RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

RESULTS OF FLIGHT TEST OF AN AUTOMATICALLY STABILIZED MODEL C (SWEPT BACK) FOUR-WING TIAMAT

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The results of the first flight test of a swept-back four-wing version of Tiamat (MX-570 model C) which was launched at the NACA Pilotless Aircraft Research Station at Wallops Island, Va. are presented.

In general, the flight behavior was close to that predicted by calculations based on stability theory and oscillating table tests of the autopilot. The flight test thus indicates that the techniques employed to predict automatic stability are valid and practical from an operational viewpoint.

The limitations of the method used to predict flight behavior arise from the fact that the calculations assume no coupling among roll, pitch, and yaw, while in actual flight some such coupling does exist.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, and as part of the general research program on guided missiles, the NACA is testing various configurations for the MX-570 (Tiamat) missile. The results of each flight are being correlated with theory in an effort to develop and improve methods of predicting the flight characteristics of autopilot controlled aircraft.

Tests of three-fin configurations of the MX-570 missile have been reported in references 1 and 2, whereas tests of four-fin models have been reported in references 3 and 4. Data in reference 1 indicated poor directional stability at high angles of attack and reference 2 showed need for a single booster rocket. Reference 3 showed that improved stability was obtained with the four-fin arrangement and reference 4 indicated a need for more complete autopilot study. This study was made and reported in references 5 and 6 and another four-fin missile was launched. Failure of the booster to separate from the missile in the flight of the third four-fin missile brought about a redesign of the booster attachment, which is described herein. The present test concerns itself with the results of a flight test of a four-fin model C (swept back) configuration of the Tiamat missile and the correlation of the flight results with data obtained from preflight frequency-response tests of the automatic pilot. The tests of this model were conducted in the same manner as previously described in references 1 to 4. Equipped with telemeter and autopilot, the missile was launched from the ground and tracked by radar and motion-picture cameras.

MODEL

The design of the four-fin MX-570 model C is basically the same as the model B (reference 4) except that swept-back wings have replaced the straight wings and a newly designed missile-booster attachment has replaced the straps previously used. The new type of attachment was incorporated after the missile and booster failed to separate in a previous flight. A sketch of the missile and booster is shown in figure 1 and a photograph of the missile is shown in figure 2. The new booster attachment (see fig. 3) consists of a tail cone casting attached to the missile and a nose casting attached to the booster and fitting within the tail cone of the missile. Inserted in the booster casting is a 500-pound-per-inch compression spring held in loaded position by an explosive break link and adjusted to butt up against the tail pipe of the missile. The explosive link is broken during the booster-on flight and when the booster rocket burns out the spring causes the missile and booster to separate. In addition, four alinement screws are located between the booster casting and the main booster fuselage to adjust the angle of incidence between the thrust line of the booster and the center line of the missile.

The physical dimensions of the C model tested are given below:

Weight, pounds:

Missile 527
Booster 400

Wing:

Area, square feet (including fuselage)	7.13
Span, feet	5.72
Aspect ratio	4.58
Airfoil section	NACA 16-009
Sweepback, 25 percent chord, degrees	41
Incidence, degrees	0
Mean aerodynamic chord, inches	15.70
Wing loading (missile alone), pounds per square foot	74.0

Control surface:

Type	Plain flap
Span, percent wing span (plan)	23
Chord, percent wing chord at inboard end	15.7
Chord, percent wing chord at outboard end	26.7

Fuselage:

Length, inches	120
Maximum diameter, inches	20

Center-of-gravity location:

Behind nose of fuselage, inches	66
Below center line of missile, inches	0.44

INSTRUMENTS

Autopilot.- The autopilot used was the same type as those previously used and is described in reference 4. It was adjusted to give a 1.78 follow-up in yaw and 2.35 follow-up in pitch. (Follow-up is the ratio of control deflection to curve deviation.) The rate gyros were adjusted so as to cause, when subjected to a rate of turn of 1° per second, a control deflection equal to one-tenth of the deflection caused by a body displacement of 1°. The roll control consisted of an Azon gyropilot with the same settings as previously described in reference 4. The deflection of the ailerons was limited to $\pm 10^\circ$. The preset-turn control was set to vary the directional gyro reference, 20 seconds after firing, at a rate of approximately 7° per second until the rudder stop (10°) was reached. The altitude control was set to maintain flight at 600 feet.

Telemeter.- A four-channel radio telemeter was installed to transmit records of the following items within the limits noted between the parenthesis signs:

(a) Normal acceleration, (±10g)

(b) Transverse acceleration, (±10g)

(c) Dynamic pressure, (0 to 16 in. Hg above sea level static pressure)

(d) Bank angle, (±30°)

(e) Rudder control position, (±10°)

(f) Elevator control position, (±10°)

A motor-driven switch was provided so as to alternate transmission of elevator control and normal acceleration data with dynamic pressure and transverse acceleration data on two of the telemeter channels.

The accelerometers used to record the normal and transverse accelerations were located approximately 8 inches below the center of gravity of the missile. This caused the components of the normal acceleration due to roll to be recorded by the accelerometer. The error introduced by this condition was small in comparison to the maximum accelerations recorded.

Radar and Camera.- The radar and camera installations were similar to those previously used consisting of TPS5 continuous wave radar, SCR 584 radar and motion-picture cameras.

METHOD OF PREDICTING AUTOMATIC STABILITY CHARACTERISTICS

The stability of the missile-autopilot combination was predicted using the methods given in references 5 and 7. The results given in reference 5 were computed for the straight wing MX-570, but the rolling motion is not believed to be appreciably affected by the amount of sweepback present in the MX-570C. The curves used for determination of stability in pitch and yaw are given in figure 4. These curves consist of plots of the phase angle ϵ and the amplitude factor R for both the autopilot and missile. The phase angle for the autopilot is a measure of the amount that the control motion is leading or lagging the displacement motion of the autopilot. The phase angle for the missile is a measure of the amount that a forcing control motion leads or lags the airplane motion that it causes. The amplitude factor for the autopilot is equal to the maximum amplitude of the autopilot displacement motion divided by the maximum amplitude of the corresponding control motion. The amplitude factor for the missile is equal to the maximum amplitude of the forcing control motion divided into the maximum amplitude of the missile motion caused by the control motion. The procedure for computing these curves is outlined in reference 7. Inasmuch as the missile is symmetrical about both the XZ- and the XY-planes and the same autopilot adjustment is used for both pitch and yaw, the curves shown in figure 4 apply to both pitch and yaw.

RESULTS

Launching

The launching rack and the firing procedure used in the subject tests were the same as those previously described in reference 2. The test records of the flight showed that the launching of the model was smooth. Photographs of the take-off are shown in figures 5(a) and 5(b). A launching acceleration of 9.1g was computed for the telemeter records (see fig. 6(a)) and an altitude of about 300 feet was reached before the booster rocket burned out. At the 0.9-second mark the link holding the booster rejection spring was exploded and at the 2.2-second mark the booster rocket burned out and was jettisoned successfully. The use of the revised booster attachment apparatus was thereby justified. The sustaining rocket fired as scheduled at the 2.9-second mark and the records show that the missile attained an altitude estimated at 600 feet and leveled out.

Automatic Stabilization

The telemeter records presented in figure 6 show that the rejection of the booster started a longitudinal oscillation which was rapidly damped by the automatic pilot until the 9-second mark. (See fig. 6(a).) After this time, the oscillation built up, again resulting in large normal accelerations. After the 12-second mark the elevator oscillated between its stops ($\pm 10^{\circ}$) causing normal accelerations of about ± 5g for the remainder of the flight.

The yaw oscillation as indicated by the rudder and transverse acceleration data of figure 6(b) was small throughout the entire flight. An initial disturbance encountered at the time of booster rejection was quickly damped and the transverse accelerations were about $\pm\frac{3}{4}$g for straight flight. The model stabilized in roll during the entire flight, the amplitude of the bank oscillations varying from ±7° in the early portion of the flight (see fig. 6(a)) to somewhat irregularly larger values during the 30- to 54-second period. (See fig. 6(c).)

Preset Turn

After 27 seconds the missile went into a preset evertightening turn until the rudder reached its stop (10°) after which the radius of the turn remained constant. Figure 7 shows a plan view of the flight path of the missile as recorded by the SCR 584 ground radar, compared with the predicted flight path based on the adjustment of the preset-turn control.

DISCUSSION

Longitudinal Stabilization

The action of the automatic pilot in pitch, previously described, can be explained by an analysis of preflight frequency-response records of the automatic pilot shown in figure 4. According to the method outlined in reference 7, the possibility of an undamped oscillation exists only when the phase angle of the automatic control $\left(\epsilon_{pilot}\right)$ is equal to the phase angle $\left(\epsilon_{missile}\right)$ for the missile. As shown in figure 4, these conditions did not exist in the subject model thus indicating that any disturbance in pitch or yaw should have damped out completely. The fact that there is no intersection between the ϵ-curves makes it unnecessary to refer to the R-curves. If there had been an intersection, the stability of the oscillation would have depended upon the value of the $R_{missile} \times R_{autopilot}$. A value less than unity would have indicated instability while one greater than unity would indicate a damped oscillation.

The initial action of the automatic pilot in damping out the pitch disturbance caused by the booster rejection is thus in agreement with the frequency-response data. A study of the data on figure 6(a) shows that during this period the control motion was leading the body motion as expected and the motion was damped. The increase in the amplitude of the longitudinal oscillation after the 9.0-second mark was probably due to the failure of the pitch rate gyro which caused the control motion to lag the pitching motion. The lag of the control after the 9.0-second mark is evident from inspection of the data of figures 6(a) and 6(c) and would be expected by theory to lead to unstable oscillations. In the subject case the elevator stops limited the body motions to a constant amplitude hunting oscillation.

Lateral Stabilization

A very small transverse acceleration, approximately $\pm\frac{3}{4}g$, was recorded for that portion of the straight line flight during which the pitch oscillation was damped. When the pitching oscillation increased in amplitude, the transverse acceleration became irregular. This effect is believed to be due to the influence of the elevon position (up or down) on the elevon yawing moment caused by differential elevon deflection. That is, if the elevons were both up, the yawing moments caused by differential deflection would be less adverse than if the differential movement had occurred when the elevons were at zero.

The stabilizing action of the lateral components of the automatic pilot was thus established. The fact that the yaw oscillation had the same period as the roll oscillation rather than one similar to the pitch oscillation (as might be expected for a symmetrical body) is interpreted as showing that coupling existed between the rolling and yawing motions.

The roll oscillation of $\pm 7^{\circ}$ in straight flight was slightly larger than that predicted by the method described in reference 5. The flight periods showed good agreement with the results of that test.

The irregular roll oscillation during the preset turn is believed to be due to wing-fuselage interference effects arising from the angle of sideslip created during the turn coupled with the pitch oscillation. (See fig. 6(c) for the period from 32 to 53 seconds.)

CONCLUDING REMARKS

In general, the flight behavior was close to that predicted by calculations based on stability theory and oscillating table tests. The flight test thus indicates that the techniques employed to predict automatic stability are valid and practical from an operational viewpoint.

The limitations of the methods used to predict automatic flight behavior arise primarily from the fact that the calculations assume no coupling among roll, pitch, and yaw, while in actual flight some such coupling does exist.

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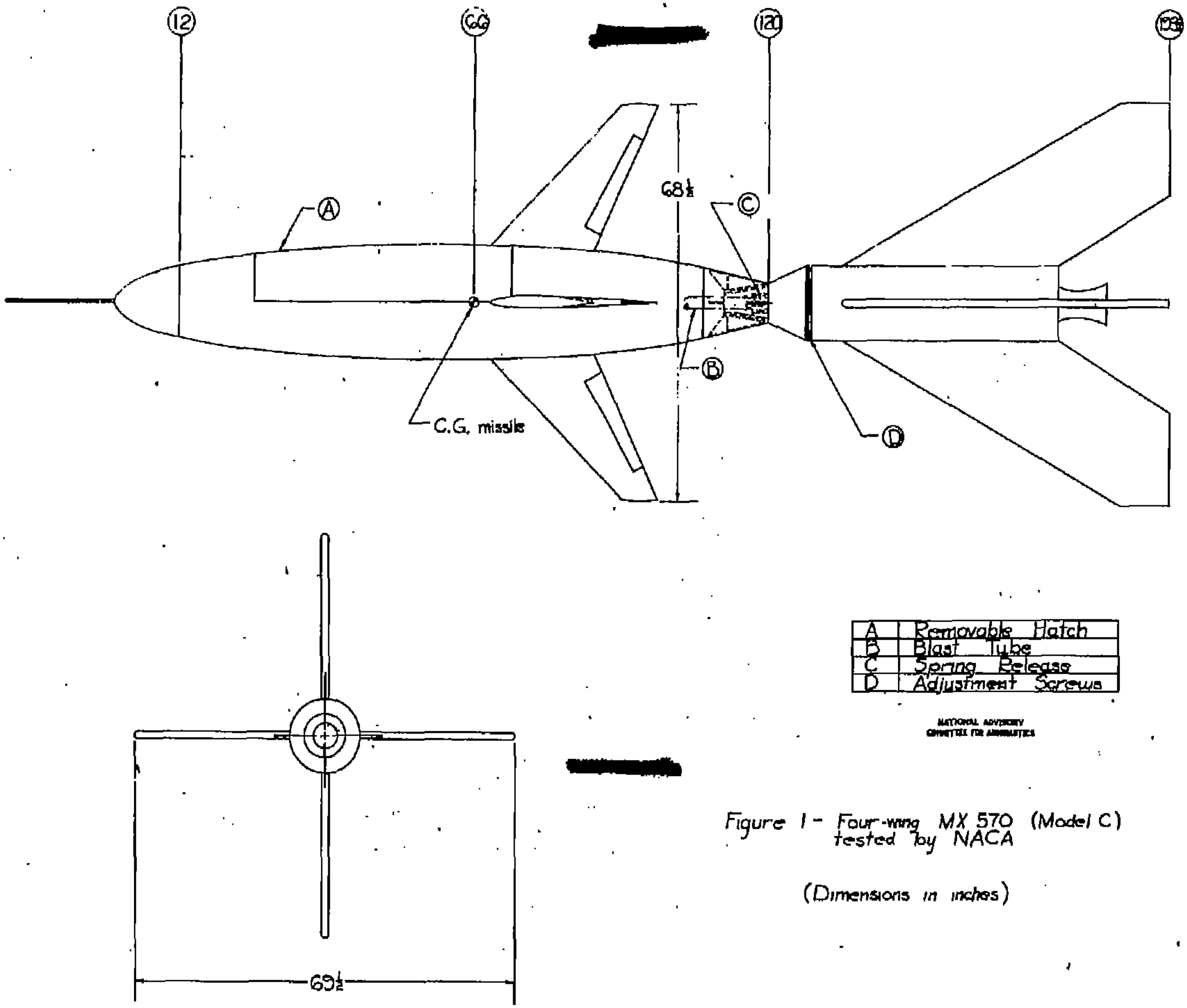
[redacted]



A	Removable Hatch
B	Blast Tube
C	Spring Release
D	Adjustment Screws

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Figure 1 - Four-wing MX 570 (Model C) tested by NACA

(Dimensions in inches)

[redacted]

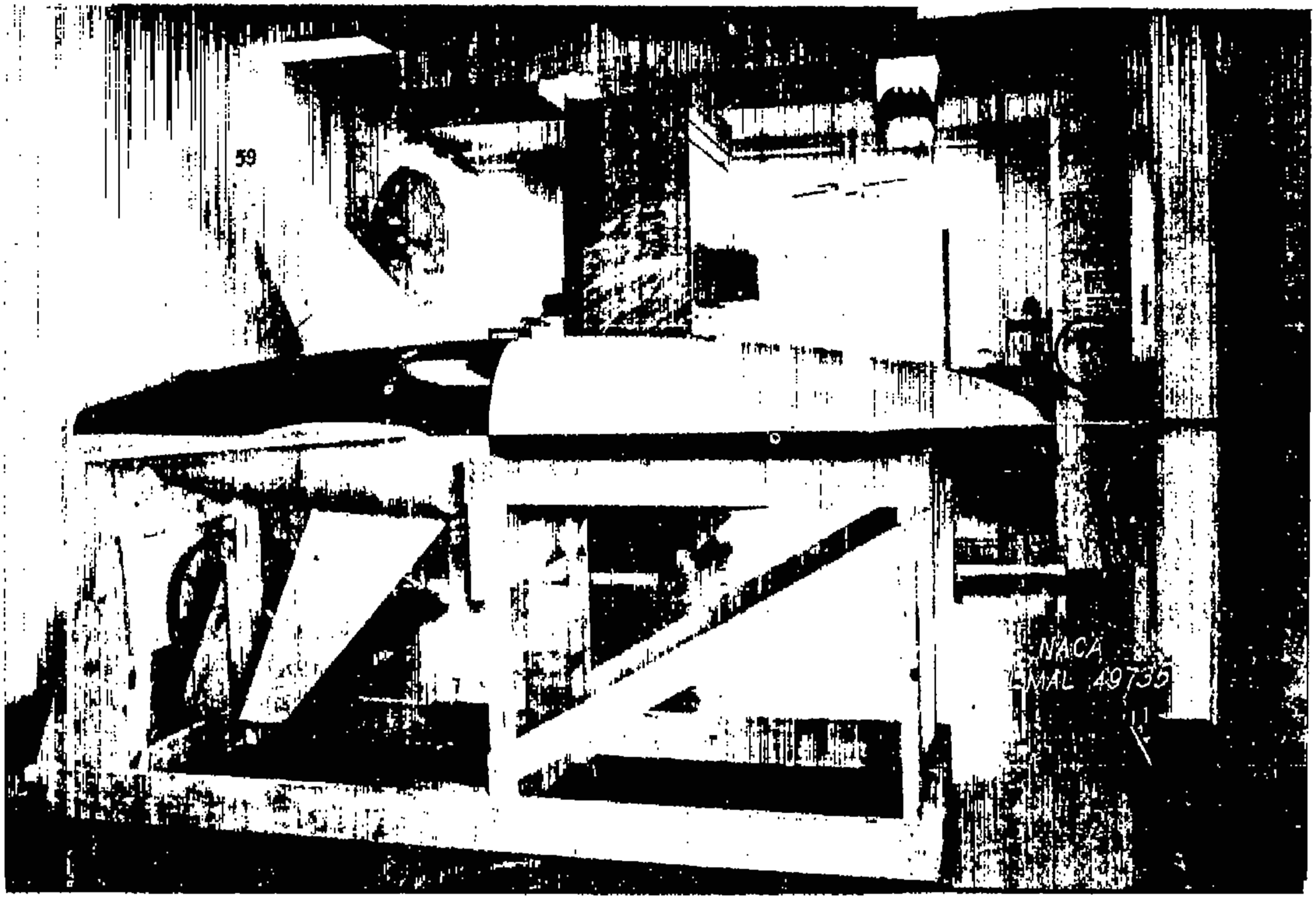

Figure 2.- MX-570 (Tiamat model C) 4-wing configuration.

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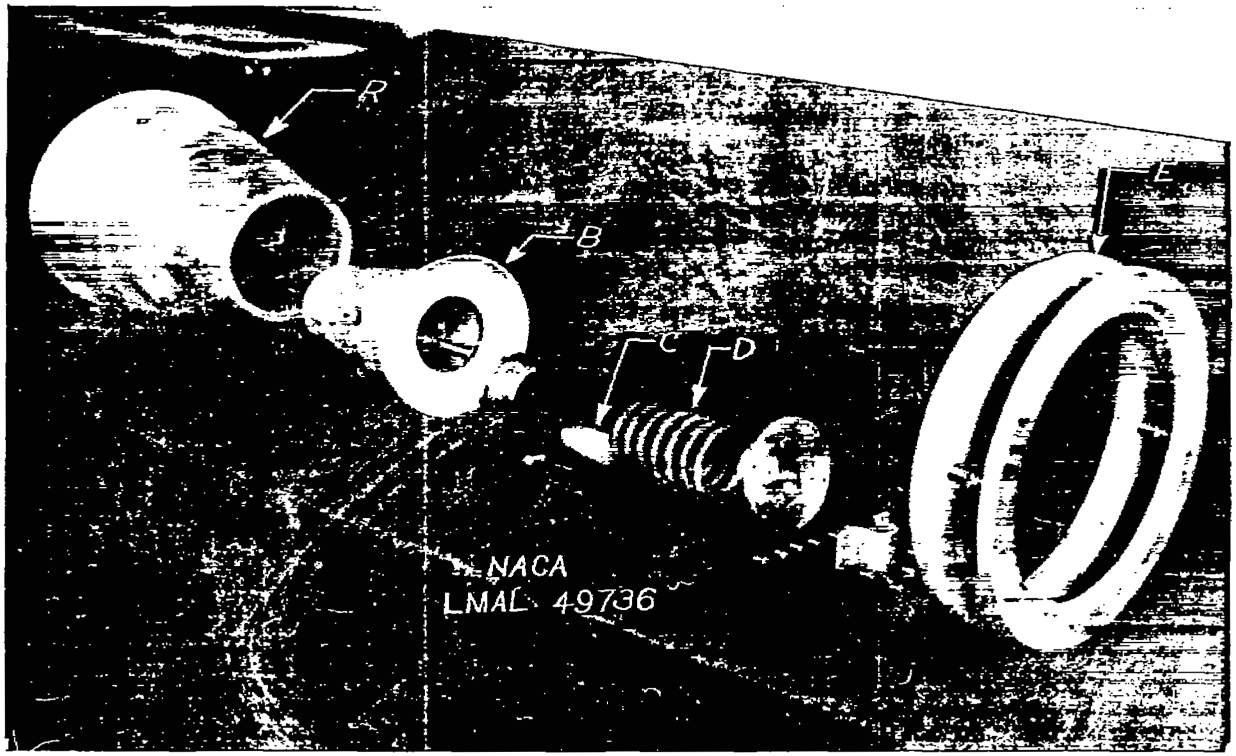

A.- Tail cone of missile

B.- Nose cone of booster

C.- Break link

D.- Compression spring

E.- Booster alignment adjusting screws

Figure 3.- Exploded view of Booster attachment of MX-570 (Model C).

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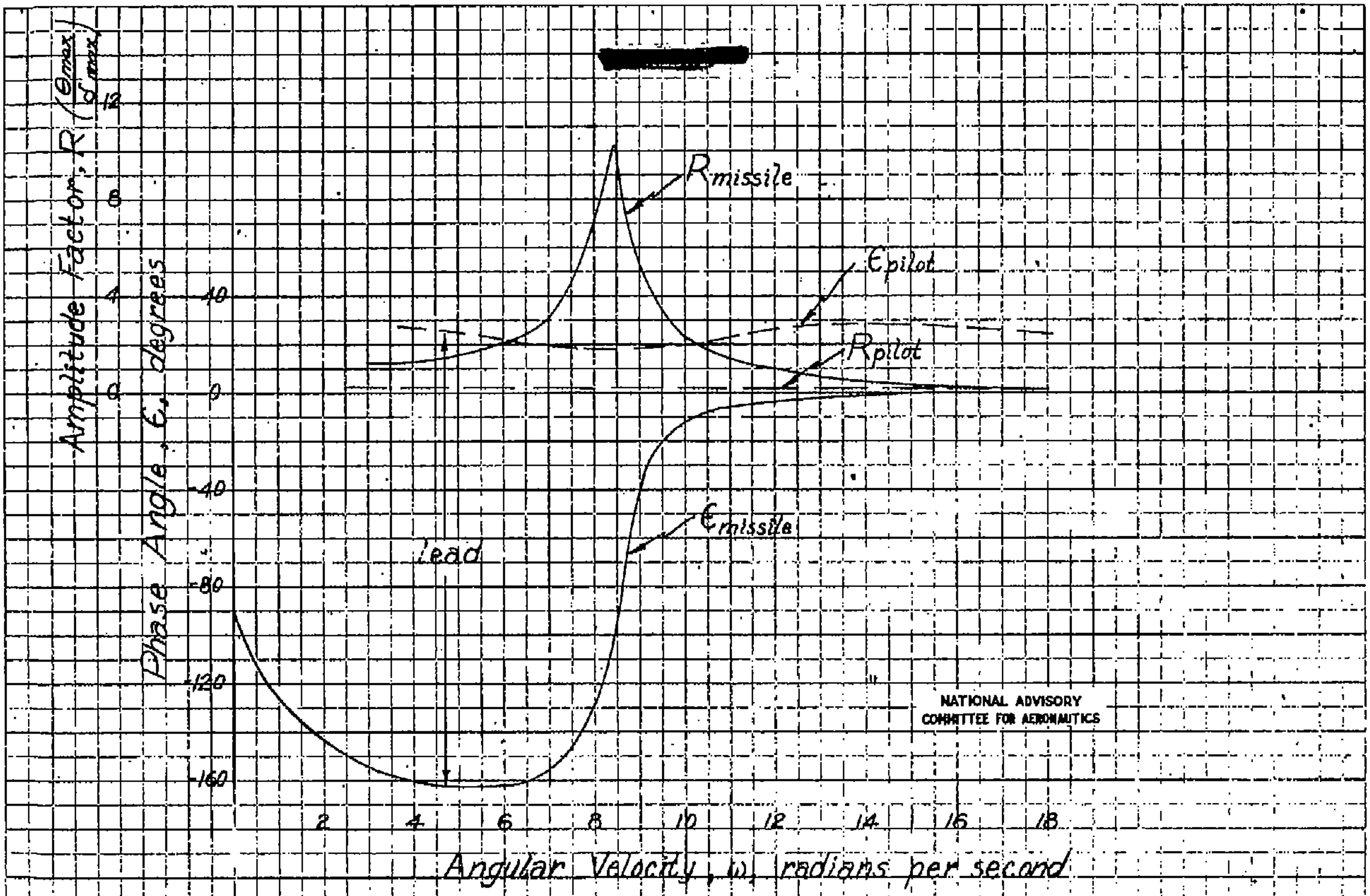

Figure 4: Frequency Response Curves for MX-570-C and Autopilot
Autopilot oscillated at ±1° $C_4 = .1$ V=550mph

[redacted]

Figure 5a.- Take-off of MX-570 (Model C-1).

[redacted]

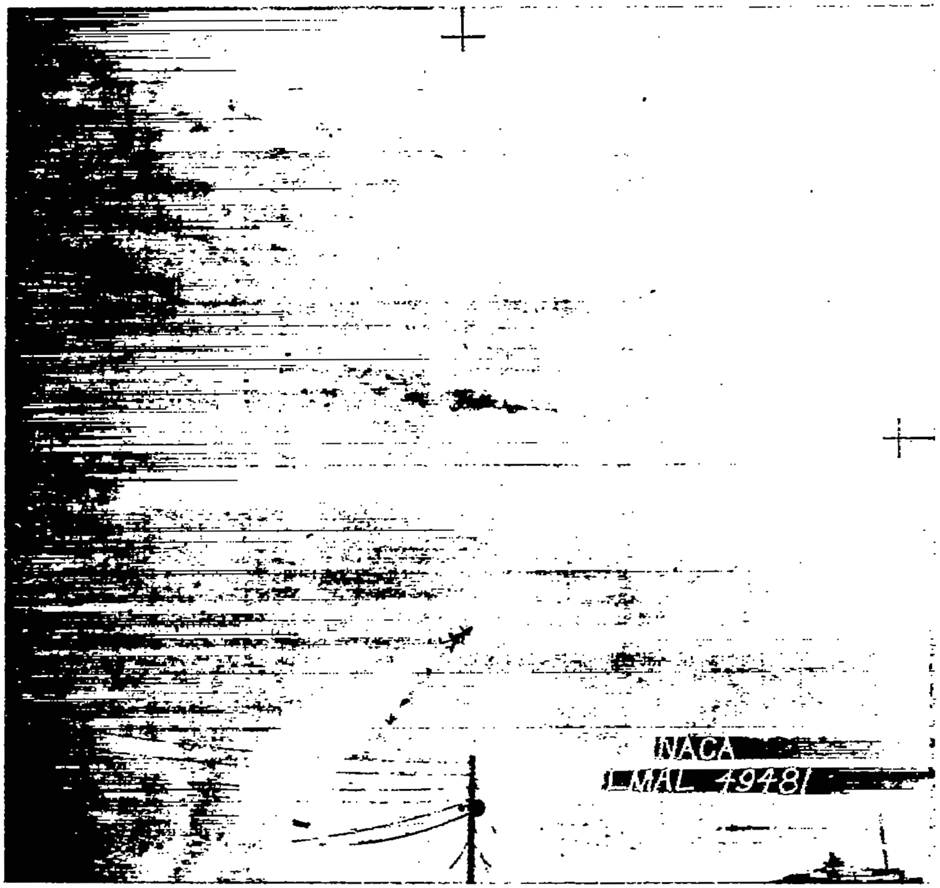

Figure 5b.- Take-off of MX-570 (Model C-1).

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[redacted]

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Figure 6a.- Telemeter data for MX-570 (Model C-1)

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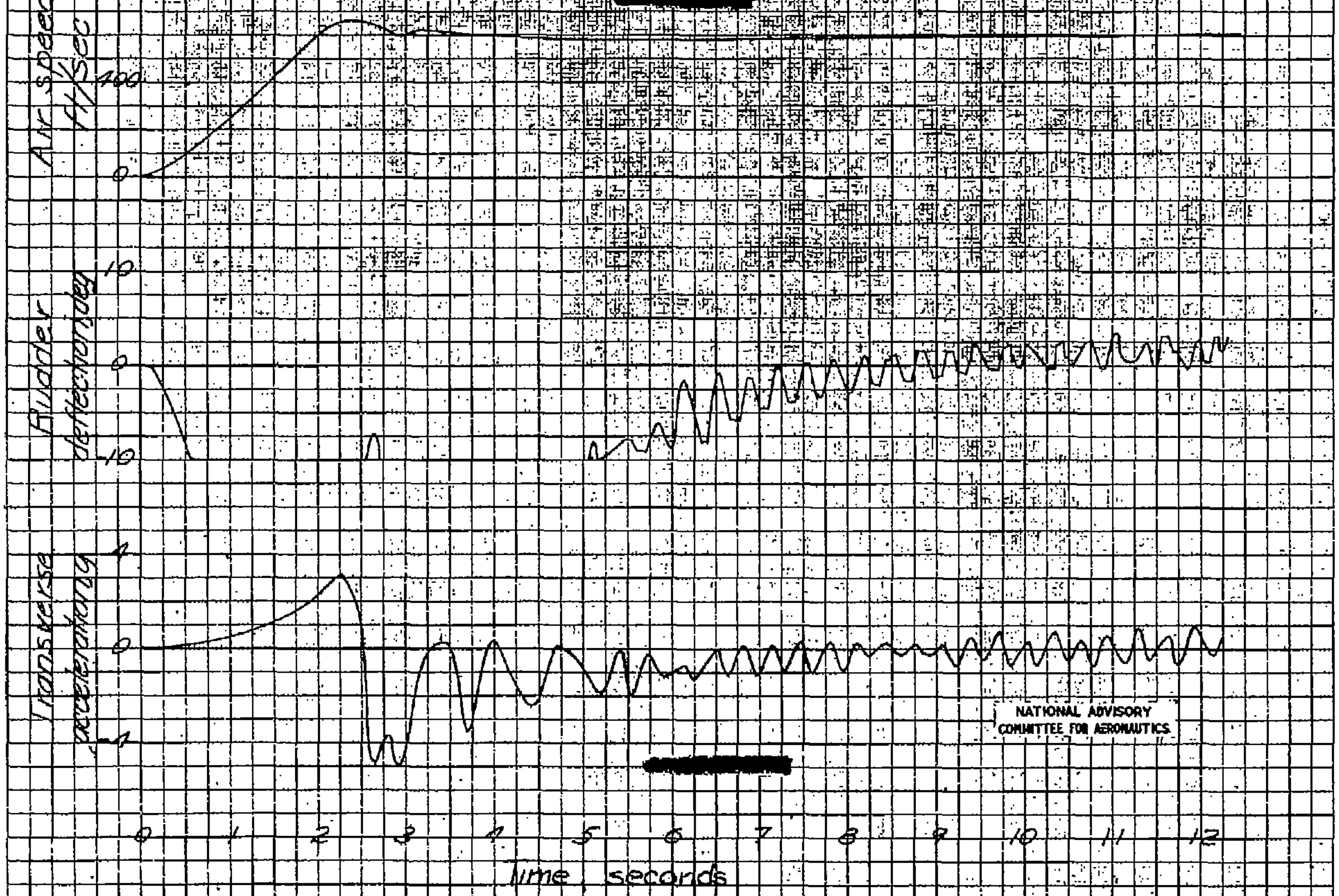

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Figure 6b. - Telemeter data for MX-570 (Model C-1)

Figure 6c.- Telemeter data for MX-570 (Model C-1)

Figure 6d - Telemeter data of MX-570 (Model C-1)

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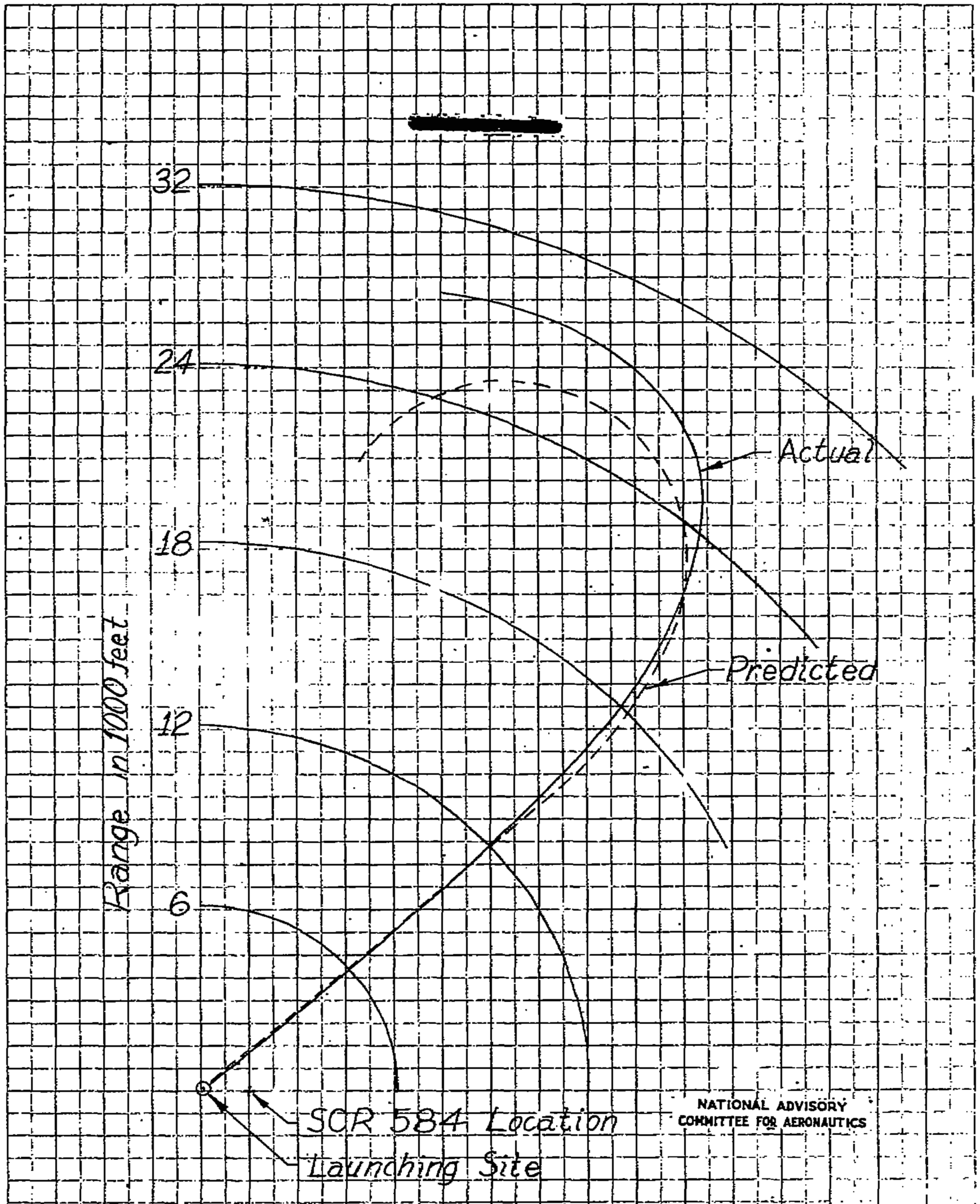

Figure 7: Plan View of Flight Path of MX-570-C-1

[redacted]