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NOTES ON THE EFFECTS OF HUMAN
ACCELERATION TOLERANCES ON
DESIGN FOR THE TERRAIN FOLLOWING
AIRCRAFT

DOUGLAS AIRCRAFT DIVISION • LONG BEACH, CALIFORNIA



DOUGLAS AIRCRAFT COMPANY, INC.

EL SEGUNDO DIVISION

Engineering

DEPARTMENT



REPORT NUMBER

ES 40621

Notes on the Effects of Human Acceleration
Tolerances on Design for the Terrain Following
AircraftCONTRACT NO. Nonr 1076(00)REPORT DATE January 1962

MODEL _____

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SALES ORDER _____

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LETTER	DATE	PAGES AFFECTED	REMARKS

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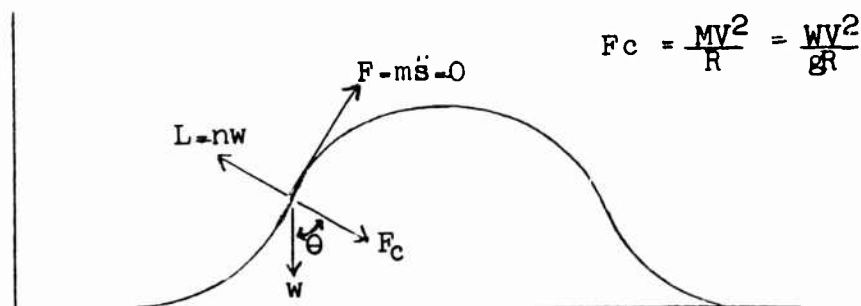
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2.0 INTRODUCTION

Under conditions of terrain following flight in the Mach 1 speed region, the physiological limitations of the pilot may pose a restriction as to how close the terrain following can be executed.

2.1 Definition of the Problem

To investigate this problem some calculations have been made to see what kinds of restrictions tolerances to both negative and positive g-forces will impose on low level high speed flight. Only a simplified model has been considered, namely: the airplane is considered to be a rigid structure flying at a constant average velocity and moving in only one plane. Evasive movements are considered to be flown in a sine wave pattern in the vertical plane. With these restrictions it is necessary to consider only the forces normal to the center line of the aircraft.



Summing these forces radially.

$$\sum F_R: \quad nw = F_c + W \cos \theta$$

$$nw = \frac{WV^2}{gR} + W \cos \theta$$

or

$$n = \frac{V^2}{gR} + \cos \theta$$

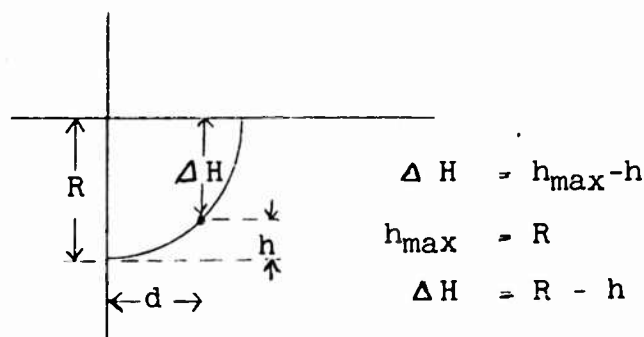
where w = vehicle weight, n = load factor
 R = radius of turn, V = velocity, g =
acceleration due to gravity. θ = pitch angle,
 $\ddot{s}$ = acceleration on path, F_s = net force and
 F_c - the total centrifugal force acting normal
acting normal to the direction of the airplane.

3.0 DISCUSSION

The load factor (g force) exerted on the pilot during any longitudinal maneuver must of course be restricted to the physiological tolerance of the pilot. This in turn defines the radius of the flight path that can be flown. Since in terrain following peaks of different heights may be encountered and since the radius of pullup is defined by the physiological tolerance of the pilot, it is necessary to know how far from different peak heights a pilot must begin his maneuver to avoid collision.

3.1 SIMPLIFYING ASSUMPTIONS

For purpose of simplifying calculations it was assumed that a circular flight path was flown at constant velocity. This would be roughly comparable with the major part of the path attempting to follow the third quarter wave of a sinisoidal flight path.



For a circle

$$x^2 + y^2 = R^2$$

or in terms of the model

$$d^2 + (\Delta H)^2 = R^2$$

or

$$d^2 + (R-h)^2 = R^2$$

then

$$d = \sqrt{R^2 - (R-h)^2} = \sqrt{h(2R-h)}$$

It is possible from these models to calculate the radius of pull-up permitted for a given g-loading and to also determine the distances required using this radius to avoid peaks of different evaluations.

3.2 POSITIVE G-FORCE LOADING AND TOLERANCE

Blackout thresholds for unprotected pilots vary with the individual over a wide range. However, with reasonable selection of personnel it would appear that the unprotected pilot might sustain a maximum of 3g positive without undue stress.

The positive g-force loading permitted on a pilot can be increased by the use of pressure suits. The use of such suits improves g-tolerance of a pilot from 1.5 to 2-g. If the pilot is selected properly it appears that a g-loading of 5g positive is not an unreal figure for maximum permitted g for the protected pilot.

Assuming these tolerance values, minimum radii have been calculated for flight at 0.95 Mach and for 1.2 Mach. Using these radii the distance at which pullups must be started for several obstacle heights has been calculated for both the protected and unprotected pilot. These values are given in Table 1 and are shown graphically in Figures 1 and 2.

3.3 NEGATIVE G-FORCE LOADING AND TOLERANCE

In passing over an obstacle there will be a change from positive to negative g exerted on the pilot. Physiological tolerance to this kind of maneuver has not been determined hence cannot be assessed in this discussion.

After passing over an obstacle, any attempt without large lateral changes, to follow the terrain will impose negative g on the pilot. Much less is known about the physiological effects and permitted loading for negative g than there is for positive g. While even 1g negative is uncomfortable after even moderate times (i.e., standing on your head), it appears that for the times involved in the present calculations (1 to 10 sec.), a pilot could sustain

TABLE I

Distance and Time Required to Avoid Obstacles
Of Different Heights

M 0.95			M 1.2		
h(ft)	d(ft)	time(sec)	h(ft)	d(ft)	time(sec.)
Unprotected pilot: Maximum 3g positive assumed					
200	2,150	2.03	200	2,719	2.03
400	3,027	2.85	400	3,836	2.86
600	3,692	3.48	600	4,685	3.50
800	4,243	4.00	800	5,395	4.03
1,000	4,723	4.45	1,000	6,014	4.49
2,000	6,528	6.15	2,000	8,390	6.26
4,000	8,788	8.28	4,000	11,520	8.60
8,000	11,060	10.42	8,000	15,280	11.40
G-suit protected pilot; Maximum 5g assumed					
200	1,662	1.57	200	2,102	1.57
400	2,333	2.20	400	2,960	2.20
600	2,836	2.67	600	3,608	2.69
1,000	3,605	3.40	1,000	4,610	3.44
2,000	4,900	4.62	2,000	6,373	4.76
4,000	6,320	5.90	4,000	8,555	6.38
7,000	7,000	6.60	7,000	10,350	7.72
8,000	7,000	6.60	8,000	10,700	7.98

TABLE II

Distance and Time Required to Recover Low Level Flight
Altitude After Avoidance of Obstacles of Different
Heights. (Maximum negative 2g assumed)

M 0.95			M 1.2		
h(ft)	d(ft)	time (sec)	h(ft)	d(ft)	time (sec)
200	2,637	2.48	200	3,340	2.49
400	3,720	3.51	400	4,714	3.52
600	4,540	4.28	600	5,763	4.30
800	5,227	4.93	800	6,643	4.96
1,000	5,830	5.49	1,000	7,413	5.53
2,000	8,120	7.65	2,000	10,385	7.75
4,000	11,130	10.49	4,000	14,410	10.75
8,000	14,680	13.84	8,000	19,590	14.62

2g negative without physiological damage. Unfortunately there are no protective devices that can be used to increase pilot tolerance to negative g. This physiological limit then defines the over-shoot that will occur after clearance of any obstacle. Assuming a permitted 2g negative tolerance, calculations of this "over-shoot" have been made for several obstacle heights. These values are given in Table II and shown graphically in Figure 3.

3.4 POSITIVE G-FORCE LOADING AND VISION

Repeated application of g forces results in other physiological modifications that may effect design decisions. Among the physiological functions that are altered by g stress is vision. The pilot need not be exposed to g levels that result in "dim-out" or blackout to show visual responses to acceleration. While these visual effects have not been studied extensively to date, there is sufficient data to show that a problem exists. W. J. White (1956, et sub) and others have examined the effects of positive acceleration on the relationship between illumination and instrument reading and also the variation in absolute visual thresholds during accelerative stress. In the first study the total error increased directly as a function of g (up to 4g) and inversely as a function of brightness at illumination levels of 0.042 millilamberts and below. Warrick and Lund (1946) had previously shown that errors in instrument reading increased from 18 percent at 1.5g to 24 percent at 3g. White has also shown that acceleration levels of 3 and 4g approximately doubles and triples foveal threshold, and the threshold levels in peripheral vision triple at 3g and quadruple at 4g. Both thresholds are effected by g levels as low as 2g. These effects are compensated for in part by use of anti-g suits.

3.5 NEGATIVE G-FORCE LOADING AND VISION

There appears to be very little systematic data on the effects of negative g on vision. There have been cases reported of blurred vision at 2g negative and doubling of vision at 3g negative. Some preliminary studies by Sieker (1952) would indicate that the use of counterpressure in a full pressure helmet

may help to alleviate these systems, however, this observation has not been confirmed or investigated and may be related to the fact that the counter pressure protects against the mechanical deformation of the eyeball which would effect vision without influencing tolerance to negative g.

Additional studies of the effects of g loading on visual functions are needed before an accurate assessment of the seriousness of the problem can be made.

4.0 CONCLUSIONS

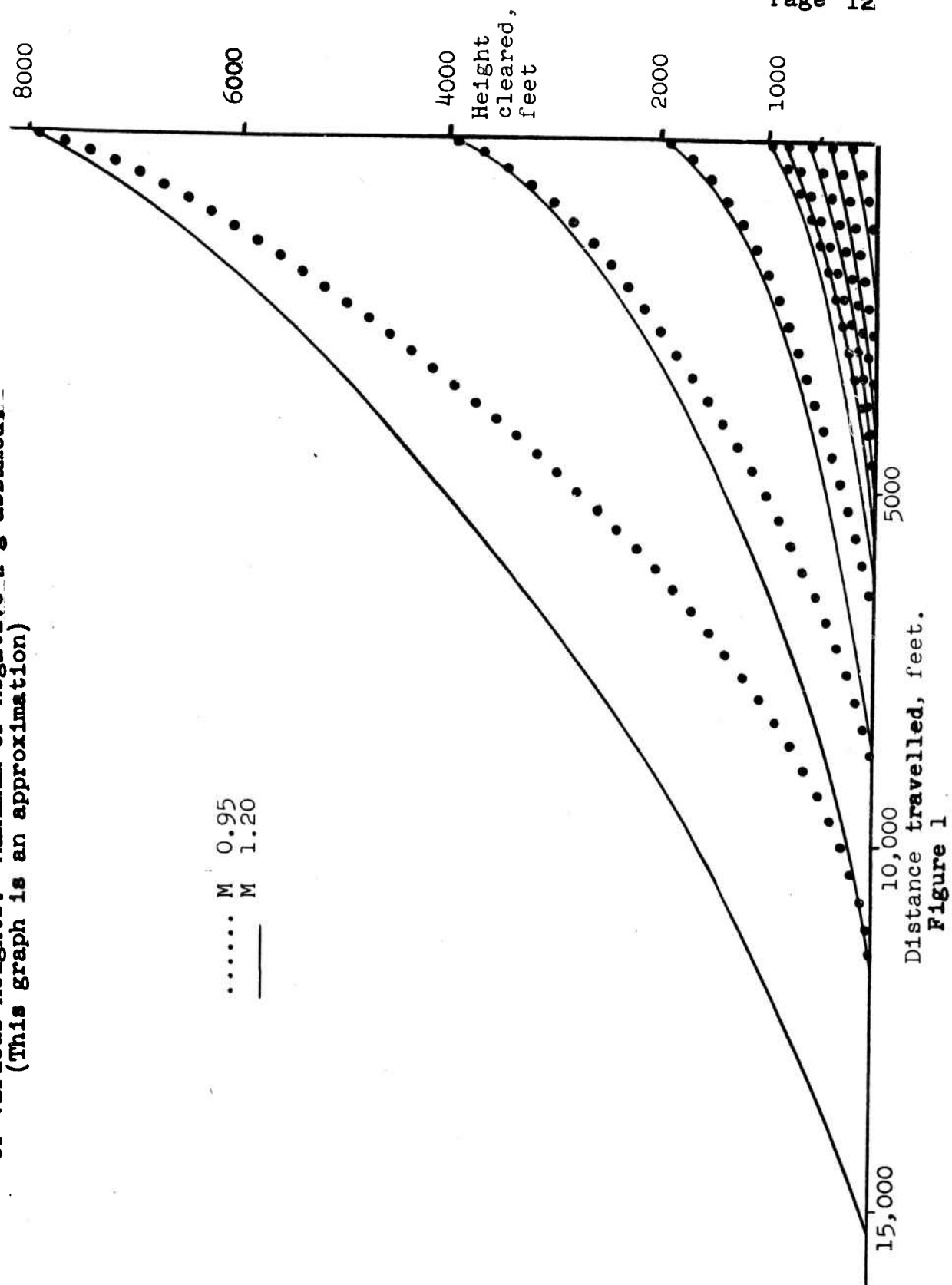
Accelerative forces acting on the pilot serve as a severe limitation on low level, high speed terrain following operations. The physiological restrictions imposed by acceleration forces essentially define the flight path permitted and hence restrict the altitudes that can be maintained over any defined terrain. While some benefit can be derived by the use of anti-g suits for positive g forces, the physiological limitations are not apparent when an attempt is made to control overshoot after passing over a barrier. At this time negative g forces are applied to the pilot.

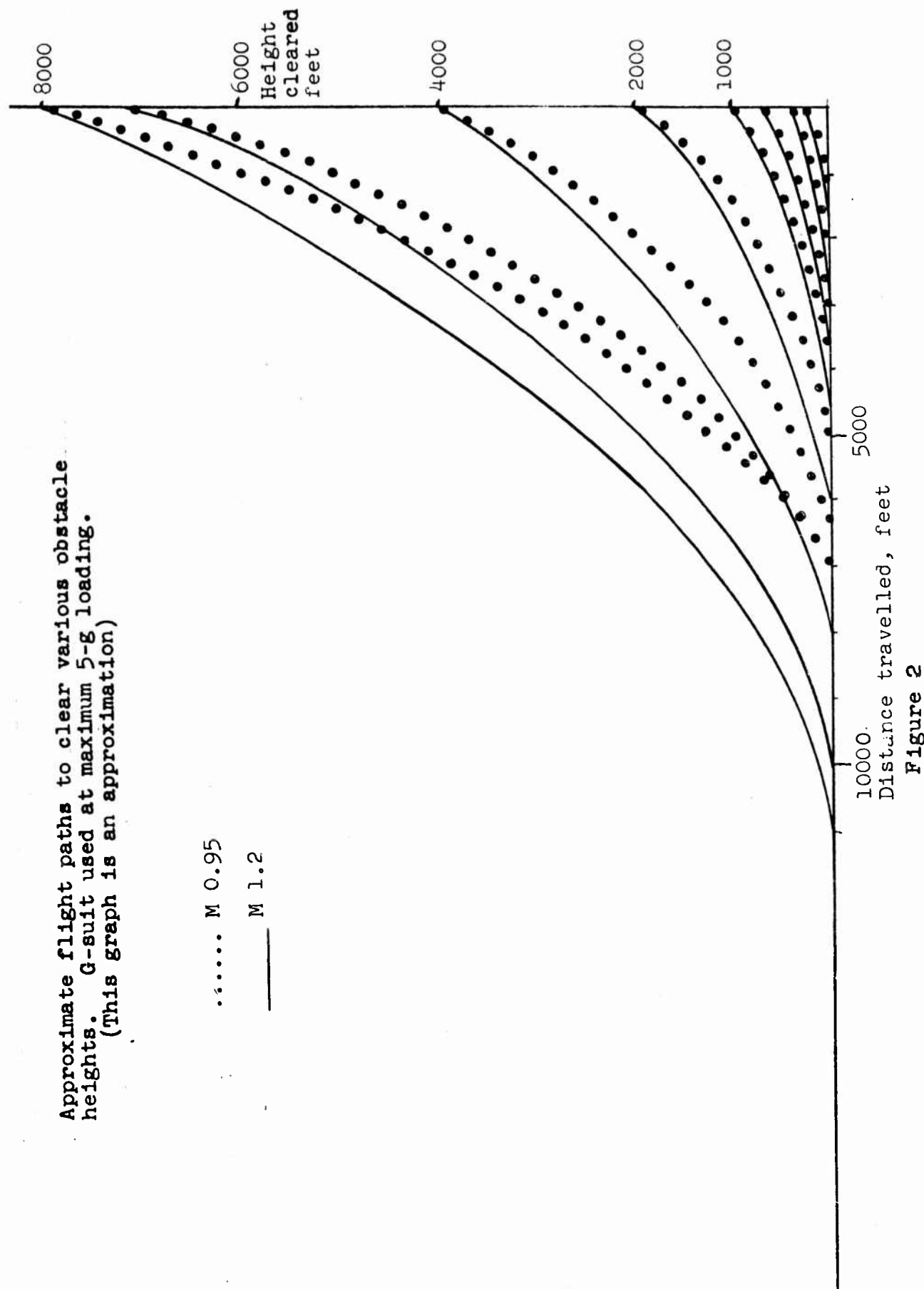
Some evidence is available to show that repeated application of g-forces may effect physiological parameters other than tolerance and may thus be of importance in defining performance characteristics or limits. More work must be done on the effects of g-loading on these parameters before a reasonable assessment can be made.

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Approximate flight paths after clearance of obstacles
of various heights. Maximum of negative 2-g assumed.
(This graph is an approximation)





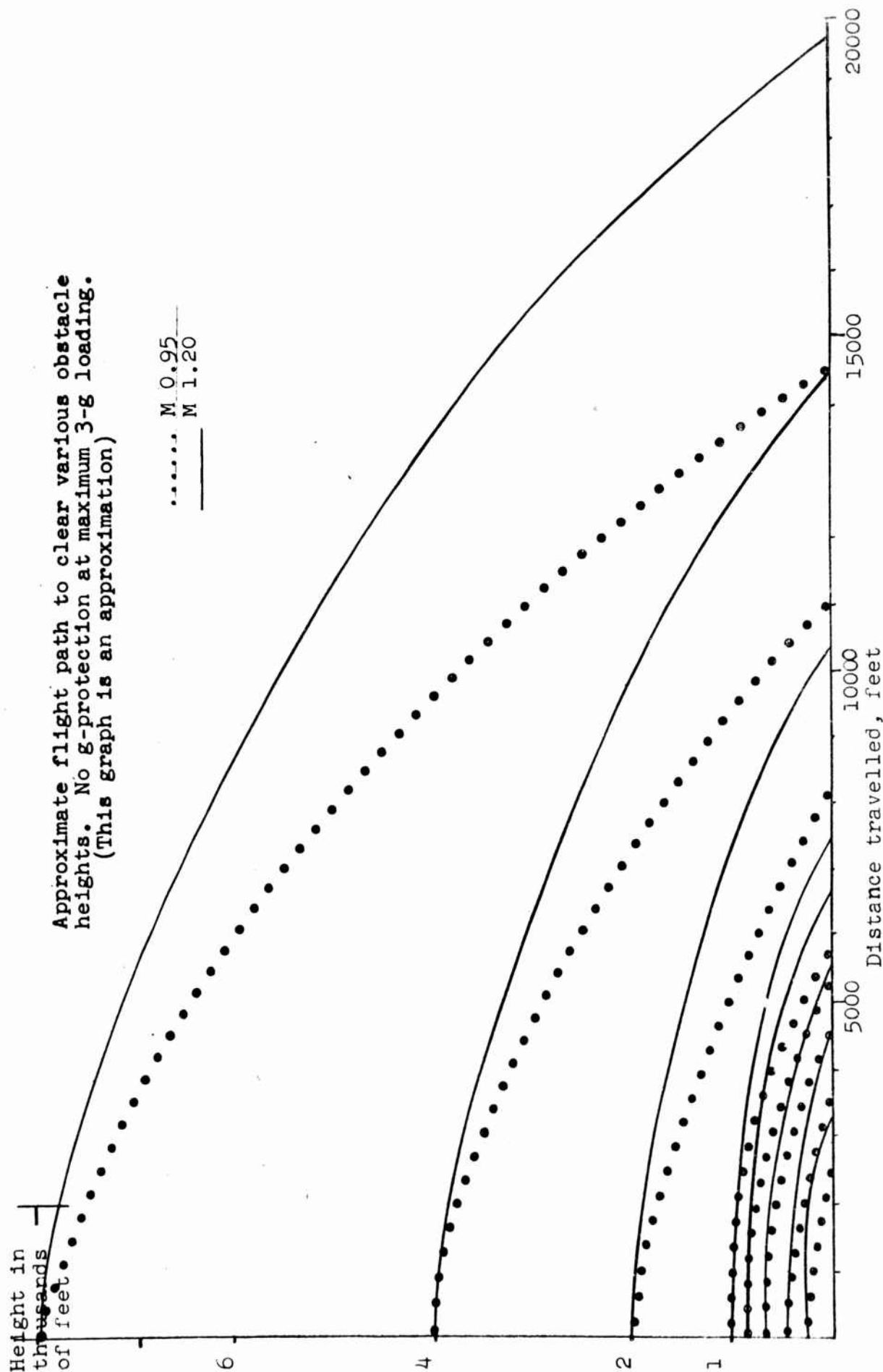


Figure 3