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SOME OPERATIONAL ASPECTS OF USING A HIGH-PERFORMANCE AIRPLANE AS A FIRST-STAGE BOOSTER FOR AIR-LAUNCHING SOLID-FUEL SOUNDING ROCKETS

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SUMMARY

Five test vehicles were air-launched from an F-104A airplane to investigate some of the operational aspects and the practicability of using the energy input of the airplane as a first-stage booster for sounding rockets. The concept used in the test proved to be practical. A launch maneuver and launcher system were developed and matched to the airplane's capabilities so that suitable repeatability of launch parameters was attained. The apparent benefits provided by an airplane-rocket combination were a recoverable first-stage booster, a means of controlling the flight parameters at second-stage ignition, and a highly flexible launch site that can be located anywhere within the aircraft's range.

INTRODUCTION

A need exists for a relatively inexpensive, but highly flexible, means of making atmospheric measurements at altitudes above the normal limit for weather balloons (100,000 ft) and below the minimum satellite orbits (500,000 ft). Such measurements are of special interest to the NASA Flight Research Center at Edwards, Calif., inasmuch as X-15 research airplane flights are being made into this atmospheric region. A more accurate knowledge of the atmosphere would enhance the analysis of the X-15 flight data, thus increasing the value of the data for future flight programs.

Computational studies of the performance capabilities of sounding rockets launched from high-performance military aircraft showed that use of the aircraft eliminated the need for an expensive first-stage rocket booster and also provided a means of controlling the flight parameters at second-stage ignition. An additional advantage was the flexibility of a launch site, in that it could be located anywhere within the range of the launch aircraft. The studies showed that a single-stage Viper rocket launched from an F-104A airplane could reach an altitude of about 800,000 feet, which is competitive with the altitude attained by the two-stage Nike-Asp sounding rocket. Similarly, two-staged Altair rockets when properly launched from an F-104A airplane could reach altitudes of over

6,000,000 feet, which is equivalent to that attained by four-stage sounding rockets such as the Honest John-Lance-Lance-Altair combination. The air launches appeared to be able to send a payload to altitudes above 100,000 feet for about one-third the cost of ground-launched sounding rockets.

As a result of these studies, a limited flight test program was conducted at the Flight Research Center using an F-104A airplane to air launch a Viper I-C rocket. Some of the operational aspects and the practicability of using the energy input of the airplane as a first-stage booster were investigated. This paper discusses the launcher system, the three different launch techniques developed, and the problems encountered during the program. Data obtained from five rocket launches are presented.

SYMBOLS

a_n	normal acceleration, g units
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
M	Mach number
t	time, sec
α	angle of attack, deg
β	angle of sideslip, deg
γ	flight-path angle, deg

TEST APPARATUS

Airplane and Launcher System

The airplane used in this investigation was an F-104A, S/N 60749 (fig. 1), which had been modified by the manufacturer for a series of air-launch tests in an earlier prototype weapons-systems program. The modification entailed provisions for a hydraulically actuated MB-1 launcher rack which, when retracted, is almost flush with the fuselage of the aircraft. A modified Sidewinder launcher rack (fig. 2), with appropriate electrically actuated linkage to provide a downward 8° angle between the rocket and airplane longitudinal axes, was attached to the MB-1 rack. This negative angle was pre-set for the airplane angle of attack of about 8° at launch, in order to provide 0° angle of attack for the test vehicle. Structural analysis of this combination of launcher racks indicated that the launch capabilities were compatible with the performance envelope of the aircraft. Both racks operated simultaneously, extending the rocket approximately

5 feet beneath the F-104A as shown in figure 3. This separation and angle were sufficient to prevent rocket exhaust from entering the airplane engine inlet and possibly initiating engine malfunction. Both rocket slipper lugs slid off simultaneously from the two launcher rails to achieve zero tip-off of the test vehicle. To accomplish this, the rails, of equal length, were stepped, as shown schematically in figure 4. A shear bolt restrained the rocket on the launcher until a thrust level in excess of 1,000 pounds was attained.

Another item of special equipment installed in the F-104A was a modified F-100C airplane MA-2 low-altitude bombing system (LABS) for automatically launching the sounding rocket at the proper airplane pitch angle.

Second-Stage Vehicle

The second-stage vehicle consisted of a solid-fuel rocket motor with four stabilizing fins at the rear and a payload nose section which screwed on to the threaded attachment ring at the forward end of the motor. The test vehicle was mounted on a launcher rail suspended beneath the fuselage of the F-104A airplane. The location of the second-stage vehicle on the airplane is shown in figure 1.

Two basic configurations (designated model A and model B) were used during this investigation. Both models were stabilized by a cruciform aluminum-fin configuration that incorporated a 10°-wedge angle for stability at hypersonic velocity. The leading edges were machined Inconel caps for protection at high aerodynamic-heating conditions. Figure 4 gives the basic dimensions of each model, including the overall vehicle specifications.

Rocket motor.- The rocket motor used in this investigation was the solid-propellant motor, 5.6KS5400, manufactured by the Grand Central Rocket Co. This production motor, commonly known as the Viper I-C, has a history of excellent safety and reliability and could, with a minimum amount of testing, be considered acceptable for air-launching from manned aircraft.

The nominal characteristics for this motor, based on reference 1, are:

Performance at sea level, 60° F	
Action time, sec	5.6
Average thrust, lb	5,395
Chamber pressure, psia	777
Impulse, lb-sec	30,185
Specific impulse, sec	209
Impulse/weight, sec	152
Weight	
Total weight, lb	199.7
Inert weight, lb	54.6
Dimensions	
Overall length, in.	106.9
Case outer diameter, in.	6.54
Case-wall thickness, in.	0.067

The igniter used was an electrically actuated metal-oxidant type which was inserted and hermetically sealed into the nozzle throat of the motor to insure satisfactory operation at the low ambient pressures existing at high altitude.

Model A second-stage vehicle.- The model A second stage was designed to be launched almost vertically to obtain maximum altitudes (800,000 ft) for atmospheric-density measurements.

The nose section separated after burnout at a predetermined time, releasing a Mylar inflatable sphere which contained a corner reflector for skin radar-tracking purposes. A photo of the Mylar sphere and pertinent physical characteristics are presented in figure 5. It was planned to obtain atmospheric-density measurements by ground-tracking the descent of the sphere and computing the drag effect of the atmosphere during its free fall. Upper-wind measurements would also be obtained from the horizontal translation of the sphere as a function of altitude.

To facilitate radar tracking for space-positioning the launch aircraft and, after launch, for determining the vehicle's trajectory to payload separation, a DPN-41 radar beacon and power supply was installed in the nose section of the rocket. An umbilical connector supplied electrical power to the vehicle's radar beacon until launcher-rack extension. Upon extension, the connector automatically disconnected from the nose cone, and the beacon continued operating on battery power. A schematic drawing of the model A nose section is shown in figure 6. The fins on this vehicle were mounted at 0° angle of incidence.

Model B second-stage vehicle.- The model B vehicle was designed for a classified experimental scanning device that telemetered a continuous signal to ground receivers during a flat-trajectory launch in which maximum range (160 nautical miles) was desired. The nose section and payload were designed and fabricated by the Naval Ordnance Test Station, China Lake, Calif. A detailed discussion and the physical characteristics of the vehicle are given in reference 2. The fins on this vehicle were yawed 0.25° to induce a spin rate of 6 rps for payload-scanning purposes.

INSTRUMENTATION

Launches made in the vicinity of the Flight Research Center used the Model II radar at the Center for aircraft vectoring and payload tracking. Launches made at the Pacific Missile Range used the FPS-16 and Model II radars at the Point Mugu Naval Air Station and San Nicolas Island.

The F-104A airplane was equipped with standard NASA instrumentation, synchronized by a common timer, to record the following quantities pertinent to the rocket launch:

Airspeed and altitude
Angle of attack and angle of sideslip
Normal acceleration

Pitching attitude
Pitching velocity

Airplane pitch attitude was obtained from the vertical gyroscope of the LABS to initiate rocket ignition. Aircraft attitude-angle settings were recorded to substantiate the angle at which launch was made. Rocket ignition and "rocket away" were also recorded.

TEST PROCEDURE

The F-104A prelaunch maneuver was essentially the same for each of the five launches. The airplane took off from Edwards Air Force Base, Calif., climbed to a given altitude, accelerated to a given Mach number, stabilized on speed, altitude, and heading for 30 seconds prior to pull-up to allow erection of the LABS, and at a predetermined geographical launch-initiation point performed a pull-up at a specified value of g until the required angle of attack was attained. This angle was maintained until the aircraft reached the pre-set pitch angle, at which time the rocket was automatically launched by the LABS. To insure accuracy of the airplane pitch angle at launch, the maximum and minimum pitch-angle switches were adjusted to $\pm0.5^\circ$ of the desired value. The angle-of-attack limits were nominally $\pm1^\circ$ from the desired angle except for launches 4 and 5 in which the limits were increased to $\pm1.5^\circ$.

To prevent inadvertent ignition of the rocket motor while it was attached to the launch aircraft, an electrical circuit was designed that required actuation of 10 switches before current could reach the rocket igniter. Schematics of the electrical circuit and a typical launch maneuver for a model A second-stage vehicle are presented in figures 7 and 8, respectively. The circled numbers on the drawings depict the switching sequence throughout the launch maneuver. For example, just prior to aircraft taxiing, a ground crewman closed switch 1. Then, when the pilot raised the gear, switch 2 closed. During the acceleration to the desired Mach number, the pilot closed switch 3. Switch 4 was then closed and could be opened at any time by the pilot to prevent a launch. Switch 5 was closed just after pull-up initiation to lower the launcher racks. Rack down-limit switches 6 and 7 closed when the racks became fully extended. When the proper angle of attack was attained, switch 8 closed. Switch 9 closed when the aircraft passed through the proper pitch attitude, completing the circuit to actuate the firing relay, switch 10, which applied current to the rocket igniter.

DISCUSSION AND RESULTS

The primary purpose of this test program--to investigate some of the operational aspects and the practicability of using the energy input of an airplane as a first-stage booster for atmospheric sounding rockets--was accomplished. Several problems encountered during the testing are discussed in this section.

Aircraft Launch Maneuver Problem

Prior to the first launch, approximately 40 practice flights were made to perfect pilot technique and the ground-control coordination necessary to achieve repeatablility of maneuver and initial conditions at launch. Early in this portion of the program, airplane and maneuver incompatibility was manifested by severe engine-compressor stalls, engine overtemperature, and flameout. The flameouts occurred, in most cases, "on top" prior to recovery and were attributed to a combination of high altitude (55,000 ft), low airspeed (40 KIAS or below), an excessive angle of attack (8°), and engine-throttle movement (for example, either out of afterburning position to military power or to idle). On subsequent flights, the throttle was not moved from the full-burning position during the maneuver, regardless of burner blowout, until a velocity of 300 KIAS or an altitude of less than 40,000 feet was reached during recovery. This procedure eliminated flameouts and compressor stalls, and succeeding flights were uneventful in this respect. However, initiation of the launch maneuver for the high-angle launches was lowered from 25,000 feet to 21,500 feet or less to provide the aircraft with more airspeed (120 KIAS) over the top. Inasmuch as the acceleration characteristics of the F-104 are dependent upon ambient temperature, the maneuver-initiation altitude was lowered in some instances to insure the desired Mach number at pull-up.

Launch Maneuvers

Figures 9(a) to 9(d) present time histories of the launch-aircraft performance from pull-up to rocket launch of the model A vehicles. The pilot did not report any undue difficulty in performing these maneuvers except in the transonic region just prior to launch in which pitching oscillations were induced. To maintain an unobstructed line of sight to the second-stage vehicle's radar beacon prior to launch, and to use the available impact area in the vicinity of Edwards Air Force Base, it was necessary to make an "over-the-shoulder" type of maneuver for launches 1 and 2. Launches 4 and 5, the other model A launches, were made at the Pacific Missile Range and used the Range impact area. The maneuver for these launches differed from the one used in launches 1 and 2 in that the rocket was fired before the vertical position was attained. Recovery from the model A launches resulted in peak altitudes of about 45,000 feet and an airspeed of approximately 120 knots.

The model B vehicle (launch 3) was launched at a low attitude angle of 38°, an altitude of 52,000 feet, and a Mach number of 1.4. Recovery from this maneuver consisted of a rollover and pull-through after launch, which resulted in a maximum altitude of 75,000 feet with a Mach number of 0.80. Figure 10 presents a time history of the launch-aircraft performance from pull-up initiation to second-stage launch for the model B vehicle. As anticipated, the pilots reported this to be the easiest to perform of the three different maneuvers.

Launcher System and Rocket Tests

To determine launcher system and rocket compatibility, two ground-launch tests were made before an air launch was attempted. For these tests, a spare MB-1 rack and the Sidewinder rack used for subsequent air launches were mounted on a steel A-frame, and two specially cast Viper I-C motors of 0.2-second thrust duration were fired from this configuration. Both tests were successful, and clean separation was achieved.

In view of the excellent safety and reliability history of the Viper I-C motor, only a minimum amount of testing was considered to be necessary to rate it as acceptable for launching from a manned aircraft. This testing consisted of mounting a Viper I-C motor on the launch aircraft and performing a Model A type of launch maneuver which subjected the motor to the stresses and temperatures encountered on an actual launch. Two tests were made, on separate days, with two different motors. After the tests, the grains were X-rayed and compared to X-rays taken when the motors were produced. The motors were then statically fired, and thrust and chamber-pressure recordings were made for comparison with the nominal characteristics of the Viper I-C motor. No abnormalities were noted, and the motor was considered to be acceptable for air launching.

Test Results

Table I presents a summary of the airplane flight conditions at launch and the subsequent maximum rocket performance. The model B vehicle, which was not equipped with an onboard radar beacon, was not successfully tracked; however, the duration of the payload telemetry signal indicated that the flight-performance predictions were essentially met, in that a telemetry signal was received for 210 seconds of the 260 seconds predicted flight time. No flight data were obtained on launch 4 because of a rocket-beacon failure. From the maximum altitudes and ranges to impact for the model A vehicles listed in table I, it is apparent that impact-area predictions were impossible to make with any sensible accuracy. This problem was encountered during another similar program (ref. 3).

CONCLUDING REMARKS

From a limited flight test program in which an F-104A airplane was used to launch solid-fuel sounding rockets, the following comments may be made:

The method employed in the tests to utilize the energy of an airplane as a first-stage booster and launcher for sounding rockets was practical.

The aircraft launch maneuver to attain the desired launch parameters was repeatable, and provided a means of controlling the flight parameters at second-stage ignition.

Care should be exercised in matching the desired launch conditions with the airplane's operational characteristics.

By modifying existing off-the-shelf hardware, launcher systems could be mounted on other types of high-performance airplanes for air-launching sounding rockets.

This method has the advantage of providing an extremely flexible launching point, in that it is limited only by the range of the launch airplane from a suitable airfield.

The major savings in cost in this type of operation is realized from the recovery of the first-stage booster.

The impact-area was impossible to predict with any sensible accuracy for launches made at high attitude angles.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., October 19, 1962.

REFERENCES

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2. Creusere, Melville C., Loper, Warren E., and Johnson, John M., Jr.: Final Report on Viperscan. NOTS Tech. Pub. 2725, NAVWEPS Rep. 7756, U. S. Naval Ordnance Test Station (China Lake, Calif.), July 24, 1961.

3. Newell, Homer E., Jr.: Sounding Rockets. McGraw-Hill Book Co., Inc., 1959, ch. 10.

TABLE I.- SUMMARY OF LAUNCH CONDITIONS AND ROCKET PERFORMANCE

Airplane					
Launch condition	Launch 1 Model A	Launch 2 Model A	Launch 3 Model B	Launch 4 Model A	Launch 5 Model A
Altitude, ft	38,200	39,100	51,100	28,600	34,250
Mach number	0.84	0.76	1.40	0.91	1.00
Aircraft attitude, deg	[a]102	[a]101	[a]41	[a]79	[a]80
Normal acceleration, g	1.48	0.70	1.60	3.10	2.15
Angle of attack, deg	8.61	6.12	7.20	9.07	8.17
Angle-of-attack limit, deg	8 ±1	7 ±1	7 ±1	8 ±1.5	8 ±1.5
Angle of sideslip, deg	0.90 left	0.22 right	0.70 left	0.40 left	0.40 left
Rocket					
Performance	Launch 1 Model A	Launch 2 Model A	Launch 3 Model B	Launch 4 Model A	Launch 5 Model B
Maximum velocity, ft/sec	6,350	6,500	[b]6,450	Unknown	4,890
Launch-attitude angle, deg	85.2	84.6	38.5	79.4	79.4
Maximum altitude, ft	243,000	383,000	[b]234,000	Unknown	204,000
Range to impact, n.m.	18	62	[b]163	Unknown	27
Desired launch angle, deg	85	85	39	80	80

[a]Approximate (by integration of pitching velocity).

[b]Predicted flight-time performance; telemetry-signal duration indicated that predictions were essentially met.

Figure 1.- Launch airplane with second-stage model A vehicle attached.

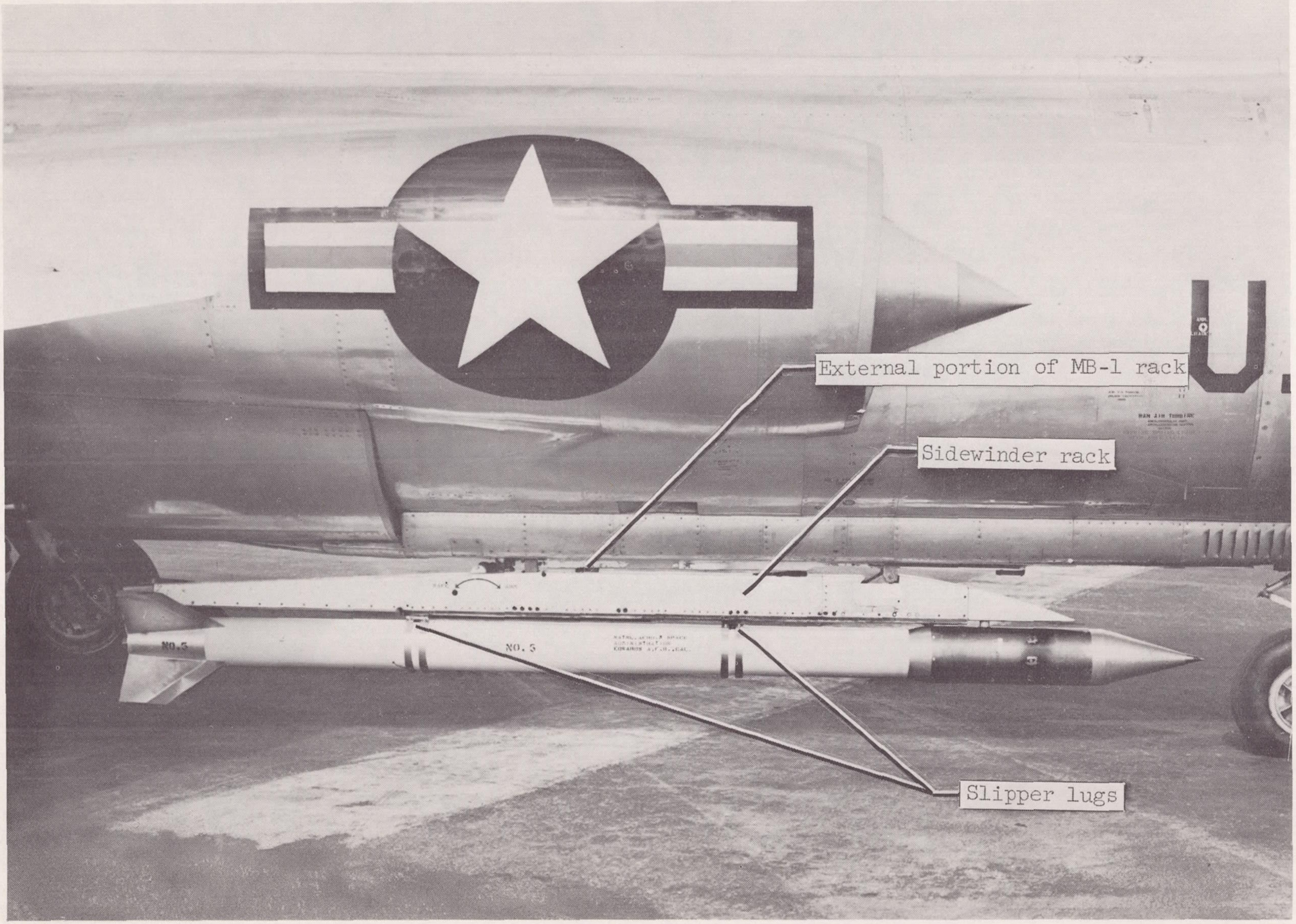


Figure 2.- Photograph of the model A vehicle mounted on the retracted launcher rack.

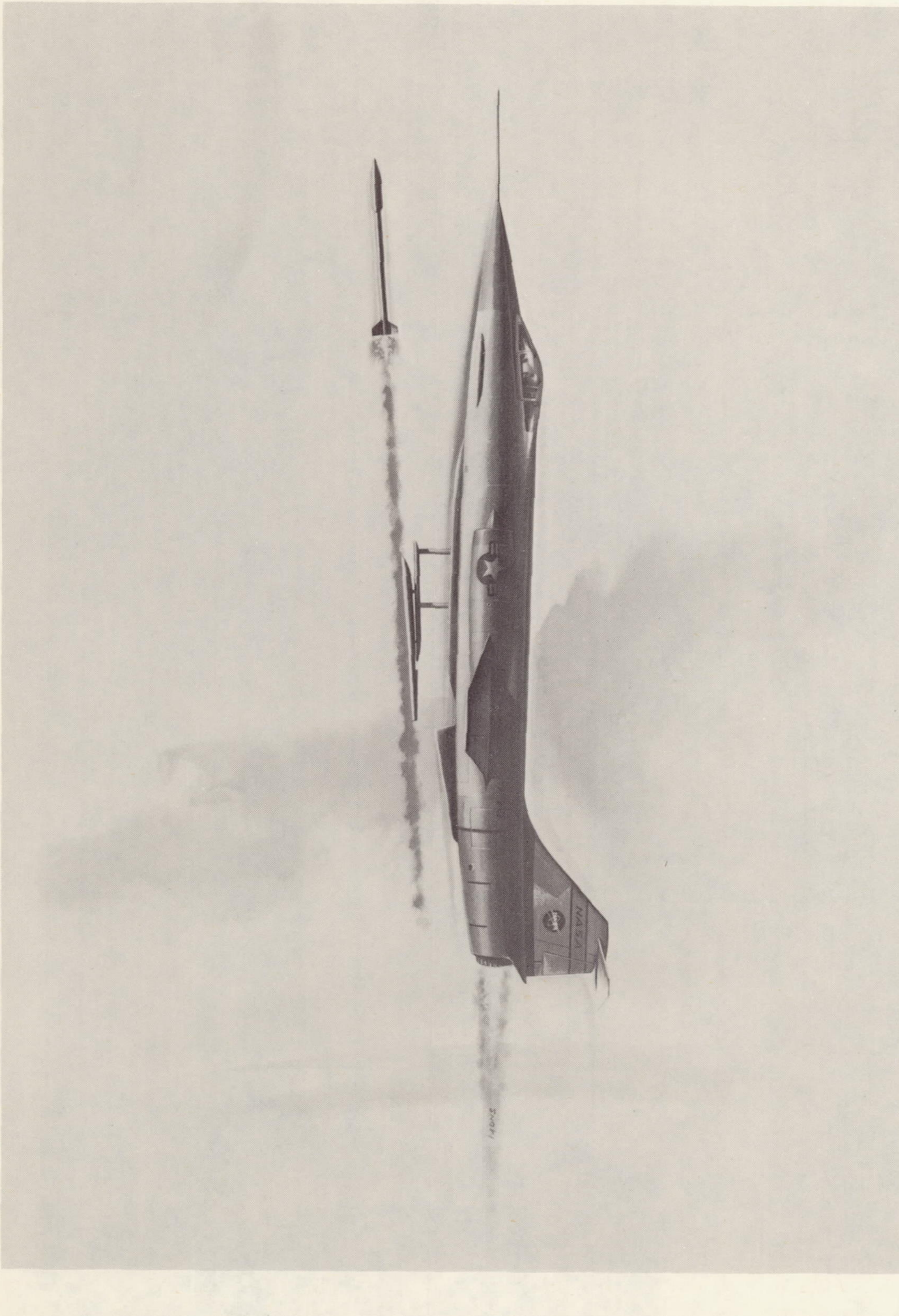


Figure 3.- Artist's conception of aircraft at launch attitude. Model A vehicle.

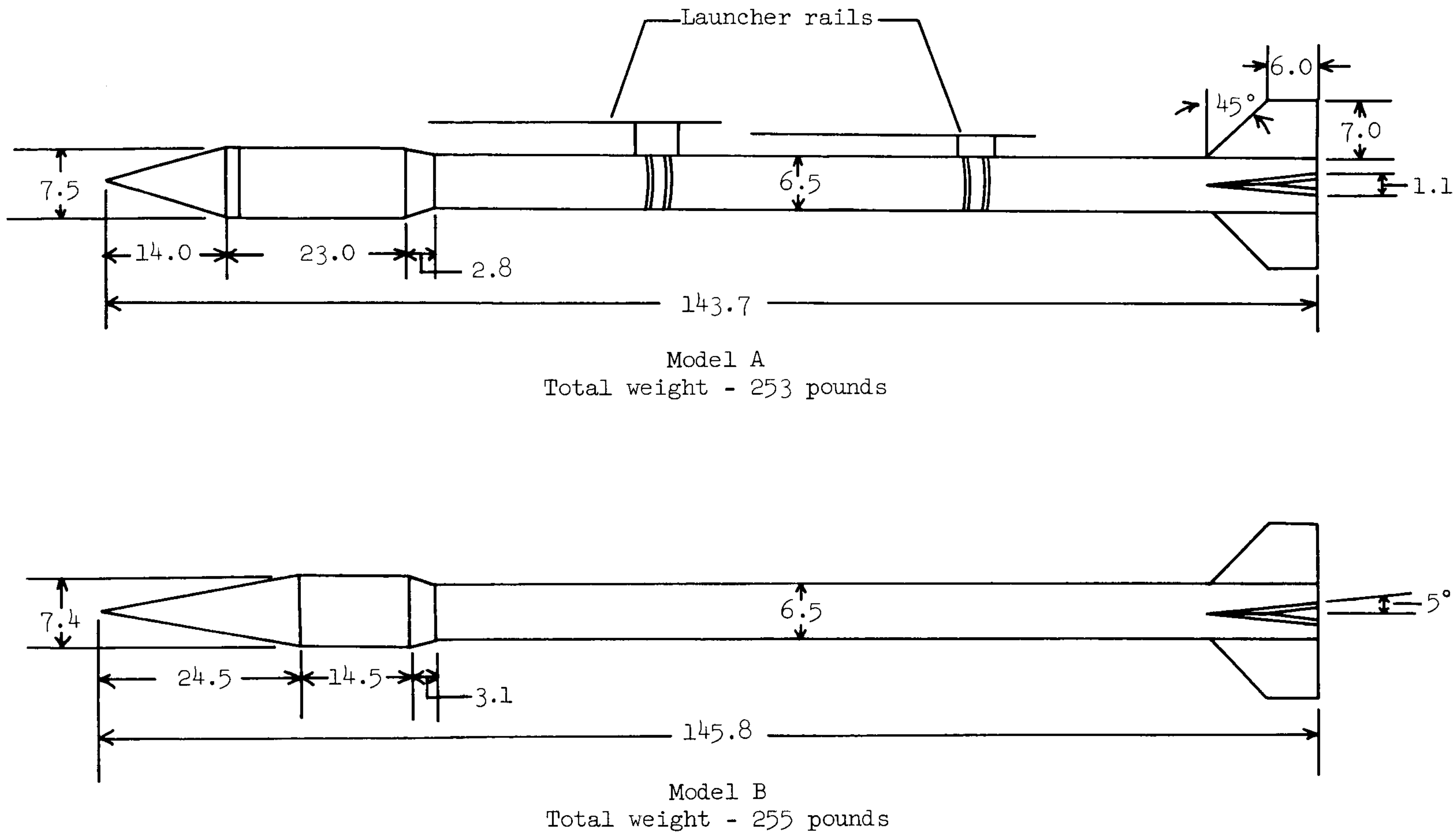
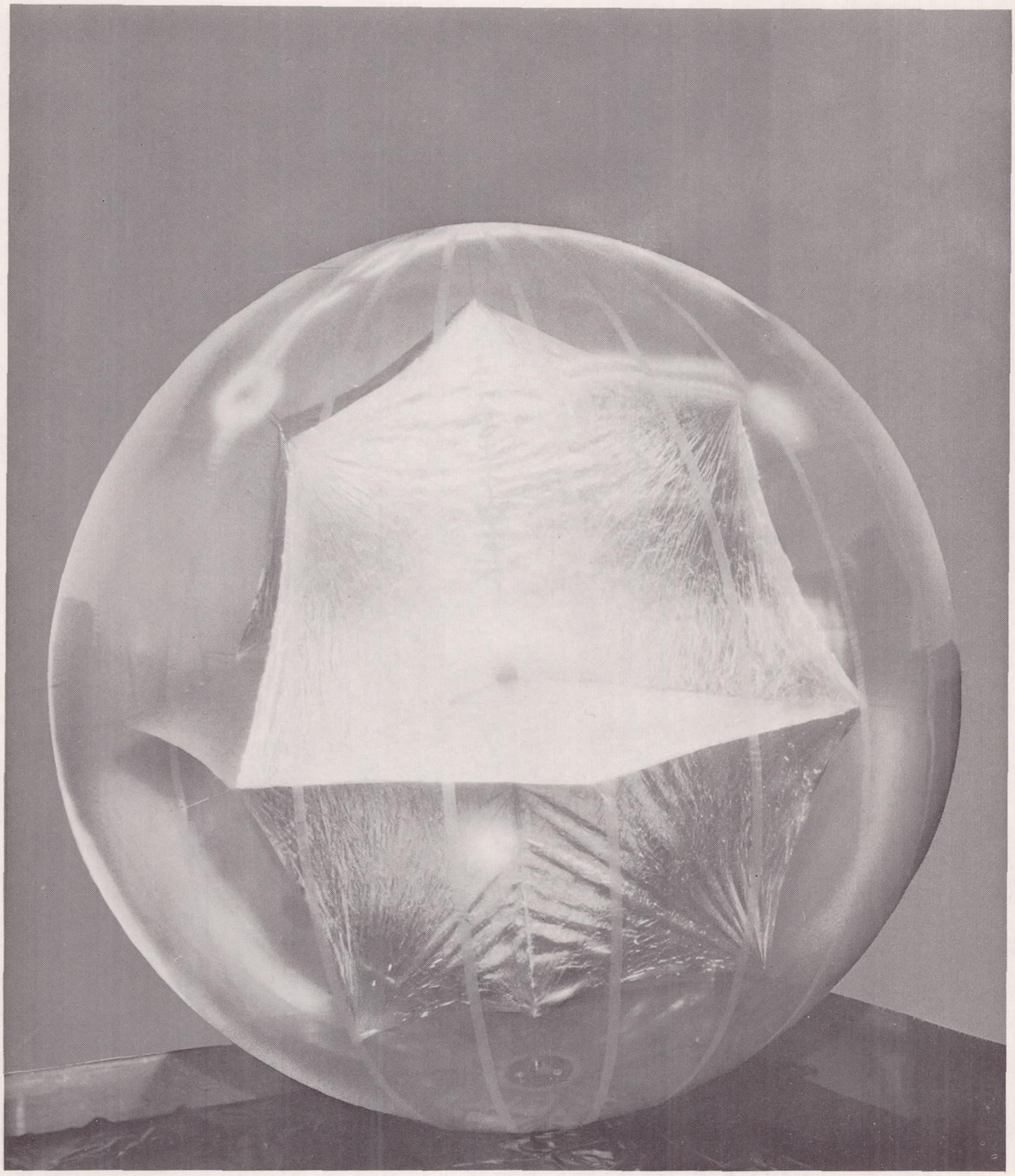


Figure 4.- Schematic drawings of the two types of test vehicles. All dimensions in inches unless otherwise noted.

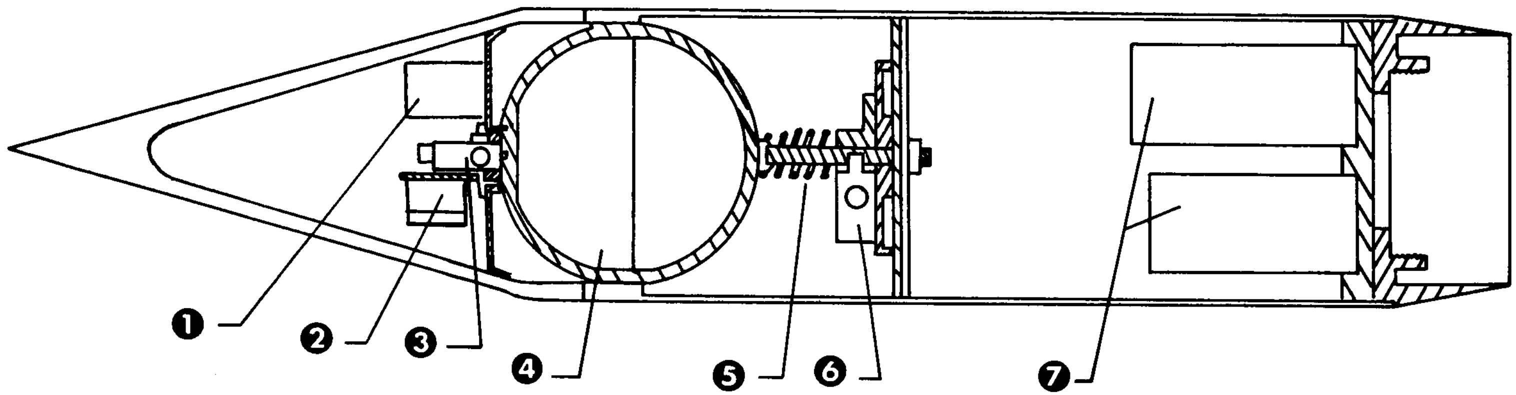


Diameter - 8 feet

Weight of sphere - 1.11 pounds

Inflation medium - 0.14 pound of isopentane
0.02 pound of water

Figure 5.- Payload of model A vehicle.



1. Mechanical timer
2. Explosive latch-pin batteries
3. Explosive latch pin
4. Inflatable sphere container
5. Spring
6. Explosive latch pin
7. Radar beacon and power supply

Figure 6.- Schematic drawing of the model A nose section.

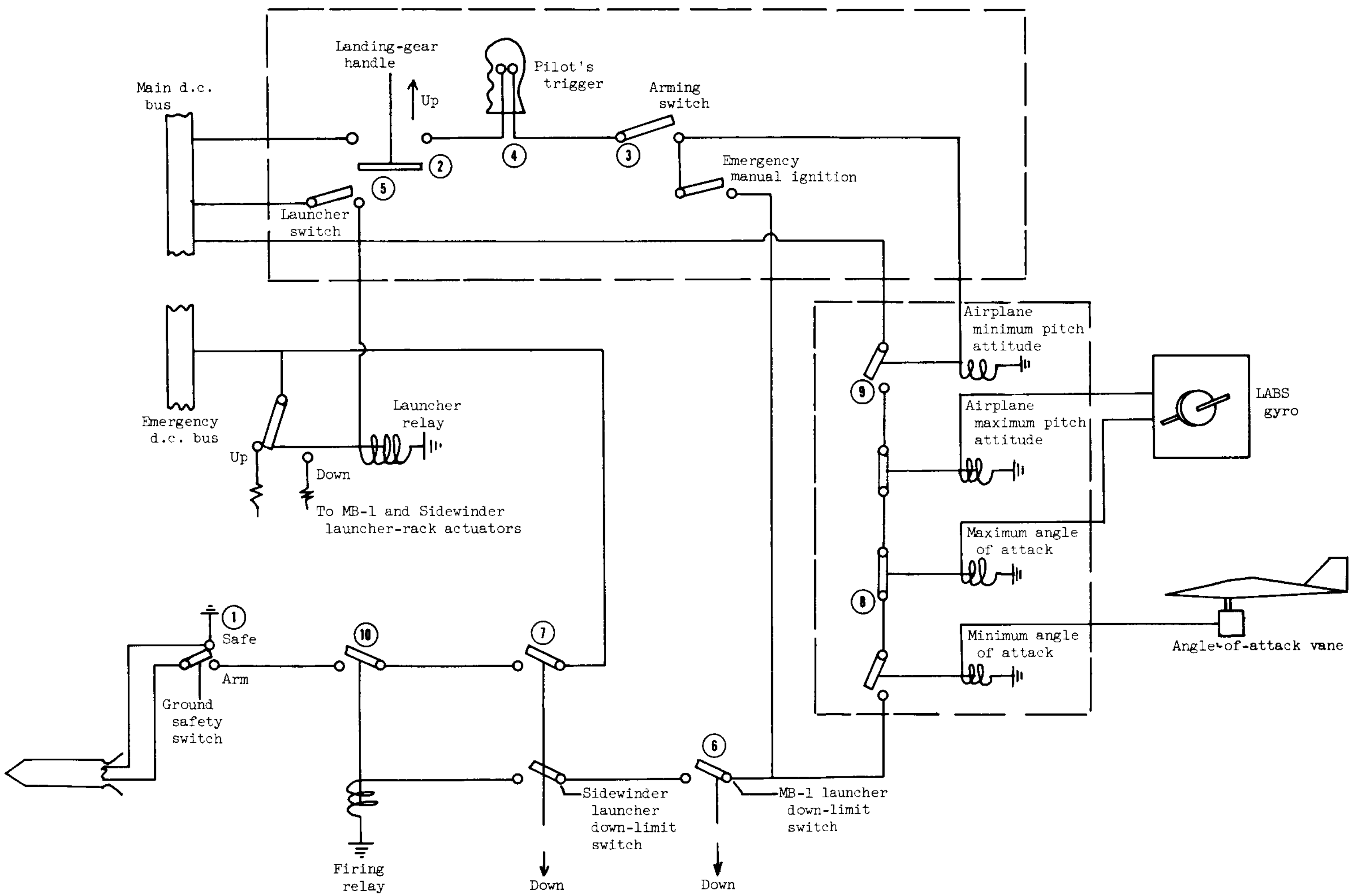


Figure 7.- Wiring diagram of second-stage ignition circuit. Numerals depict switching sequence (see fig. 8).

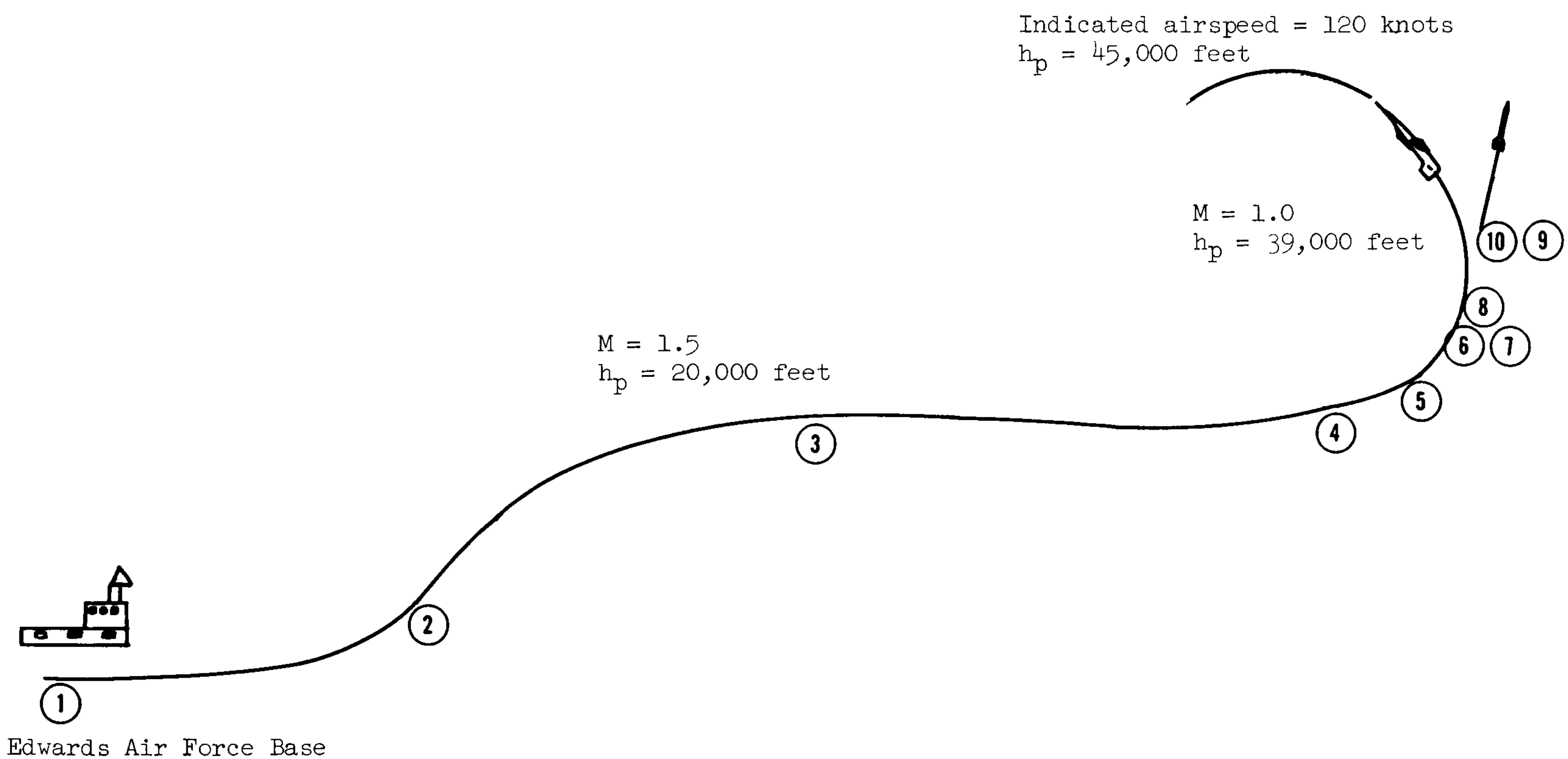
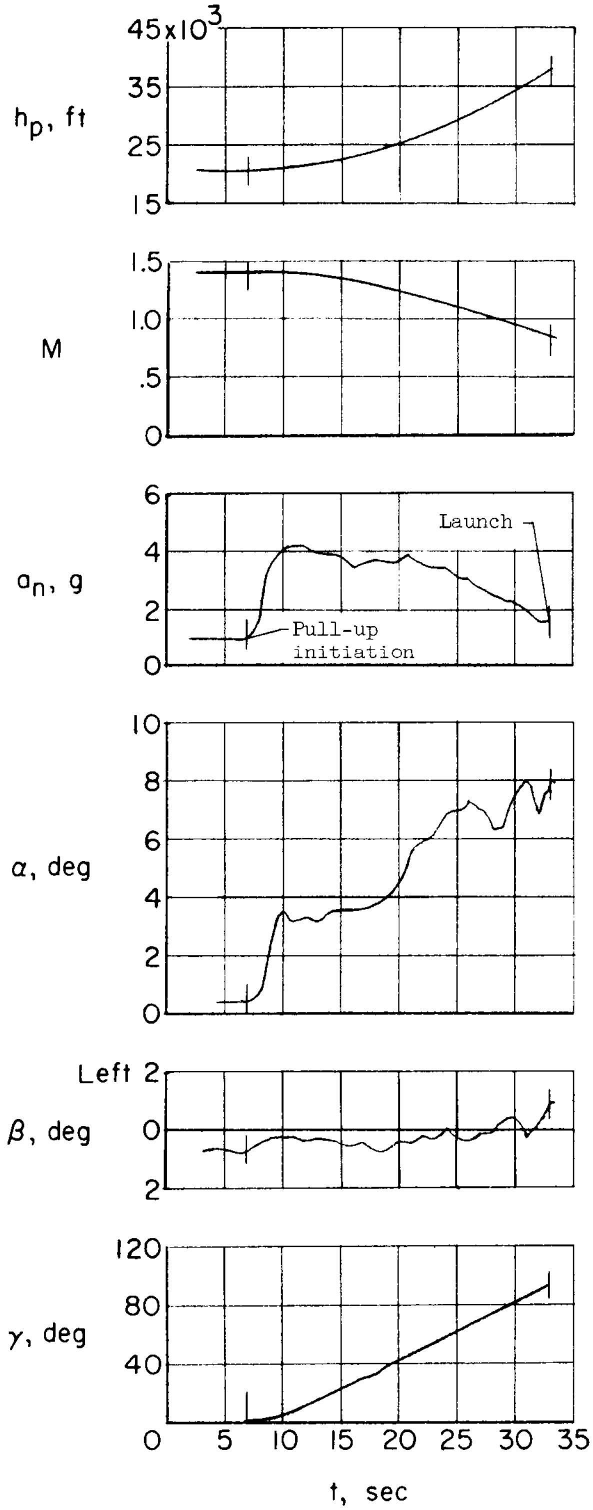
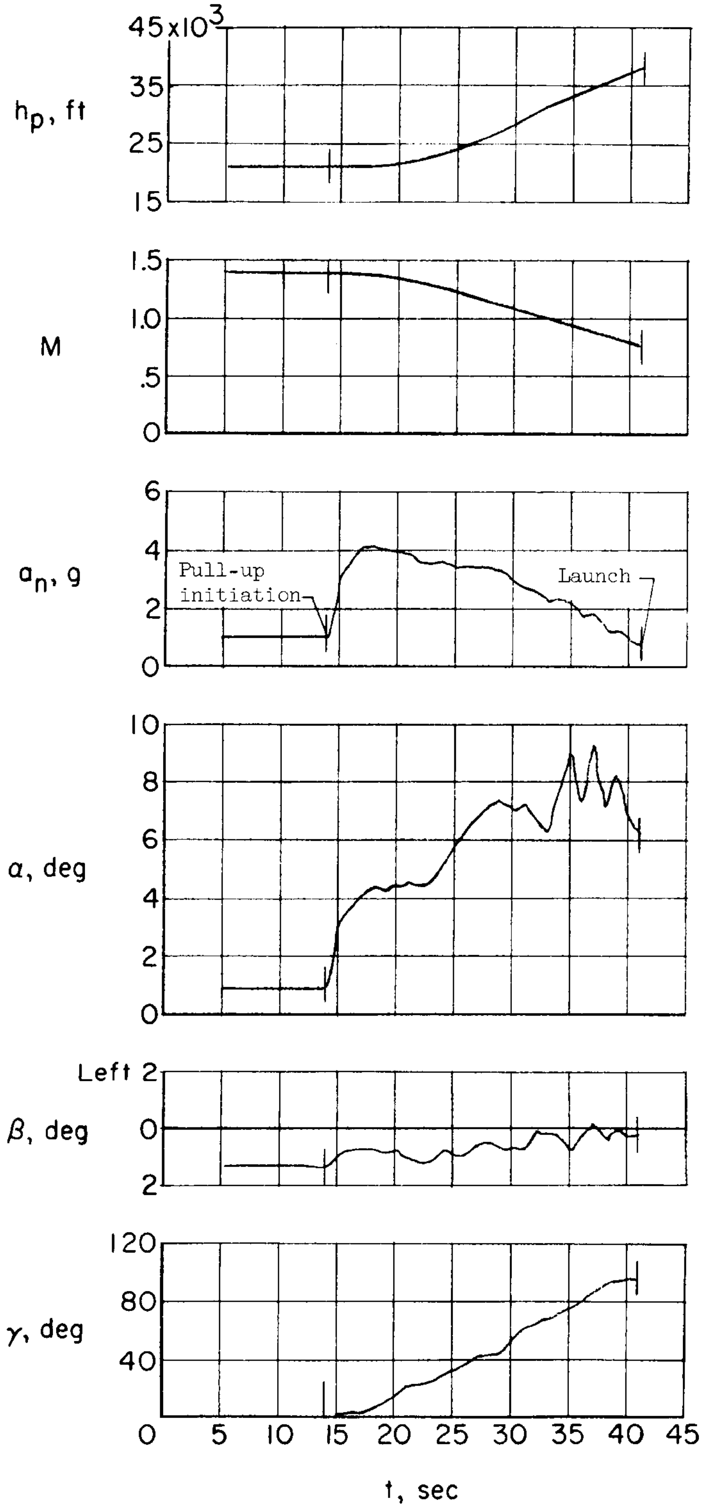


Figure 8.- Typical model A second-stage launch maneuver. Numerals correspond with switching sequence of figure 7.



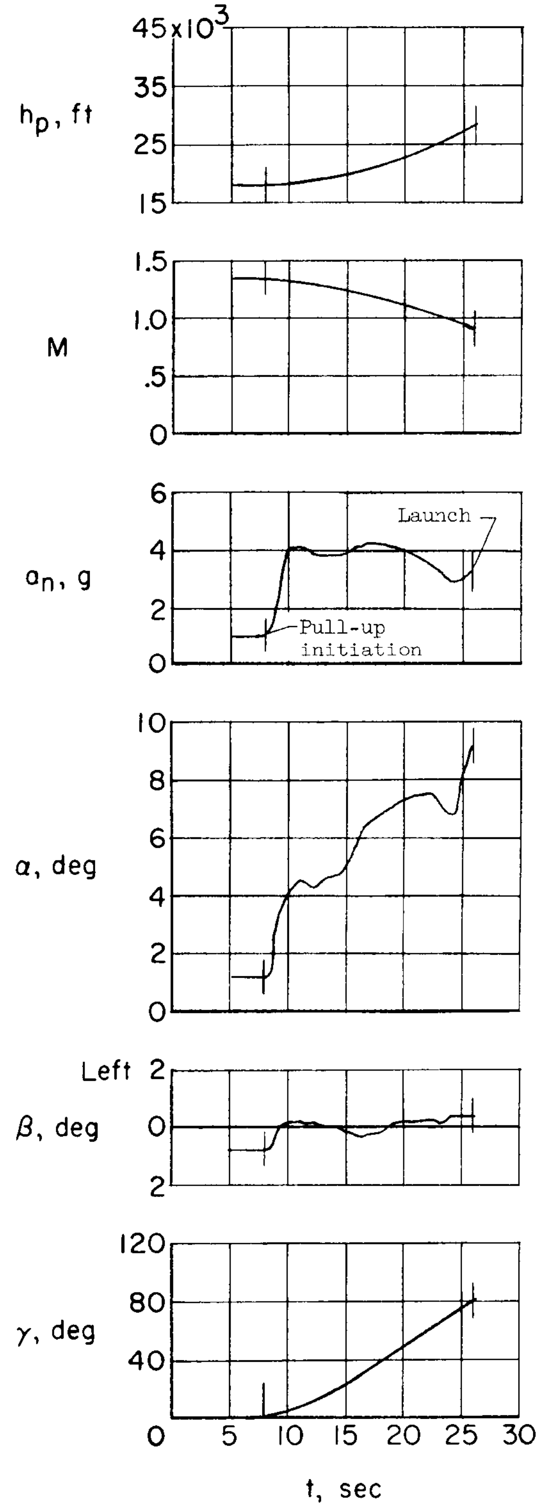
(a) Launch 1.

Figure 9.- Time history of launch-airplane performance from pull-up to launch for the model A vehicle.



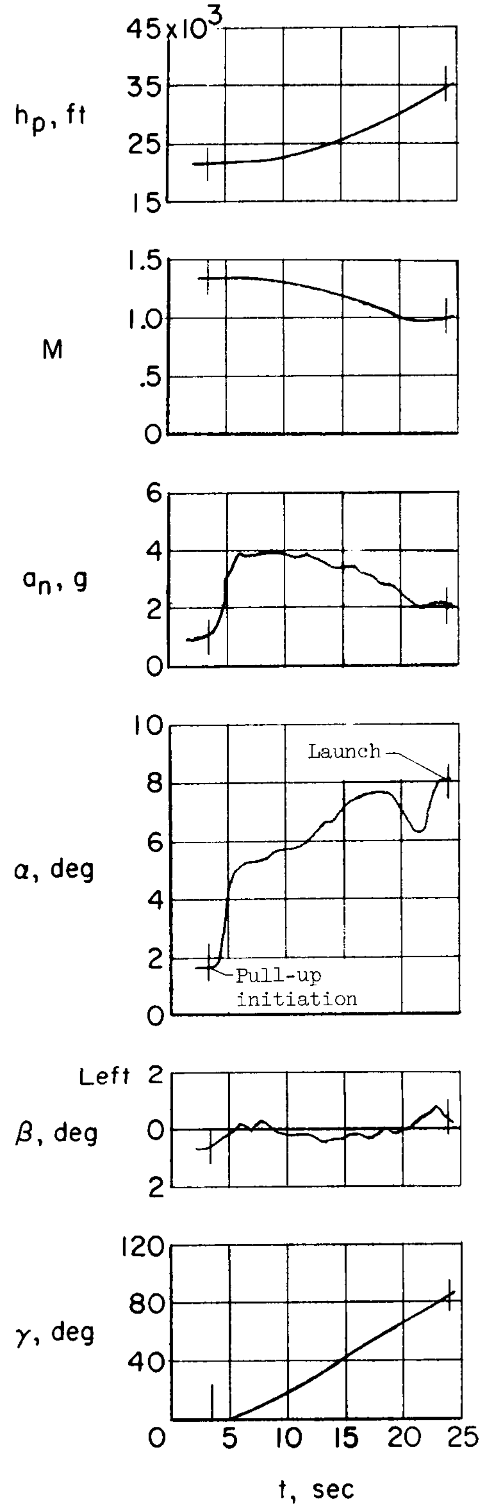
(b) Launch 2.

Figure 9.- Continued.



(c) Launch 4.

Figure 9.- Continued.



(d) Launch 5.

Figure 9.- Concluded.

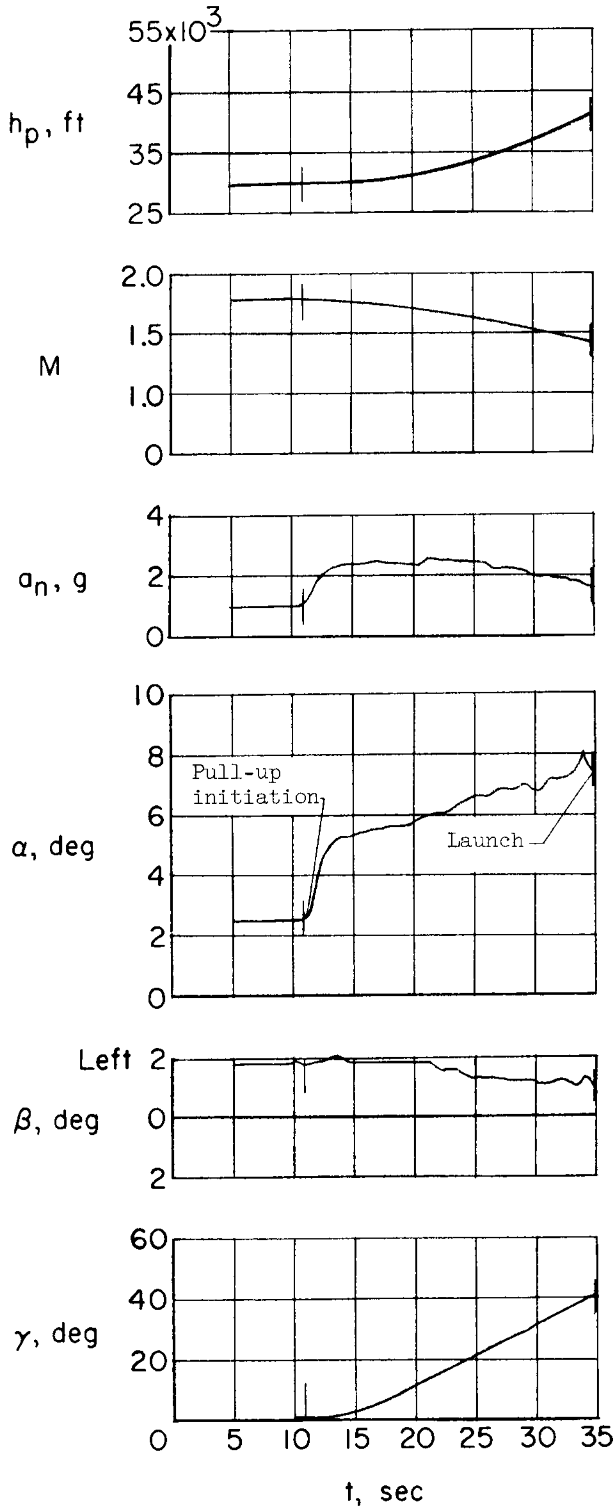


Figure 10.- Time history of launch-airplane performance from pull-up to launch for the model B vehicle. Launch 3.

NASA-Langley, 1963 H-289