C-105 P/STABILITY/92

NOTE ON AERODYNAMIC STABILITY PROBLEMS.

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Avro
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Avro Aircraft Ltd., Canada.

Note on aerodynamic stability problems.
J.A. Chamberlin. June 1955. 18p.

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1. Aeroplanes (Avro CF-105)

A NOTE ON THE AERODYNAMIC STABILITY PROBLEMS ENCOUNTERED ON THE CF-105

There has recently been considerable discussion about the stability and control problems of the CF-105. In some cases these discussions were confused by lack of accurate information. Accordingly the R.C.A.F. have outlined their requirements for the content of a report which Avro was requested to prepare to correct this situation.

(A) AERODYNAMIC STABILITY PROBLEMS

Introduction

In the analysis of stability problems, it is necessary to use the 38 derivatives shown in Figure 1. Most of these derivatives are subject to fairly wide variations, and may be non-linear especially at high angles of pitch or yaw. Their inter-relationship and coupling with inertia parameters is also particularly important. This situation is aggravated to a certain extent by the configurations found suitable for supersonic flight, but most of all by the extremely wide range of conditions covered by the flight envelope of a supersonic aircraft. It has now become almost impossible to make any judgments on the stability problems of any particular aircraft by examining only a few selected derivatives. The range is so vast and the couplings so important, that only by extensive study of numerous flight conditions with the aid of a large analogue computer can any real appreciation of the problems be gained.

However, in order to focus attention on some of the problems that must be dealt with, the weathercock stability derivative, C_{n_β}, will be selected as an example for detailed discussion. Since, this derivative is a particularly important one and has presented certain problems, it is of special interest.

Static Weathercock Stability

Weathercock stability is achieved by the stabilizing moment due to the fin counteracting the destabilizing moment due to the fuselage. The relative values of the derivatives for these components, and the sum total are shown in Figure 2, for the rigid airplane at zero angle of attack. It can be seen that the resultant stability is the small difference between large quantities. It thus becomes subject to large variations for relatively small variations in its components.

The unstable yawing derivatives of the fuselage is shown in Figure 3 for $\beta < 4°$. Extensive wind tunnel data are only available up to a Mach number of 1.23. However, some recent checks at higher speeds have inspired some confidence in these extrapolations. It can be seen that there is a certain amount of variation with both Mach number and incidence, but that this variation is not excessive.

One of the problems with supersonic aircraft is that there is an incentive to use fuselages of very high fineness and especially long pointed noses. This tends to increase the fuselage yawing moment to a value much higher than for the corresponding subsonic aircraft.

The fin effectiveness is shown in Figure 4 for $\beta < 3^{\circ}$. The variation with α and M is seen to be quite small. The most significant thing, however, is the very low value of $a_{1(v)}$. This is characteristic of supersonic aircraft. Surfaces must be thin. To achieve this, the aspect ratio must be low, whether the surfaces are straight or swept, to get a reasonable structural weight. This means that even a large fin can produce only a relatively modest moment even though its arm about the c.g. is quite reasonable, as shown by Figure 5. Increasing the size of the fin not only reduces the arm for purely geometric reasons, but also because its extra weight makes the c.g. move aft. Accordingly it can be seen that there is a point where enlarging a fin in a supersonic airplane will bring diminishing returns.

It should not be.

The resultant rigid C_{n_β} is shown on Figure 6. In spite of variations with α and M, the value of C_{n_β} is relatively small but positive for small values of β. For larger values of β the stability is slightly greater as shown on Figure 7 for moderate values of α. For higher incidence, the airplane becomes unstable at yaw angles of from 6 to 8 degrees for transonic Mach numbers, as shown in Figure 8. This non-linearity is not regarded as having any practical significance, since the yaw should be restricted to values considerably less than this in normal operation. Tests by N.A.C.A. on a similar configuration exhibit similar characteristics. There does not seem to be any incentive to try to do anything about this situation.

By whom? Avro, yes; Everybody else, no.

The data given in Figure 6 are for the rigid aircraft. Unfortunately, the fin is elastic and deflects so as to reduce its effectiveness when loaded. The elastic behaviour is mainly a function of the dynamic pressure and to a certain extent of Mach number, and, of course, of the stiffness and hence the weight of the fin. The effect of elasticity on the weathercock stability is shown in Figure 9 for level flight, and Figure 10 for a 2g manoeuvre. The large effect on the stability is actually a relatively small effect on the fin effectiveness. This causes the aircraft to be unstable in the high Mach number medium altitude range. The effect of applying moderate g is not large for most practical flight cases. At very large angles of incidence and low speeds, there is a considerable reduction of stability as shown by Figure 11. The angles are, however, sufficiently high to make this not important.

To even partially offset the loss of stability at high Mach numbers and moderate altitudes would require a very large increase in the fin weight which would either require more ballast or a lengthened nose, which in turn would require a larger fin.

There are various ways in which the stability could be increased. It has been suggested that an end plate be fitted to the tip of the fin. The tip is relatively small, but some increase in load could be achieved by the end plate. This would cause higher bending moments on the fin and hence increase its weight.

The extra load would act at a point very susceptible to elastic distortion and hence would result in very little gain for the weight increase. Other proposals include erecting auxiliary fins in various places. All these add weight and drag. In fact, there seems to be very little possibility of getting any more than has already been achieved for nothing.

Brilliant!

However, the problem is not to find ways of increasing the stability by aerodynamic means, but of finding how low the stability can be and still be adequate. Only in this way can the overall performance be optimized.

To illustrate the effect of reduced stability on performance, Figure 12 has been prepared. It shows the beneficial effect of aft c.g. position on the drag required to achieve any particular "g" at 50,000 feet. This is due to the reduction in trim drag. Moving the c.g. aft reduces the tail arm and hence the weathercock stability. For example, the manoeuvrability can be increased 10% for a rearward shift of the c.g. of 4% which corresponds to a reduction of .00016 in. C_{n_β}. This sort of adjustment in c.g. can be achieved by a suitable fuel system. However, the unstable area is considerably increased.

Dynamic Lateral Stability

The real criterion of the adequacy of the stability derivatives is their accumulative effect on the dynamic response. This can be analyzed on an analogue computer. The lateral derivatives shown in Figure 1 have been used together with the appropriate inertia parameters and a representation of the hydraulic servos. The simulations that have been carried out show that there is an area in the neighbourhood of M = 2.0 at 30,000 feet in which the aircraft would diverge too quickly for the pilot to control. At slightly lower speeds or higher altitudes, the oscillation in yaw is unstable but of such long period and slow divergence that it should be easily controllable. Other conditions are damped. The areas covered by these conditions are shown in Figure 13. At high altitudes, the damping will always be unsatisfactory, although perfectly safe for manual flight. The conditions at landing are particularly exemplary due to the long period and inertia coupling. The unstable region will be considerably increased, if the c.g. is moved aft for combat weights in order to increase the performance. For a 4% movement of the c.g., a 0.3 Mach number increase in the unstable area might be typical.

Some calculations involving 5 degrees of freedom have revealed that the response for increasing aileron deflection is not linear. It is anticipated that catastrophic yawing will result from high rates of roll (e.g. 100°/sec.) unless suitable synthetic derivatives are introduced.

Longitudinal Stability

There are several problems associated with longitudinal stability. One of the most troublesome of these is pitch-up. This means that the aircraft tends to continue to pitch after a certain normal acceleration has been applied. This is due to a discontinuity in the pitching moment curve. Recently, it has been found that this condition can be cured by notches or leading edge extensions of the wing. Several permutations and combinations of these were tried and it was found that a 5% deep notch located at about 60% of the semi-span from the centre line together with a 10% leading edge extension outboard of this was completely successful in eliminating the severe moment discontinuity that was observed on the plain wing as shown by Figure 14 for .9 Mach number.

To improve the buffet and subsonic drag characteristics, some leading edge camber was applied. This did some good for the purpose intended, but also had a very marked and beneficial effect on the weathercock stability. The effect on the longitudinal stability is included in Figure 14. The characteristics are excellent up to angles of attack of about 12°. Above this, there seems to be a tendency for reduced stability as the elevator angle is increased. The effect is just perceptible for 10° and quite marked for a deflection of 20°. Since lift coefficients of about 0.5 are achieved with about 10° of elevator, any limitation due to this source should not be serious, since it is expected that buffet will restrict further manoeuvrability in the transonic region. It should be noted that extension of the c.g. aft will be favorable in this case.

At altitudes below about 25,000 feet, the damping in pitch is exemplary, but it becomes quite unsatisfactory at altitudes above 50,000 feet. Although it is perfectly possible to fly safely at all altitudes, the aircraft cannot be controlled with adequate precision at height. To correct this synthetic damping is required.

Since the idea that an aircraft need not necessarily be inherently stable, and can have stability imparted to it by appropriate control motions, has been regarded as somewhat unconventional, it is felt that it is highly appropriate to quote from the 43rd Wilbur Wright Memorial Lecture given by Dr. C.S. Draper. Dr. Draper maintains that this idea dates from the Wright brothers and was in fact their major contribution to the science of flight. He states "The Wright brothers broke with the high inherent stability concept and combined inherently unstable aircraft with three-axis control operated by human pilots to achieve stable flight systems. This improvement in performance possibilities provided all that was needed to make powered flight practical and begin the fantastic trail of developments in machines that go through the air. It is equally certain that these machines will very often be unstable components of flying systems that are made stable, not by men, but by devices that perform the same functions that the human pilots provided for the first time in the airplane of Kitty Hawk on December 1903."

FIG. 1

DERIVATIVES USED FOR STABILITY AND CONTROL ANALYSIS

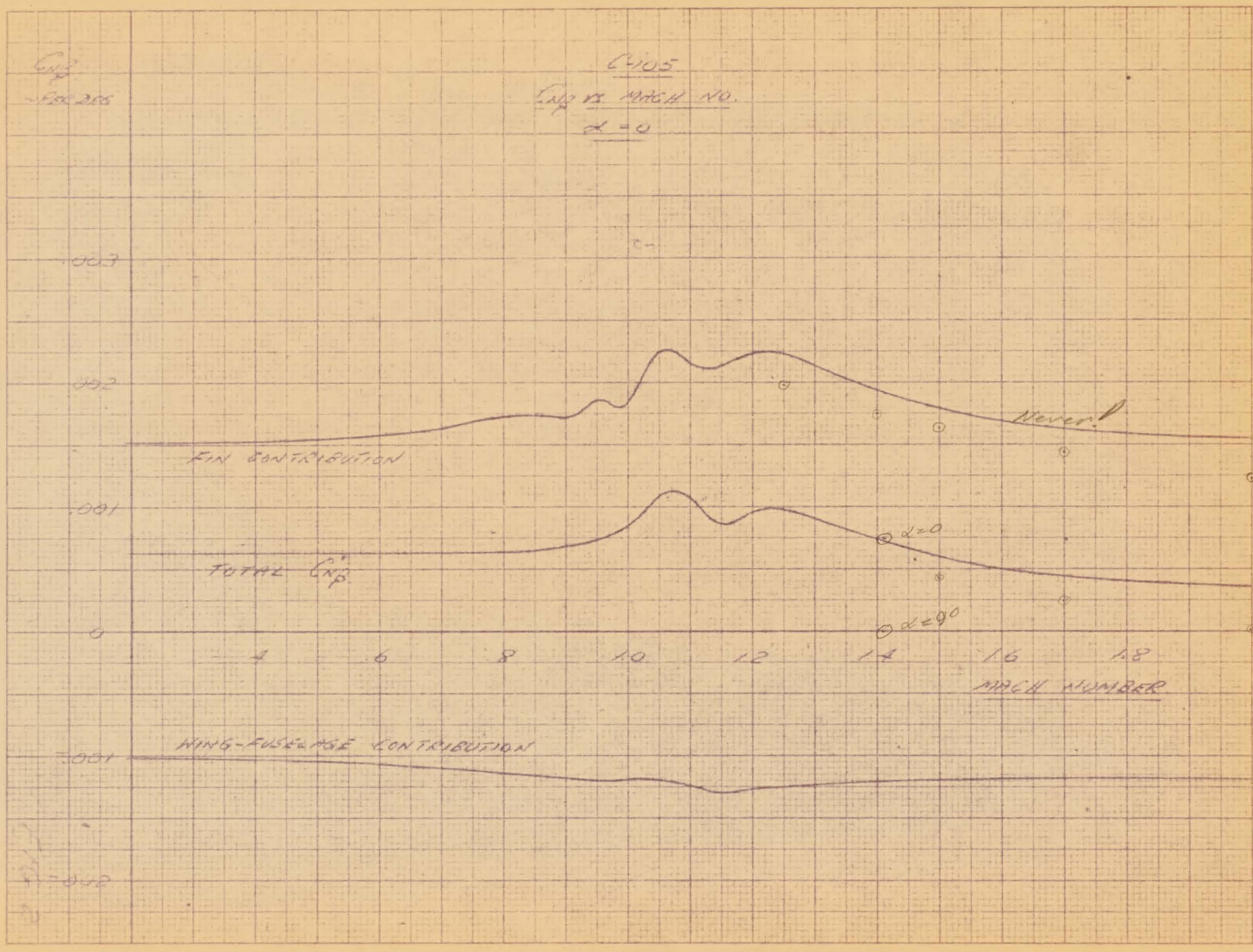
LONGITUDINAL

$\underline{C_{L_\alpha}}$			$C_{L_{\dot\theta}}$		
$\underline{C_{M_\alpha}}$	$C_{M_{\dot\alpha}}$	$\underline{C_{M_U}}$	$C_{M_{\dot\theta}}$	$\underline{C_{M_{\delta e}}}$	$C_{M_{\dot\delta e}}$
$\underline{C_{h_\alpha}}$			$C_{h_{\dot\theta}}$	$\underline{C_{h_{\delta e}}}$	$C_{h_{\dot\delta e}}$
$\underline{C_{D_\alpha}}$		$\underline{C_{D_u}}$			

LATERAL

$\underline{C_{Y_\beta}}$	C_{Y_r}	C_{Y_p}			$\underline{C_{Y_{\delta_r}}}$	$C_{Y_{\dot\delta_r}}$	
$\underline{C_{n_\beta}}$	C_{n_r}	C_{n_p}	$C_{n_{\delta_a}}$		$\underline{C_{n_{\delta_r}}}$	$C_{n_{\dot\delta_r}}$	
$\underline{C_{\beta}}$	C_{r}	C_{p}	$\underline{C_{\delta_a}}$	$C_{\dot\delta_a}$	$\underline{C_{\delta_r}}$		
$\underline{C_{h_{r_\beta}}}$		$C_{h_{a_p}}$	$\underline{C_{h_{a\delta a}}}$	$C_{h_{a\dot\delta a}}$	$\underline{C_{h_{r\delta r}}}$	$C_{h_{r\dot\delta r}}$	$\underline{C_{h_\alpha}}$

Underlined Derivatives can be measured in the wind tunnels normally available.


C-105
C_{n_p} vs MACH NO.
α = 0
C_{n_p}
~PER DEG
.003
.002
.001
0
-.001
-.002
FIN CONTRIBUTION
TOTAL C_{n_p}
WING-FUSELAGE CONTRIBUTION
Never!
α=0
α=90
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
MACH NUMBER

AIRCRAFT C105 COMPONENT SHEET No. 6.1 REPORT No. P/WT/80

A.U.W. DATE June 55 PREP. BY Kwiatkowski

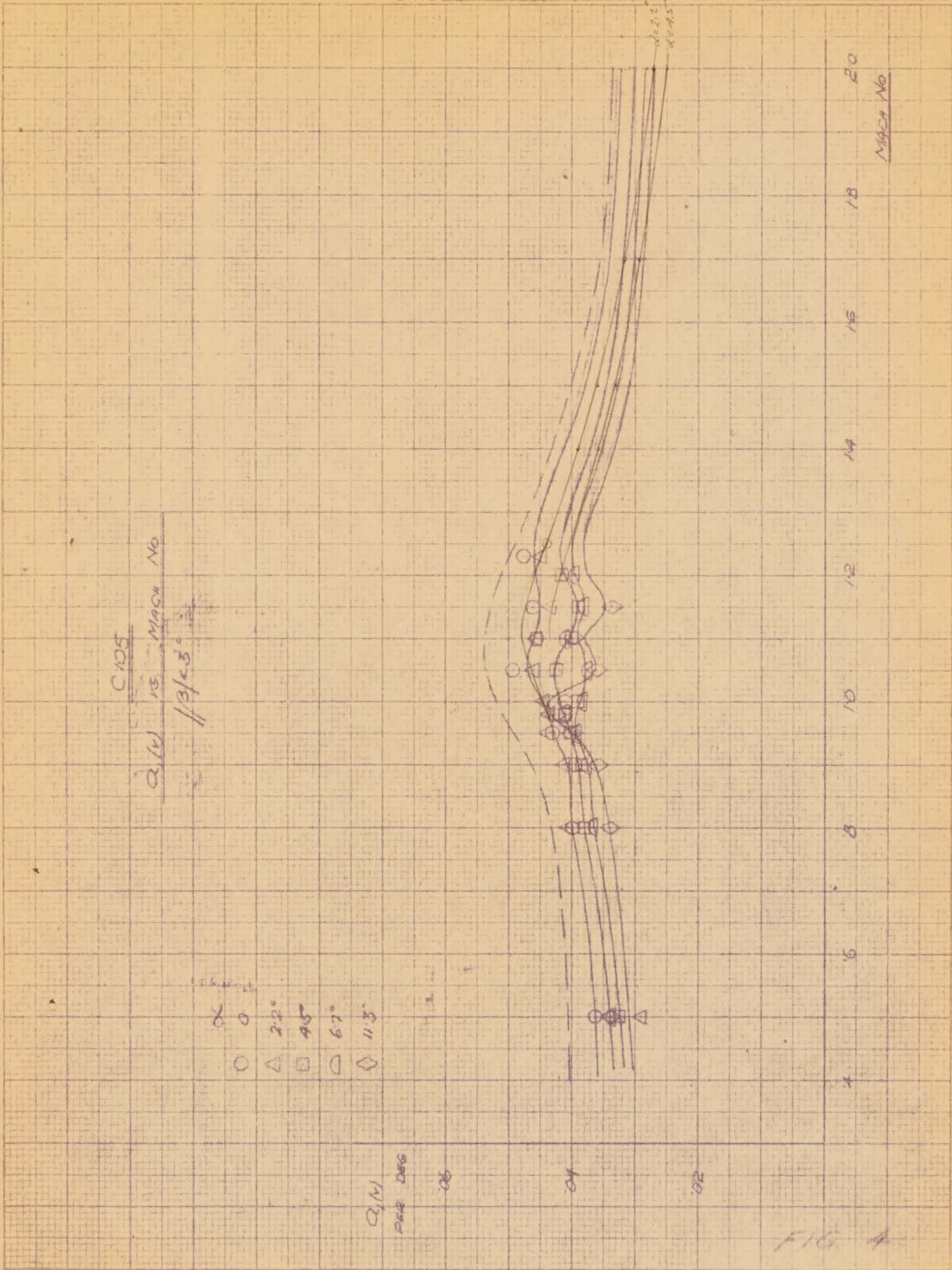
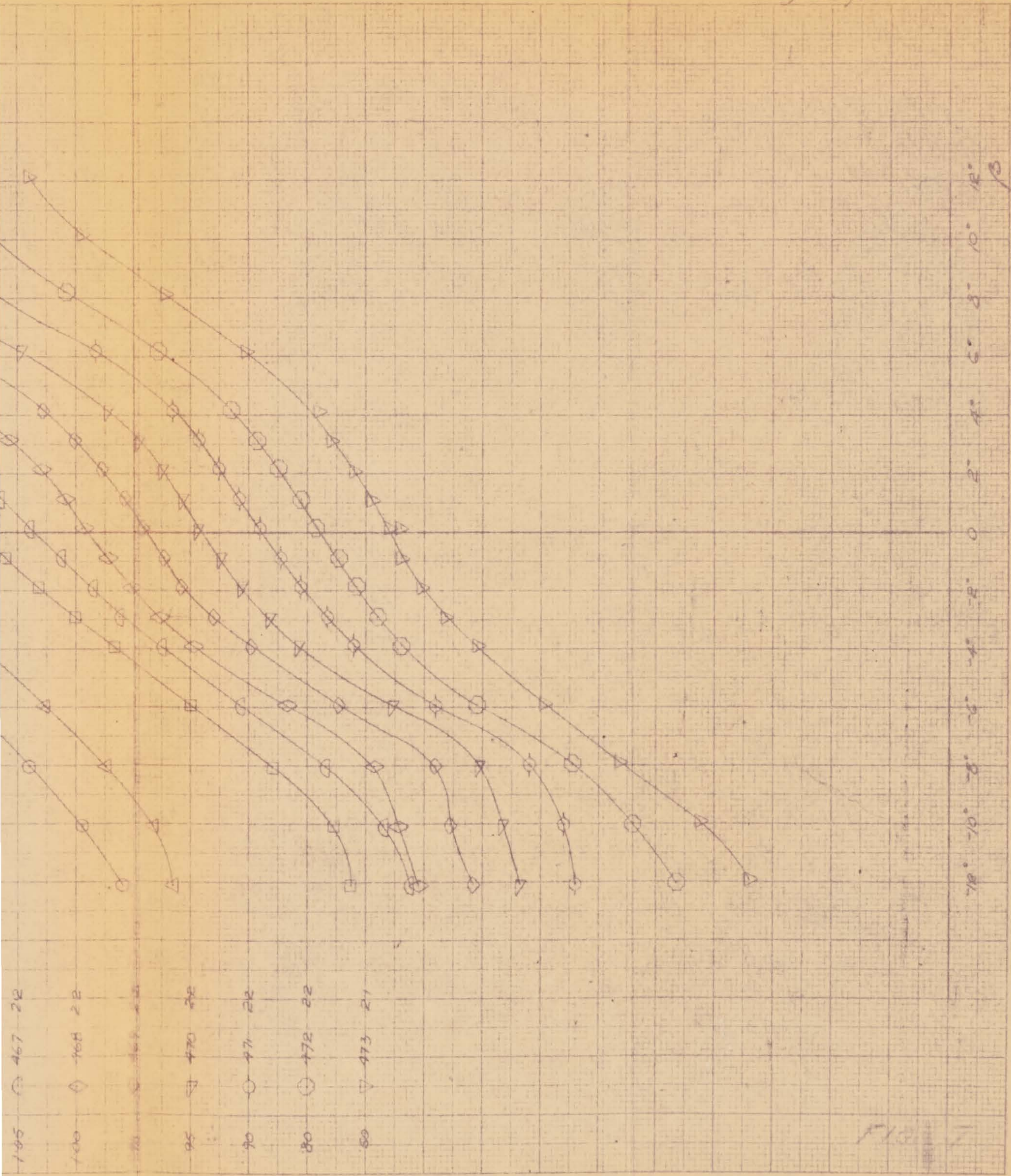


FIG. 4

Plot 174 8.15

June /55 Kwiatkowski



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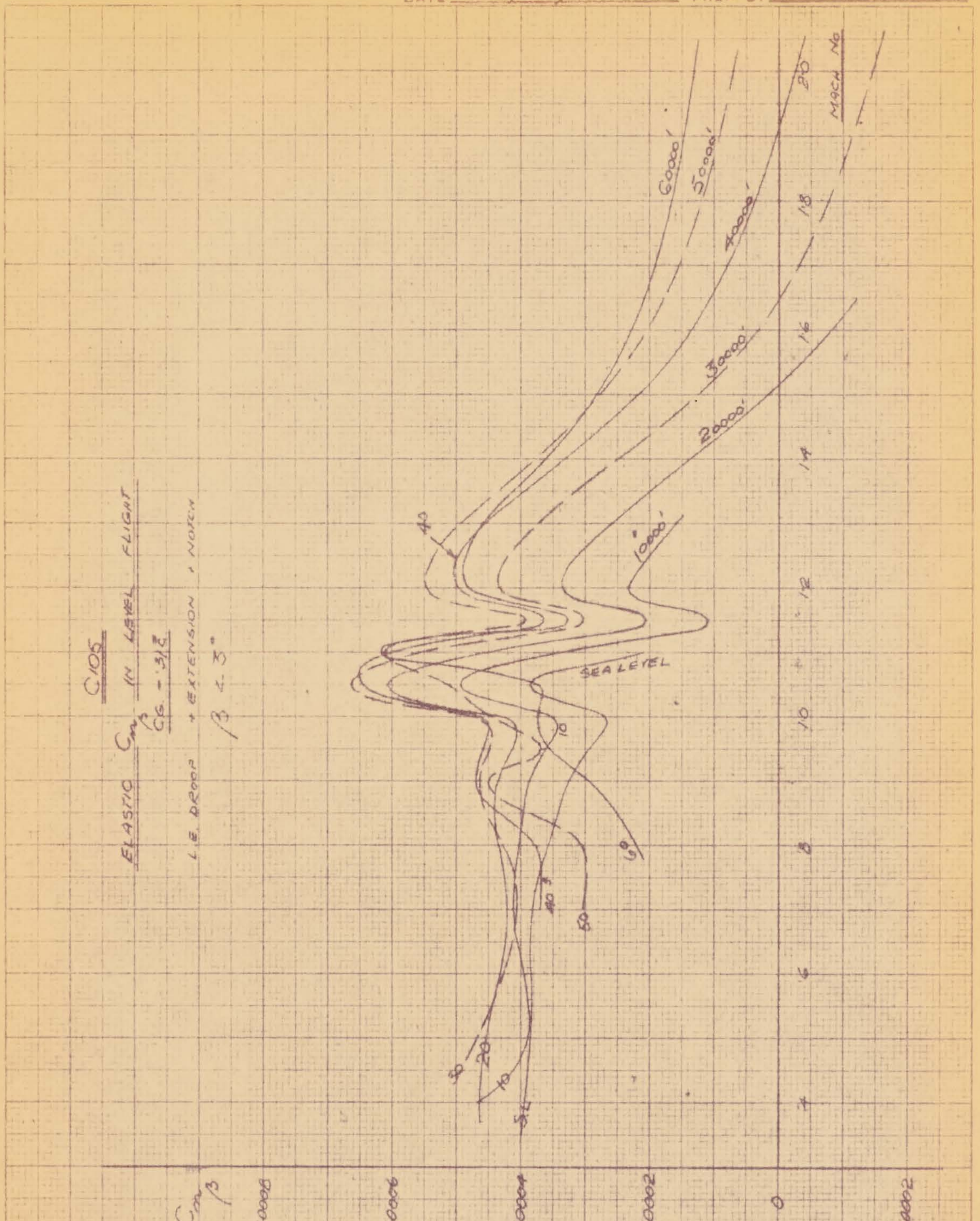

FIG 9

FORM 1746

P/WT/84 4.1.A.

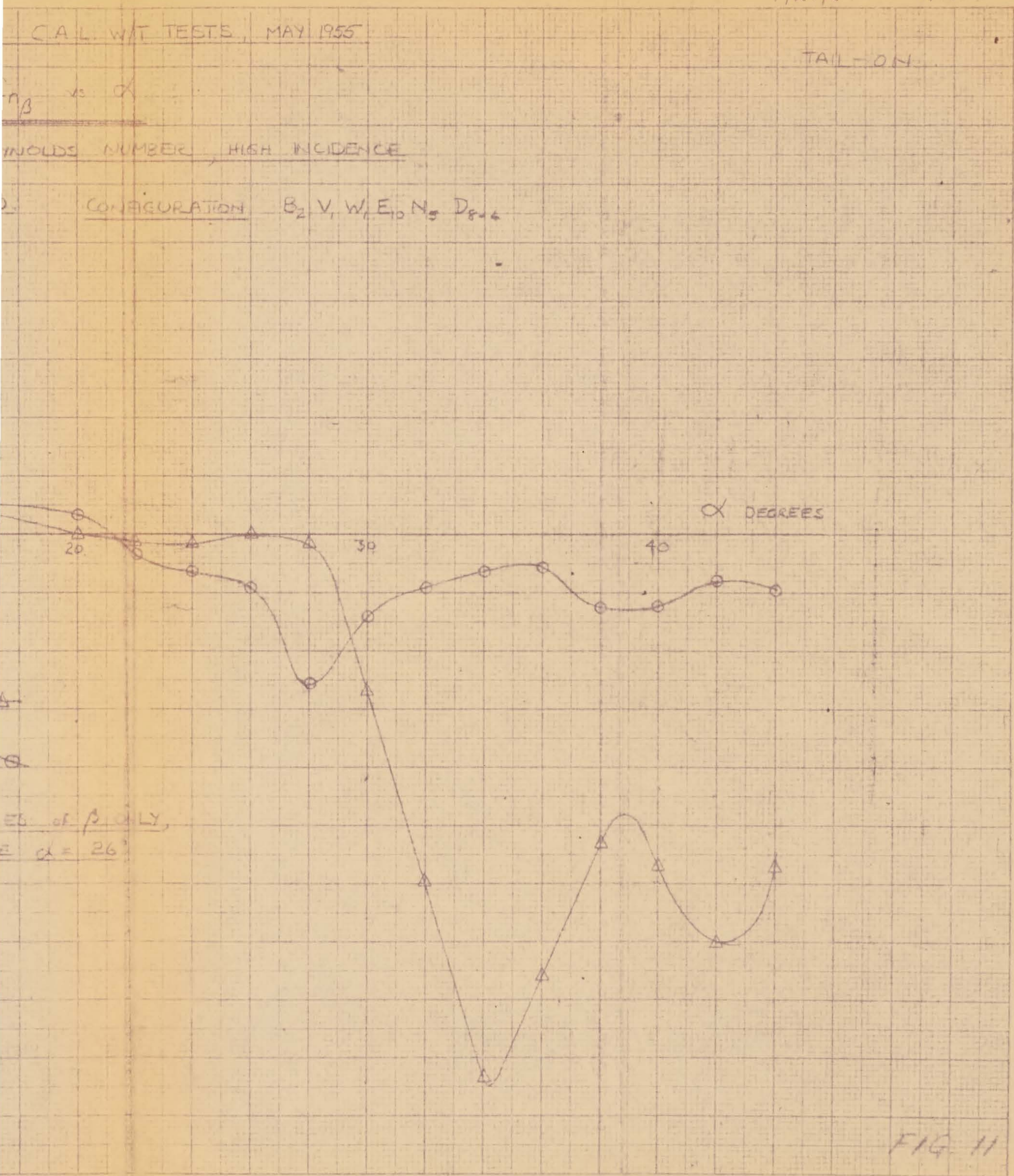

FIG 11

SEPT '55'

PRELIMINARY

C105 G AT 1.5 MACH NO. 50000 FEET

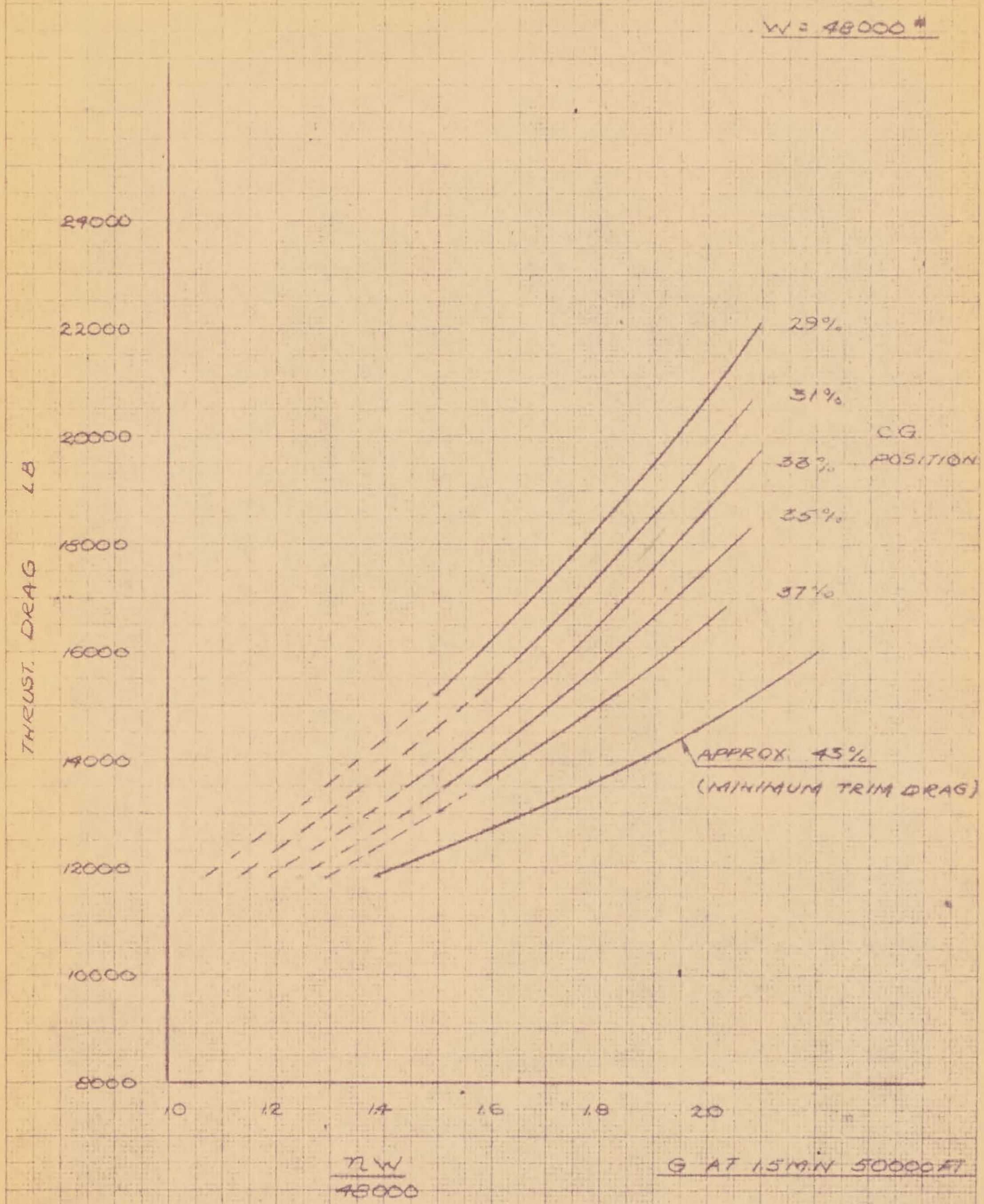

FIG 12

CLARK

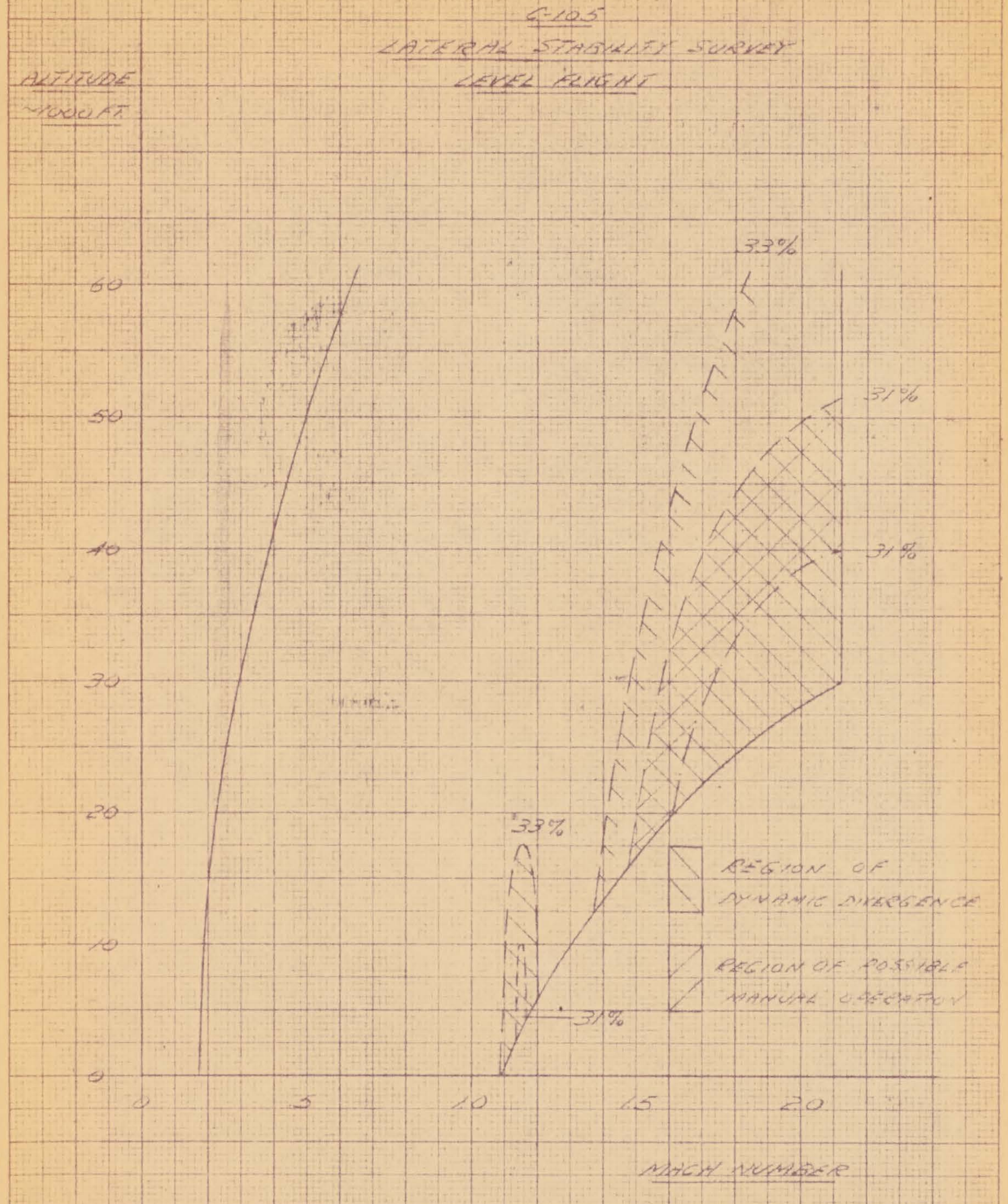
C-105
LATERAL STABILITY SURVEY
LEVEL FLIGHT
ALTITUDE
~1000 FT.
0
10
20
30
40
50
60
0
.5
1.0
1.5
2.0
MACH NUMBER
33%
31%
31%
33%
31%
REGION OF
DYNAMIC DIVERGENCE
REGION OF POSSIBLE
MANUAL OPERATION

FIG. 13