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Calculation of the Initial Phase of the Trajectory in the Pitching Plane of the Velvet Glove Missile when launched from the CF-100 Aircraft.

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A. V. Roe.

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SUBJECT

CALCULATION OF THE INITIAL PHASE OF THE TRAJECTORY IN THE PITCHING PLANE OF THE VELVET GLOVE MISSILE WHEN LAUNCHED FROM THE CF-100 AIRCRAFT. (INBOARD UNDER-WING POS'N)

PREPARED BY D. G. Gould

ISSUED TO Internal

SUMMARY

Preliminary calculations of the trajectory of the Velvet Glove missile when launched from the present under-wing position with zero tip-off distance and 2 ft. of guided travel showed that the peak pitch oscillation of the missile from the flight path direction amounted to 15°. Guidance considerations require that the maximum transient rotation of the missile axis must be less than $\pm 6^{\circ}$. The effect of length of guided travel, and fore and aft positioning of the launcher on the wing, on the pitch trajectory of the missile has been investigated in this memorandum. It was concluded that the best compromise to give a suitable trajectory from an under-wing position on the CF-100 was to shift the pylon 1 ft. farther aft of the wing leading edge than the present position and use 1 ft. of guided travel with zero tip-off distance. It is believed that this is possible on the CF-100 by shifting the pylons inboard on the wing. A proposed location has been given.

Some general conclusions regarding launcher configuration and launching positions may be made as a result of the trajectory computations made in this memorandum and those made in References 1 and 2.

(i) Tip-off should be avoided if possible. If tip-off is used the pitching trajectory of the missile would be expected to depend considerably on the lift coefficient and normal acceleration of the launching aircraft.

(ii) A finite length of travel with the missile restrained in pitch and yaw is desirable. A length of guided travel allows the missile to accelerate to a finite velocity relative to the launching aircraft before release. Hence the time interval that the missile is in the flow field induced by the launching aircraft and free to build up large pitch velocities is reduced. The amount of finite travel that should be provided may vary with the installation. A length of travel of between 1 and 2 ft. seems to be the most desirable.

(iii) The effect of launcher incidence (within limits) on the pitching trajectory is small with zero tip-off distance.

(iv) The pitching trajectory may vary considerably with changes in the fore and aft position of the missile on the wing. In general it is desirable to keep the missile and launcher as far aft as possible on the wing where the flow field is more uniform. The missile then has an opportunity to accelerate to a larger velocity relative to the aircraft before it passes through the flow field near the wing leading edge where the major pitching disturbances occur.

CALCULATION OF THE INITIAL PHASE OF THE TRAJECTORY IN THE PITCHING PLANE OF THE VELVET GLOVE MISSILE WHEN LAUNCHED FROM THE CF-100 AIRCRAFT. (INBOARD UNDER-WING POS'N)

1. INTRODUCTION

A semi-experimental method of investigating the effects of aerodynamic interference induced by the launching aircraft on the pitching trajectory of an air launched guided missile was described in Reference 1. In Reference 1 the method was used to investigate the effects of stowed missile incidence and tip-off distance on the pitching trajectory of the Velvet Glove missile when launched from an under-wing position on the F86E. The same method was used in Reference 2 to investigate the effects of tip-off distance on the pitching trajectory of the Velvet Glove missile when launched from two under-nacelle positions on the CF-100. Some conclusions can be made from the above investigations that may be applied with reservations to launches from different positions and from different aircraft. These are:

(i) Tip-off should be avoided if possible. If tip-off is used the pitching trajectory of the missile would be expected to depend considerably on lift coefficient and normal acceleration of the launching aircraft.

(ii) A finite length of travel with the missile restrained in pitch and yaw is desirable. A length of guided travel allows the missile to accelerate to a finite velocity relative to the launching aircraft before release. Hence the time interval that the missile is in the flow field induced by the launching aircraft and free to build up pitch velocities is reduced.

(iii) The effect of launcher incidence on the pitching trajectory is small with zero tip-off distance.

The investigations given in References 1 and 2 showed that the under-wing position on the F86E and the under-nacelle positions on the CF-100 were satisfactory from the launching point of view using zero tip-off distance and guided travel of two feet.

An under-wing position for stowing four Velvet Glove missiles has also been proposed for the CF-100. It was felt that the suitability of the under-wing position should be investigated from a launching point of view in the same manner as had been done for the F86E under-wing and CF-100 under-nacelle positions.

This memorandum presents preliminary results of the investigation since it was found that the present position was unsuitable with zero tip-off distance and a guided travel of two feet. Recommendations are made for re-positioning of the under-wing missiles to give trajectories having more desirable characteristics.

2. DESCRIPTION OF FULL SCALE INSTALLATION

Pertinent missile physical and aerodynamic characteristics are given in Reference 1. The distance the missile travels with rear lugs only on the rails has been called tip-off distance as defined in Reference 1 and may be varied from 3.54 ft. to 0 ft. The initial guided travel of the missile with two sets of lugs on the rails (restrained in pitch and yaw) is 2.0 feet on the present installation. This may be reduced by providing a third slot in the forward part of the rails for the first set of lugs.

The location of the missiles in the stowed position for both the under-nacelle and under-wing installations is shown in Figure 1. The launching rail direction is parallel to the fuselage reference line (-1.5° to the wing chord).

3. METHOD AND SCOPE OF INVESTIGATION

The method used was identical to that described in Reference 1. The normal force and pitching moment acting on a missile model were measured with the missile in the vicinity of a 1/10 scale CF-100 model at a number of stations in the pitching plane of the trajectory.

The coordinates of the various stations and the corresponding missile effective angle of attack and zero-lift pitching moment coefficient are tabulated in Tables 1, 2 and 3 for the inboard under-wing position at aircraft lift coefficients of 0.118, 0.374 and 0.73.

The present memorandum presents the results of trajectories computed at aircraft lift coefficients of 0.118 and 0.374 only. The effect of the for and aft position of the missile on the wing, reduction of the guided travel from 3 ft. to 0 ft, and the effect of adding 1.77 ft. of tip-off was investigated.

4. NOTATION

The notation used is the same as that of Reference 1, some of which is reproduced here for ready reference.

$\bar{X}$ = displacement of the missile centre of gravity in the direction of the launching rails relative to axes fixed in the launching aircraft.

$\bar{X}'$ = horizontal displacement of missile centre of gravity relative to axes fixed in the launching aircraft, taken equal to $\bar{X}$ in this memorandum.

$\bar{Z}$ = displacement of the missile centre of gravity relative to axes fixed in the launching aircraft and in a direction perpendicular to $\bar{X}$, positive downward.

$\bar{Z}'$ = vertical displacement of the missile centre of gravity, positive downward.

Θ = angular position of missile axis relative to launching rail direction, positive for downward rotation.

Θ' = angular position of missile axis relative to horizontal flight path, positive for downward rotation.

$\frac{d\Theta}{dt}$ = angular velocity of missile axis in pitch plane, degrees/second, positive for downward rotation.

5. RESULTS AND DISCUSSION

The first trajectory was computed using the following initial conditions:

(i) Mach number of launching aircraft = 0.80
(ii) Altitude of launching aircraft = 15,000 ft.
(iii) Lift coefficient of launching aircraft = 0.118
(iv) Level flight.
(v) Tip-off distance = 0 ft.
(vi) Launching rail incidence relative to fuselage datum line = 0°
(vii) A guided travel of 2 ft. during which the missile is restrained in pitch and yaw.
(viii) Pylon position normal (Figure 1(b))

The vertical displacement of the missile centre of gravity, $\bar{Z}'$, the angular position of the missile axis relative to the horizontal, Θ', and the angular velocity of the missile axis, $\frac{d\Theta}{dt}$, are plotted for this case against the horizontal displacement of the missile centre of gravity relative to the launching aircraft, $\bar{X}'$, in Figures 2(a), 2(b) and 2(c) for values of $\bar{X}'$ up to 135 ft. The missile pitched upward to a value of $\Theta' = -15.2°$ at $\bar{X}' = 54$ ft. and was displaced upward to $\bar{Z}' = -49.5$ ft. at $\bar{X}' = 130$ ft. as shown in Figures 2(a) and 2(b). CARDE has requested that the transient pitch oscillation should be kept to 6° or less since the missile must remain locked on the target during the boost period. Furthermore the maximum normal acceleration experienced by the missile during this period amounted to 18g. The present PTV type vehicle is only stressed to $\pm$ 15g yield.

Various changes in initial conditions were tried in an attempt to decrease the magnitude of the transient pitch oscillation of the missile. These are shown in Figures 2(a) 2(b) and 2(c). A decrease of 1° in the launching rail incidence resulted in an increase in the peak value of Θ' to -18.4°. The maximum normal acceleration was increased to 21g. An aft movement of the pylon from the present position of 1 ft. reduced the peak value of Θ' to -12.5° and the maximum normal acceleration to 15.5g. The guided travel was reduced from 2 ft. to 1 ft. with the pylon in the normal position. The results were almost identical to those obtained by using 2 ft. of guided travel and moving the pylon aft 1 ft. One case was computed with the pylon in the normal position, 2 ft. of guided travel with two sets of lugs on the rails and a tip-off distance of 1.77 ft. This implies that the rear lugs remain on the rails for an additional 1.77 ft. of travel. During this time the missile is free to pitch about the rear lugs. This resulted in a reduction of the peak value of Θ' to -11.3° and a maximum normal acceleration of 14.2 g. An aft movement of the pylon of 2 ft. from the present position with 2 ft. of guided travel and zero tip-off distance resulted in a satisfactory trajectory. The peak angular displacement of the missile axis, Θ', amounted to -6.6° and the maximum normal acceleration experienced by the missile was 8.7g.

It seems likely that the peak value of Θ' could be reduced by increasing the tip-off distance beyond 1.77 ft. It is felt, however, that tip-off should be avoided if possible since the missile trajectory would be expected to depend considerably on the lift coefficient and normal acceleration of the launching aircraft. (See Section 1 and Reference 2). A satisfactory trajectory was computed if the pylon was moved aft 2 ft. from its present position. This is physically impossible without prohibiting use of the dive brakes since the trailing edge of the missile would have to overlap the existing dive brake position. It was therefore felt that the effect on the trajectory of a combination of a fore and aft movement of the pylon and a variation in the amount of guided travel should be investigated more thoroughly.

The trajectories computed and shown in Figures 2(a), 2(b) and 2(c) require about one week of computation time per trajectory. It was felt that an approximation to the angular velocity and position of the missile axis during the interval when the missile is in the flow field induced by the launching aircraft would be useful in qualitatively arriving at the best initial conditions.

The approximate values of θ and $\frac{d\theta}{dt}$ during this period can be calculated much more quickly than using the method employed for the trajectories in Figure 2. The procedure used in approximating θ and $\frac{d\theta}{dt}$ was

(i) The time vs. Mach number and time vs. $\bar{X}$ curves are assumed to be the same for all trajectories computed for the same launching Mach number, altitude and lift coefficient.

(ii) The missile centre of gravity position is given as a function of time (Reference 1). The neutral point position is given as a function of Mach number but can be converted to a function of time using (i). Hence the missile static margin may be computed as a function of time.

(iii) The zero lift moment coefficient, C_{M_o}, and effective angle of attack, α_e, as obtained from the wind tunnel measurements is a function of $\bar{X}$. This data can be converted to a function of time and corrected for compressibility using (i).

(iv) The dynamic pressure, q, can be obtained as a function of time using (i).

(v) The missile moment of inertia, $I_{c.g.}$, is given as function of time in Reference 1.

(vi) The assumption is then made that the angular acceleration of the missile axis is given by

$$\frac{d^2\theta}{dt^2} = -\frac{qSc}{12\, I_{c.g.}}\left[C_{M_{o}} + C_{M_\alpha}\alpha_e\right]$$

where S and c are the wing reference area and wing chord respectively. The most important assumption made in the above equation is that the missile angle of attack is given by α_e. The missile angle of attack should be given by $\alpha_e - \theta$, plus a correction for the deviation of the instantaneous flight path direction from the launching rail direction. In determining $\ddot{\theta}$ during the period that the missile is in the flow field induced by the launching aircraft, the term $C_{M_\alpha}\alpha_e$ is generally small compared to $C_{M_{o}}$. Hence the net effect on $\ddot{\theta}$ in making the above assumption is small.

(vii) A simple graphical integration of $\frac{d^2\theta}{dt^2}$ as a function of time gives $\frac{d\theta}{dt}$, and a second integration gives θ and θ'. The angular position and angular velocity of the missile axis as the missile leaves the flow field induced by the launching aircraft may be used in a qualitative manner to indicate whether or not the peak angular displacement of the missile axis will be large. Only about one half day's computation time is required to compute $\frac{d\theta}{dt}$ and θ for a given set of initial conditions using this method.

The results of the investigations made using this method are shown in Figures 3(a), 3(b) for a lift coefficient of 0.118 and in Figures 4(a) and 4(b) for a lift coefficient of 0.374. In all cases the tip-off distance was taken as zero. Of the cases computed at $C_L = 0.118$, four pylon configurations resulted in angular velocities of the missile axis less than 0.85 radians per second when the missile was free of the flow field induced by the launching aircraft (Figure 3(b)). These were:

(i) Pylon moved aft 2 ft. with 2 ft. of guided travel.
(ii) Pylon moved aft 1 ft. with 1 ft. of guided travel.
(iii) Pylon moved forward 1 ft. with 0 guided travel.
(iv) Pylon in normal position with 0 guided travel.

The other two cases computed, the pylon in the normal position and 3 ft. of guided travel and the pylon moved forward 1 ft. with 1 ft. of guided travel gave values of $d\theta/dt$ from 1.6 to 1.9 when the missile was free of the induced flow field.

Of the four cases above, case (iv) with the pylon in the normal position and zero guided travel may be discarded since the value of θ' reached 16° during the initial phase of the trajectory. (Figure 3(a)).

At a lift coefficient of 0.374, the resultant angular velocity of the missile axis was less than 0.50 radians per second for all cases. The values of θ' at $C_L = 0.374$ ranged from -4.7° to 7° for all cases except that for zero guided travel with the pylon in the normal position. The values of $\frac{d\theta}{dt}$ and θ' for these cases at $C_L = 0.374$ are given in Figures 4(a) and 4(b).

Of the pylon configurations investigated, the ones that indicated that the trajectory characteristics would be suitable were:

(i) Pylon moved aft 2 ft. with 2 ft. of guided travel.
(ii) Pylon moved aft 1 ft. with 1 ft. of guided travel.
(iii) Pylon moved forward 1 ft. with 0 guided travel.

Figures 3(a) and 3(b) show that with 0 guided travel the resultant θ' and $\frac{d\theta}{dt}$ are very dependent on the fore and aft location of the pylon. θ' changed by 14° and $\frac{d\theta}{dt}$ by 1.4 radians per second when the pylon was shifted 1 ft. forward. Hence this type of launcher is probably very sensitive to fore and aft movements of the flow field velocity components. Such movements may be expected at high Mach numbers and have not been taken into account. The physical difficulties in moving the pylon aft 2 ft. have been discussed previously. It was concluded, therefore, that the best compromise in launcher configuration would be case (ii) with the pylon moved aft 1 ft. and only 1 ft. of guided travel.

The possibility of re-positioning the pylon on the CF-100 aircraft to meet the requirements for case (ii) was investigated. A proposed location for the under-wing pylons is given in Figure 6. The pylons have been shifted inboard from the present position and may be shifted aft 13 inches and still maintain ground clearance in the critical landing condition. It is felt the proposed position relative to the dive brakes is probably more favourable than the present location from the point of view of possible blast damage to the dive brakes. No consideration was given to the structural details involved in attaching the pylons at the proposed location.

Trajectories were computed for case (ii) as far forward as $\bar{X}' = 130$ ft. at aircraft lift coefficients of 0.118 and 0.374. These are shown in Figures 2(a), 2(b), 2(c), 5(a), 5(b), and 5(c). At $C_L = 0.118$, θ' reached a peak value of -6.6° at $\bar{X}' = 60$ ft. and $\bar{Z}'$ was -8 ft. at $\bar{X}' = 130$ ft. At $C_L = 0.374$, θ' reached a peak value of -7.6° at $\bar{X}' = 68$ ft. and $\bar{Z}'$ was -16 ft. at $\bar{X}' = 130$ ft.

The possibility of fouling between the missile fin and the pylon is increased by decreasing the guided travel to 1 ft. It seems doubtful if there is any real danger of fouling except under very severe flight conditions at the instant of launch.

The selection of the present pylon configuration using 1 ft. of guided travel and moving the pylon 1 ft. aft was made primarily on the basis of computations done at M = 0.80, altitude = 15,000 ft. C_L = 0.118. This represents the flight configuration giving maximum q in the altitude range from 15,000 to 30,000 ft. The variation of the zero lift moment coefficient of the missile at a given station with aircraft lift coefficient is not large. This term in general is of a much larger magnitude than the other aerodynamic pitching moment coefficients. Therefore the angular acceleration in pitch and the angular deviation of the missile axis from the flight path direction is approximately proportional to the dynamic pressure q. Hence the assumption that the high q launching case is the most critical is probably justified.

6. CONCLUSIONS

Preliminary computations of the trajectory of the Velvet Glove missile when launched from the present under-wing position showed that for the launching case of M = 0.80, altitude = 15,000 ft., C_L = 0.118, zero tip-off distance, 2 ft. of guided travel, the peak angular displacement of the missile axis from the flight path direction amounted to 15.2°. Guidance considerations require that the maximum transient rotation of the missile axis from the flight path direction be kept within 6°. Possible methods of reducing the pitch oscillation of the missile have been investigated in this memorandum. The amount of guided travel with the missile restrained in pitch and yaw was varied from 0 ft. to 3 ft. The fore and aft position of the missile on the wing was varied from 2 ft. aft of the present position to 1 ft. forward of the present position. One case was computed with the launching rail direction decreased 1 degree from the present direction. The effect of 1.77 ft. of tip-off distance with a guided travel of 2 ft. was calculated.

Of the configurations investigated, three cases gave suitable trajectory characteristics. These were:

(i) Pylon moved aft 2 ft. with 2 ft. of guided travel. zero tip-off distance.

(ii) Pylon moved aft 1 ft. with 1 ft. of guided travel, zero tip-off distance.

(iii) Pylon moved forward 1 ft. with 0 ft. of guided travel.

Case (i) is physically impossible since the pylon and missile would have to overlap the aircraft dive brakes. It has been shown that although a suitable trajectory may be obtained by using a zero length launcher and moving the pylon forward, the correct fore and aft positioning of the missile and pylon is very critical.

It was concluded, therefore, that the best compromise to give a suitable trajectory was to use configuration (ii). A preliminary investigation was made to see if it was physically possible to shift the pylons aft 1 ft. and still maintain sufficient ground clearance and clearance between the missile and dive brakes. It was found that this was possible by shifting the pylons inboard on the wing. A proposed re-location of the pylons on the wing has therefore been made.

Some general conclusions regarding launcher configuration and launching positions may be made asa result of the trajectory computations made in this memorandum and those made in References 1 and 2.

(i) Tip-off should be avoided if possible. If tip-off is used the pitching trajectory of the missile would be expected to depend considerably on the lift coefficient and normal acceleration of the launching aircraft.

(ii) A finite length of travel with the missile restrained in pitch and yaw is desirable. A length of guided travel allows the missile to accelerate to a finite velocity relative to the launching aircraft before release. Hence the time interval that the missile is in the flow field induced by the launching aircraft and free to build up large pitch velocities is reduced. The amount of finite travel that should be provided may vary with the installation. A length of travel of between 1 and 2 ft. seems to be the most desirable.

(iii) The effect of launcher incidence (within limits) on the pitching trajectory is small with zero tip-off distance.

(iv) The pitching trajectory may vary considerably with changes in the fore and aft position of the missle on the wing. In general it is desirable to keep the missile and launcher as far aft as possible on the wing where the flow field is more uniform. The missile then has an opportunity to accelerate to a larger velocity relative to the aircraft before it passes through the flow field near the wing leading edge where the major pitching disturbances occur.

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2. GOULD, D.G. Estimates of the Initial Phase of the Trajectory in the Pitching Plane of the Velvet Glove Missile when Launched from the CF-100 Aircraft (Under-Nacelle Position). NAE Lab. Memo FR-16(b).

TABLE 1

$C_L = 0.118$

SECRET

STATION	$\bar{X}$	$\bar{Z}$	θ	α_e	C_{m_0}
A_0	0	0	0.08	-3.28	-0.281
A_2	2.00	0	0.28	-2.79	-0.079
A_3	2.83	0	0.08	-1.33	0.095
			2.43	-4.09	0.094
			4.44	-6.90	0.123
A_4	3.66	0	0.28	-0.67	0.186
			2.58	-4.00	0.222
			4.59	-6.32	0.251
A_5	4.50	0	0.28	-0.50	0.252
			2.37	-3.17	0.286
			4.74	-6.07	0.314
A_6	5.54	0	0.28	-0.46	0.284
			2.58	-3.10	0.302
			4.74	-6.11	0.320
A_7	6.79	0	0.28	0.30	0.202
			2.58	-2.32	0.215
			4.94	-4.93	0.200
A_8	8.04	0	0.72	0.80	0.052
			2.86	-1.44	0.045
			4.37	-3.78	0.036
A_9	9.29	0	0.72	0.90	0.003
			2.93	-1.42	-0.009
			4.81	-3.12	-0.007
A_{10}	10.54	0	0.43	1.11	-0.006
			2.72	-1.01	-0.016
			4.81	-3.16	-0.020
A_{11}	11.79	0	0.43	1.06	-0.008
			2.58	-1.62	-0.020
			4.87	-3.27	-0.030
A_{12}	13.04	0	0.72	0.82	-0.019
			2.86	-1.51	-0.021
			4.87	-3.28	-0.027
A_{13}	14.29	0	0.72	0.86	-0.016
			2.86	-1.43	-0.017
			4.59	-3.87	-0.025

TABLE 2

$C_L = 0.374$

SECRET

STATION	$\bar{X}$	$\bar{Z}$	θ	α_e	C_{M_0}						
A_0	0	0	0.24	-0.79	-0.154						
A_2	2.00	0	0.45	2.42	0.112						
A_3	2.83	0	0.38	3.03	0.224						
			2.82	0.27	0.265						
			4.68	-3.08	0.286						
A_4	3.66	0	0.52	4.08	0.296						
			2.81	1.05	0.333						
			4.68	-0.77	0.352						
A_5	4.50	0	-0.05	5.16	0.321						
			2.09	2.23	0.344						
			4.10	-0.76	0.369						
A_6	5.54	0	0.02	5.45	0.305						
			2.31	2.15	0.301						
			4.60	-0.06	0.309						
A_7	6.79	0	0.09	6.13	0.151						
			2.24	3.73	0.146						
			4.53	1.76	0.120						
A_8	8.04	0	0.09	6.98	0.042						
			1.80	4.24	-0.009						
			3.96	2.11	-0.015						
A_9	9.29	0	-0.05	6.69	-0.021						
			2.24	4.37	-0.052						
			4.39	2.05	-0.053						
A_{10}	10.54	0	0.09	6.34	-0.044						
			2.39	3.18	-0.056						
			4.82	1.90	-0.055						
A_{11}	11.79	0	0.67	4.95	-0.051						
			2.62	3.50	-0.047						
			4.68	1.53	-0.048						
A_{12}	13.04	0	1.52	4.26	-0.041						
			3.10	2.48	-0.041						
			3.53	-0.02	-0.078						
A_{13}	14.29	0	2.45	3.15	-0.031						
			4.40	1.16	-0.035						
			6.83	-1.34	-0.042						

TABLE 3

$C_L = 0.73$

SECRET

STATION	$\bar{X}$	$\bar{Z}$	θ	α_e	C_{M_o}
A_0	0	0	0.12	2.51	0.019
A_2	2.00	0	0.12	6.09	0.179
A_3	2.83	0	0.70	7.44	0.282
			2.71	4.56	0.276
			5.16	1.91	0.346
A_4	3.66	0	0.71	6.37	0.314
			2.79	5.40	0.301
A_5	4.50	0	0.70	9.83	0.357
			3.15	7.73	0.359
			5.38	4.98	0.363
A_6	5.54	0	1.29	10.09	0.310
			3.38	7.89	0.302
			5.31	5.79	0.288
A_7	6.79	0	1.28	12.69	0.114
			3.61	10.14	0.075
			6.02	7.09	0.043
A_8	8.04	0	1.28	13.07	-0.055
			3.51	9.85	-0.112
			5.95	7.42	-0.107
A_9	9.29	0	1.37	12.59	-0.113
			3.78	9.92	-0.138
			6.19	6.88	-0.132
A_{10}	10.54	0	2.00	11.64	-0.114
			4.07	8.90	-0.126
			6.19	6.10	-0.118
A_{11}	11.79	0	1.76	10.83	-0.090
			4.01	8.51	-0.112
			6.13	6.14	-0.125
A_{12}	13.04	0	1.76	10.40	-0.069
			4.01	7.97	-0.091
			6.07	5.50	-0.094
A_{13}	14.29	0	1.76	9.90	-0.055
			4.13	7.39	-0.072
			6.02	5.14	-0.076

TABLE 3

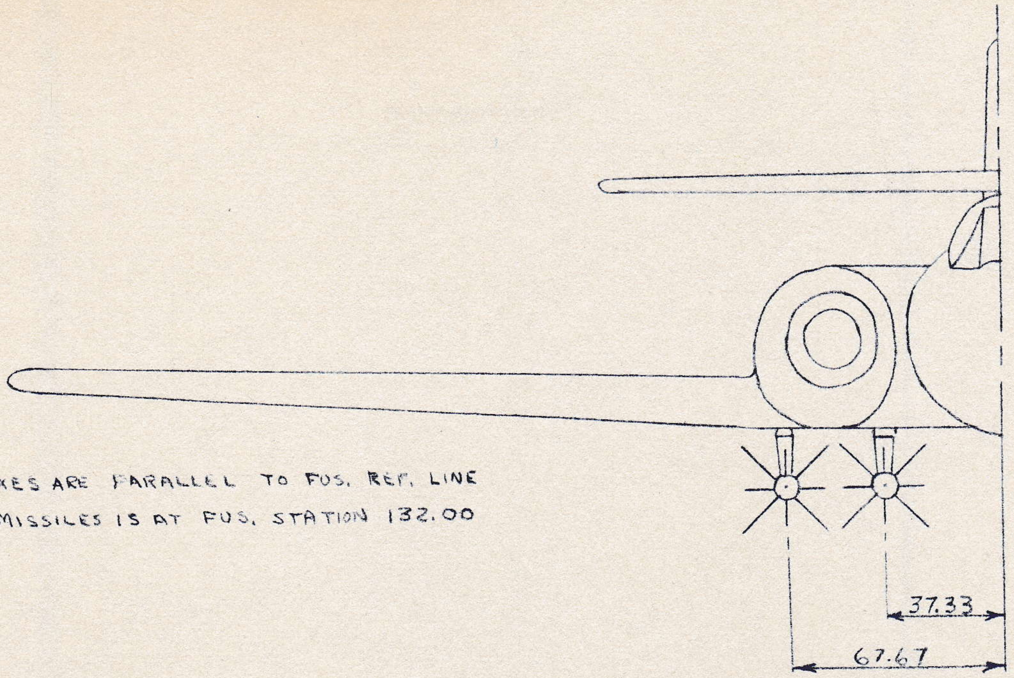
(cont.)

$C_L = 0.73$

SECRET

Station	$\bar{x}$	$\bar{z}$	θ	α_e	C_{M_0}						
B_7	6.79	1.00	2.57	9.79	0.111						
			4.58	7.39	0.115						
			6.23	5.70	0.085						
B_8	8.04	1.00	2.36	10.33	-0.010						
			4.66	7.87	-0.034						
			6.88	5.55	-0.035						
B_9	9.29	1.00	2.65	10.20	-0.072						
			4.65	7.90	-0.088						
			6.88	5.41	-0.107						
B_{10}	10.54	1.00	2.58	9.57	-0.084						
			4.87	7.10	-0.096						
			7.02	4.89	-0.108						
B_{11}	11.79	1.00	3.22	9.28	-0.078						
			4.58	6.90	-0.088						
			6.59	4.86	-0.093						
B_{12}	13.04	1.00	1.87	9.80	-0.047						
			4.44	7.02	-0.071						
			6.88	4.43	-0.073						
B_{13}	14.29	1.00	1.85	9.33	-0.040						
			4.23	6.79	-0.058						
			6.30	4.78	-0.058						

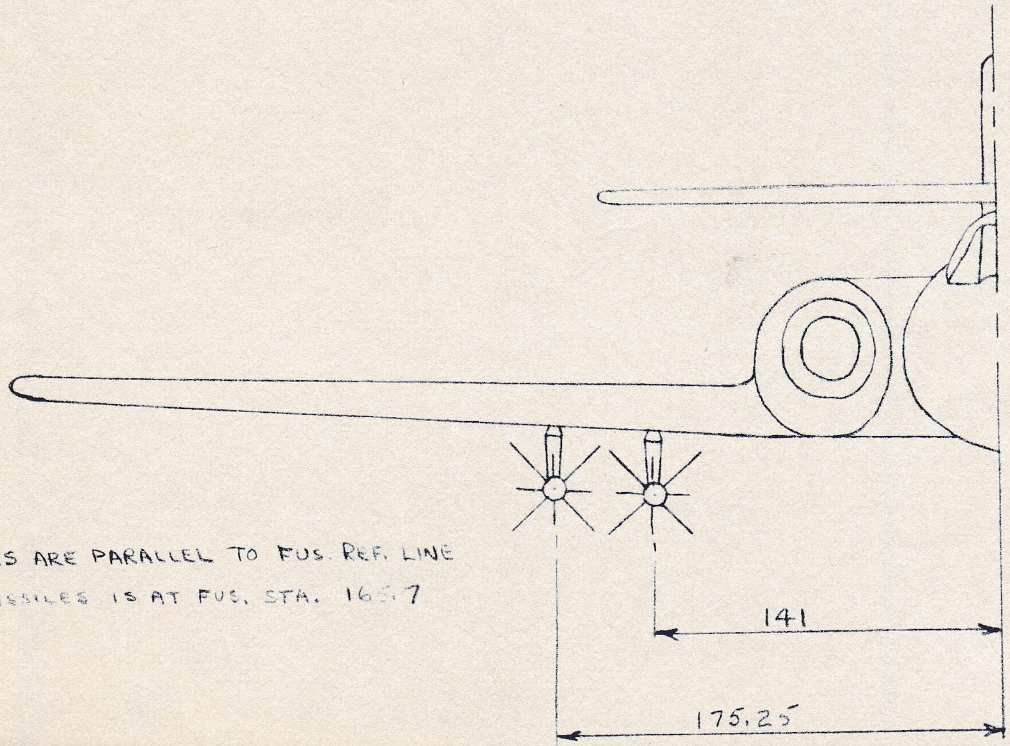
FIG. 1



NOTES:

1. MISSILE AXES ARE PARALLEL TO FUS. REF. LINE
2. NOSE OF MISSILES IS AT FUS. STATION 132.00

a) UNDER-NACELLE POS'N

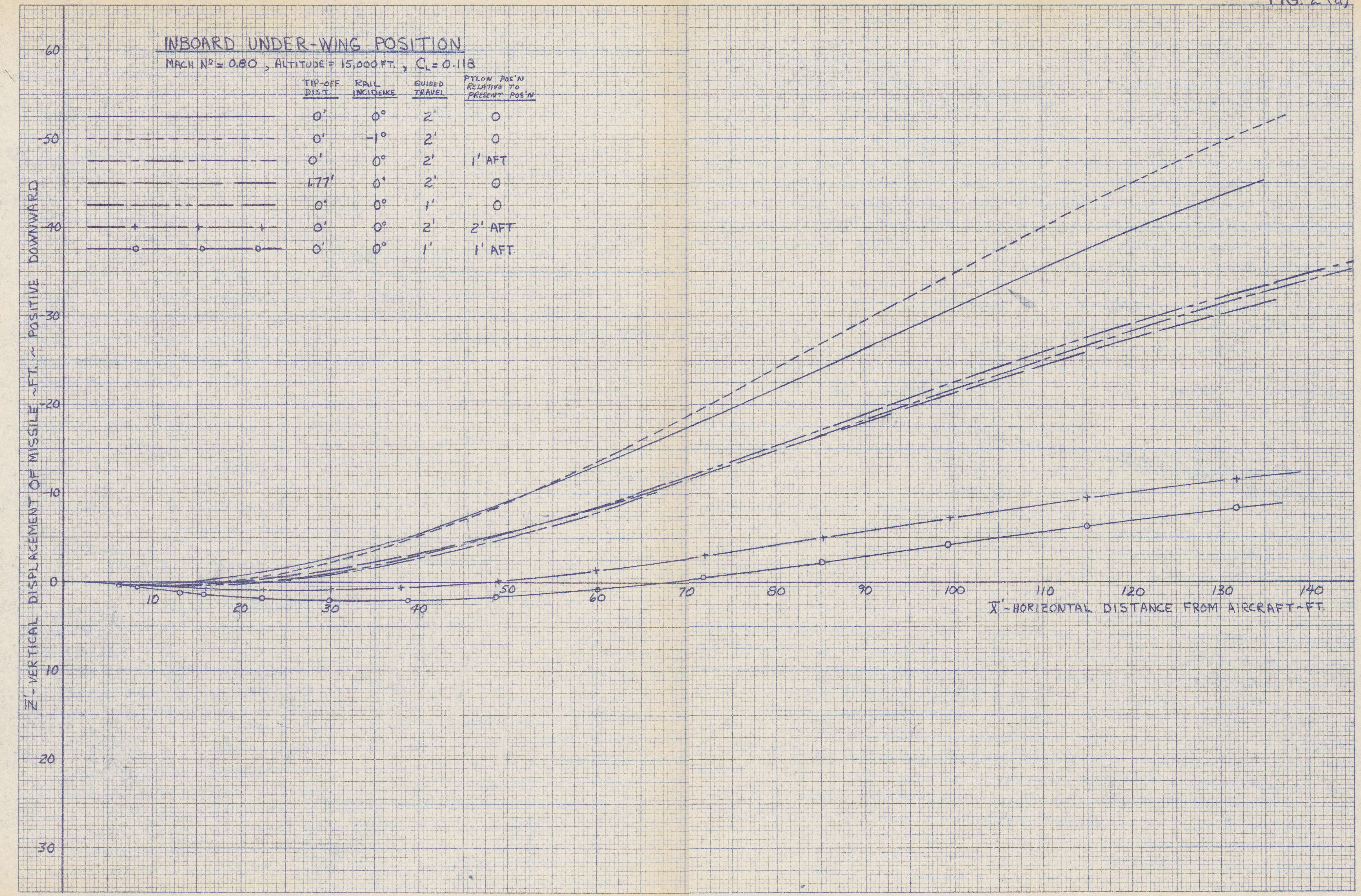


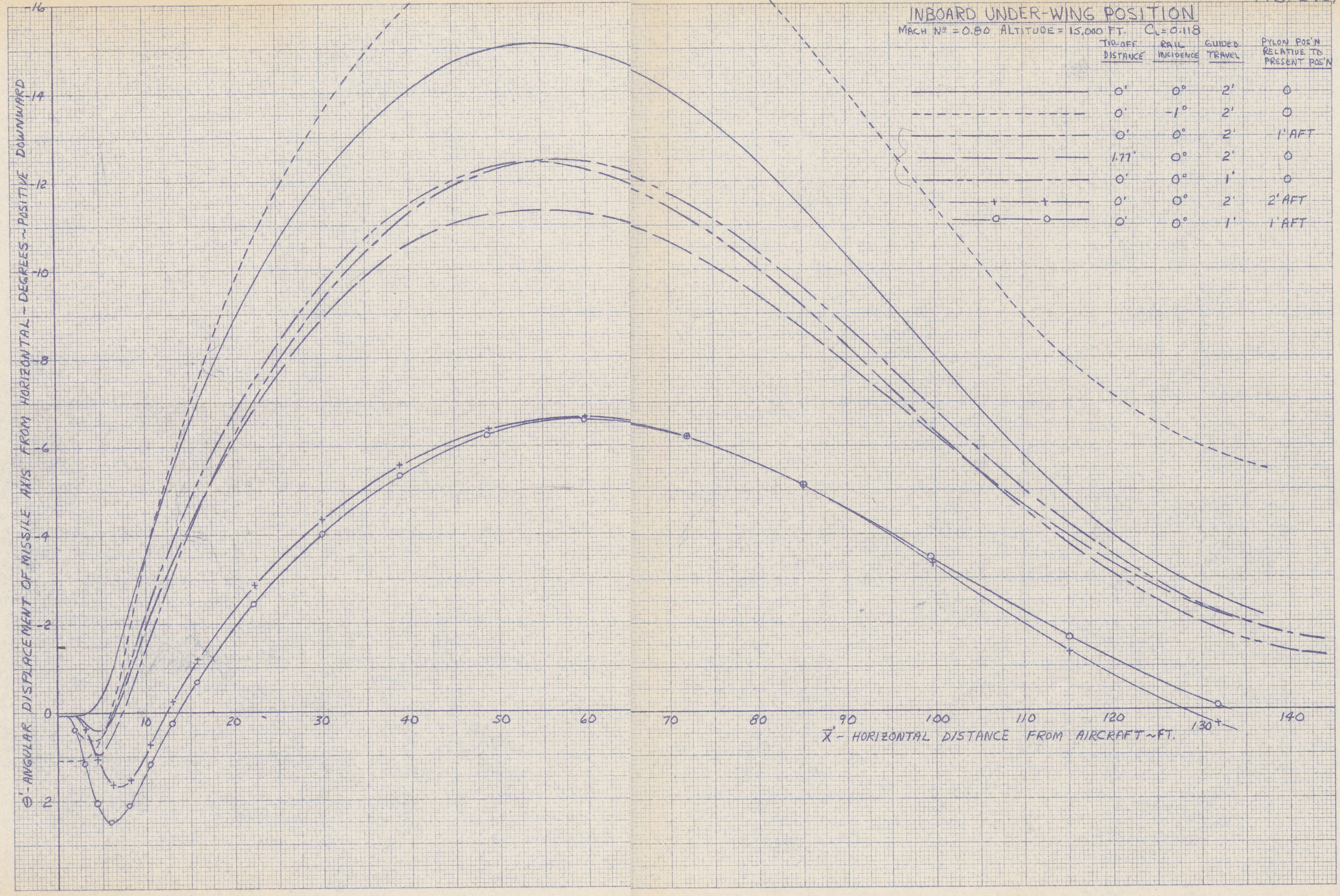
NOTES:

1. MISSILE AXES ARE PARALLEL TO FUS. REF. LINE
2. NOSE OF MISSILES IS AT FUS. STA. 165.7

b) UNDER-WING POS'N

STOWAGE POSITIONS OF VELVET GLOVE MISSILES ON CF-100 AIRCRAFT


INBOARD UNDER-WING POSITION
MACH N° = 0.80 , ALTITUDE = 15,000 FT. , C_L = 0.118
TIP-OFF DIST. | RAIL INCIDENCE | GUIDED TRAVEL | PYLON POS'N RELATIVE TO PRESENT POS'N
0' | 0° | 2' | 0
0' | -1° | 2' | 0
0' | 0° | 2' | 1' AFT
1.77' | 0° | 2' | 0
0' | 0° | 1' | 0
0' | 0° | 2' | 2' AFT
0' | 0° | 1' | 1' AFT
$\overline{Z}'$ - VERTICAL DISPLACEMENT OF MISSILE ~ FT. ~ POSITIVE DOWNWARD
$\overline{X}'$ - HORIZONTAL DISTANCE FROM AIRCRAFT ~ FT.



INBOARD UNDER-WING POSITION
MACH Nº = 0.80 ALTITUDE = 15,000 FT. C_L = 0.118
TIP-OFF DISTANCE
RAIL INCIDENCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0' 0° 2' 0
0' -1° 2' 0
0' 0° 2' 1' AFT
1.77' 0° 2' 0
0' 0° 1' 0
0' 0° 2' 2' AFT
0' 0° 1' 1' AFT
θ - ANGULAR DISPLACEMENT OF MISSILE AXIS FROM HORIZONTAL ~ DEGREES ~ POSITIVE DOWNWARD
X - HORIZONTAL DISTANCE FROM AIRCRAFT ~ FT.
-16
-14
-12
-10
-8
-6
-4
-2
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140

FIG. 2(b)

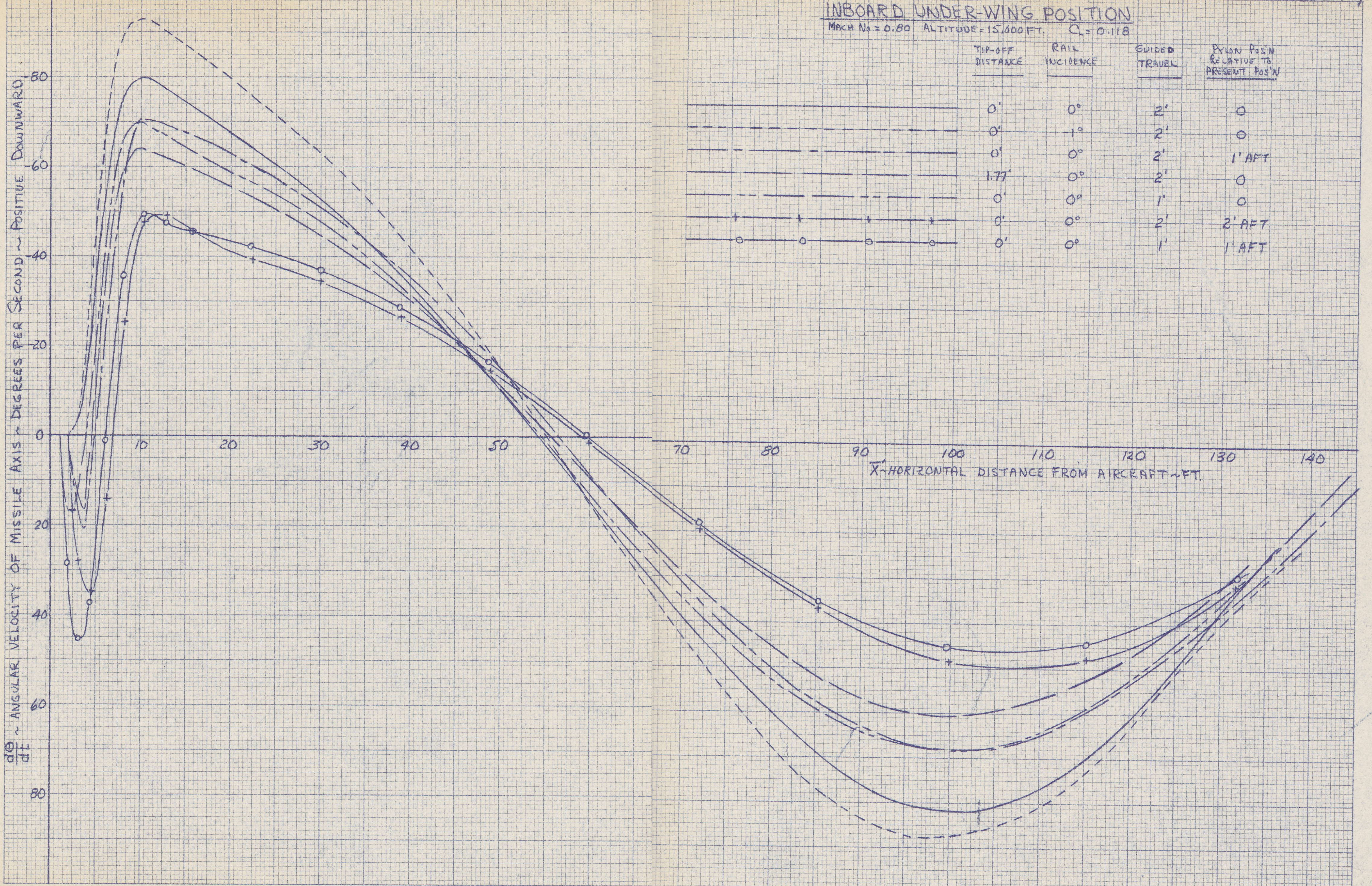
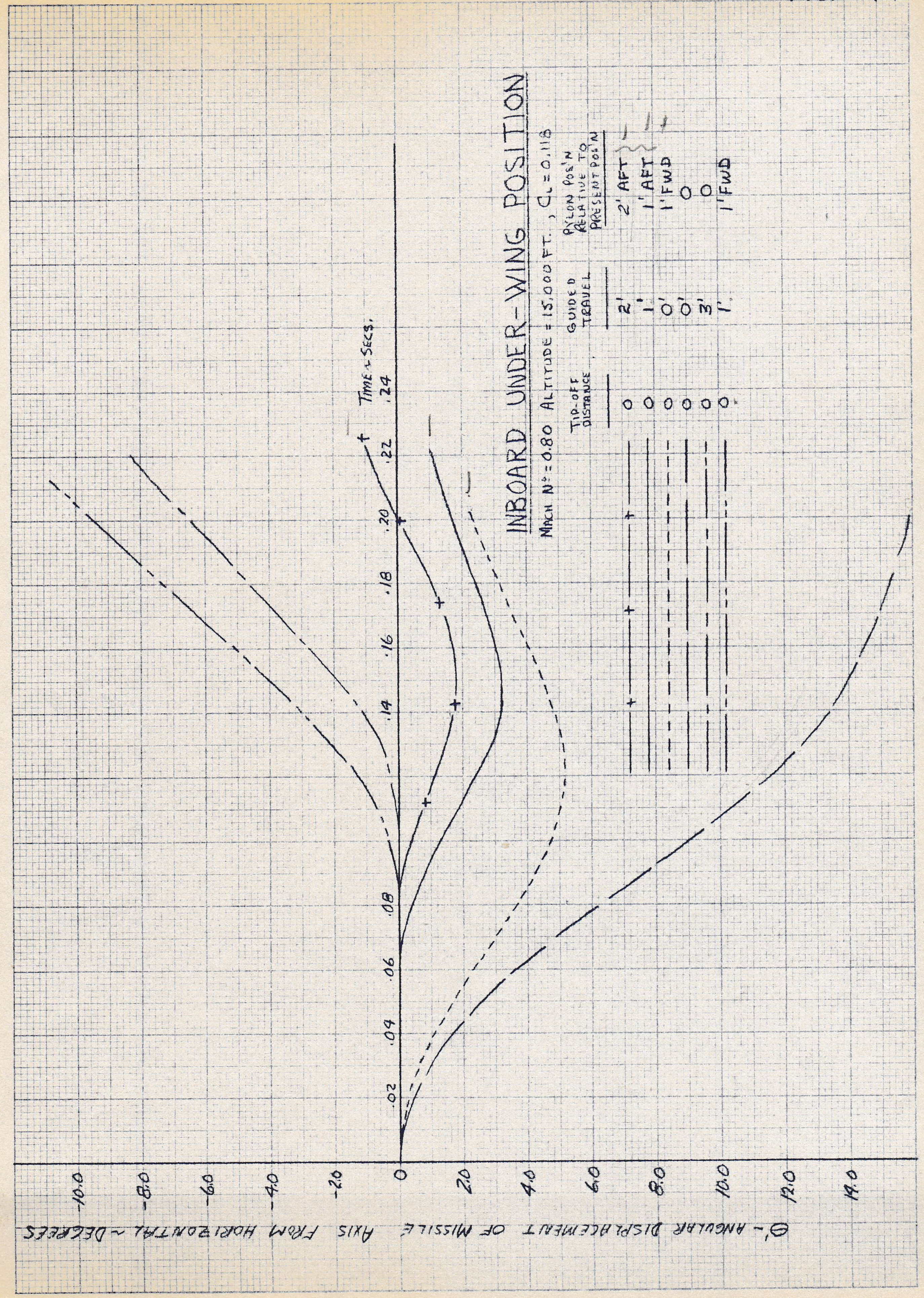
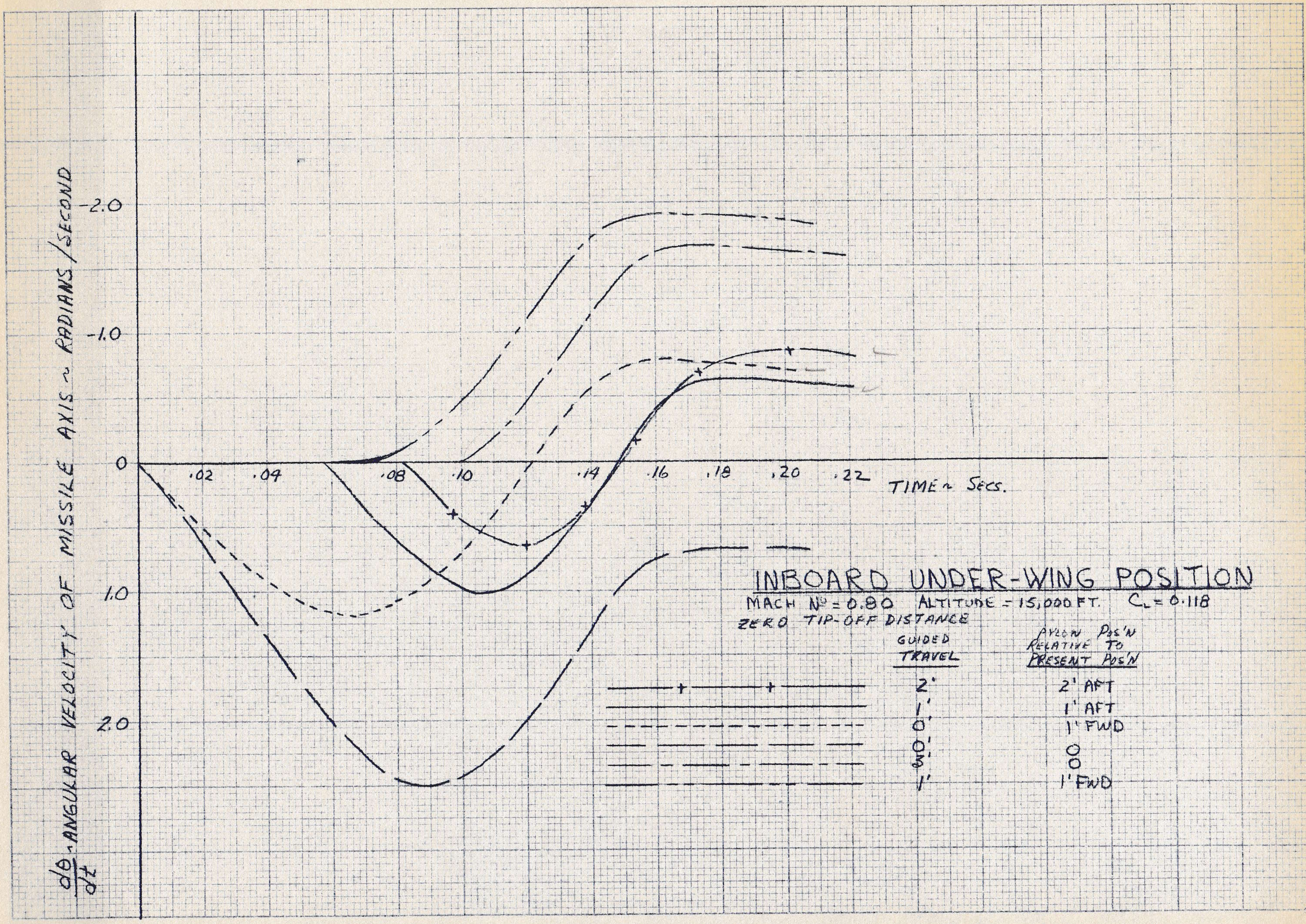

INBOARD UNDER-WING POSITION
MACH No = 0.80 ALTITUDE = 15,000 FT. C_L = 0.118
TIP-OFF DISTANCE
RAIL INCIDENCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0' 0° 2' 0
0' -1° 2' 0
0' 0° 2' 1' AFT
1.77' 0° 2' 0
0' 0° 1' 0
0' 0° 2' 2' AFT
0' 0° 1' 1' AFT
$\frac{d\theta}{dt}$ ~ ANGULAR VELOCITY OF MISSILE AXIS ~ DEGREES PER SECOND ~ POSITIVE DOWNWARD
80
60
40
20
0
20
40
60
80
10
20
30
40
50
70
80
90
100
110
120
130
140
X' HORIZONTAL DISTANCE FROM AIRCRAFT ~ FT.

FIG. 3(a)



INBOARD UNDER-WING POSITION
MACH No = 0.80 ALTITUDE = 15,000 FT., CL = 0.118
TIP-OFF DISTANCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0 2' 2' AFT
0 1' 1' AFT
0 0' 1' FWD
0 0' 0
0 3' 0
0 1' 1' FWD
TIME ~ SECS.
.02
.04
.06
.08
.14
.16
.18
.20
.22
.24
-10.0
-8.0
-6.0
-4.0
-2.0
0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
θ ~ ANGULAR DISPLACEMENT OF MISSILE AXIS FROM HORIZONTAL ~ DEGREES



INBOARD UNDER-WING POSITION
MACH No = 0.80 ALTITUDE = 15,000 FT. C_L = 0.118
ZERO TIP-OFF DISTANCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
2' 2' AFT
1' 1' AFT
0' 1' FWD
0' 0
3' 0
1' 1' FWD
TIME ~ SECS.
.02
.04
.08
.10
.14
.16
.18
.20
.22
$\frac{d\theta}{dt}$ - ANGULAR VELOCITY OF MISSILE AXIS ~ RADIANS/SECOND
-2.0
-1.0
0
1.0
2.0

FIG. 3(b)

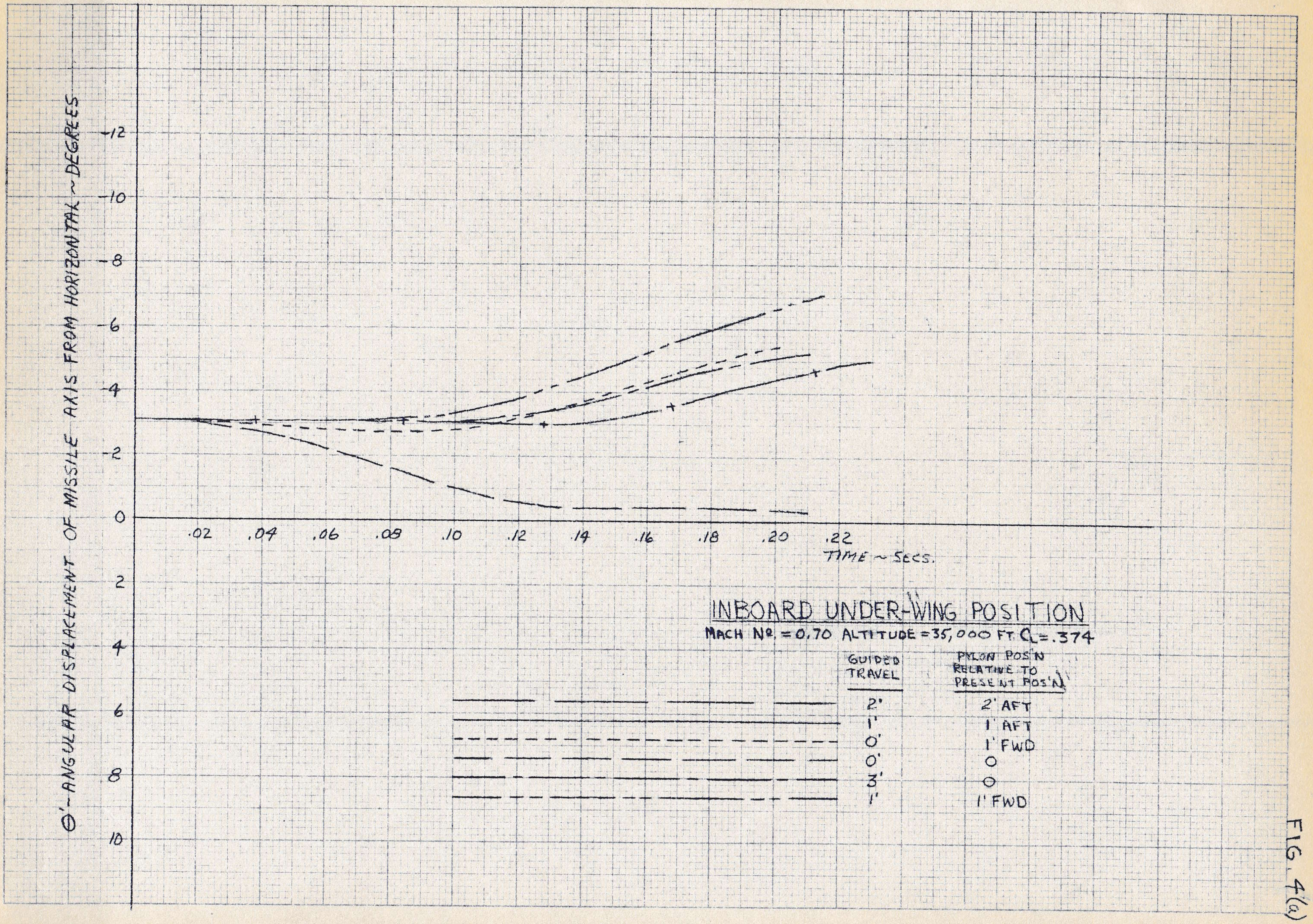

INBOARD UNDER-WING POSITION
MACH No. = 0.70 ALTITUDE = 35,000 FT. C_L = .374
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
2' 2' AFT
1' 1' AFT
0' 1' FWD
0' 0
3' 0
1' 1' FWD
θ' - ANGULAR DISPLACEMENT OF MISSILE AXIS FROM HORIZONTAL ~ DEGREES
TIME ~ SECS.
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22

FIG. 4(a)

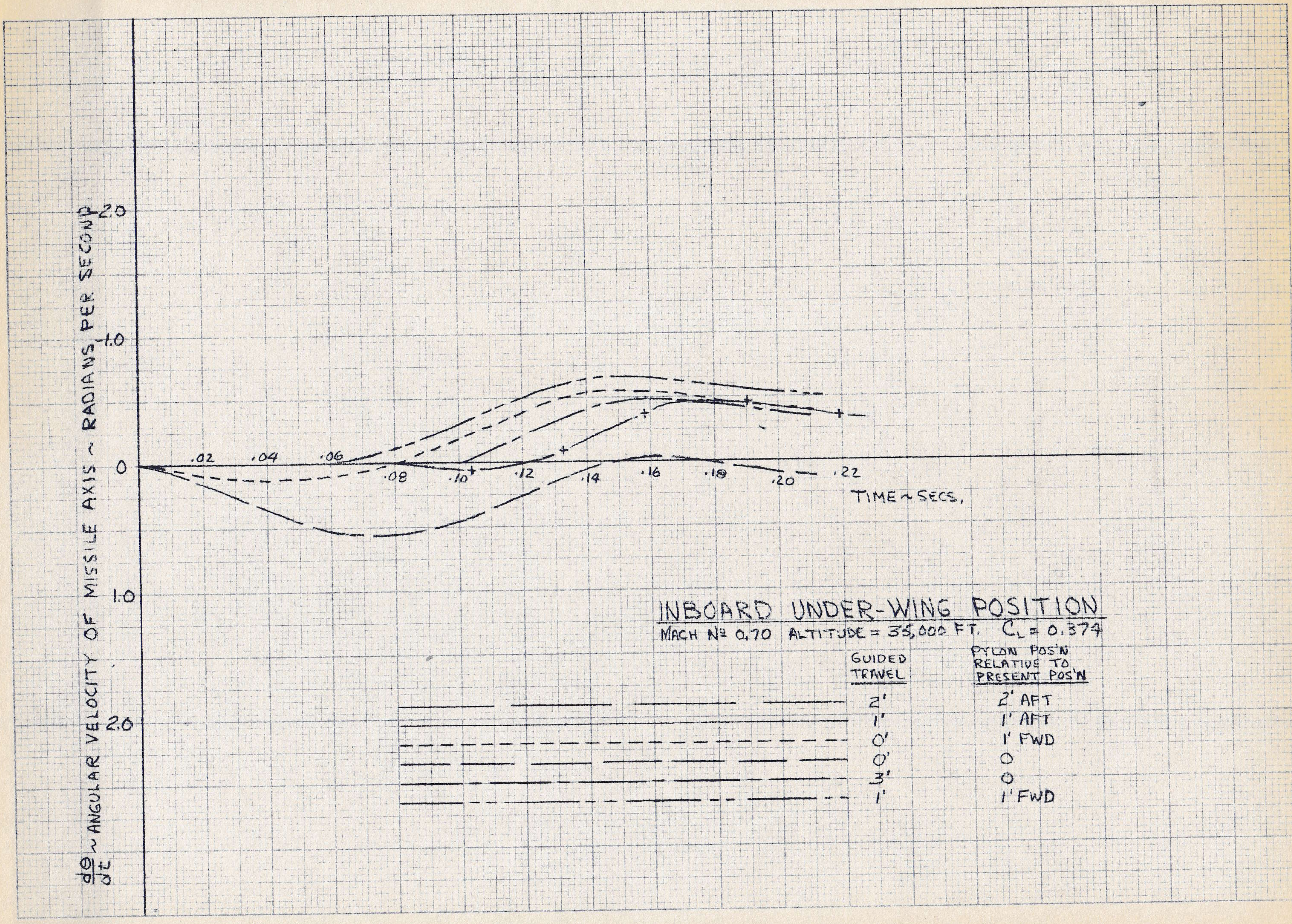
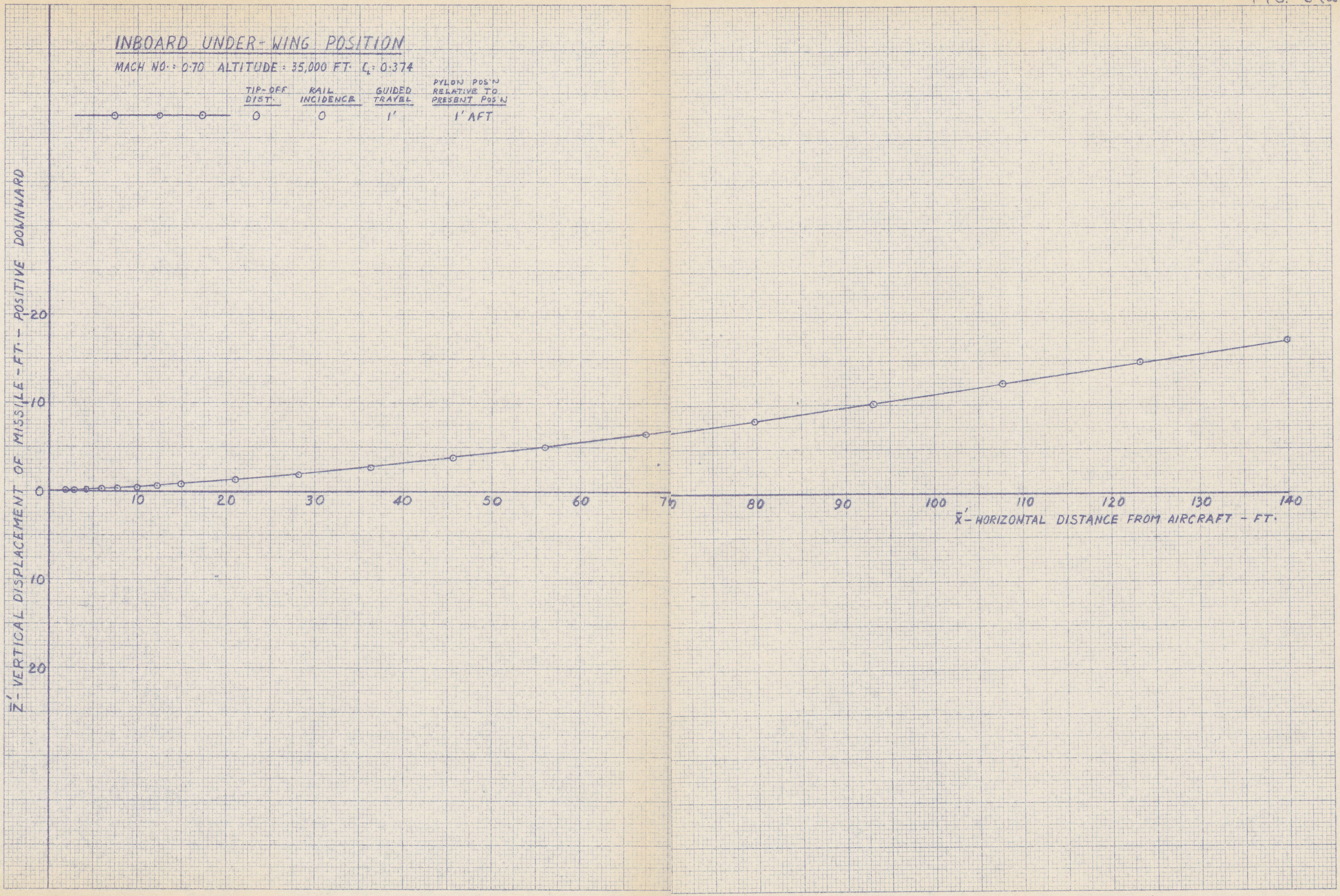

$\frac{d\theta}{dt}$ ~ ANGULAR VELOCITY OF MISSILE AXIS ~ RADIANS PER SECOND
-2.0
-1.0
0
1.0
2.0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
TIME ~ SECS.
INBOARD UNDER-WING POSITION
MACH No 0.70 ALTITUDE = 35,000 FT. C_L = 0.374
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
2' 2' AFT
1' 1' AFT
0' 1' FWD
0' 0
3' 0
1' 1' FWD

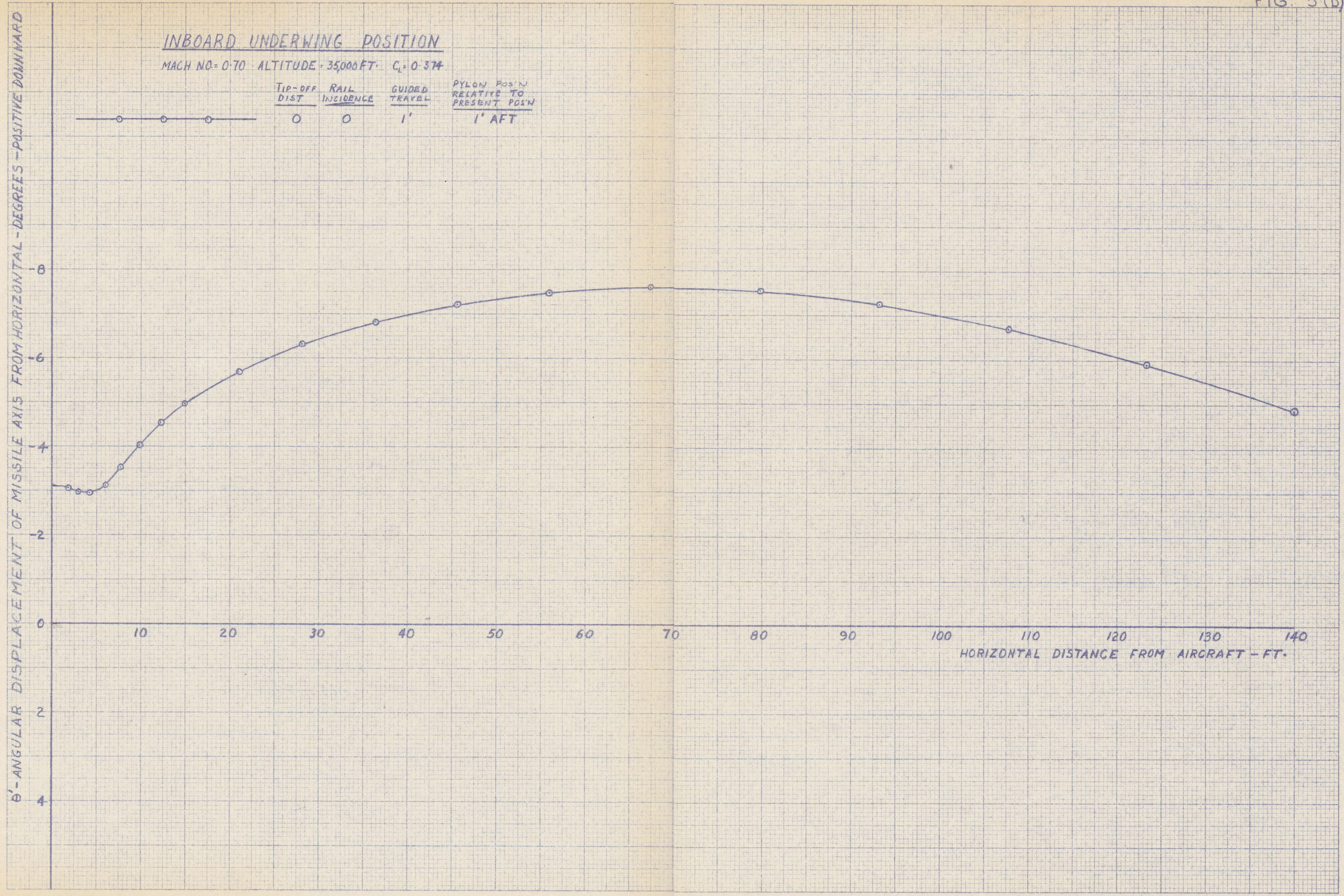
FIG. 4(b)

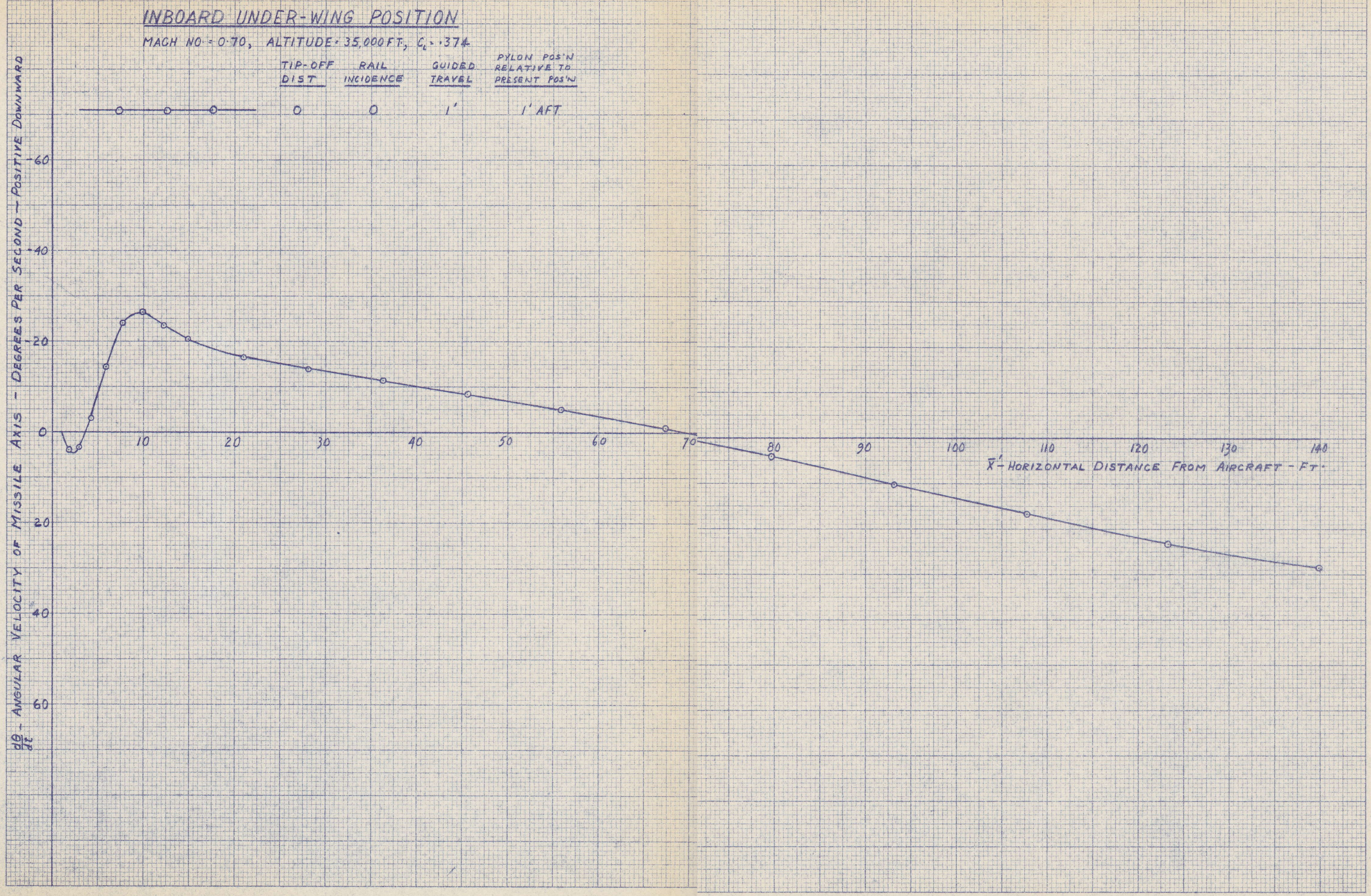
FIG. 5(a)

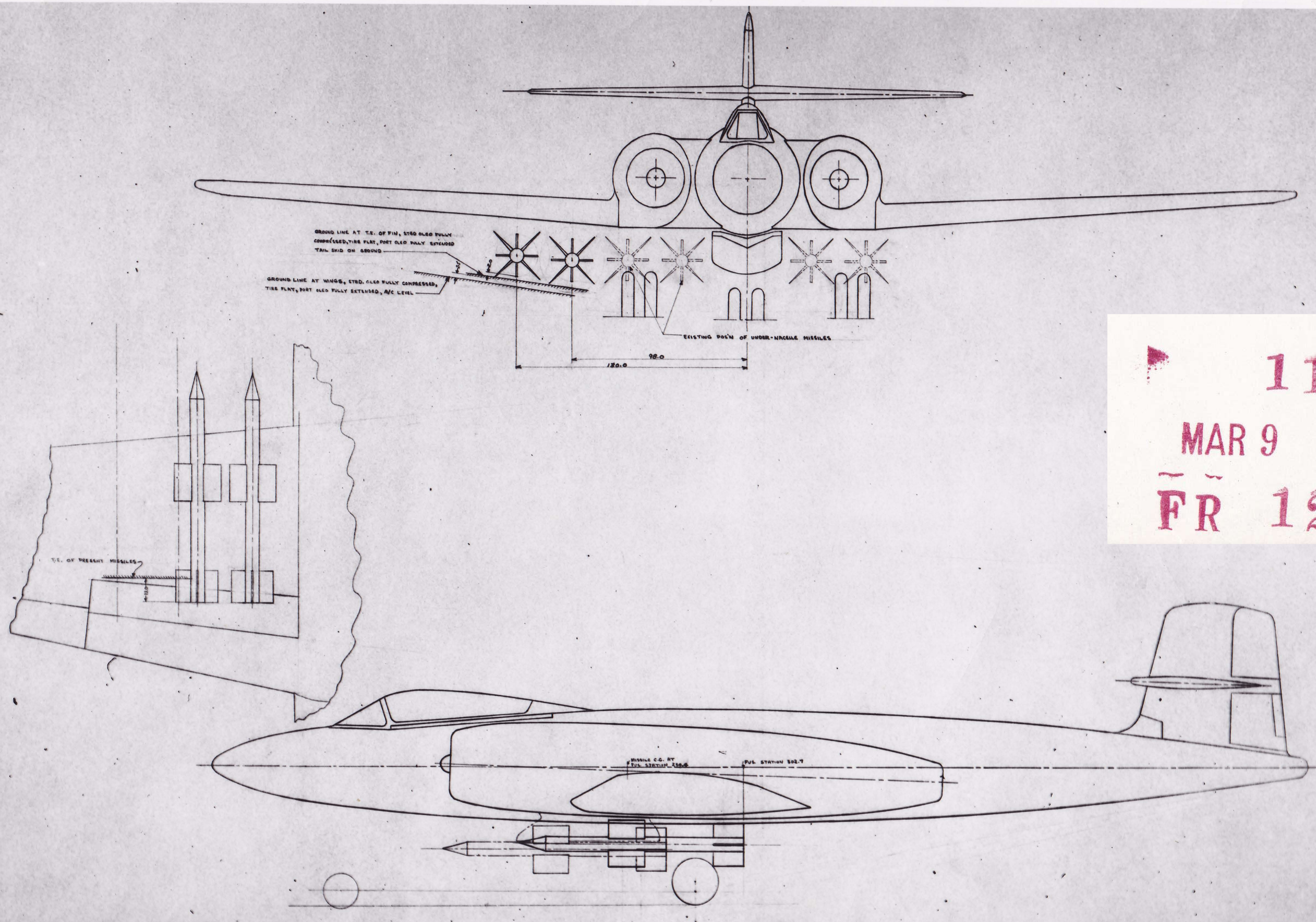


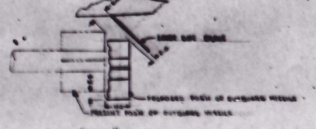
INBOARD UNDER-WING POSITION
MACH NO.: 0·70 ALTITUDE: 35,000 FT. C_L: 0·374
TIP-OFF DIST.
RAIL INCIDENCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0
0
1'
1' AFT
$\bar{Z}'$- VERTICAL DISPLACEMENT OF MISSILE - FT. - POSITIVE DOWNWARD
$\bar{X}'$- HORIZONTAL DISTANCE FROM AIRCRAFT - FT.

FIG. 5(b)


INBOARD UNDERWING POSITION
MACH NO = 0·70 ALTITUDE · 35,000 FT · C_L = 0·374
TIP-OFF DIST
RAIL INCIDENCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0
0
1'
1' AFT
θ' - ANGULAR DISPLACEMENT OF MISSILE AXIS FROM HORIZONTAL - DEGREES - POSITIVE DOWNWARD
-8
-6
-4
-2
0
2
4
10
20
30
40
50
60
70
80
90
100
110
120
130
140
HORIZONTAL DISTANCE FROM AIRCRAFT - FT.


INBOARD UNDER-WING POSITION
MACH NO = 0·70, ALTITUDE = 35,000 FT, C_L = ·374
TIP-OFF DIST
RAIL INCIDENCE
GUIDED TRAVEL
PYLON POS'N RELATIVE TO PRESENT POS'N
0
0
1'
1' AFT
$\frac{d\theta}{dt}$ - ANGULAR VELOCITY OF MISSILE AXIS - DEGREES PER SECOND - POSITIVE DOWNWARD
$\bar{X}'$ - HORIZONTAL DISTANCE FROM AIRCRAFT - FT.
60
40
20
0
20
40
60
10
20
30
40
50
60
70
80
90
100
110
120
130
140





REFERENCE. - AVRO CANADA LTD. DRWG. NO. SK25483

PROPOSED RE-LOCATION OF V.G. UNDER-WING INSTALLATION

NATIONAL RESEARCH LABORATORIES
DIVISION OF MECHANICAL ENGINEERING
OTTAWA CANADA

SCALE 1/8 IN. = 1 FT

FIG. 6

N.A.E. FR-16(c) UNCLASSIFIED

Calculation of the initial phase of the trajectory in the pitching plane of the velvet glove missile when launched from the CF-100 aircraft.

DATE	ISSUED TO	CLOCK CARD & DEPT. NO.
APR 2 1954	L. Marsh	83182 2909
APR 13 1954	J. Chamberlin per J.C.	
NOV 22 1955	Dimock	86805 2921
NOV 8 1956	Haynes	2921
NOV 22 1956	Lindow	

AVRO M 1294A

UNCLASSIFIED

NAE FR-16(c)

of t