout forces for the aileron and elevator in normal and emergency modes with booster units installed in each control circuit meet the specified values in Table I.

The breakout force for the rudder pedals is 14 lb in both normal and emergency modes.

Therefore the specification is not met for the normal mode but the aircraft in this mode is basically a two control aeroplane and rudder pedals will only be used occasionally. The emergency mode satisfies the specification requirements, see para. 3.2.1.2.

3.2.1.1 Measurement of the breakout forces on the ground will ordinarily suffice in lieu of actual flight measurement, provided that qualitative agreement between ground measurement and flight observation can be established to the satisfaction of the procuring activity.

Due to the artificial nature of the breakout forces for the aileron and elevator controls, the forces in flight should be identical to those measured on the ground.

The breakout force for the rudder pedals increases slightly with increase in dynamic pressure and the figures quoted apply to the case of zero pressures.

3.2.1.2 For emergency manual operation upon failure of a power-operated or power-boosted control system, the allowable breakout forces specified in table I may be doubled.

In the emergency mode, the elevator and aileron breakout forces do not exceed the forces specified in table I. The rudder pedal breakout force is twice the value stated in table I.

3.2.2 Adjustable Controls:- When a cockpit control is adjustable for pilot physical dimensions or comfort, the control force as defined in paragraph 6.2 shall refer to the mean adjustment; a force referred to any other adjustment shall not differ by more than 10 percent from the force referred to the mean adjustment.

Only the position of the rudder pedals is adjustable. This adjustment is effectively a movement of the fulcrum fore and aft on a line level with the foremost point of the seat and there is no appreciable change in the required control force.

3.2.3 Rate of Control Displacement:- The ability of the airplane to perform the manoeuvres expected of it shall not be limited by the rates of control surface deflection or auxiliary control operation, nor shall the rates of operation of either primary controls or auxiliary devices result in objectionable flight characteristics.

Consideration has been given to the available control hinge moment and rate of control application where ever necessary. All response rates quoted are obtainable with the existing rates of control surface deflection. No objectionable flight characteristics are obtained due to the rate of control surface deflection in either the normal or the emergency mode.

3.2.4 Cockpit Control Free Play:- The free play in each cockpit control, i.e. the motion of the cockpit control, from the trim position, which does not move the control surface in flight, shall not be excessive.

Very little free play exists in any of the cockpit controls.

3.2.5 Artificial stability devices:- Normal operation of an artificial device for improvement of any characteristic shall not introduce any objectionable flight or ground handling characteristics. Failure of such a device shall not result in a dangerous or intolerable flight condition (See paragraphs 3.4.1.3 and 6.6 for additional discussion.)

No objectionable flight or ground handling characteristics are introduced by the damping system. Reliability of the damping system is achieved by complete duplication of essential parts and provision is made for automatic reversion to the emergency mode. (For fuller discussion see paragraph 6.6).

3.3 Longitudinal Stability and Control

3.3.1 Elevator fixed static stability:- In the flight conditions and throughout the speed ranges listed in columns 1 and 2 of Table II, the elevator-fixed neutral points shall be aft of the c.g. position in the aft critical loading.

TABLE II

Required conditions for longitudinal static stability

Configuration	Speed Range	"Trim Speeds" 1/ for elevator-free stability
CR	1.4 V_{S_G} to V_{NRP}	Speed for maximum range, 2 additional trim speeds
P	0.75 V_{NRP} to V_H	V_{NRP}, 1 additional trim speed
P (Climb)	0.85 $V_{R/C}$ or 1.15 V_{S_G}, whichever is greater, to 1.3 $V_{R/C}$	$V_{R/C}$
CO	V_{NRP} to V_M	V_H, 1 or more additional trim speeds
G	V_{S_G} to V_H	1.4 V_{S_G}, 1 or more additional trim speeds.
D	All speeds normally attained in configuration D dives	1 or more representative configuration D dive speeds
L	V_{S_L} to limit structural speed in configuration L	1.4 V_{S_L}
PA	V_{S_L} to limit structural speed in configuration PA	1.15 V_{S_L}
	NOTE: For -C airplanes, lower speed shall be V_{S_L} or design maximum arresting speed, whichever is lower	

1/ Additional "trim speeds" shall be so selected that the trim speeds effectively span the specified speed range.

3.3.1 Elevator-fixed static stability:- (Continued)

The elevator fixed neutral point is defined in paragraph 6.2 as the c.g. position for zero elevator cockpit control travel with change in speed, in straight flight at constant throttle. Hence the condition that the elevator-fixed neutral points shall be aft of the c.g. position is equivalent to the requirement that a forward movement of the stick is needed to trim out an increment in speed in straight flight and constant throttle.

For the Arrow 1, the stick movement is directly proportional to the steady state elevator deflection and therefore the slope of the elevator angle to trim curve against Mach number is a measure of the elevator fixed static stability. An increase in down elevator to re-trim at a slightly higher speed corresponds to positive elevator fixed static stability.

(a) Configurations CR, P and CC

The carpet showing the variation of elevator angle to trim with Mach number for level flight at various altitudes presented in figure (6) covers the specified speed ranges and flight conditions corresponding to configuration CR, P and CC. It can be seen from the slopes of the curves that the Arrow 1 possesses positive elevator fixed static stability in these configurations, except for the following cases:

(1) For the speed range M = .5 to M = .8 at altitudes of 10,000 feet and less.

(2) In the transonic speed range at all altitudes.

(3) For M = 1.7 at 30,000 feet.

In case (2), considerable control movements in the unstable sense are required with increase of speed, but a relaxation for the case of transonic flight is given in paragraph 3.3.3.

(b) Configuration L

Graphs showing the elevator angle to trim for low speed, power off flight, but with the landing gear retracted, are shown in figs (7) and (8) for fore and aft centre of gravity positions. The effect of the landing gear on trim is small as can be seen by comparing fig. (9) with fig. (23).

In the configuration L, the Arrow 1 possesses positive elevator fixed static stability and this stability becomes more positive as the ground is approached.

3.3.1 Elevator-fixed static stability:- (Continued)

(c) Configuration PA

Increased power has an adverse effect on the elevator fixed static stability, as shown in figure (9). However, during the approach, the power requirement will be of the order of 30% of military power and the power off case will be approached in the flare out. In this case, the Arrow 1 will possess positive elevator fixed static stability.

Climbing, diving configurations

The elevator angles to trim for climbing and diving cases have not been specifically determined, because the elevator angles to trim in these cases are nearly equal to those required in a steady push-over at the same Mach number and altitude, where the normal loading is the same in both cases. Small increments to allow for change in thrust moment and the moment due to the pitch rate in the push-over are required to be added to the elevator angle to trim in the equivalent push over.

Carpets showing the variation of elevator angle to trim with Mach number for a range of normal acceleration are shown in figs (10) to (12). At zero 'g', there is a reduction in static stability at subsonic speeds compared with the level flight case, but there is little change in the stability at transonic and supersonic speeds.

(d) Configuration D

During a dive, the variation of the elevator angle to trim with speed compared with the push over case is stabilising to a small degree at subsonic speeds, and has a neutral effect at transonic and supersonic speeds. Another increment in elevator angle needs to be added to the equivalent push over case with speed brakes retracted to allow for the pitching moment produced by the extension of these brakes. However, as shown in figure (5), the extension of the speed brakes produces a positive increase in normal acceleration which is either constant or increases with speed except for specific cases in the transonic range.

In configuration D, dives, the elevator fixed static stability will be positive at all speeds except in the transonic range. The relaxation given in paragraph 3.3.3 covers this exception.

3.3.1 Elevator-fixed static stability:- (Continued)

(e) Configuration P (Climb)

Climbing flight is a little less stable than for the equivalent push-over case at subsonic speeds, but at transonic and supersonic speeds the elevator fixed static stability is unchanged.

The speed for maximum rate of climb at sea level is 527 knots, representing a Mach number of .8 and therefore the speed range, covered by the requirement is from M = .68 to M = 1.04. In this range the Arrow 1 possesses neutral elevator fixed static stability.

(f) Configuration G

The elevator angles to trim in configuration G are shown in figure (13). The effect of the speed brakes are also shown.

In this configuration the Arrow 1 possesses positive elevator fixed static stability.

3.3.1.1 At the aft critical loading, in the flight conditions and throughout the speed ranges listed in columns 1 and 2 of table II, the elevator-fixed static longitudinal stability with respect to angle of attack at constant speed shall be positive. This requirement shall also apply to configuration WO at 1.15 VS_L .

The normal acceleration is proportional to the lift coefficient devloped and the variation of the lift coefficient with angle of attack is very nearly linear for lift coefficients within the flight envelope. The slope of the graph of elevator angle to trim against normal acceleration at constant Mach number is therefore a measure of the elevator-fixed static longitudinal stability with respect to angle of attack at constant speed.

Carpets showing the variation of the elevator angle to trim with Mach number, with normal acceleration as parameter are shown in figures (10), (11), and (12). These show that the Arrow 1 possesses positive elevator-fixed static longitudinal stability with respect to angle of attack at all altitudes and speeds above M = .5.

The elevator fixed static longitudinal stability with respect to angle of attack is positive if $-\frac{d\,C_m}{d\,\alpha}$ measured at constant speed. and elevator angle is positive. This condition will be used to determine the stability at low speeds. Figures (14) and (15) show the variation of pitching moment with angle of attack and elevator angle as measured in a low speed wind tunnel for fore and aft c.g. positions. The above quantity is positive or zero at angles of attack less than 16 degrees for the most aft c.g. and less than 20 degrees.

3.3.1.1 (Continued)
for the most forward c.g. position.
An incidence greater than 16 degrees is not required in the flight conditions of table II and therefore this requirement for elevator fixed, static longitudinal stability with respect to angle of attack is met.

3.3.2 <u>Elevator-free static stability</u>:- In the flight conditions and throughout the speed ranges listed in columns 1 and 2 of table II, the elevator-free neutral points shall be aft of the c.g. position in the aft critical loading. In general, this requirement shall be considered satisfied if the requirement of paragraph 3.3.2.1 is met. For configurations PA and P (climb), this requirement may be waived, provided paragraph 3.3.2.1 is met.

The term elevator-free has no meaning when applied to the Arrow 1, because the controls are power operated and irreversible. The equivalent case to this condition is "control-column-free" and this will be assumed to be the meaning of 'elevator free' wherever it is included in the specification.

(a) <u>Normal flight control mode</u>

The control system has been designed so that in the normal mode, if the control column, is left free the aircraft will automatically trim itself to within narrow limits at all flight speeds and all c.g. positions. This will give the pilot the feel of flying an aircraft with its centre of gravity at the elevator free neutral point, with respect to speed changes.

(b) <u>Emergency flight control mode</u>

In the emergency mode a spring feel system is employed and therefore the control column free stability will be identical with the elevator fixed case (Paragraph 3.3.1).

3.3.2.1 In the aft critical loading, with the airplane trimmed at the speeds listed in column 3 of table II, the variation of elevator control force with speed shall be a smooth curve, with a gradient which is stable through trim and remains stable throughout the specified speed range. (In configurations PA and P (climb), a reversal in slope may be permitted below the trim speed; if a reversal does occur, however, the force shall not decrease to less than 1 pound for classes I and II airplanes, or 3 pounds for class II airplanes). This requirement applies throughout the speed ranges listed in column 2 of table II, but need be considered only at speeds within ± 15 percent (or ± 50 knots, whichever is less) of the trim speed, and need not be considered at speeds where the control force exceeds 50 lb. As used in this paragraph, the term gradient shall not include that portion of the force versus speed curve within the preloaded breakout force or friction range.

3.3.2.1 (Continued)

(a) Normal flight control mode

In this mode, variation of elevator control force is only required to command an increment in normal acceleration. No control force is required to trim out a change in speed. An exception to this occurs when undercarriage down is selected; operation is then similar to that in the emergency flight mode.

(b) Emergency flight control mode

In this mode, the elevator control force is proportional to the change in elevator angle from the trimmed position. Therefore, the remarks in paragraph 3.3.1 apply equally well to this case of control column free static stability.

The variation of elevator control force with speed is a smooth curve except at transonic speeds (see paragraph 3.3.3) and in general the slope is stable. In configuration P (Climb) and at low speed and low altitude in configurations CR, P and CO the control column free static stability is essentially neutral. In these cases, the out of trim control forces in the unstable sense will be small.

In the transonic speed range the control column free static stability is negative, but this case is covered by the relaxation of this requirement given in paragraph 3.3.3.

3.3.3 Exception in transonic flight:- The requirements of paragraphs 3.3.1 and 3.3.2 may be relaxed, if necessary, in the transonic-speed range, provided that any reversals in slope of elevator angle or elevator control force with speed are mild and gradual and not seriously objectionable to the pilot. Howeverm on airplanes with cruising speeds or mission requirements necessitating prolonged operation at transonic speeds, the requirements of paragraph 3.3.2 shall be satisfied. For this purpose, the use of artificial means satisfactory to the procuring activity is permissible. The relaxation of paragraph 3.3.1 is not intended to include paragraph 3.3.1.1, which shall remain applicable throughout the entire speed range.

It is intended that the Arrow 1 will cruise at transonic speeds and therefore the relaxation to requirement 3.3.2 does not apply to the normal flight control mode.

(a) Normal flight control mode

There is no change in stick force to trim throughout the transonic range.

3.3.3 Exception in transonic flight:- (Continued)

(b) Emergency flight control mode

Reference to fig. (6) shows that for altitudes above 10,000 feet the elevator fixed static stability (and also the control column free static stability) is negative. For altitudes up to 50,000 feet the reversals in slope of elevator angle (and of control force) with speeds are mild and gradual and therefore may be excluded from the requirements of 3.3.1 and 3.3.2. At an altitude of 60,000 feet the unstable changes of trim in passing through the transonic region are large (6 degrees of elevator angle)and occur suddenly.

The above relaxation does not strictly apply in this case but considering that the elevator angle per "g" in this region is of the order of 8 - 10° the resulting disturbance should not be objectionable.

3.3.4 Stability in accelerated flight:- The slope of the curve of elevator deflection versus gravity (g) at constant speed shall be stable (increasing up elevator required for increasing 'g') throughout the range of attainable load factors in all configurations and in all conditions of flight.

Reference to figs (10) (11) and (12) shows that for all speeds and altitudes within the flight envelope, for Mach numbers greater than .5, this requirement is met. Using the same argument as in paragraph 3.3.1.1, the low speed wind tunnel measurements of pitching moment for various angles of attack and elevator angles, figures (14), (15) show that the low speed stability in accelerated flight is also positive, for angles of attack less than 16 degrees, at the most aft c.g., and to approx. 20° at the fwd. c of g. An incidence of 16 degrees approximately represents the buffet boundary at low speed of the operational flight envelope and therefore this requirement is met.

3.3.5 Short-period oscillations:- The dynamic oscillations of normal acceleration, which occur at approximately constant speed and which may be produced by abruptly deflecting and returning the elevator control to the trimmed position, shall damp to 1/2 amplitude in 1 cycle, and the magnitude of any residual oscillations shall not exceed ± 0.02 'g'. Residual oscillations in angular attitude shall not be of objectionable magnitude and shall not adversely affect the tactical utility of the airplane. (For gunnery of bombing applications, pitch deviations greater than ± 5 mils are ordinarily considered excessive). Any longitudinal oscillations with period less than 6 seconds shall be governed by this requirement.

(a) Normal flight control mode:-

This mode includes artificial damping about all axes designed to give approximately 'dead beat' motion throughout the flight envelope, and therefore meets easily above requirements.

3.3.5 Short-period oscillations:- (Continued)

(b) Emergency flight control mode:-

In this mode the artificial damping about the pitch and roll axes is removed and therefore the short period oscillations in pitch will be those of the basic configuration. The region where this requirement is not met is shown on the operation speed, altitude envelope in figure (16). Only supersonic flight at altitudes greater than 50,000 feet has unsatisfactory short period damping.

3.3.5.1 When the elevator is abruptly deflected and released, the motion of the elevator following the release shall be essentially deadbeat, unless the elevator oscillations are of such frequency and amplitude that they do not result in an objectionable oscillation in normal acceleration.

In both normal and the emergency flight modes, when the elevator is abruptly deflected and released it will return to its original position and the motion is essentially deadbeat.

3.3.5.2 There shall be no tendency for a sustained or uncontrollable oscillation resulting from efforts of the pilot to maintain steady flight.

(a) Normal flight control mode:-

In this mode damper system gives essentially dead-beat motion.

(b) Emergency flight control Mode:-

There is no tendency for any sustained or uncontrollable oscillation.

3.3.5.3 The requirements of paragraphs 3.3.5, 3.3.5.1 and 3.3.5.2 shall apply at all permissible airspeeds and loadings, both in straight flight and in turns.

The requirement has not yet been investigated in turns.

3.3.6 Long period oscillations:- Although there is no specific requirement for damping of the conventional long-period, or phugoid oscillation which occurs at approximately constant angle of attack, there shall be no objectionable flight characteristics attributable to apparent poor phugoid damping. In addition, if the period of a longitudinal oscillation is less than 15 seconds, the oscillation shall be at least neutrally stable.

(a) Normal mode:-

Final investigation of the long period oscillations is not yet complete, but preliminary work indicates that the phugoid effects will be reduced to a negligible level.

3.3.6 Long period oscillations:- (Continued)

(b) Emergency mode:-

Generally at subsonic speed the periods will be well in excess of 15 seconds. At supersonic and transonic speeds some objectionable effects may be expected.

3.3.7 Control effectiveness in unaccelerated flight:- In erect unaccelerated flight at any altitude, the attainment of any permissible speed above the stalling speed V_S, as defined in paragraph 3.6.2, shall not be limited by the effectiveness of the longitudinal control, or controls. This requirement shall apply to all airplane configurations and permissible loading.

The normal acceleration flight envelopes, showing the elevator limitations where they arise, are presented in figures (1), (2) and (3). For a load factor of 1 it can be seen that the speed range is not limited by the available elevator angle.

3.3.8 Control effectiveness in accelerated flight:- In the forward critical loading, when trimmed at any permissible speed and altitude in the configurations listed in table II, it shall be possible to develop at the trim speed, by the use of the elevator control alone, the limit load factor, the lift coefficient corresponding to V_S as defined in paragraph 3.6.2 or 3.6.2.2, or a load factor consistent with the operational flight envelope specified in paragraph 3.1.3.

The operational flight envelope presented in paragraph 3.1.3 applies for a centre of gravity position of .31 $\bar{c}$. The elevator limitations will be some what more severe with a more forward centre of gravity position and the operational flight envelopes for a centre of gravity position at .29$\bar{c}$ will be presented when available.

3.3.9 Control forces in steady accelerated flight:- In steady turning flight and in pullouts, increases in pull force shall be required to produce increases in positive normal acceleration throughout the range of attainable accelerations. The variation of force with normal acceleration at all points beyond the breakout force shall be approximately linear, except that an increase in slope upward (such as might be introduced by an acceleration restrictor) is permissible above 0.85 n_L. In general, a departure from linearity resulting in a local gradient which differs from the average gradient by more than 50 percent is considered excessive. The average force gradient shall be within the limits specified in table III in configurations P, CO, D, and PA throughout the operational flight envelope up to 0.85 n_L.

3.3.9 Control forces in steady accelerated flight:- (Continued)

TABLE III

Elevator control force gradient limits, lb per 'g'

Class	Maximum	Minimum
I, III	$\frac{56}{n_L - 1}$	$\frac{21}{n_L - 1}$
II	$\frac{120}{n_L - 1}$	$\frac{45}{n_L - 1}$

The Arrow 1 is a class III aircraft and the limit load factor is 7.33 'g', therefore it is required that the average stick force gradient should be within the range:

Max = 8.33 lb/g
Min = 3.33 lb/g

(a) Normal flight control mode:-

Stick force per "g" gradient will be 6 lb. per "g" up to the command limiter setting of approx. 5.5 "g's". Commanding "g's" in excess of command limiter setting will generally result in an automatic switch-over from normal to emergency mode, through the action of the "g" limiter. Force gradients will then be as in the emergency mode.

In normal mode gear down configuration proportional feel will be provided and stick force per "g" will be identical with emergency mode.

The stick force per "g" gradient up to 5.5 "g's" is well within the requirements.

(b) Emergency flight control mode:-

In this mode proportional feel is provided. Variation of stick force per "g" with Mach number and altitude is shown on Fig. 17, 18. Values shown apply strictly only to manoeuvres between one and 2 "g's" since some small non-linearities exist when higher "g's" are reached.

3.3.9 Control forces in steady accelerated flight:- (Continued)

(b) Emergency flight control mode:- (Continued)

Up to and including 30,000 feet, the requirements are met since stick forces per 'g' do not exceed 8.83 lb and the minimum of 3.33 lb can never be reached since the bob-weight of 4.25 lb is used.

For the cases which do not meet this requirement a relaxation is given in paragraph 3.3.9.3.

3.3.9.1 In all configurations at all permissible speeds and accelerations, the local value of the force gradient shall never be less than 3 pounds per 'g'.

The minimum stick force per 'g' is limited by the bob-weight to 4.25 lb per 'g'.

3.3.9.2 For configurations P, CO and D on airplanes intended primarily for high altitude missions, the maximum allowable force gradients specified in table III need not apply below the medium altitude. The maximum forces at the low altitude, however, shall be not more than 50 percent greater than the maximum values specified in table III.

(a) Normal mode:- See paragraph 3.3.9 (a)

In the emergency mode for any given Mach number the stick force gradient increases with altitude and the low altitude gradients meet the requirements of paragraph 3.3.9.

3.3.9.3 Under conditions in which maximum attainable normal acceleration is less than n_L (e.g. limited by stall or control effectiveness), an increase in the maximum force gradient, up to a value no higher than 50 percent greater than that specified in table III, may be permitted.

In those cases where the stick force gradient is greater than that required by paragraph 3.3.9, the flight envelopes are limited by the maximum control surface deflection. The maximum allowable value of stick force per 'g' becomes 13.22 lb. per 'g'.

(b) Emergency mode:-

Allowing for this relaxation, the requirement is still not met at 50,000 and 60,000 feet. However the pull force required at these altitudes to reach the maximum attainable normal acceleration is of the order of 50 - 60 lb, and this is somewhat less than is required to pull the maximum normal acceleration at the lower altitudes. Therefore, although the high gradients obtained at high altitude do not meet the requirement, they will not produce objectionable handling characteristics.

3.3.9.4 For configurations P, CO, and D on class III airplanes with c.g. positions in combat loadings which are aft of the c.g. positions in other normal service loadings, the maximum allowable forces specified in table III shall not apply at c.g. positions forward of the most forward combat position. The maximum forces in any normal service loading, however, shall be not more than 50 percent greater than the values specified in table III.

The effect of the missiles on the centre of gravity position is small and the centre of gravity position with the missiles is forward of c.g. position without the missiles. This requirement is therefore not applicable.

3.3.9.5 The requirements of paragraph 3.3.9 apply to negative as well as positive accelerations, except that the maximum force gradients specified in table III may be exceeded in the negative acceleration range. This increase, however, shall not exceed 50 percent of the value specified in table III.

Both negative and positive force gradients have been considered in the above paragraphs. The relaxation allowed has already been applied to those cases which do not meet the requirement of paragraph 3.3.9, because of the relaxation allowed in paragraph 3.3.9.3.

3.3.10 Control forces in sudden pull-ups:- In sudden pull-ups from trimmed straight flight, in which the elevator cockpit control is rapidly deflected and returned to its initial position, the ratio of the maximum elevator control force to maximum(peak) change in normal acceleration shall never be less than the ratio of force to acceleration change obtained in steady accelerations under the same conditions. In investigating the sudden pull-up, several rates of cockpit control motion shall be considered, the elapsed time from start to return varying, for example, from 1/2 second to 6 seconds.

(a) Normal flight control mode:-

Generally a tail-less aeroplane will not meet this requirement due to high lift effectiveness of the pitch control. In the Arrow normal mode the damping system will tend to minimize these effects, through the action of the differential servo.

(b) Emergency mode:-

In the majority of flight conditions this requirement will not be met.

3.3.11 Control effectiveness in take-off:- Elevator effectiveness shall not unduly restrict the take-off performance of the airplane. As a minimum, elevator effectiveness shall be adequate to permit compliance with take-off performance guarantees;, if the take-off performance is not specifically guaranteed in the airplane contract, it shall be possible, on a hard-surface runway at a minimum speed no greater than V_{STO}, to obtain take-off attitude, on nose-wheel airplanes or to maintain any attitude up to thrust line level on tail-wheel airplanes. (For propeller-powered airplanes, V_{STO} may be estimated, with the concurrence of the procuring activity, on the basis of stall speeds determined with various amounts of power up to the highest feasible). The requirements shall be met with the airplane loading which produces the most critical nose-heavy moment on nose-wheel types and the most critical tail-heavy moment on tail-wheel types. The loadings considered for this purpose shall include all full and partial loads which might normally be employed during training, as well as operational take-offs. For class I tail wheel airplanes, the required minimum speed for maintaining attitudes up to thrust line level shall be 0.5 V_{STO} and shall be applicable on sod as well as hard surface runways.

This requirement is met.

3.3.12 Control in catapult take-off:- This is not applicable.

3.3.13 Control forces in take-off:- With trim optional but constant, the elevator control forces required throughout the take-offs described in paragraphs 3.3.11 and 3.3.12, and during the ensuing acceleration to a speed of 1.3 V_{STO} (flaps, gear, and power held constant) shall be within the following limits.

Nose-wheel and bicycle-gear airplanes	
Class III	30 lb pull to 10 lb push

These requirements shall apply also in rocket-assisted or other power-augmented take-offs, and shall include consideration of assist cessation.

The recommended take-off technique requires that the nose be raised at a speed 10 knots below the recommended take-off speed shown on Fig. (19) (20). By examining Fig. (21) and (22) it can be seen that the elevator angle to raise the nose will not be more than 10° up resulting in stick force not exceeding 16 lb. with neutral trim setting. Stick forces just after take-off will be of the order of 5 - 10 lb.

3.3.14 Control effectiveness in landing:- At the forward critical loading, with the airplane trimmed for 1.2 V_{SL} in configuration PA, longitudinal control shall be sufficiently effective, in order that in configuration L, V_{SL} or the guaranteed landing speed, if such a guaranty is included in the contract, can be obtained in close proximity to the ground.

3.3.14 <u>Control effectiveness in landing</u>:- (Continued)

The variation of elevator angle to trim with speed for various power settings is shown in fig. (23). The effect of the proximity of the ground is shown in fig. (7).

It is evident that this requirement is met.

3.3.15 <u>Control force in landing</u>:- It shall be possible to meet the requirement of paragraph 3.3.14 with an elevator pull force not exceeding 35 lb for classes I, II-C, and III airplanes, or 50 lb for class II-L airplanes.

The requirement for the Arrow 1 is that the elevator pull force shall not exceed 35 lb.

The maximum elevator angle to trim in landing is required at low speed, with the most forward c.g. position and with maximum ground effect. Fig. (7) indicates that at a speed of 150 knots, 9.5 degrees of elevator angle are required. This represents a stick force of approximately 15 lb which is well within the requirement.

3.3.16 Control forces in dives:- With the airplane trimmed for level flight at V_H, the elevator control forces required in dives to any attainable speed within the operational flight envelope shall not exceed 50-lb. push or pull in class III airplanes, or 75 lb. in class II airplanes. In similar dives, but with trim optional following the dive entry, it shall be possible with normal piloting technique to maintain the forces within the limits of 10-lb. push or pull in class III airplanes, or 20-lb. push or pull in class II airplanes. The forces required for recovery from these dives shall be in accordance with paragraph 3.3.9.

(a) Normal flight control mode

In this mode the required stick force is proportional to the normal acceleration. In a dive, the change in normal acceleration will always be less than 1 'g', therefore, the change in stick force will be less than 6 lb. which is the stick force per 'g' gradient.

The damper will function so that a constant stick force is required for a constant angle of dive.

(b) Emergency flight control mode

A graph showing the maximum speed in level flight with augmented power, V_H, is presented in figure (24). If we consider the change in trim from level flight at 900 knots (Mach 1.57) and 50,000 feet to a vertical dive at a Mach number of 2.12 at 30,000 feet, the approximate change in elevator angle to trim is from -.2 degrees to +6.2 degrees.

The control surface deflections, control forces, breakout forces and trim ranges for the emergency mode are shown in figure (25). If the aircraft is initially in trimmed flight, a push force of 11 lb. is required for this dive. If the trim can be varied this force can be reduced to zero. The forces required for recovery from these dives are in accordance with paragraph 3.3.9.

3.3.16.1 With the airplane trimmed initially in level flight at V_H, but with trim optional in the dive, it shall be possible to maintain the elevator control forces within the limits of 50-lb. push or 35-lb. pull in dives to any attainable speed within the maximum permissible speed envelope. The forces required for recovery from these dives (see paragraph 3.1.4) shall not exceed 120 lb. Trim, deceleration devices, etc. may be used to assist in recovery provided that no unusual pilot technique is required.

The maximum permissible speed envelope represents the same maximum speed boundary as the operational flight envelope for the Arrow 1. Therefore, the first part of this requirement has already been discussed and has been shown to be satisfied.

The limiting values for the control forces during recovery from the dives are as follows:-

(a) Normal flight control mode

The maximum load factor obtainable in this mode is 5.5 "g" with approximately 30 lb. force.

To obtain a higher normal load factor it is necessary to either:

(1) Overpower the parallel servo which requires additional 50 to 80 lb. force at the stick.

(2) Trip the "g" limiter which will cause automatic change over to emergency mode.

In practice condition (1) will not occur frequently since only a slight increase of the load factor over 5.5 "g" will cause the "g" limiter action.

Both conditions meet the above requirements.

(b) Emergency flight control mode

Maximum elevator control forces are less than 75 lb. This also is well within the allowable 120 lb.

3.3.17 Auxiliary dive recovery device:- Operation of an auxiliary device for dive recovery at any speed shall always produce a positive increment of normal acceleration, but the total normal load factor shall never be greater than $0.8n_L$, controls free, at the most aft critical loading.

No auxiliary dive recovery device is fitted. The speed brakes may be used to assist in recovery from a dive (see paragraph 3.3.18).

3.3.18 Effects of drag devices:- Operation of the speed brakes or other drag devices provided for deceleration, dive-speed limitation, glide-path control, etc. shall not produce objectionable buffet or other undesirable flight characteristics. This requirement shall apply to partial as well as full operation. Drag devices intended for employment in the landing approach shall not produce an objectionable nose-down trim change when operated during the approach. Additional requirements for trim change caused by drag devices are included in paragraph 3.3.19.

Incremental changes in normal acceleration due to operating the speed brakes are shown in figure (5).

(a) Normal flight control mode.

In this mode the change in normal acceleration is automatically trimmed out and will not be apparent to the pilot.

(b) Emergency flight control mode

The change in trim produced is always nose-up and the maximum increment in normal acceleration is about 1.8 "g" at Mach 2.0 and 40,000 feet. This should not prove objectionable.

Speed brake operation is not expected to produce objectionable buffeting, but this must be proved by flight test.

3.3.19 Longitudinal trim changes:- The longitudinal trim changes caused by changes in power, flap setting, gear operation, deceleration devices, etc. shall not be so large that peak longitudinal control forces in excess of 10 lb. for classes I and III, or 20 lb. for class II, are required when such configuration changes are made in flight under conditions representative of operational procedure. Generally, the conditions listed in table IV will suffice for determination of compliance with this requirement. With the airplane trimmed for each specified initial condition, the peak force required to maintain the specified constant parameter following the specified configuration change shall not exceed 10-lb. push or pull for classes I and III airplanes, or 20-lb. push or pull for class II airplanes. This requirement shall apply to a time interval of at least 5 seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be such that the forces are easily trimmable by use of the normal trimming devices.

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TABLE IV

LONGITUDINAL TRIM CHANGE CONDITIONS

Condition No.	Altitude	Initial Trim Condition				Configuration change	Parameter to be held constant
		Speed	Gear	Flaps	Power		
1	Low	$1.4V_{S_G}$	Up	Up	PLF	Gear down	Altitude
2	Low	$1.4V_{S_G}$	Down	Up	PLF	Flaps "	Altitude
3	Low	$1.4V_{S_L}$	Down	Down	PLF	Idle Power	Speed
4	Low	1/ $1.15V_{S_L}$	Down	Down	PLF	Take-off Power	Altitude
5	Low	$1.3V_{S_{TO}}$	Down	Take-off	Take-off	Gear up	Rate of climb
6	Low	$1.5V_{S_{TO}}$	Up	Take-off	Take-off	Flaps up	Rate of climb
7	Medium, high	Level flight	Up	Up	MRP	Idle power	Altitude
8 2/	Medium, high	Level flight	Up	Up	MRP	Actuate deceleration device	Altitude
9	Low medium	Speed for best range	Up	Up	PLF	Actuate deceleration device	Altitude
10	Low	$1.15V_{S_L}$	Down	Down	PLF	Extend approach drag device	Speed
11 3/	Medium high	Level	Up	Up	MRP	Augmented power	Altitude

Footnotes to Table IV:

1/ Normal approach speed, if lower than $1.15\ V_{S_L}$.

2/ Class III only. If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device shall be accompanied by the allowable power reduction.

Footnotes to Table IV: Cont'd.

3/ Class III only.

(a) Normal flight control mode

In the normal flight control mode, gear up, the change in trim due to these configuration changes will be automatically trimmed out and no stick force will be required.

In the gear down mode, the forces required to trim for the new configuration will be the same as in the emergency flight control mode.

(b) Emergency flight control mode

In this mode, the requirement is met in all cases except for case 8. At 50,000 feet and Mach 1.57 a push force of 13 lb. is required to maintain the point of aim when the speed brakes are extended. This represents an extreme case and in general the required push force will be within the allowable limit of 10 lb.

3.3.20 Longitudinal trim change caused by sideslip:- With the airplane trimmed for straight flight in each of the configurations and at the trim speeds specified in table II, the longitudinal control force required to maintain constant speed in sideslips shall not exceed numerically the lowest force which in the same configuration would produce a normal acceleration change of 1.0 g in the accelerated manoeuvres of paragraph 3.3.9. In no event, however, shall the force exceed 10-lb. pull or 3-lb. push on classes I, III, and II-C airplanes, and 15-lb. pull or 10-lb. push on all others. The sideslips considered shall include angles up to the largest obtainable with 50 lb. rudder pedal force applied in either direction for wings-level trimmed flight. If a variation of longitudinal control force with sideslip does exist, it is preferred that increasing pull force accompany increasing sideslip, and that the magnitude and direction of the trim change be similar for right and left sideslips.

The longitudinal coupling due to sideslip is small and it is expected that the Arrow 1 will meet this requirement.

3.4 Lateral-directional stability and control:-

3.4.1 Damping of the lateral-directional oscillations:- In the configurations and over the corresponding speed ranges specified in table II, the damping of the lateral-directional oscillations, with controls fixed and with controls free, shall be such that the damping parameter $\frac{1}{C_{\frac{1}{2}}}$ has a value not less than that required by curve A of figure 40. Residual undamped oscillations may be tolerated only if the amplitude is sufficiently small that the motions are not objectionable. Generally, the conditions listed in table V will suffice for determination of compliance with these requirements. (See paragraph 6.8 for additional discussion).

The Arrow 1 employs artificial stabilization devices and therefore the more stringent requirements of paragraphs 3.4.1.1 and 3.4.1.2 need to be met.

3.4.1.1 For armed airplanes in the firing or bombing configuration and under the critical flight conditions consistent with the tactical mission requirements, the damping parameter $\frac{1}{C_{\frac{1}{2}}}$ shall be at least that required by curve A of figure 40, or at least 1.73, whichever is higher. Under these conditions, the magnitude of any residual oscillation shall not be so great as to cause yaw or pitch deviations which adversely affect bombing or tracking accuracy. (For gunnery or bombing applications, deviations greater than $\pm$ 5 mils are ordinarily considered excessive.) If it can be established to the satisfaction of the procuring activity that the armament system is such that provision of the degree of damping specified herein will afford no significant improvement in tactical effectiveness, this requirement shall be waived and the requirement of paragraph 3.4.1 shall apply.

The normal mode will easily meet requirements specified by curve A in all flight conditions. Data will be presented when available.

3.4.1.2 If an artificial stabilization device is employed, the damping parameter $\frac{1}{C_{\frac{1}{2}}}$ with the artificial device inoperative, shall be at least 0.24 in all configurations. In configuration PA this parameter shall, moreover, have a value at least as high as that required by curve B of figure 40.

Since the Arrow has a duplicated yaw damping system this paragraph should apply to emergency mode only but in addition a third mode of control namely "dampers off" will be considered.

(a) Emergency Mode

This mode will not only meet the required curve B but also the curve A with damping generally somewhat smaller than the normal mode.

(b) Damper off mode

Graphs of the variation of the damping parameter $\frac{1}{C_{\frac{1}{2}}}$ with the value of $\left| \phi / v_e \right|$, with altitude as parameter, are shown for level flight with c.g. position at .29 $\bar{c}$ in figure (26). Graphs showing the periodic time of the Dutch-roll oscillation for the same conditions are presented in figure (27).

(b) Damper off mode Cont'd.

Reference to paragraph 6.8 indicates that for very short periods (i.e., below 1.8 seconds), and for values of $|\phi / v_e|$ greater than 1.2 the desired damping may be considerably greater than that specified in figure 40. For the Arrow 1, the periods are greater than 1.8 seconds, but values of $|\phi / v_e|$ much greater than 1.2 are obtained, and therefore, in this comparison, curve B will be taken to be the requirement in all configurations.

The regions within the operational speed envelope which meet this modified requirement are shown for the fore and aft c.g. positions in figures (28). Boundaries are also shown where the oscillation becomes divergent and where the time to double amplitude is less than 10 seconds.

In general, this requirement is not met at the extremes of high or low speed, but a large part of the low speed region has lateral oscillations which are convergent and only at high speeds are there regions with divergent oscillations with periods less than 10 seconds.

In accelerated flight there is a decided improvement in the dutch roll damping for the dampers off mode. Graphs showing the variation of the damping parameter $\frac{1}{C_{\frac{1}{2}}}$ with the value of $|\phi / v_e|$ with altitude as parameter for the case of 2 "g" flight are shown in figure (29). The regions within the operational flight envelope where the specification is met in this case is shown in Figure (30). The dutch roll is damped in all cases except for flight at high dynamic pressures.

3.4.2 Spiral stability:- Spiral stability is not required, but if the spiral motion is divergent, the rate of divergence shall not be so great that, following a small disturbance in bank with controls fixed, the bank angle is doubled in less than 20 seconds in the PA and CR conditions of table V, or 4 seconds in any of the other flight conditions of table II.

The roll rate and yaw damping in the normal mode and the yaw damping alone in the emergency mode will give an improvement of the spiral stability obtained in the dampers off case. However, investigation of the damper off case shows that the spiral mode is always convergent.

3.4.3 Steady sideslip conditions:- Requirements for static directional stability, dihedral effect, and side force variation are expressed in terms of characteristics in steady sideslips. Unless otherwise stated, such requirements shall apply in straight-path (zero turn rate) sideslips up to sideslip angles produced by full rudder deflection or 250 lb. of rudder force, whichever is reached first. The requirements shall be met at the lightest normal loading, in the configurations and speed ranges specified in table II, with the airplane trimmed for wings-level straight flight.

3.4.3 Steady sideslip conditions:- (Continued)

In addition, the requirements shall be met on class III and class II-C airplanes in configuration WO at all permissible speeds above VSP_A, with the airplane trimmed for wings level straight flight at 1.15 VS_L in configuration PA. Although the requirements apply over the entire specified speed range, investigation at the trim speeds specified in table II, and at 1.15 VS_L in configuration WO, will ordinarily suffice for determination of compliance.

The normal flight control mode is designed to minimize sideslip in all flight conditions with the landing gear retracted, (configurations CR, P, P(Climb) and CO). The sideslip angles which can be developed using rudder pedal forces are severely restricted by the damping system and the automatic turn coordination allows only small sideslip angles to develop during manoeuvres. Rudder pedals are required only for trimming of asymmetric yawing moments.

Upon selection of "landing gear down", the control system automatically switches to the normal, gear down, mode, (configurations L, PA and WO). In this mode positional feel is provided for all axes and provision is made for the application of large rudder angles and the attainment of considerable sideslip angles. (e.g. for cross-wind landings).

In both the normal mode and the normal gear down mode, the system automatically switches to the emergency mode if the sideslip angle exceeds 10°. This limitation is due to the presence of significant non-linearities in the yawing moment vs sideslip characteristics resulting in control difficulties when 10° of sideslip are exceeded.

3.4.4 Static directional stability (rudder position):- The airplane shall possess rudder-fixed directional stability such that, in the sideslips specified in paragraph 3.4.3, right rudder pedal deflection from the wings-level position is required in left sideslips, and left rudder pedal deflection is required in right sideslips. For angles of sideslip between ± 15° from the wings-level condition, the variation of sideslip angle with rudder pedal deflection shall be essentially linear. Throughout the remainder of the range of required pedal deflections, an increase in pedal deflection shall always be required for an increase in sideslip.

(a) Normal mode

This mode is designed to minimize sideslip angle without the use of pedal force and this requirement is not really applicable.

(b) Normal 'gear down' mode

In steady sideslips the rudder deflections and forces will be the same as in the emergency mode.

(c) Emergency mode

For all speeds greater than 119 knots, the rudder pedal deflection is in the conventional sense up to the sideslip angle as limited by aileron deflection as shown on figure (31a). Within the range of available sideslip, the variation of rudder pedal deflection with sideslip angle is essentially linear.

3.4.4 Static directional stability (rudder position):- Cont'd.

The Arrow 1 possesses positive static directional stability based on rudder position for all the cases within boundaries shown on Figure (31a).

3.4.5 Static directional stability (rudder force):- The airplane shall possess rudder-free stability such that, in the sideslips specified in paragraph 3.4.3, right rudder force is required in left sideslip and left rudder force is required in right sideslip. For angles of sideslip between ± 15 degrees from the wings-level, straight flight condition, the variation of sideslip angle with rudder force shall be essentially linear. At greater angles of sideslip, a lightening of the rudder force is acceptable, but the rudder force shall never reduce to zero or overbalance.

The rudder pedal forces are derived from a spring feel system and therefore the rudder force, static directional stability has the same characteristics as the rudder position, static directional stability.

The requirement is met with limitations as stated in paragraph 3.4.4.

3.4.6 Dihedral effect (aileron position):- The airplane shall exhibit positive control-fixed dihedral effect as indicated by the variation of aileron cockpit control deflection with sideslip in the sideslips specified in paragraph 3.4.3. Left aileron deflection shall be required for left sideslip, and right aileron deflection shall be required for right sideslip.

In steady sideslips, the aileron control forces and deflections in both the normal and the emergency mode are identical. Separate consideration is therefore not required.

Throughout the operational speed range and at positive angles of attack the dihedral effect is in the conventional sense. However, at negative angles of attack particularly at subsonic speeds the dihedral effect is reversed.

In both regimes the variation of aileron angle with sideslip is linear. Figure (31b) shows the linearity at low speeds.

This meets the requirements since sideslips specified in paragraph 3.4.3 apply only in straight flight which will not result in negative angle of attack.

3.4.6.1 Configuration WO may, if necessary, be excepted from the requirement of paragraph 3.4.6. The aileron cockpit control deflections required in the sideslips of paragraph 3.4.3, however, shall never exceed one-half of full deflection in the negative-dihedral direction.

This relaxation is not required.

3.4.6.2 The positive effective dihedral shall never be so great that more than 75% of full aileron cockpit control deflection is required in any of the sideslips specified in paragraph 3.4.11.1.

See paragraph 3.4.11.1.

3.4.6.3 Throughout rolls similar to those required in paragraph 3.4.16 but performed with rudder free, the rolling velocity shall always be in the correct direction.

(a) Normal mode

Rolls are performed with "rudder free" e.g. there is no pilot input but sideslip coordination is provided automatically by the damping system which tends to minimize the sideslip. Therefore, the rolling velocity will always be in the correct direction.

(b) Emergency mode

Similar to normal mode.

3.4.7 Dihedral effect (aileron force):- The airplane shall exhibit positive control-free dihedral effect as indicated by the variation of aileron control force with sideslip in the sideslips specified in paragraph 3.4.3. Left aileron control force shall be required for left sideslip, and right aileron control force shall be required for right sideslip. The variation of aileron control force with sideslip angle shall be essentially linear, and the aileron force required shall not exceed 15 lb. for stick-control airplanes or 30 lb. for wheel-control airplanes.

The aileron control forces are derived from a spring feel system and therefore the aileron force, dihedral effect has the same characteristics as the aileron position; dihedral effect. Therefore, statements in paragraph 3.4.6 apply. Requirement met.

3.4.7.1 Configuration WO may, if necessary, be excepted from the requirements of paragraph 3.4.7. The aileron control forces required in the sideslips specified in paragraph 3.4.3, however, shall never exceed 10 lb. in the negative-dihedral direction.

This relaxation is not required.

3.4.8 Side force in sideslips:- The side force characteristics shall be such that in the sideslips specified in paragraph 3.4.3, an increase in right bank angle accompanies an increase in right side-slip, and an increase in left bank angle accompanies an increase in left sideslip.

A graph showing the variation in bank angle with sideslip angle at low speed is presented in Figure (32). It is evident that the Arrow 1 meets this requirement.

3.4.9 Adverse Yaw:- The angle of sideslip developed during a rudder-pedal fixed abrupt roll out of a trimmed, level, steady 45-degree banked turn at 1.4 $V_{S_{CR}}$ in configuration CR, and at 1.4 $V_{S_{PA}}$ in configuration PA, shall not exceed 15 degrees. The roll shall continue until a bank angle of 45 degrees is reached in the opposite direction. The aileron deflection held during the roll shall be at least that required for compliance with the lateral control requirements of paragraph 3.4.16. In similar rolls with partial aileron deflections, the angle of sideslip shall be proportional to the aileron cockpit control deflection. If an automatic turn coordination device is employed, the rudder pedals may be free rather than fixed during the roll.

Simulator studies show that only 3.0 degrees of sideslip are produced in configuration PA, and 2.0 degrees in configuration CR, when this manoeuvre is performed in the emergency mode with full aileron deflection. In the normal mode, the sideslip angle developed will be of the same order of magnitude.

3.4.10 Asymmetric power (rudder free):- On multiengine airplanes, the airplane motions following sudden failure of one engine shall be such that dangerous flight conditions can be avoided by normal pilot corrective control action. As a measure of compliance with this requirement, the following conditions shall be fulfilled: In configuration P, with the most critical engine inoperative (with r.p.m. and pitch simulating the static condition after an engine has failed in flight with no corrective action unless automatically provided), and with the other engine or engines developing normal rated power, it shall be possible at all speeds above 1.4 V_{S_G}, with rudder free, to maintain steady straight flight by sideslipping and banking. The weight shall be that corresponding to the lightest normal service loading, and trim shall be as required for wings-level straight flight with symmetric power. On airplanes with 2 or more engines connected to 1 propeller system by means of a common drive mechanism, "engine inoperative" shall connote complete loss of power to the propeller system.

(a) Normal Mode

It is possible to maintain steady straight flight by sideslipping and banking with rudder free above 1.4 V_{S_G}. At 167 knots (1.4 V_{S_G}) with starboard engine out and the other giving military rated power the sideslip angle will be -3.42^{o} bank angle -6.4^{o} and rudder angle as applied by the damping system 3.45^{o}.

(b) Emergency Mode

Similar conditions will exist in emergency mode.

3.4.11 Directional control (symmetric power):- For all airplanes directional control shall be sufficiently effective to maintain wings-level straight flight in the configurations and speed ranges specified in table II, with rudder control forces not greater than 180 lb. when the airplane is trimmed directionally at the trim speeds specified in table II. Additional requirements for directional control in dives are contained in paragraph 3.4.15. For class III and all carrier-based airplanes in configuration WO at the lightest normal loading, directional control shall be sufficiently effective to maintain wings-level straight flight at all speeds down to $V_{S_{P_A}}$, with rudder control force bit exceeding 100 lb. when trimmed in configuration PA at 1.15 V_{S_L}.

The directional control is sufficiently effective to meet this requirement.

3.4.11.1 For all airplanes, except land-based airplanes equipped with crosswind landing gear, directional control shall be sufficient to permit development of at least 10 degrees of steady sideslip in configuration L at 1.1 V_{S_L}, with rudder control forces not greater than 180 lb.

Reference to Figure (33) indicates that at a speed of 131 knots (1.1 V_{S_L}) there is sufficient directional control, but the lateral control is insufficient.

The maximum sideslip angle attained with 75% of the maximum aileron angle is 6.3 degrees and this is only increased to 8.4 degrees when using full aileron deflection. Requirements are not met below 150 knots and met above this speed.

3.4.12 Directional control (asymmetric power):- On all multiengine airplanes in configuration TO with the most critical outboard engine inoperative (with r.p.m. and pitch simulating failure in flight with no corrective action unless automatically provided), it shall be possible, at the lightest normal take-off loading and with take-off power on the remaining engine, or engines, to maintain straight flight with a bank angle not greater than 5 degrees, at all speeds above 1.2 $V_{S_{TO}}$.

Automatic devices which normally operate in the event of power failure may be used. With trim settings normally employed in a symmetric power take-off, the rudder pedal force required to maintain stright flight with asymmetric power, as defined above, shall not exceed 180 lb.

The Arrow meets the requirement of not exceeding 5° of bank under conditions stated above as shown on Figure (35).

The rudder required for these conditions is shown on Figure (36). These rudder deflections may result in pedal forces in excess of 180 lb. at supersonic speeds and full trim may be required to keep the pedal forces within the 180 lb. However, in estimating the required rudder deflections the effect of shock movements on

3.4.12 Directional control (asymmetric power):- Cont'd.

intake ramps were neglected due to insufficient data. These effects relieve the rudder requirement appreciably such that probably the level of forces will be reduced below 180 lb.

Figure (37) shows the rudder angle available with 180 lb. foot force, at low speed and the rudder angle required for this case of engine failure at take-off.

The proposed feel system provides sufficient directional control to balance one engine giving augmented military thrust at all speeds above 107 knots. The requirement is met at 1.2 $V_{S_{TO}}$ (143 knots) with the use of 110 lb.ft. force.

3.4.13 Directional control during take-off and landing:- The rudder control, in conjunction with other normal means of control, shall be adequate to maintain straight paths on the ground during normal take-offs, and landings. For class I airplanes, this requirement shall apply in calm air, and in 90 degree cross-winds of at least 50 percent V_{S_L} or 20 knots, whichever is less. For classes II and III airplanes, the requirement shall apply in calm air, and in 90 degree cross-winds of at least 30 percent V_{S_L} or 40 knots, whichever is less. For water-based airplanes, the requirement shall apply to straight paths on the water in calm air and in 90 degree cross-winds of at least 20 percent V_{S_L} or 15 knots, whichever is less. This requirement shall be met with not more than 180 lb. pedal force.

The most critical condition for cross-wind control will exist just after take-off or just prior to touchdown since on the ground differential braking and/or steering is available. Therefore, these conditions will be used to determine the limiting allowable cross-winds.

The hinge moment limiter tends to restrict the maximum cross-wind at higher speeds, while the aileron power restricts it at lower speeds. In addition, the aircraft is limited to 10 degree of sideslip.

Figure (33) shows the characteristics of the hinge moment limiter in terms of forward speed and sideslip angle with 180 lb. pedal force.

Figure (34) shows the resulting limitations of the cross-wind velocities.

3.4.13 Directional control during take-off and landing:- Cont'd.

Since the expected minimum touchdown speed will be approximately 140 knots the cross-wind is restricted to a maximum of 25 knots. For higher touchdown speeds, e.g. 160 knots it increases to 28 knots.

The requirement, as based on the arbitrary stalling speed of 119 knots used in this report, specifies that a 35.7 knot cross-wind component be balanced.

The Arrow does not meet this requirement.

3.4.13.1 Without the use of wheel brakes, classes II-C and III-C airplanes shall be capable of maintaining a straight path on the ground, at airspeeds of 30 knots and above, during take-offs, and landings in a 90 degree cross-wind of at least 10 percent V_{S_L}, without exceeding a pedal force of 180 lb.

The Arrow 1 is not a carrier based aircraft and therefore this specification is not applicable.

3.4.13.2 For airplanes intended to operate under cold weather conditions, the requirements of paragraph 3.4.13 shall be applicable on snow-packed and ice-covered runways.

It is expected that the braking effect will be sufficient to give directional control at low speed under these conditions, but flight test verification is required.

3.4.14 Directional control to counteract adverse yaw:- In the rolling manoeuvres described in paragraph 3.4.9, but with the rudder employed for coordination rather than held fixed, directional control effectiveness shall be adequate to maintain zero sideslip, with rudder forces not greater than 180 lb.

In both the normal and the emergency flight control modes automatic turn coordination will be employed, and optimum performance will be obtained when the rudder pedal position remains fixed. This requirement is therefore not applicable to the Arrow 1.

3.4.15 Directional control in dives:- When trimmed directionally at the service ceiling in configuration P, the rudder control shall be capable of maintaining zero sideslip throughout the dives and pull-outs of paragraph 3.3.16 without exceeding 50 lb. rudder pedal force for classes I and III airplanes, or 180 lb. for class II airplanes.

In both the normal and the emergency modes the yaw damper will maintain zero sideslip throughout these dives and pull-outs. No rudder pedal force will be required.

3.4.16 Lateral control:- Lateral control shall be adequate for compliance with the rolling performance specified in table VI. In those requirements involving measurement of time, the time shall be measured from the instant of initiation of pilot control action. Unless otherwise established by agreement between the contractor and the procuring activity on the basis of intended tactical employment limitations, the altitudes at which the rolling performance requirements are to be met shall be as specified in table VI. For those requirements which are specified in terms of peak pb/2V, the rate of roll need not exceed 220 degree/second. In obtaining the required rolling performance, the rudder pedals on classes I-L and II-L airplanes may be held fixed in the position required for steady flight prior to the roll, or may be employed to reduce adverse sideslip (not to produce favourable sideslip). On class III and all carrier-based airplanes; the rudder pedals shall remain fixed in the position required for steady flight prior to the roll. Automatic coordinating devices are permissible, provided that no objectionable characteristics result. If such a device is employed, the rudder pedals may be free rather than fixed during the roll.

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TABLE VI

MINIMUM ROLLING PERFORMANCE REQUIREMENTS

	Configuration P, CO (Speeds up to V_H)	Configurations P, CO (at 0.95 V_M)	Configuration L 1.1 V_{S_L}
Altitude	Low, medium, high	Lowest altitude at which highest value of V_M (in terms of Mach number) may be attained	Low
Class I	$\frac{pb}{2V}$ = 0.09 at speed up to 0.8 V_H	$\frac{pb}{2V}$ = 0.03	$\frac{pb}{2V}$ = 0.09
Class II	Where V_H is less than 500 knots: $\frac{pb}{2V}$ = 0.07 at speeds up to 0.8 V_H or 300 knots, whichever is lower Where V_H is greater than 500 knots: $\frac{pb}{2V}$ = 0.07 up ro 0.6 V_H $\frac{pb}{2V}$ = 0.05 at 0.8 V_H	$\frac{pb}{2V}$ = 0.015	(a) $\frac{pb}{2V}$ = 10 ft. per sec. (b) Class II-L: $\frac{pb}{2V}$ = 0.07 Class II-C: Same as Class III
Class III	(a) $\frac{pb}{2V}$ = 0.09 between 1.1 V_{S_G} and minimum combat speed (b) Bank angle= 100° in one second, between minimum combat speed & V_H, up to 20,000' altitude (Min. combat speed = V_R/C_{max} or 300 knots true, whichever is higher).	Bank angle = 50° in 1 sec.	Average $\frac{pb}{2V}$ = 0.05 for first 30° of bank, where average $\frac{pb}{2V}$ is based on an average p obtained from the time required to reach 30° of bank

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3.4.16 Lateral control:- Cont'd.

The variation of the maximum attainable steady roll rates with Mach number and altitude is shown in Figure (38). These have been obtained assuming that there is no response in sideslip or yaw during the roll. Because of the presence of the yaw dampers, this assumption will be very nearly true and therefore these steady state roll rates will be reasonably accurate for both flight control modes.

In the normal flight control mode the roll rate command is limited to 120 degrees per second. In the emergency mode the roll rate limiter is inoperative.

The variation of the maximum attainable wing tip helix angle in steady rolling flight is shown in Figure (39).

Configurations P, CO (Speeds up to V_H)

(a) The speeds 1.1 V_{S_G} and the minimum combat speed at each altitude have been marked on the graphs in Figure (39).

Normal flight control mode

It is evident that over the greater part of the speed range the helix angle developed by a roll rate of 120 degrees per second is less than the required value of 0.09.

Emergency flight control mode

Apart from flight at subsonic speed at high altitudes, the rolling performance is capable of meeting this requirement. However, it is not expected that the Arrow 1 will be rolled at these high rates when the emergency mode is engaged.

(b) To meet this part of the requirement the steady state roll rate must be at least 100 degrees per second, at speeds between minimum combat speed and V_H, and altitudes up to 20,000 feet. Figure (38) indicates that the requirement is not met at speeds greater than Mach 1. This is true of both the normal and the emergency modes.

Configurations P, CO (at .95 V_M)

Rate of roll at the highest dynamic pressure in normal and emergency modes will be in excess of values shown on Figure 47 since favourable sideslip is built up automatically to increase the available rate of roll.

The lowest altitude at which the highest values of V_M (in terms of Mach number) may be attained is 31,300 feet at Mach number of 2.00. At a Mach number of 1.90 (.95 V_M), the maximum steady roll rate is 40 degrees per second. A value of at least 50 degrees per second is required and therefore this requirement is not met. This applies to both the normal and the emergency mode.

Configuration L (1.1 V_{S_L})

Simulator studies have shown that in the emergency control mode this requirement is met with a helix angle of .058. The response in the normal mode will be of the same order of magnitude.

3.4.16.1 On class III airplanes:- The lateral control requirements relative to configurations P and CO shall apply under all conditions of spanwise weight distribution which may be encountered in combat. On classes III and II-C airplanes in configuration L, the requirements shall apply to all normal take-off and landing loadings, except that fuel tanks mounted externally at the wing tips or at outboard wing stations may be empty. When these tanks are full, a value of 0.03 may be substituted for 0.05 as the required average $\frac{pb}{2V}$ value.

There will be no large change in lateral centre of gravity movement in any flight role. Fuel sequencing will be employed to prevent a large out of balance rolling moment and the out of balance moment due to asymmetric storage of missiles is negligible.

3.4.16.2 On Class II-L airplanes, the rolling acceleration shall be such that in the normal loading condition which produces the most critical rolling moment of inertia (light weight, heavy outboard concentration of spanwise weight), it is possible to attain the peak rate of roll, corresponding to the pb/2V values specified in table VI, in no more than (0.5 + b/100) seconds after initiation of pilot control action, with peak control forces not greater than 25 lb. (stick) or 50 lb. (wheel).

This is not applicable to the Arrow 1.

3.4.16.3 The peak lateral control force required to obtain the rolling performance specified in table VI shall not exceed the following values:-

Class I - 25 lb. stick force or 50 lb. wheel force

Class II - 25 lb. stick force or 50 lb. wheel force

Class III - 20 lb. stick force or 40 lb. wheel force

Classes II-C and III-C in 20 lb. stick or wheel force

For the Arrow 1, the peak lateral control force should be 20 lb.

(a) Normal mode

In the normal mode, a force of 20 lb. is required to command the maximum attainable roll rate of 120 degrees per second.

An unconventional device called an "a_y fader" is used in the aileron circuit to prevent prohibitive build up of transverse acceleration due to cross-coupling effects. Its effect is particularly noticeable at angles of roll greater than 180 degrees at high dynamic pressures. The "a_y fader" effectively increases the stick force per unit rate of roll whenever transverse acceleration approaches 0.4 'g' as measured 40 feet ahead of the aircraft c.g. The total stick force, however, is not increased, this in effect limits the roll rate available to the pilot. To over-power this action in case of malfunction an additional stick force of 40 lb. is required.

The requirement is met.

(b) Emergency mode

At maximum control deflection from neutral trim in the emergency mode, the aileron control force is 22 lb.

The requirement is exceeded by 2 lb.

3.4.16.4 For all airplanes with wheel-type controls, the wheel throw necessary to meet the lateral control requirements shall not exceed 90 degrees in each direction.

The Arrow 1 has a control stick and therefore this requirement does not apply.

3.4.16.5 Lateral control shall be sufficiently effective to balance the airplane laterally under the conditions specified in paragraphs 3.4.10, 3.4.11, 3.4.11.1, 3.4.12, and 3.4.13, with aileron control forces not exceeding those specified in paragraph 3.4.16.3.

Because, at full aileron control deflection, the stick force is only 20 lb. the specification in paragraph 3.4.16.3 cannot be exceeded.

Lateral control effectiveness has been considered in the investigations for these paragraphs and has been found to meet the requirements with the exception of paragraph 3.4.11.1 (requirements met only above 150 knots) and paragraph 3.4.13 (not met).

The following additional remarks apply to conditions of paragraph 3.4.13:-

In cross-winds up to speeds of 25 knots, while the nose wheel is on the ground there is no possibility of the aircraft over-turning and no aileron deflection is required. With the nose wheel off the ground to give an incidence of 10 degrees, a small amount of aileron is required to balance, the overturning moment at a forward speed of 150 knots.

3.4.16.6 When trimmed laterally at the service ceiling in configuration P, lateral control effectiveness shall be adequate to maintain the wings level throughout the dives and pullouts of paragraph 3.3.16, with aileron control forces not exceeding 10 lb. for stick control or 20 lb. for wheel control.

(a) Normal flight control mode

Damping is present in all three axes and no aileron control forces will be required throughout the dives and pullouts of paragraph 3.3.16.

(b) Emergency flight control mode

In this mode only the yaw axis has artificial damping. However, this will effectively dampen the Dutch roll mode and reduce the inertia coupling in pullouts, so that aileron control forces in excess of 10 lb. will not be exceeded.

3.4.16.7 Although table VI contains no requirement for speeds in excess of 0.95 V_M. It is required that lateral control in the correct direction exist at all permissible speeds.

The aileron reversal speeds are in excess of all maximum permissible speeds and therefore this requirement is met.

3.5 General control and trimmability requirements

3.5.1 Control for spin recovery:- In configurations G and L, the normal controls on classes I and III airplanes shall be adequate to provide consistent prompt recoveries from fully developed erect and inverted spins. Recovery shall require no abnormal effort on the part of the pilot, and recovery control forces shall not exceed 250 lb. (rudder), 75 lb. (elevator), or 35 lb. (aileron). Spin recovery characteristics shall be adequate to permit spin demonstration as required by the procuring activity.

A number of tests has been carried out in the N.A.E. spinning tunnel with a 1/24 scale model of the Arrow. These tests indicate that recoveries from established spins are possible in the conditions tested. A further, more extensive program is necessary to establish the validity of this statement for all conditions of weight, configuration and altitude.

An additional program to evaluate incipient spins or so called post-stall gyrations will also be required. Since some full scale configurations flight tests do not agree very well with spin tunnel predictions it is not possible at this time to make any further statements on spin recoveries.

3.5.2 Control for taxiing:- It shall be possible to perform all normal taxiing operations without undue pilot effort or inconvenience.

Normal taxiing operations have been performed and this requirement is met.

3.5.3 Control surface oscillations:- All control surfaces, and surfaces such as flaps, slats, and speed brakes, shall be free of any tendency toward undamped oscillations apparent to the pilot under the flight conditions specified in table II, at all permissible speeds.

In both the normal and the emergency mode the control system is irreversible, so this requirement will be satisfied.

3.5.4 Primary flight control trimmability:- The trimming devices shall be capable of reducing the elevator, rudder, and aileron control forces to zero, at all speeds between the minimum trim speeds specified in table VII and the upper limits of the speed ranges specified in table II. In addition, the rate of operation and the effectiveness of the longitudinal trim device shall be such that the elevator control force can be maintained within 10 lb. push or pull (20 lb. for class II airplanes) throughout the dives specified in paragraph 3.3.16.

TABLE VII

Conditions for trimming to zero control forces

Condition		Class	Minimum Trim Speed
1	Configuration P, at forward and aft critical loading	All	1.2 $V_{S_{CR}}$
2	Configuration L, at forward and aft critical loading	All	1.4 V_{S_L}
3	Configuration PA, at forward and aft critical loading	Carrier-based	1/1.15 V_{S_L}
		All others	1.4 V_{S_L}
4	Configuration CR, with up to two most critical engines on one side inoperative, wings, level.	All Multi-engine	Speed for maximum range

1/ Or normal approach speed, whichever is lower.

(a) Normal flight control mode

Elevator trim is provided for normal acceleration between the limits -1.43 'g' to 4.3 'g'.

Aileron trim is in terms of roll rate and is used essentially to obtain zero roll rate. The trim limits vary between 45 degrees per second at low dynamic pressure and 81 degrees per second at high dynamic pressure.

Rudder trim is provided for ± 20 degrees at low speed reducing to approximately ± 3 degrees at dynamic pressures at and above 1400 p.s.f.

These trimming ranges meet this requirement.

In the normal, gear down, mode the trim ranges are the same as in the emergency mode.

(b) Emergency flight control mode

The trim ranges are shown in figure (25). These are sufficient to meet this requirement.

3.5.5 Irreversibility of trim controls:- All trimming devices shall maintain a given setting indefinitely, unless changed by the pilot, by a special automatic interconnect, such as to the landing flaps, or by the operation of an artificial stability device. If an artificial stability device or automatic interconnect is used in conjunction with a trim device, provision shall be made to insure the accurate return of the device to its initial trim position on completion of each artificial stabilization or automatic interconnect operation.

(a) Normal flight control mode

Unconventional trimming devices are used in all three axes:

Pitch: The trimmer operates on normal load factor and stick force and will hold a fixed setting of normal load factor indefinitely.

Roll: The trimmer operates on roll rate and stick force and will hold a fixed setting of roll rate indefinitely.

Yaw: Trimmer authority is a function of dynamic pressure and therefore the rudder trim will change with speed and altitude. The rudder trim does not meet the requirement of this specification. The variable trim was introduced as a safety precaution to prevent excessive fin loadings when aircraft is accelerated from a low speed condition requiring a substantial rudder angle out of neutral.

For trimmer behaviour when switching from normal to emergency see paragraph 3.7.3.

(b) Emergency flight control mode

Elevators and ailerons have conventional trimming devices which meet the requirement.

Rudder trim is the same as in normal mode.

3.5.6 Trim system failure:- Failure of a power-actuated trim system (including sticking or runaway in either direction) shall not result in an unsafe flight condition. Following such failure, it shall be possible to cruise for extended periods and to make a safe landing (including carrier landing for carrier-based aircraft). The use of override provisions or alternate trim mechanisms normally available to the pilot shall be permissible. This requirement shall apply to both aerodynamic and feel-system trim devices.

3.5.6 Trim system failure:- (Continued)

Consideration is being given to install an emergency release mechanism in the elevator trim and feel unit which may be actuated by the pilot.

Safety devices are incorporated which will cause reversion to the emergency mode if the roll rate, normal acceleration, or acceleration in pitch or yaw become excessive.

3.6 Stall Characteristics

3.6.1 Required flight conditions:- The requirements for stall characteristics shall apply at all permissible c.g. positions, for configurations G, CR, L, and PA in straight unaccelerated flight, and with normal acceleration up to the limits of the operational flight envelopes. Unless otherwise specified by the procuring activity, all stall characteristics requirements apply for normal symmetric external store installations throughout the entire range of store loadings, as well as for the clean airplane if such stores are not installed for some training or tactical missions.

3.6.2 Definition of stalling speed, V_S:- The stalling speed, V_S, is defined as the minimum speed attainable in flight, and is normally associated with the breakdown of airflow over the wing immediately after attaining the maximum overall trimmed lift coefficient of the airplane. In order to minimize dynamic lift effects, the rate of reduction of speed during an approach to the stall should be not greater than 1 knot per second. The complete stall is generally characterized by uncontrollable pitching or rolling, or by a decrease in normal acceleration in turning flight.

The definition is not applicable because there is no breakdown of the flow over the Arrow 1 wing near the incidence for maximum lift. See paragraph 3.6.2.2.

3.6.2.1 For some airplanes, the technique of paragraph 3.6.2 will not result in a true aerodynamic wing stall because of insufficient longitudinal control. Such airplanes, at a given weight, will have varying minimum speeds depending upon the c.g. position. For purposes of this specification, the stalling speed, V_S, for such an airplane shall be defined as the minimum speed attainable in the applicable configuration with the airplane loaded at its aft critical loading.

This definition is not applicable because the wing incidence is not limited by insufficient longitudinal control.

3.6.2.2 In the event that considerations other than wing maximum lift or available longitudinal control determine the minimum usable flying speed in any configuration (e.g. ability to perform altitude corrections, ability to take wave off, visibility, etc.) the stalling speed V_S for that configuration shall, for the purpose of this specification, be defined as the minimum usable flying speed as agreed upon between the contractor and the procuring activity, provided, however, that such definition is consistent with the definition of stalling speed as employed in structural design considerations, performance guarantees, etc.

For the Arrow 1, V_S represents a minimum usable flying speed. The maximum usable lift coefficient has been chosen by consideration of the ability to perform altitude corrections to be 0.8. For an all-up-weight of 47,000 lb. this gives V_S = 119 knots and this value for V_S applies to all the conditions of paragraph 3.6.1.

It should be noted that an accurate estimation of the minimum usable flying speed is not possible, and in flight the speed V_S should be approached with caution. Flight test may show that this minimum usable speed is in excess of the 119 knots as quoted here.

3.6.3 Stall-warning requirements:- The approach to the complete stall shall be accompanied by an easily perceptible stall warning which occurs between 1.05 and 1.15 times the stalling speed in configuration G, L, and CR, and between 1.05 and 1.10 times the stalling speed in configuration PA. Acceptable stall warning shall consist of shaking of the cockpit controls, buffeting, or both, or shaking of the airplane, or both.

Flight tests on similar aircraft suggest that buffeting will occur at incidences slightly above 16 degrees at low speeds. Stalling characteristics, however, must be determined by flight tests.

3.6.3.1 Artificial stall warning closely simulating the warning required in paragraph 3.6.3 shall be permitted only if it can be shown that it is not feasible to provide aerodynamic stall warning, and if the artificial device is approved by the procuring activity.

It is thought that no artificial stall warning device will be required. See paragraph 3.6.3.

3.6.3.2 For airplanes with limiting elevators described in paragraph 3.6.3.1 no stall warning is required provided a true aerodynamic stall cannot be obtained while loaded at the aft critical loading, and provided no dangerous flight characteristics or motions occur at the minimum attainable speed.

This paragraph is not applicable.

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3.6.4 Requirements for acceptable stalling characteristics:-

Although it is desired that no nose-up pitch occurs at the stall, a mild nose-up pitch may be accepted, provided that no dangerous or seriously objectionable flight conditions result. The stall shall be considered unacceptable if the airplane exhibits uncontrollable rolling or downward pitching at the stall in excess of 20 degrees from level for classes I and II airplanes, or 30 degrees from level for class III airplanes. These requirements shall apply not only to airplanes with conventional (maximum lift) stalling speeds, but also to complete stalls when attainable by any means on airplanes with stalling speeds as defined in paragraphs 3.6.2.1 or 3.6.2.2.

Incipient spin tests which are scheduled for the near future will help to define the stall characteristics. Further information will have to be obtained by flight testing.

3.6.4.1 It shall be possible to prevent the complete stall by normal use of the controls at the onset of the stall warning. In the event of a complete stall, it shall be possible to recover by normal use of the controls with reasonable control forces, and without excessive loss of altitude or build-up of speed.

The remarks for the above paragraph apply here also.

3.7 Requirements for power-and boost-control systems:-

3.7.1 Normal control system operation:- The control system shall satisfy the applicable mechanical design requirements of the procuring activity, as well as the requirements of this specification. The system shall be capable of providing rapid repeated control movements as might be required in very rough air operation.

Mechanical design was to the applicable specifications. There is ample power for all probable turbulent flight conditions.

3.7.2 Power or boost failure:- All airplane employing power - or boost-control systems shall be provided with suitable means for control following complete loss of power or boost. The means for control following such failure (e.g., independent boost, direct mechanical control) is referred to herein as the alternate control system.

The hydraulic power is derived from two pumps per engine, with one pump for each providing fluid under pressure for the 'A' system and the other pump supplying the 'B' system. The hydraulic control surface actuators are of the tandem type, the 'A' system driving one piston and the 'B' system driving the other. Both the 'A' and the 'B' systems supply power to the actuators in the normal and in the emergency control modes.

3.7.2 Power or boost failure:- Cont'd.

Engine failure does not cause loss of control power. Failure of one engine will result in reduced rates of control application, but will not affect the steady state hinge moments. In the event of both engines failing at high speeds, the pumps will be driven by the windmilling engines and for low speed applications consideration is being given to installing a ram air turbine to produce the required power.

Loss of hydraulic pressure in the 'B' system will cause automatic switching to the emergency control mode. In this case, only the 'A' system will be supplying the power for jack actuation and the maximum jack force will be halved. This will be referred to in the following paragraphs as the 'alternate emergency control mode'.

3.7.3 Transfer to alternate control system - Trim change:- The trim change associated with transfer to the alternate control system, when such transfer is either caused by control power failure or performed intentionally in accordance with routine procedure, shall never be such as to bring about dangerous flight conditions. This shall apply not only in trimmed level flight, but also in dives to V_M with elevator control force, prior to transfer, out of trim by as much as ± 5 lb. If dual independent control systems are used, a transfer at cruising altitude in trimmed level flight in configuration P shall cause no perceptible trim change. If the alternate system is not an independent power system, the out-of-trim conditions resulting from a transfer at cruising altitude in trimmed level flight in configuration P shall be within the following limits:

(a) Pitch - with control free, the change in normal acceleration shall not exceed ± 0.5 g.

(b) Roll - with controls free, the resulting rate of roll in either direction shall not exceed 5° per second or 10% of the rate corresponding to the requirement of table VI, whichever is less.

(c) Yaw - the rudder control force required to maintain zero sideslip shall not exceed 100 lb.

Transfer to the emergency control mode or to the alternate emergency control mode will possess the same characteristics as follows:

(a) Pitch - Automatic trimming is provided for the elevator control to give desirable feel effects at transfer. It operates as follows:

(1) With pilot exerting force on the stick.

3.7.3 Transfer to alternate control system - Trim change:- (Continued)

(1) With pilot exerting force on the stick (Continued)

Trim motor is actuated by a pressure pick-up in the parallel servo transmitting the servo load to the feel spring in such a manner that there is no appreciable change in stick force level upon disengagement to emergency control mode.

(2) With no force on the stick

Trim motor is actuated in the same manner as above but stops whenever an incremental .5 'g' is exceeded in any direction. Thus on disengagement the aircraft returns to within 1/2 'g', of level flight. The requirement is therefore satisfied.

(b) Roll - No automatic trimming is provided for the ailerons, however, the manual, electrical trimming in the normal mode will be small and it is not expected that the conventional aileron trim in the emergency mode will be far from neutral when the emergency mode is engaged.

The requirement is met when the aircraft is initially trimmed in level flight. If the aircraft is rolling when the transfer takes place there will be a small bump in the aileron control force.

(c) Yaw - The same rudder trim unit is used in the emergency mode as in the normal mode and therefore this requirement is met.

3.7.3.1 Upon transfer to the alternate control system in configuration PA at 1.15 V_{S_L}, with trim set for zero control forces prior to transfer, it shall be possible on all airplanes to maintain the airplane attitude with elevator control forces not exceeding 20 lb. for all classes of airplanes, aileron control forces not exceeding 10 lb. for all classes of airplanes, and rudder control forces not exceeding 50 lb. for classes I, II-C, and III airplanes, and 100 lb. for class II-L airplanes.

This requirement is met. With trim set for straight level flight prior to transfer there will be no change in the control forces.

3.7.3.2 On airplanes intended for tactical employment at low altitude, it shall be possible upon transfer to the alternate control system at sea level in configuration P, to maintain straight level flight, at 1.4 V_{S_L} and at V_H, with control forces not exceeding 20 lb. elevator, 10 lb. aileron, and 50 lb. rudder (100 lb. rudder on class II-L airplanes). The longitudinal trim change under these conditions shall never be nose down.

It is possible to trim the control forces to zero in these conditions.

3.7.4 Longitudinal control on alternate system:- At maximum level flight speed at sea level, it shall be possible, with the primary control system, inoperative, to obtain at least 3g on class III airplanes, and at least 1.5g or $0.6n_L$, whichever is less, on all other airplanes. Elevator control force in this manoeuvre, with the airplane trimmed for 1g flight, shall not exceed 75 lb. for class I airplanes, 150 lb. for class II airplanes, and 120 lb. for class III airplanes. This requirement shall be met with the most forward c.g. location corresponding to a combat loading.

The control feel forces are the same in the alternate emergency mode as in the emergency mode, but the maximum available elevator hinge moment will be halved. At maximum level flight speed at sea level the maximum operational normal acceleration is attainable in the emergency mode, and a normal acceleration in excess of 3 'g' will be attainable in the alternate emergency mode. In both cases, the elevator stick forces will be less than 50 lb.

3.7.4.1 It is desired that longitudinal control on the alternate system be adequate to permit recovery from any dive condition normally attained in service operation. As a minimum required, it shall be possible on class III airplane to recover from a dive of at least 50 degrees (or dive angle resulting in V_D, whichever is less) initiated from service ceiling and maximum level flight speed, with the primary control power system rendered inoperative at 20,000 feet. With the elevator control force trimmed within 10 lb. push or pull prior to the simulated failure, and with pilot trim setting operational during recovery, the elevator control force in the recovery shall not exceed 120 lb. The use of any auxiliary dive-recovery or deceleration device having an independent power supply and readily available to the pilot is permissible during the recovery.

This requirement is met for both the emergency and the alternate emergency control modes.

3.7.4.2 With the primary control power or boost system inoperative and the elevator control force trimmed to within 5 lb. at 1.4 V_{SL} (1.15 V_{SL} for carrier-based airplanes) in configuration PA, it shall be possible to execute a safe landing with elevator control forces not exceeding 35 lb. for classes I, II-C, and III airplanes, and 50 lb. stick force or 80 lb. wheel force for class II-L, airplanes, when loaded at the most forward c.g. location corresponding to a normal service loading.

This requirement is met for both the emergency and the alternate emergency control modes.

3.7.5 Lateral control on alternate system:- With the primary control power or boost system inoperative, it shall be possible to obtain a peak steady rolling velocity of 15 degrees per second or 50% of the pertinent requirement of table VI, whichever is less, with aileron control forces not exceeding 30 lb. stick force or 60 lb. wheel force. In addition, on class II-C and class III airplanes in configuration L, at 1.1 V_{SL}, the average helix angle obtainable over the first 30 degrees of bank, as defined in table VI under class III configuration L, shall be at least pb/2V (average) = 0.02, with aileron control force not exceeding 20 lb. stick or wheel force. During these rolls, the aileron trim shall remain fixed in the wings-level setting, and requirements regarding use of the rudder shall be as specified in paragraph 3.4.16, except that on class III-L airplanes, the rudder requirements shall be as specified for class II-L airplanes in paragraph 3.4.16.

The steady state rolling velocity in the alternate emergency mode is approximately 50% of that shown in Figure (38) at supersonic speeds and 75% of that shown at subsonic speeds. It can be seen that this requirement for a steady roll rate of 15 degrees per second is met throughout the operational flight envelope, except at speeds near to V_D at altitudes from sea level to 30,000 feet.

The requirement for a helix angle of .2 is less than half the requirement met in the normal and emergency modes (see paragraph 3.4.16). At this low speed the reduction in available hinge moment will not limit the available aileron angle, and in the alternate emergency control mode the rate of control application is still high and therefore this requirement will also be met.

3.7.6 Directional control on alternate system:- With the primary control power or boost system inoperative, it shall be possible to perform the landing of paragraph 3.7.4.2 in a cross-wind of 50% of the value specified in paragraph 3.4.13, with rudder control forces not exceeding 180 lb.

The emergency and alternate emergency modes will be exactly the same as normal mode in this respect as stated in paragraph 3.4.13. Therefore this requirement will be met.

3.7.7 Ability to trim on alternate system:- With the airplane operating on the alternate control system, it shall be possible to trim the elevator, aileron, and rudder control forces to zero at all level-flight speeds above the minimum speeds specified in table VII.

The trim range available in the alternate emergency control mode is identical with that in the emergency mode and therefore this requirement is met (see paragraph 3.5.4).

3.7.8 Feel system failure:- Failure of an artificial feel system shall not result in unsafe flight conditions, and shall not impair the ability to effect a satisfactory landing (including carrier landing for carrier-based aircraft). This requirement may be waived only if it is established to the satisfaction of the procuring activity that the possibility of feel system failure is extremely remote.

In the normal flight control mode, the feel system is an inherent part of the control system and is rendered inoperative by any failure of the system. In such a case, control is transferred to the emergency system.

In the emergency flight mode, feel is provided by a simple, rugged, spring system which is not likely to fail.

Failure of both systems is extremely unlikely, but upon this happening it should still be possible to perform a satisfactory landing.

4. QUALITY ASSURANCE PROVISIONS

4.1 Quality assurance provisions shall be as specified by the procuring activity.

5. PREPARATION FOR DELIVERY

5.1 Not applicable to this specification.

6. NOTES

6.1 Intended use:- This specification contains the flying quality requirements for piloted airplanes and shall form one of the bases for determination, by the procuring activity, of the airplane acceptability. The specification shall serve as design requirements, and as criteria for use in stability and control calculations, analysis of wind tunnel test results, and flight testing and evaluation.

6.2 Definitions:- Terms and symbols used throughout this specification are defined as follows:

$V_{R/C}$	-	Speed for maximum rate of climb with normal rated power
V_S	-	See paragraph 3.6.2. The subscripts, e.g., G, L, etc. refer to the airplane configurations described in paragraph 3.1.9.
V_H	-	High speed, level flight, augmented power.
V_{NRP}	-	High speed, level flight, normal rated power.
V_D	-	Maximum permissible speed as defined by the maximum permissible speed envelope of paragraph 3.1.4.
M_D	-	Maximum permissible Mach number (associated with V_D)
V_M	-	Maximum operational speed as defined by the maximum operational speed envelope of paragraph 3.1.3.
$\frac{pb}{2V}$	-	The helix angle, in radians, described by a wingtip during a rolling manoeuvre: p is the rate of roll about the body axis in radians per second, b is the wingspan in feet, and V is the true airspeed in feet per second.
n	-	Normal load factor, in g units, normal to body axis.
n_L	-	Limit load factor for a given loading based on structural considerations.
C 1/2	-	Number of cycles for the lateral oscillations to damp to half amplitude.
ϕ	-	Bank angle, degrees.
β	-	Sideslip angle, degrees.
$\left\lvert \frac{\phi}{\beta} \right\rvert$	-	Ratio of amplitudes of bank and sideslip angles in oscillatory mode.

6.2 Definitions:- (Continued)

$\left|\frac{\phi}{v_e}\right|$ - Rolling parameter, degrees/feet per second.

$$\left|\frac{\phi}{v_e}\right| = \frac{57.3}{v_e} \cdot \left|\frac{\phi}{\beta}\right|,$$ where V_e is equivalent airspeed in feet per second.

MRP - Military rated power, which is the maximum power (not including augmentation) at which the engine can be operated for a specified period.

NRP - Normal rated power, which is the maximum power at which the engine can be operated continuously.

PLF - Power for level flight at the specified condition.

Augmented power - Military rated power plus augmentation e.g., jato, afterburner.

Power and thrust - For reaction-type engines, the word "power" shall be replaced by the word "thrust" throughout the specification.

Control surface - An external surface or device which is positioned by a cockpit control, and which produces aerodynamic or jet-reaction type forces in such manner as to control the attitude of the airplane. As used in this specification, the elevator, ailerons, and rudder are the control surfaces or devices which are controlled by the stick (or wheel) and rudder pedals to provide longitudinal, lateral, and directional control, respectively.

Control-fixed - A condition, where the pilot's cockpit control is held firmly at a given position. Elevator-fixed, rudder-fixed, and aileron-fixed refer to the condition of the individual cockpit control.

Control-free - A condition where the cockpit control is unrestrained by the pilot. Elevator-free, rudder-free, and aileron-free refer to the condition of the individual cockpit control.

6.2 Definitions:- (Continued)

Elevator-fixed neutral point	- The c.g. position for zero elevator cockpit control travel with change in speed, in straight flight at constant throttle.
Elevator-free neutral point	- The c.g. position for zero elevator control force with change of speed for trim, in straight flight at constant throttle.
Elevator-Control force	- Component of applied force, exerted by the pilot on the cockpit control, in or parallel to the plane of symmetry, acting at the center of the stick grip or wheel in a direction perpendicular to a line between the center of the stick grip or wheel and the stick or control column pivot.
Rudder-Control force	- Difference of push-force components, of the forces exerted by the pilot on the rudder pedals, lying in planes parallel to the plane of symmetry, measured along lines connecting the foremost point of the seat (at mid-adjustment) and the normal points of application of the pilot's instep on the respective rudder pedals.
Aileron control force	- For a stick control, the component of control force exerted by the pilot in a plane perpendicular to the plane of symmetry, acting at the center of the stick grip in a direction perpendicular to a line between the center of the stick grip and the stick pivot. For a wheel control, the total moment applied by the pilot about the wheel axis in the plane of the wheel, divided by the average radius of the pilot's grip.
Aft critical loading	- The normal service loading which results in a combination of weight and c.g. position producing minimum stability. (Ordinarily the lightest gross weight at which the most aft c.g. position can be obtained in a given configuration at a normal service loading.)

6.2 Definitions:- (Continued)

Forward critical loading: - Ordinarily, the heaviest gross weight at which the most forward c.g. position can be obtained in a given configuration at a normal service loading.

Sideslip angle: - Angle between the undisturbed flow and plane of symmetry of the airplane, measured in a plane parallel to the relative wind and perpendicular to the plane of symmetry. Plus, or right sideslip, corresponds to incident flow approaching from the right side of the plane of symmetry.

Power Off: - Reciprocating engine: Throttle closed, propeller windmilling; for configuration L, propeller pitch control in "low pitch" setting or in setting normally used in landing approach; for configuration G, propeller control setting optional.

Jet engines: Idling thrust.

Turboprop engines: Flight idle setting; for configuration L, propeller control setting as normally employed in landing approach; for configuration G, propeller control setting optional.

Rocket engines: Thrust condition normally used in landing touchdown.

The following additional definitions have been used in the interpretation of these requirements to apply for the Arrow:-

Normal mode: - This sytem of control will normally be used. Stability augmentation about all three axes, electric, stick steering and automatic trimming about the pitch axis is provided.

Emergency mode: - In this mode, stability augmentation is provided for the yaw axis only and proportional feel is provided for all three controls. This mode can be selected by the pilot or it may be selected automatically upon system mal-function in the normal mode.

6.2 Definitions:- (Continued)

Alternate emergency mode: - Pressure failure in the hydraulic system for the normal mode will cause automatic selection of this mode. It differs from the emergency mode in having reduced available control hinge moments.

Dampers off mode: - This mode cannot be selected by the pilot, nor can it be selected automatically by any set of circumstances. It defines the theoretical mode obtained when all artificial stabilization is assumed to be zero and no restriction is imposed upon any of the degrees of freedom.

Control column free:

(a) Normal mode:

Although the controls are irreversible the term stick free is not strictly the same as stick fixed. Some small stick movements will be present in stick free condition due to air gustiness, change of speed etc.

(b) Emergency mode:

In this case the controls are still irreversible and the stick free position will remain fixed. In this case the terms stick fixed and stick free are synonymous.

Rudder free: - The rudder is irreversible and automatic yaw damping is incorporated into the control system in both normal and emergency modes. Both rudder pedal fixed and rudder pedal free cases give the same rudder free steady trim conditions.

6.3 Interpretation of qualitative requirements:- In several instances throughout the specification requirements, qualitative terms, such as "objectionable flight characteristics," "unacceptable flight conditions," "Unusual pilot technique," etc, have been employed as a means of permitting latitude where absolute quantitative criteria might be unduly restrictive. Final determination of compliance with requirements so worded will be made by the procuring activity.

6.4 Rates of operation of auxiliary aerodynamic devices:- Although it has not been considered feasible to include in this specification quantitative requirements for rates of operation of trim tabs, trimmable stabilizers, artificial feel trimmers, etc, or for rates of extension and retraction of flaps, speed brakes, etc, the influence of such rates on the flying qualities may be appreciable and is treated qualitatively in paragraph 3.2.3. In general, trim devices should be operable rapidly enough to enable the pilot to maintain trim under changing conditions as normally encountered in functional and tactical employment of the airplane, and yet must not be so rapid in operation as to induce over-sensitivity or trim precision difficulties under any flight condition. Flaps and other high lift devices should operate at a rate sufficient to permit transition into the high lift configuration without undue delay, and yet must not operate so rapidly as to cause sudden or erratic trim or lift changes. This limitation on rate of operation applies also to speed brakes, which, nevertheless, must function at a rate sufficient to meet the tactical and operational needs.

The effect of the rates of movement of the controls on the flying characteristics of the Arrow 1 have been investigated using the flight simulator. Satisfactory characteristics have been obtained.

In the normal control mode, retrimming action for change of speed, operation of dive brakes etc. is automatic and can be applied at the maximum rate of which the control surfaces are capable. Trimming into manoeuvres is at compromise fixed rate. e.g. In pitch a fixed rate of 0.1 'g' per second is available at all speeds and altitudes. In roll, 3 degrees per second of roll rate per second are available to the pilot at low dynamic pressure; this rate of trim increasing to 5.4 degrees per second at high dynamic pressure. The rudder is trimmed conventionally with rates varying with dynamic pressure.

In the emergency control mode, the rates of trim are a compromise between high and low speed requirements and are expected to fulfill all operational requirements.

6.5 Control force coordination:- The control forces required to perform manoeuvres which are normal for the airplane should have magnitudes which are related to the pilot's capability to produce such forces. As a tentative guide on this subject, it is desired that the relative magnitudes of control forces in coordinated manoeuvres should be approximately in the ratio of 50, 175, and 25 pounds (or 2:7:1) for elevator, rudder and aileron force, respectively, for a stick-control airplane. For a wheel-control airplane, the elevator and aileron control forces may be increased by 50 percent. These ratios refer to the peak forces obtained when starting from level flight in configuration P at medium altitude, a rolling pullout manoeuvre is performed in which approximately 2/3 of the available rolling velocity is obtained simultaneously with a normal load factor of approximately $1 + 2/3\ (n_L - 1)$, maintaining zero sideslip with the rudder.

In both the normal and the emergency mode, coordinated manoeuvres will normally be performed without application of rudder force. The relative magnitudes of the elevator and aileron forces for coordinated turns will be approximately in the ratio of 2:1 as required, for both modes of control.

6.6 Artificial stability devices:- In general, the use of artificial devices, such as rate dampers or static-stability augmenters, should be considered only when provision of the required degree of stability by aerodynamic or simple mechanical means, such as bob weights, down springs, spring tabs, etc. is shown to be impossible or impracticable. When artificial devices are employed, it is ordinarily desired that, subject to reasonable limitations on weight and complexity, the improvement in the affected flight characteristics be such that an appreciable margin is provided beyond the pertinent minimum requirements. When extensive automatic provisions are incorporated (e.g. automatic pilot with control-stick steering), the requirements of this specification will ordinarily be augmented by specifications governing the procurement of the specialized equipment.

Because the Arrow 1 is to operate over a wide range of speeds and heights, (Mach numbers up to 2 and heights up to 60,000 feet) extensive automatic provisions have been incorporated. These provisions include automatic trimming about the pitch axis, stick steering and artificial damping in roll, pitch and yaw. The yaw damper, but none of the other automatic provisions, is retained in the emergency control mode. For this reason the aircraft behaviour in the emergency control mode as well as in the normal control mode has been quoted throughout.

In addition to this equipment an automatic pilot and an automatic fire control system are incorporated.

6.7 Effects of aeroelasticity, control equipment, structural dynamics, etc:- Since the effects of aeroelasticity, control equipment, and structural dynamics may exert an important influence on the airplane flying qualities, such effects should not be over-looked in calculations or analysis directed toward investigation of compliance with the requirements of this specification.

Aeroelastic effects have been included wherever practicable in the investigation.

6.8 Lateral oscillations:- The inclusion of the roll parameter in the lateral-dynamic stability requirements of paragraph 3.4.1 is based on partial results of several research programs still in progress. Evidence indicates that for very short periods (i.e. below 1.8 seconds) and for values of $|\phi / v_e|$ greater than 1.2, the desired damping may be considerably greater than that specified in Figure 40. Pending the incorporation of later research results in the requirements, periods and rolling parameters in these areas should be treated with caution, with the values shown in Figure 40 employed as minimums.

See Section 3.4.1.2.

6.9 Control position measurement:- In this specification, requirements involving control position have generally been written in terms of cockpit control rather than surface deflection because of the more direct influence of cockpit controls on pilot impressions. Because of the more basic engineering significance of, and need for, surface deflection data, proof of compliance with such requirements will ordinarily be accepted in terms of surface deflections unless linkage peculiarities, stretch, deformation, etc. appear to render such proof invalid.

Because of the artificial damping system, the assumption that the terms cockpit control fixed and control surface fixed are synonymous is not always valid. The assumption is true for the elevator and aileron controls in the emergency mode and for the three controls in both modes in steady state conditions. When the control surface deflections are not influenced by the damper, the variation of cockpit control position with control surface deflection is essentially linear.

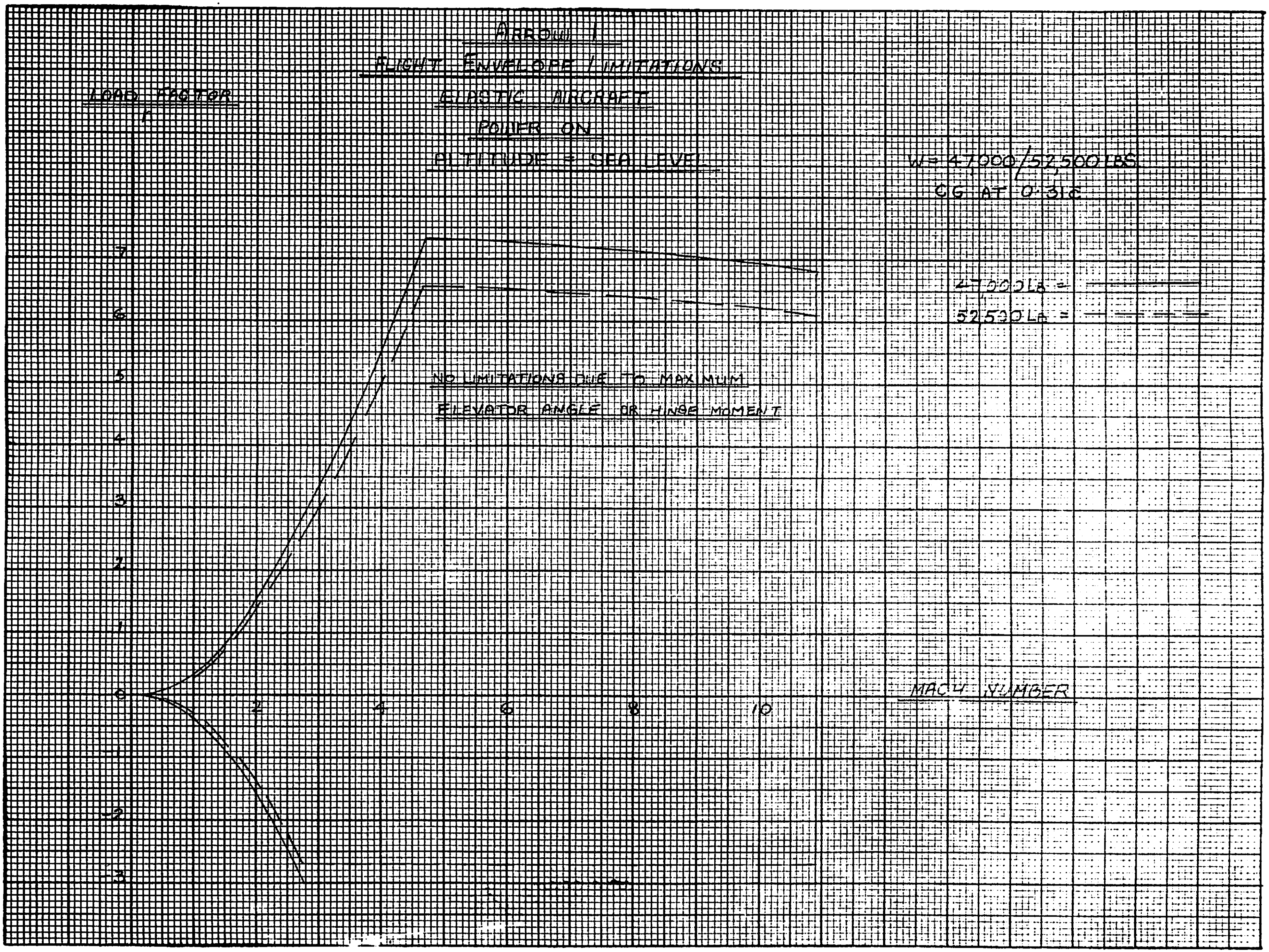
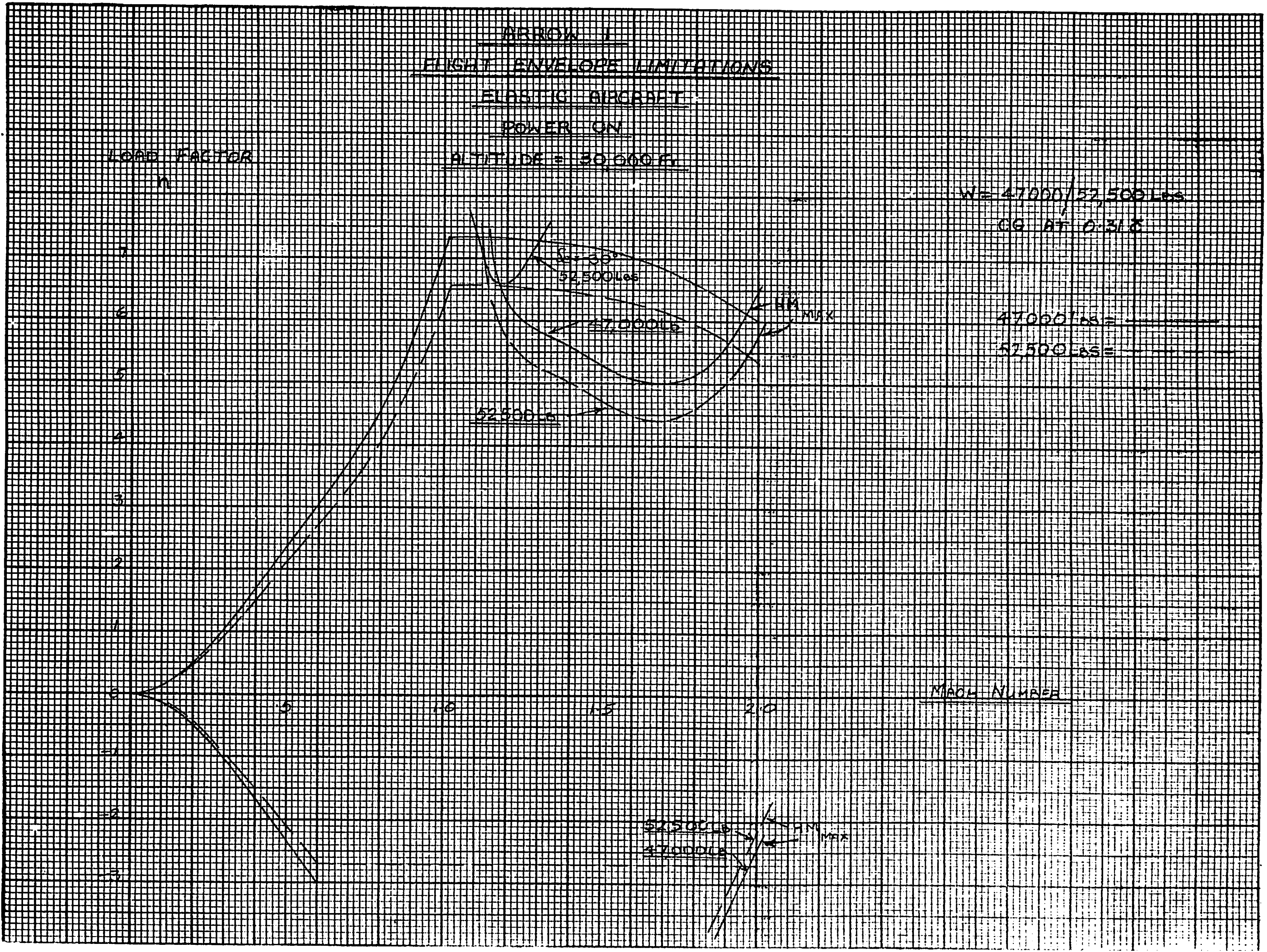

ARROW I
FLIGHT ENVELOPE LIMITATIONS
ELASTIC AIRCRAFT
POWER ON
ALTITUDE = SEA LEVEL
LOAD FACTOR
n
W = 47,000/52,500 LBS
CG AT 0.31c
47,000 LB =
52,500 LB =
NO LIMITATIONS DUE TO MAXIMUM
ELEVATOR ANGLE OR HINGE MOMENT
MACH NUMBER
7
6
5
4
3
2
1
0
-2
-3
2
4
6
8
10

FIG. 1

G9-12
10 X 10 TO THE ½ INCH
MADE IN CANADA



DISTRIBUTED BY RAPID BLUE PRINT

FIG. 2

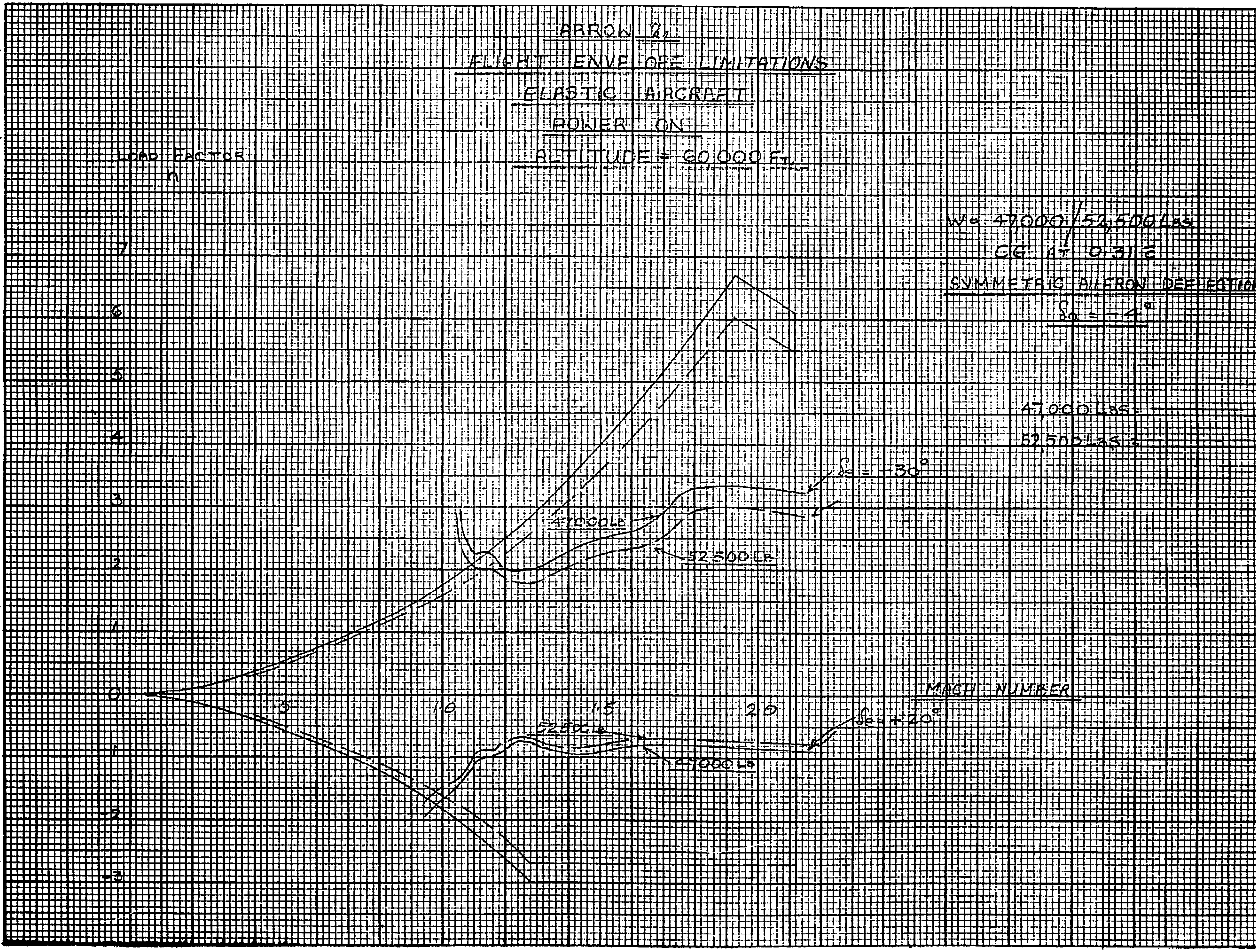

ARROW 2
FLIGHT ENVELOPE LIMITATIONS
ELASTIC AIRCRAFT
POWER ON
ALTITUDE = 60,000 FT.
LOAD FACTOR
n
W = 47000/52,500 LBS.
CG AT 0.31 c̄
SYMMETRIC AILERON DEFLECTION
$\delta_a = -4°$
47,000 LBS.
52,500 LBS.
$\delta_a = -30°$
47000 LB
52,500 LB
MACH NUMBER
$\delta_a = +20°$
52500 LB
47000 LB
7
6
5
4
3
2
1
0
-1
-2
-3
.5
1.0
1.5
2.0

FIG. 3 NT.

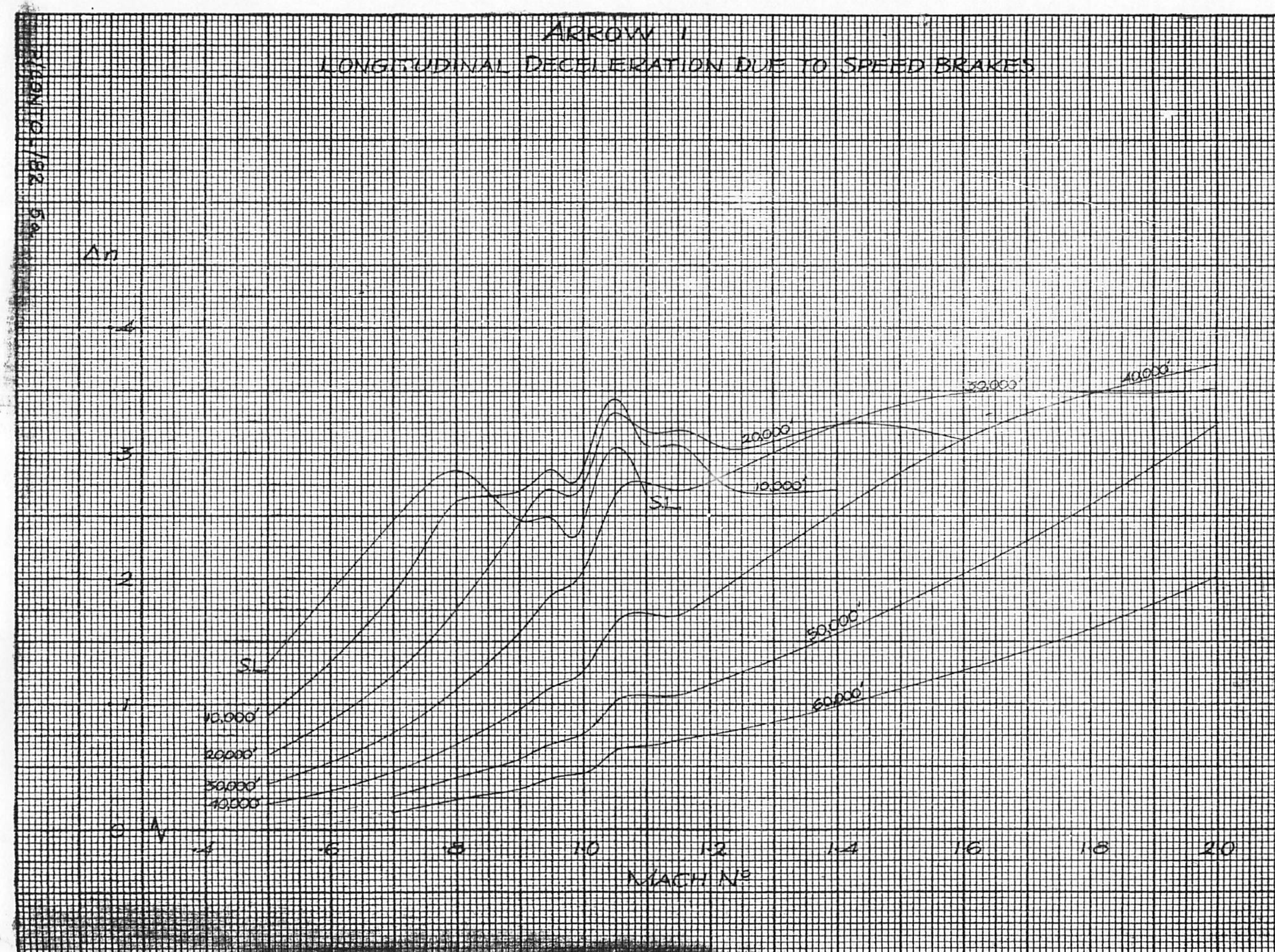
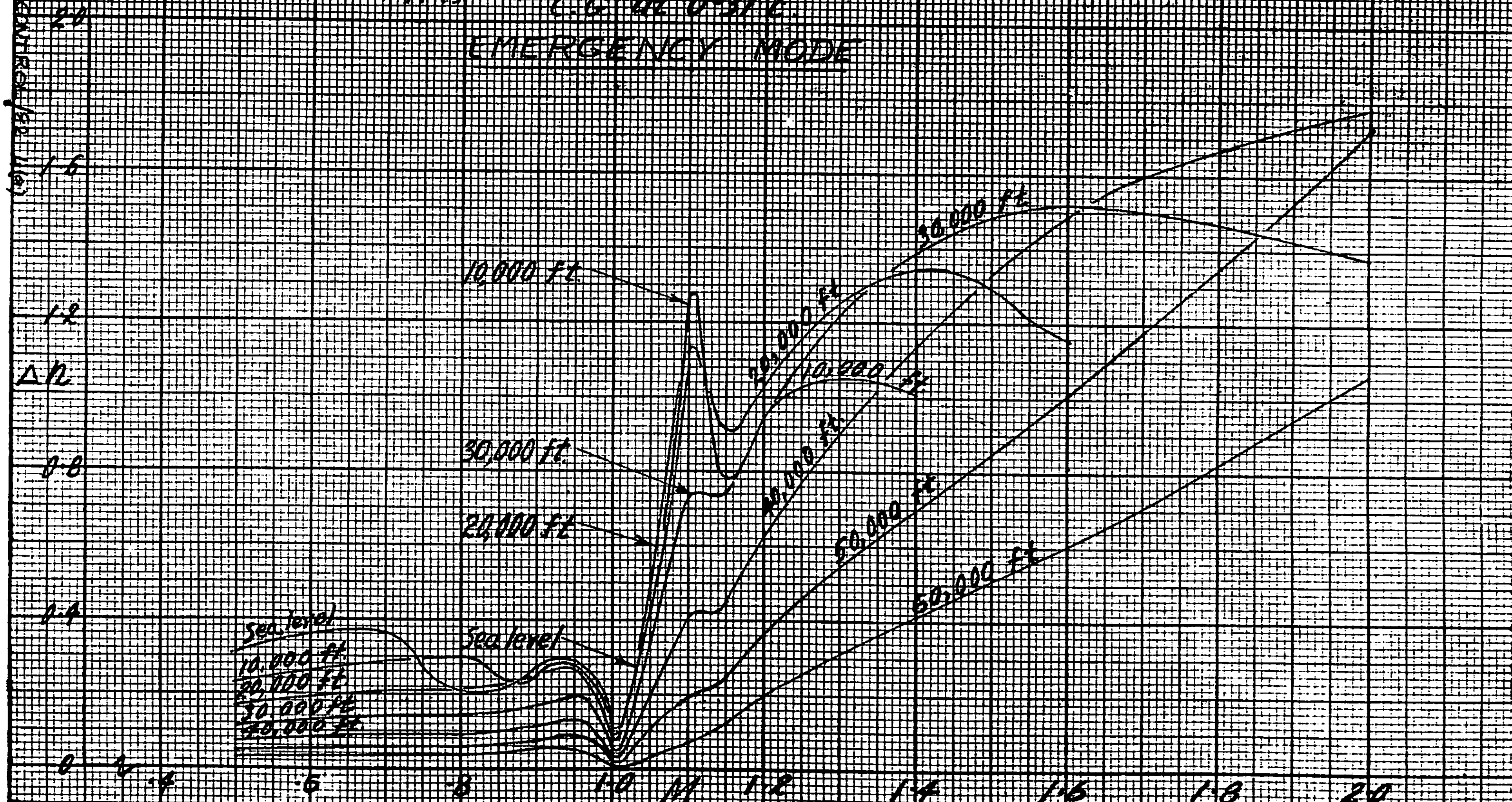

ARROW 1
LONGITUDINAL DECELERATION DUE TO SPEED BRAKES
Δn
MACH Nº
S.L.
10,000'
20,000'
30,000'
40,000'
50,000'
60,000'
32,000'
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
0
1
2
3
4
P/CONTO/82 5a

FIG. 4

FIG. 5

C105 INCREMENTAL NORMAL ACCELERATION AT THE C.G. DUE TO EXTENDING THE SPEED BRAKES.

C.G. at 0·31 C̄.
EMERGENCY MODE



Note:- Δn is the incremental increase in normal acceleration at the c.g. due to extending the dive-brakes, divided by the gravitational acceleration. The speed and the elevator angle are constant throughout the manoeuvre.

P/CONTROL/82 1(a)

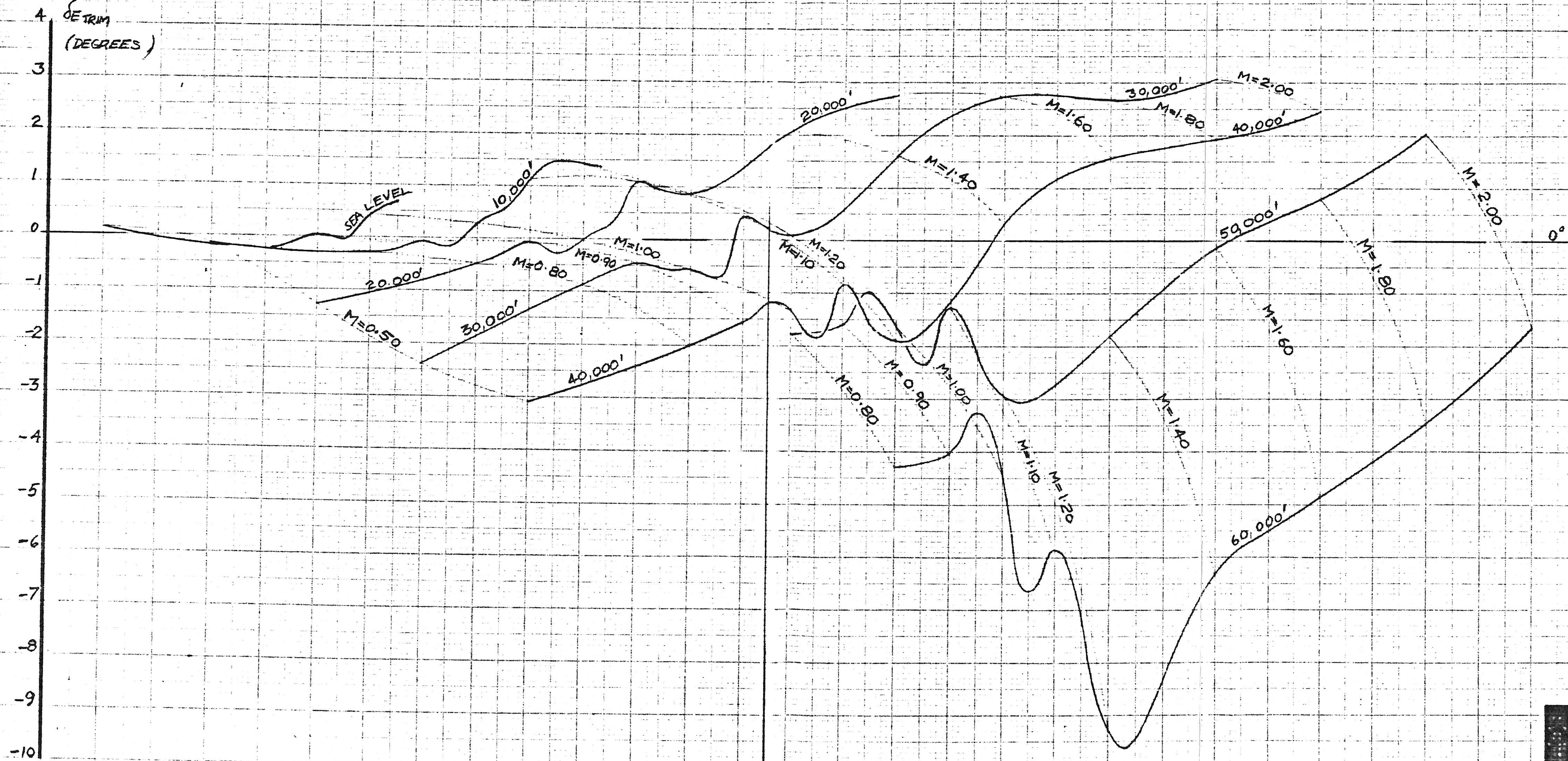
[redacted]

C-105

ELEVATOR ANGLE TO TRIM vs MACH N° AND ALTITUDE

LEVEL FLIGHT (n=1)

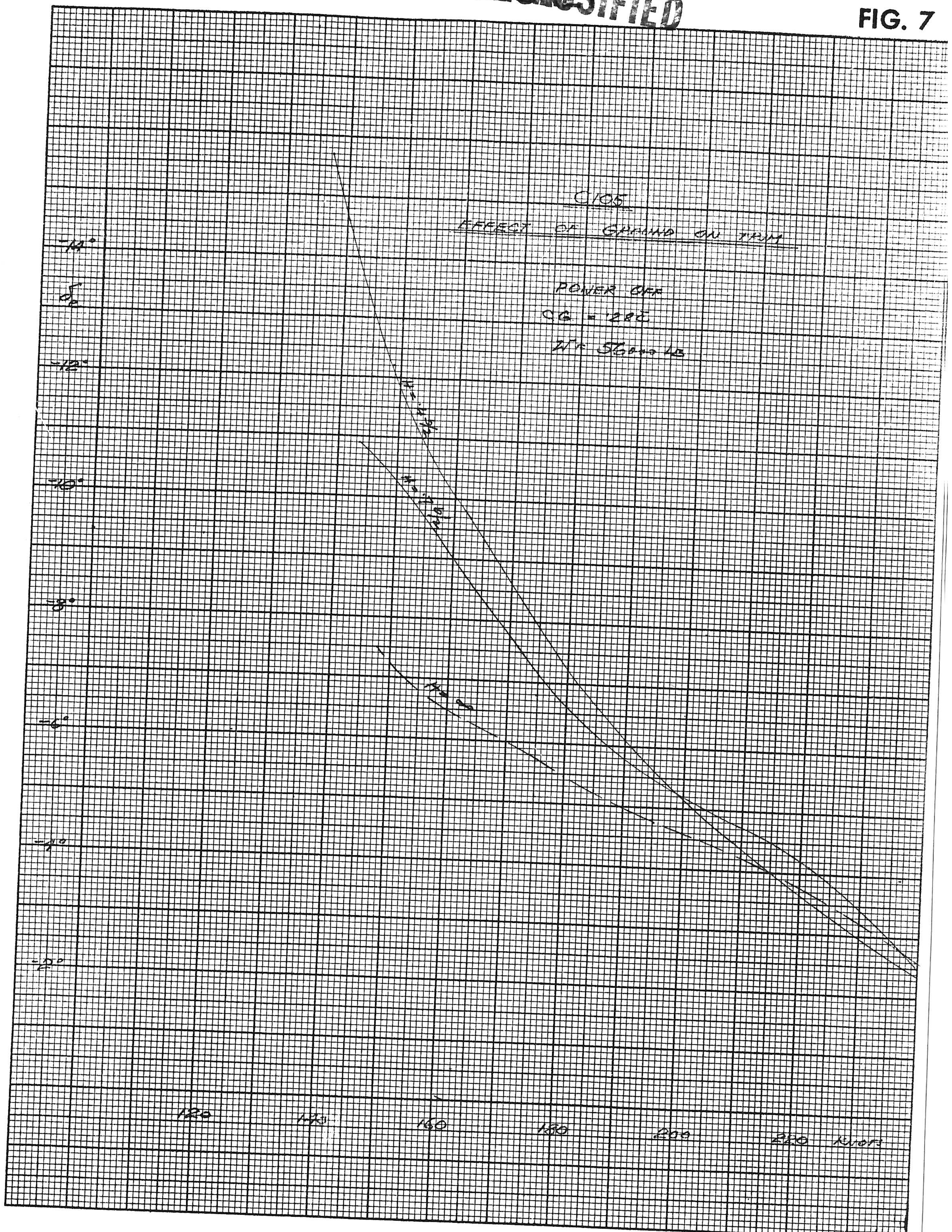
ELASTIC A/C ; POWER ON ; W=47,000 lb ; CG AT 0·31 c̄
SYMMETRIC AILERON DEFLECTION (δ_a=-4°) AT 50,000 AND 60,000'



UNCLASSIFIED

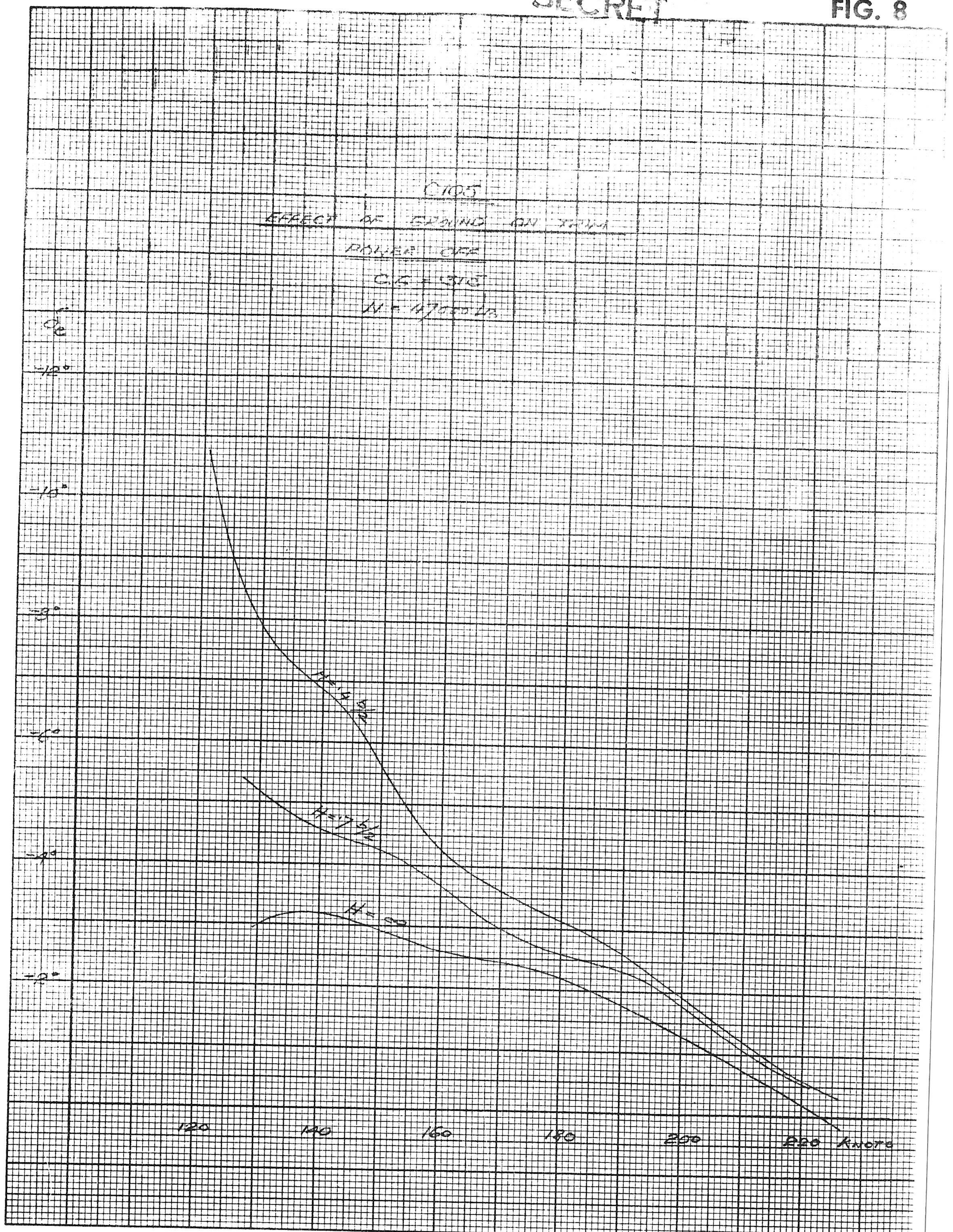
SECRET

FIG. 7



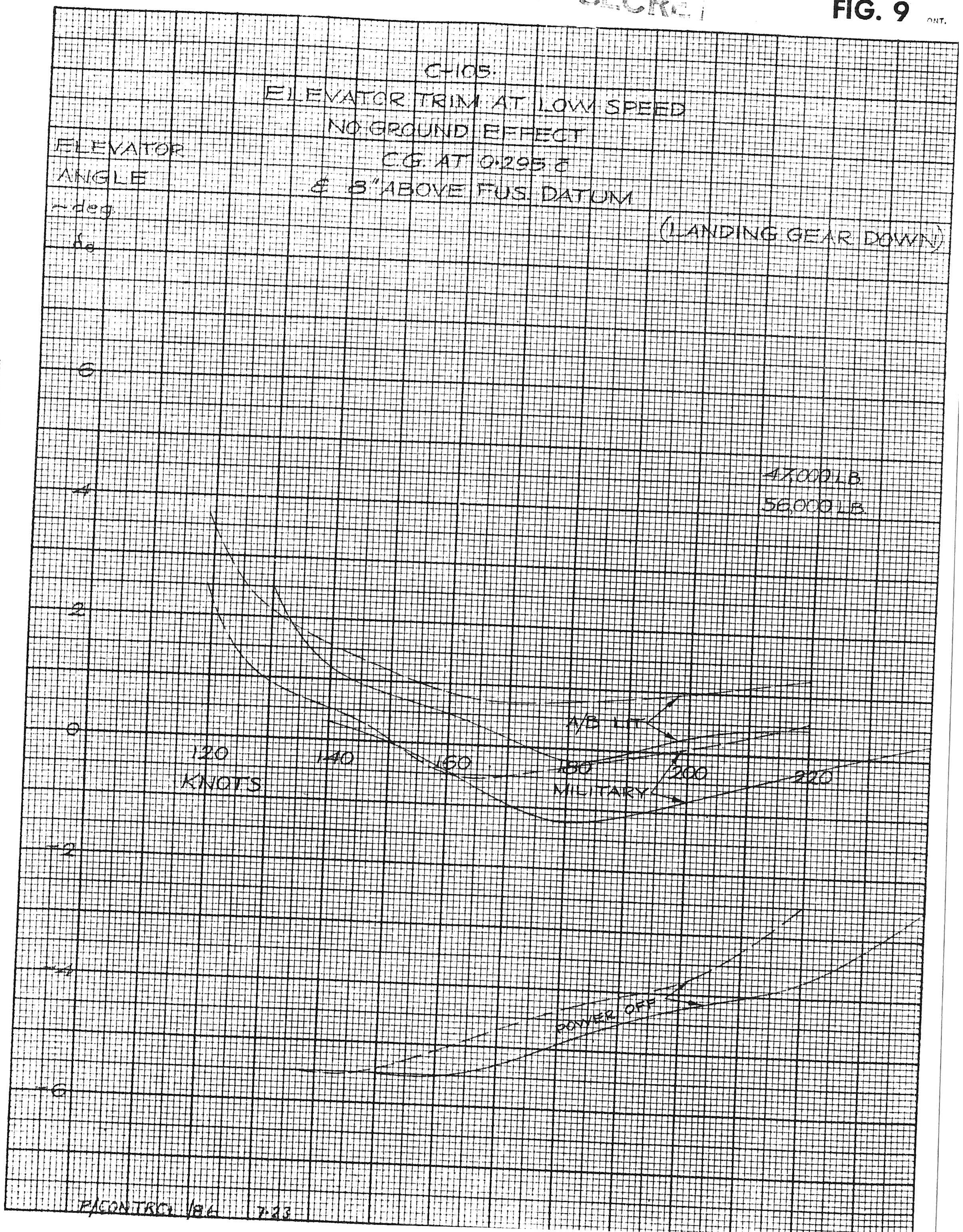
SECRET

FIG. 8


C105
EFFECT OF GROUND ON TRIM
POWER OFF
W = 47000 LB
-12°
-10°
-8°
-6°
-4°
-2°
120
140
160
180
200
220 KNOTS

SECRET

FIG. 9



G9-12
10 X 10 TO THE ½ INCH
MADE IN CANADA

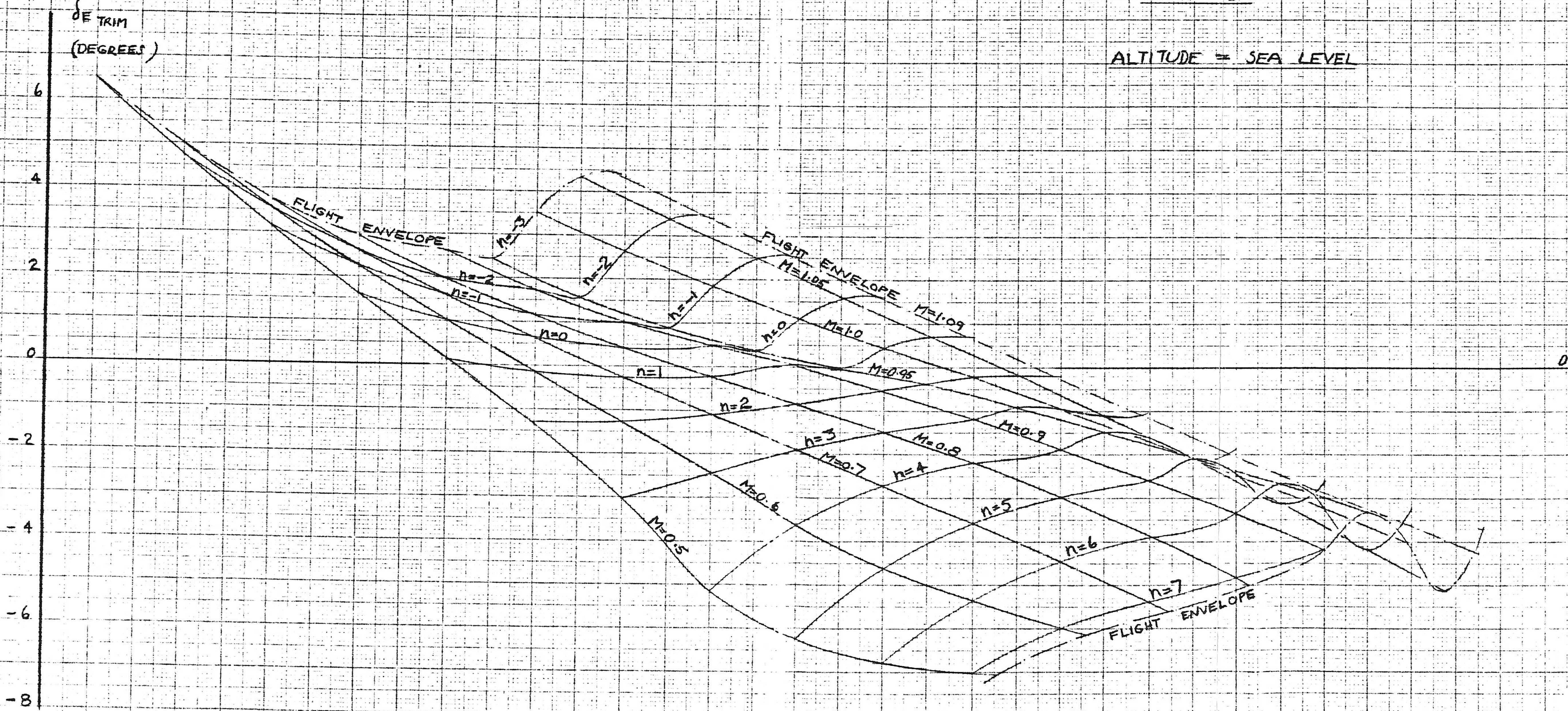
C-105

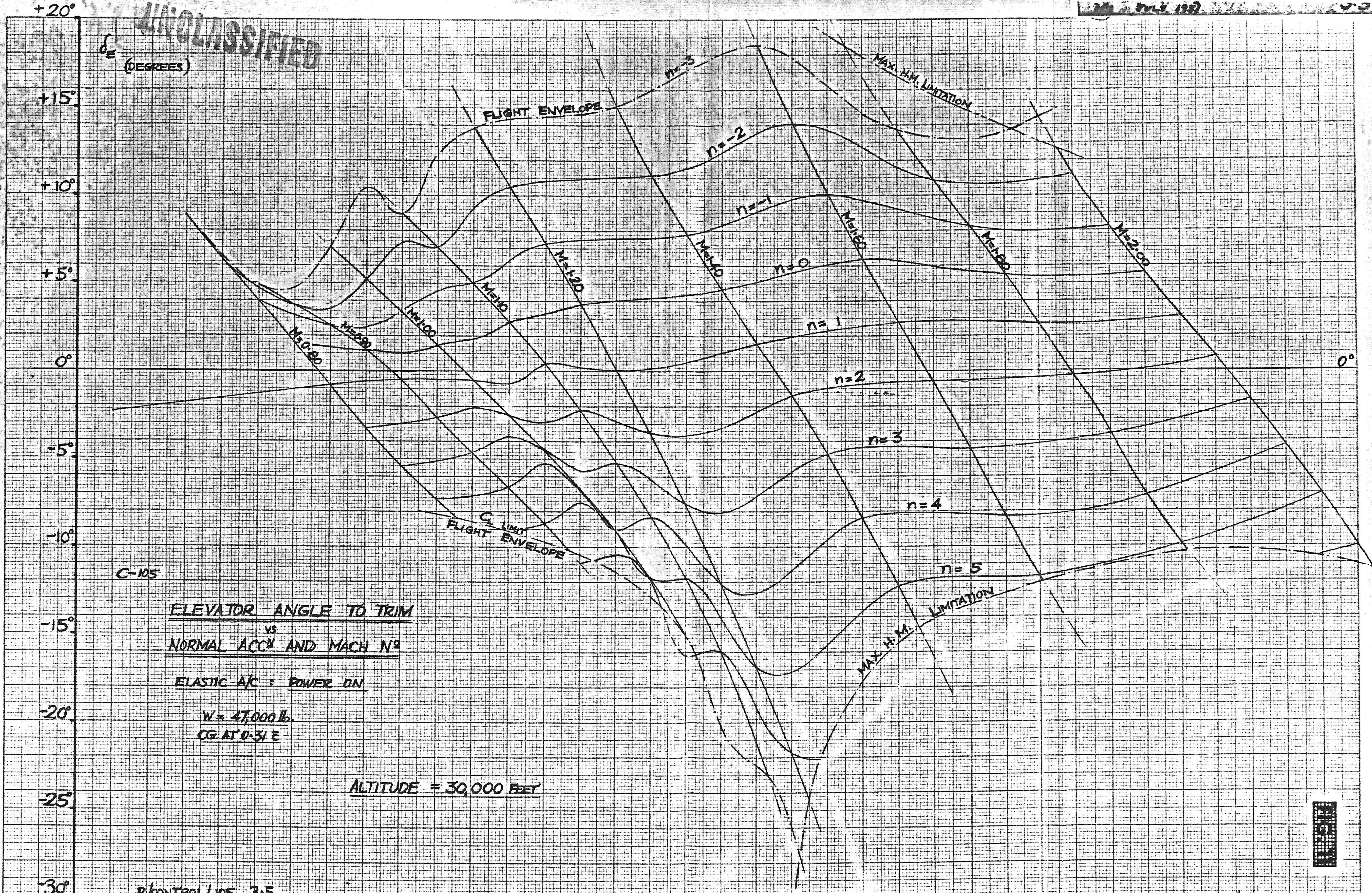
ELEVATOR ANGLE TO TRIM
vs
NORMAL ACCᴺ AND MACH Nᴼ

ELASTIC A/C : POWER ON

W = 47,000 lb
CG AT 0.31 $\bar{c}$

ALTITUDE = SEA LEVEL




UNCLASSIFIED
δ_E (DEGREES)
+20°
+15°
+10°
+5°
0°
-5°
-10°
-15°
-20°
-25°
-30°
0°
FLIGHT ENVELOPE
MAX. H.M. LIMITATION
n=-3
n=-2
n=-1
n=0
n=1
n=2
n=3
n=4
n=5
M=0.80
M=0.90
M=1.00
M=1.10
M=1.20
M=1.40
M=1.60
M=1.80
M=2.00
C_L LIMIT
FLIGHT ENVELOPE
MAX. H.M. LIMITATION
C-105
ELEVATOR ANGLE TO TRIM
VS
NORMAL ACC^{N} AND MACH N^{o}
ELASTIC A/C : POWER ON
W = 47,000 lb.
CG AT 0.31 $\bar{c}$
ALTITUDE = 30,000 FEET
P/CONTROL/105 3.5

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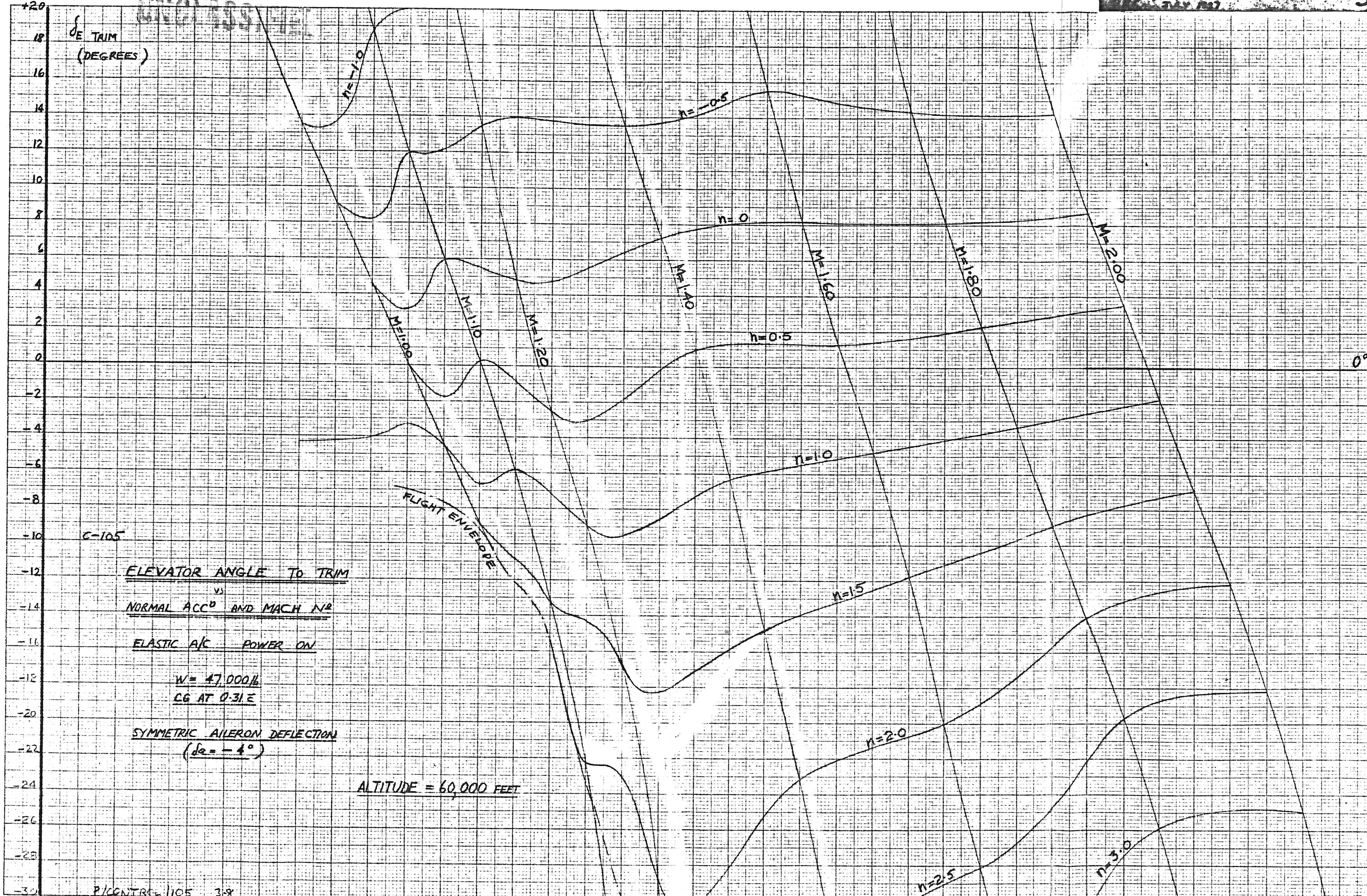
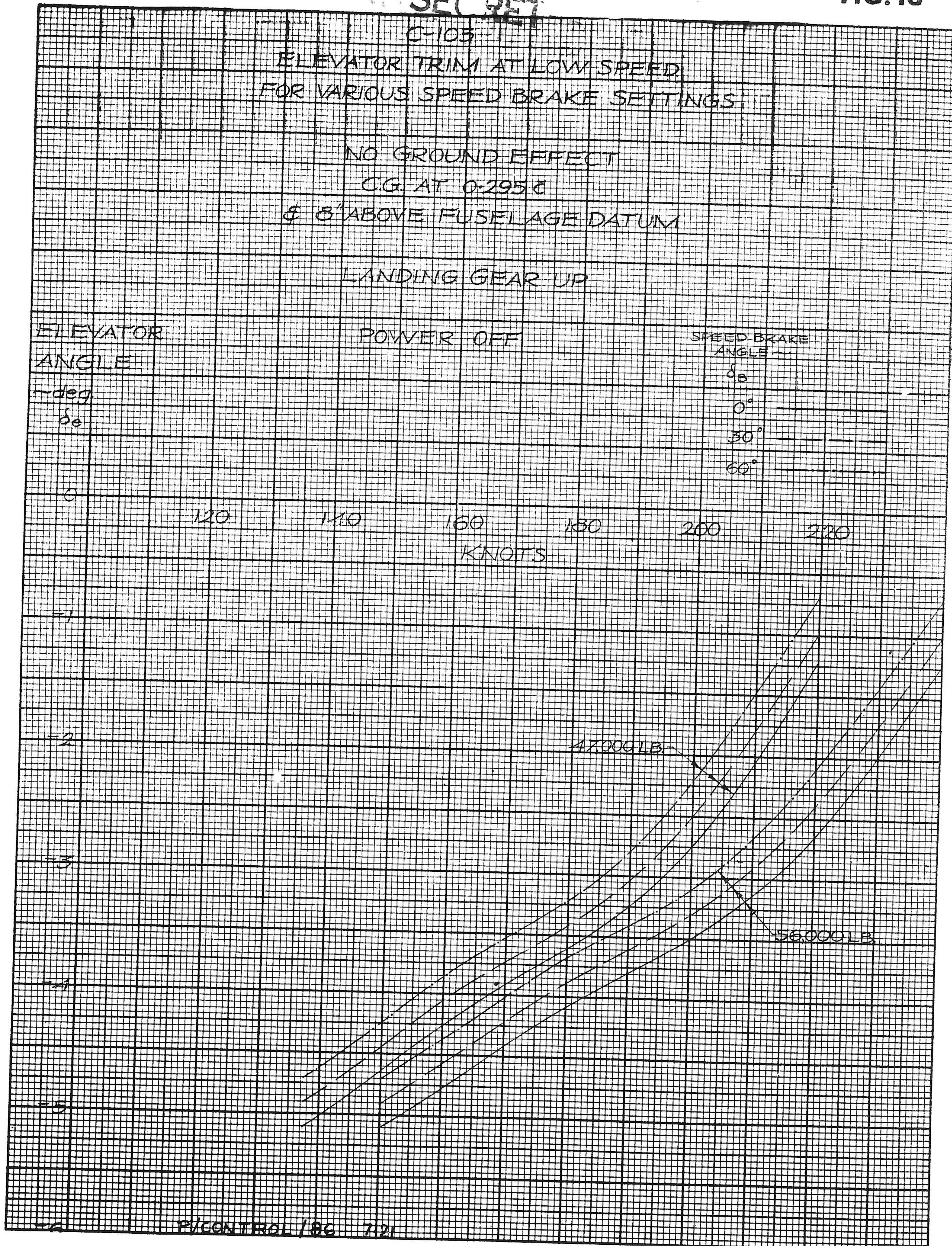
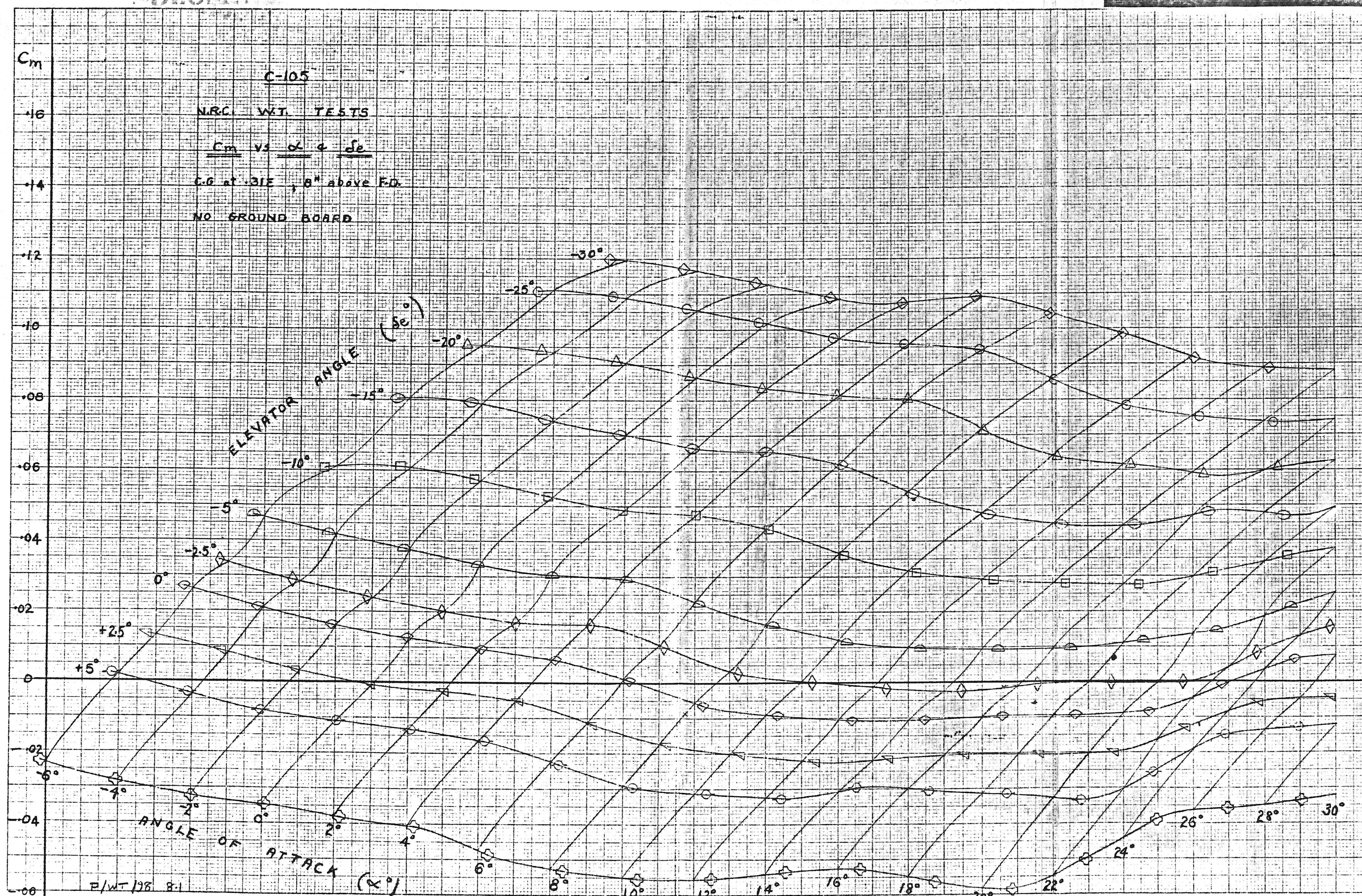


FIG. 12

SECRET

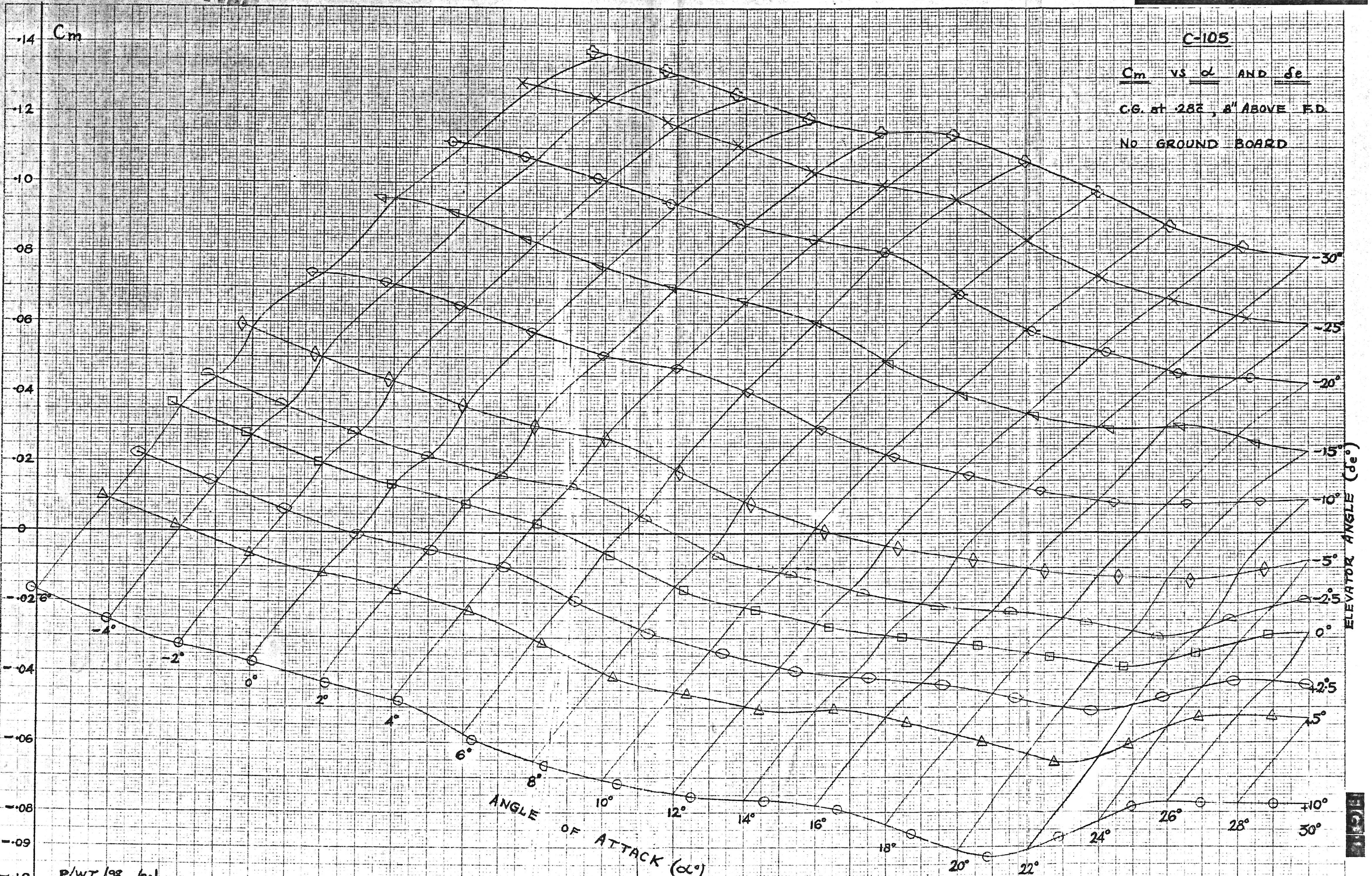
FIG. 13




SECRET
C-105
N.R.C. W.T. TESTS
Cm vs α & δe
C.G at .31C, 8" above F.D.
NO GROUND BOARD
Cm
ELEVATOR ANGLE (δe°)
ANGLE OF ATTACK (α°)
-30°
-25°
-20°
-15°
-10°
-5°
-2.5°
0°
+2.5°
+5°
.16
.14
.12
.10
.08
.06
.04
.02
0
-.02
-.04
-.06
-6°
-4°
-2°
0°
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
F/WT 198 8.1
10 X 10 TO THE CM. 359-14L
KEUFFEL & ESSER CO.
FIG. 17

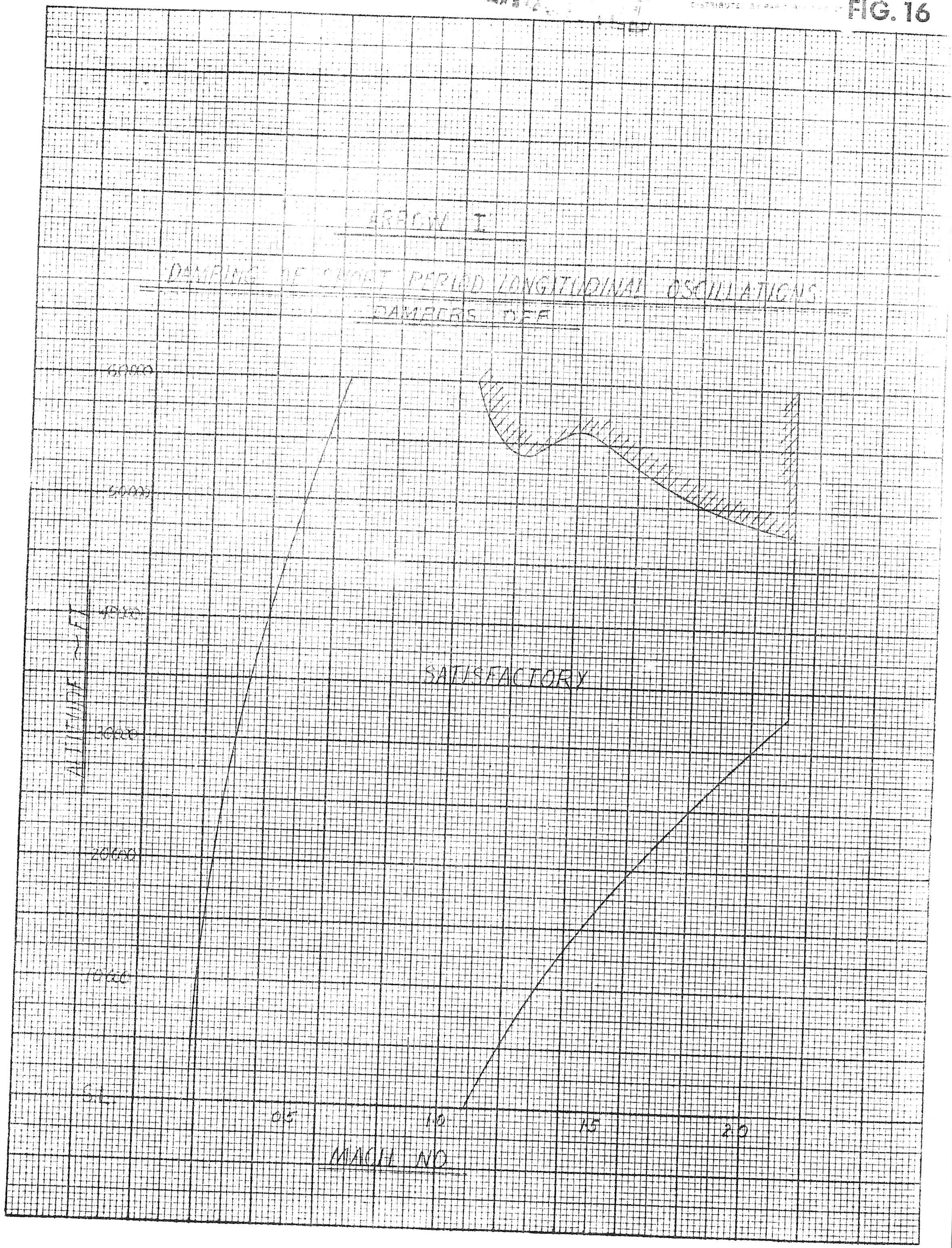
UNCLASSIFIED

[redacted]



SECRET

FIG. 16

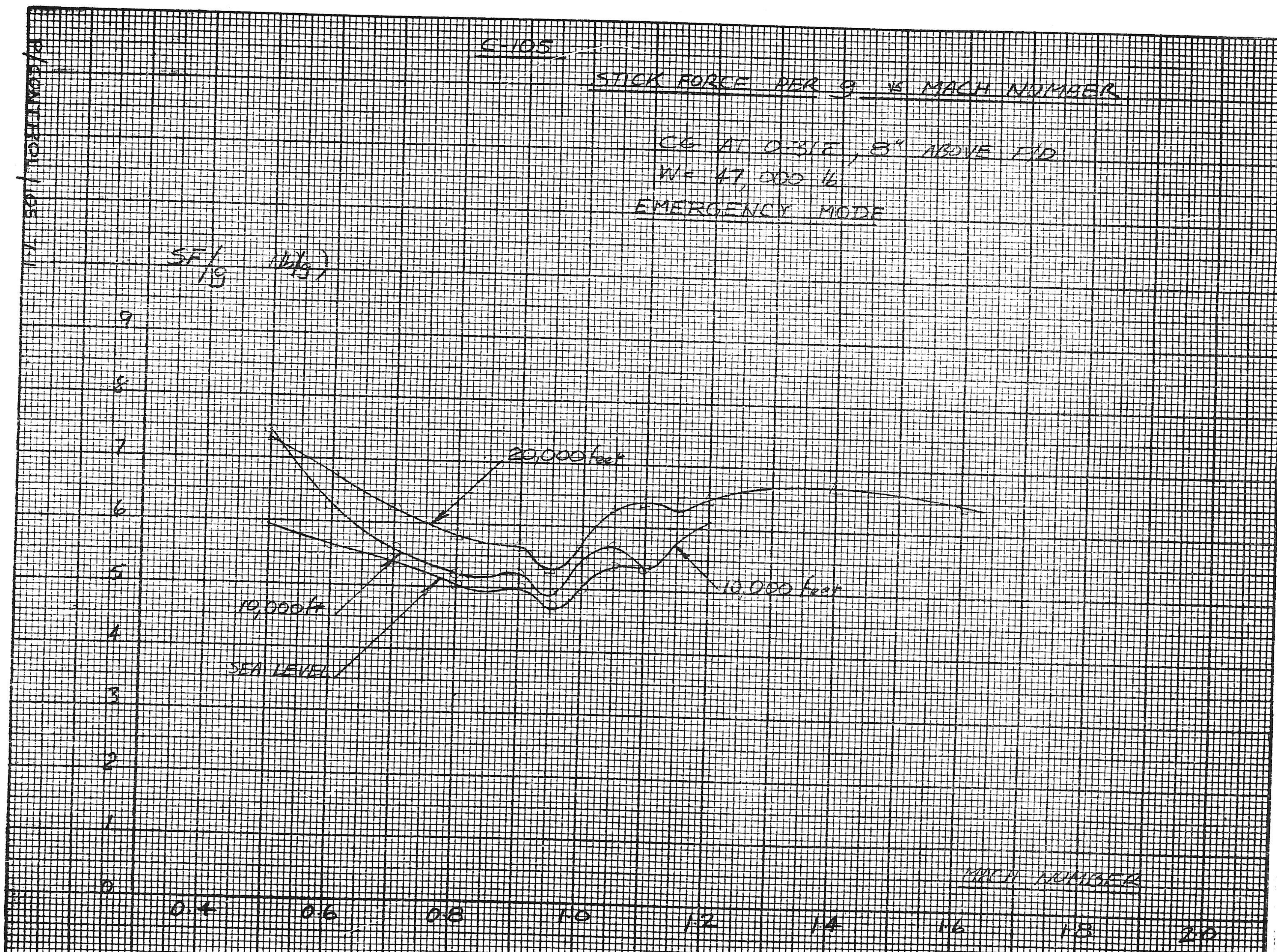


SECRET

FIG. 17

CANADIAN CHARTS AND SUPPLIES, LTD.
OAKVILLE, ONT.

G7-12
10 X 10 TO THE ½ INCH
MADE IN CANADA



UNCLASSIFIED

FIG. 18

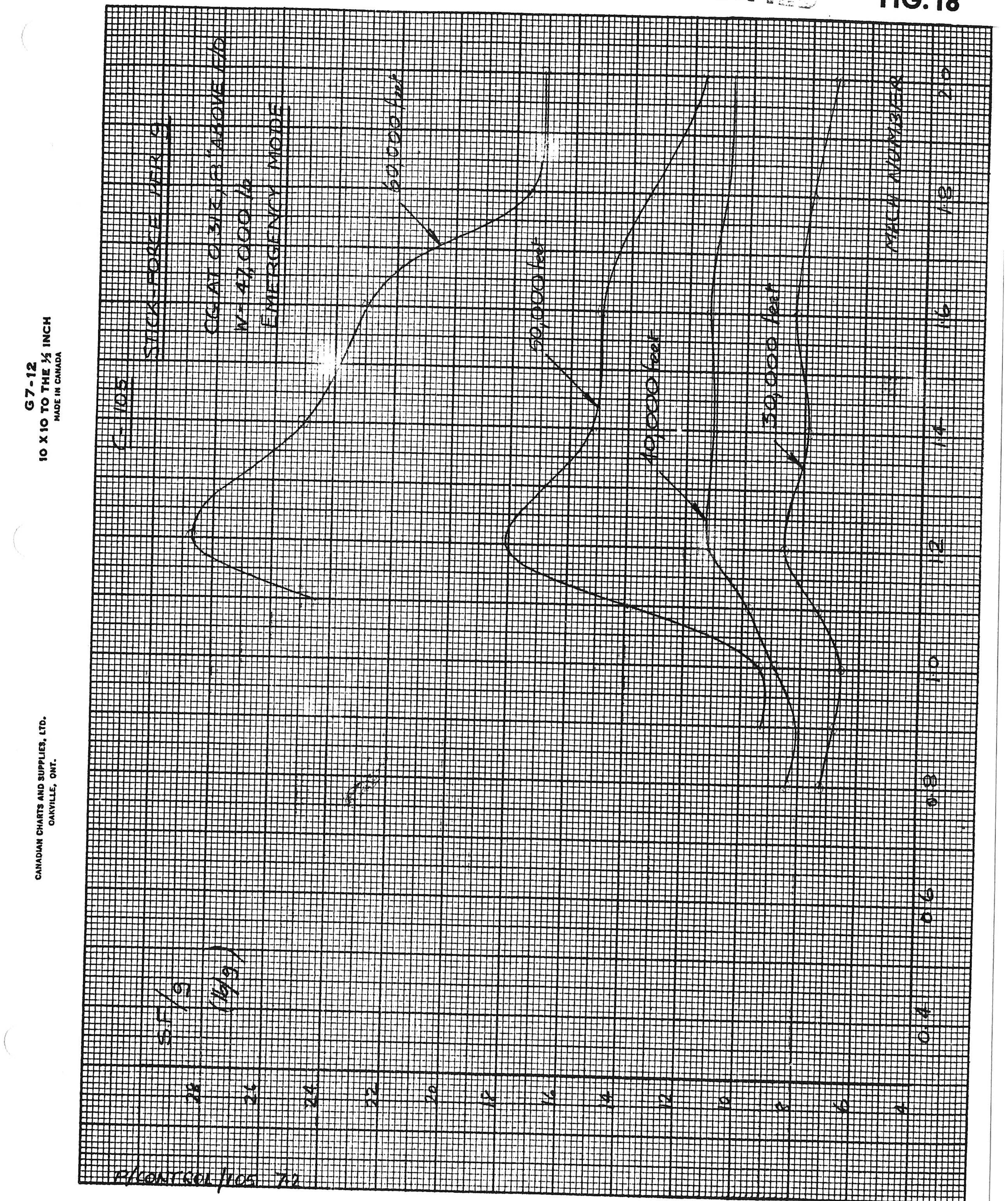


FIG. 19

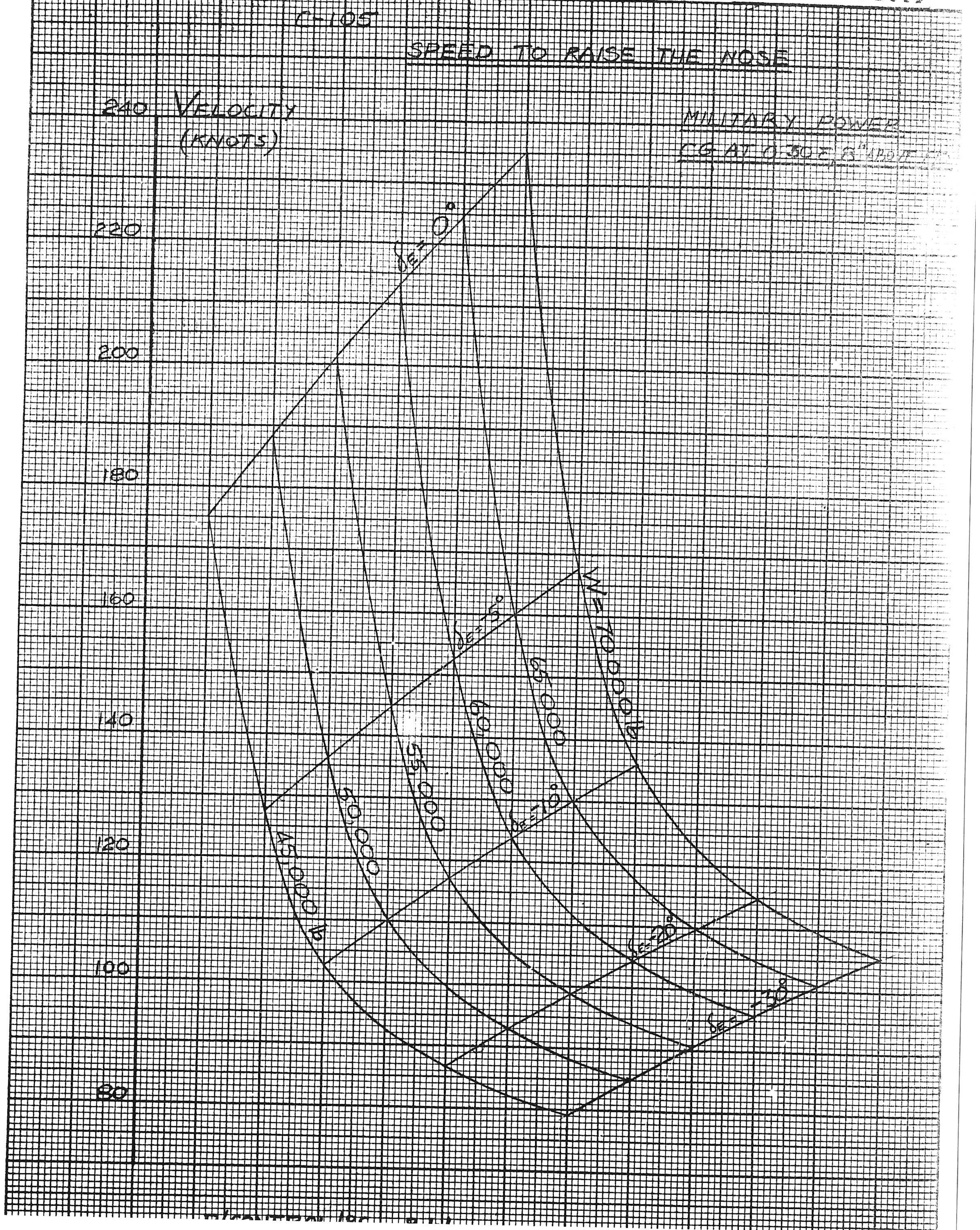
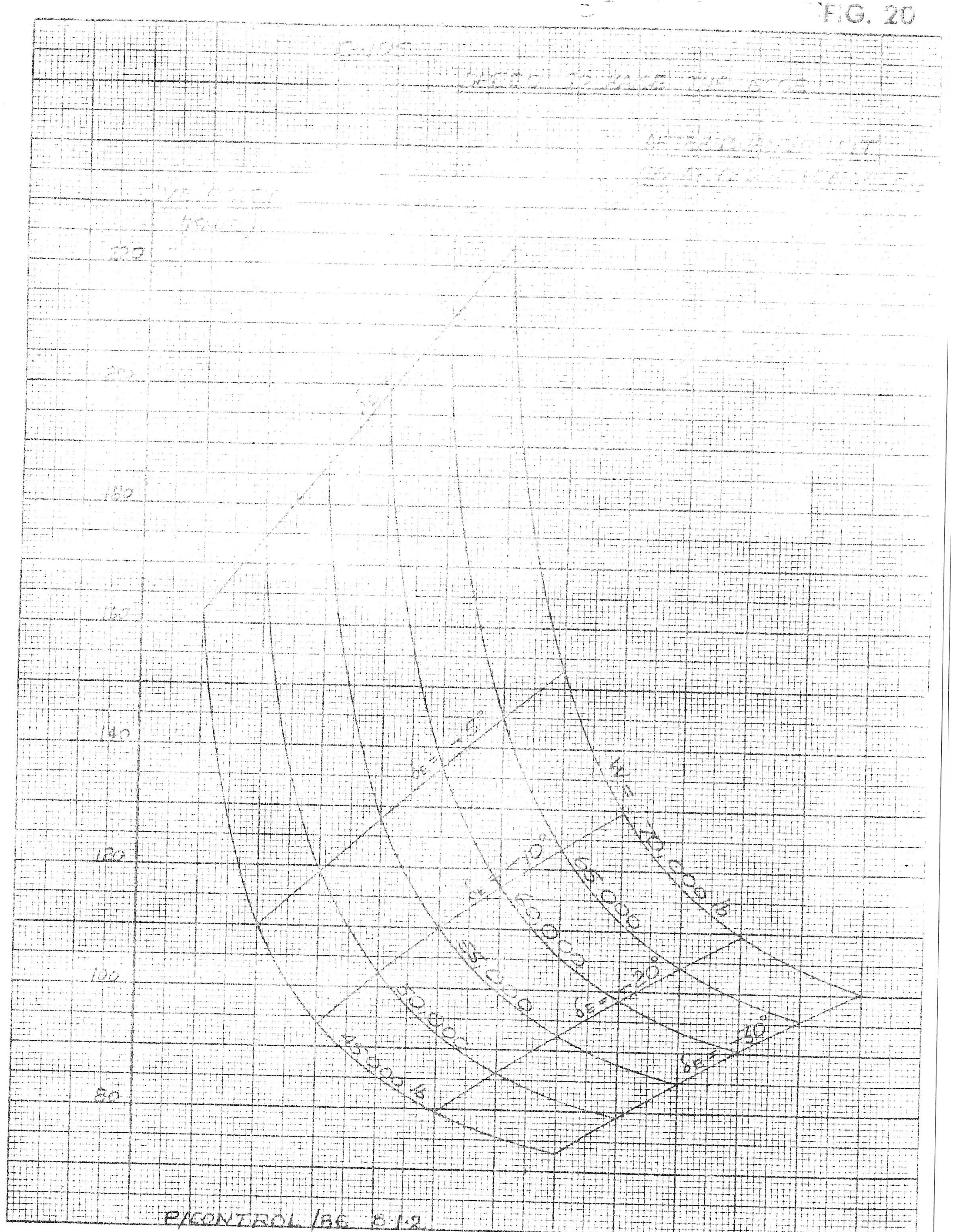

C-105
SPEED TO RAISE THE NOSE
VELOCITY
(KNOTS)
MILITARY POWER
240
220
200
180
160
140
120
100
80
$\delta_E = 0°$
$\delta_E = -5°$
$\delta_E = -10°$
$\delta_E = -20°$
$\delta_E = -30°$
W = 70,000 lb
65,000
60,000
55,000
50,000
45,000 lb

FIG. 20



220
200
180
160
140
120
100
80
W = 70,000 lb
65,000
60,000
55,000
50,000
45,000 lb
δe = -10°
δe = -20°
δe = -30°
P/CONTROL/BC 812.

10 X 10 TO THE ½ INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

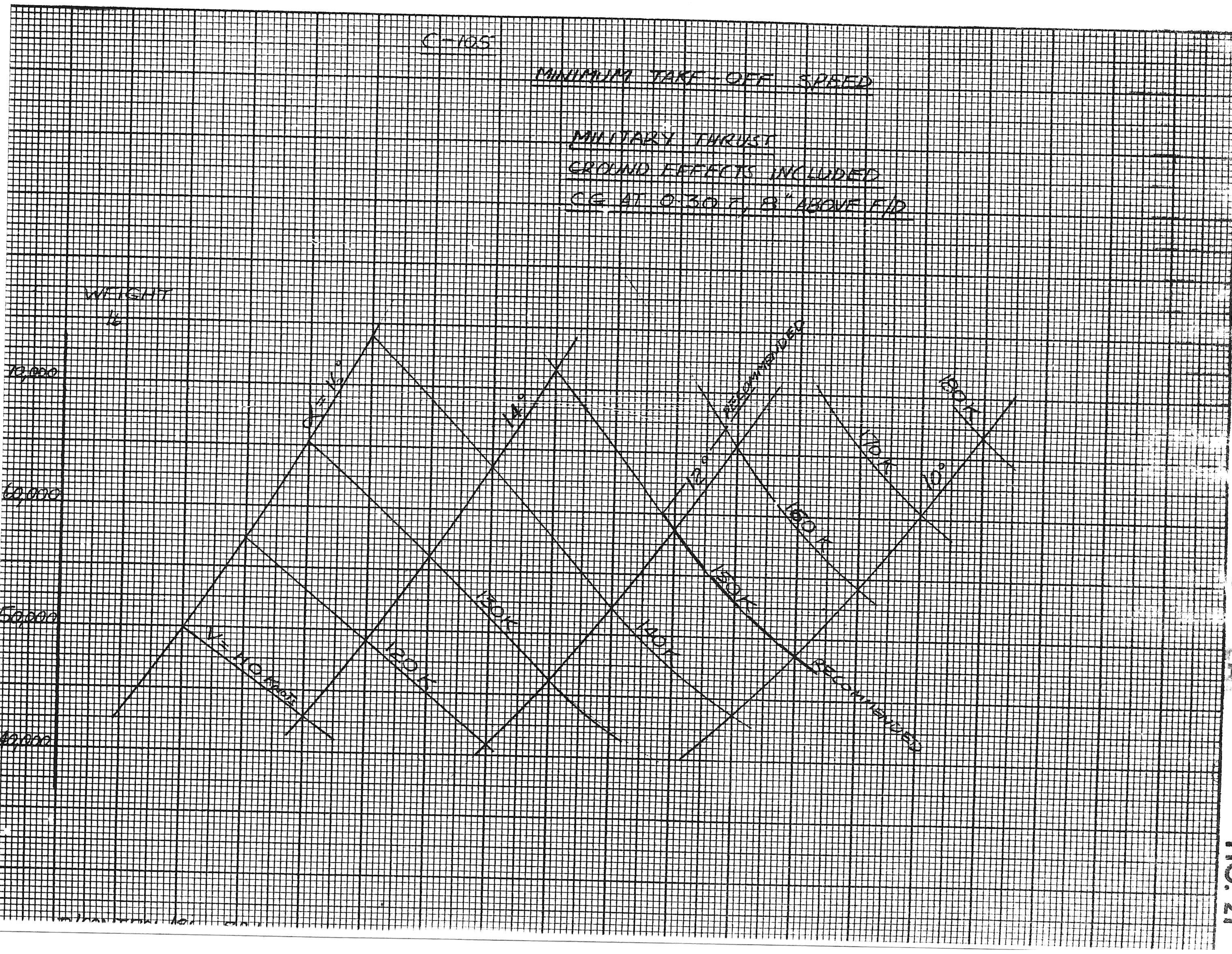
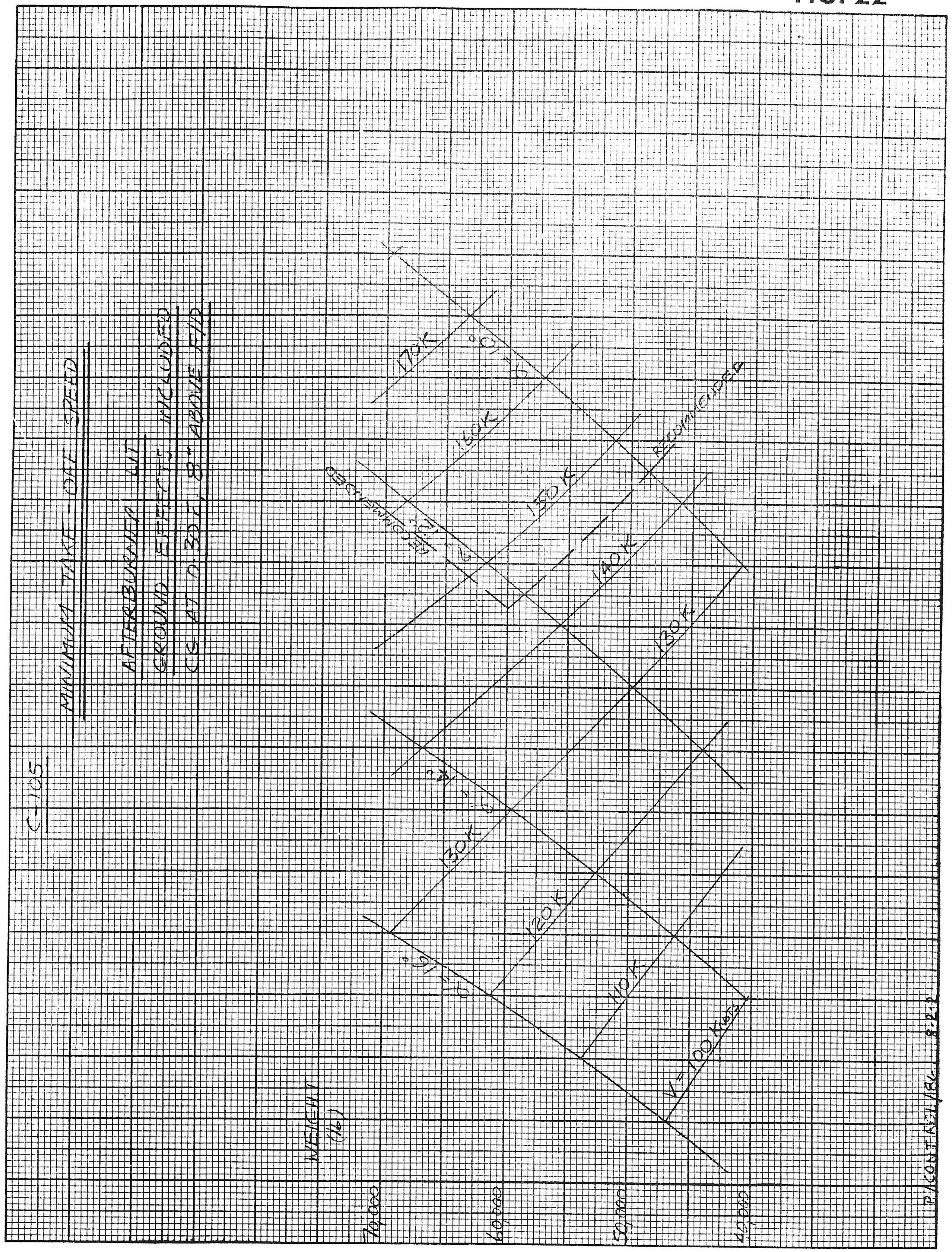


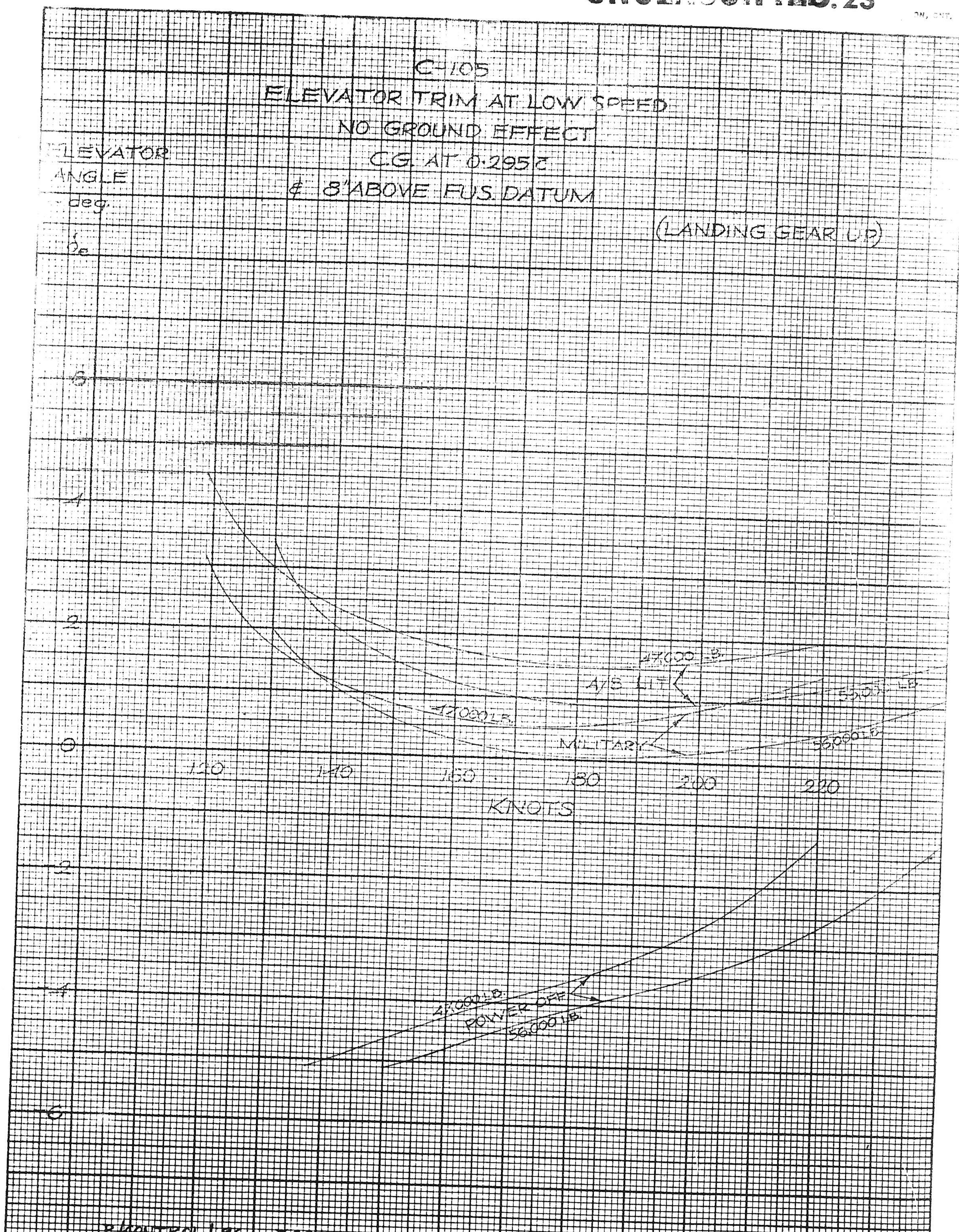
FIG. 21

FIG. 22



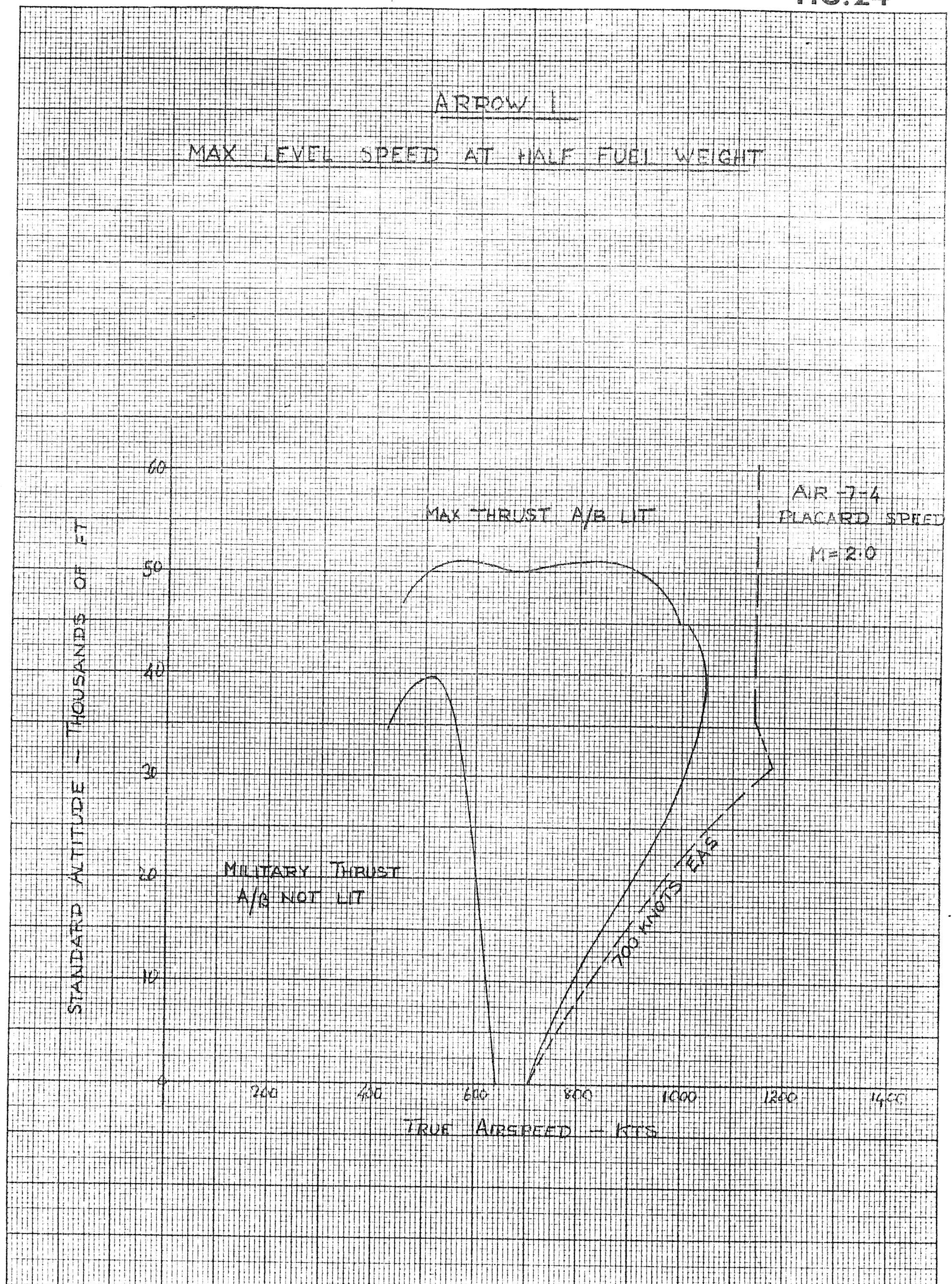
C-105
MINIMUM TAKE OFF SPEED
AFTERBURNER LIT
GROUND EFFECT INCLUDED
WEIGHT
(lb)
70,000
60,000
50,000
40,000
V = 100 KNOTS
110 K
120 K
130 K
130 K
140 K
150 K
160 K
170 K
RECOMMENDED
RECOMMENDED

FIG. 23



P/CONTROL/86 7.23

FIG.24



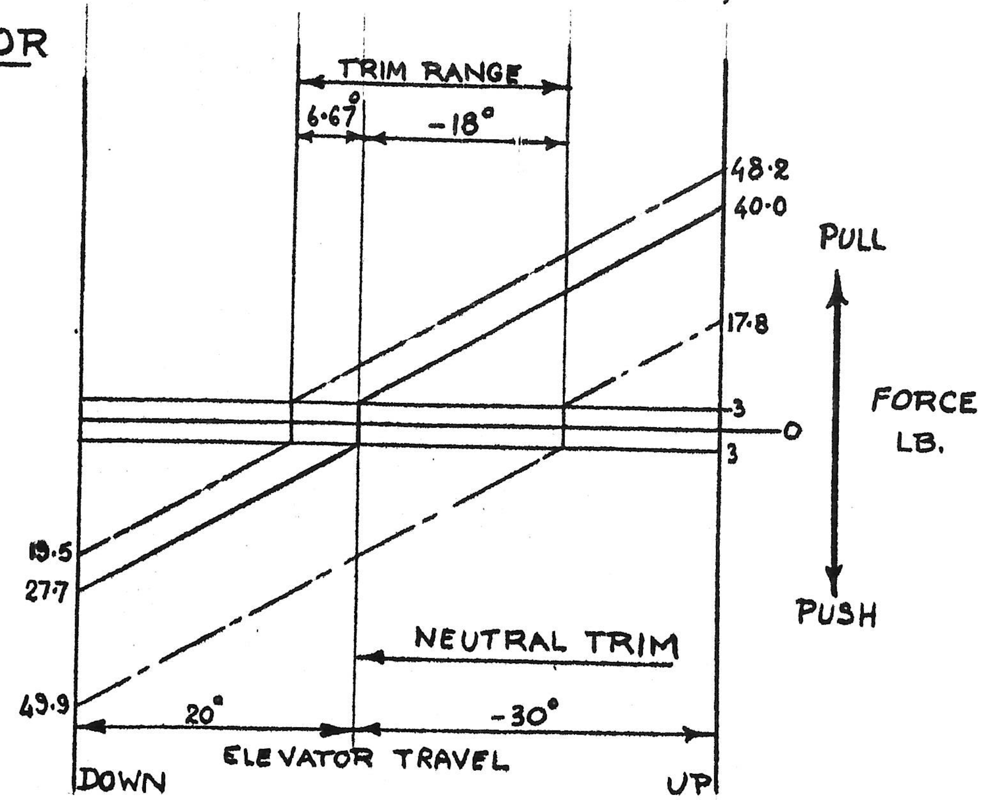
10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

SECRET ARROW I (EMERGENCY MODE) FIG. 25

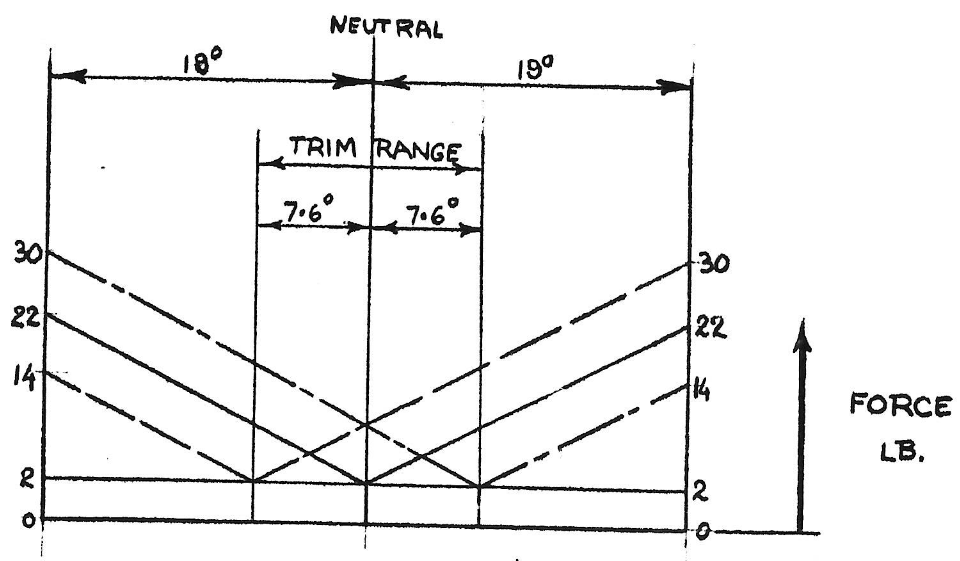
SPRING FEEL FORCES - BREAKOUT - TRIM RANGES.

(DIAGRAMS NOT TO SCALE)

(a) ELEVATOR



(b) AILERON



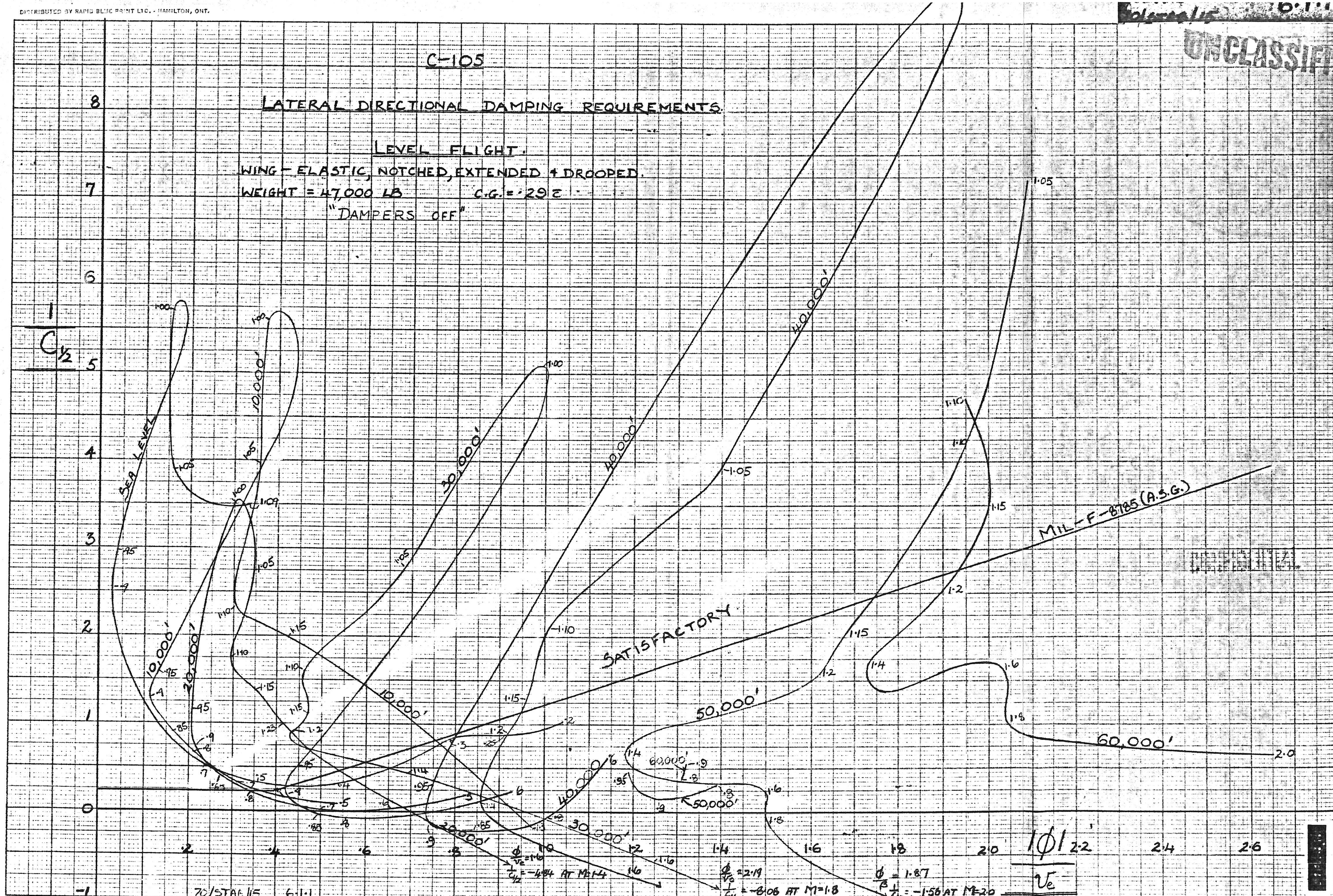
(c) RUDDER:

SPRING RATE VARIES WITH DYNAMIC HEAD

BREAK-OUT AT ZERO DYNAMIC HEAD = 14 LB.

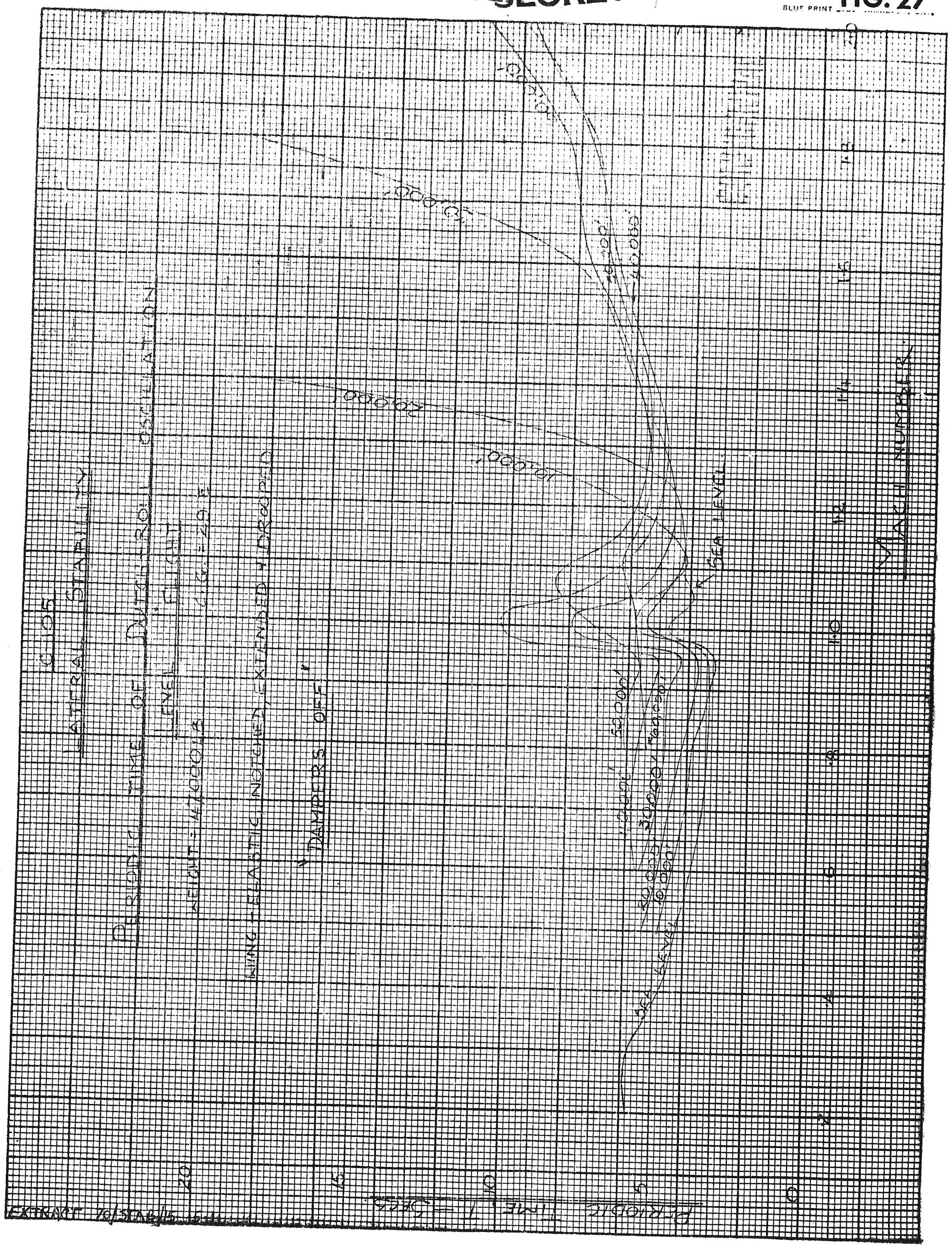
TRIM RANGE ± 20°

TOTAL RANGE ± 30°


C-105
LATERAL DIRECTIONAL DAMPING REQUIREMENTS.
LEVEL FLIGHT.
WING - ELASTIC, NOTCHED, EXTENDED & DROOPED.
WEIGHT = 47,000 LB
C.G. = ·29 c̄
"DAMPERS OFF"
1 / C½
|φ| / Ve
SEA LEVEL
10,000'
20,000'
30,000'
40,000'
50,000'
60,000'
MIL-F-8785 (A.S.G.)
SATISFACTORY
φ/Ve = 1·6
1/C½ = -4·84 AT M=1·4
φ/Ve = 2·19
1/C½ = -8·08 AT M=1·8
φ/β = 1·87
1/C½ = -1·56 AT M=2·0
70/STAB/15 6.1.1

UNCLASSIFIED SECRET

FIG. 27



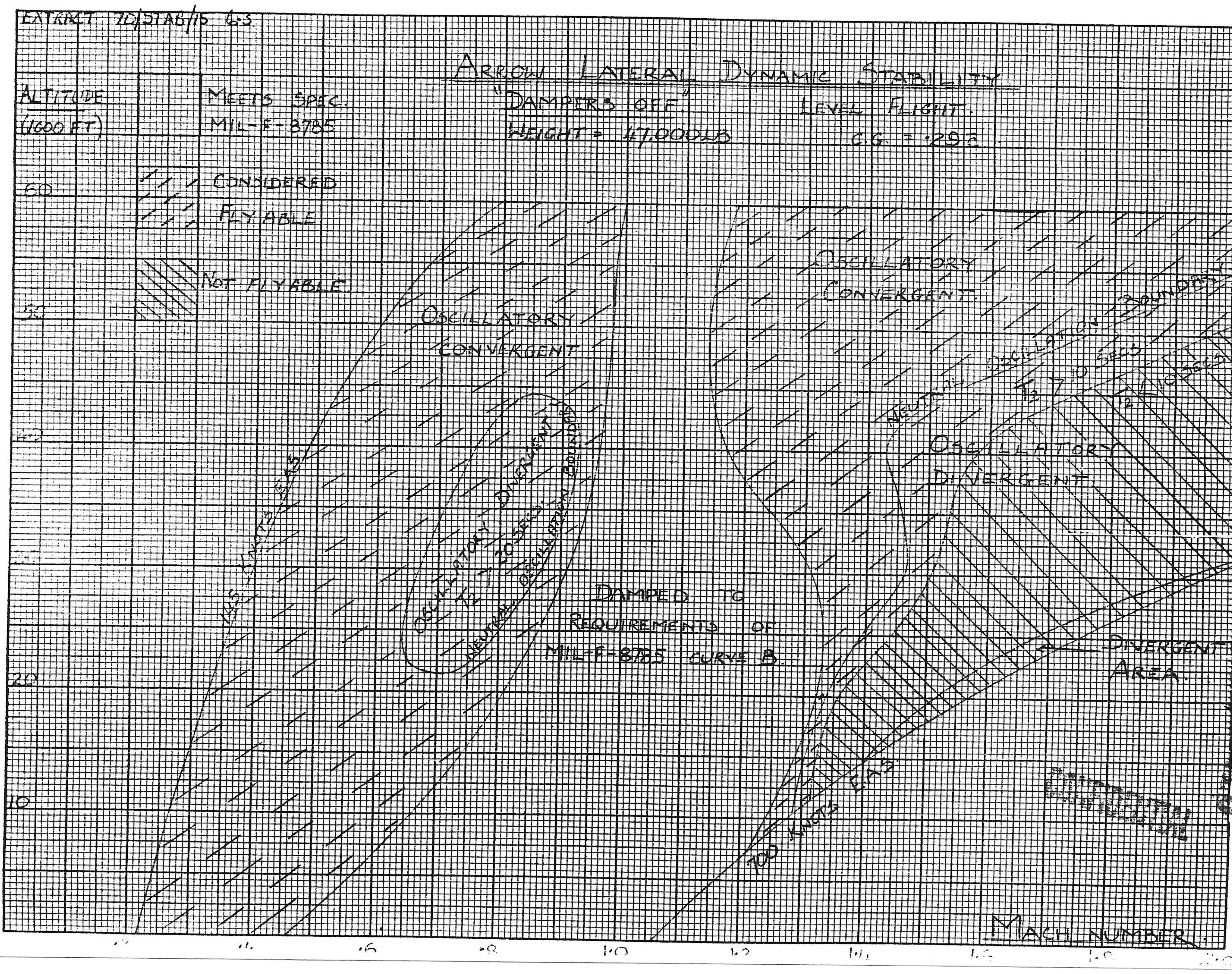
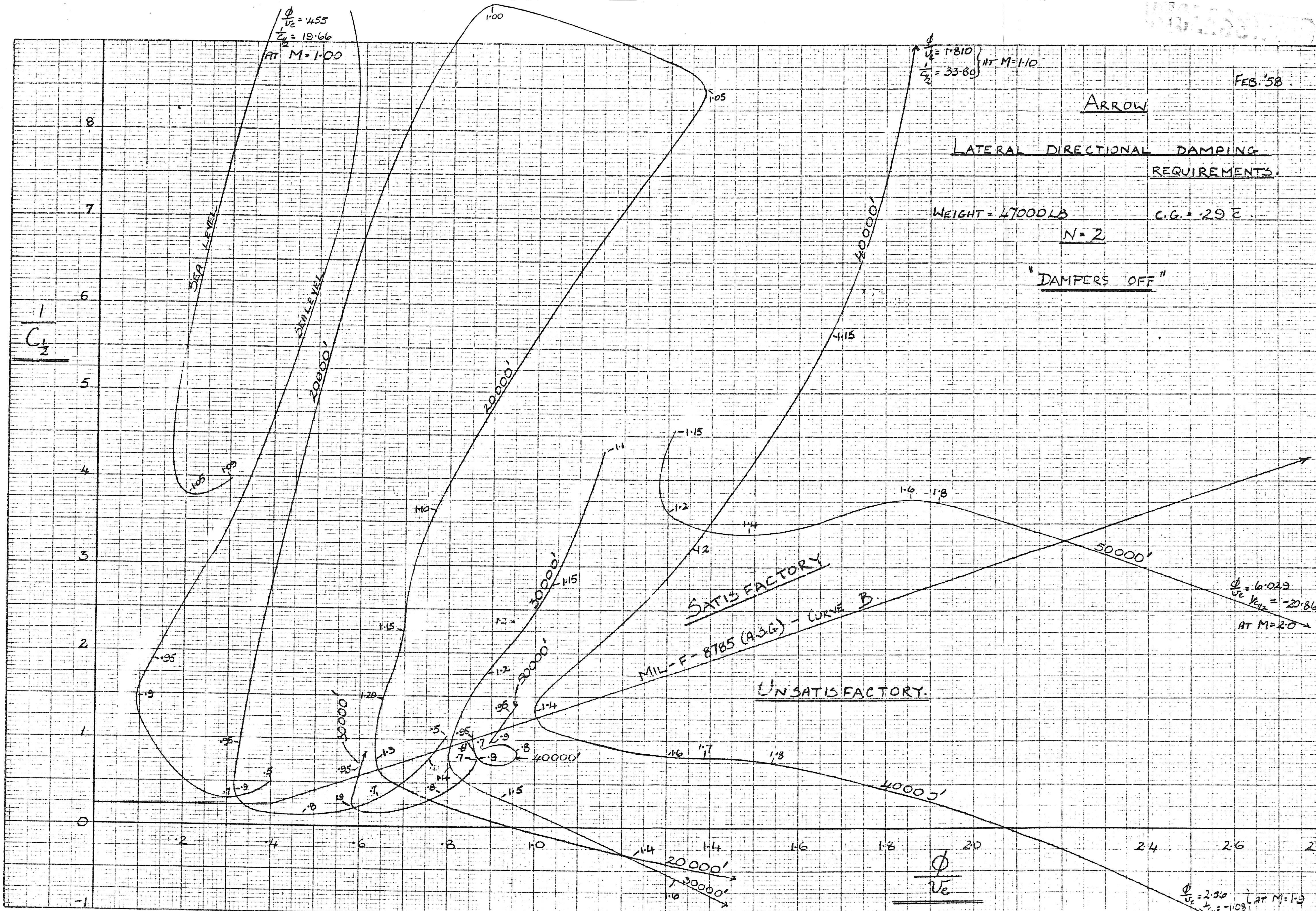

EXTRACT 7D/STAB/15 6-3
ARROW LATERAL DYNAMIC STABILITY
"DAMPERS OFF"
WEIGHT = 47,000 LB
LEVEL FLIGHT
C.G. = .29 c̄
ALTITUDE
(1000 FT)
MEETS SPEC. MIL-F-8785
CONSIDERED FLYABLE
NOT FLYABLE
60
50
20
10
OSCILLATORY CONVERGENT
OSCILLATORY DIVERGENT
NEUTRAL OSCILLATION BOUNDARY
DAMPED TO REQUIREMENTS OF MIL-F-8785 CURVE B.
OSCILLATORY DIVERGENT
DIVERGENT AREA
100 KNOTS EAS
MACH NUMBER

FIG. 28



FEB. '58.
ARROW
LATERAL DIRECTIONAL DAMPING REQUIREMENTS.
WEIGHT = 47000 LB
C.G. = .29 C̄
N = 2
"DAMPERS OFF"
SATISFACTORY
UNSATISFACTORY.
MIL-F-8785 (ASG) - CURVE B.
SEA LEVEL
20000'
30000'
40000'
50000'
1/C½
φ/υc

176
Part 3

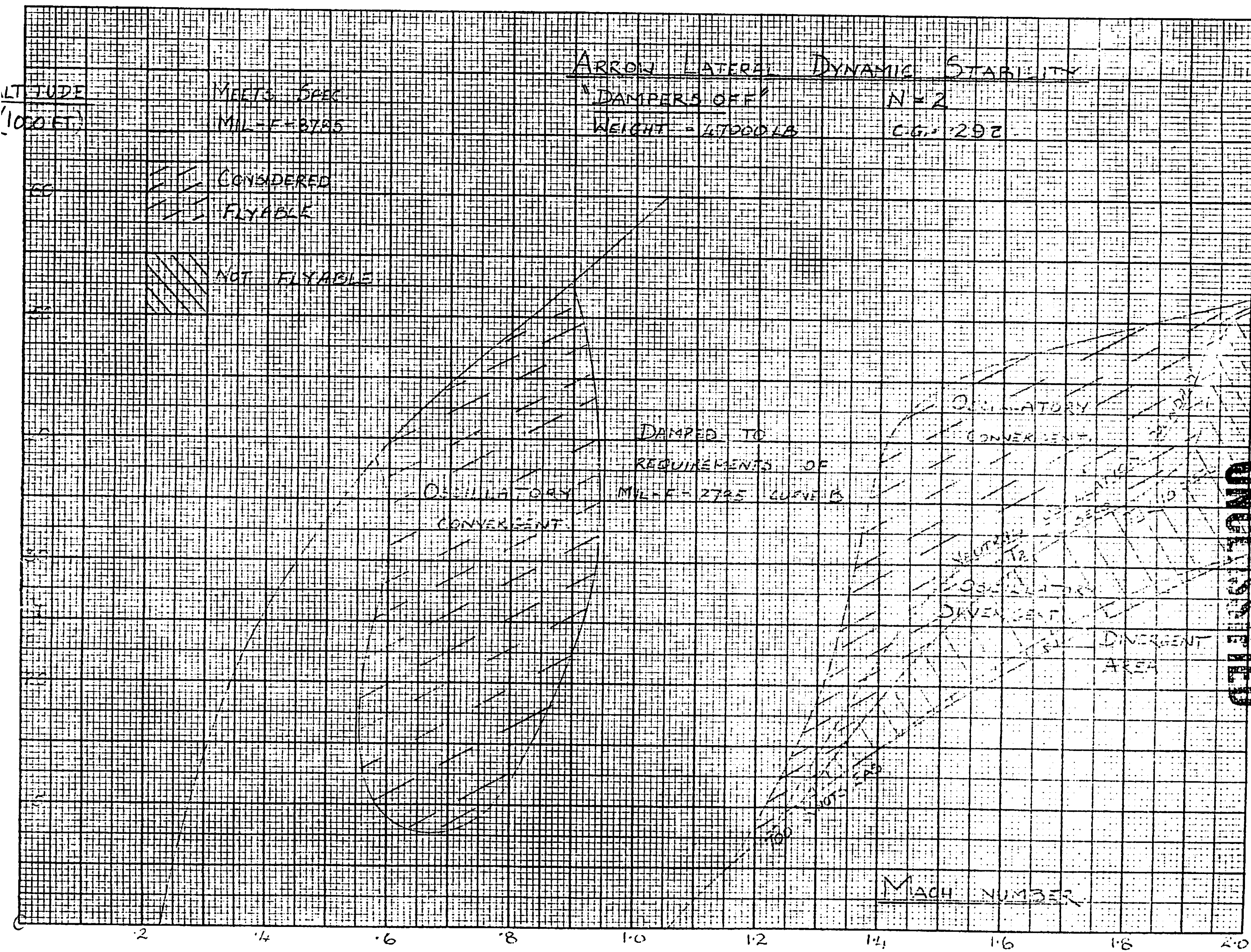
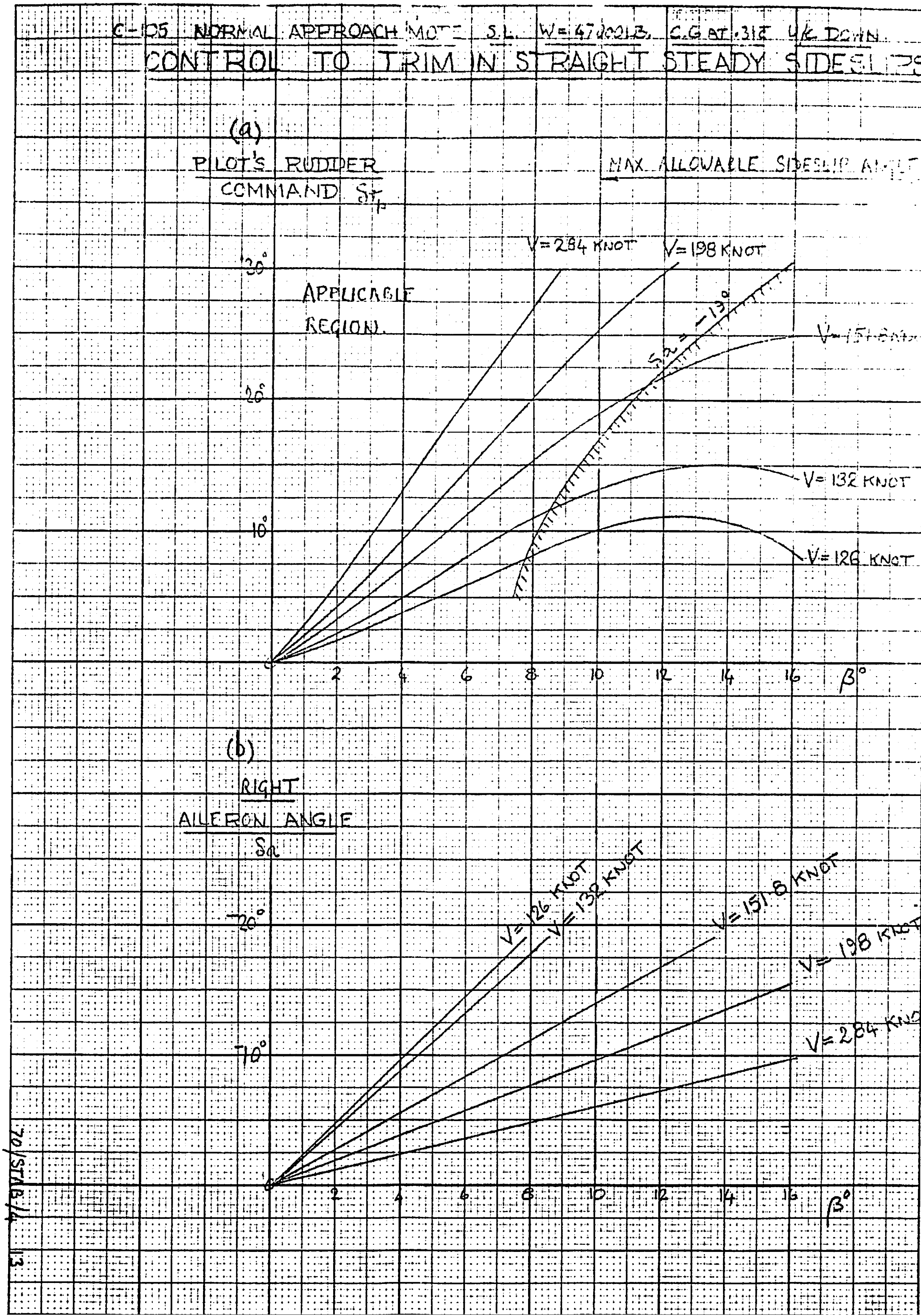


FIG. 30

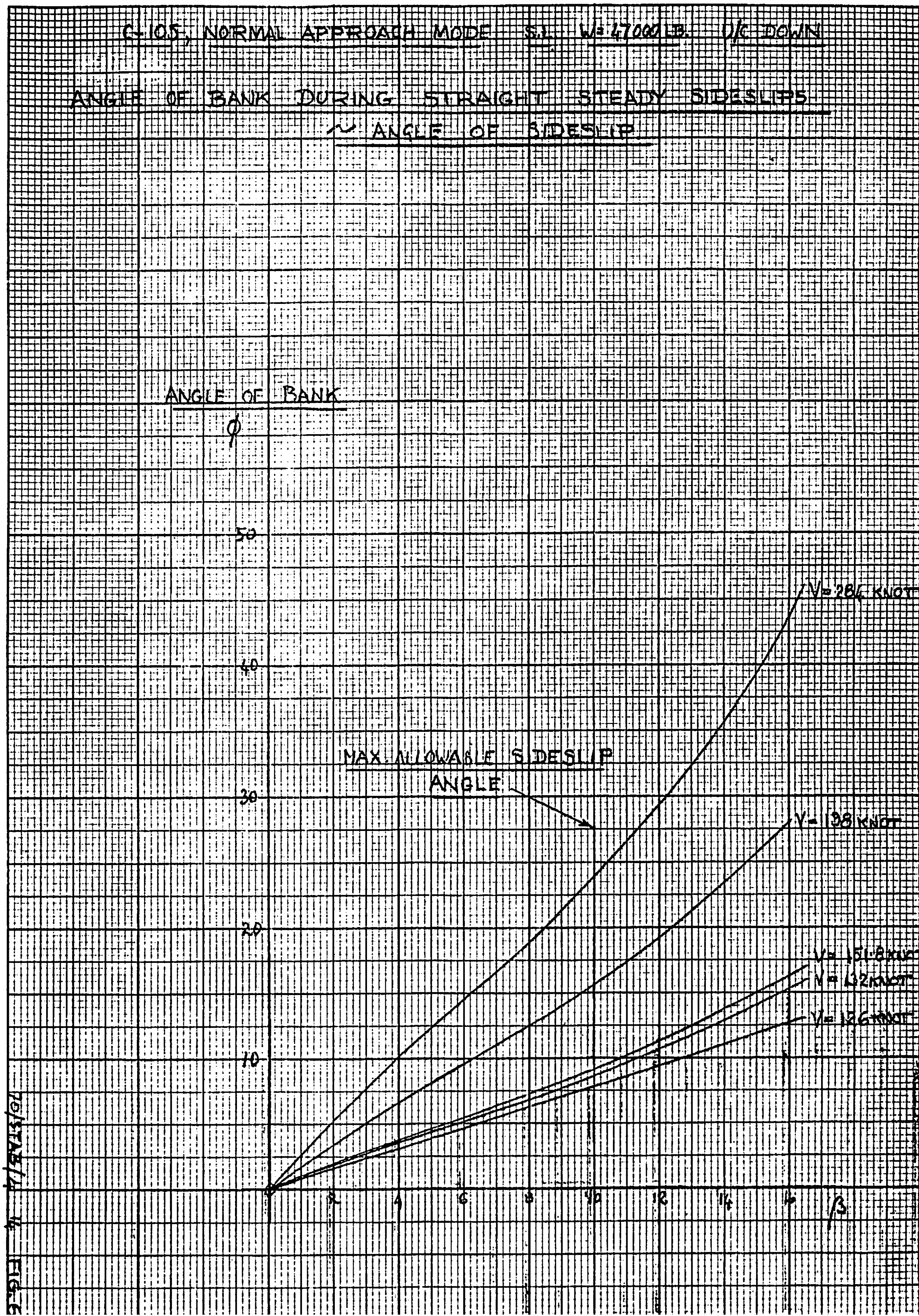
SECRET

FIG. 31



SECRET

FIG. 32



G9-12
10 X 10 TO THE ½ INCH
MADE IN CANADA

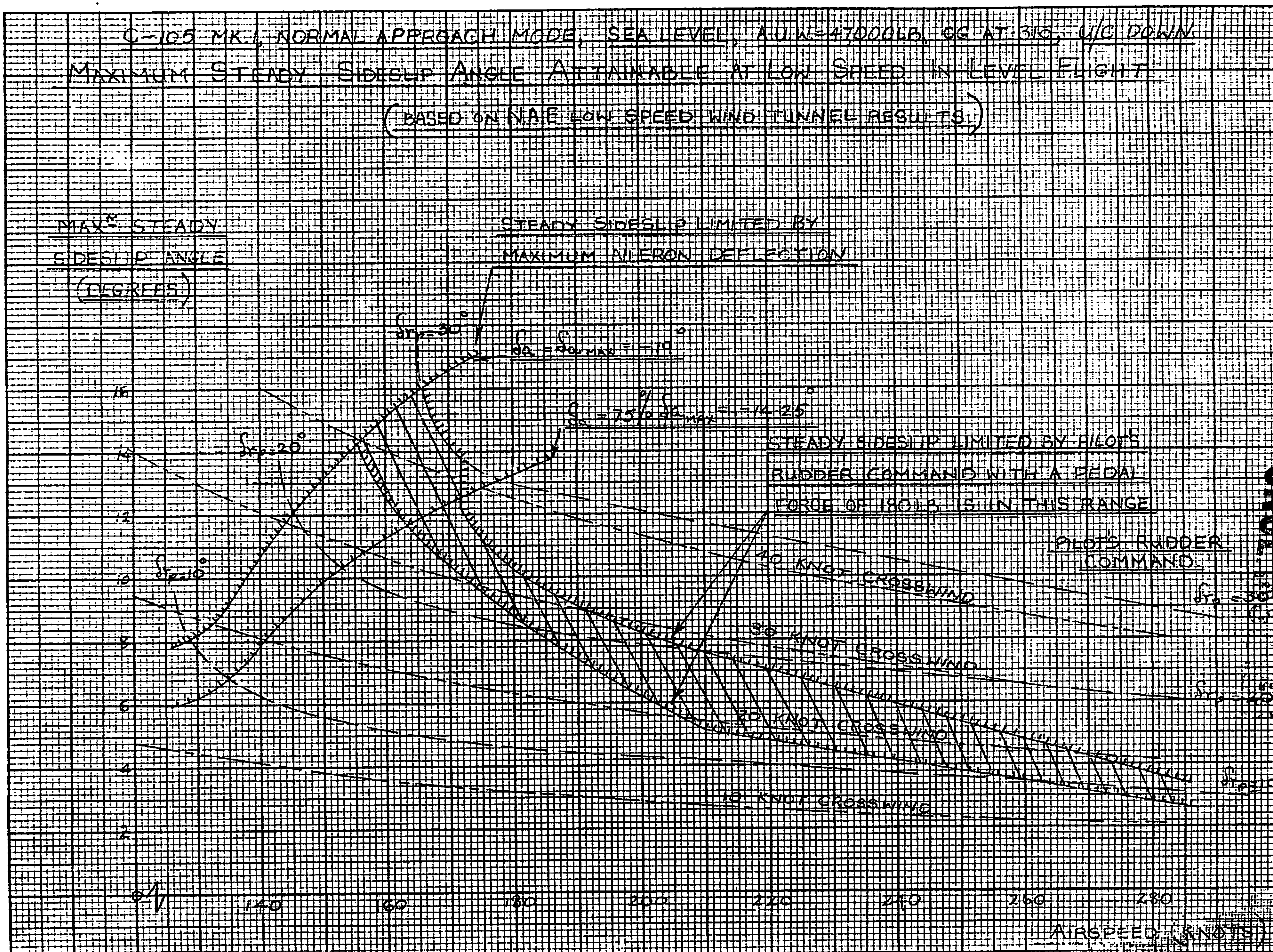


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FIG. 33

G9-12
10 X 10 TO THE ½ INCH
MADE IN CANADA

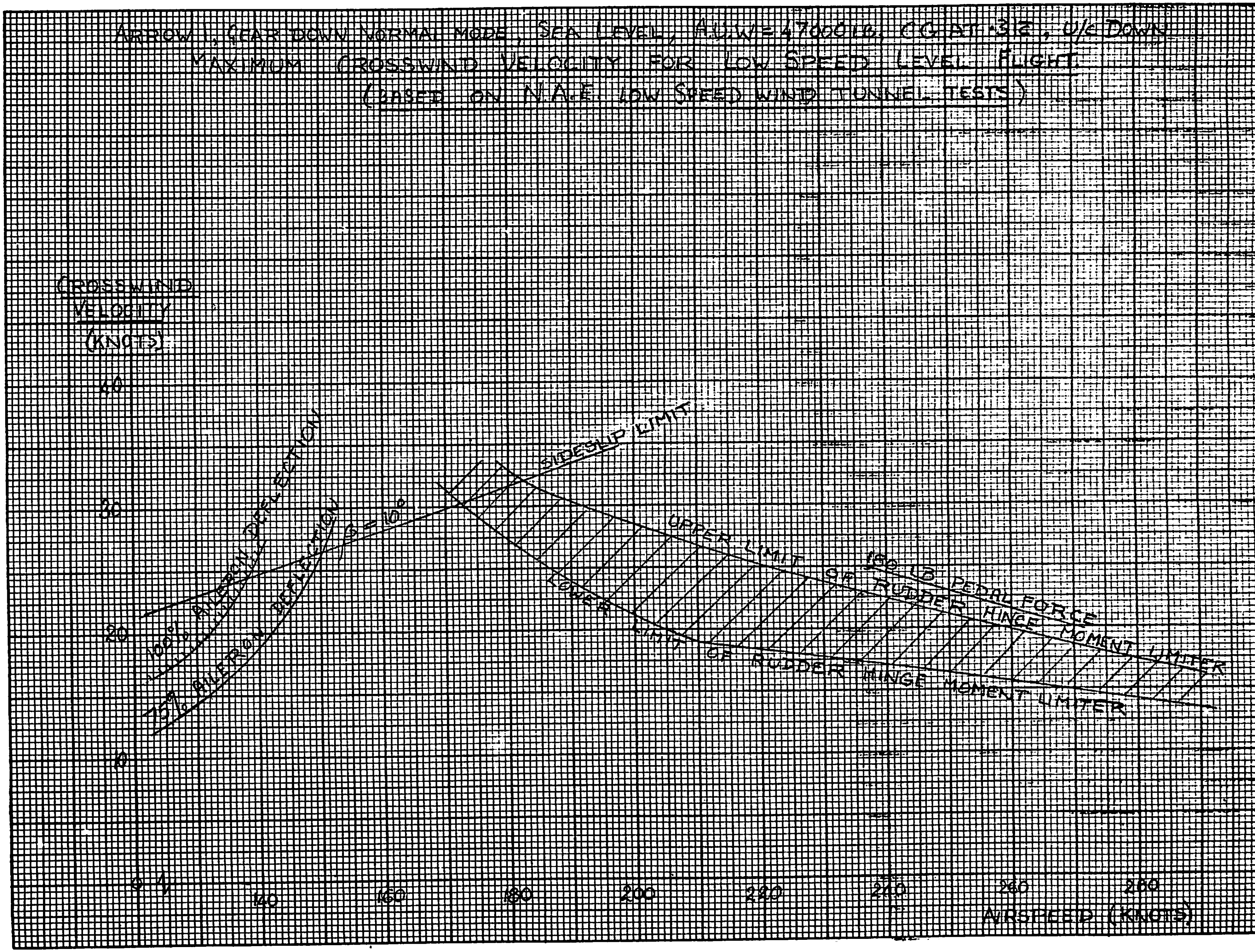

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FIG. 34

C105

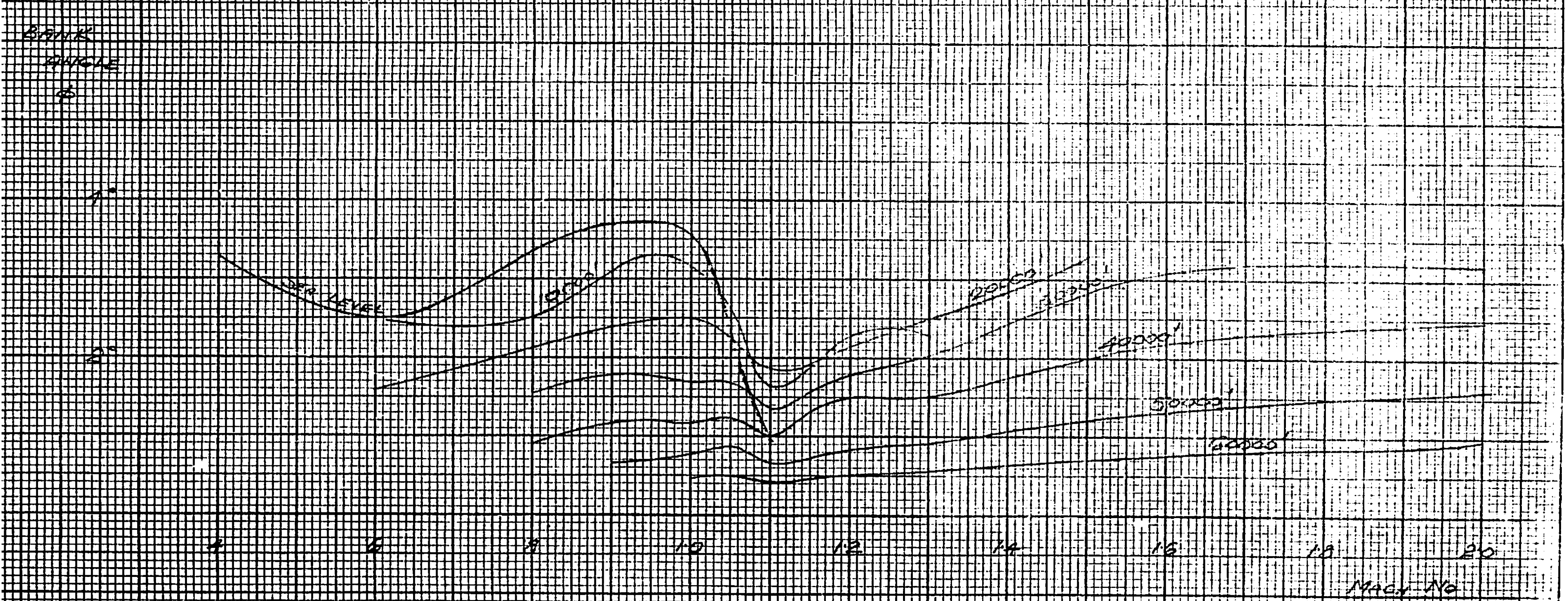
BANK ANGLE FOR ASYMMETRIC POWER

ONE ENGINE AT FULL POWER WITH AFTERBURNER

C.G. = 31 % $\bar{c}$

W = 47000 lb

NO SIDESLIP



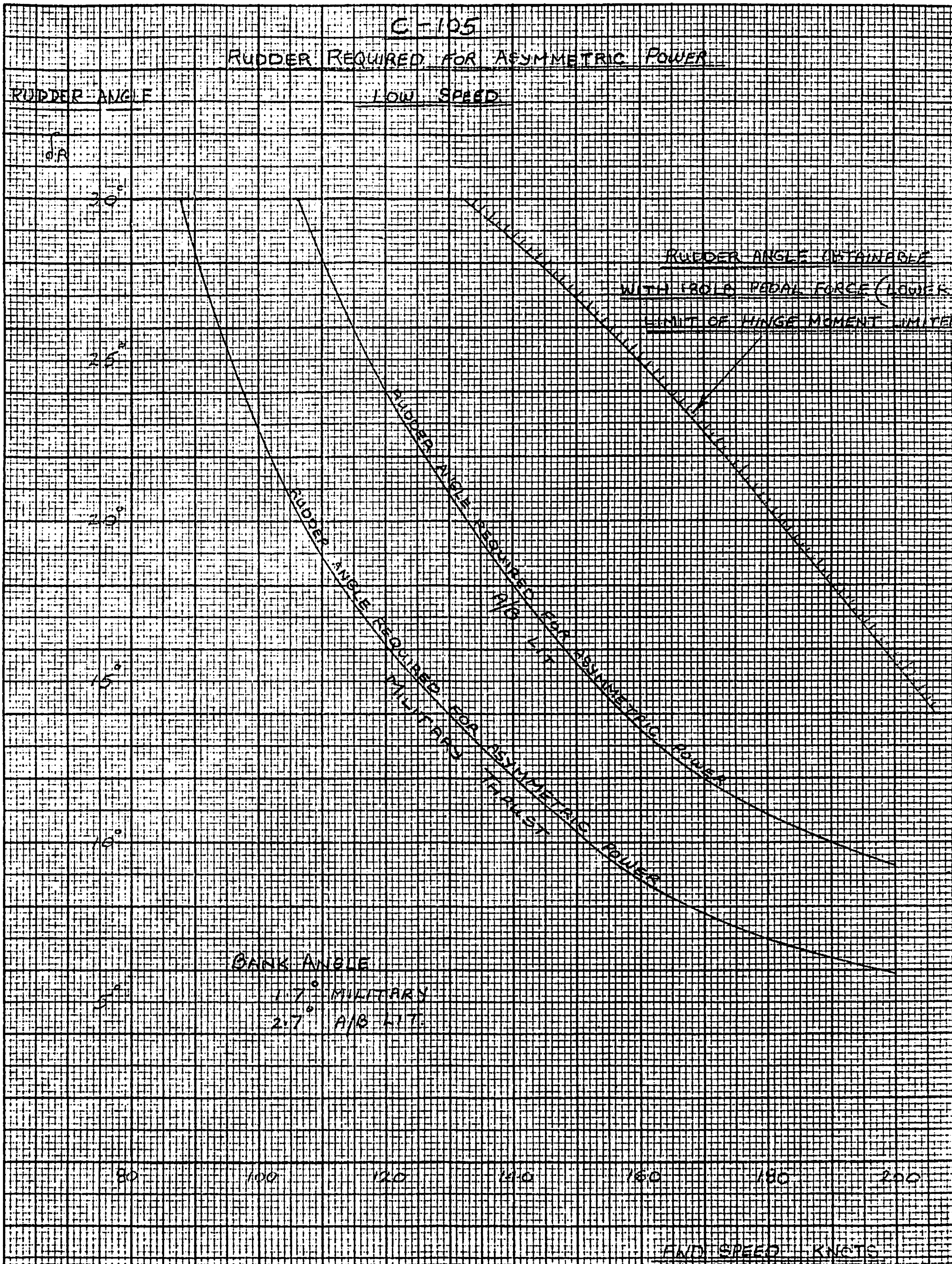
E/CONTROL/173 211

SECRET

FIG. 36

UNCLASSIFIED

FIG. 37



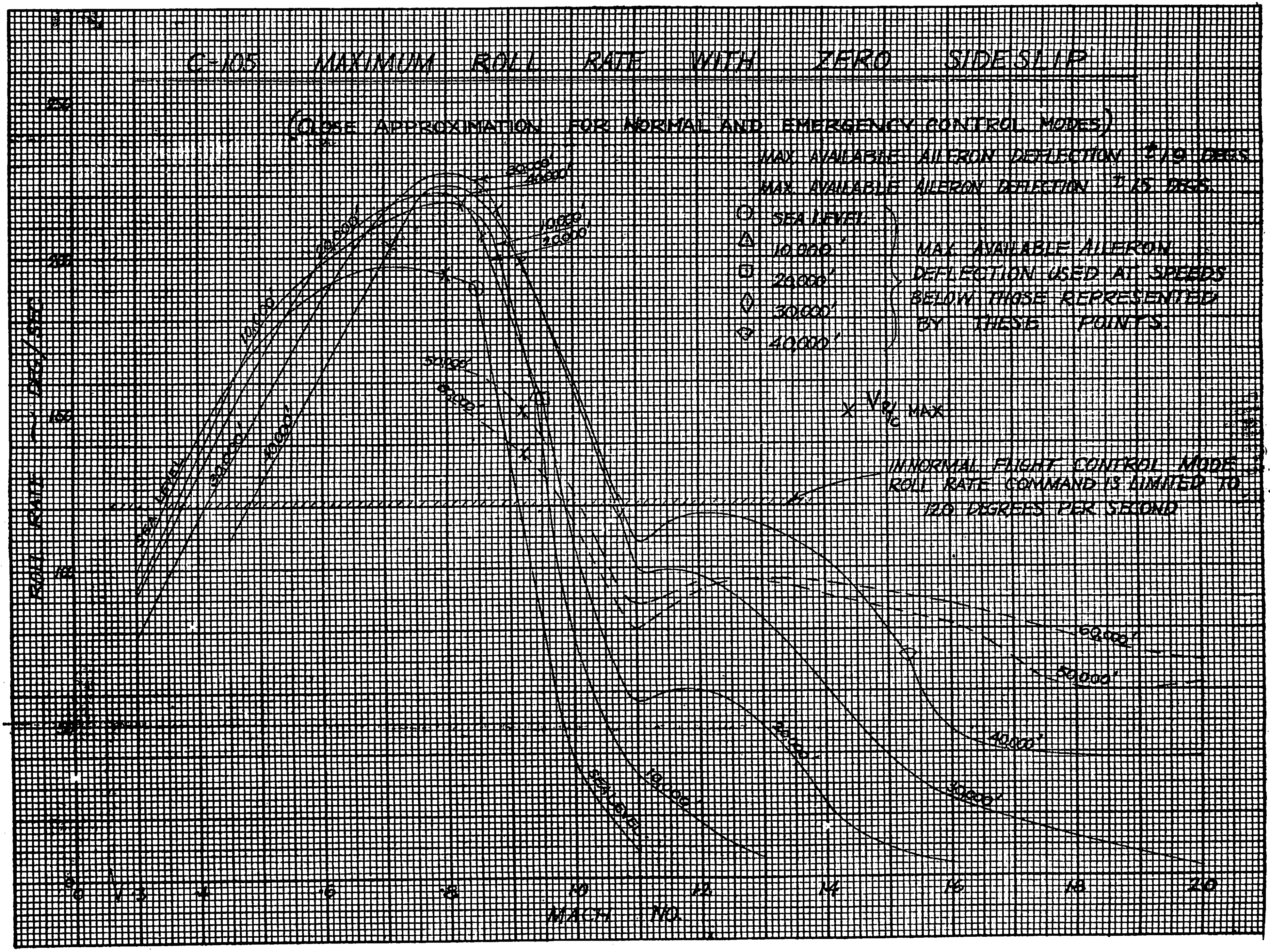

C-105 MAXIMUM ROLL RATE WITH ZERO SIDESLIP
(CLOSE APPROXIMATION FOR NORMAL AND EMERGENCY CONTROL MODES)
MAX AVAILABLE AILERON DEFLECTION ±19 DEGS
MAX AVAILABLE AILERON DEFLECTION ±15 DEGS
SEA LEVEL
10,000'
20,000'
30,000'
40,000'
MAX AVAILABLE AILERON DEFLECTION USED AT SPEEDS BELOW THOSE REPRESENTED BY THESE POINTS.
X $V_{R/C}$ MAX
NORMAL FLIGHT CONTROL MODE ROLL RATE COMMAND IS LIMITED TO 120 DEGREES PER SECOND
ROLL RATE ~ DEG/SEC
MACH NO.
250
200
150
100
50
0
.3
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
SEA LEVEL
10,000'
20,000'
30,000'
40,000'
50,000'
60,000'

FIG. 38

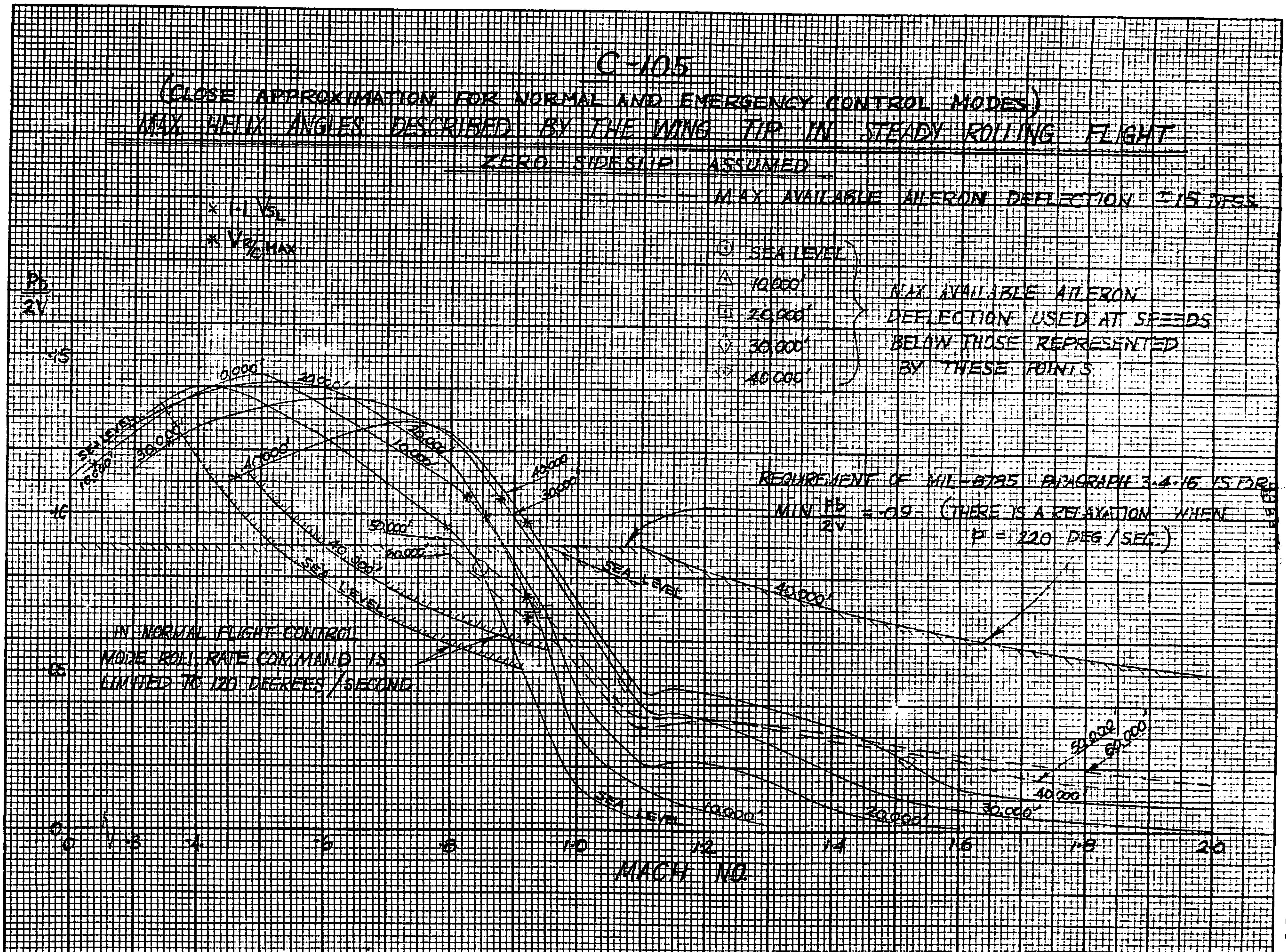

C-105
(CLOSE APPROXIMATION FOR NORMAL AND EMERGENCY CONTROL MODES)
MAX HELIX ANGLES DESCRIBED BY THE WING TIP IN STEADY ROLLING FLIGHT
ZERO SIDESLIP ASSUMED
MAX AVAILABLE AILERON DEFLECTION ±15 DEGS.
× 1.1 V_{SL}
✱ $V_{P/C\,MAX}$
SEA LEVEL
10,000'
20,000'
30,000'
40,000'
MAX AVAILABLE AILERON DEFLECTION USED AT SPEEDS BELOW THOSE REPRESENTED BY THESE POINTS
$\frac{Pb}{2V}$
REQUIREMENT OF MIL-8785 PARAGRAPH 3.4.16 IS FOR MIN $\frac{Pb}{2V}$ = .09 (THERE IS A RELAXATION WHEN P = 220 DEG/SEC.)
IN NORMAL FLIGHT CONTROL MODE ROLL RATE COMMAND IS LIMITED TO 120 DEGREES/SECOND
50,000'
60,000'
MACH NO.

FIG. 39

FIG. 4C

ARROW I

LATERAL DIRECTIONAL DAMPING REQUIREMENTS

MIL-F-8785 (ASG)