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P/STRUCTURES/32

THE FLIGHT LIMITATIONS OF THE C-105

J. Morris November 1953.

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SECRET

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SUMMARY

The flight envelopes of the C-105 are presented in this report and are in accordance with U.S.A.F. Spec. R 1803-2B. They deviate from this specification between points A and B on the envelopes where the load factor has been reduced to allow for the reduction in material properties at elevated temperatures. The high temperatures are due to the effects of kinetic heating at high aircraft speeds.

The design dive speed (V_D) is the lesser of 720 Knots E.A.S. and the speed corresponding to a surface temperature of 248°F. In the stratosphere on a standard day, this corresponds to a Mach No. of 2.12. At V_D, the minimum structure life is 1,000 hours.

The C-105 has sufficient thrust to enable it ot fly at speeds far in excess of V_D in level flight but due to high impact pressures and temperature at these speeds, there is a rapid reduction in controllability and structure life. It has been necessary, therefore, to impose a speed limitation lower than the maximum level speed which is called the Never Exceed speed (V_{NE}) and this is 720 Knots E.A.S. or the speed corresponding to a surface temperature of 348°F, whichever is the lesser. At lower altitudes, the limit is set by control reversal and in the stratosphere by structure life. The structure life at 348°F is 3.6 hours which corresponds to a minimum of 10 missions at this speed. The Never Exceed speed in the stratosphere is M = 2.42 on a standard day.

THE FLIGHT LIMITATIONS OF THE C-105

Design Limitations

The flight envelopes have been drawn in accordance with U.S.A.F. Spec. R 1803-2B (October 1945) with one exception and that occurs between points A and B (see fig. 1 - 9). The reason for this difference is that at high speeds the temperature on the wing surface increases very rapidly with speed, at M = 2.0 at 30,000 ft. on a standard day the surface temperature* is approximately 248°F and at this temperature, according to ANC 5a, the yield strength of 75 S-T is only 84% of that at 75°F. To design for a load factor of 7.33 at 248°F would mean accepting a large weight penalty, whereas if we design for 7.33 'g' at 75°F the available load factor at 248°F would fall to 6.15. Statistical evidence shows that with high altitude interceptors, high load factors are not usually associated with speeds near V_D (the design dive speed) and this is reflected in the AP 970 envelope which cuts the high speed corner of the envelope limiting the load factor at V_D to $0.75n_1$ (= 5.49). It was therefore decided that the aircraft be designed for a limit load factor of 7.33 at the speed corresponding to 75°F, at higher speeds the load factor would be reduced in the ratio of the yield strength at the temperature appropriate to the higher speed to the yield strength of 75°F. The line between points A and B has been drawn on this basis.

It is clear, from the above discussion, that temperature is to play a very important part in the structural design of this aircraft and no

* See note at end of report.

Design Limitations (Continued)

structural problem should be considered without taking into account temperature effects. The variation of surface temperature with Mach No. is given for various heights on an NACA standard day on Fig. 10, and it is to be assumed that the temperature is uniform over the whole aircraft surface.

The flight envelopes are also based on the standard day and the question arises as to what should be done about atmospheres other than standard such as the Army Summer Day. It is proposed that the design dive speed be defined as follows:-

V_D shall be the lesser of 720 Knots E.A.S. or the speed corresponding to a temperature of 248°F. With V_D defined in this way, we eliminate the necessity for considering atmospheres other than standard by adjusting the max. flight speed on the non-standard day to give the same surface temperature as would be obtained at the maximum flight speed on the standard day; the structural problem is then identical in all atmospheres. This is not strictly true because at a given surface temperature and pressure altitude the Mach No. will be a function of ambient temperature, e.g. at 30,000 ft. and surface temp. 248°F, M = 2.0 on a standard day and approximately M = 1.8 on an Army Summer Day. There will be a difference in the aerodynamic load distribution at these speeds but the difference will be small and can be neglected.

Operation at Speeds in Excess of V_D

The performance of this aircraft is such that speeds well in excess of its design limitations can be achieved in level flight and some preliminary consideration has been given to the problems involved in flying at speeds in excess of V_D, from the structural and operational points of view.

Two structural problems present themselves:- (1) What is the reduction in strength at elevated temperatures (with heating time less than half an hour.) (2) For what time can the structure be heated at a given high temperature before there is a permanent reduction in the room temperature strength? or the strength at any other temperature!

A.N.C. 5a gives the % reduction in the yield strength at elevated temperatures and if we assume that the load factor at a given surface temperature is reduced in the ratio of the yield strength at that temperature to that at 75°F, we can predict what the variation of load factor will be with Mach No. at a given height in a given atmosphere. A graph has been drawn (fig. 11) which shows the variation of available load factor with Mach No. at 30,000 ft. on an NACA standard and an Army Summer day. From this, it would appear that the aircraft could fly to M = 2.4 providing only mild manoeuvres are performed (i.e. < 3.0g) and if speeds in excess of M = 2.4 are achieved, the possibility of structural failure would be high even in moderately gusty conditions.

The only data available relating to the second problem is contained in Met. Dept. Report M 2234, from which we can determine the

Operation at Speeds in Excess of V_D (Continued)

time for which the structural material can be heated at a given temperature without incurring any permanent reduction in the room temperature strength. With this data, we can predict the variation of permanent damage time with Mach No. in a given atmosphere and this has been done for the NACA standard atmosphere and plotted on fig. 12. It will be noted that at the design dive speed above 30,000 ft. the permanent damage time is 1,000 hours and this time increases rapidly as the Mach No. is reduced. At speeds in excess of V_D, it decreases very rapidly e.g. at M = 2.5, T_{P_D}* = 2.7 minutes: obviously, the aircraft should not be operated under these conditions.

The question now arises as to what is the maximum speed to which the aircraft can be flown on a reasonable number of occasions during its life without damage to material properties. It was felt that this problem could best be approached by considering the minimum number of missions that could be flown under given conditions before heating damage effects occur. The absolute minimum number of missions can be obtained if we specify the mission as follows:-

Taxi, take-off and climb to altitude, accelerate to appropriate Mach No. and continue to fly at that speed until only sufficient fuel remains to descend, complete circuit, approach and land. The aircraft takes off with full fuel.

* T_{P_D} = permanent damage time.

Operation at Speeds in Excess of V_D (Continued)

A graph has been drawn (see fig. 13) showing the minimum number of missions against Mach No. at 15,000, 30,000 and 50,000 ft. At V_D, the minimum number of missions are:-

Height (ft.)	Min. No. of Missions
15,000	1,500,000
30,000	5,600
50,000	2,200

and these are much higher than anything likely to occur in practice.

When determining the maximum speed to which the aircraft may be flown in excess of V_D, it would seem reasonable to define it as the speed at which a certain minimum number of missions could be flown (say X) before damage occurs. The following table shows the effect of 'X' on the limiting speed (we will call this speed the limiting temperature speed V_{LT}).

Altitude	X = 10		X = 20		X = 50	
	V_{LT} (Mach No.)	Surf. Temp.	V_{LT}	Surf. Temp.	V_{LT}	Surf. Temp.
15,000	2.12	380	2.08	366	2.03	350
30,000	2.36	365	2.32	350	2.27	335
50,000	2.42	348	2.39	338	2.34	320

The value of V_{LT} is not very sensitive to 'X' in the range X = 10 to 50 and a small reduction in V_{LT} gives a large increase in X. If, for example, a figure of ten missions were to be used to define V_{LT} and the aircraft designed for infrequent operation at this speed, then if operational considerations should indicate at a later date that

Operation at Speeds in Excess of V_D (Continued)

frequent operation between V_D and V_{LT} is likely, we can increase our safety margin considerably by a small decrease in V_{LT}. As the acceptable minimum number of missions at V_{LT} is not likely to be less than 10, and as the lower the value of X is, the more difficult the design problem, it is proposed that this number used for defining V_{LT} at this time.

So far, V_{LT} has been referred to in terms of Mach No., but from the structural point of view, this is not a good reference because the permanent damage time is a function of ambient temperature as well as Mach No. whilst the mission time is mainly a function of Mach No. at a given pressure altitude. The effect of ambient temperature on the value of X at a fixed Mach No. is demonstrated in the following example:-

On a standard day at 30,000 ft. and M = 2.36, X = 10 whilst on an Army Summer day at 30,000 ft. and M = 2.36, only a small fraction of a mission can be flown before the structure is damaged. It can be shown that the variation of V_{LT} with ambient temperature for a fixed X at a given height corresponds closely to a fixed surface temperature and it would therefore be more convenient to refer to V_{LT} in terms of the surface temperature rather than Mach No. The data in the above table shows that the surface temperature at V_{LT} varies with altitude, but the variation is not large and is a minimum at 50,000 ft. It would be convenient to refer to V_{LT} in terms of a fixed surface temperature and it would be conservative to choose the value at 50,000 ft. ie. $348^{\circ}F$.

Operation at Speeds in Excess of V_D (Continued)

The limiting temperature speed, V_{LT}, is then defined as the speed corresponding to a surface temperature of 348°F, and the variation of V_{LT} with altitude is shown plotted in fig. 14 on a standard day. Also included in the figures are the all out level speeds and the design dive speeds. It will be noted that at low altitudes, V_{LT} is very much in excess of the 720 Knots E.A.S. V_D limit and control reversal is certain at some intermediate speed. Obviously, operation at speeds close to and in excess of the reversal speed cannot be considered and as the reversal speeds are not known at this stage, the speed should be limited to 720 Knots E.A.S. at low altitudes. The maximum speed to which the aircraft can be flown is then the lesser of

(1) 720 Knots E.A.S.

or (2) The speed corresponding to a surface temperature of 348°F.

This limitation, which we will call the Never Exceed speed (V_{NE}), is plotted on P. 14.

The permanent damage problem imposes a lower speed limitation than the short duration strength at elevated temperatures and the margin of manoeuvrability is therefore improved. In the height range, where 348°F surface temperature limits the speed, the available load factor does not drop below 4.5. There is then adequate manoeuvrability and no danger of structural failure in gusty conditions.

A factor which has been ignored in the above discussion is the cumulative effect of heating. This may be important and modify the conclusions of this report, but no data is available at this time.

It is felt however, that within the limitations of the data, the conclusions of this report are very conservative and probably contain an adequate allowance for this factor.

NOTE:

It has been assumed that the temperature over the whole wing surface is uniform and equal to the ambient temperature plus 90% of the ram temperature rise. This is a conservative assumption as parts of the surface will be cooler due to flow acceleration and due to the presence of laminar flow. Large areas will, however, be at a temperature close to that assumed.

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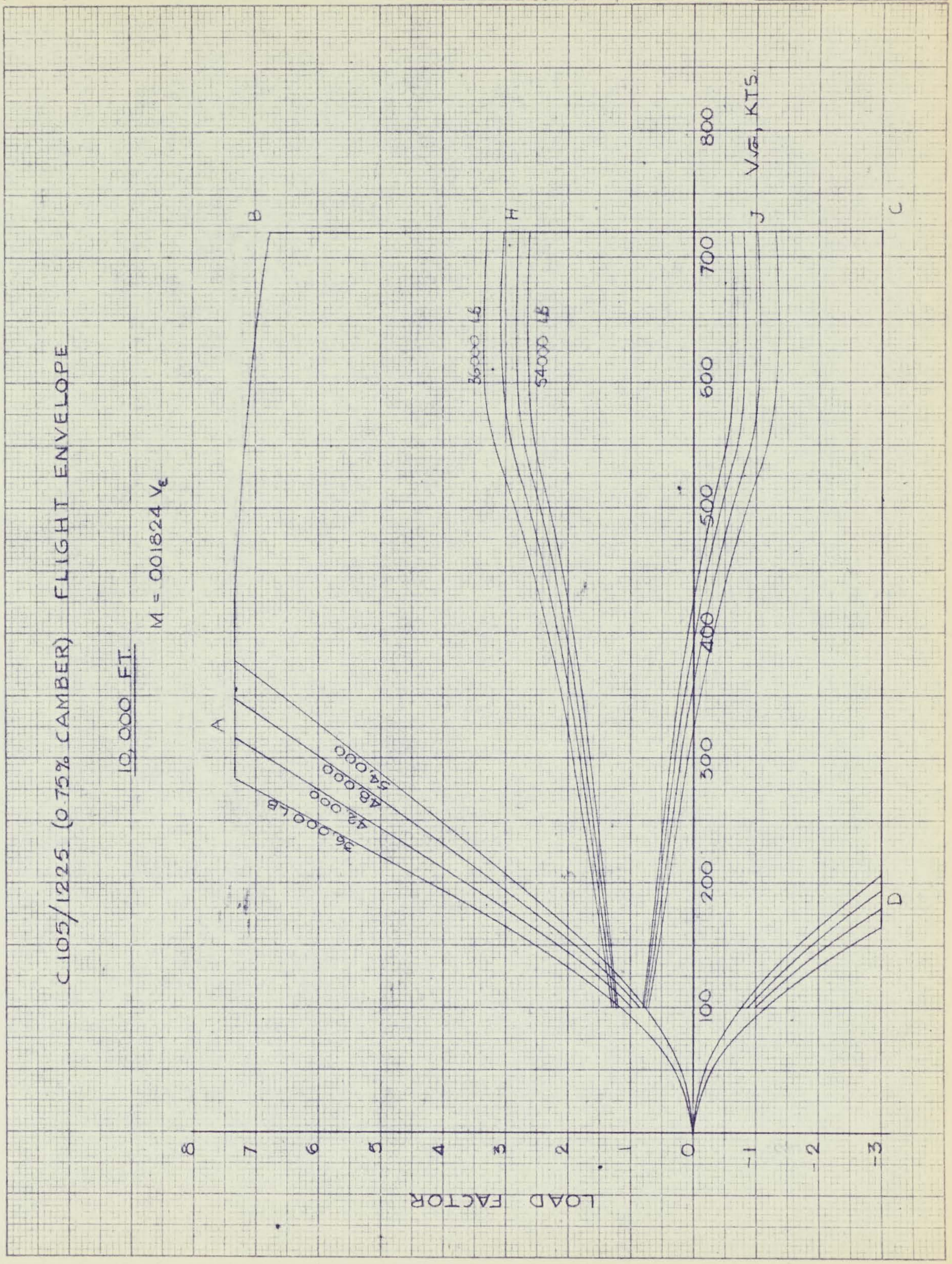

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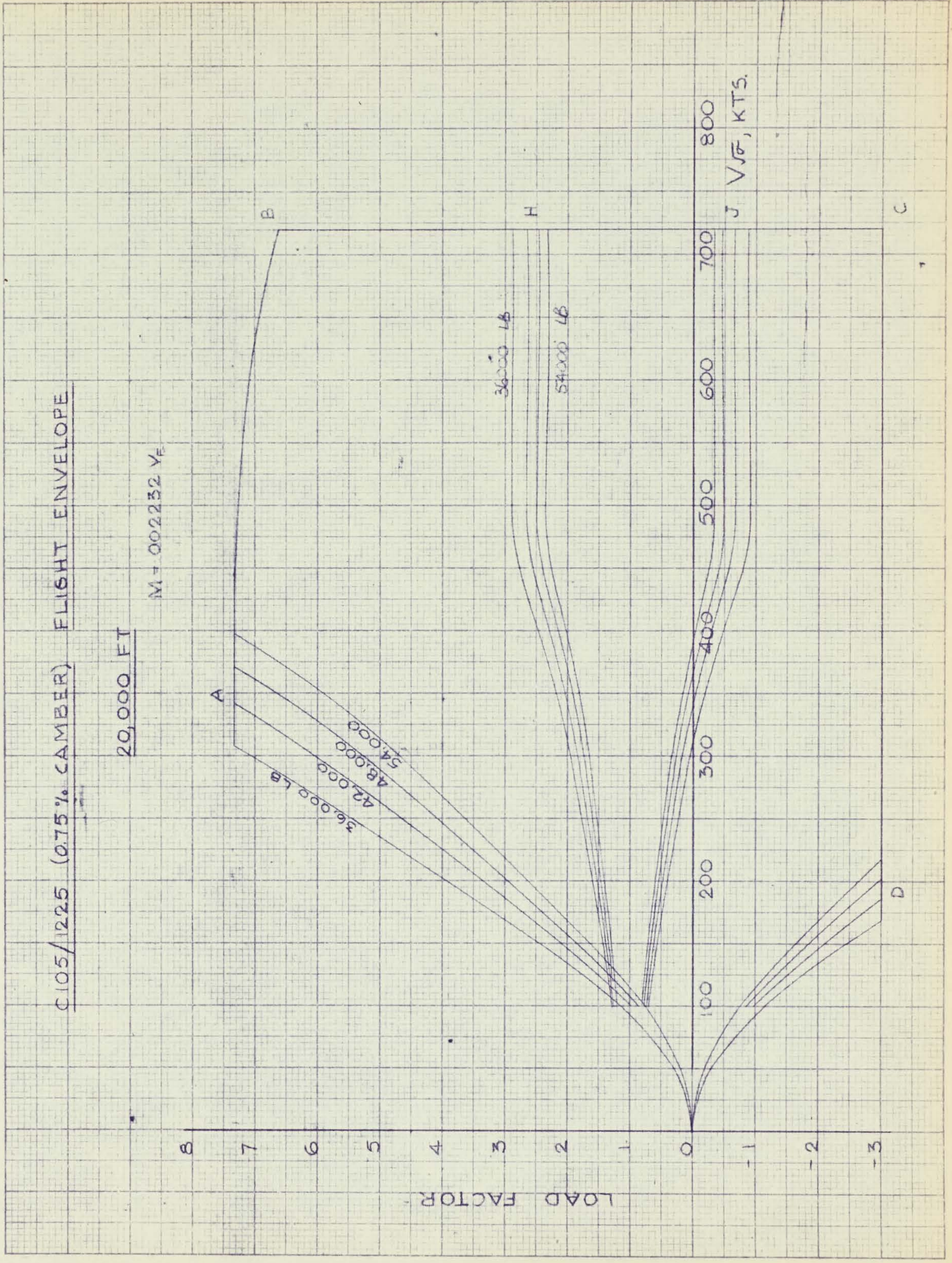

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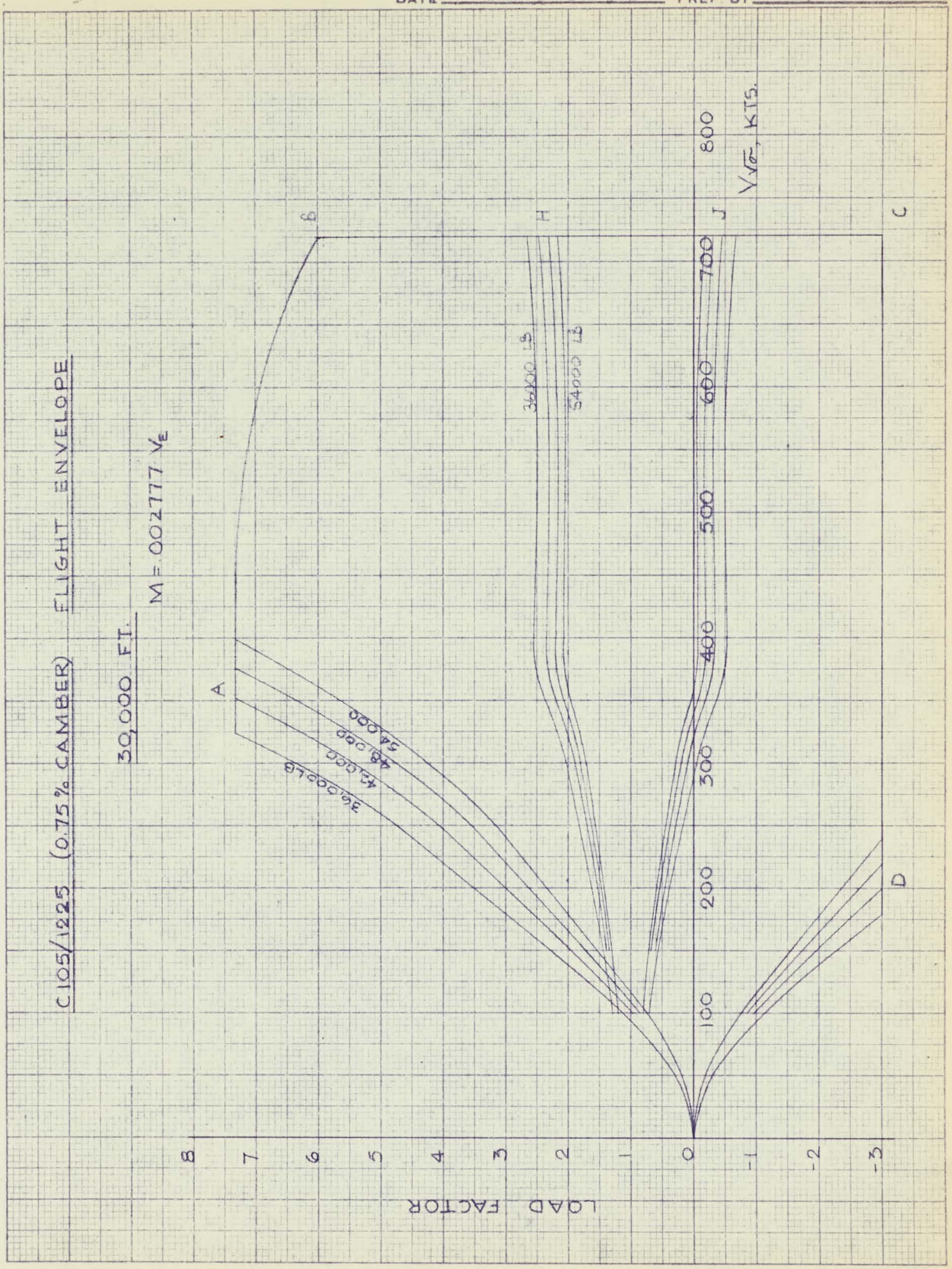

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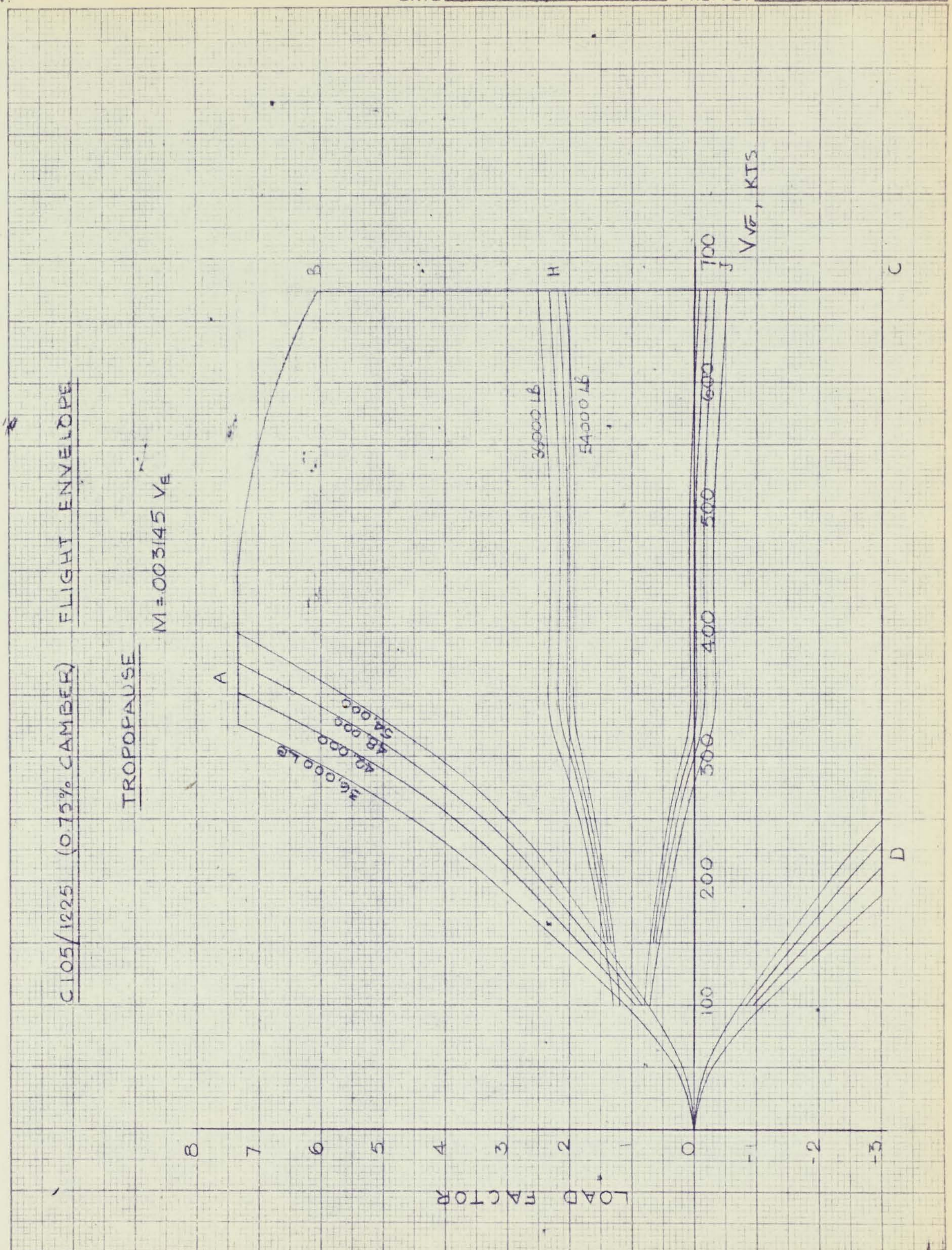

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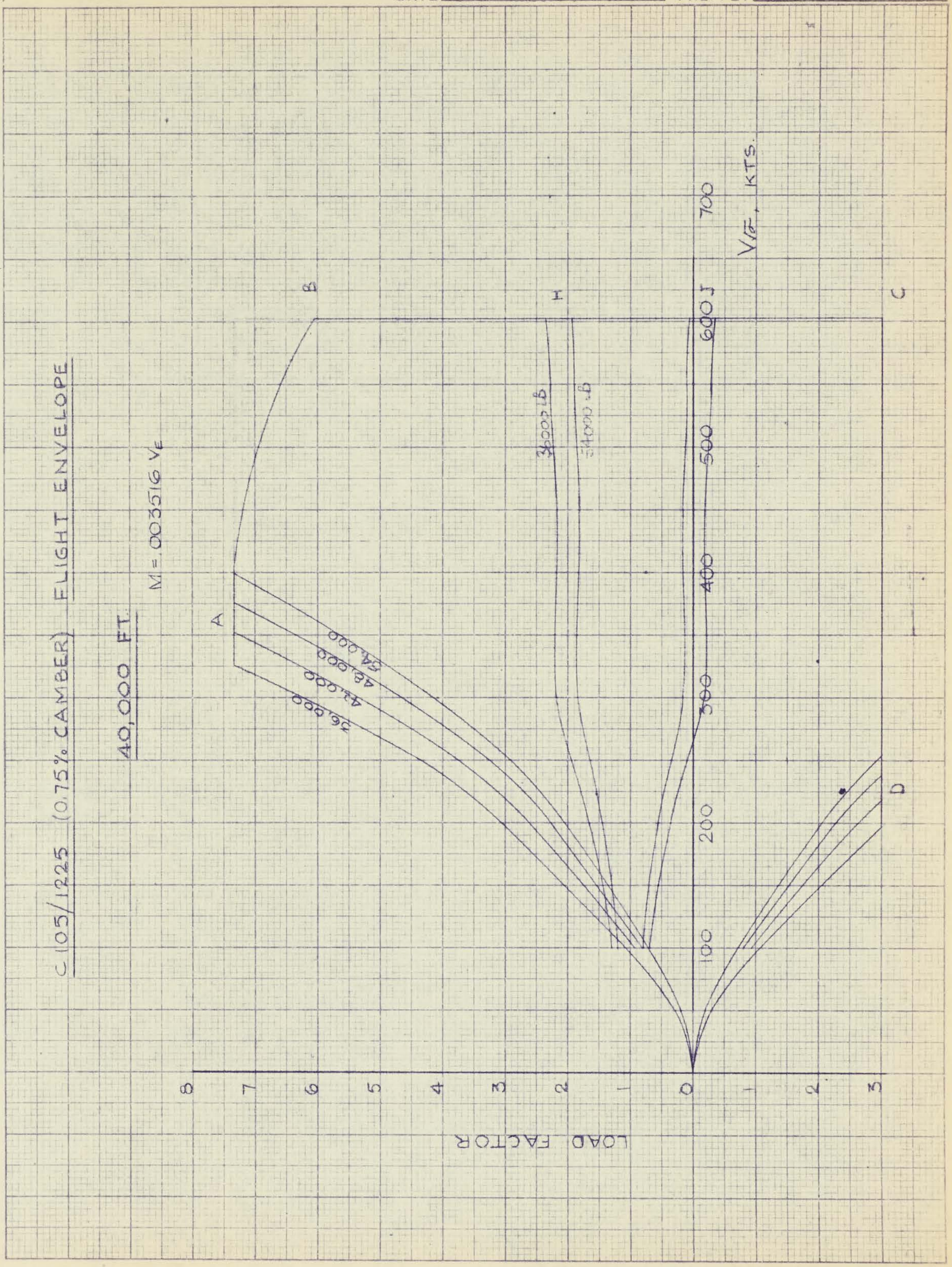

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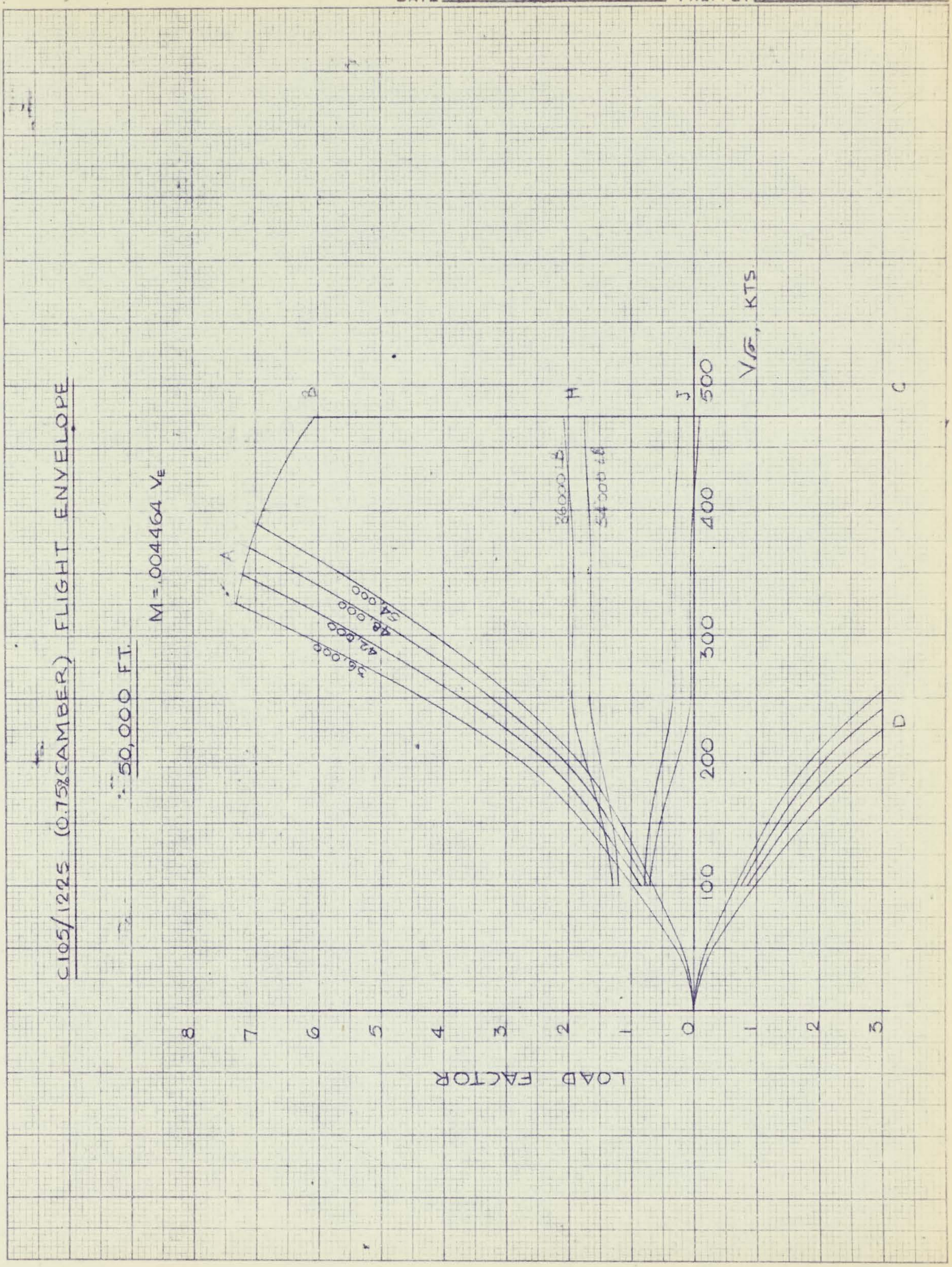

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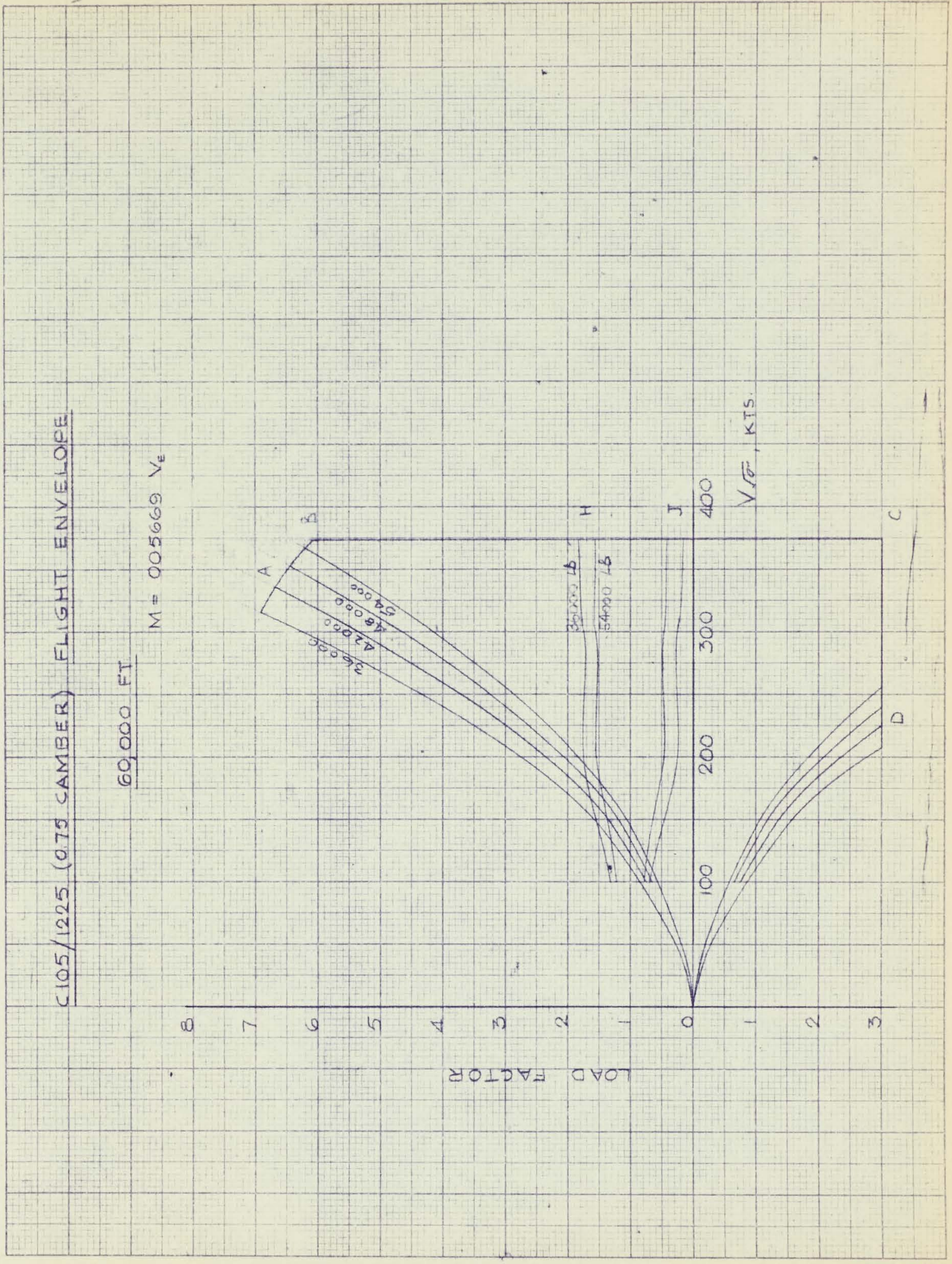

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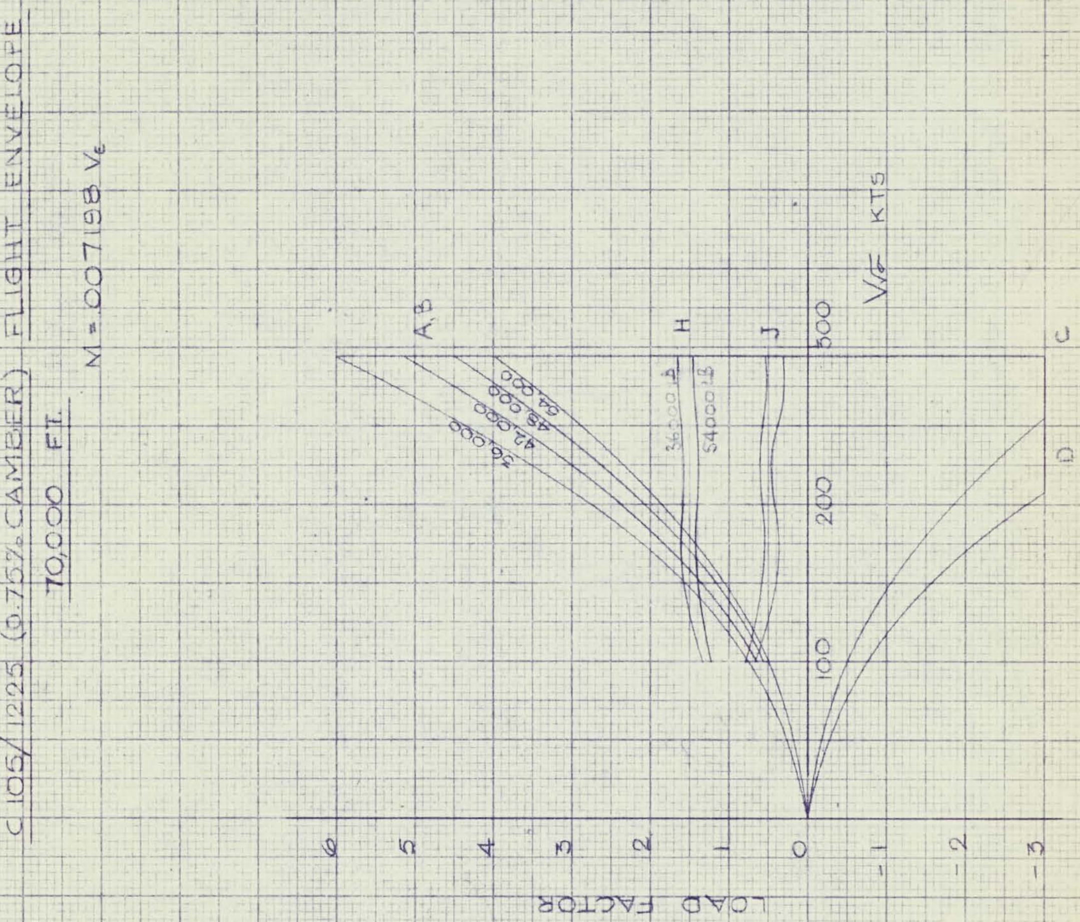

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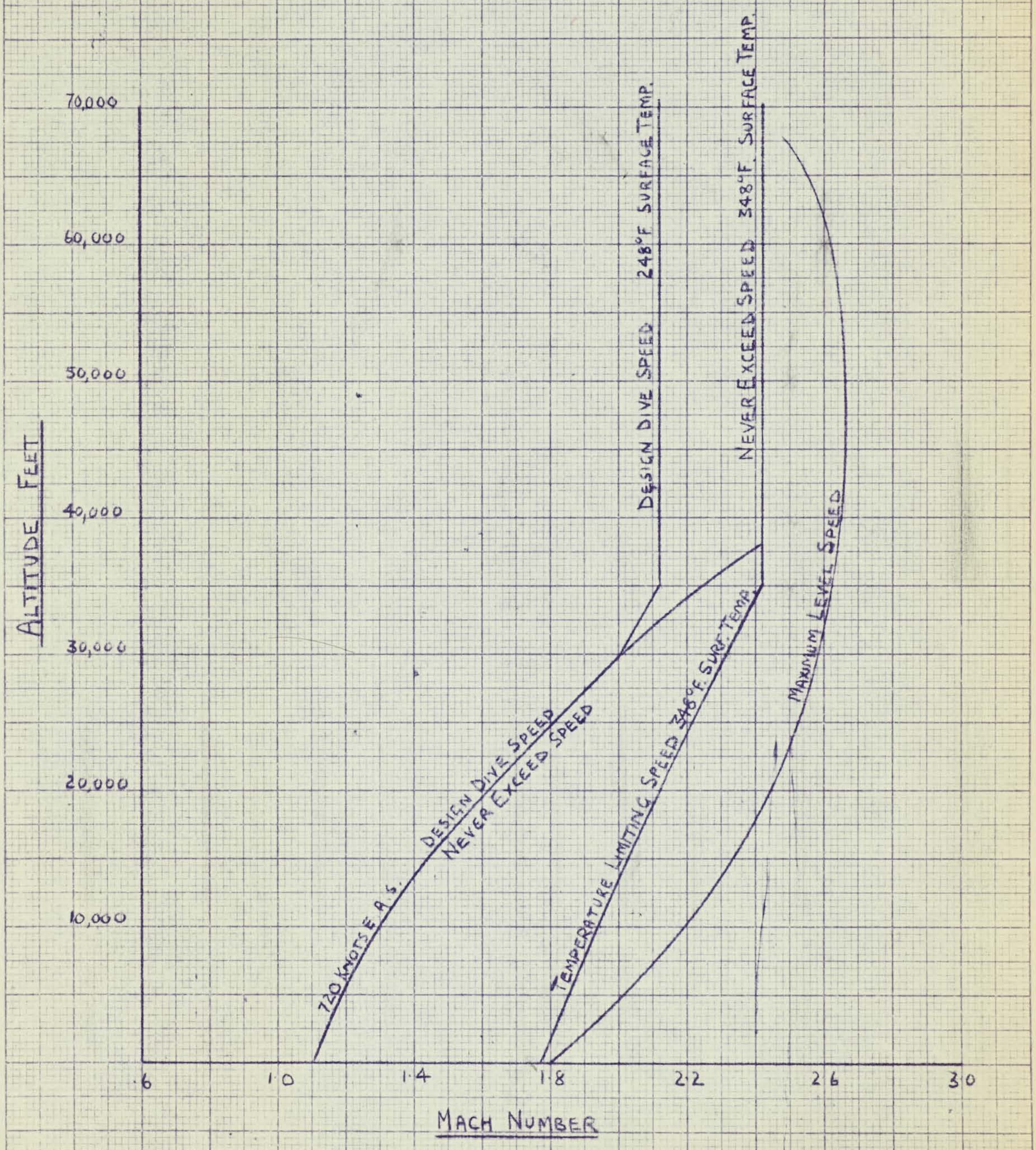
C105

LIMITING SPEEDS v ALTITUDE
NACA STANDARD DAY



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