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RESEARCH MEMORANDUM

INITIAL FLIGHT TEST OF THE NACA FR-1-A, A LOW-ACCELERATION ROCKET-PROPELLED VEHICLE FOR TRANSONIC FLUTTER RESEARCH

By

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

The first of a series of flutter rockets, designated the NACA FR-1-A, was successfully launched and flown at the Pilotless Aircraft Research Station, Wallops Island, Va. Two identical swept wings were tested; the left wing failed at 967 feet per second (659 miles per hour, Mach number M = 0.89) and the right wing remained on the model throughout the entire flight (maximum Mach number of 1.0).

The experimental value of failure speed obtained at a Mach number of 0.89 was 76.2 percent greater than the flutter speed obtained using the two-dimensional, incompressible, unswept-wing flutter theory.

INTRODUCTION

With present-day piloted and nonpiloted aircraft approaching a Mach number of unity, the problem of flutter or aerodynamic instability of wings is becoming more and more important. This importance arises in the speed range between Mach numbers 0.7 and 1.2 where the values of the aerodynamic parameters which affect the flutter speed are practically unknown. It is therefore important that experimental data be obtained by testing wings with predetermined flutter characteristics in this speed range. Such results could be used to assist in the development of a transonic flutter theory.

In order to obtain such data, the Pilotless Aircraft Research Division is conducting free-flight transonic flutter tests by means of low-acceleration rocket-propelled test vehicles. Such tests will yield information concerning the flutter speed and flutter frequency.

The design and flutter analysis of the wings investigated was made with the theory developed by and with the cooperation of the Physical Research Division of the Langley Laboratory.

The first of a series of flutter rockets has been launched and was equipped for determining the wing failure speed only. The results of this flight are presented herein along with a description of the test vehicle.

SYMBOLS

f_{h_1}	natural flexural frequency (first mode) in cycles per second
f_{h_2}	natural flexural frequency (second mode) in cycles per second
f_t	natural frequency of torsional vibration in cycles per second
f_α	torsional frequency about torsional axis in cycles per second
$\omega_\alpha = 2\pi f_\alpha$	natural torsional frequency in radians per second
x_α	location of center of gravity behind torsional axis in terms of half-chord
a	location of torsional axis of wing behind midchord in terms of half-chord
$\frac{1}{2} + a + x_\alpha$	location of center of gravity behind the 25 percent chord in terms of half-chord
r_α	mass radius of gyration referred to torsional axis in terms of half-chord
κ	ratio of mass of cylinder of air of diameter equal to chord of wing to mass of wing, both taken for equal lengths along span
b	half-chord length in feet, measured normal to leading edge
l	leading-edge length in feet
$\frac{l}{2b}$	ratio of leading-edge length to chord length

v_{f_o} flutter speed, feet per second, determined from reference 1 (two-dimensional incompressible flow theory employing first bending torsion mode and density at time of failure)

APPARATUS

Model

The NACA FR-1-A is essentially a tailless airplane with four laminated spruce wings located at the rear of the body. The two horizontal wings are the flutter test wings, and the vertical surfaces are for directional stability and have a flutter speed greater than the maximum speed of the model. A tailless configuration was chosen in order to keep the weight and drag as small as possible.

A sketch of the model showing physical dimensions and location of the different internal units is shown in figure 1. Two photographs showing external appearance are shown as figures 2 and 3.

This model is propelled by a 1000-pound thrust rocket engine at an average calculated acceleration of 2.8 times gravity. It is launched without the aid of a booster and flies with power on for approximately 15 seconds. The physical characteristics of the model and wings are as follows:

Weight, pounds	246
Fuselage:	
Length, inches	93
Maximum diameter, inches	10.625
Horizontal wings:	
Weight, pounds (each)	6.00
Area (total), square feet	7.45
Area (exposed), square feet	6.18
Span, feet	5.25
Aspect ratio	3.7
Airfoil section (normal to the leading edge)	NACA 65-009
Sweepback angle, degrees	45
Loading, pounds per square foot	39.8
Mean aerodynamic chord, inches	17
Taper ratio	1:1

Vertical fins:

Area (total), square feet	3.40
Area (exposed), square feet	2.22
Span, feet	2.55
Aspect ratio	1.71
Airfoil section (normal to leading edge)	NACA 65-009
Sweepback angle, degrees	60
Loading, pounds per square foot	115
Mean aerodynamic chord	16
Taper ratio	1:1

The flutter parameters obtained from measurements made of the horizontal wings are listed below.

	Left wing	Right wing
f_{h_1}	20.7	20.4
f_{h_2}	125	124.5
f_t	70.7	69.0
f_α	69.0	67.2
a	−0.2	−0.2
x_α	0.06	0.06
r_α^2	0.21	0.21
l	3.09	3.09
b	0.5	0.5
$\frac{1}{\kappa}$ (standard conditions)	26.9	26.9

Instrumentation

In order to determine the failure speed of the wings, a simple break-wire circuit is made by routing a wire through each of the test wings. This wire is connected to the power supply of a small radio transmitter located in the nose of the model. A continuous signal from the transmitter is received at the ground station as long as both wings remain intact and is recorded on film with chronograph marks synchronized at the time of firing. When either wing fails, the signal abruptly reduces to zero and the failure point is known. A portion of the record obtained from the flight of the NACA FR-1-A at the time of wing failure is shown in figure 4.

Launching Technique

The NACA FR-1-A was launched by means of a zero-length type launching rack; that is, the rack does not offer any support or restraint to the model after it first starts to move. Because of the inherent characteristics of the rocket engine to build up thrust slowly, it was necessary to design a break-link assembly that would retain the model on the launching rack until a thrust of approximately 800 pounds was developed.

Flight-Path Approximation

Emphasis is placed on the determination of the flight path since it is important that the altitude at the time of wing failure be known. Calculations based on predetermined aerodynamic characteristics were made to show the expected trajectory. The results of these calculations are shown in figure 5 as the variation of altitude, horizontal distance, acceleration, and velocity (Mach number) with time.

Radar Equipment

The velocity of the model was obtained by a continuous wave Doppler radar unit set behind the launching site approximately in line with the azimuth of the expected flight path. The record obtained – velocity against time – is shown by curve d of figure 5. This velocity is the component of the true velocity in line with the radar beam. However, the maximum error involved in correcting the velocity is small and can be neglected.

Radiosonde

The atmospheric conditions prevailing at the time of flight and pertinent to flutter calculations were determined by use of a radiosonde. The data are presented in figure 6 as a plot of the velocity of sound and density against the altitude.

Cameras

A K-24 aerial camera operating at 2 frames per second was placed normal to the vertical plane of the expected line of flight to obtain a record of the flight path and attitude of the model during the first 2 seconds of flight.

Two tracking movie cameras, a 35-millimeter and a 16-millimeter, were placed about 2000 feet from the launching site with the line of sight of the cameras normal to the vertical plane of the expected flight path at the point where the wings were expected to fail.

One other 35-millimeter movie camera was used to record a close-up of the actual launching.

RESULTS AND DISCUSSION

Launching

The launching of the NACA FR-1-A was entirely successful in that the break-link assembly released the model at the proper time and the launching was performed smoothly. In order to aid in the visualization of the take-off, a sequence of pictures made at approximately $\frac{1}{4}$-second and $\frac{1}{2}$-second intervals is shown in figures 7 and 8, respectively.

Flight

After the model was free of the launcher, its attitude changed from the initial angle of 63° (launching angle) to an angle of 39° in 2 seconds. This change is shown in the sequence of pictures in figure 8. The preflight calculation had indicated that the angle of pitch at this time would be 41°. This calculation compares favorably with the actual change in attitude angle.

The flight path determined from the data of figure 8 is shown in figure 9 superimposed on the calculated flight path. Since these two curves compare closely and since the change in attitude compares closely, the remainder of the actual flight path is assumed to be close to the calculated trajectory. This assumption is further justified by noting the close comparison up to the time of wing failure between the calculated velocity variation and the velocity obtained by radar, as shown by curves c and d of figure 5.

Movies showed that the model traversed a smooth trajectory, made no appreciable deviation from the direction of launching, and developed only 90° of roll during the portion of the flight that the test wings remained intact. The evidence of little roll during the first 2 seconds of flight can be seen by referring to figure 8.

Immediately after wing failure the model developed a corkscrew flight path.

Wing Failure

A motion picture taken of the flight shows that the left wing failed near the root. The time of failure of the left wing is recorded by the small radio transmitter as 9.875 seconds after the beginning of the flight (fig. 4). Curve d in figure 5 indicates that the velocity of the model at 9.875 seconds is 967 feet per second or 659 miles per hour (Mach number 0.89). This velocity is the measured failure speed of the wing. The flutter speed calculated from reference 1 for both test wings (corrected for an altitude of 2000 ft) is about 550 feet per second or 374 miles per hour (Mach number 0.505). These values were obtained assuming a wing of zero sweepback, of infinite aspect ratio, and traveling in an incompressible fluid. (See reference 1.) It is seen that this experimental value obtained at a Mach number of 0.89 is 76.2 percent greater than that obtained using the two-dimensional, incompressible, unswept theoretical value.

It is interesting to note that, by applying a cosine correction – an approximate correction for sweepback – to the flutter speed calculated by reference 1, the experimental value obtained at a Mach number of 0.89 is only 24.3 percent greater than the corrected calculated flutter speed.

The motion picture also shows that the right wing remained on the model throughout the entire flight, probably due to the change in configuration and the disturbed and erratic flow conditions existing during the corkscrew flight path following failure of the left wing. The model attained a maximum Mach number of 1.00.

The foregoing data on failure and nonfailure of the wings tested indicate that the two-dimensional, incompressible, unswept flutter theory is inadequate in determining failure speeds of sweptback finite-aspect-ratio wings in the transonic range. Similar trends are noted in the freely-falling-body tests reported in reference 2. More data will be necessary (flutter frequency as well as failure speed) to extend the flutter results of this test and to provide a basis for the development of a transonic flutter theory.

CONCLUSIONS AND REMARKS

The flutter parameters of the wings tested were such that the flutter speed calculated assuming an infinite unswept wing in an incompressible flow was 374 miles per hour (Mach number 0.505). In flight, the left wing failed to complete destruction at 659 miles per hour (Mach number 0.89), and the right wing remained on the model throughout the flight (maximum Mach number 1.00). It is seen that this experimental value obtained at a Mach number of 0.89 was 76.2 percent greater than that obtained using the two-dimensional, incompressible, unswept theoretical value.

More data (flutter frequency as well as failure speed) will be necessary to extend the flutter results of this test and to provide a basis for the development of a transonic flutter theory.

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REFERENCES

1. Theodorsen, Theodore, and Garrick, I. E.: Mechanism of Flutter - A Theoretical and Experimental Investigation of the Flutter Problem. NACA Rep. No. 685, 1940.

2. Barmby, J. G., and Clevenson, S. A.: Initial Test in the Transonic Range of Four Flutter Airfoils Attached to a Freely Falling Body. NACA RM No. L7B27, 1947.

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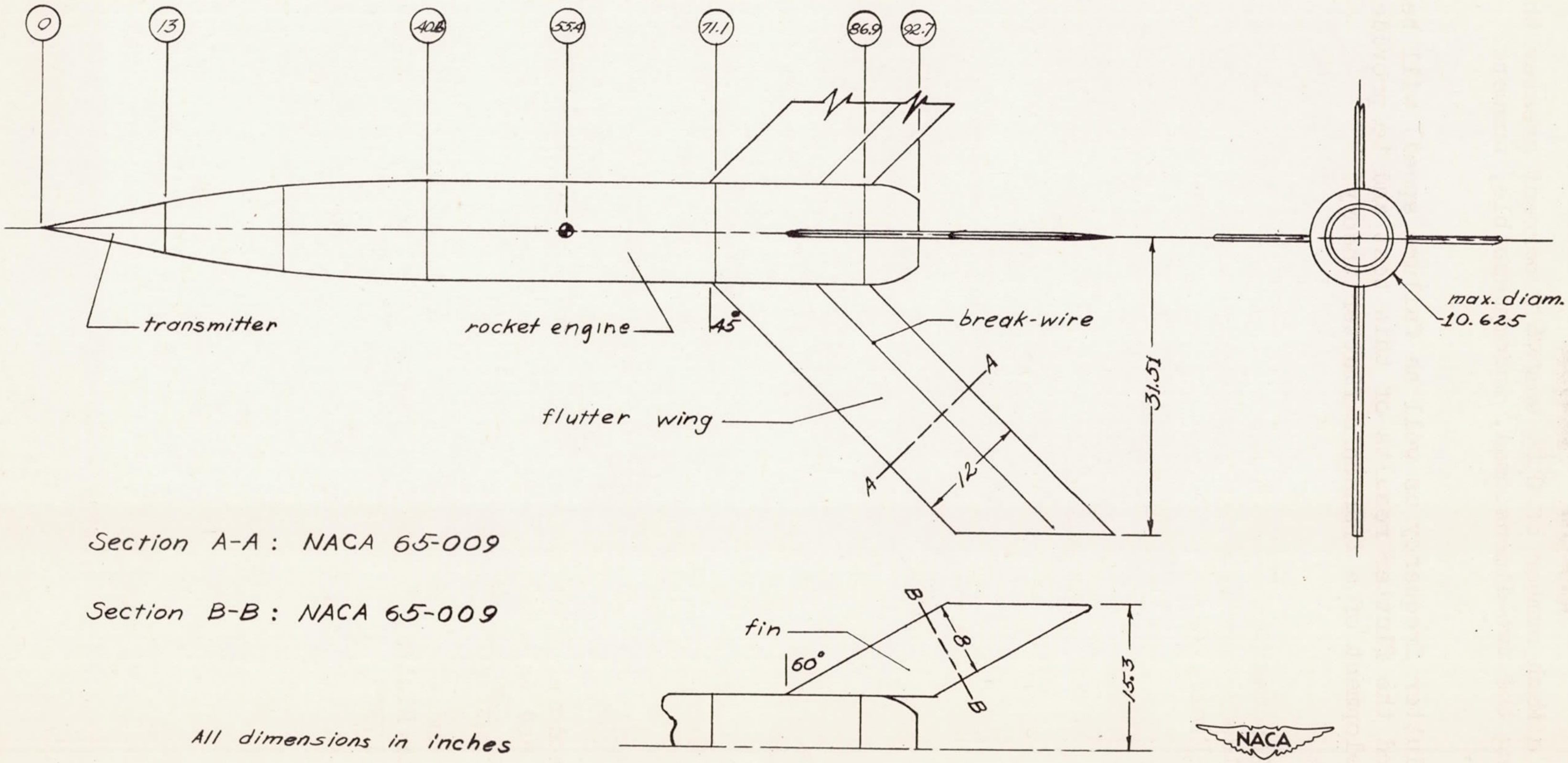

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Figure 1.- FR-1-A flutter test vehicle.

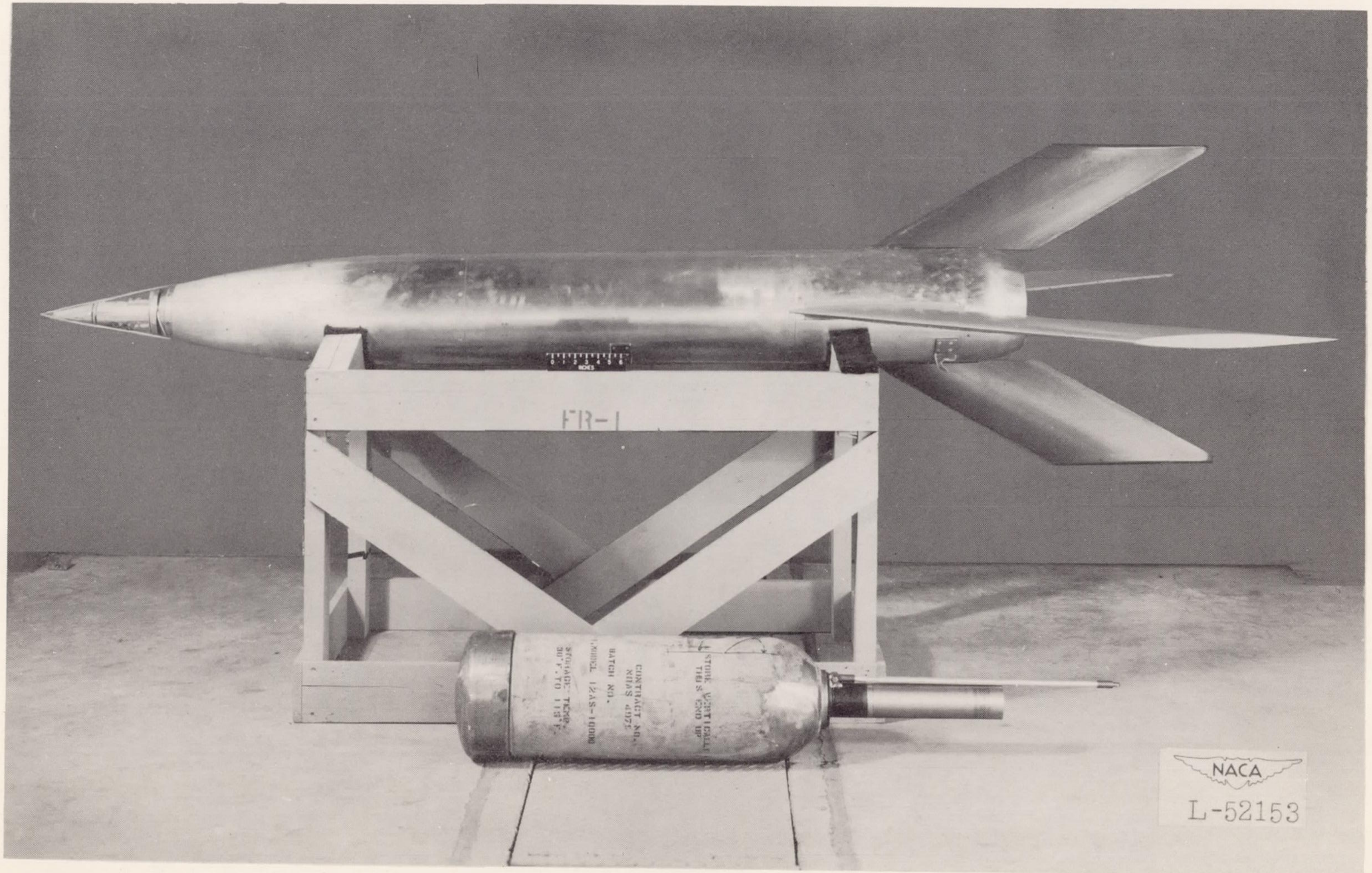

Figure 2.- Side view of the FR-1-A with power plant.

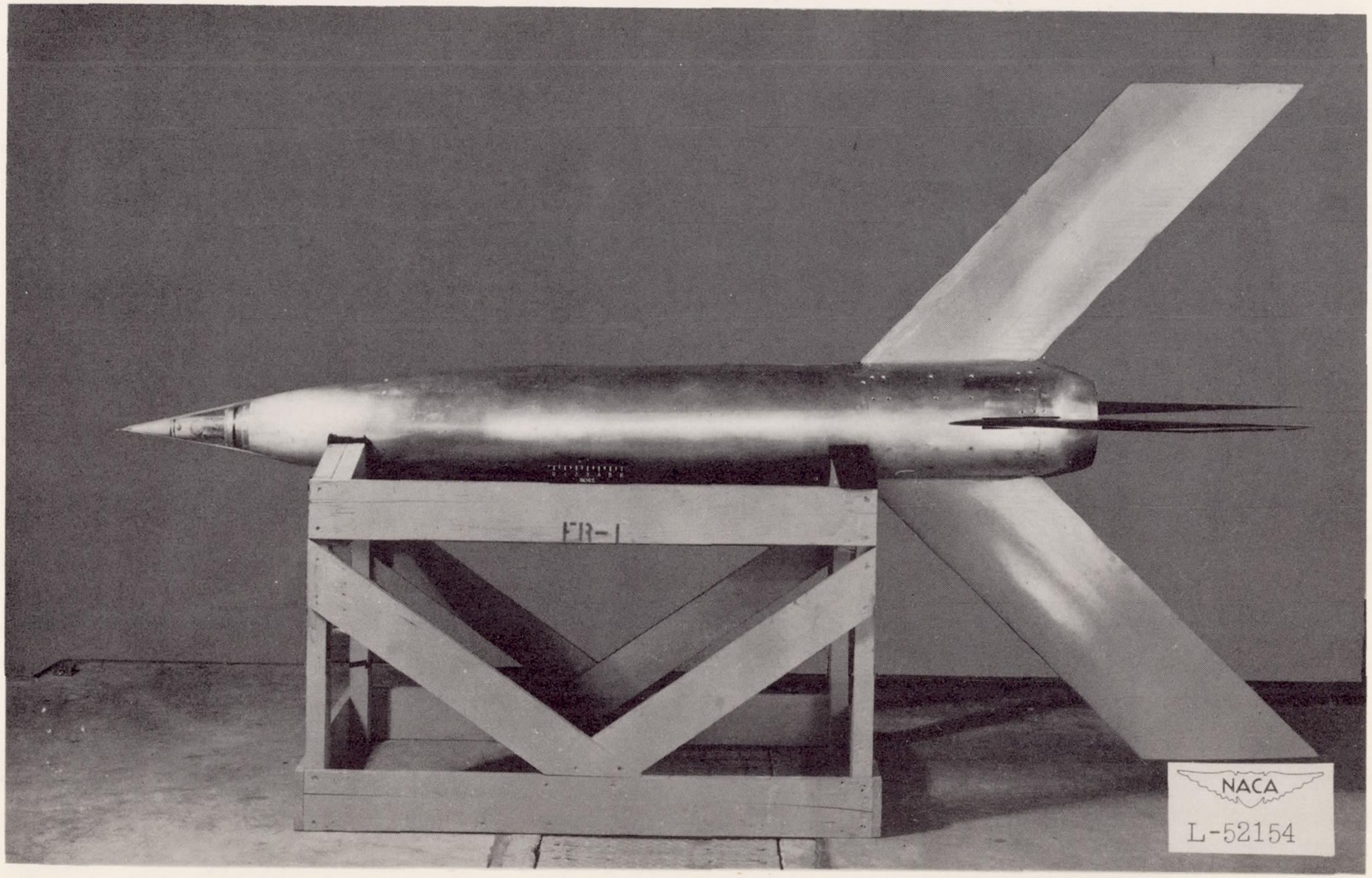

Figure 3.- Top view of the FR-1-A showing the flutter test wings.

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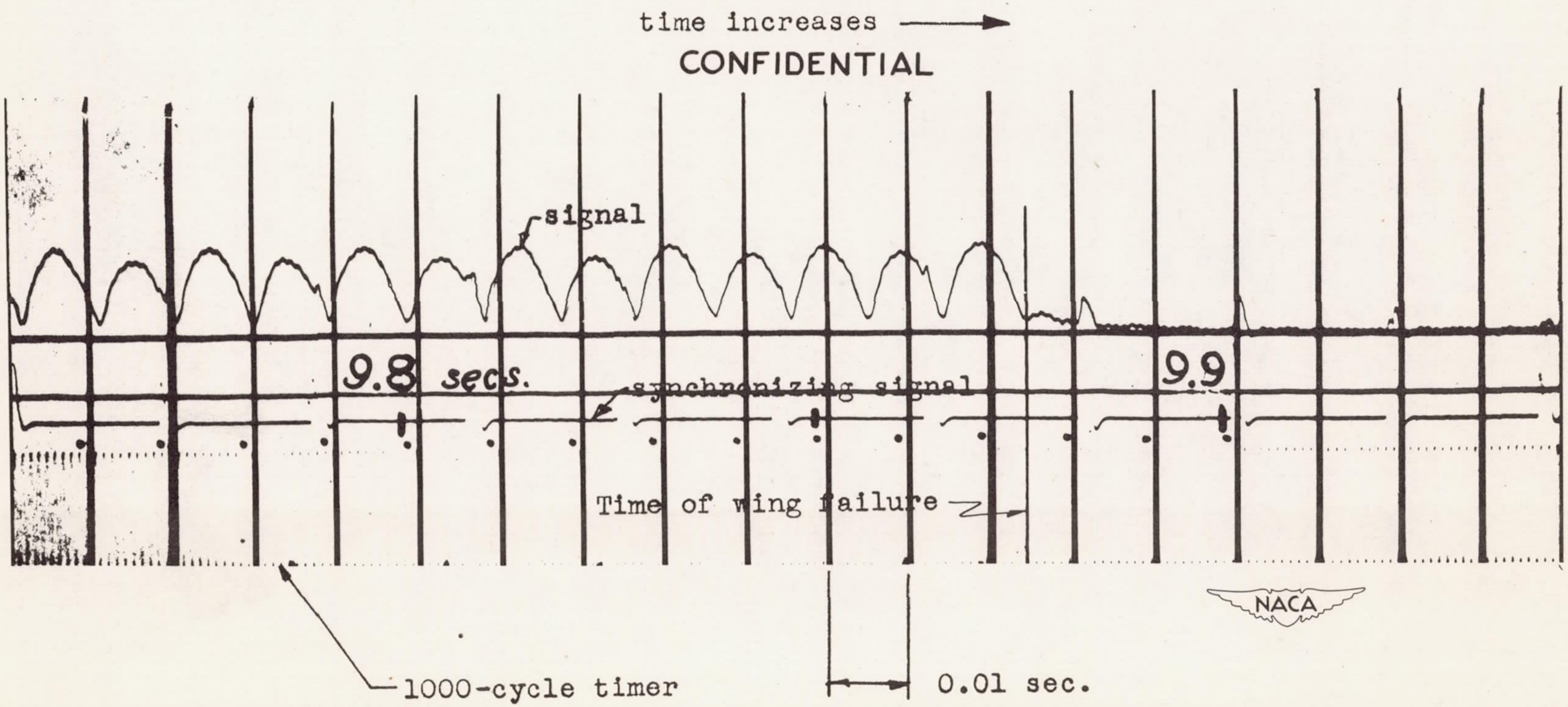

Figure 4.- Portion of telemetered record showing time of wing failure.

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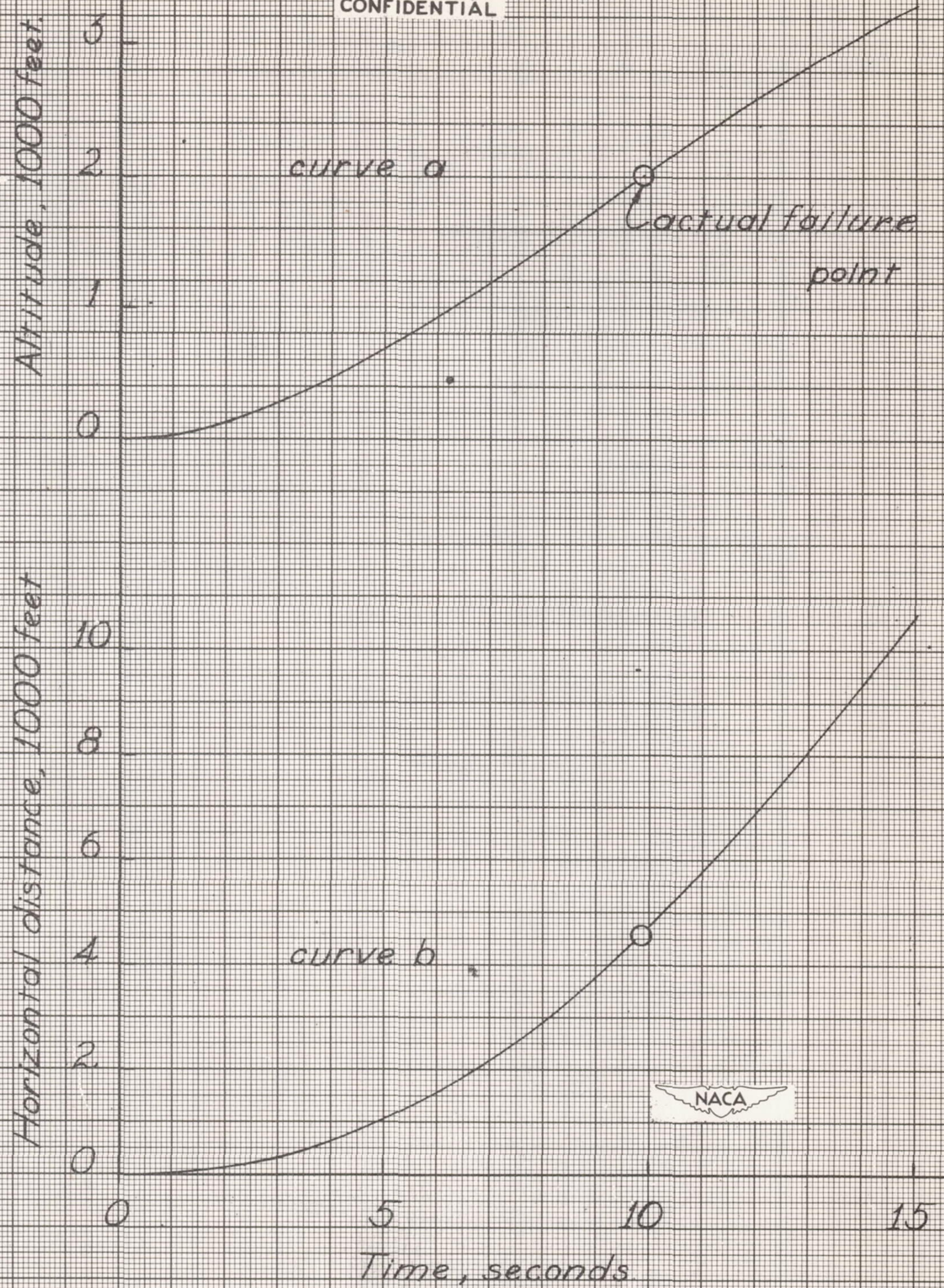

Figure 5.- Calculated trajectory characteristics of the FR-1-A.

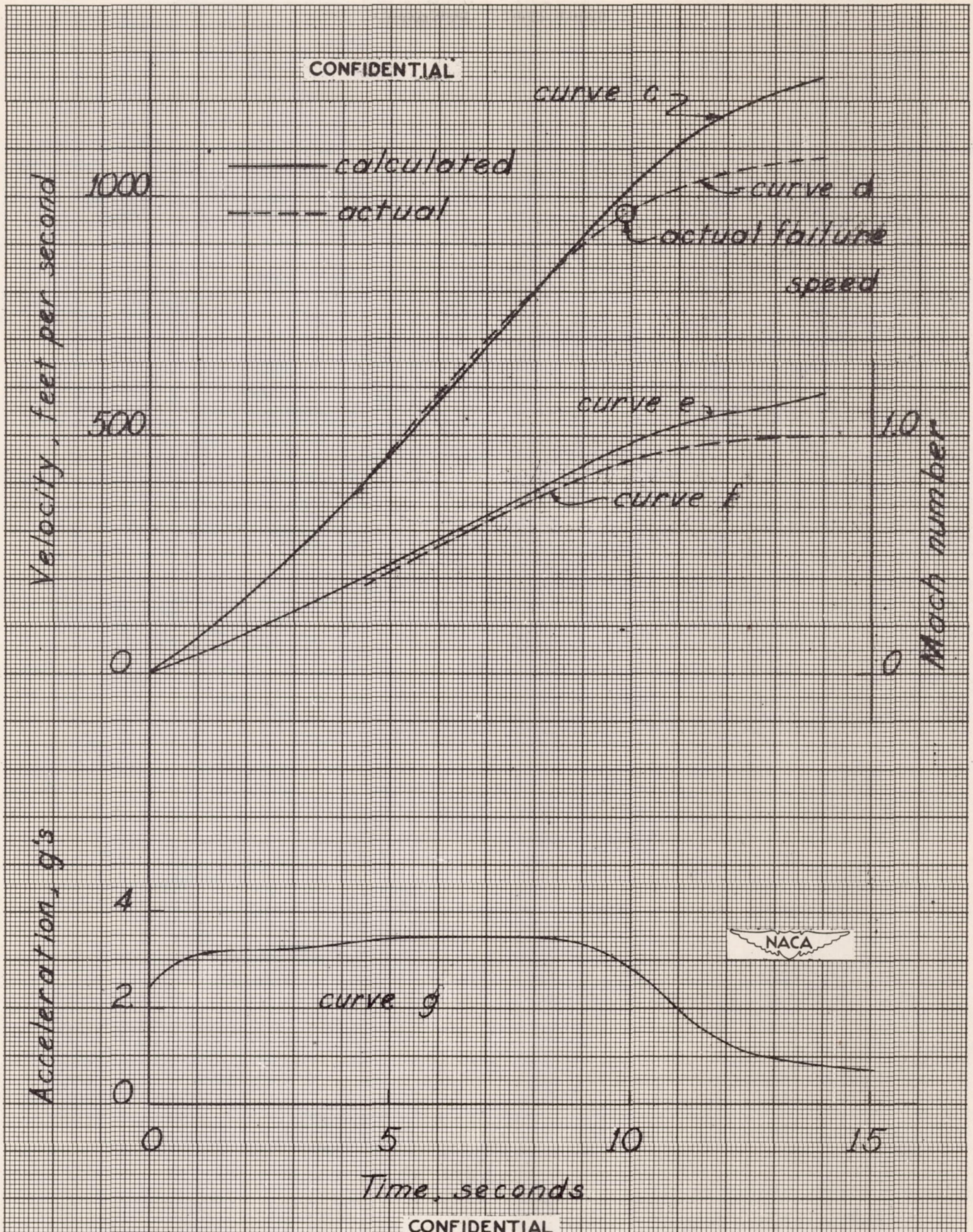

Figure 5.-Concluded.

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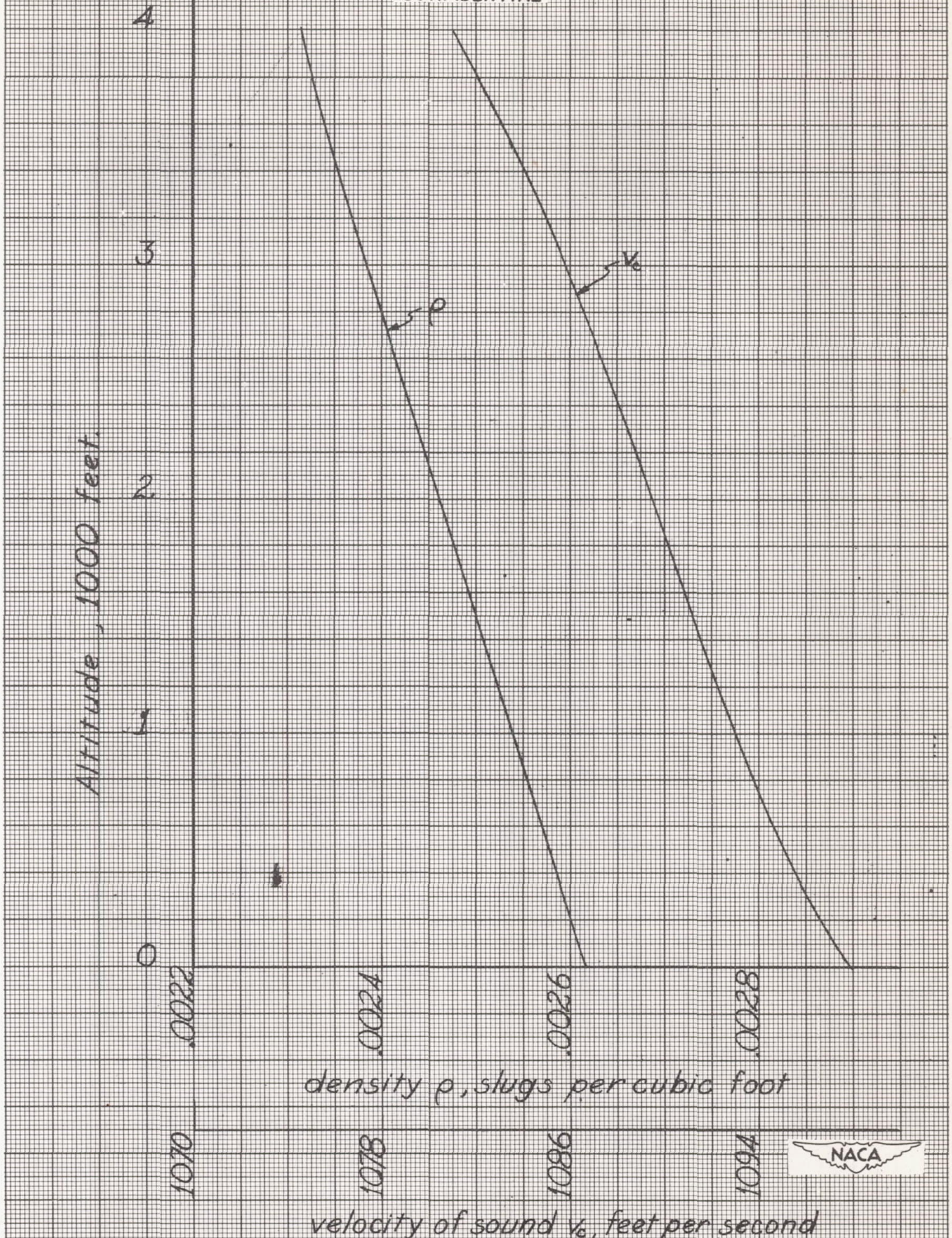

Figure 6.- Results of radiosonde record.

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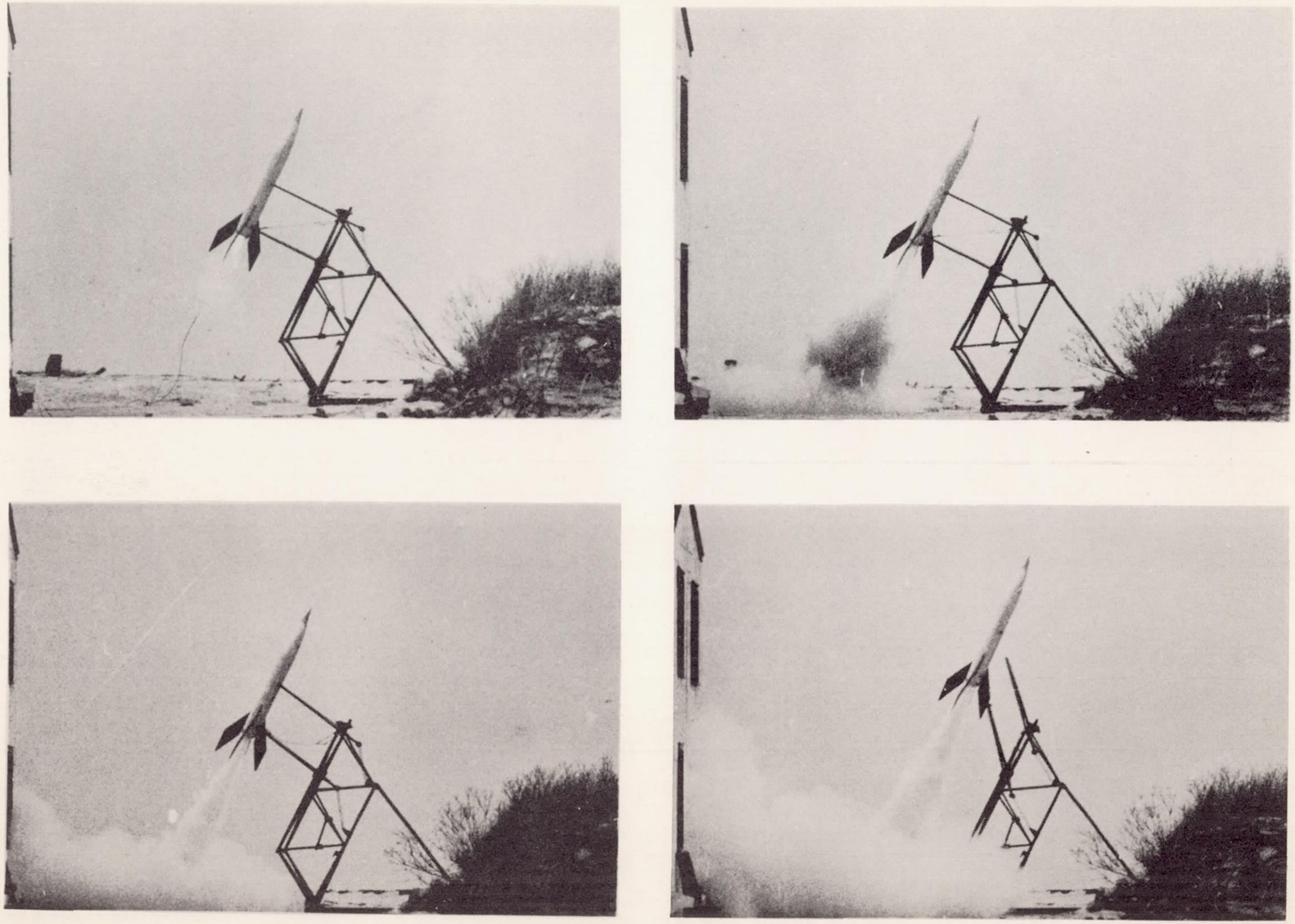
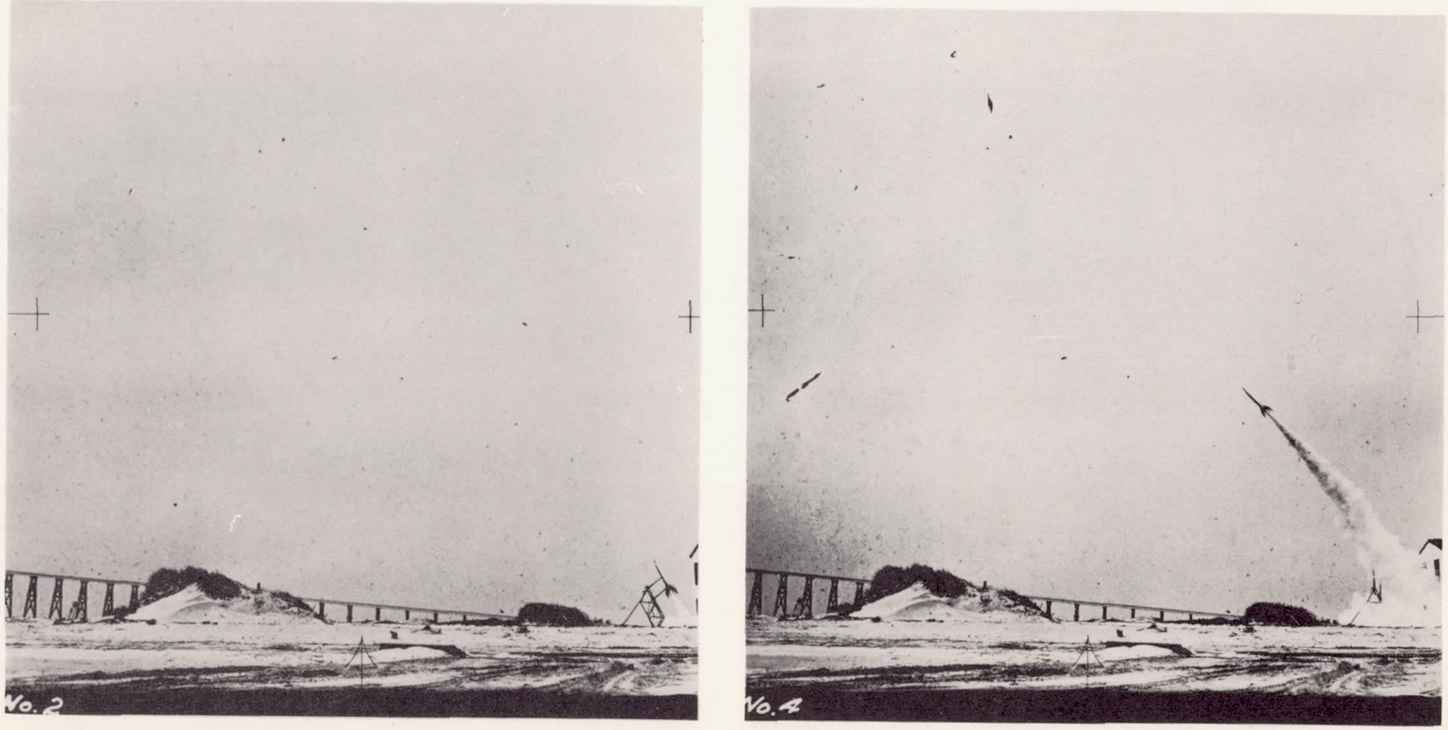


Figure 7.- Sequence of pictures of the launching of the FR-1-A at approximately $\frac{1}{4}$-second time intervals.



Time, 0 secs.

Time, 1.0 sec.

Figure 8.- Sequence of pictures of the first two seconds of flight of the FR-1-A.

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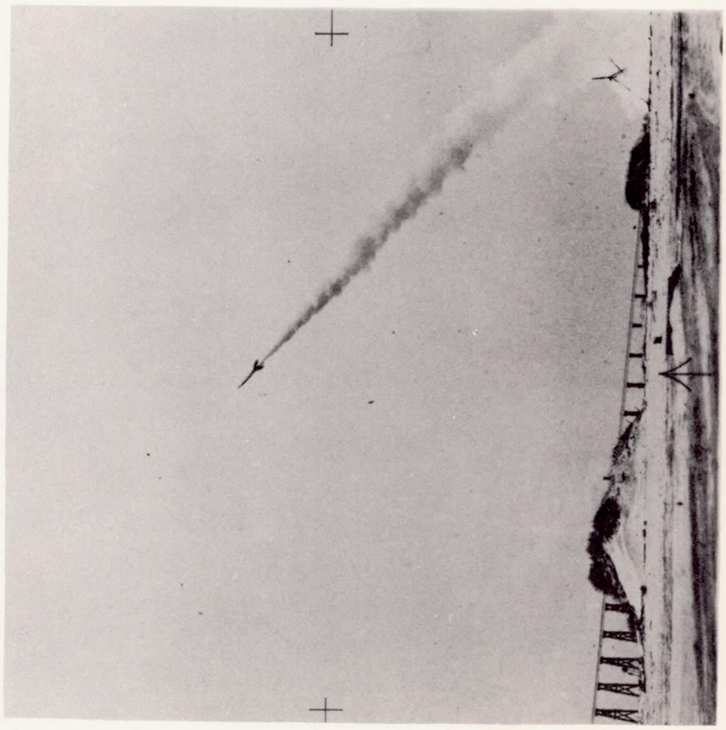
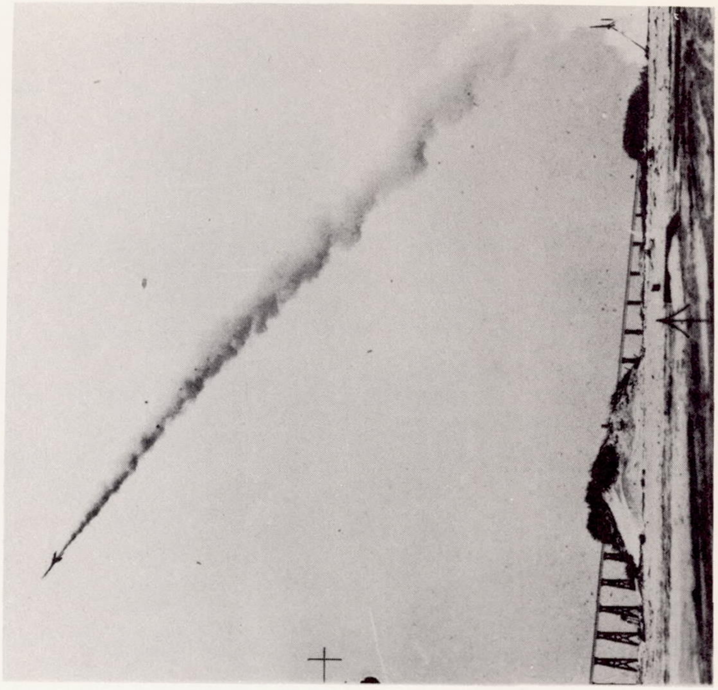


Time, 1.5 sec.



Time, 2.0 secs.

Figure 8.- Concluded.

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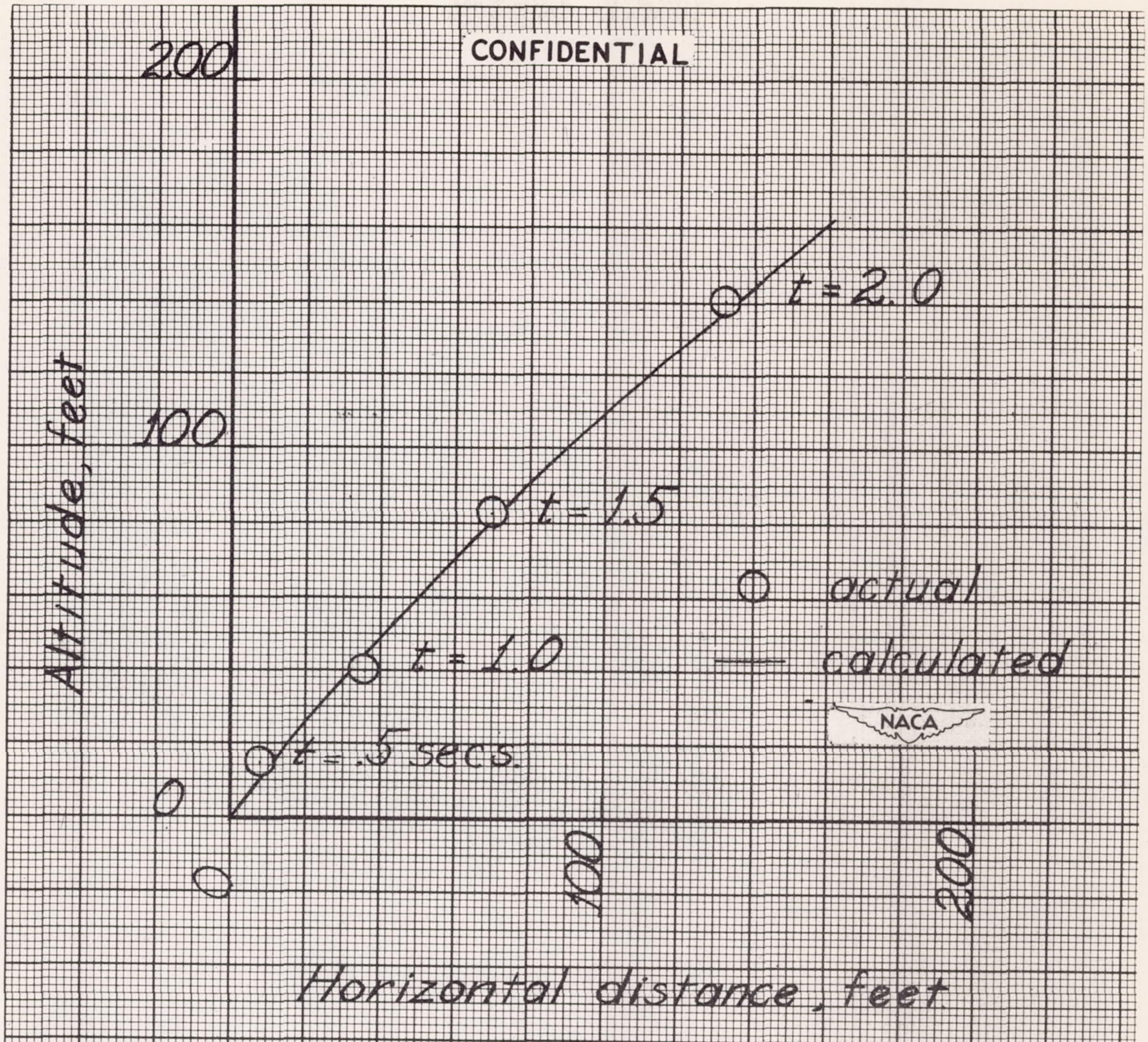

Figure 9.- Comparison of calculated flight path with actual data.