Copy 6
RM L56E28

RESEARCH MEMORANDUM

A BRIEF SUMMARY OF EXPERIENCE

IN BOOSTING AERODYNAMIC RESEARCH MODELS

By Joseph G. Thibodaux, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

July 27, 1956

 [redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A BRIEF SUMMARY OF EXPERIENCE IN BOOSTING AERODYNAMIC RESEARCH MODELS[1]

By Joseph G. Thibodaux, Jr.

SUMMARY

Approximately 2,000 flights of rocket-propelled models have been made in which model configuration, model size, type and number of booster rockets, number of booster stages, and booster arrangements varied. A brief summary of the results obtained with some of the more unusual arrangements, descriptions of boosting hardware and techniques, and discussions of some factors responsible for the choice of these configurations are presented in this paper. The results show that unconventional boosting techniques may be used successfully when conventional tandem arrangements are unsuitable or unwieldy.

INTRODUCTION

Ten years ago, the Langley Aeronautical Laboratory organized a Pilotless Aircraft Research Division (PARD) to obtain aerodynamic research data using free-flying rocket-propelled models. Over 2,000 boosted models have been flown. These models varied widely in size and weight and were either models of specific airplanes or missiles or could be considered representative of configurations of future airplanes or missiles currently under consideration as well as those now in operation. Although most of the flights have been in the Mach number range of 1 to 4, many models have been flown in the Mach number range of 4 to 10.5. Altitudes traversed by these models have varied from sea level to an estimated 216 miles and ranges up to an estimated 600 miles. In order to handle the wide variety of models and test conditions with existing rockets, it has been necessary to use single and multiple clusters of rockets in two-, three-, and four-stage boost systems and in tandem, underslung, and wrap-around arrangements. Preliminary launchings of tow boosters have been successful and

[1] The information presented herein was the basis for a talk presented at the thirtieth meeting of the Bumblebee Aerodynamics Panel, Buffalo (N.Y.), Jan. 4, 1956.

[redacted]

additional work along these lines is continuing. Five-stage models are now being constructed and attempts to fly them will be made in the near future. None of the programs conducted have included enough models to allow systematic investigation of all problems associated with each boosting arrangement, although techniques are available for conducting these investigations for specific model-booster combinations. Differences between model configurations utilizing a specific booster arrangement have been great enough to preclude anything but generalizations regarding the desirability or undesirability of various design features and model booster interactions. Some of the work is still in a preliminary stage and has not been reported.

As missile velocities will increase, booster requirements will also increase and it is felt that the same reasons which are responsible for the use of unusual booster arrangements will require use of similar arrangements for full-scale missiles. For this reason, it is felt that the information presented, although neither complete or extensive, should be of assistance to the missile industry in choosing suitable boosting arrangements for future missiles.

It is recognized that similar work is being done by other research agencies and although no specific reference to work outside the National Advisory Committee for Aeronautics is made, it is not intended to claim that all the boosting schemes described herein were originally conceived or executed by the NACA. The words missile and model will be used interchangeably in this paper and the missile or model, if powered, will be considered to be a separate booster stage.

This paper includes a bibliography of NACA papers on successful research programs which used the technique described and which presents more detailed desciption of booster designs, arrangements, and performance.

BOOSTER REQUIREMENTS AND TEST LIMITATIONS

In order to assess any boosting problem accurately, one must consider the primary mission of the missile, the variation of Mach number and altitude with time during boost, the model-booster combination shape and structure, aerodynamics, separation problems, booster performance, method of launching, and limitations imposed by instrumentation and range safety. The primary mission of all models flown has been to secure aerodynamic research data. On occasions, a secondary purpose has been to develop new hardware or research techniques. Solid-propellant rockets of current design are used primarily because of availability in the size, shape, and performance range most suited to NACA requirements. Operational simplicity, reliability, and cost also influenced this choice. Models are made of metal, wood, plastic, and composite materials and follow more or less conventional design and construction practice. Model size is kept to a minimum consistent with other requirements. Wing loadings vary between 20 to 70 pounds per square foot, approximately one-half that of current airplane designs and one-quarter that of current missile designs.

All models are launched at sea level from rail, platform, or zero length launchers. Models are fired toward the Atlantic Ocean and it is attempted to limit the splash point to a sector 7.5° on either side of the launching azimuth. Launching elevation angles have been limited to 75° or less and, as no guidance or artificial stabilization is used, launching accelerations usually have been limited to a minimum of about 10g. Model trajectories are specified; however, any deviations which do not cause the model to fall into an inhabited area or do not cause instrument or structural failure can usually be tolerated and yield some useful data. Telemeters and flight instruments have functioned successfully under accelerations of 110g longitudinally and 70g normally and have been remarkably free of trouble resulting from rocket-motor shock and vibration.

As the requirements and limitations of many missile programs will be much more stringent than those outlined, the various booster systems to be described may require refinement and detailed analytical and experimental studies to make them suitable for missile boosting. It should also be noted that the rockets were available before the models were designed and that the various systems may represent compromises necessary to accomplish a desired result by using existing rockets.

For the purpose of this discussion, missiles are considered to fall into general categories; symmetric configurations with relatively small lifting surfaces in both planes; and unsymmetric (bank to turn) configurations with relatively large lifting surfaces in one plane only. The first type would be represented by Nike, Terrier, Falcon, and so forth; the second, by Snark, Navaho, Triton, Bomarc, and so forth.

Symmetric missile configurations are easily boosted by a tandem or a wrap-around arrangement, the difficulty involved being largely dependent on the variation of boost Mach number with altitude and time and on some booster rocket design and performance characteristics.

High overall performance boosters are desired because they give the required boost velocity with a minimum booster weight. Low booster weight results in a more favorable location of the center of gravity of the combination and smaller lighter booster fins. Drag and stability analyses indicate the desirability of high-fineness-ratio booster shapes which also reduce booster-fin requirements. Unfortunately, a high-performance, high-fineness-ratio booster is a poor primary structural component in the combination and can give rise to aeroelastic divergence because of excessive booster-case bending under design loads. Good booster rockets must be designed on the basis of both aerodynamic and internal ballistic requirements and should represent the best compromise between shape, structure, and overall performance. Experience with first-stage boosters of current design having overall performance indices between 100 and 160 pound-seconds per pound weight indicates that fineness ratios between 12:1 and 16:1 represent a good overall compromise, although, for unusual configurations, this may vary between 6:1 and 25:1.

MODEL-BOOSTER CONFIGURATIONS

Four-Stage Tandem Booster

When the desired boost velocity cannot be obtained with a single boost stage, additional tandem or wrap-around stages may be used provided the forward stages are locked together to prevent premature separation at burnout of the preceding stages. A typical four-stage model is shown in figure 1. The first two stages were M-5 Jatos, the third stage was a cluster of three "Deacon" rockets enclosed in a cylindrical magnesium fairing, and the fourth stage, a flare skirt stabilized cone-cylinder model powered by a T-40 Jato. This model was designed to study aerodynamic heating and to reach a Mach number of approximately 9. The first three stages have relatively short burning times; consequently, the combination is launched at high angles and flies a boost and coast type of trajectory calculated to minimize heating of the lower stages without a drastic reduction in performance. As the third stage reaches a Mach number of 6 at an altitude of approximately 50,000 feet, skin temperatures are high enough to require protection for the aluminum-alloy rocket cases to prevent rocket explosion. Although a cluster of rockets is used here, it is only an expedient and is not as desirable as a single rocket. The fourth-stage skin temperature reaches approximately 1,500° F; therefore, a flare skirt is used in preference to fins to eliminate the problems which might be associated with fins at high temperatures.

Figure 2 shows typical model-booster couplings. The first two stages of a tandem arrangement may use a simple male or female coupling which carries the bending loads, transmits thrust, and alines the model and booster. Separation is usually automatic at booster burnout because the booster drag-to-weight ratio is greater than the model drag-to-weight ratio. When separation is to occur at high altitudes and high Mach numbers, drag separation should not be presumed to occur but should be definitely established if separation is required to program other events in the flight sequence. Difference in trim before and after separation due to construction tolerances, atmospheric conditions, or power effects is seldom great enough to cause trouble during separation. Stages two and three and stages three and four are coupled by a threaded ring which is attached to a diaphragm and then split into segments. Second- and third-stage separation is effected by a mechanical actuator which causes the threaded segments to be drawn towards the center. Force is furnished by a powder-driven piston which is initiated at some predetermined time after burnout of the second stage by electric-delay squibs. The third and fourth stages are separated by firing of the fourth-stage rocket. Gas pressure causes the diaphragm to bulge, draws the threaded segments in toward the center, and releases the fourth stage.

Programing of the firing of all rockets and release devices may be accomplished by electric-delay squibs which are fired on the ground and during takeoff, by electrical or mechanical timing devices initiated at takeoff, by lanyard or switches at separation of the various stages, or by rocket chamber pressure.

THREE-STAGE WRAP-AROUND BOOSTER

Occasionally, aeroelastic studies indicate that an intermediate booster stage cannot tolerate design loads or that deflections are excessive when a tandem arrangement is considered. In this event, a wrap-around arrangement may be used as is shown in figure 3. The first stage consists of the three outer Deacon rockets spaced 120° apart. These rockets are each fitted with a single fin and are hinged together at the rear through a common coupling. Each rocket is able to fall free after rotation through a 45° angle about its hinge axis. All rockets are fitted with a forward fin which causes the rocket to rotate about its hinge axis when the booster moves back a few inches. All rockets are fastened together at the forward end, and must separate as a unit after all have burned out. The second stage is a single Deacon rocket fitted with three fins and is coupled to the third stage with a lock-type male adapter. This lock is released by a piston operated by chamber pressure from the second-stage rocket when it fires. The third-stage model consists of a nose and fins attached to an HPAG rocket which is wrapped with insulating tape and painted with an insulating paint.

UNDERSLUNG BOOSTER

Unsymmetric models with large lifting surfaces in one plane may be boosted to fairly high Mach number with tandem boosters, provided the ratio of booster size to model size is large. Many model-booster configuration studies show that the same velocity can be obtained with smaller rockets if the large booster fins and aeroelastic troubles associated with tandem boosters could be avoided. In order to circumvent these problems, an underslung (ventral, pick-a-back) booster as shown in figure 4 may be used. Wing location or other configuration characteristics may make it impossible to locate the model and booster center of gravity in the same vertical position; consequently, canted or eccentric nozzles are required to insure that the thrust of each rocket passes through the vertical center of gravity of the combination at takeoff. As propellant is expended, the vertical center of gravity will shift and create nonaerodynamic pitching moments. As velocity increases, the combination trims itself to counteract these nonaerodynamic moments. Some models have been flown with eccentric nozzles which located the thrust axis between the initial and final combination center-of-gravity location so that the model would trim at negative angles for portions of the flight and at positive angles for the remaining portion. Although the system was successfully used, it requires careful analysis to prevent disaster before the model acquires enough velocity to furnish sufficient aerodynamic restoring forces.

When two rockets are used, they are rigidly coupled together and act as a single unit during boost and separation. The booster is designed to be stable after separation. Separate units which were not stable after separation have been used successfully; however, on occasions violent lateral motions of the booster during separation have wrecked models. In order to assist in translational separation of model and booster, some boosters have been fitted with small canard fins located in various positions relative to model lifting surfaces. Subsequent tests, although inconclusive, show that these fins may be unnecessary or undesirable because of flow fields set up by the fins impinging on the model wing or tail surfaces during separation.

Separation problems associated with underslung boosters have been rather severe in many model-booster configurations and oscillations of the model caused by changes in trim power-on and power-off may be present at burnout and during separation. Flow fields in the vicinity of the model and booster are complicated by shocks and relative upwash and downwash of model and booster lifting surfaces. Model normal accelerations higher than 70g have been recorded during separation and some models have been destroyed by collision with the booster.

In order to investigate separation problems encountered with underslung booster arrangement, model-booster combinations in which model and booster were independently instrumented were flown to a boost Mach number of 1.2. Accelerations of the model measured during separation as a function of time are shown in figure 5. Acceleration of the booster during the same period and model-booster-separation distance as a function of time are shown in figure 6. Double integration of these accelerations will give relative position and attitude of the model and booster as is shown in figure 7. On this particular flight, the booster struck the model as is indicated in figure 7 and as is shown by the rapid change in transverse acceleration of the booster in figure 6. Subsequent results of this flight show that only one-half of the horizontal tail was broken off and indicated that a complete history would also require some roll instrumentation. Similar models have been flown with different canard fin location in some of which separation was marginally successful and in some of which both horizontal tails were lost.

Other studies, although not as detailed, have been made of flights and separation of a single underslung model-booster configuration, as is shown in figure 8. The relative position of model and booster were obtained by photographic means and the normal-force coefficients of the model, from telemetered data. Maximum normal-force coefficient at these conditions of Mach number and altitude represents a normal acceleration of approximately 35g and corresponds to a normal force of 2,100 pounds.

TANDEM-UNDERSLUNG BOOSTER

Occasionally, combinations of the various systems may be used. A tandem-underslung booster system is shown in figure 9. This configuration uses a double Deacon tandem booster and a double Deacon underslung booster. Model and second-stage booster are locked together and are released by a mechanism actuated by motor pressure at firing of the second stage.

TOW BOOSTER

On one occasion, a model configuration essentially resembling a flying wing did not seem capable of being boosted to the required velocity in a reasonable manner by any of the conventional boost systems. The configuration did appear to be capable of being towed; thus, the problems involved in towing the model along behind the booster were analyzed. A dynamic analysis indicated that acceleration would exert a large stabilizing effect on the combination. Separation would be a problem as the booster would decelerate faster than the model; consequently, separation would have to occur before booster burnout. Simple uninstrumented model-booster combinations were designed to test a tow booster arrangement. One of these is shown in figure 10. Two booster rockets were fastened together and the nozzles canted outward at an angle of 15°. The model was attached to the booster by means of a $\frac{3}{8}$-inch steel cable and an explosive bolt containing an electric-delay squib which would fire approximately 0.1 second before booster burnout. The first launching failed to separate and at booster burnout began to oscillate violently until the cable snapped; thus, the stabilizing effect of acceleration was demonstrated. A second model separated at the proper time and performed as expected. Fully instrumented research models which will use tow boosters are being constructed and will be flown in the near future.

UNUSUAL PHENOMENA

When a wide variety of models using different boosting arrangements is boosted, unusual phenomena which would not reasonably be predicted occur. One particular model-booster combination was troublesome, although a model of the model-booster combination has been flown successfully. The configuration was ducted as is shown in figure 11, and the model-booster adapter which was used blocked the duct completely. All flights of this configuration showed rapidly fluctuating normal acceleration which increased in intensity until failure. Pressure oscillations of the duct were also observed at the same frequency; however, it was not immediately apparent how inlet buzz could force a divergent type of oscillation. Analysis indicated that the buzz frequency corresponded to the fundamental organ-pipe frequency of the duct, and further investigation indicated that the first-bending frequency of the nose on which a canard fin was mounted was exactly the same. This coincidence led to the assumption that a nose oscillation resembling flutter was being excited by inlet buzz. A model adapter which allowed air to flow through the inlet during boost eliminated inlet buzz and the unstable oscillation of the nose as is shown in figure 11.

CONCLUDING REMARKS

When booster rockets and booster systems for propulsion of a wide variety of models to supersonic speeds are chosen, most of the design studies and flight experience indicate the desirability of high-fineness-ratio, high-performance rockets. Booster-model combinations must be engineered as a system taking into account all factors affecting the design and performance of the model and booster both as a unit and as separate items. Experience has shown that, when multiple rocket boosters are used, it is more desirable to have them act as much like a single unit as possible and that both model-booster combination and booster be aerodynamically stable individually as well as collectively at least until the separation phase is completed.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 8, 1956.

BIBLIOGRAPHY

Two-Stage Models - Single Tandem Boost

1. Pitkin, Marvin, Gardner, William N., and Curfman, Howard J., Jr.: Results of Preliminary Flight Investigation of Aerodynamic Characteristics of the NACA Two-Stage Supersonic Research Model RM-1 Stabilized in Roll at Transonic and Supersonic Velocities. NACA RM L6J23, 1947.

2. Alexander, Sidney R., Chauvin, Leo T., and Rumsey, Charles B.: Flight Tests To Determine the Drag of Fin-Stabilized Parabolic Bodies at Transonic and Supersonic Speeds. NACA RM L8A05, 1948.

3. Gillis, Clarence L., and Mitchell, Jesse L.: Flight Tests at Transonic and Supersonic Speeds of an Airplane-Like Configuration With Thin Straight Sharp-Edge Wings and Tail Surfaces. NACA RM L8K04a, 1949.

4. Lundstrom, Reginald R., and O'Kelly, Burke R.: Flight Investigation of the Jettisonable-Nose Method of Pilot Escape Using Rocket-Propelled Models. NACA RM L9D11, 1949.

5. Rumsey, Charles B., Piland, Robert O., and Hopko, Russell N.: Aerodynamic-Heating Data Obtained From Free-Flight Tests Between Mach Numbers of 1 and 5. NACA RM L55A14a, 1955.

Two-Stage Models - Multiple Tandem Boost

1. Faget, Maxime A., and Dettwyler, H. Rudolph: Initial Flight Investigation of a Twin-Engine Supersonic Ram Jet. NACA RM L50H10, 1950.

2. Dettwyler, H. Rudolph, and Trout, Otto F., Jr.: Flight and Preflight Evaluation of an Automatic Thrust-Coefficient Control System in a Twin-Engine Ram-Jet Missile. NACA RM L53K13, 1954.

3. Jackson, H. Herbert: Free-Flight Measurements of the Zero-Lift Drag of Several Wings at Mach Numbers From 1.4 to 3.8. NACA RM L56C13, 1956.

Two-Stage Model - Single Underslung Booster

1. Judd, Joseph H.: A Free-Flight Investigation of the Drag Coefficients of Two Single-Engine Supersonic Interceptor Configurations From Mach Number 0.8 to 1.90 To Determine the Effect of Inlet and Engine Locations. NACA RM L55G05a, 1955.

Two-Stage Model - Double Underslung Booster

1. Peck, Robert F.: Jet Effects on Longitudinal Trim of an Airplane Configuration Measured at Mach Numbers Between 1.2 and 1.8. NACA RM L54J29a, 1955.

2. Chapman, Rowe, Jr.: Aerodynamic Characteristics at Mach Numbers From 0.7 to 1.75 of a Four-Engine Swept-Wing Airplane Configuration As Obtained From a Rocket-Propelled Model Test. NACA RM L55F23, 1955.

Three-Stage Model - Single-Tandem Boosters

1. Rumsey, Charles B., and Lee, Dorothy B.: Measurements of Aerodynamic Heat Transfer and Boundary-Layer Transition on a 10° Cone in Free Flight at Supersonic Mach Numbers up to 5.9. NACA RM L56B07, 1956.

Four-Stage Model - Single-Tandem Boosters

1. Piland, Robert O.: Performance Measurements From a Rocket-Powered Exploratory Research Missile Flown to a Mach Number of 10.4. NACA RM L54L29a, 1954.

Booster Fins

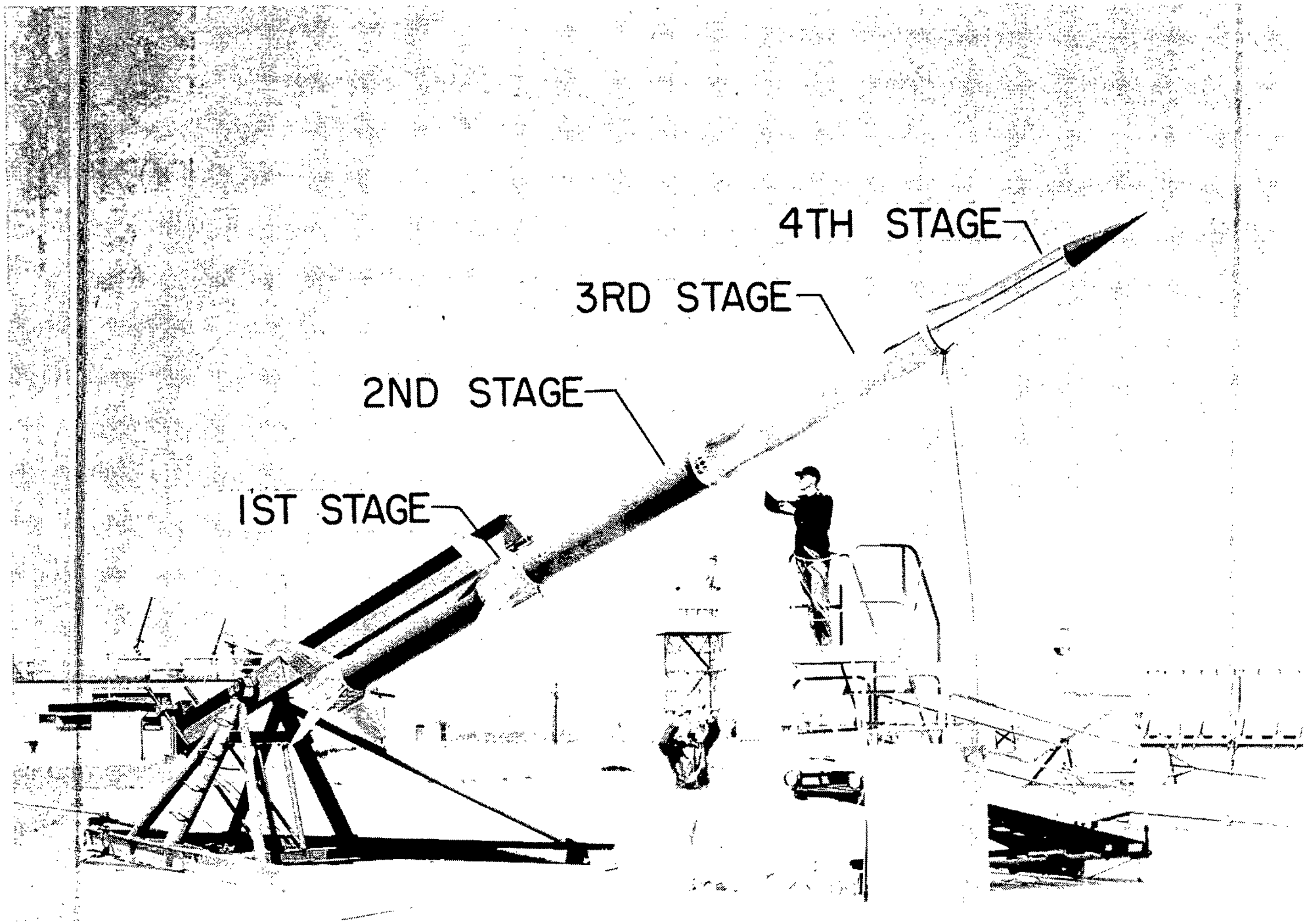
1. McFall, John C., Jr.: Drag Investigation of Some Fin Configurations for Booster Rockets at Mach Numbers Between 0.5 and 1.4. NACA RM L50J12, 1950.

Booster Aeroelasticity

1. Arbic, Richard G., White, George, and Gillespie, Warren, Jr.: Some Approximate Methods for Estimating the Effects of Aeroelastic Bending of Rocket-Propelled Model-Booster Combinations. NACA RM L53A08, 1953.

Model-Booster Adapters

1. Robinson, Ross B.: Effects of Free-Flight Rocket-Model Booster-Adapter Configurations on the Aerodynamic Characteristics in Pitch and Sideslip of a Swept-Wing Fighter Airplane Model at a Mach Number of 2.01. NACA RM L55B01, 1955.



L-89105.1

Figure 1.- Typical four-stage model.

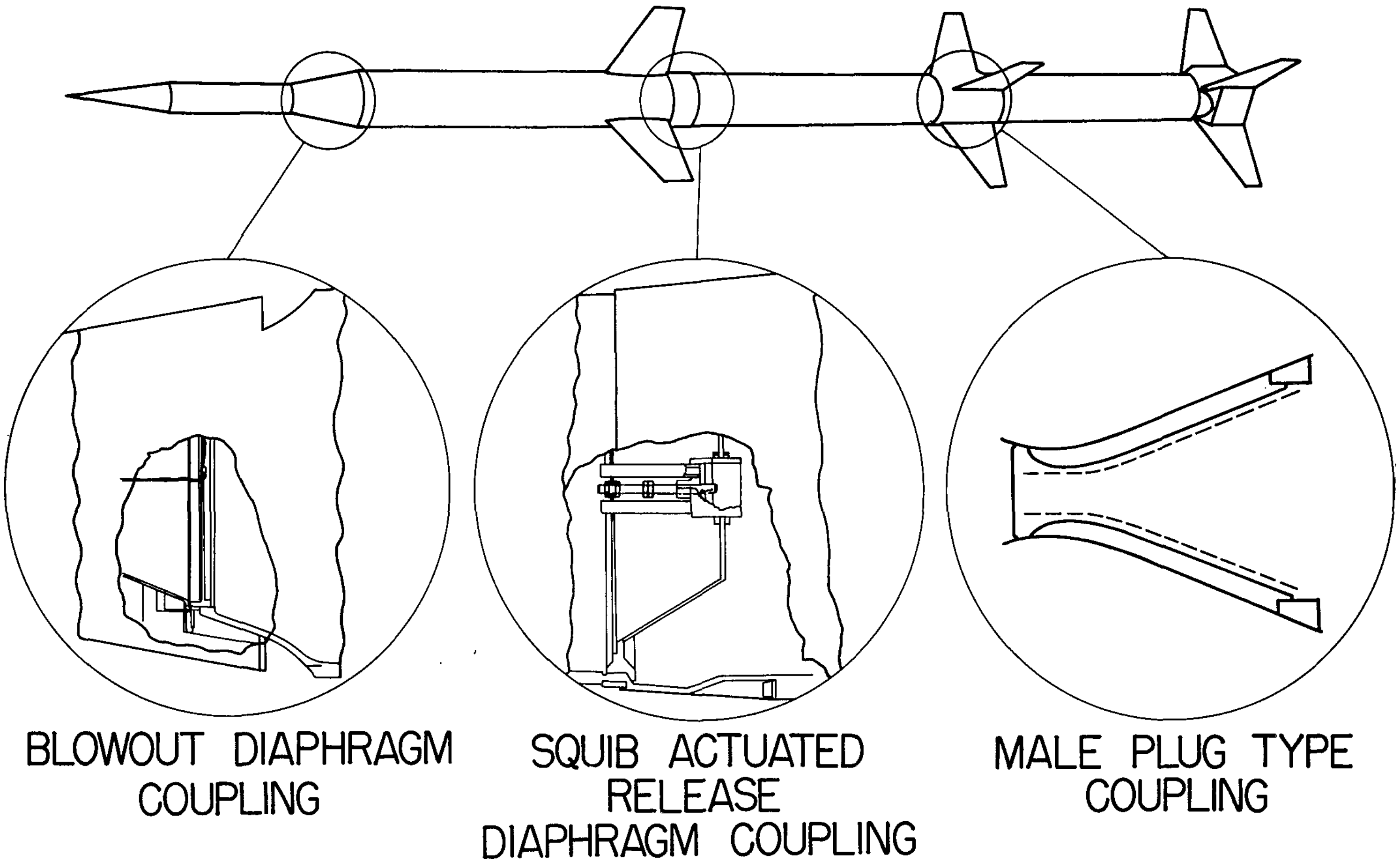
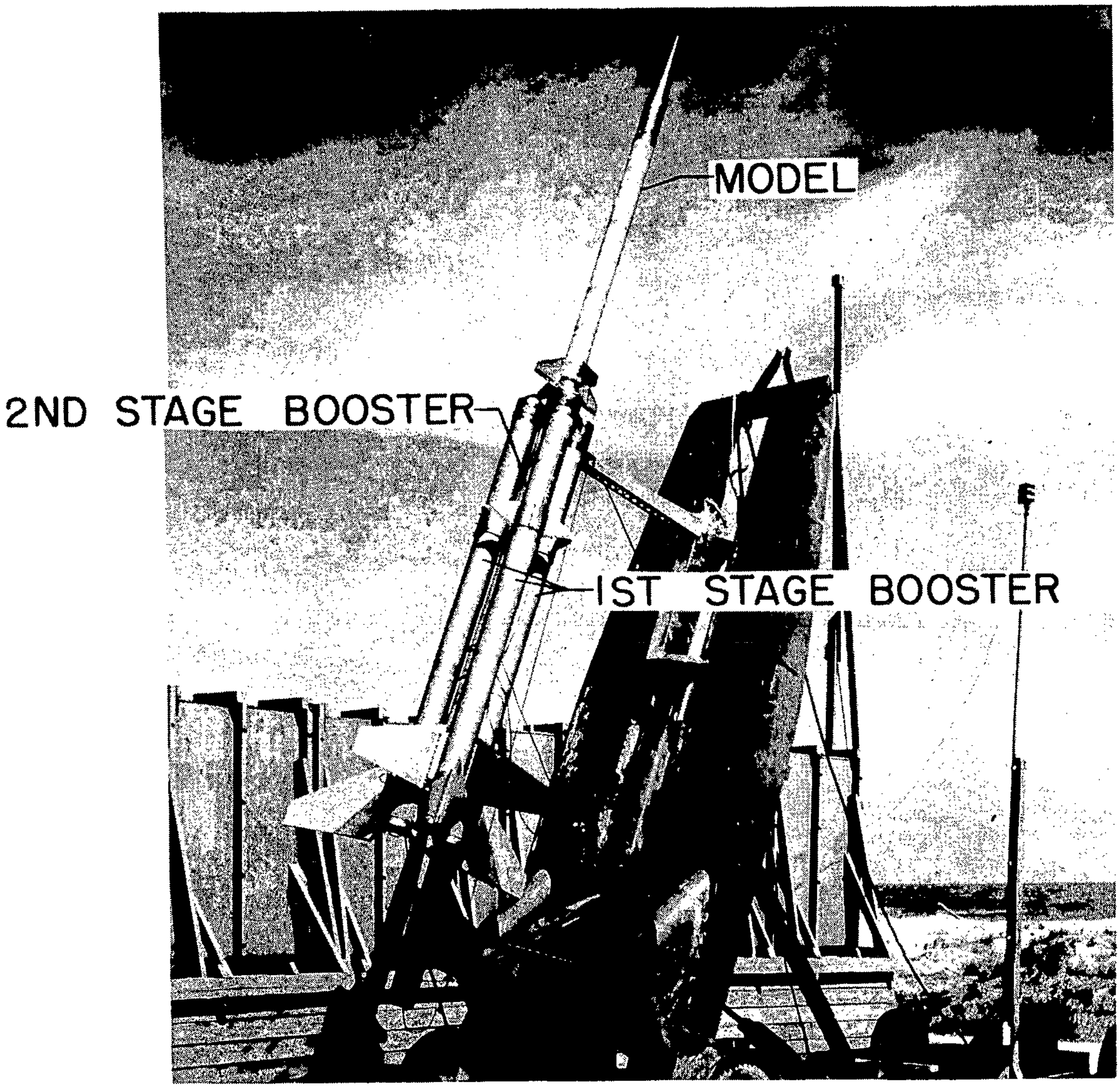


Figure 2.- Typical model-booster couplings.



L-84725.1

Figure 3.- Typical wrap-around three-stage model.

[redacted]

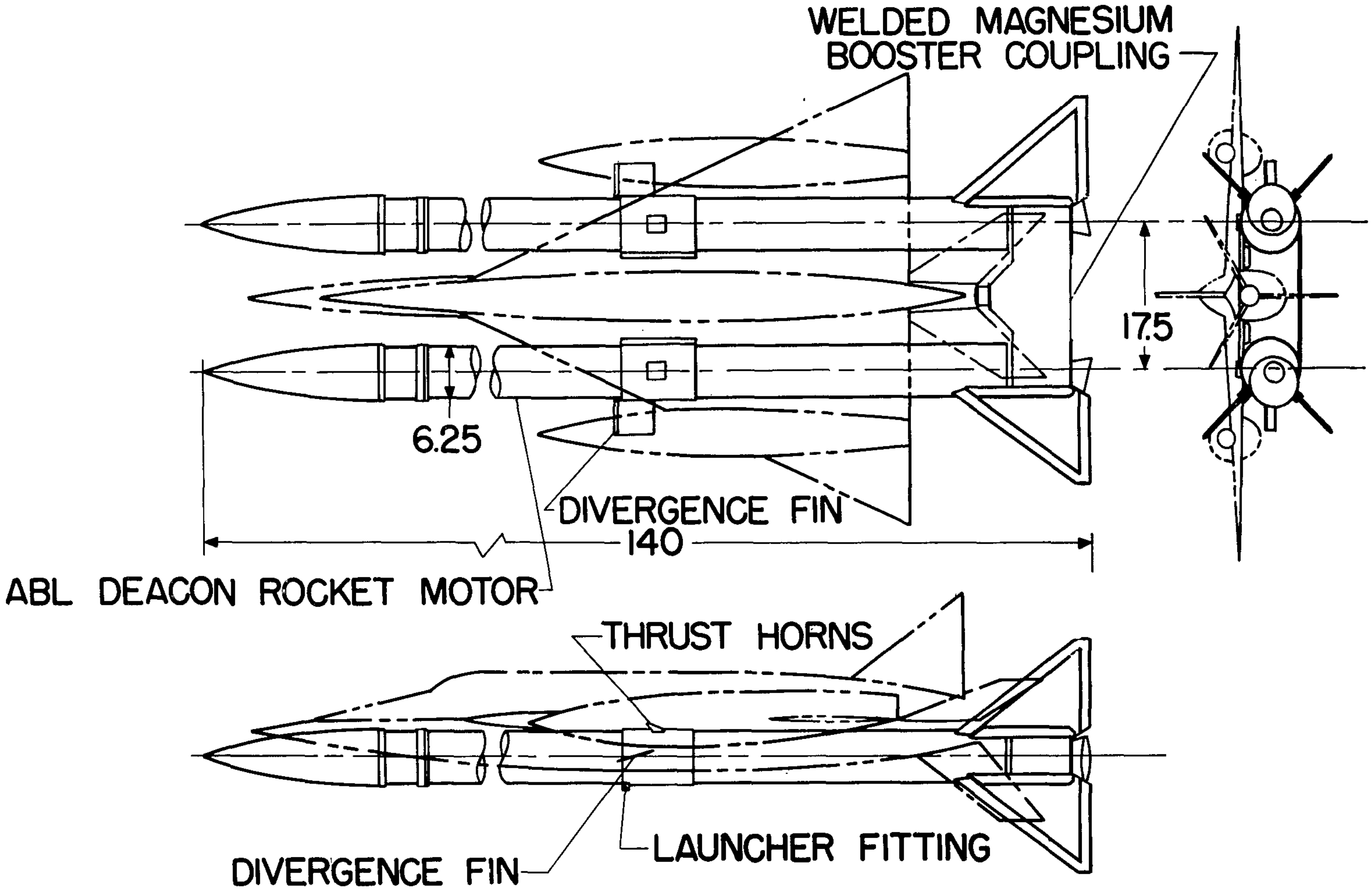


Figure 4.- Typical double underslung booster arrangement.

[redacted]

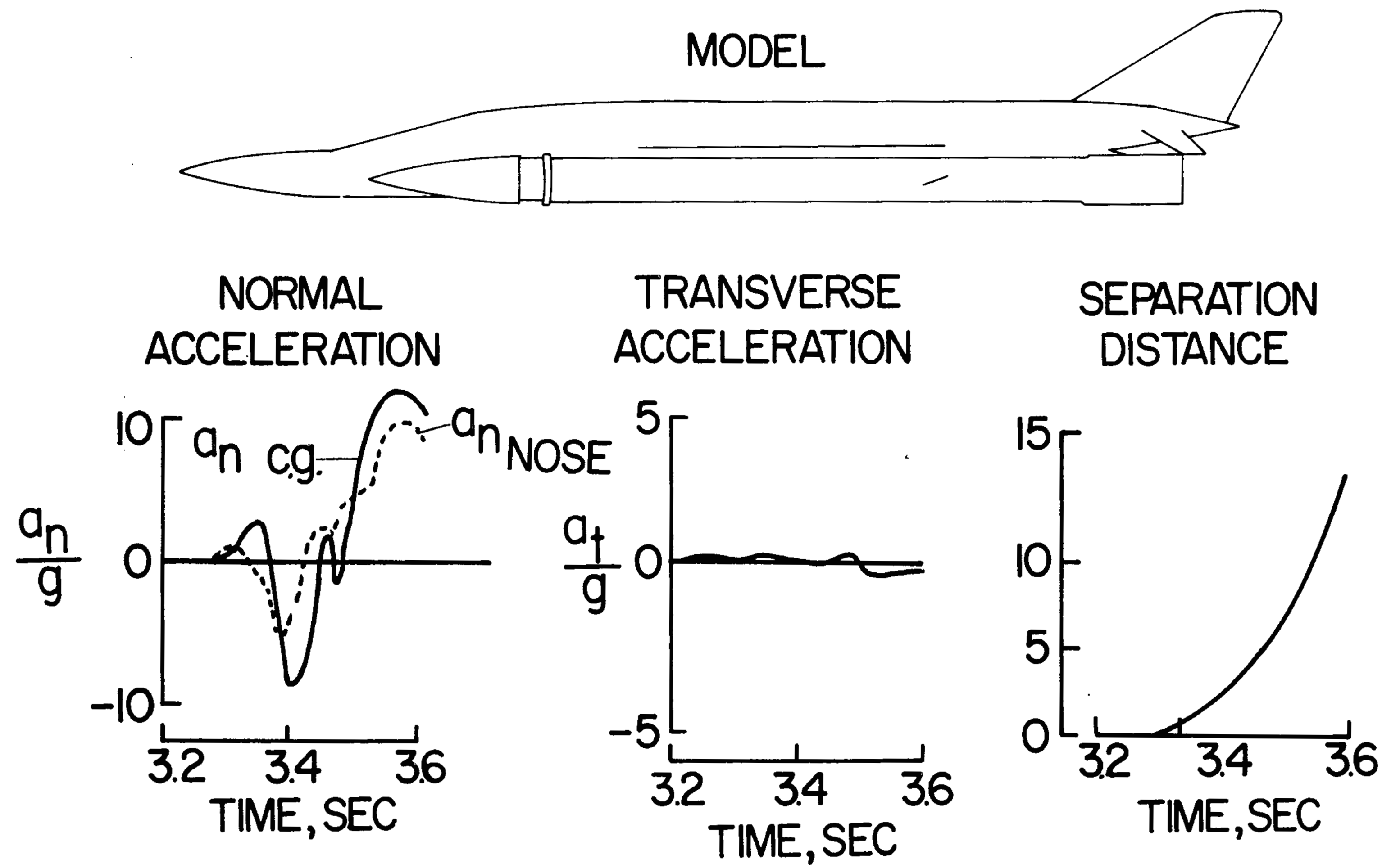


Figure 5.- Model accelerations during separation.

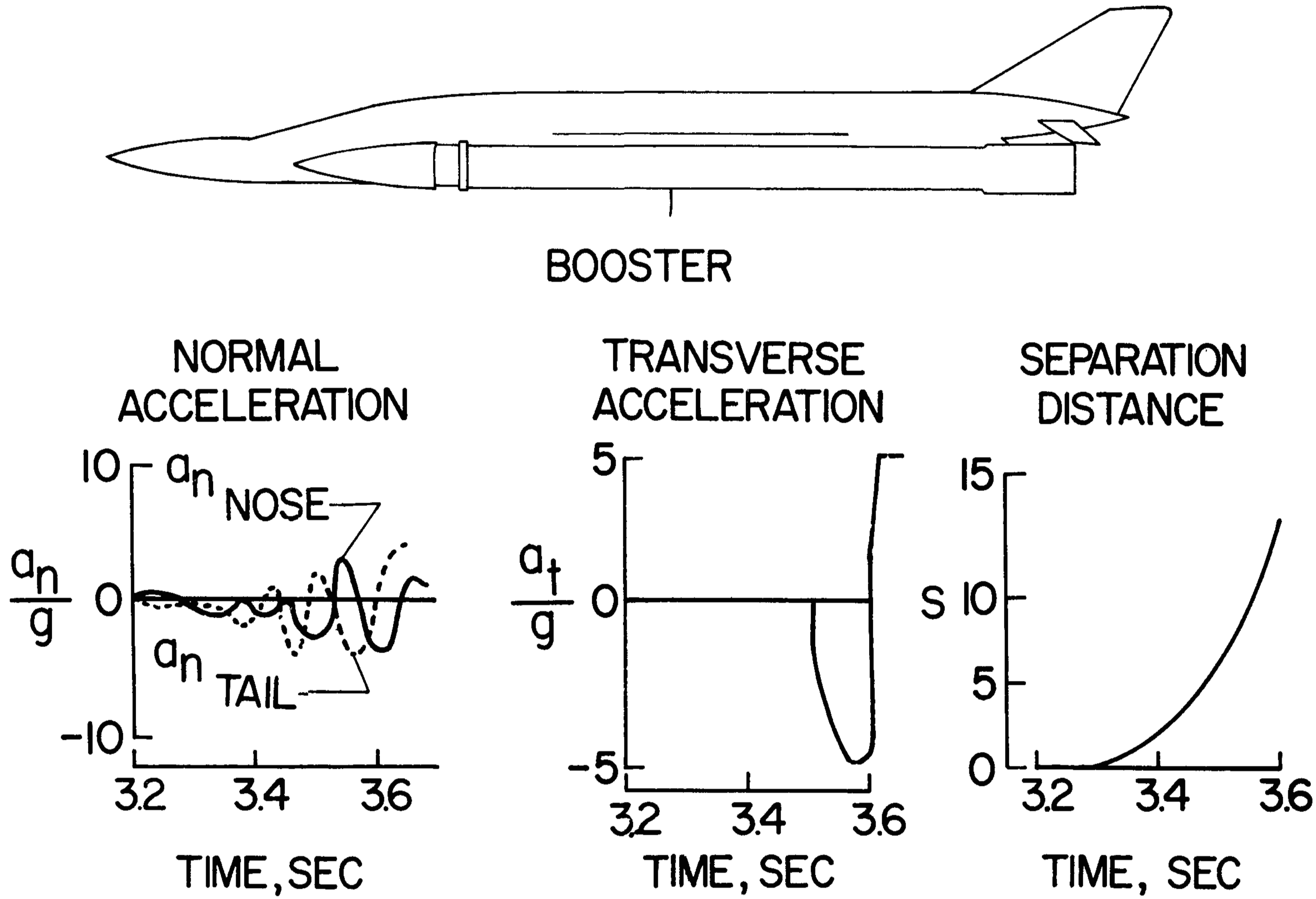


Figure 6.- Booster acceleration during separation.

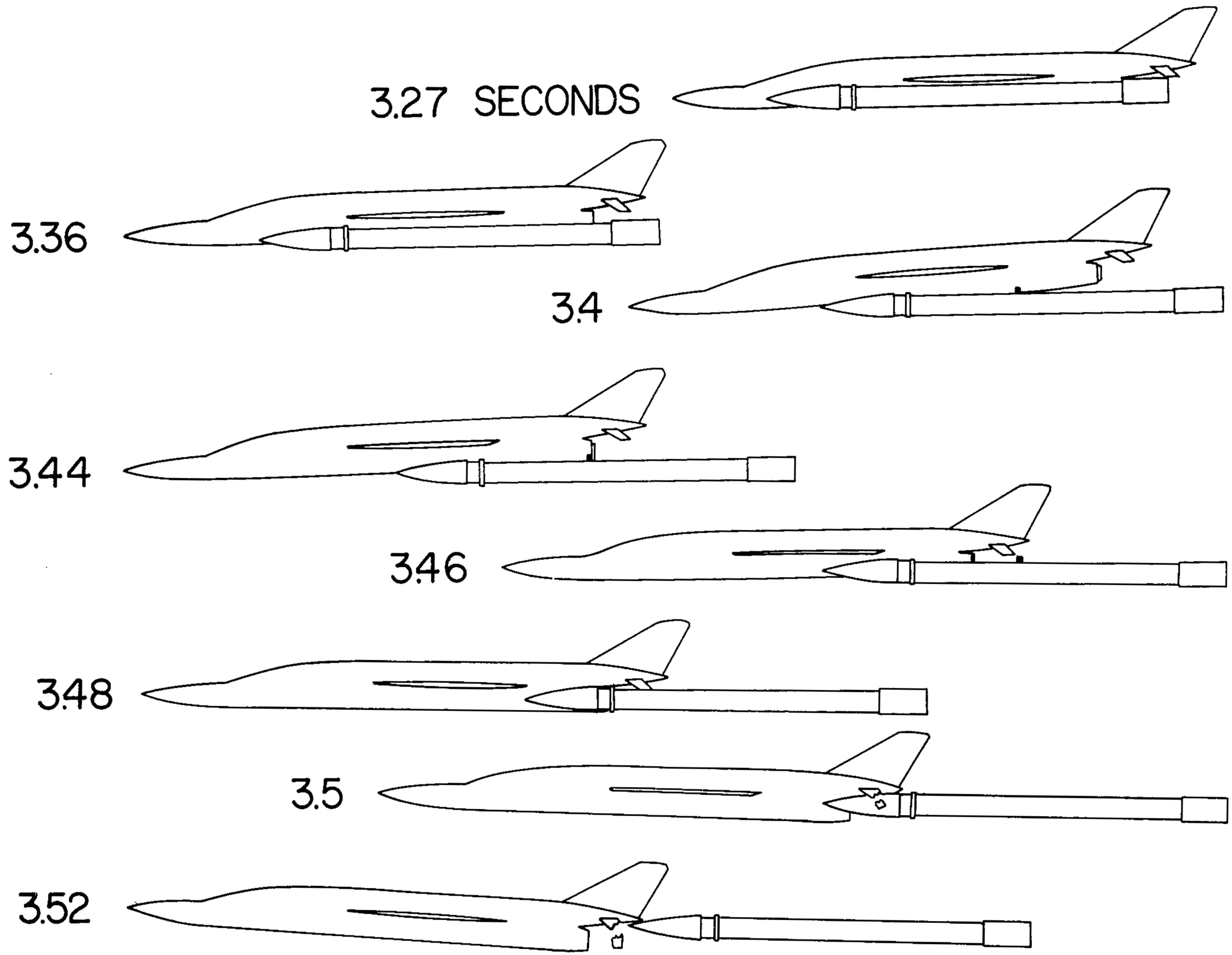
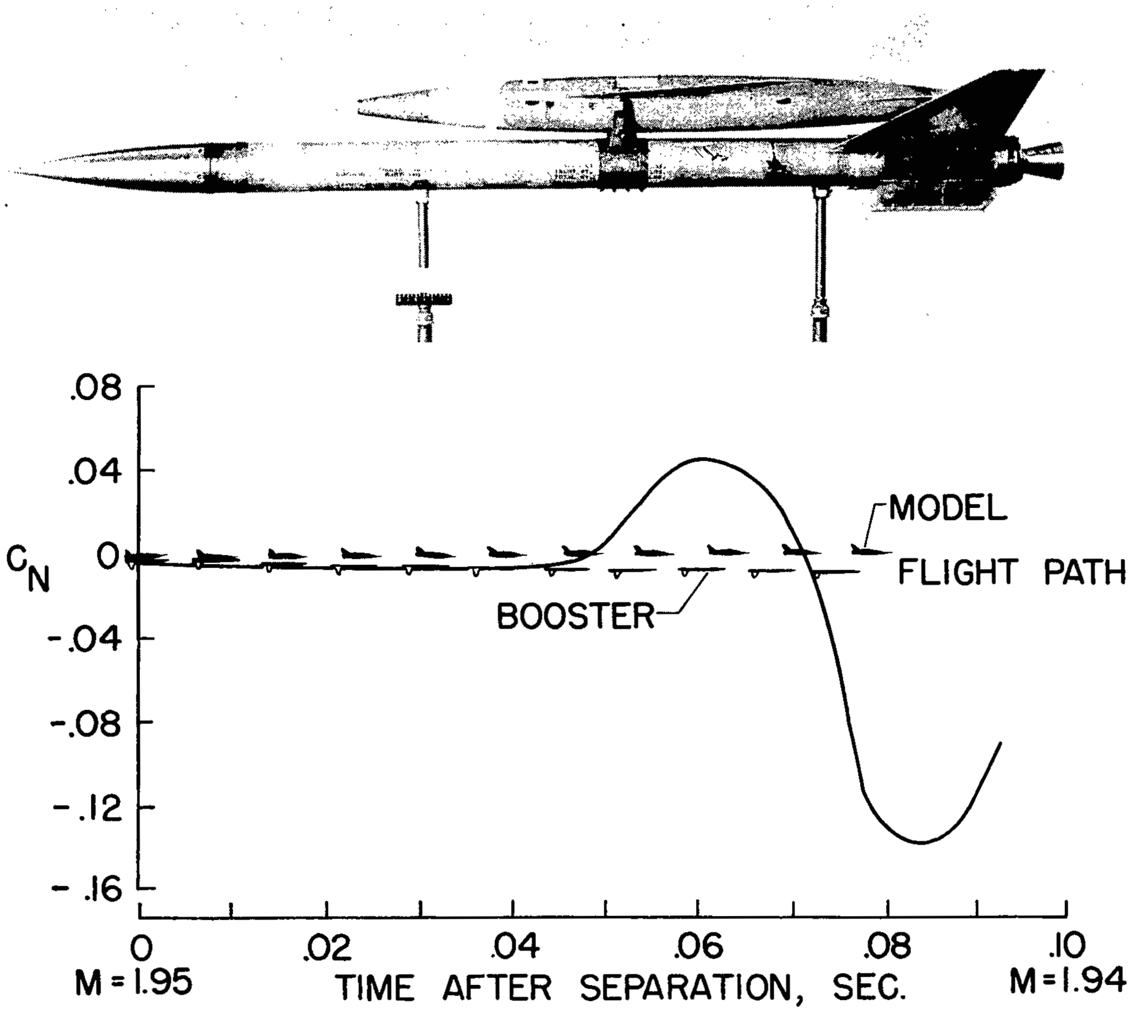
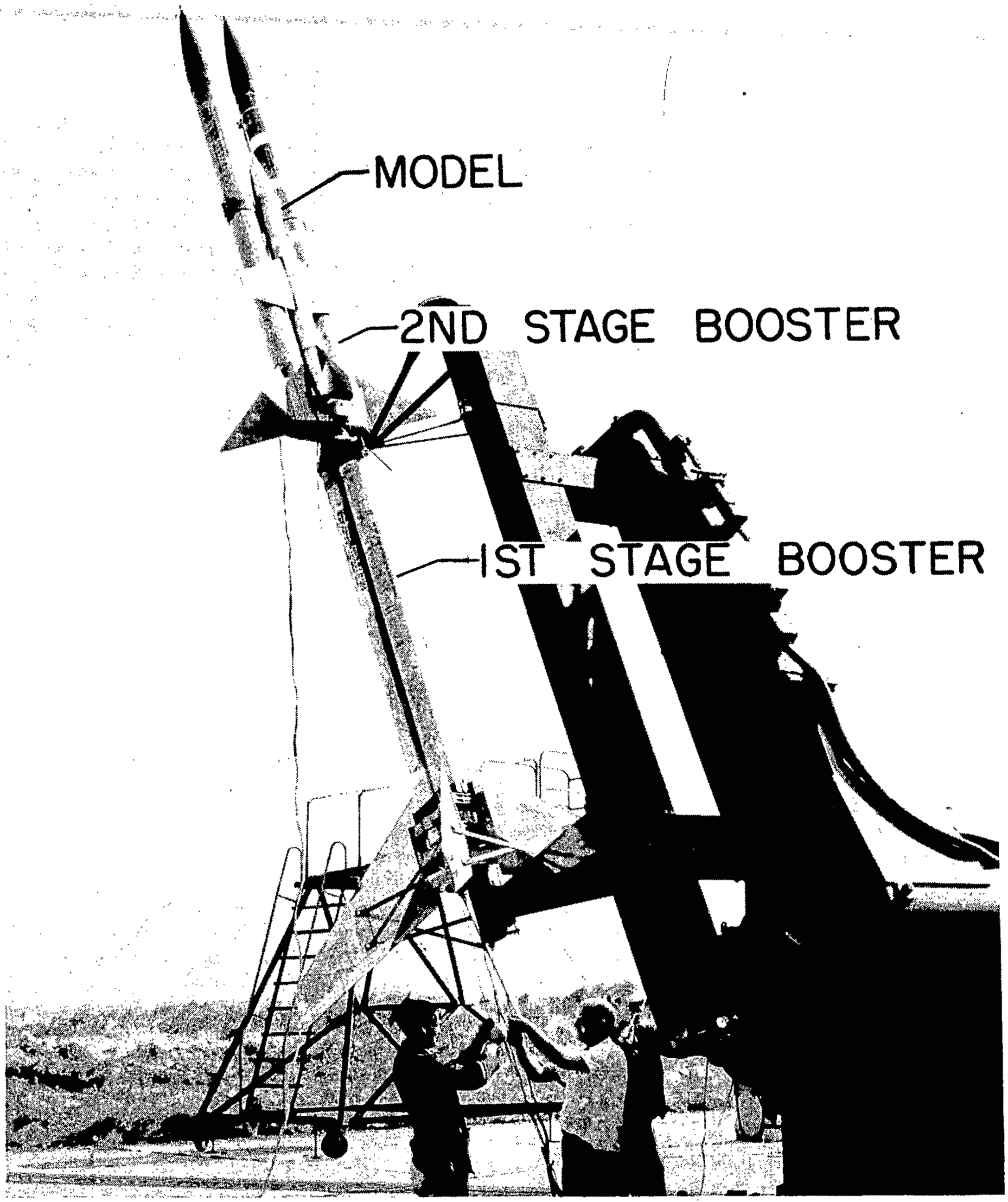


Figure 7.- Relative motion of model and booster during separation.



L-93519

Figure 8.- Separation study of single underslung booster.



L-91139.1

Figure 9.- Typical tandem-underslung boost arrangement.

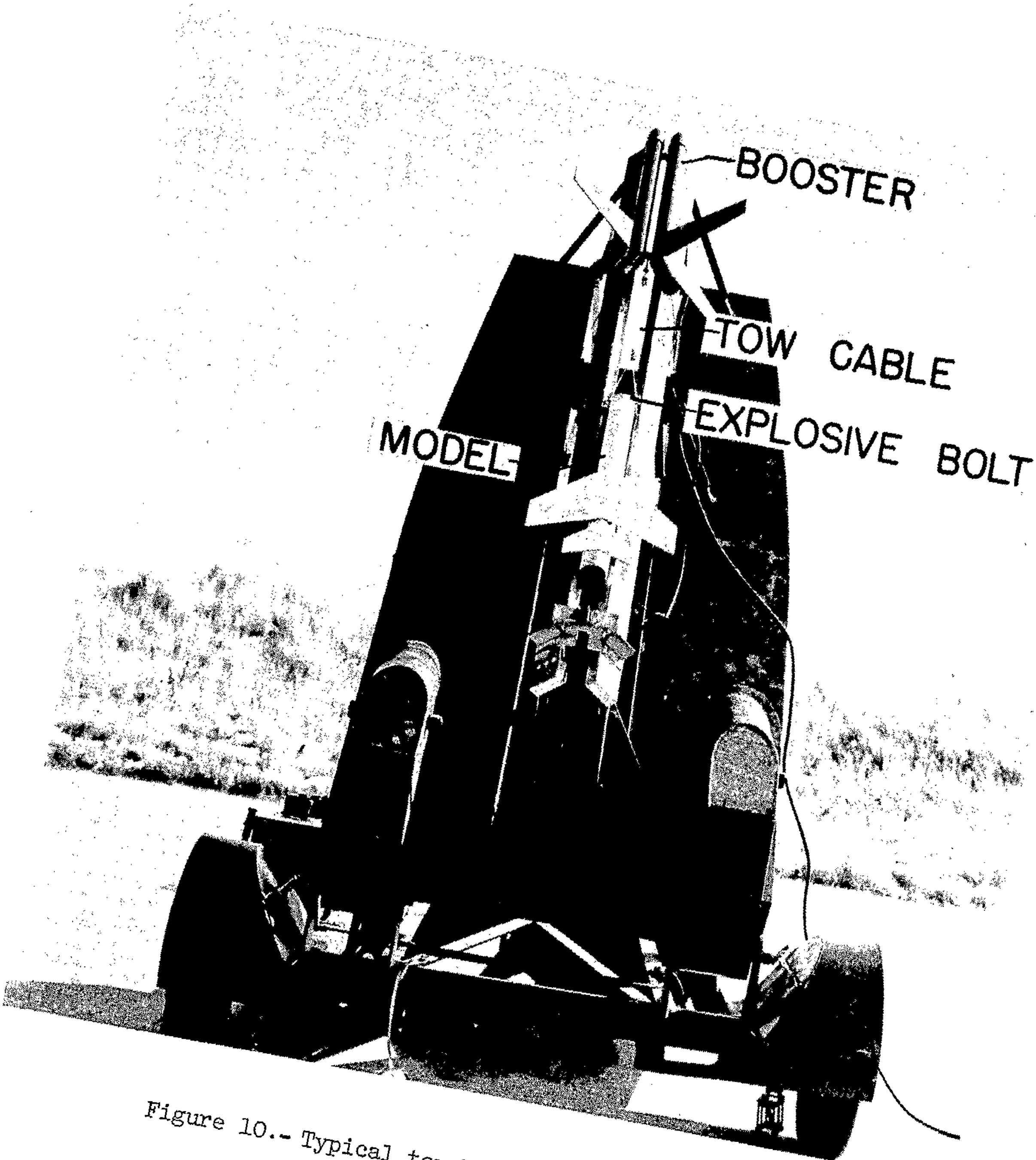
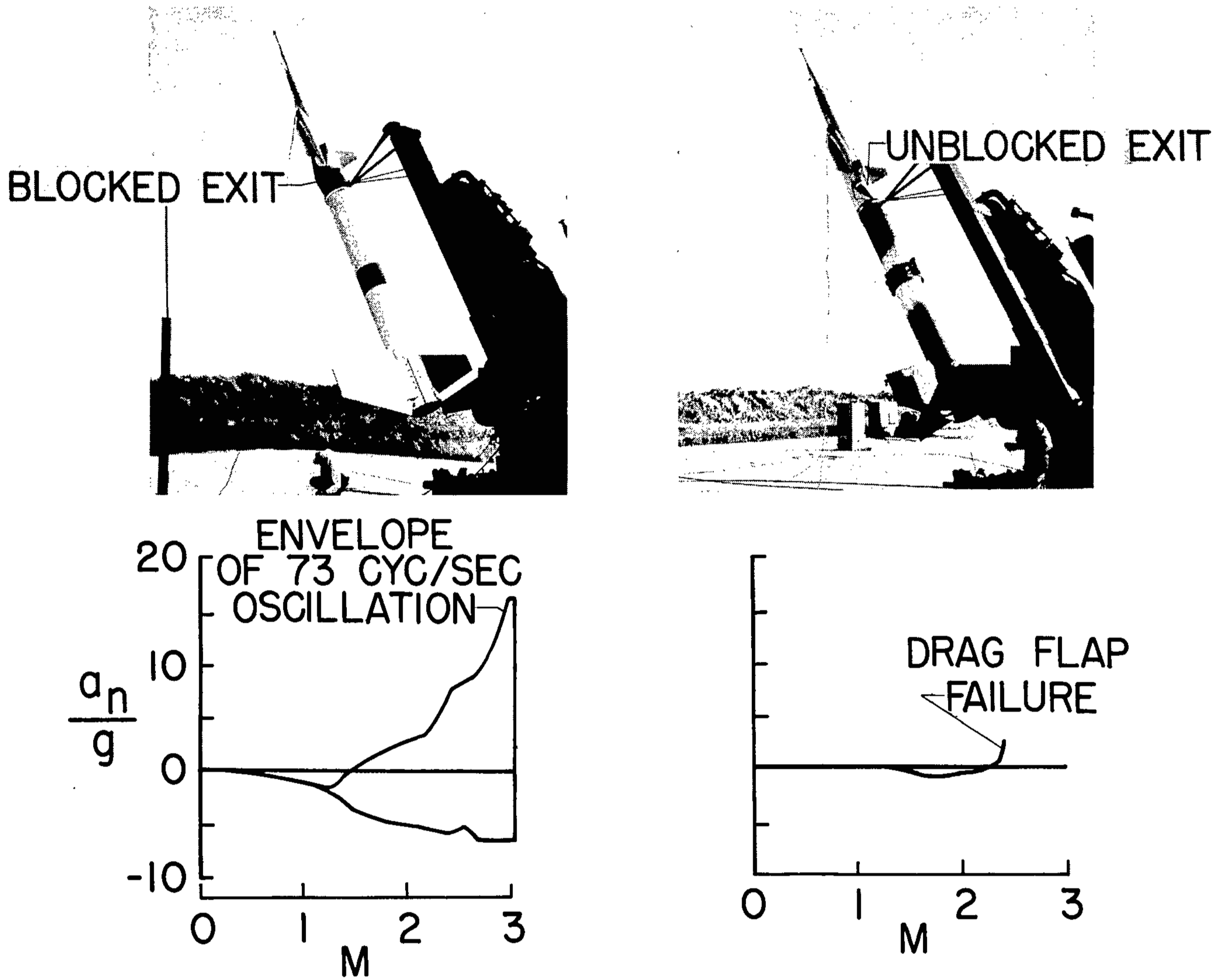


Figure 10.- Typical tow booster arrangement. L-87886.1



L-93520

Figure 11.- Duct buzz-nose flutter phenomena caused by exit blockage.

NACA - Langley Field, Va.