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FEASIBILITY STUDY ON CONDUCTING OVERFLIGHT MEASUREMENTS OF SHAPED SONIC BOOM SIGNATURES USING THE FIREBEE BQM-34E RPV

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SUMMARY

The feasibility of experimentally establishing the persistence of modified sonic boom signatures to representative flight conditions using a relatively large supersonic remotely-piloted and recoverable vehicle has been established. It has been determined that the Firebee BQM-34E (Firebee II) vehicle is a suitable test vehicle in terms of its adaptability to geometric modifications, operational capabilities regarding Mach-altitude, availability, and costs. The experimental program involves wind tunnel tests on models and full-scale flight tests. Wind tunnel tests would be conducted in the Langley Research Center 8-foot Transonic Tunnel at Mach 1.3. It is also highly desirable to conduct tests in the Langley Unitary Plan Wind Tunnel at Mach 1.5 for correlation with past sonic boom experience. Flight tests would be conducted at Pt. Mugu, California, with the White Sands Missile Range, New Mexico, as an alternate site. A minimum of ten full-scale Firebee flights would be required in order to accomplish the test objective.

A number of other approaches to experimentally establish the persistence of modified sonic boom signature to very large distances were also addressed. The use of nonrecoverable vehicles and missiles were deemed inappropriate since the required sonic boom shape modifications would have a significant influence on the basic flight characteristics and stability and control. Costs are also a significant factor since each flight would require a vehicle and its associated geometric modifications. Very large wind tunnels, supersonic sled tracks, and aircraft nose probes are also considered not applicable; large wind tunnels because they are nonexistent, sled tracks because of the presence of the ground surface, and nose probes because of the overwhelming influence of the airplane shock flow field. The ballistic range and whirling-arm techniques are, however, considered applicable, especially the former. Each of these latter two simulation techniques may be used to generate a substantial data base on sonic boom signatures relative to vehicle geometries and atmospheric influences.

INTRODUCTION

The future success of commercial high-speed overland flight may depend, in large part, on providing a solution to the sonic boom problem. Without some unforeseen technological breakthrough that may eliminate the sonic boom, current efforts (refs. 1 and 2) are aimed at modifying the boom signature in order to make it more acceptable. The term "more acceptable" infers modifications to the signature that includes not only reducing the peak overpressure (or intensity of the boom), but shaping the signature to look something other than the typical N-wave. Sonic boom signature variations include so-called "flattop" waveforms, "ramp-type," and variations on each that provide for increased shock rise times and also alter the signature frequency spectra; all have been shown to reduce loudness and noisiness (ref. 3) to observers out-of-doors. More recent studies on such waveforms, that are both symmetric and asymmetric, indicate increased acceptability for both outdoor and indoor exposures (refs. 4 and 5).

Three major thrusts are required in the solution of the sonic boom problem associated with overland flight of the High-Speed Civil Transport (HSCT) as indicated by the three outer circles shown in figure 1. These three major thrusts include the establishment of criteria for an acceptable waveform, being able to design a viable aircraft to an existing shaped (or acceptable) waveform, and quantifying the effects of the atmosphere through which this shaped waveform will propagate. These three major thrusts are, in fact, the three major research priorities that were recognized by a panel of experts from industry, government, and universities as the key areas to be addressed (ref. 6). Note that each of these three major thrusts also interact with each other as illustrated by the dashed lines in figure 1.

A reasonable data base from small model wind tunnel tests (refs. 7 and 8) and theory (refs. 9 and 10) exists indicating that vehicles can be designed to produce modified sonic boom signatures (non N-wave types) of the type that may be more acceptable from a people and structural response aspect. There is, however, one aspect of this vehicle/waveform design modification process that requires confirmation prior to committing to the final design of an HSCT and that is to experimentally establish whether a "shaped" waveform shown to be "do-able" on wind tunnel models out to about 10 to 30 body lengths will persist out to representative flight conditions of from 200 to 300 body lengths.

The purpose of this report is to present the results of a study to determine the feasibility of experimentally establishing the persistence of modified sonic boom signatures to representative flight conditions using a relatively large supersonic remotely-piloted vehicle (RPV). Other simulation methods that may accomplish this objective are also addressed and include use of nonrecoverable target drones, missiles, full-scale drones, very large wind tunnels, ballistic facilities, whirling-arm techniques, rocket sled tracks, and airplane nose probes. In addition, this report will also present a background on the origin of the feasibility study including a brief review of the equivalent body concept, a listing of the basic sonic boom signature characteristics and requirements, identification of candidate RPV vehicles in terms of desirable features/availability, vehicle characteristics including geometries, area distributions, and resulting sonic boom signatures. A program is developed that includes wind tunnel sonic boom and force models and tests for both a basic and modified RPV vehicle and full-scale flight tests.

BACKGROUND

Equivalent body concept.- Sonic boom signature minimization/modification, along with the present feasibility study, is based upon the equivalent body concept established by Whitham (ref. 11) and illustrated in figure 2 and developed from reference 7. The message to be conveyed from figure 2 is that for sonic boom purposes, if the actual airplane wind tunnel model shown in the upper left is replaced by an equivalent symmetrical body of revolution (upper right of fig. 2) having the same equivalent area distribution (A_e) as shown by the center plot, then similar sonic boom signatures will result. The two sonic boom signatures shown at the bottom of the figure illustrate the experimental correlation that is, in fact, predicted by theory. Some slight variations are noted to exist between the recompression (negative) phase of the waveform but these are primarily a result of the body-sting support termination.

Sonic boom signature.- An indication of the status of sonic boom signature modifications as established by wind tunnel model tests and theory is in order. The ingredients contained within the current sonic boom prediction program are schematically illustrated in figure 3. Two procedures are indicated; the one on the left side being the analytical path and the path shown on the right side being designated the wind tunnel model path. The analytical path begins with the geometry of the vehicle that is converted into a numerical model. Area developments for the desired Mach number and azimuth angle are obtained through use of a computer program whose primary purpose is the evaluation of airplane wave drag. Lift development is also provided by computing programs. The resulting equivalent area distributions evolve into the Whitham F-function and then into the near-field signature. This near-field signature is then an input to the atmospheric propagation program (ray tracing) providing both the sonic boom signature at ground level and sonic boom footprint for standard or actual (nonstandard) atmosphere.

The wind tunnel model path in the sonic boom prediction program was developed in order to utilize the near-field signatures measured on small sonic boom models of unconventional configurations or for vehicles such as Shuttle Orbiter operating at Mach numbers in excess of 3.0 and at very high roll angles and angles of attack. These models, in themselves, are already representing the preceding inputs of the analytical path (geometry, volume, lift, etc.). This wind tunnel model path is especially valuable when sonic boom information is required on bodies designed to provided non N-wave type signatures, that is, those addressing boom minimization concepts. An illustration of the application of wind tunnel sonic boom model tests results and analysis is given in figure 4, which has been developed from results in reference 7. Measured sonic boom signatures are shown for various distances from the models for two vehicle configurations; one designated a basic body which is to produce an N-wave signature in the far-field and the other designated a modified body which is to produce a flattop signature in the far-field. Signature measurements at 2.5, 5, and 10 body lengths (h/l) from the model illustrate the development of the waveforms for the two models. Note that the basic configuration signature sketches to the left side of figure 4, which is to result in an N-wave on the far-field, still retains the multiple saw-tooth shock characteristic out to 10 body lengths. However, the signatures on the right side of the figure relating to the model designed to produce a flattop signature in the far-field show flattop waveforms at all three measurement positions. Tunnel test section /model size constraints limit the furthest measurement, in this case, to 10 body lengths from the model.

Wind tunnel model near-field signatures of the type shown in figure 4 are then inserted into the sonic boom prediction program and propagated to distances/body lengths equivalent to full-scale aircraft flying at cruise altitudes; the resulting sonic boom signatures are established as illustrated by the shock-field signature schematics given in figure 5 taken from reference 6. Although the original intent of figure 5 was to highlight the so-called low-boom high-drag paradox, the figure is used herein to illustrate the rapid coalescence of the near- and mid-shock field of the basic saw-tooth signature into an N-wave at the ground. The modified flattop signature appears to propagate as a flattop waveform from near- and mid-field to the far-field at ground level. Experimental verification of the coalescence of the basic saw-tooth signature into an N-wave, as predicted by theory and wind tunnel model tests, has been established from in-flight measurements in the near- and mid-field and at ground level for large aircraft flying at high altitudes (refs. 12, 13, 14, and 15). A corresponding full-scale/large-scale experimental verification for configurations designed to produce modified (non N-wave signatures) waveforms has not yet been demonstrated. In fact, in the more than 13,000 sonic boom signatures that have been measured to date involving some 18 different size, shape, and weight aircraft and even space vehicles operating at a range of Mach-altitude combinations from Mach 1 to 23 and heights to 250,000 feet, all have had typical saw-tooth or N-wave shapes. Thus, there is the need for experimentally establishing whether a "shaped" waveform, shown to be "do-able" on wind tunnel models out to about 10 to 30 body lengths, will persist out to representative flight conditions of about 200 to 300 body lengths.

Test program factors.- In order to accomplish such an experimental program, study efforts were required to be performed in four fundamental areas as shown on Table 1, and includes the selection of a test vehicle, performing a series of analytical tasks, conducting wind tunnel tests, and providing flight support. Selection of the test vehicle would be based upon the size, Mach number, altitude, and flight duration required for the test; also, whether the vehicle is recoverable or expendable, operational and, of course, modifiable. Analytical efforts would include prediction of the boom characteristics of the basic and modified vehicles and the selection of a modified signature shape. In addition, predictions are required for both wind tunnel and flight situations as they relate to the measured boom signatures and also as an assessment of the impact of the modification on the basic vehicle performance. Wind tunnel measurements will be necessary in order to validate the analytically predicted signatures of the basic and modified vehicles, at least out to 2 to 6 body lengths and to establish the impact of vehicle changes on its performance and stability and control. Finally, flight-support issues would include the selection of a suitable test range in terms of vehicle launch and recovery, availability of tracking and typical weather patterns, and the ambient noise level and other ongoing activities. The need for proper communications, time synchronization, and an area to deploy specific microphone arrays will also be important requirements. After examining the findings relative to these four main program factors, the feasibility of performing the flight test verification would be established.

THRUSTS OF FEASIBILITY STUDY

The primary objective of the present study is to assess the feasibility of utilizing relatively large remotely piloted vehicles (RPV's) or drones to experimentally establish the persistence of "shaped" sonic boom signatures out to representative cruise flight distances (200 to 300 body lengths) in a real atmosphere. A secondary objective would be to provide an indication of the influence of the atmosphere on "shaped" waveforms as they propagate from the vehicle to the ground. This would be especially informative since the present data base on atmospheric influences on sonic boom signatures is based entirely on saw-tooth or N-wave type sonic boom shapes.

As previously mentioned, the selection of an appropriate RPV/drone-type vehicle involves a number of considerations including, among the more significant items, suitability, availability, and affordability. Before addressing these and other concerns, it is necessary to discuss some basic issues relative to real and scaled simulations and the significant features of modified boom signatures and vehicle area distributions.

Real and scaled simulation.- A fundamental question that needs to be addressed regarding the present feasibility study is whether or not the proposed scheme to utilize relatively large RPV's will more firmly establish the credibility of "modified" waveforms. Some of the concerns being expressed can be illustrated with the use of figure 6. Shown in the figure are two schematics of the shock-signature patterns representing the full-scale real airplane case of a 200-foot long vehicle flying supersonically at 60,000-feet altitude (300 body lengths) shown on the left side of figure 6, and the situation for a 30-foot RPV flying supersonically at about 9,000-feet altitude (also 300 body lengths) shown on the right side of the figure. Although the requirement to simulate the 300 body length equivalency is duplicated for both full-scale and RPV cases, the consistency of the atmosphere in terms of the influence of atmospheric pressure, temperature, sound speed, density (viscosity), oxygen-nitrogen relaxation effects, and relative humidity at the vehicle altitudes is not duplicated. In addition, the so-called "scaled height" and "frozen signature" must be addressed. The questions, therefore, are twofold: first, do atmospheric parameters play a significant role in the persistence of "modified" "signatures; second, is "scale height" required to establish "frozen" modified signatures? Discussions relative to these two issues suggest that confirmation of the persistence of "modified" sonic boom signatures will be established based upon the simulation of equivalent body lengths, especially since atmospheric density is increasing with decreasing altitude.

Characteristics of modified signatures.- In order to establish the persistence of modified sonic boom signatures to large distances, a number of concerns must be addressed. First of all, the shape of the signature is of paramount importance. That is to say that the overpressure level of the "shaped" signature is of secondary importance in the sense that the "modified" or "shaped" RPV/ drone may have Δp's larger than the "basic' unmodified vehicle. Also, the "shaped" signature need not have similar bow and tail shocks. It was previously shown from laboratory studies that any modifications to sonic boom signatures should be equally applied to both bow and tail shocks; that is, if a flattop signature is developed, it should be symmetrical in regards to bow and tail shocks. Waveform symmetry places a significant constraint on vehicle modifications. Recent laboratory studies (ref. 5), however, indicate that signature symmetry relative to loudness of booms is not required. Designing a vehicle to produce a nonsymmetrical "modified" waveform is more easily acquired. Finally, the "modified" signature must be distinguishable from an N-wave as measured at ground level after it has propagated down through the atmosphere some 200 to 300 body lengths.

Some insight into the selection of the type "modified" signature, that should be designed into the appropriate RPV/drone from the viewpoint of atmospheric influences (that is, alteration of the signature shape during its propagation to the ground), may be attained with the aid of figure 7 taken from reference 16 which illustrates the influence of the lower layer of the atmosphere on measured sonic boom signatures. Two temperature profiles are shown for the desert area associated with Edwards Air Force Base in California, one taken early in the morning and one in the afternoon. Note that for all altitudes above about 2,000 feet of the surface, the two temperature profiles are essentially the same with temperatures decreasing with increasing altitude. In those first few thousand feet of Earth's surface boundary layer, however, there is a strong inversion in the morning due to night surface cooling resulting in a very quiescent stable layer. As the atmosphere heats up in the afternoon, this lower layer becomes very unstable. Surface temperatures increase and a so-called superadiabatic temperature lapse rate exists which is conducive to large thermal and turbulent activities. Sonic boom signatures generated by a fighter aircraft flying at similar Mach altitude combinations in these morning and afternoon situations result in significant variations in signature shapes. As illustrated in figure 7, signatures measured in the morning hours for the quiescent stable lower layer show the predicted (expected) clean N-wave signatures. During the afternoon, sonic boom signatures that propagated through the unstable lower layers are distorted from the nominal N-waves to waveforms that are "peaked" and "rounded". Since the bow and tail shocks are composed of the higher frequency components of the waveform spectrum, these are the frequencies that are most influenced by the turbulence/ thermal structure of the lower layers of the atmosphere (ref. 14). The upper layers of the atmosphere (the macro weather effects) have been shown to have a second order effect on signature variations (ref. 17).

The signature variations brought about by the lower layer of the atmosphere for smaller fighter aircraft, shown in figure 7, have also been observed in other geographic locations and on other size aircraft. These results are illustrated in figure 8 taken from reference 14. Note that the bow and tail shocks of the boom signature measured from small fighters (54 ft) and medium and large bombers (97 ft and 185 ft, respectively) can vary from peaked, normal, or rounded. This suggests that the lower layer turbulence eddy sizes are the same order as the sonic boom signature waveform frequencies. Similar waveform distortions have been observed on even smaller aircraft such as the F-16 (47 ft) and the F5/T38 (46 ft). It follows that for an RPV/drone of about 30 feet, one would also expect similar atmospheric influences on its sonic boom signature. Thus, two important situations would exist in simulating large-scale "modified" waveform signatures using RPV/drones relative to "real" atmospheric effects. An illustration of these two situations is shown in the schematic sketches of sonic boom ray paths given in figure 9.

Two situations are illustrated in figure 9; the so-called "quiescent" stable lower-layer atmosphere associated with the early morning hours shown to the left and of the so-called "active-unstable" lower layer associated with afternoon hours on the right. The shock-wave/ray-path patterns of the vehicles flying at similar Mach numbers and at two different altitudes are shown in the figure. In order to accomplish the primary objective of the present feasibility study, flights of the basic unmodified and modified RPV/drones would be made in the early morning hours when the lower-layer atmospheric conditions are stable and conducive to observing the predicted/nominal boom signatures. On the other hand, flying the basic and modified vehicles in the afternoon when the lower layers are quite active would allow for some insights as to the influence of the atmosphere on standard N-waves and the "modified" waveform, each of which would have a different frequency spectrum, especially, with regards to the high end of the spectrum. Thus, the shape of the "modified" sonic boom signature for this feasibility study in terms of its identifiability should be dependent, in part, upon its frequency spectrum.

Noise spectra associated with four symmetrical sonic boom waveforms are given in figure 10 and include an N-wave, a finite rise-time, a flattop and a ramp-type waveform. The fundamental frequency associated with each of the four waveforms is approximately the reciprocal of the wave period. The basic difference in each spectrum lies in the shape of the curves. To the left of the fundamental peak, the spectra of all four signatures decays 6 dB/octave. To the right of the fundamental peak, the frequency spectrum of the N-wave decays at the rate of 6 dB/octave. For the finite rise time signature, the fall-off varies from 6 dB/octave to 12 dB/octave. The flattop and ramp-type signatures appear to decay at about the same rate as for the N-wave (6 dB/octave). Since the present study is aimed at developing "modified" signatures that are nonsymmetrical, that is, changing the positive portion of the signature but not the negative phase, it is of importance to examine the signature spectra to see if any significant changes are evident. A comparison of the spectra for both symmetrical and nonsymmetrical ramp and flattop type sonic boom signatures is given in figure 11. Little difference is noted to exist between the two sets of waveform spectra. In fact, unlike the finite rise time signature shown in figure 10, little differences exist between the N-wave spectrum shape and those of the symmetrical or non symmetrical ramp or flattop signatures. This suggests that from the standpoint of signature identification due to atmospheric influences, either a ramp-type "modified" signature or one having a flattop type waveform shape may be selected. This allows for some latitude in the selection of and modification to a particular RPV-drone configuration.

Modified signature/vehicle area distributions.- In order to design a vehicle to have a "modified" sonic boom waveform, it must combine its equivalent area due to both volume and lift to produce a reasonably smooth total area development along its longitudinal axis similar to the one shown in figure 12 taken from reference 6. Note that once an equivalent area is established to produce a "flattop" signature, shown to the left of the figure, very little change in area development is required to the vehicle in order to produce the ramp-type waveform shown to the right of the figure. However, each of these equivalent area distributions are significantly altered from that associated with a basic/standard vehicle design that is illustrated in figure 2, especially in the initial one-half of the area development beginning at the vehicle nose section. Since the required modifications to any RPV/drone must be made in terms of "adding" rather than "taking away" area, in this feasibility study, serious consideration must be given to vehicles that will be amendable to such alterations.

VIEWS ON VARIOUS METHODS OF ESTABLISHING PERSISTENCE OF MODIFIED BOOM SIGNATURES

In addition to the preferred use of RPV/drones and/or low-cost nonrecoverable vehicles to accomplish the objectives of this feasibility study, five other approaches to establishing the persistence of modified sonic boom signatures were identified and an examination was made of the pros and cons of each technique. These five techniques consist of the use of very large supersonic wind tunnels and very small models, the use of large ballistic range firing equivalent bodies of revolution, the use of a large whirling-arm technique in a large anechoic wind tunnel or enclosure, the use of a full-scale rocket sled track and, finally, the adapting of a model shape nose probe attached to a current supersonic aircraft. Each of these five approaches will be discussed in some detail in the following sections.

Very large supersonic tunnel/very small model.- In order to provide for a sonic boom signature measurement to be made at a distance of even 200 body lengths from the model, which is assumed to be one-inch (1 in.) in length, the tunnel dimension would have to be at least 200 inches (about 16 ft.). Supersonic wind tunnels with test section of the order of 16 feet are available; however, the ability to suitably construct such a small model that would have the geometric fidelity to represent the actual "modified" area development is in doubt, especially, when one considers boundary layer effect and model vibrations (see, for example, ref. 13). Increasing model size to the nominal 4 inches or so, which is typical of many sonic boom wind tunnel model sizes, allows for designing model details and fidelity and minimizes model vibration/boundary layer concerns but requires a wind tunnel test section of about 65 feet. Such a facility does not presently exist. In addition to the above mentioned concerns, wind tunnels, by their very nature, provide a uniform or more homogenous media (atmosphere) where the pressure temperature and density are essentially constant. Thus, some question would exist as to whether the signature measurements are representative of the true propagation/signature development.

Ballistic range/bodies of revolution.- The ballistic range (in which bodies of revolution of various caliber from 1/4-in. in diameter to 1.25-in. in diameter and from 1/2-in. to 1-in. in length) has been used with great success in simulating sonic boom signature distortions as a result of turbulence and thermal effects (ref. 18). Distances on the order of 200 body lengths were attained and turbulent air jets and heated plates provided the "scaled" full-scale turbulence spectrum atmospheric characteristics. Such a facility, as schematically shown in figure 13 or one even larger as proposed in reference 18, would be a very useful device for conducting a series of studies in which the projectile can be altered to produce various modified waveforms and the media (atmosphere) can be varied to represent ranges of turbulence spectral characteristics. Thus a significant experimental data base can be established, one that would be difficult and expensive to acquire using larger scale RPV/drones in the real atmosphere. It should be noted that use of "winged" or "actual" aircraft type vehicles in any ballistic facility poses real difficulties in acquiring steady-level flight conditions (see ref. 19).

Whirling-arm technique/large anechoic enclosure.- A whirling-arm technique used to provide simulated forward motion to large model vehicles has been developed at the NASA/Ames Research Center in conjunction with the large 80-foot x 120-foot wind tunnel whose test section is acoustically treated. Using such an arrangement could allow for models of up to 1/2-foot in length to be tested to distances out to about 200 body lengths. Free-field acoustic conditions would be provided as a result of the test section acoustic treatment and a "variable" atmosphere could be made to exist between the model and measurement location through the use of airflow and heating-cooling techniques. The whirling-arm technique does, however, pose a few concerns that are not thought to be insurmountable. The first of these has to do with the circular or "arc" motion of the arm versus true rectilinear flight; second, there is a component of centrifugal force that is not present in true rectilinear flight. The use of such a facility can also assist in generating the required sonic boom data base relating to both model/signature shapes (here, detailed real winged aircraft configuration can be duplicated) and atmospheric propagation for correlation with and development of an improved analytical capability.

Supersonic rocket sled track.- Rocket sled tracks have been utilized in previous sonic boom studies, in particular, one that related to defining the overpressures and signatures associated with the superbooms occurring in focus areas due to acceleration from subsonic to supersonic speeds (ref. 20), a maneuver that is inherent to all supersonic and hypersonic vehicles. Rocket sled tracks have sufficient track length and supersonic capability to provide the simulated conditions and also are of a size to allow for the adoption of fairly large-scale vehicle shapes designed to produce "modified" boom signatures. However, there are two situations inherent with sled tracks that are detrimental to the sonic boom simulation that is desired. First of all, there is the ever presence of the ground surface which does not allow the sonic boom signature to develop in three dimensions and thus precludes the development of a clean free-field sonic boom waveform. Second, in order to make measurements at relatively large distances (200 to 300 body lengths), they would have to be made off to the side or up in the air, the former having the shock propagate sideways through a horizontally stratified atmosphere and the latter having the shock propagate upward and backward through the atmosphere. Measurements at significant heights above the sled track would also present difficulties.

Nose probe on supersonic aircraft.- As a result of recent successful flights by NASA Ames/ Dryden of the F-15 aircraft having a relatively large and long nose probe, it was considered appropriate to consider adapting an equivalent body-nose probe that would simulate a "modified" boom signature. The initial first cut look considered a 20-foot equivalent body probe that somehow would be attached some 13 feet or so ahead of the nose of an F-15 airplane, illustrated in the sketches at the top of figure 14, and the corresponding sonic boom signatures shown at the bottom of the figure. The aircraft is assumed to fly at Mach 1.3 and 10,000-feet altitude. Such a simulation technique, if feasible, would provide a highly controllable, reliable, and repeatable source of data at a relatively low cost in comparison to the other methods just described and, in addition, RPV's/drones. Although there should be little or no problem getting the aircraft to sustain the Mach-altitude combination for a short period, the biggest drawback, actually a "show stopper," is the fact that the probe "modified" signature, evident in the very near-field of the aircraft as shown in the calculated signature on the left side of figure 14, is completely overwhelmed by the very strong shock-field of the aircraft at ground level as noted by the signature on the right of the figure.

NONRECOVERABLE/RECOVERABLE VEHICLES

In selecting what is considered to be the most suitable vehicle, a recoverable RPV, to be utilized in the experimental verification of the persistence of "modified" waveforms to large distances in a real atmosphere, a number of areas of concern were addressed along with such obvious factors as availability, suitability, cost, and operational/launch capability.

Desirable RPV features.- At least six features were identified as being desirable, if not required, in the selection of an RPV and these were to have a relatively large vehicle of 20 to 30 feet in length that could operate in the Mach 1.2 to 2.0 range and at altitudes of from about 5,000 to 10,000 feet, be controllable in terms of flight path, have minimum lifting surfaces, be able to hold steady-level Mach altitude for about 5 miles, be air or ground launched, and be recoverable. A few comments on some of these features is appropriate.

Vehicle length is critical in terms of establishing the altitude at which it will operate as dictated by the 200 to 300 body length simulation requirement. In addition, since the secondary objective of this effort is to acquire an early look at the effects of atmospheric turbulence in the first 1,000 to 3,000 feet or so of the Earth's boundary layer, vehicle flight altitudes greater than 3,000 feet will be required. This sets a minimum vehicle length of about 13 to 20 feet. Although current HSCT studies are focussing on vehicle Mach numbers in the 2.0 to 2.5 range, some sonic boom minimization studies (ref. 21) have been conducted at Mach numbers as low as 1.5. In fact, the minimization concept and signature persistence can be demonstrated at even lower Mach numbers. The only real concern is that the vehicle be able to operate at a Mach number that is sufficiently greater that the cutoff Mach number (Mach number below which boom will not reach the ground) associated with a particular altitude in both a standard and nonstandard atmosphere with and without winds. For altitudes in the range of 5,000 to 10,000 feet, the highest cutoff Mach number is the order of 1.1 or less (ref. 22). Thus, vehicle flights at Mach numbers of 1.2 and greater are appropriate.

It is highly desirable to acquire a vehicle which contains a minimum amount of lifting surfaces. Another way of stating this is that the vehicle should be of minimum gross weight. Since the vehicle is to be modified in the sense of changing its equivalent area distribution, it is preferred to make the area additions to the nonlifting portions of the vehicle which will, hopefully, have little effect on the basic vehicle loads and stability and control. The drag of the modified vehicle may also differ from that of the basic configuration, either increasing or possibly decreasing.

Finally, a recoverable vehicle that can be either ground launched or airlaunched would be very cost effective. Whichever vehicle is selected, a 5-mile region of steady-level flight at the desired Mach-altitude conditions is sufficient in order to acquire the necessary sonic boom signature measurements. This translates to less than a minute on conditions at even the lowest test Mach number.

Nonrecoverable vehicles.- There are two candidates in this class of nonrecoverable vehicles that were considered in this study and they tend to represent the so-called end points in terms of size and cost. The first of these is the Bendix Vandal (MQM-8G) shown in figure 15. The Vandal (Talos missiles with minor modifications to make them into targets) is a controllable supersonic

RPV target of about 22 feet in length, weighs about 3500 pounds, is driven by a combination rocket ramjet system and is of 1960 vintage. It is ground launched and expendable and has a Mach capability in the range of 1.8 and 2.0 at about 6,700 feet. A number of these vehicles are available and it has a very successful launch-mission record. Costs are estimated to be on the $250K-$300K per copy and an operating cost for set up and launch of around $35K-$50K. These vehicles are routinely launched from Pt. Mugu and have been launched from both WSMR and Wallops Island. Operational status is current and expected to be such for some years to come.

The Sidewinder missile shown in figure 16 is an example of a relatively low-cost vehicle that is considered for this study purpose as being on the extreme low end in terms of suitability with respect to its length (about 10 ft) and utility. There are a few points that should be highlighted regarding the use of missiles for the purpose of the present study. First of all, these missiles are typically airlaunched and, thus, involve an aircraft; second, missiles of this type are usually "boost-glide" in terms of their flight profiles; so there is little, if any, steady-state Mach-altitude phase; third, most of these type vehicles require a target to "home in" on and it would pose difficulties to provide such a target at, say, 5,000-feet altitude. Costs of airlaunched Sidewinders, which are still available in large numbers, are thought to be the order of $50K.

Aside from the above features cited for either the nonrecoverable Vandal or Sidewinder, there is an even more critical concern that relates to their suitability in terms of their "modifiability." This is illustrated by the data given in figure 17 which presents the equivalent area distributions for each vehicle for the Mach-altitude combinations required for the simulation. Also shown are the sonic boom signatures that would be observed for the basic unmodified vehicles. It can first be noted that at a Mach number of about 2 and altitudes on the order of 6,000 feet, the boom signatures are "saw-tooth" in character in that the shocks have not coalesced into a far-field N-wave. What is worthy of note is the manner in which the equivalent areas develop as compared to the type of slowly increasing smooth area development required to produce a ramp or flattop signature (see fig. 12). Since vehicle modifications necessitate "adding" volume (area) to the basic configuration rather than removing volume (area), an extension to the nose of both the Vandal and Sidewinder (see fig. 17) would be required to establish the proper ramp or flattop equivalent area development. This presents serious problems for each vehicle. For the Vandal, the nose section is actually designed as the inlet for the ramjet propulsion system. Altering this portion of the vehicle, especially an extension of the nose with a long cone inlet spike, could completely change the inlet capture/recovery characteristics and alter the operating characteristics such that the vehicle may not even fly. In the case of the Sidewinder, not only is an nose extension required, but a fairly large buildup in area (diameter) would be necessary to fill in the midlength regime. This large increase in area would, of course, increase drag significantly. More importantly, the required nose extension may also necessitate the forward movement of the forward fin controls in order to retain required stability and control requirements.

Recoverable vehicles.- There are three candidates in the class of recoverable vehicles that were considered in this study. These too, like the nonrecoverable vehicles considered, represent the so-called end points in terms of size and cost. The first of these recoverable vehicles is the Teledyne-Ryan Firebee BQM-34E (also known as the Firebee II) shown in figure 18 taken from reference 23. The Firebee is a winged-tailed aircraft type controllable-recoverable supersonic RPV target of about 28 feet in length, weighs about 1,900 pounds, is powered by a J-69 turbojet, and is of 1970 vintage. It can be either air- or ground-launched, is recoverable, and has a Mach capability of about 1.3 at about 9,000 feet. They have been phased out of operation by the Navy and Air Force so only about six of these vehicles are in existence. Four complete vehicles with spares (including an engine) are currently retained by the NASA/Langley Research Center. The BQM-34E has a 90 percent mission success rate and each vehicle could have a reuse rate of up to about 10 sorties. Costs are estimated to be on the order of about $500K per copy and an operating cost for setup and launch of about $50K to $80K. These vehicles were routinely launched from Pt. Mugu, Puerto Rico, and Tyndall AFB. One has been flown (airlaunched) at WSMR. Although the vehicle is phased out of DoD operations, the capability to set up, check out, and launch these vehicles is expected to be available for some time at Pt. Mugu by Navy civilian personnel, at Puerto Rico by General Electric personnel, Teledyne-Ryan personnel, or civil service retirees who formerly were involved in their operations.

The second recoverable vehicle considered is the Martin-Marietta SLAT shown in figure 19 is a missile-finned type controllable-recoverable supersonic RPV target of about 18 feet in length, weighs about 2,500 pounds, is powered by an airbreathing ramjet, and is of 1990 vintage. It is airlaunched and recoverable and has a Mach capability of 2.5 at 8,000 feet. The "SLAT," which at the time of this study was in the contractor development test phase, was estimated to cost on the order of $2,000K per copy with an estimated operating cost for setup and launch of about $125 to $150K. These vehicles were being launch tested at Pt. Mugu. At present, the SLAT development program has been cancelled.

An QF-4 drone aircraft (unmanned) was the third recoverable vehicle to be considered in this study and is shown in figure 20. The QF-4 is a drone version of the F-4 fighter and is about 60 feet in length, has an average weight of about 45,000 pounds, is powered by two J-79 turbojet engines, and is of 1960 vintage. As a drone, it is remotely operated as a normal aircraft in terms of performing takeoff-climbouts and landings and supersonic flights. It has a Mach capability of about 1.3 to 1.4 at about 20,000 feet. It is understood that the QF-4 drones will probably be in use at Pt. Mugu for the next decade or so. Also, as a drone (unmanned), modifications to this vehicle, if appropriate, would not involve the numerous requirements and costs associated with a man-rated vehicle. Cost estimates are as follows: $5K/hr for manned flight and about $50K/flight in the unmanned mode.

For these recoverable vehicles, as was the case of the nonrecoverable vehicles, the driving feature which has a significant influence on the selection of an appropriate vehicle, independent of cost and availability, is the "modifiability" of the vehicle in terms of its present equivalent area development. The area developments of the Firebee, SLAT, and QF-4 are given in figure 21 along with their associated sonic boom signature that would be observed at the specified Mach-altitude combinations (equivalent to about 300 body lengths). Note, first of all, that all three signatures are of the "saw-tooth" character and are rapidly approaching a N-wave shape. Note, too, that the equivalent area distributions for the "airplane-type" Firebee BQM-34E and the QF-4 drone airplane are similar as would be expected since they are both winged-tailed airplane configurations and, thus, more gradual in their area buildup than the missile-finned SLAT configuration which displayed a very rapid area buildup from the nose to a flatter more constant area development along the mid-aft constant diameter portion of this vehicle. Here again, as was the case for the nonrecoverable Vandal whose nose is the inlet, the SLAT has a "chin-type" inlet scoop that is designed to provide the inlet flow for the ramjet propulsion system. In order to emphasize this situation, the normalized equivalent area distributions of these three vehicles are also presented in the center portion of the figure 21. Note that an extension of the nose section of the SLAT, to provide for the required more gradual area buildup to produce a ramp or flattop sonic boom waveform, could seriously alter the existing matched nose-inlet design of the basic SLAT vehicle. In addition, as was the case for the Sidewinder missile, area must also be added to the mid-aft sections of the SLAT in order to develop the smoothly increasing area development shown in figure 12.

Both the Firebee RPV and QF-4 drone have equivalent area developments that are more amendable to modification in terms of providing for a ramp or flattop type sonic boom signature. Because the Firebee RPV has a higher fineness ratio (ratio of vehicle length over maximum equivalent diameter) than the QF-4 drone, it also has a more gradual equivalent area development as noted in figure 21. Extension of the nose section on the smaller more slender Firebee would appear to present less of a problem than to do the same procedure on the full-scale QF-4 unmanned drone airplane. In addition, the two inlets on each side of the QF-4 could present more difficulties than the single "belly" type inlet on the Firebee in terms of uniformity of flow and boundary layer buildup. Finally, the necessary area additions required on the midsections of each vehicle suggest that the Firebee would be least difficult to alter.

Vehicles selection/initial assessment.- Based upon the above discussions regarding non-recoverable and recoverable vehicles relative to their appropriateness to this feasibility study, a down-selection was made of all five vehicle candidates on the basis of suitability (in terms of vehicle modifiability), availability, and cost. First of all, the two nonrecoverable vehicles are not suitable candidates for a number of reasons but, primarily, because they would not be amenable to modification: the Vandal, because the nose consists of the very critical inlet to the ramjet propulsion system and extension of the vehicle nose section, would severely alter the vehicle operational capability; the Sidewinder because a large nose extension would alter/interfere with the forward control fins and the vehicles very high fineness ratio necessitates large area additions to the midbody region.

Of the three recoverable vehicles considered, the SLAT is deemed not suitable, not only because of its nonavailability but because it can only be airlaunched and is of relatively high cost. More importantly, like the Vandal, it too contains a nose inlet which is not readily and easily amenable to a nose extension modification. Difficulties (large drag increase) would also arise because of the large area additions that would be required to the more cylindrical mid-aft sections of the missile-type vehicle.

Although both the Firebee and QF-4 drone, each a basic airplane type configuration, are more suitable from the standpoint of modifiability, area changes to the full-scale QF-4 look to be more serious challenges than those required on the Firebee (two inlets versus one inlet, large scale modifications versus smaller scale modifications, etc.). The cost of making changes to the QF-4 will obviously be greater than those relating to the much smaller Firebee RPV.

Therefore, the supersonic Firebee BQM-34 E/T is deemed worthy of further consideration as the primary vehicle to be utilized in the present feasibility study. As such, additional "tests" will be made regarding its suitability, particularly to modifications and how it will fit into the overall program plan involving analysis, wind tunnel model tests, and flight tests in a real atmosphere.

ASSESSMENT OF THE BQM-34E FIREBEE VEHICLE

In this section, the suitability of utilizing the Firebee vehicle to establish the persistence of "modified" sonic boom waveforms to large distances representing full-scale aircraft flight altitudes will be examined. Discussions relating to vehicle modifiability and launch, flight, and recovery operations are presented.

Vehicle modifiability.- Selection of the 28-foot long Firebee vehicle as a primary candidate immediately sets the flight altitude-Mach combination of 8,700 feet (300 body lengths) and 1.3, respectively, as given by the speed/altitude envelope plot of figure 22 taken from reference 23. At these given Mach-altitude conditions, calculations were made of the equivalent area distributions for the basic vehicle and the equivalent area developments required to produce a boom signature having a flattop positive phase and one having a ramp-positive phase signature at ground level. These results are presented in figure 23. At the top of the figure are schematic illustrations of the profile view of the basic Firebee and profiles of the two altered vehicles that are designed to give a flattop and ramp-type signature. Note that the nose and midsection portions (just beyond the inlet) of the latter two vehicles required modification in the form of a nose extension (of about 3 feet) and added area to the midsection. The basic (unmodified) vehicle area distribution shown on the left part of the figure has been carried over to the other two area plots as dashed lines in order to give a visual feel for where area (or volume) had to be added in order to attain the area developments that produce the flattop and ramp-type positive phase of the boom signature.

It was noted previously that waveform symmetry places a significant constraint on vehicle modifications and designing a vehicle to produce a nonsymmetrical "modified" uniform is more easily acquired. For example, the positive portion of the boom signature is pretty much established by the shape of the first half of the equivalent area distribution (from the nose to the maximum area). The latter half of the equivalent area distribution (from Ae_{max} to area closure at exhaust exit) influences the negative portion of the boom signature. As such, consideration of the influence of the exhaust plume expansion, which is not large for this vehicle for the Mach number and altitude being considered (ref. 24), does not play a role in the required modification process. The inlet shock (due to flow spillage), however, could play an important role if the modified forebody does not provide a uniform onset flow. In addition, examination of wind tunnel tests of the inlet spillage drag (ref. 25) suggests that although the influence of inlet shocks will be minimal, care must be exercised in developing the required area additions to the basic vehicle in this vicinity to provide for a shock-free equivalent area development.

Some further discussion of the sonic boom signatures and spectra of the basic and modified vehicles shown at the bottom of figure 23 is warranted, especially, in terms of what one might expect to measure in the real atmosphere. It was indicated earlier that the flight tests would be made under stable atmospheric conditions, particularly the lower layers, to minimize its influence on the boom signatures. Recall, too, that the "modified" waveform must be distinguishable from an N-wave (or saw-tooth type waveform) associated with the basic unmodified vehicle. It was noted earlier that, with the exception of a "finite" real time signature, there is little difference in the frequency spectra of basic N-wave, a flattop, or ramp-type signature. The spectra associated with the basic Firebee and its two modifications to a flattop and ramp positive phase are given in figure 24. Note that there is very little distinguishable difference between the three spectra; thus, demonstration of the persistence of a modified waveform will depend almost entirely on being able to distinguish its shape. It would be highly desirable to have a flattop waveform with as long a "flat" duration as possible or a ramp-type with as "large" ramp (i.e., very little initial vertical bow-shock rise) as possible. Increasing the boom signature emphasis of the flattop and ramp characteristics required, primarily, greater extensions to the vehicle nose which has been extended about 3.0 feet for the two cases shown.

Figure 25 has been prepared to provide an indication of the persistence of the modified signatures, designed for the Firebee operating at Mach 1.3 and 8,700 feet altitude (300 body lengths), to an increased Mach-altitude combination of 1.5 and 20,000 feet (700 body lengths), respectively. Below each of the schematics of the basic and modified vehicles is shown the predicted sonic boom signatures that would be observed at ground level. Comparing these signatures with those of figure 23, it can be seen that the flattop positive-phase waveform, apparent at 300 body lengths and a Mach of 1.3, is still apparent at the Mach 1.5 at 20,000 feet (700 body lengths) condition. However, the ramp positive waveform, apparent at 300 body lengths and a Mach of 1.3, are no longer retained at a distance of 700 body lengths and Mach 1.5 (an N-wave results). Note, too, in figure 26, that when the Mach number is maintained at 1.3 and the vehicles flown at 20,000 feet (700 body lengths), the two modified signatures still exhibit the same characteristic that was shown in figure 25; that is, the flattop waveform still persists, whereas the ramp type develops to an N-wave.

One further item must be addressed before leaving the discussion on vehicle modifiability and that relates to the increase in vehicle drag that the area additions will cause. Any drag increase will have an effect on the vehicle performance and could possibly influence stability and control. The effect of the Firebee modifications on vehicle performance for the two cases previously discussed (flattop and ramp-type positive phase signature) and for both the Mach 1.3 and 1.5 conditions at 8,700 feet and 20,000 feet, respectively, are given in Table 2. In these calculations, drag due to friction and lift are assumed unchanged and only wave drag is addressed. The method of reference 25 was used in these calculations. From Table 2, it is shown that wave drag of either of the two modified vehicles is actually less than the basic vehicle (about 15 percent); thus, it is expected that, at most, the basic and modified vehicles will have the same total drag characteristics. Force tests, using wind tunnel models are planned for establishing whether significant change in the vehicle flight qualities result from the modifications as far as attaining the design Mach-altitude flight condition.

Launch/flight/recovery.- The Firebee can be either ground launched or airlaunched. An indication of the ground launch sequence is given in figure 27 (taken from ref. 23). The vehicle is mounted to a carriage rail arrangement, the engine is started and the vehicle launched with a JATO-type assist. This rocket assist canister is eventually dropped and the vehicle is guided on its mission. The pictures show a vehicle with the large belly fuel tanks which render the vehicle to subsonic operation. This tank is dropped prior to the start of the supersonic run using the "clean" configuration. The vehicle can also be ground launched in the "clean" configuration.

The airlaunch is accomplished by attaching the Firebee under the wing of an airplane as illustrated in figure 28 (also taken from ref. 23). Following takeoff, the aircraft climbs to an altitude of about 10,000 feet, which is the nominal launch altitude. Once the aircraft is in the vicinity of the test measurement site, the vehicle engine is started and it is then air-dropped to commence its mission.

Some observations regarding ground launch and airlaunch methods are in order at this point. BQM-34E airlaunches are normally conducted at 10,000 feet altitude. The first few seconds of flight is the most likely time for a malfunction to occur, resulting in a flight failure. Should a failure occur shortly after airlaunch, considerable time and altitude are available to initiate parachute recovery and save the costly drone. Ground launches are conducted from zero feet elevation and a malfunction occurring shortly after launch nearly always results in loss of the drone. Ground launches also place high "g" loads on the vehicle tending to cause equipment malfunctions, whereas in the airlaunching, the Firebee simply is released and it drops and flies away from the mother aircraft.

Airlaunching the BQM-34E allows it to be at the optimum location from a mission support standpoint at the time launch is initiated. This allows for greater operational efficiency for both mission start time and mission endurance aspects. Ground launches, on the other hand, can only be conducted from a permanent Firebee launch site and considerable fuel is consumed by the vehicle in getting to its mission start point.

A few final notes regarding airlaunch approval and also costs for airlaunch and ground launch methods. The standard configuration BQM-34E vehicles are cleared for airlaunches from the Lockheed DC-130 Hercules aircraft. The BQM-34E vehicles that NASA will modify cannot be airlaunched unless authorized by NAVAIR 530. Obtaining NAVAIR-530 certification could be a long process; however, the results of the planned wind-tunnel force tests, to be discussed later in this report on the modified vehicle, may very well shorten this process.

The current cost of a DC-130 flight hour is about $2500 and the cost of a JATO booster is also about $2500 which gives the appearance that airlaunch and ground launch costs are equal. However, there are other factors to consider. Ground launches incur booster alignment and launcher support personnel labor costs. Airlaunches may require transit time flight costs for ferrying the DC-130 to Pt. Mugu from its home base at Mojave, California, if it is not already on site. Since these are varying costs, it is not possible to firmly estimate these associated expenses, but it can generally be said that airlaunching is somewhat more expensive than ground launching.

The number of supersonic passes over the test measurement array per flight (sortie launch) will depend upon the test site launch and recovery areas, the Mach-altitude conditions desired, and whether the vehicle is ground launched or airlaunched. Airlaunches will always be in closer proximity to the test measurement site, thus, the potential for as many as two supersonic passes per sortie (launch) will be greater than for ground-launched vehicles. The basic (unmodified) vehicle can be ground launched with the "belly fuel tanks" to carry it in near proximity of the test measurement site where it is then dropped to perform the supersonic mission. However, for the "modified" vehicles, a "belly tank," cannot be incorporated and the internal fuel supply will only allow for one supersonic pass. Airlaunch will assure there is enough internal fuel to perform at least one supersonic pass.

Since the vehicle in the basic unmodified condition is thrust limited to Mach 1.3 at about 8,700 feet, it is proposed to dive the Firebee from about 15,000 feet leveling out at Mach 1.3 at 8,700 feet and holding this condition for about 5 miles (25 seconds or so). At 20,000 feet altitude, the vehicle is capable of Mach 1.5 in level flight. Once again, the vehicle would dive from about 25,000 feet leveling out at Mach 1.5 at 20,000 feet and hold this condition for about 5 miles (20 seconds or so). The modification to the Firebee will involve changes in the nose and midsections of the vehicle where the external fuel pod attaches. Thus, as mentioned above, the modified Firebees will be flown without the external belly fuel tank and, thus, be limited to one supersonic pass per sortie.

The Firebee recovery sequence is illustrated in figure 29 from reference 23. Following the completion of the flight runs, the vehicle is guided to the recovery area and a drag chute, stored in the vehicle tail cone, is deployed. The drag chute eventually pulls the main chute out, then releases and lowers the main chute can to the surface. The main chute inflates in a reefed condition for 6 seconds, then fully inflates and lowers the vehicle to the surface at this point; be it water or land recovery, the main chute is released and the vehicle recovered. As mentioned previously, the recovery operations out of Pt. Mugu have been very successful regarding water landings and these are noted to be easier on the vehicle than on-land recoveries.

WIND TUNNEL AND FLIGHT TEST PROGRAM

In this section, discussions will be provided regarding the use of the Firebee vehicle in both wind tunnel and flight tests in order to assure that the primary objective of the flight program is attained to experimentally demonstrate the persistence of a modified sonic boom signature to distances of 200 to 300 body lengths representing realistic flight situations. In so doing, the feasibility of conducting overflight measurements of modified signatures using RPV's will be established.

Scope of wind tunnel and flight tests.- The scope of the Firebee wind tunnel and flight test program may be illustrated with the aid of the block diagram flow chart given in figure 30. It is proposed, as indicated by the upper portion of the figure, that sonic boom and force models of the basic (unmodified) and modified Firebee configurations be tested at Mach numbers of 1.3 and 1.5 in the NASA-Langley Research Center 8-foot transonic tunnel (8'TT) and the Unitary plan wind tunnel (UPWT), respectively. A model of about 1-foot in length, which is considered to be large enough to provide geometric fidelity and also of suitable size to house an existing six-component, internally-mounted strain-gage balance, would suffice for both sonic boom and force tests in each facility and would also provide for boom signature measurements of from one to about four body lengths away from the model. This single model with interchangeable nose and area bumps to the vehicle midsection aft of the inlet is also envisioned as sufficing for both the basic and modified vehicles. Definitions of the modified nose section for flattop (mod 1) signature along with the basic BQM-34E nose section are given in figure 31.

Force model wind tunnel tests are necessary to determine if the sonic boom modifications of the basic Firebee configuration significantly alter the vehicle flight characteristics. Measurements of lift, drag, and moments would be obtained from the internally mounted model six-component balance. The results of these force tests obtained on the basic and modified models would then be compared with each other and with the high-speed force test data of reference 27.

Sonic boom wind tunnel tests are necessary to provide confirmation of and guidance to the flight test program with respect to the sonic boom signatures expected for the baseline and modified vehicles and, also, for using the measured pressure signatures for an alternate prediction method. As previously mentioned, the same model used in the force tests would be utilized for these tests and, in fact, force and sonic boom tests could be conducted simultaneously. Pressure signatures in the near-field from one (1) to four (4) body lengths would be made for both zero-lift angles of attack and at angles of attack associated with cruise. Pressure surveys directly beneath the model and at angles of 10 degrees and 20 degrees off axis will provide for both on-track and lateral spread measurements.

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The flight test program would begin upon completion of the wind tunnel tests. As noted in the lower portion of the block-diagram flow chart of figure 30, a flow path for the primary tests, those basic to accomplishing the primary object and indicated by the solid lines, and so-called "desirable" tests that are designed to accomplish the primary and secondary objectives are indicated by the dashed lines. Note that the primary flow path of flight tests, represented by the four blocks to the left of the figure, are all conducted under minimal atmospheric influences and involve two passes each of the baseline and modified vehicles at the design Mach-altitude conditions of 1.3 and 8,700 feet (300 body lengths), respectively. This is followed by a similar set of runs at Mach 1.5 and 20,000 feet (700 body lengths).

Depending on the Firebee flight recovery success rate, test range area, and atmospheric characteristics, the basic and modified vehicles would be flown at repeat conditions of the Mach-altitude conditions, only for highly active lower-layer atmospheric conditions (represented by the four boxes to the right of figure 30). In so doing, information regarding the second objective of the study, obtaining an indication of the influence of the lower turbulent layers of the atmosphere on modified signatures, will have been established.

Firebee flight tests are required to establish whether a "shaped" sonic boom signature, shown to be "do-able" on wind tunnel models out to about 10 to 30 body lengths, will persist to representative flight conditions of about 300 body lengths. One full scale baseline and one full scale modified vehicle as a minimum are required. Modifications to the vehicle involve changes to the nose section forward of the inlet and on the vehicle midsection behind the inlet as per the wind tunnel model modification just discussed. In addition to acquiring sonic boom measurement at ground level along the vehicle ground track and at locations to each side of the track, boom measurements are also planned to be acquired at altitudes of 3,000 and 6,000 feet above ground level using a airborne platform system. Radar tracking and atmospheric measurements are also to be obtained. These latter items will be discussed in more detail in a later section of this report.

Reasons for tests at Mach of 1.3 and 1.5.- There are a number of key reasons for conducting the wind tunnel and flight tests at Mach numbers of 1.3 and 1.5. First of all, the basic/standard Firebee BQM-34 E is thrust limited at 8,700 feet altitude ($h/l = 300$) to Mach 1.3 and at 20,000 feet altitude ($h/l = 700$) to Mach 1.5. Modifying the vehicle to some nonstandard N-wave signature by adding area and extending the nose section may increase the wave drag but is not expected to increase the vehicle total drag. Thus, Mach 1.3 should also be attainable by the modified vehicle at 8700 feet ($h/l = 300$). In order to match this primary flight test Mach number of 1.3 in the wind tunnel, use must be made of the LaRC's 8-foot transonic tunnel or the ARC's 11-foot transonic tunnel. These two tunnels are advertised as Mach 1.3 and Mach 1.4 capability, respectively, although they are really most suitable at Mach 1.25 and 1.3, respectively. The Mach 1.5 condition is included since it is highly desirable to acquire wind tunnel boom signatures on the basic and modified models in the LaRC UPWT. Tests at this Mach number in the UPWT are felt to be mandatory since a substantial experimental data base regarding wind tunnel model sonic boom measurements have been generated using this facility. The minimum stable flow for the LaRC UPWT is Mach 1.5. It should be noted that the AEDC 16-foot propulsion tunnel is capable of Mach 0.8 through 1.6 but scheduling and operations costs ($8K/hr) discourage its use.

Predicted wind tunnel sonic boom signatures.- The predicted sonic boom signatures for the wind tunnel tests of the 1-foot model representing the baseline Firebee configuration and one modified to produce a flattop or ramp positive phase signatures operating at Mach 1.3 in the 8-

Foot Transonic Tunnel and at distances of 1, 2, 3, and 4 body lengths (h/l) from the model are illustrated in figure 32. The signatures are drawn to scale in terms of the pressure and time scale in order to provide a better feel for how much change is taking place in the signature characteristics as distance from the model is increased and, also, to provide a view of the difference between the basic and modified signatures. Such comparisons will provide insights into the final selection of a modified waveform relative to the final vehicle design. Note that the signatures are fairly complex in terms of number of shocks and that the flattop and ramp-type positive phase designs appear more identifiable and persistent than the basic (unmodified) design as distance from the model is increased.

The predicted sonic boom signatures for the 1-foot model representing these same three configurations tested at Mach 1.5 in the UPWT are shown in figure 33. Note, first of all, that since the UPWT test section is about half the size of the 8'TT, signatures are only calculated at distances of 1 and 2 body lengths from the model (which will also be the limits of experimental measurements). It can be observed that although the vehicle is operating at the off-design Mach number of 1.5, the flattop and ramp signature characteristics are still quite pronounced at the 1 and 2 body length distances and still quite different than the basic vehicle signatures.

Predicted flight sonic boom signatures.- The predicted sonic boom signatures, for flights of the full-scale 28-foot Firebee and one modified to produce the flattop or ramp-positive phase signatures operating at Mach 1.3 and at 8,700-feet altitude, are shown for distances of 50, 100, 200, and 300 body lengths from the vehicle and are illustrated in figure 34. Once again, as for the wind tunnel case, the signatures are plotted to scale in terms of pressure and time so that a visual display of what would be observed if measurements could be made at each of the distances that the calculated signature are shown. In addition to the planned sonic boom measurements at ground level (300 body lengths), it also appears feasible to acquire measurements at 100 and 200 body lengths from the vehicle using an airborne platform. These near- and mid-field signature measurements will greatly enhance the program findings and add significant insight and confidence in sonic boom signature minimization as it relates to vehicle design.

The predicted sonic boom signatures for flights of these same three Firebee configurations at Mach 1.5 and at 20,000-feet altitude are shown in figure 35. Sonic boom signatures for this off-design operating condition are shown for distances of 50, 450, 550, and 700 body lengths from the vehicle. Note that although the near-field signatures of the modified vehicles at 50 body lengths are distinctly flattop and ramp shape and are quite different than the basic vehicle waveform, the basic and ramp positive phase signatures develop rapidly into the near N-waves at distances of 450 body lengths and beyond while the flattop positive phase design persists to ground level. A similar situation exists when the vehicle is flown at Mach 1.3 at 20,000 feet altitude as noted in figure 36. Here again, signature measurement at ground level and at altitudes corresponding to about 300 and 550 body length using the airborne measurement system will add immensely to our understanding of signature aging.

One final note, the calculated flight signatures at ground level at 300 and 700 body lengths shown in figures 34 and 35, respectively, are the same as those shown previously in figures 23 and 25.

Sonic boom flight test measurement setup.- An indication of the manner in which sonic boom measurements will be acquired during the Firebee flight tests is presented in figure 37. Shown in the figure are schematic illustrations of the Firebee flying at the design condition (relative to boom signature modifications) of Mach 1.3 and an altitude of 8,700 feet; also, at the off-design condition of Mach 1.5 and an altitude of 20,000 feet above ground level over two ground arrays of 13 microphones each set up at each end of a 10,000 foot runway and along the vehicle ground track. In each of the two arrays, microphones are spaced 200 feet apart and cover a total distance of 1200 feet parallel and perpendicular to the flight track. Having such an arrangement eases the constraints on having the vehicle fly exactly along the desired ground track centerline both in terms of its lateral displacement and heading. The microphone separation will also provide an indication of the stability of the atmosphere through which the shock waves propagate and information on character of the signatures at lateral locations. Most importantly, the dual array, separated by about 10,000 feet will provide the equivalence of two supersonic passes (per sortie) over a signal array. This is especially significant in terms of flights of the modified vehicle which will only be able to make a single supersonic pass per sortie. It is planned to make use of the digital-remote self-triggering measurement systems developed by NASA-Johnson Space Center (Portable Automated System described in ref. 28) and USAF-Wright Patterson Air Force Base (Boom Event Analyzer Recorder described in ref. 29) shown in the lower portion of figure 37. The equivalence of these systems as compared to the previously employed NASA analog sonic boom measurement system has been demonstrated (ref. 30).

Also shown on the figure is a schematic of an orbiting airborne measurement platform carrying one of the remote-digital boom measurement units aloft to altitudes of 3,000, 6,000, and even 10,000 feet aboard a RPV surveillance vehicle such as the USMC Pioneer. The combination of the relatively low speed of the vehicle, about 40-miles per hour, and the high signal-to-noise ratio associated with the sonic boom signature in reference to airflow noise over the microphone, should permit quantitative boom signature measurements. The weight of the digital-remote boom measurement unit is well within the current payload capability of the Pioneer vehicle. However, an initial flight test using the Pioneer/sonic boom unit arrangement would be required to assure that the concept is valid.

Wind tunnel and flight test program plans.- Upon completion of the present feasibility study and concurrence that a determination of the persistence of modified boom signature can be experimentally established using the relatively large Firebee, it will be necessary to develop two detailed test program plans; one that addresses wind tunnel model force and sonic boom tests and the other addressing the flight tests.

A detailed wind tunnel test plan has been written in which model size and type construction are specified, including a flow-through inlet exhaust. A model with interchangeable noses and midsection "area bumps" aft of the inlet are provided to minimize costs and for ease of adapting and testing in the 8' TT and UPWT. Model loads, strain-gage balance, sting and sting adapter arrangements are also being addressed. Sonic boom measuring probes including cones and wedges, their locations in the tunnel, and the traversing mechanism all have been examined for their appropriateness to the models, type tests, and facilities. Finally, the model-run schedule and program schedule are provided.

A detailed flight test program would address a number of items including the flight vehicle, test range, test flights, measurements, schedules, participants, and costs. Flight vehicles include not only the basic and modified Firebee but also the airborne measurement platform. Two test ranges are considered candidates for the flight test phase and include Pt. Mugu and WSMR. At each site, a number of items would be addressed and include safety of flight, launch method, launch and recovery areas, work-storage-assembly areas, security, clearances, and coordination.

Measurements include not only acquiring the ground based and airborne platform sonic boom signatures, but also vehicle tracking and surface and upper-air weather, all time correlated. The flight test schedule will be influenced by the primary and alternate test range available, time of year regarding atmosphere test conditions, time required to assemble and check out all vehicles and systems, availability of Firebee modification kits, shipping, and availability of spare parts. Depending upon when the program is committed (based on funding availability and the findings from the wind tunnel test program), provisions need to be made to have available the required talent to operate and support the flight vehicles and will include NASA, contractors, and test range personnel. Finally, cost numbers relating to vehicle assembly, checkout, recovery, and modification along with range cost (tracking, weather, boom measurements, etc.) would be defined.

Points of contact.- In Table 3 is a listing of the points of contact that assisted greatly during the conduct of the present study by providing information and guidance regarding candidate flight vehicles, especially, the Firebee, Vandal, and SLAT as to their characteristics, status, availability, and costs. It should be noted that through the combined cooperation of the USN, USAF, and NASA-Langley Research Center, four complete Firebee vehicle systems with spares (including an engine) and manuals were acquired at no cost.

CONCLUDING REMARKS

A study has been made to determine the feasibility of experimentally establishing whether a "shaped" sonic boom signature, shown to be "do-able" wind tunnel models out to about 10 body lengths, will persist out to representative flight conditions of from 200 to 300 body lengths. Although the study focuses on the use of a relatively large supersonic remotely piloted and recoverable vehicle, other simulation methods that may be utilized to accomplish the objective are also examined. A key ingredient addressed within the study includes the selection of a modified (shaped) and identifiable sonic boom signature that differs from the normally observed saw-tooth and N-wave signatures, and also one that is compatible with vehicle geometric alterations.

The results of the study indicate that it is feasible to experimentally demonstrate the persistence of a shaped sonic boom signature to representative flight conditions using the relatively large supersonic Firebee BQM-34 E remotely-piloted recoverable vehicle. This vehicle has been found to be a suitable candidate in terms of its size, Mach-altitude capability, availability, and costs; in particular, its adaptability to geometric modifications to produce suitably modified boom waveforms with relatively minor changes which involves a reshaped nose extension and the addition of volume to the belly section. Such changes should have no significant effect on the basic vehicle operation.

As a result of this finding, a test program is developed that includes the design and testing of a one-foot model of the basic and modified vehicle in order to acquire sonic boom signatures and model force data. It is proposed to conduct these tests in the LaRC 8'TT at Mach 1.3, representing the full-scale vehicle flight test condition and also in the LaRC UPWT at Mach 1.5 to acquire sonic boom signature data for correlation with both flight vehicle results and the bulk of the existing wind tunnel experimental data base on sonic boom minimization. Full-scale flight tests would be conducted at Pt. Mugu, CA, with WSMR, NM, as an alternate site. Ten full-scale Firebee flights, utilizing the four available Firebee vehicles, will be required as a minimum to accomplish the test objective.

Study findings regarding the six other alternate approaches to experimentally establishing the persistence of shaped sonic boom signatures to very large distances were, for the most part, not suitable. Only two of the six techniques addressed are considered promising. The following remarks highlight the study findings regarding the six alternate schemes. The use of non-recoverable vehicles and missiles were deemed inappropriate since the required sonic boom shape modifications would have a significant influence on the basic flight characteristics and stability and control. Costs are also a significant factor since each flight would require a vehicle and its associated geometric modifications. Very large wind tunnels, supersonic sled tracks, and aircraft nose probes are also considered not applicable; large wind tunnels because they are nonexistent, sled tracks because of the presence of the ground surface, and nose probes because of the overwhelming influence of the airplane shock flow field. The ballistic range and whirling-arm techniques are, however, considered applicable, especially the former. Each of these latter two simulation techniques may be used to generate a substantial data base on sonic boom signatures relative to vehicle geometries and atmospheric influences.

REFERENCES

1. Douglas Aircraft Company: Study of High Speed Civil Transports - Summary. NASA CR-4236, 1990.

2. Boeing Commercial Airplanes: High Speed Civil Transport Study - Summary. NASA CR-4234, 1989.

3. Niedzwiecki, A.; and Ribner, H. S.: Subjective Loudness and Annoyance of Filtered N-Wave Sonic Booms. J. Acoust. Soc. America, vol. 6, no. 3, 1974, pp 705-707.

4. Leatherwood, Jack D.; and Sullivan, Brenda M.: Laboratory Study of Effects of Sonic Boom Shaping on Subjective Loudness and Acceptability. NASA TP-3269, 1992.

5. Shepherd, Kevin P.; and Sutherland, L. C.: Recent Studies of Human Response to Sonic Booms. Presented at 124th Meeting of Acoust. Soc. of America. New Orleans, LA, October 31 - November 4, 1992, Session Paper 2pPA6.

6. Darden, Christine M.; Powell, Clemans A.; Hayes, Wallace D.; George, Albert R.; and Pierce, Allan D.: Status of the Sonic Boom Methodology and Understanding. NASA CP-3027, 1988.

7. Carlson, Harry W.; McLean, F. Edward; and Shrout, Barrett L.: A Wind Tunnel Study of Sonic Boom Characteristics for Basic and Modified Models of a Supersonic Transport Configuration. NASA TM X-1236, 1966.

8. Carlson, Harry W.; Barger, Raymond L.; and Mack, Robert J.: Application of Sonic Boom Minimization Concepts in Supersonic Transport Design. NASA TN D-7218, 1973.

9. Seebass, R.; and George, A. R.: Sonic Boom Minimization. J. Acoust. Soc. America, vol. 51, 1972, pp. 686-694.

10. Darden, Christine M.: Minimization of Sonic Boom Parameters in Real and Isothermal Atmospheres. NASA TN D-7842, 1975.

11. Whitham, G. B.: The Flow Pattern of a Supersonic Projectile. Commun. Pure & Appl. Math, vol. V, no. 3, 1952, pp. 301-348.

12. Maglieri, Domenic J.; Ritchie, Virgil S.; and Bryant, John F.: In-Flight Shock-Wave Pressure Measurements Above and Below a Bomber Airplane at Mach Numbers 1.42 to 1.69. NASA TN D-1968, 1963.

13. Carlson, Harry W.: Correlation of Sonic Boom Theory With Wind Tunnel and Flight Measurements. NASA TR R-213, 1964.

14. Garrick, I. E.; and Maglieri, Domenic J.: A Summary of Results on Sonic Boom Pressure-Signature Variations Associated With Atmospheric Conditions. NASA TN D-4588, 1968.

15. Morris, Odell A.; Lamb, Milton; and Carlson, Harry W.: Sonic Boom Characteristics in the Extreme Near Field of a Complex Airplane Model at Mach Numbers of 1.5, 1.8, and 2.5. NASA TN D-5755, 1970.

16. Maglieri, Domenic J.: Sonic Boom Flight Research - Some Effects of Airplane Operations and the Atmosphere on Sonic Boom Signatures. NASA SP-147, 1967, pp 25-48.

17. Kane, Edward J.; and Palmer, Thomas Y.: Meteorological Aspects of the Sonic Boom. SRDS Report No. RD64-160 (AD 610 462), FAA, 1964.

18. Bauer, A. B.; and Bagley, C. J.: Sonic Boom Modeling Investigation of Topographical and Atmospheric Effects. Report No. FAA-NO-70-10, 1970.

19. Callaghan, J. G.: A Feasibility Investigation Concerning the Simulation of Sonic Boom Ballistic Models. NASA CR-603, 1961.

20. Reed, Jack W.: Sonic Boom Measurements from Accelerating Supersonic Tracked Sleds. NASA CR-132388, 1974.

21, Mack, Robert J.; and Darden, Christine M.: Wind-Tunnel Investigation of the Validity of a Sonic-Boom-Minimization Concept. NASA TP-1421, 1979.

22. Randall, D. G.: Methods for Estimating Distributions and Intensities of Sonic Bangs. R&M no. 3113, British A.R.C., 1959.

23. Teledyne Ryan Supersonic Firebee II. Briefing brochure, June 1970.

24. Aircraft Turbojet Engine Model Specification YJ-69-T-406, Teledyne CAE Model 356-34A. Specification No. 2312-A, November 1, 1968, Rev. A, July 15, 1970.

25. Keller, James D.; and South, Jerry C., Jr.: RAXBOD: A Fortran Program for Inviscid Transonic Flow Over Axisymmetric Bodies. NASA TM X-72331, 1976.

26. Begg, H. A., and Hahn, T.: Test Data Report - Inlet Test, Engineering Report No. 16628-14, January 31, 1967.

27. Aerodynamic Investigation Program Report - High Speed Force Test Data from Cornell Aeronautical Laboratory, Teledyne Ryan Report No. 1628-11, Vols. I through III, May 2, 1966.

28. Stansbery, E. G.; and Stanley, J. F.: Descent Sonic Boom Measurements for STS-26 Including a Mach 23 Measurement. NASA JSC-23579, 1989.

29. Lee, Robert A., et al: Boom Event Analyzer Recorder (BEAR): System Description. USAF AAMRL-TR-89-035, 1989.

30. Lee, Robert A.: Air Force Boom Event Analyzer Records (BEAR): Comparison With NASA Boom Measurement System. USAF AAMRL-TR-88-039, 1988.

Table 1.- Overflight Measurements Of Modified Sonic Boom Signatures

Main Factors of the Test Program

Selection of Test Vehicle

- Size
- Mach number
- Altitude / duration
- User / frequency / location
- Reusable / expendable
- Modifiable

Analytical Tasks

- Boom characteristics of standard / modified vehicle
- Selection of modified signature
- Prediction of wind-tunnel and flight situations
- Assess impact of modifications on vehicle performance

Wind Tunnel Measurements

- Boom signatures of standard and modified vehicles
- Basic aero characteristics of modified configuration

Flight Support

- Tracking
- Suitability of test range
- Type weather situation
- Ambient noise / activities
- Microphone number and array
- Communications / time correlation

Table 2.- Estimates of changes in wave drag for modified Firebee vehicles operating at Mach 1.3 at 8,700 feet altitude and Mach 1.5 at 20,000 feet altitude

Configuration	Signature	Drag* (percent change)	
		M = 1.3 @ 8700 ft.	M = 1.5 @ 20000 ft.
Basic	N-Wave	0.0	0.0
Modification 1	Flatop P.P.	-16.6	-13.7
Modification 2	Ramp P.P.	-14.2	-11.7

* Drag in percent change from basic vehicle

Drag due to friction and lift are assumed unchanged

Table 3. - Listing of points of contact who provided information/guidance regarding candidate vehicles.

Name	Affiliation
Hal Murrow	NASA/Langley Research Center (retired)
Jim Jensen	U.S. Navy - Pacific Missile Range Point Mugu, CA (retired)
Bill Dean	U.S. Navy - Pacific Missile Range Point Mugu, CA
Captain Merickel	U.S. Navy - Pacific Missile Range Point Mugu, CA
Captain Lewis	Navy Pentagon - Aerial Target Program Manager
Art Hamlet	Navy Pentagon - Procurement
Colonel Mathews	USAF 475th Weapons Evaluation Group, Tyndall AFB, FL
Major McFall	USAF GQ TAC, Langley AFB, VA
Lt. Col. Cowan	USAF 6513th Test Squadron, Hill AFB, UT
Major Loskill	USAF Pentagon, Systems Command
Wayne Sparks	US Army Redstone Arsenal, Huntsville, AL
Walt Hamilton	Teledyne Ryan
Lou Duesterberg	Bendix
Shirley Gray-Lewis	Martin Marietta, FL

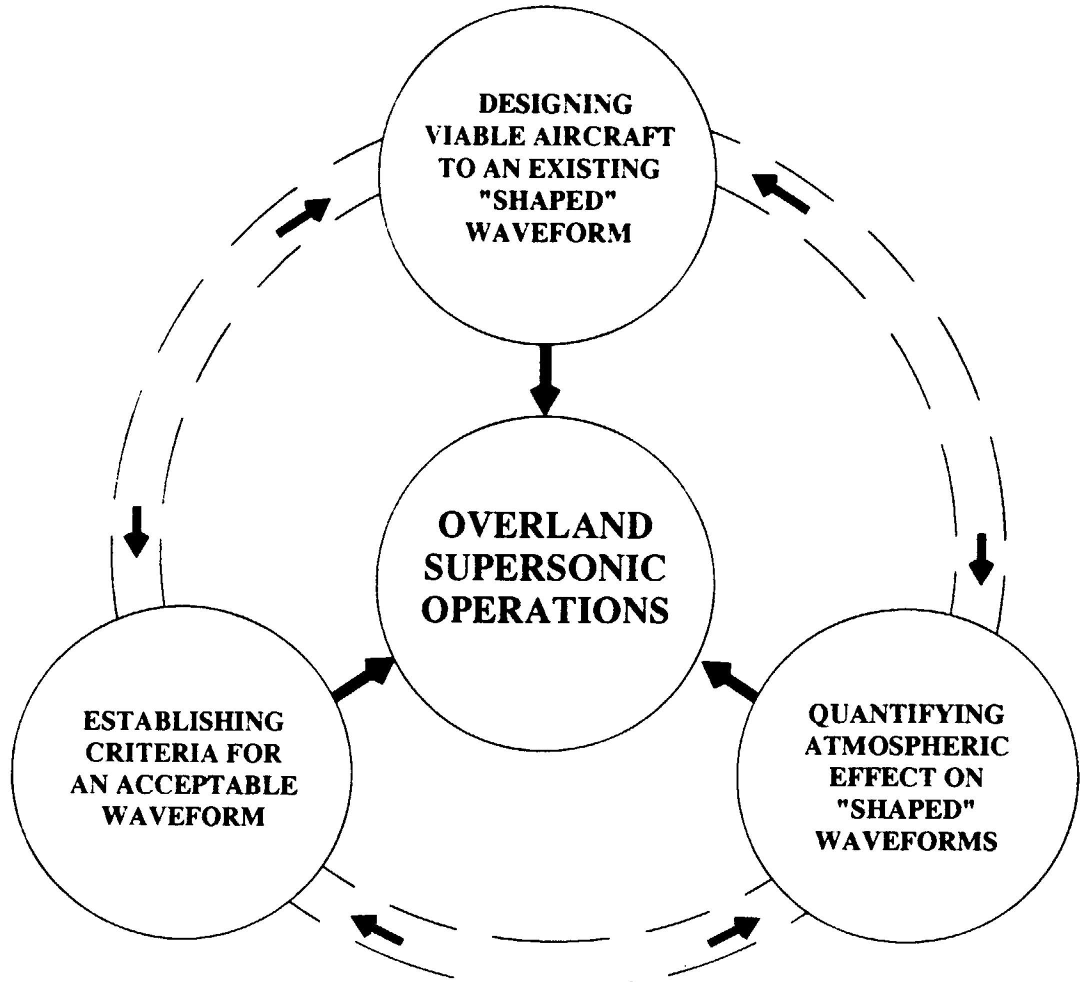


Figure 1.- Three major thrusts required for solution to HSCT overland sonic boom.

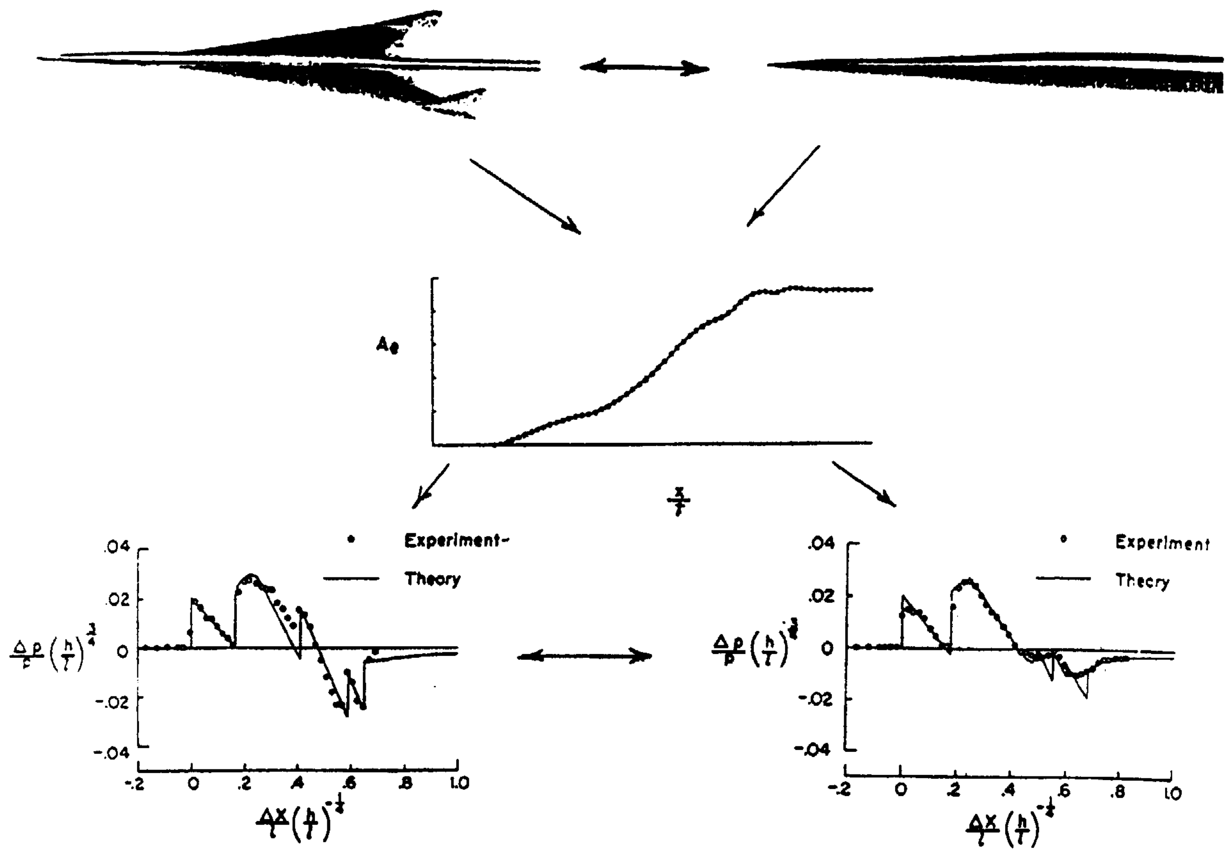


Figure 2.- Illustration of the equivalent body concept for conditions of $M = 1.41$, $C_L = 0.1$, $h/l = 10$.

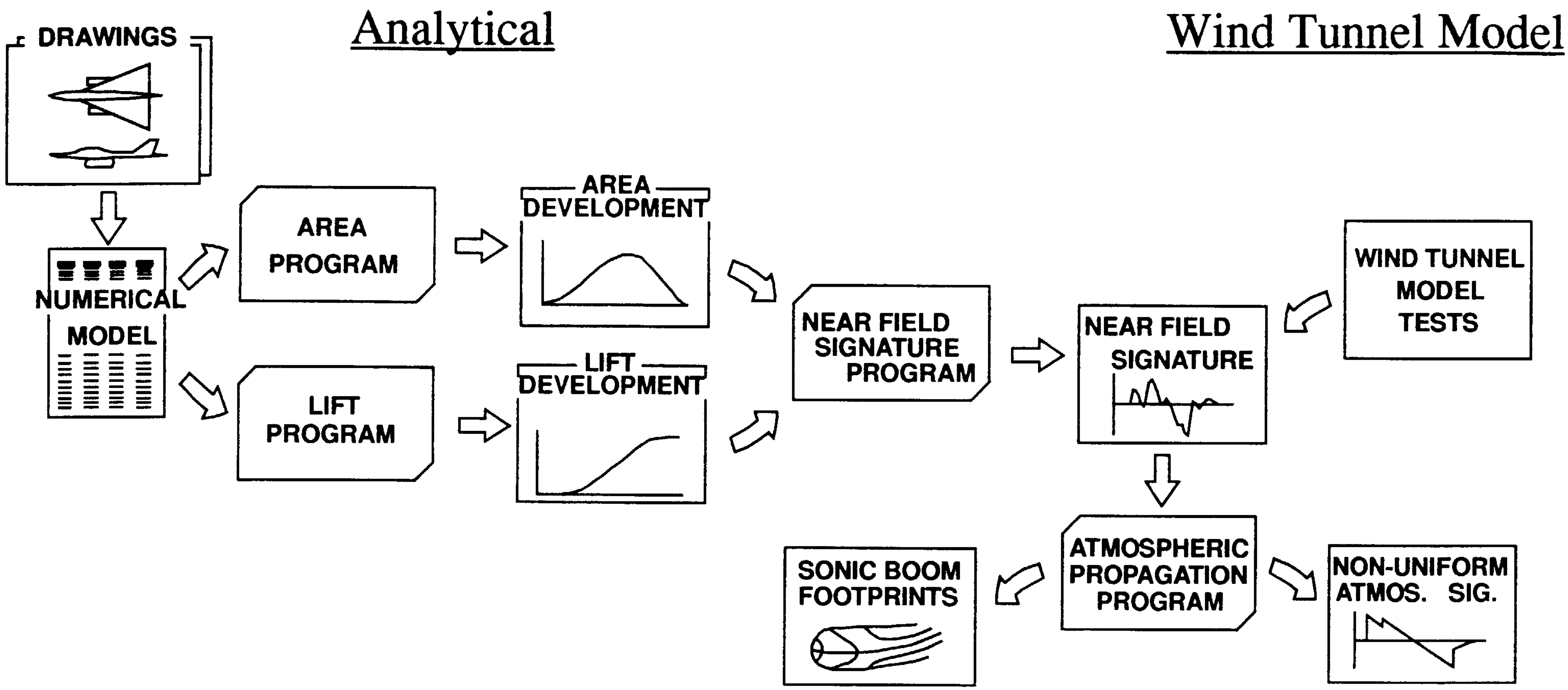


Figure 3.- Ingredients in sonic boom prediction program.

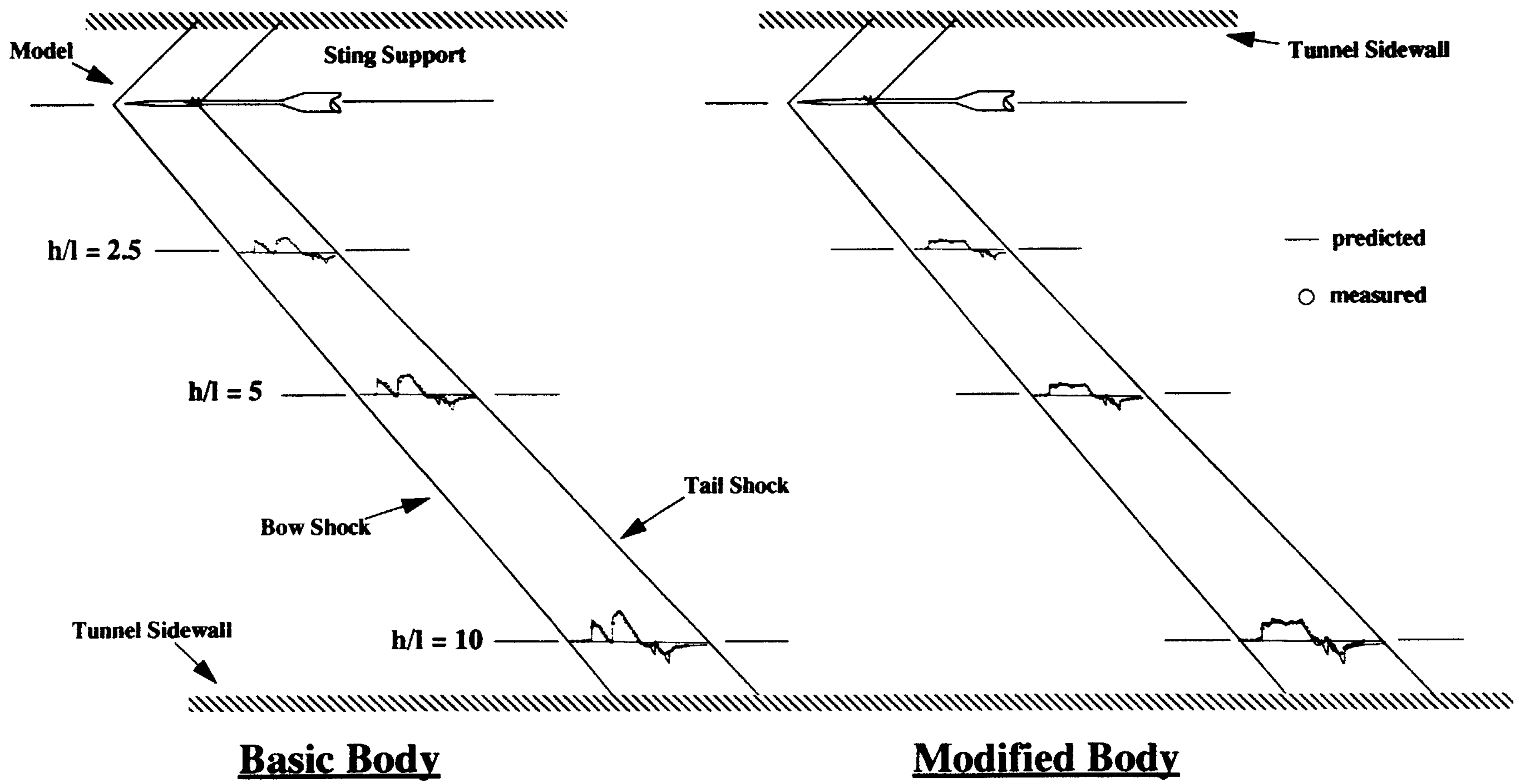


Figure 4.- Measured sonic boom signatures on a basic and modified equivalent body of revolution in the wind tunnel. $M = 1.41, C_L = 0.1$

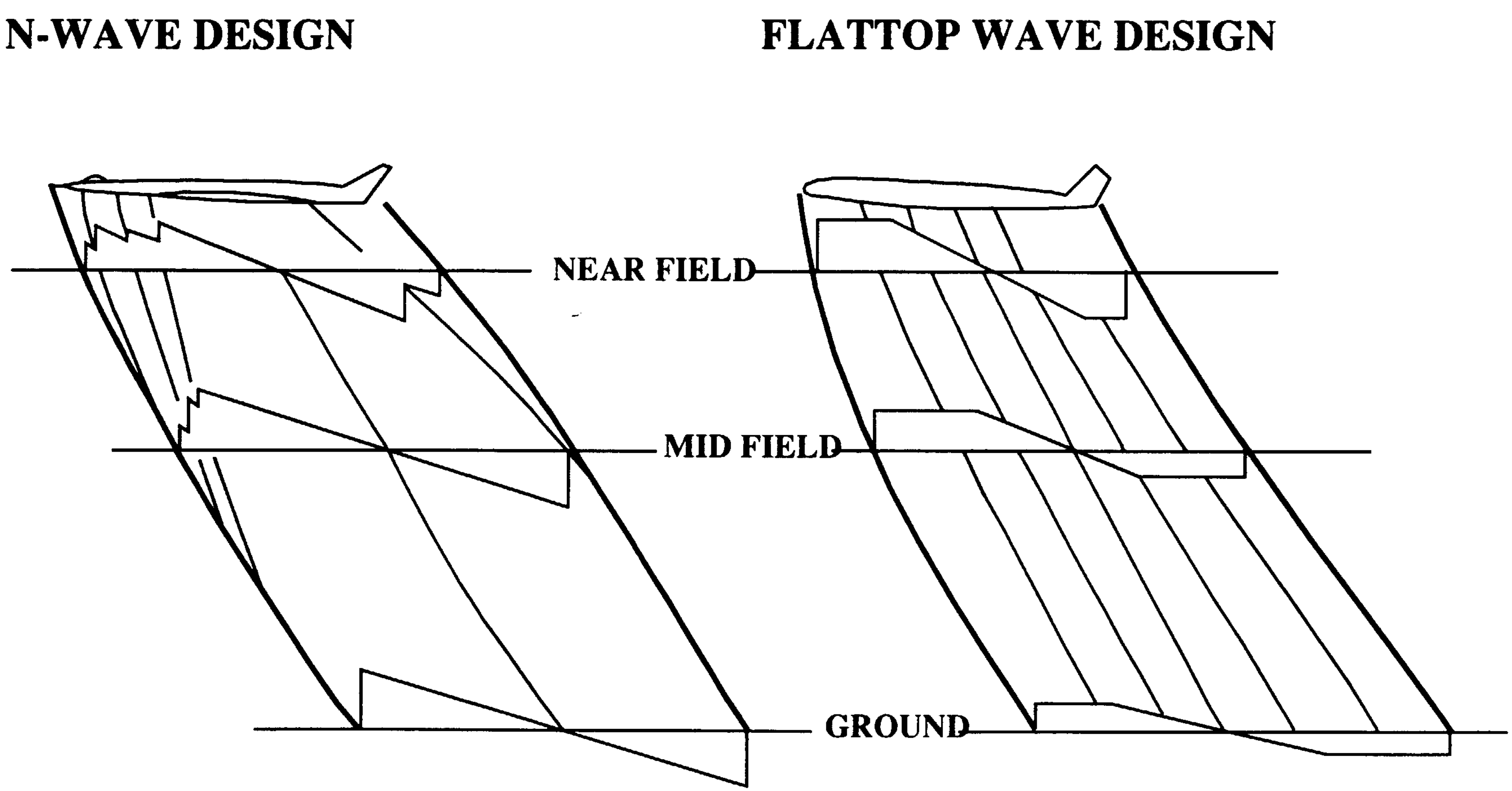


Figure 5.- The low boom - high drag paradox.

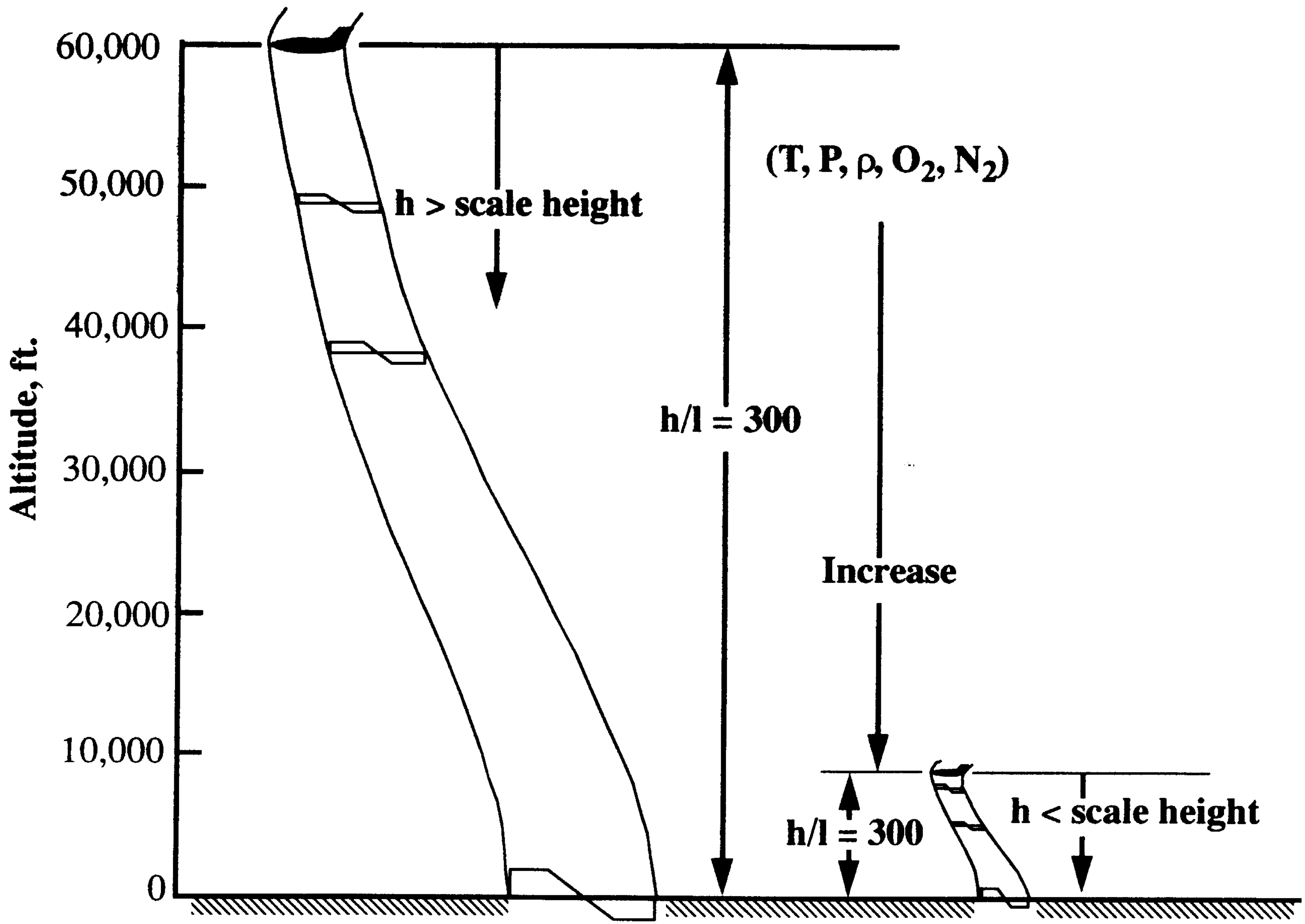


Figure 6.- Comparison of real and scaled simulation.

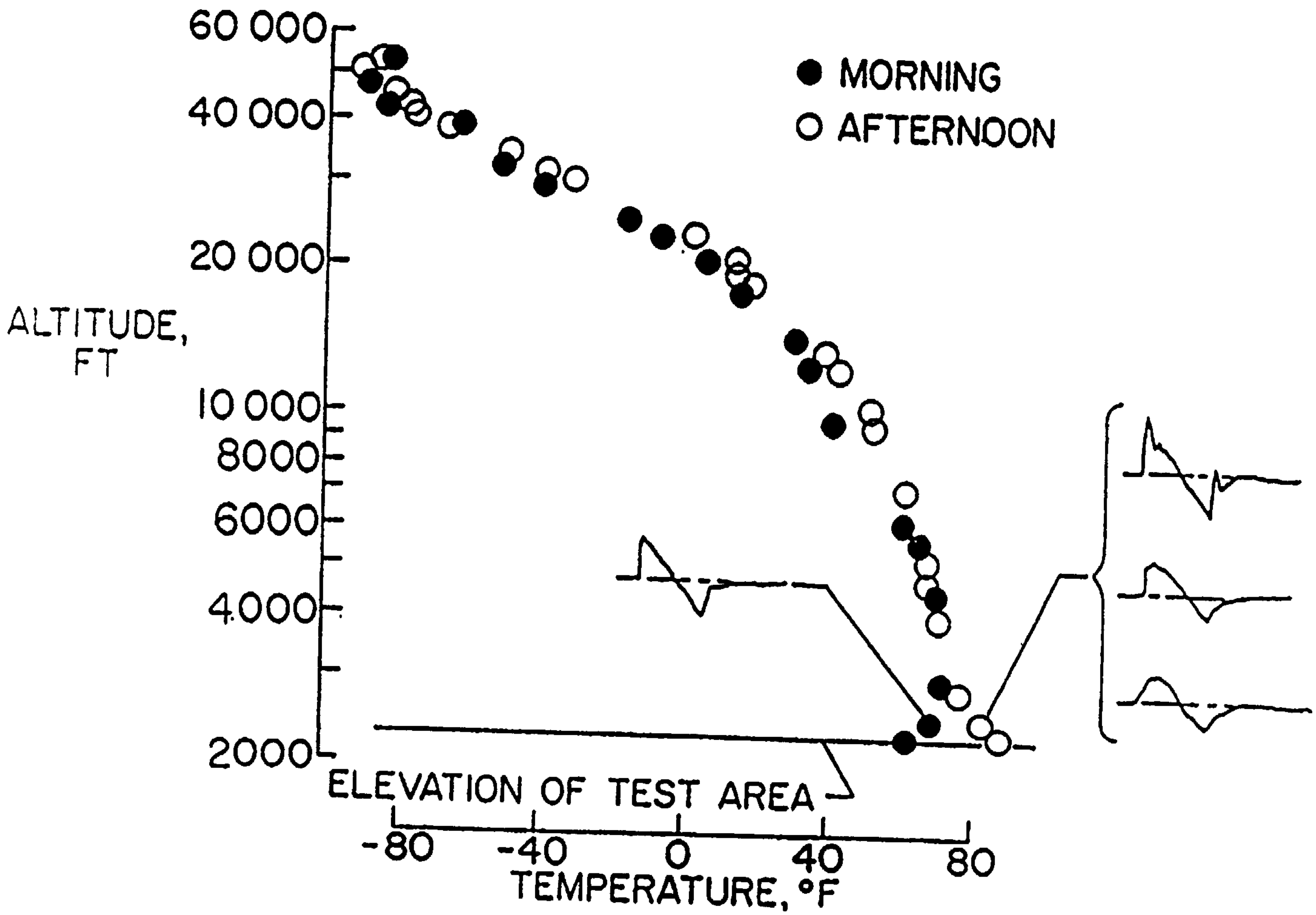


Figure 7.- Effect of temperature profile on measured sonic boom pressure signature.

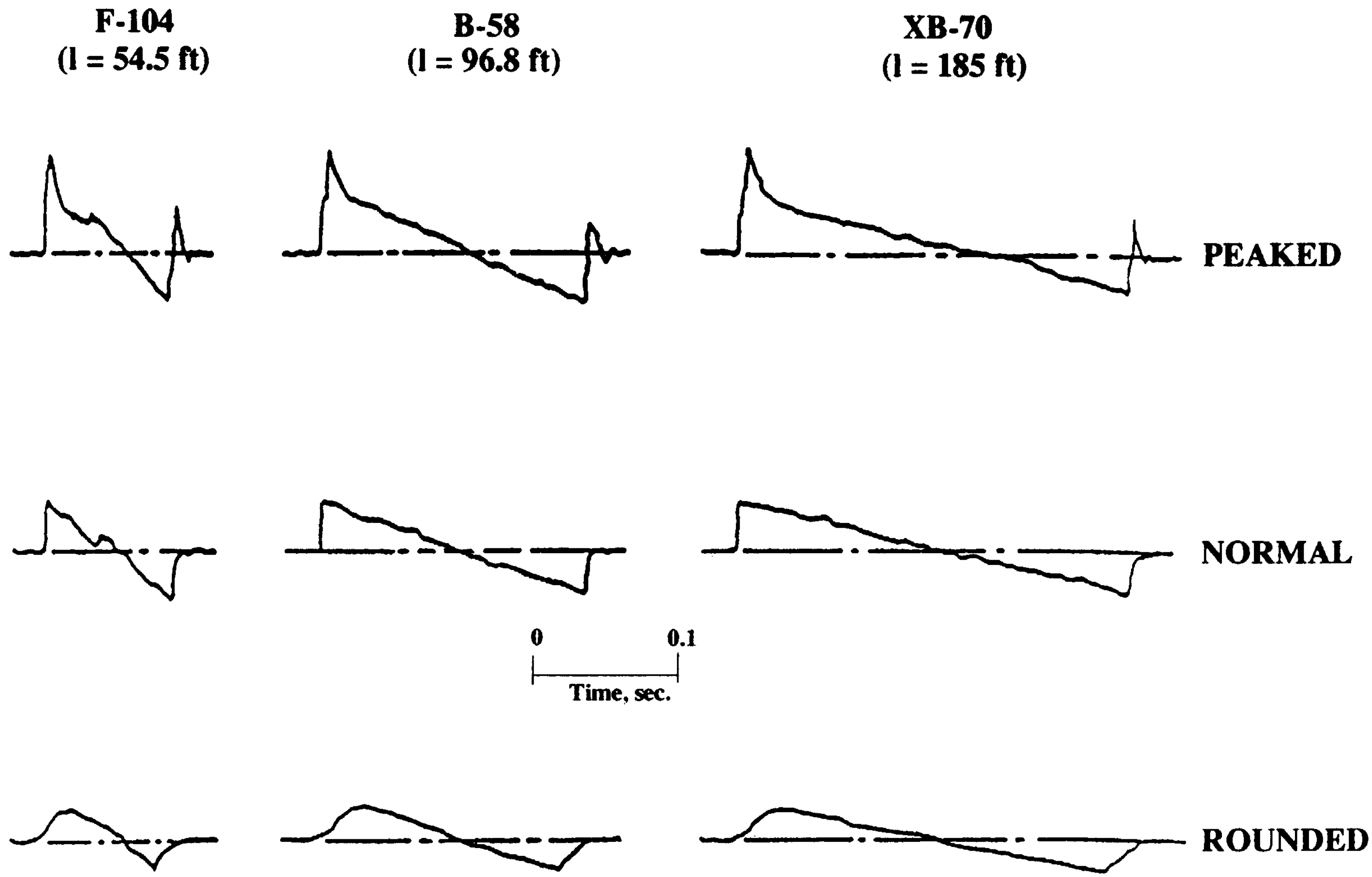


Figure 8.- Signature variability for various aircraft.

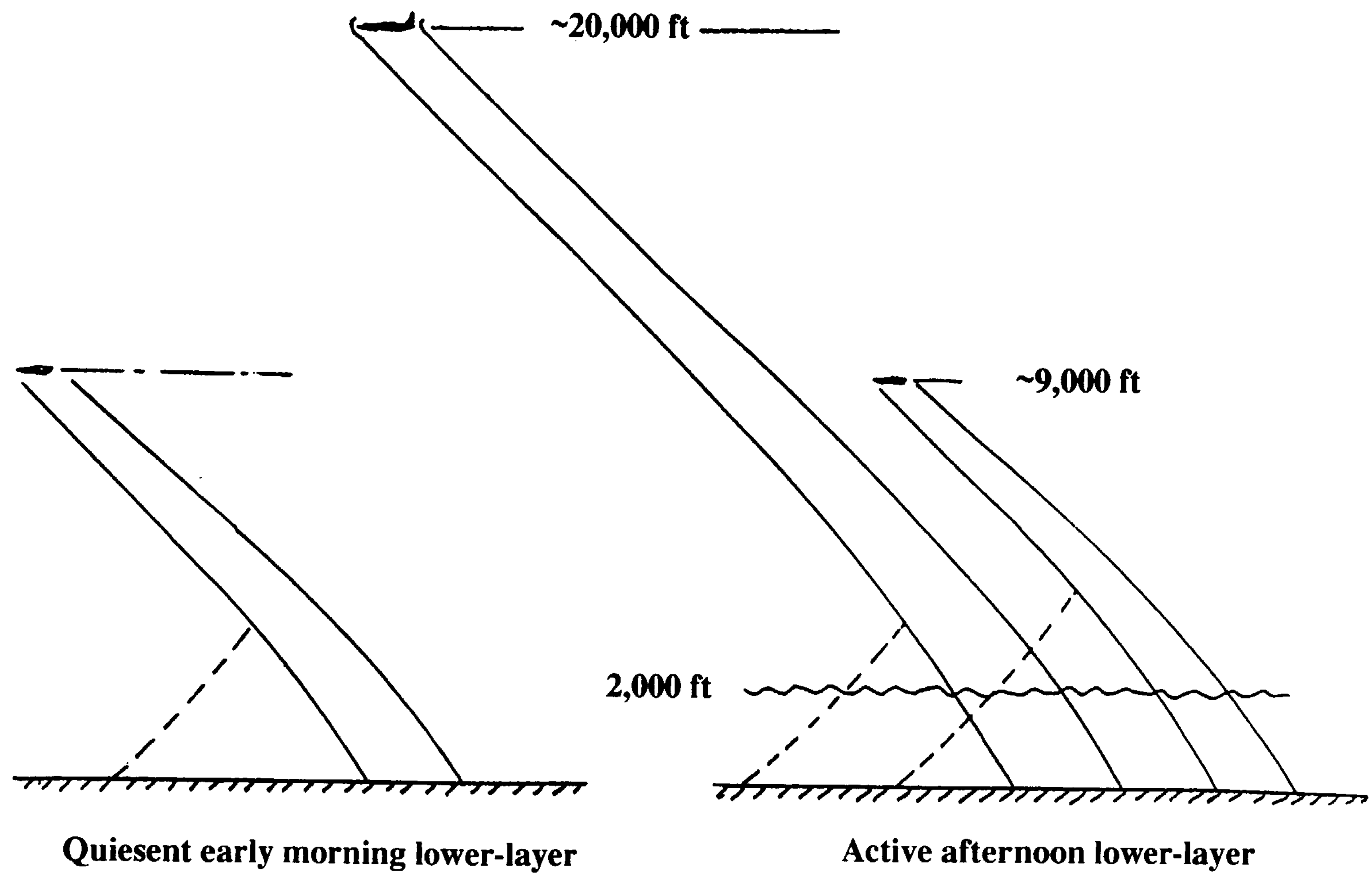


Figure 9.- Schematic of boom ray paths.

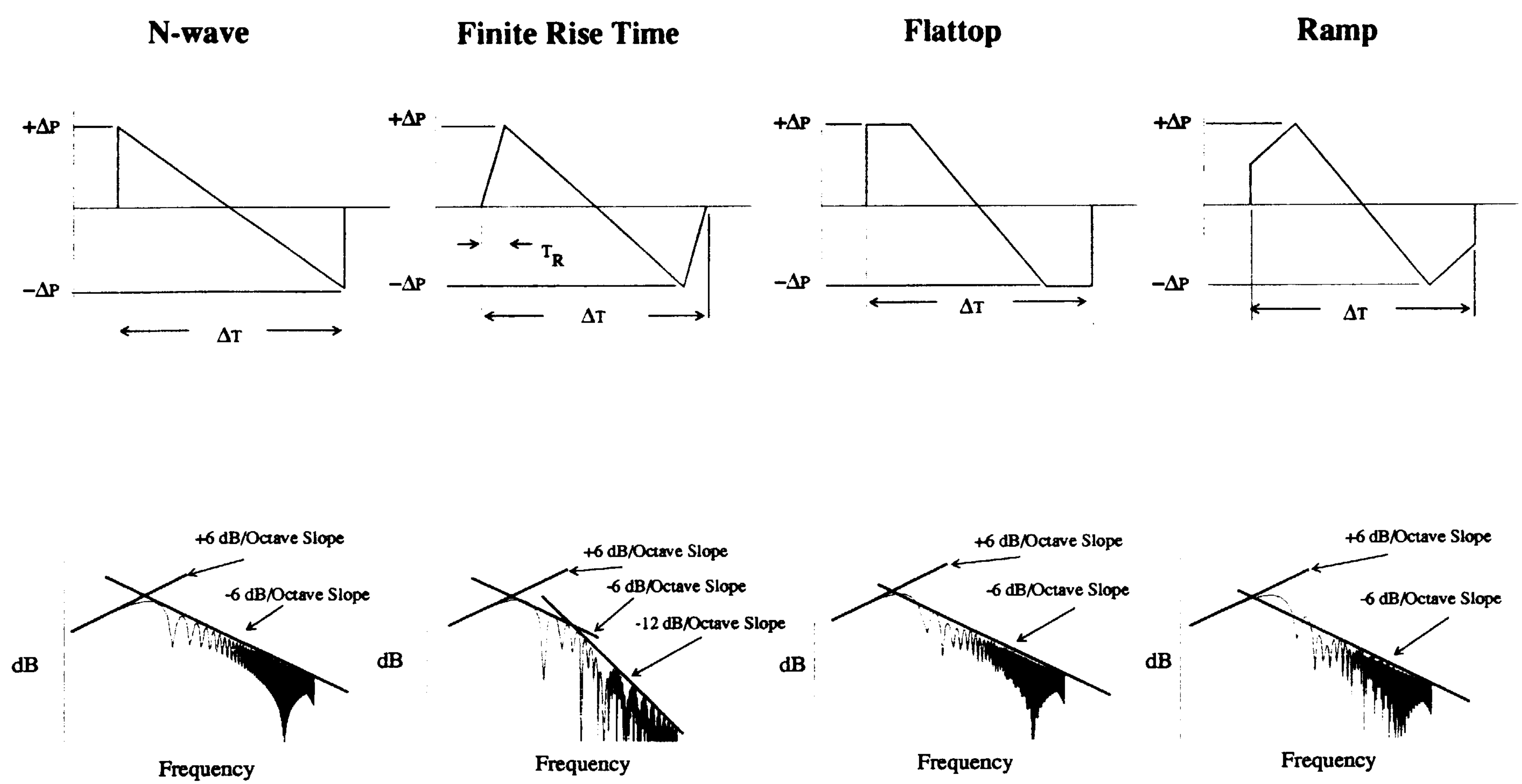


Figure 10.- Sonic boom signatures and noise spectra.

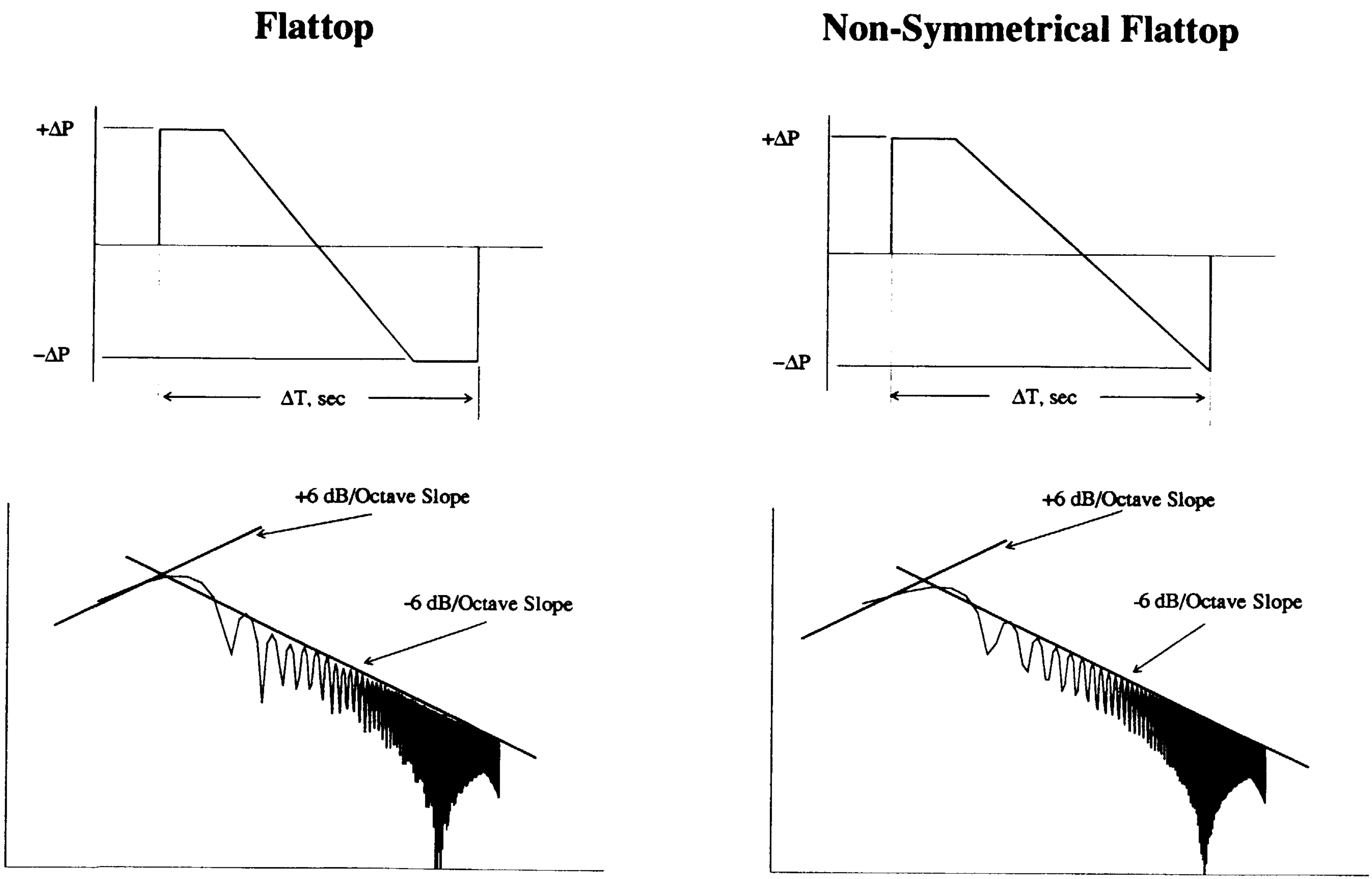


Figure 11.- Spectra of non-symmetrical vs. symmetrical.

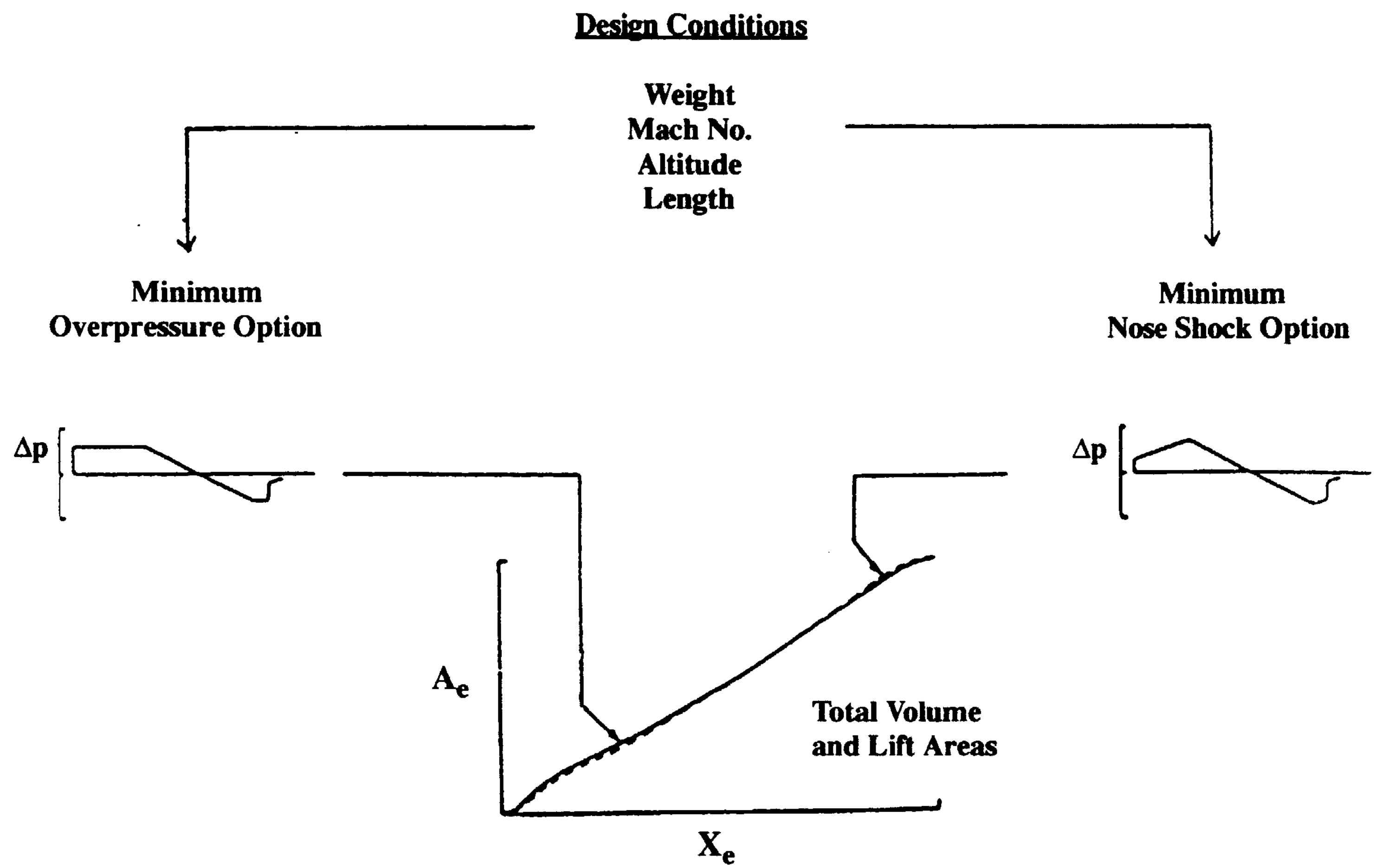


Figure 12.- Schematic of minimization process.

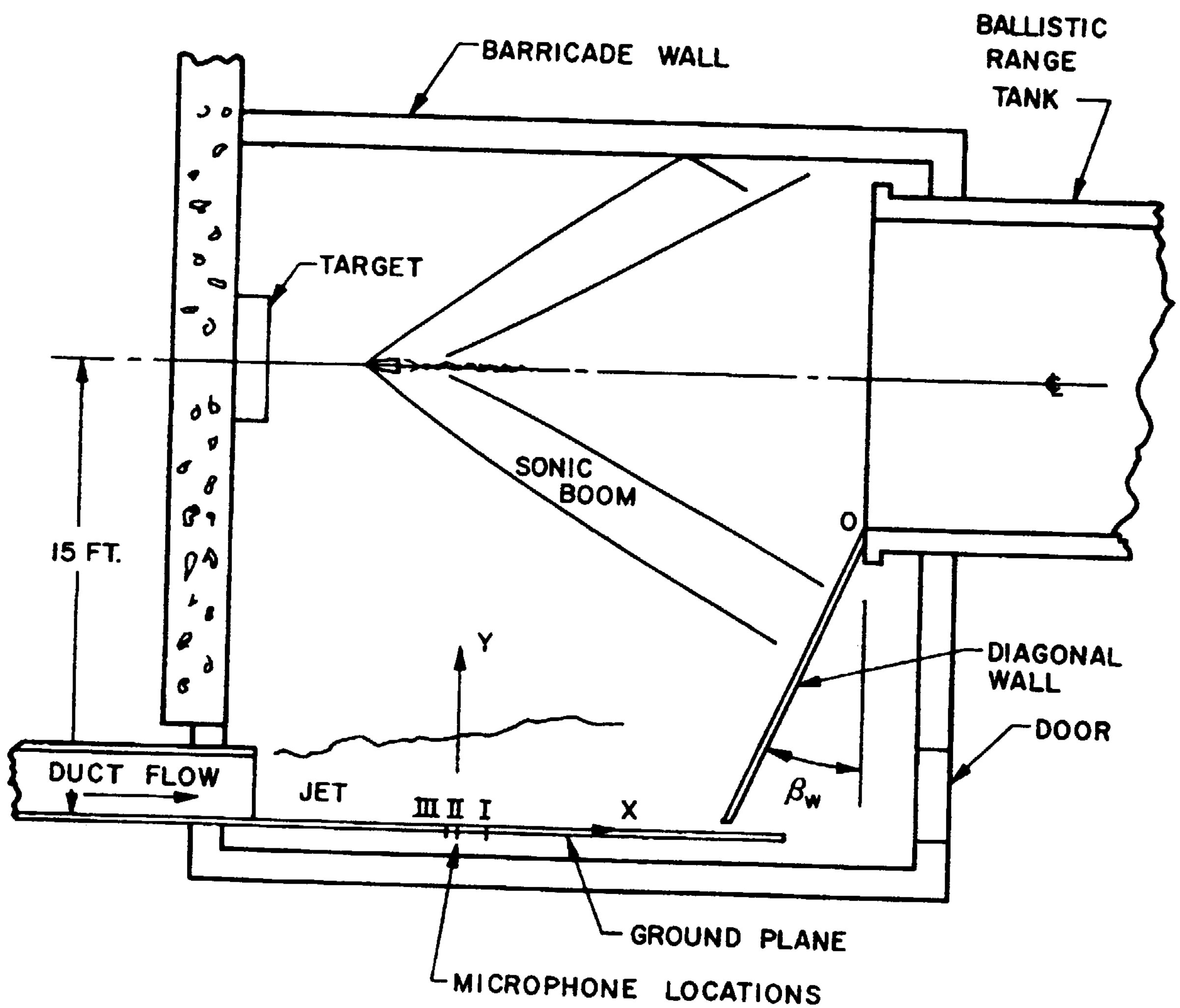


Figure 13.- Schematic of ballistic range test setup.

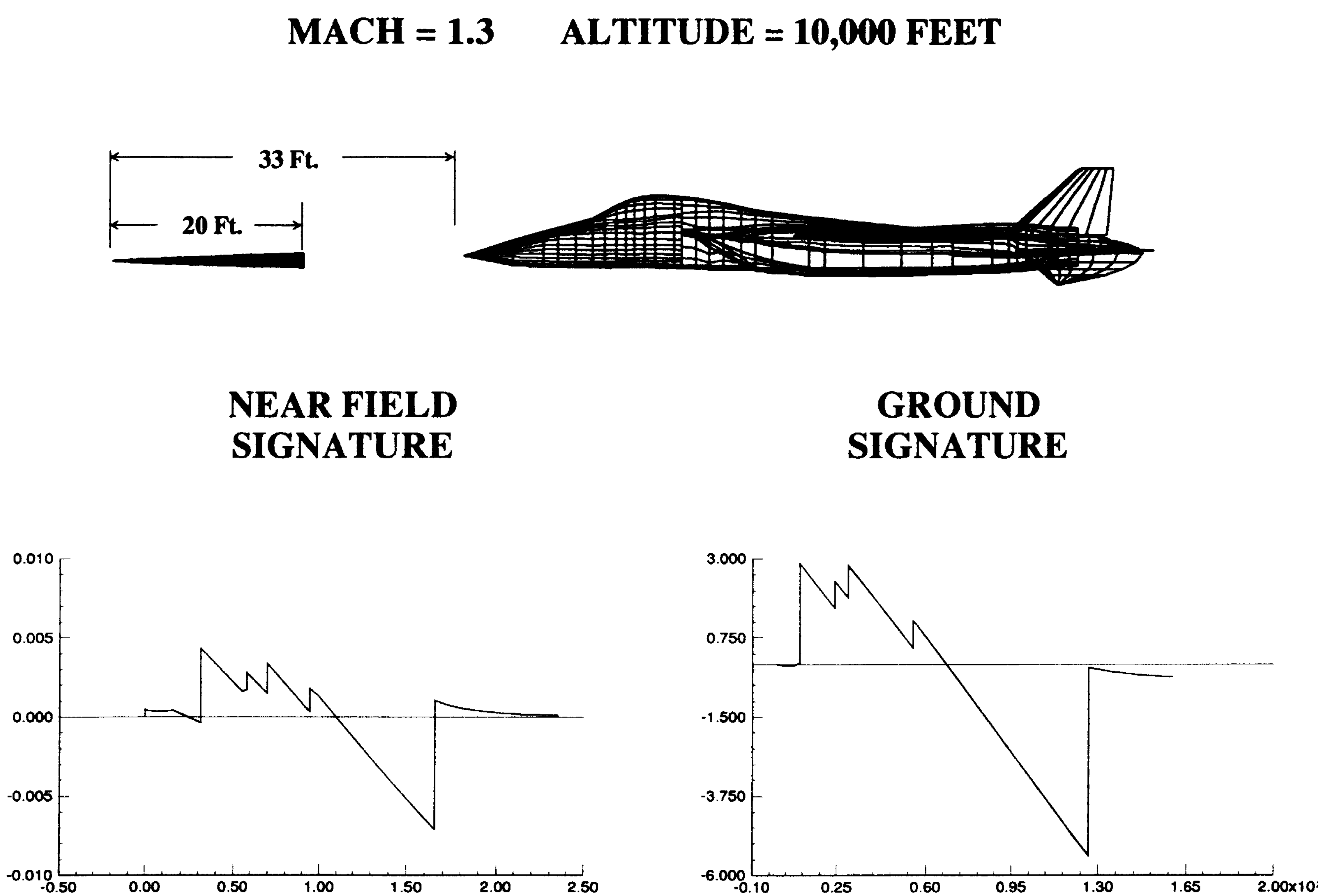


Figure 14.- Aircraft noise probe equivalent body concept.

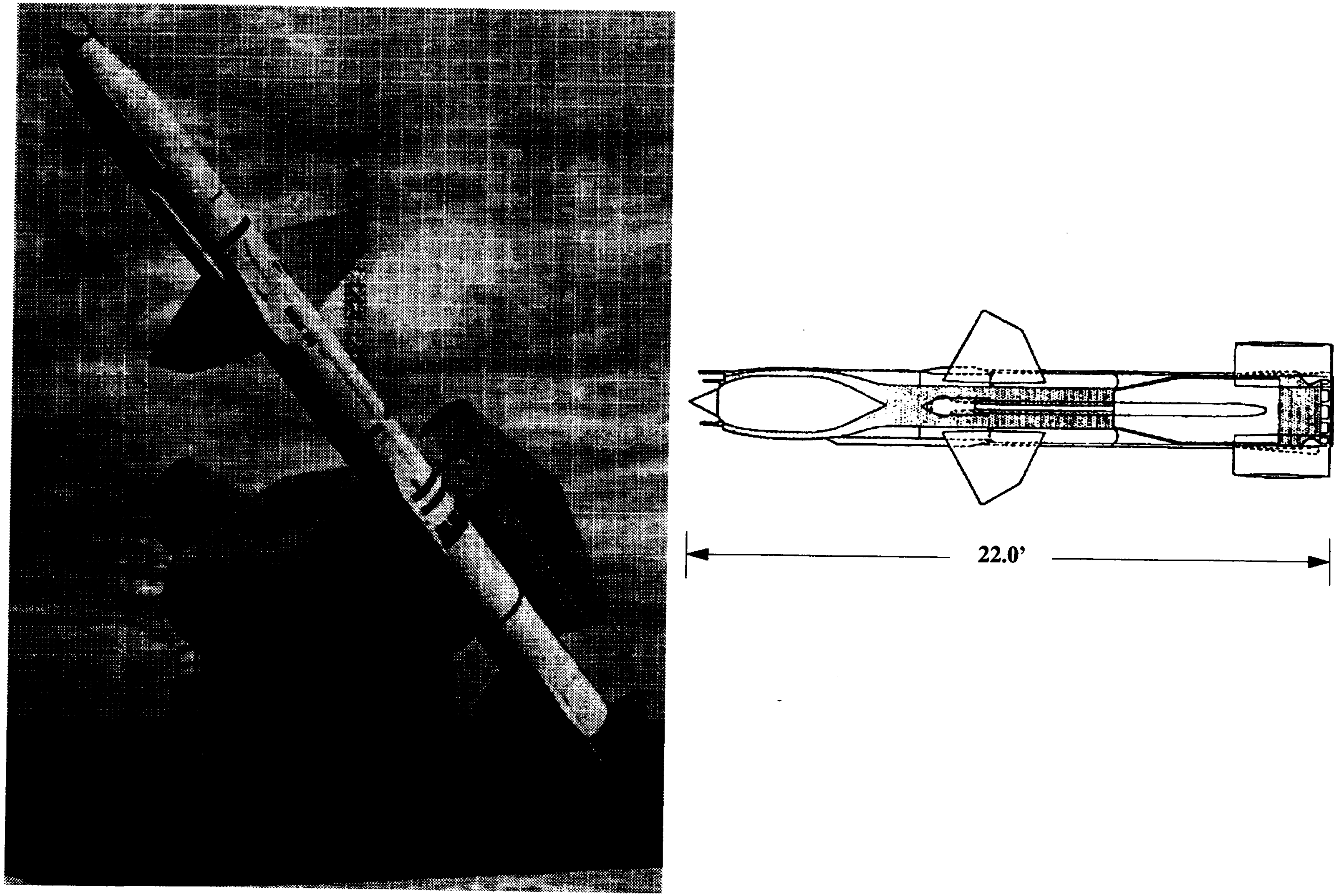
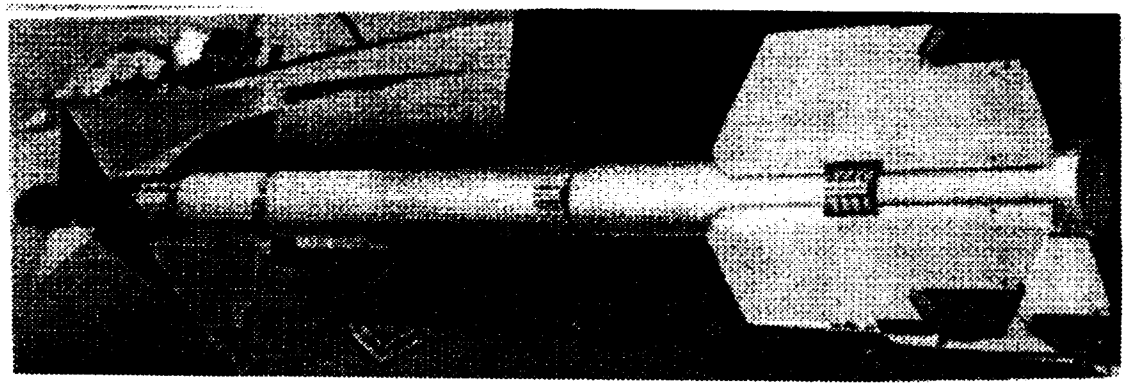


Figure 15.- Photograph and sketch of Bendix MQM-8G “Vandal” ground launched expendable vehicle.



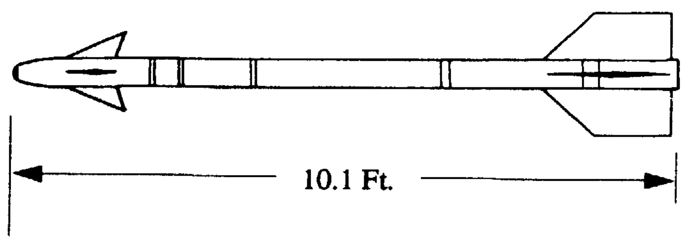


Figure 16.- Photograph and sketch of Sidewinder missile.

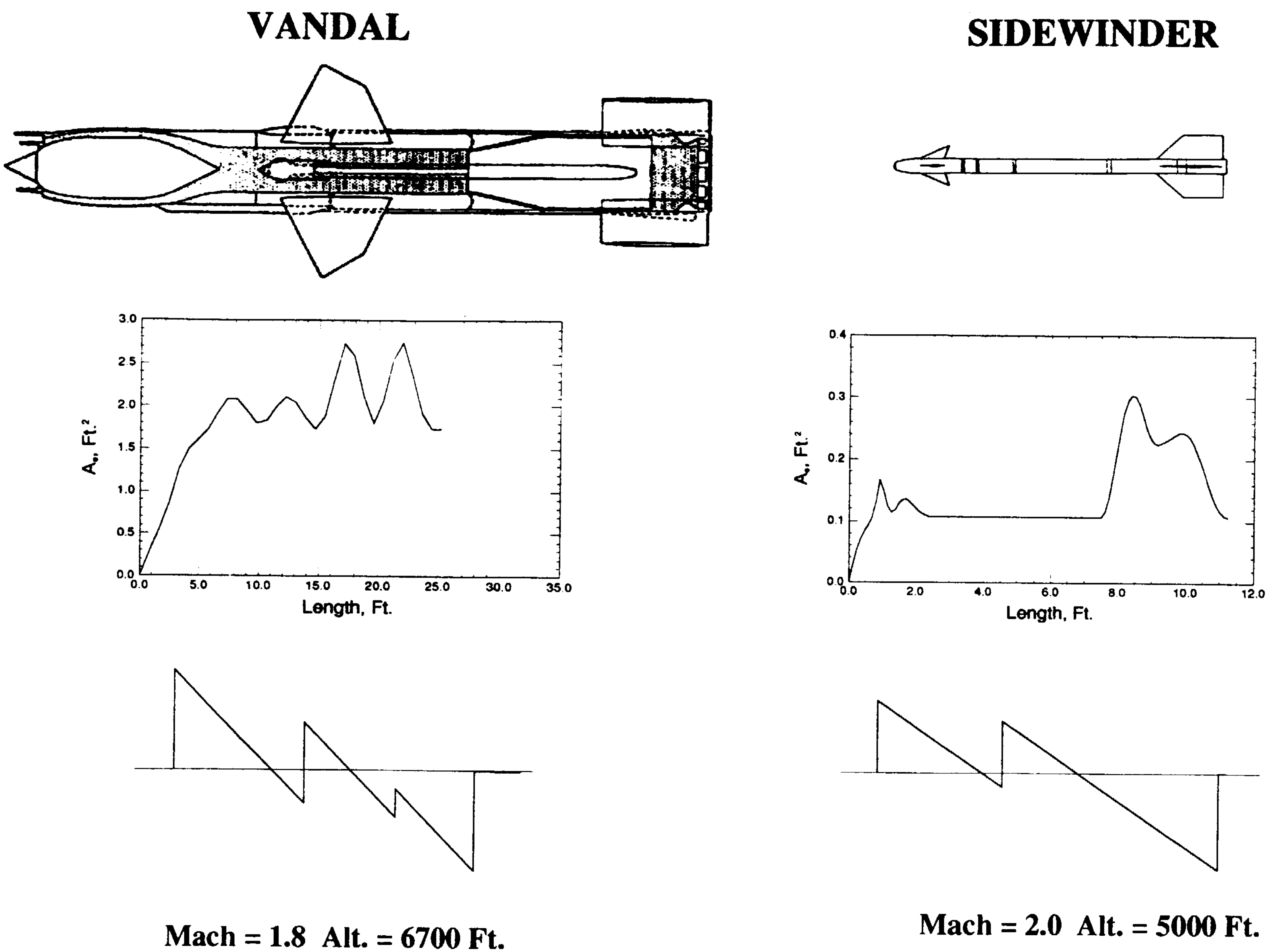


Figure 17.- Area distributions and sonic boom signatures of Vandal and Sidewinder vehicles.

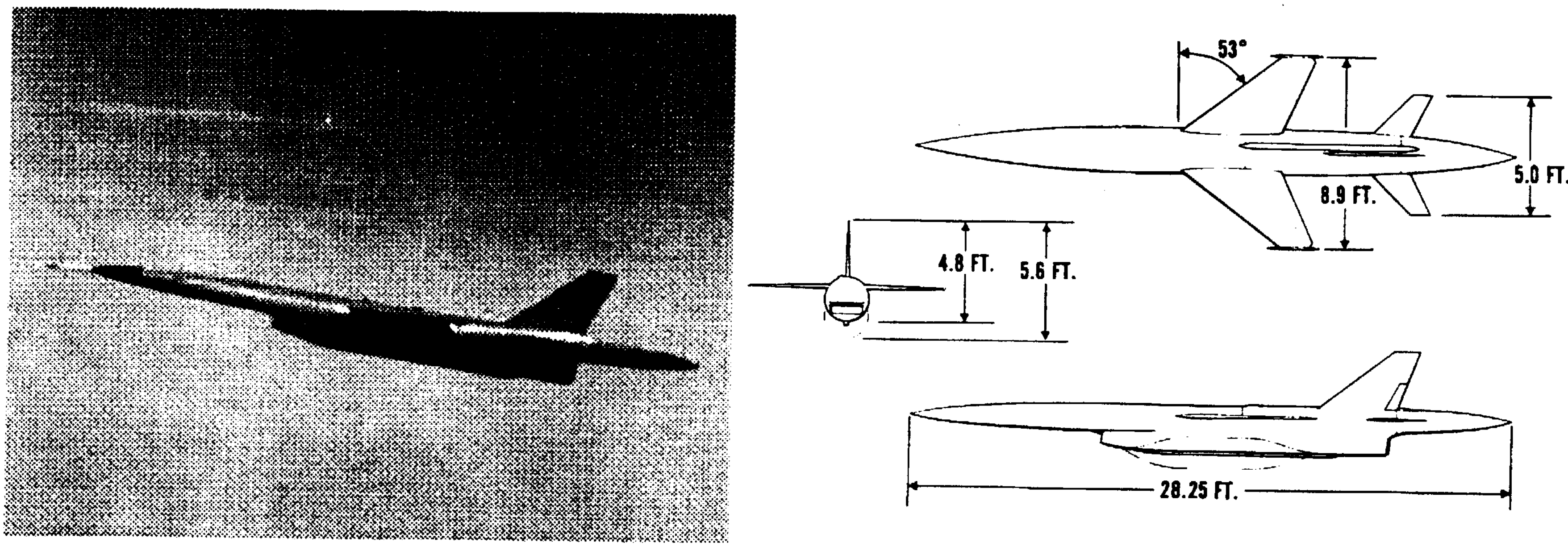


Figure 18.- Photograph and schematic illustration of Teledyne Ryan Firebee BQM-34E air or ground launched recoverable vehicle.

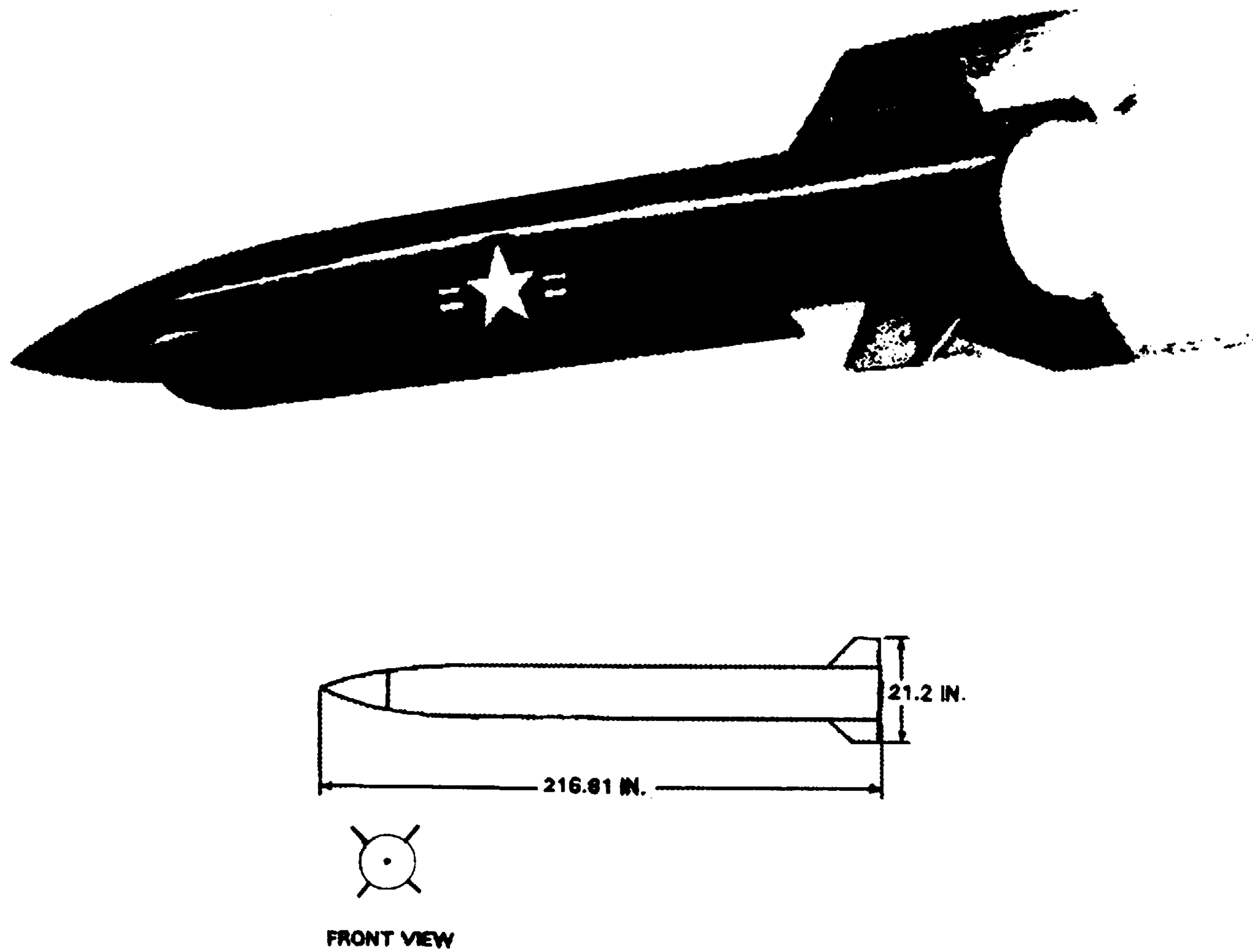


Figure 19.- Photograph and schematic illustration of Martin Marietta SLAT AQM-127A air-launched recoverable vehicle.

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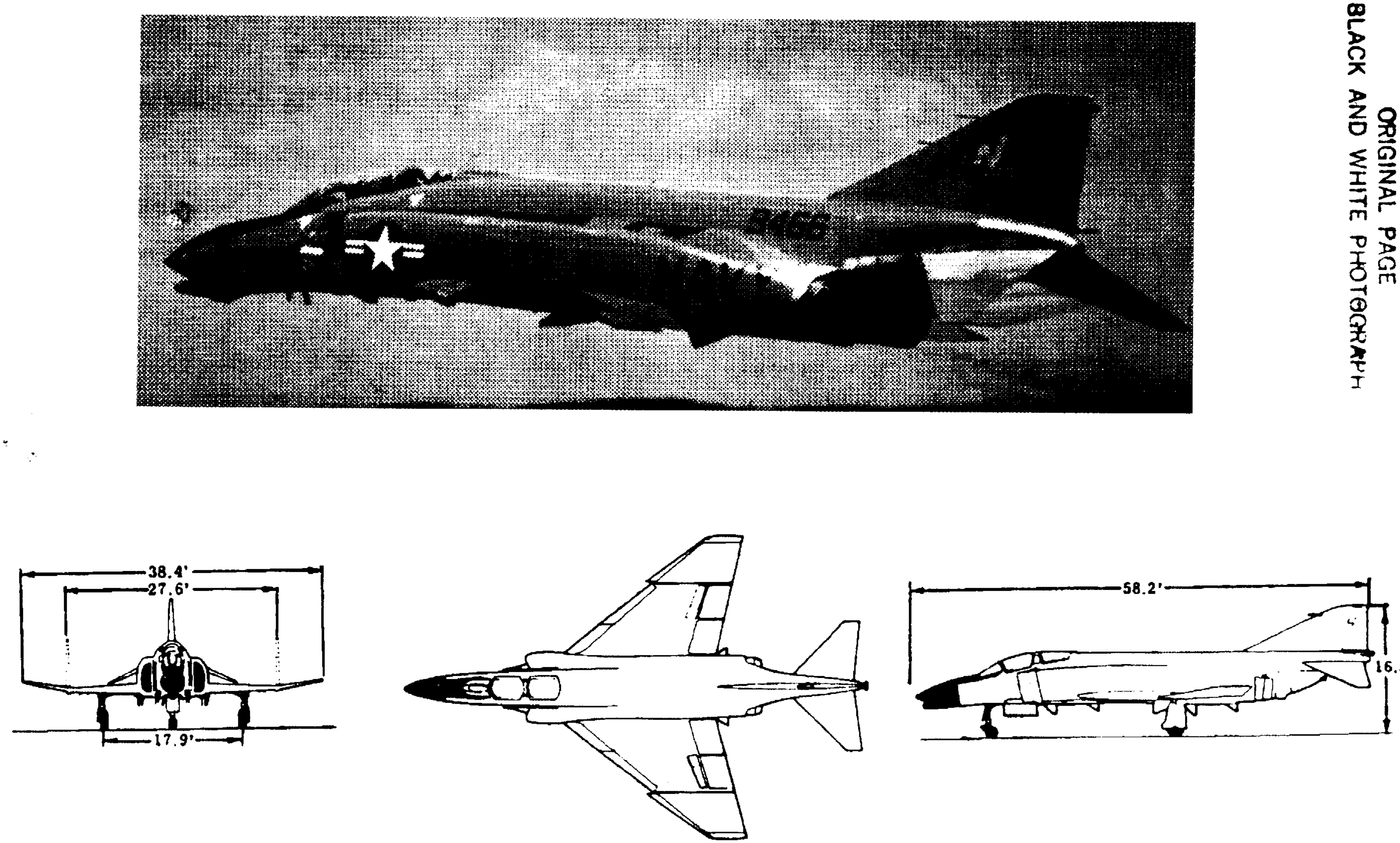


Figure 20.- Photograph and schematic of McDonnell-Douglas QF-4 remotely piloted drone aircraft.

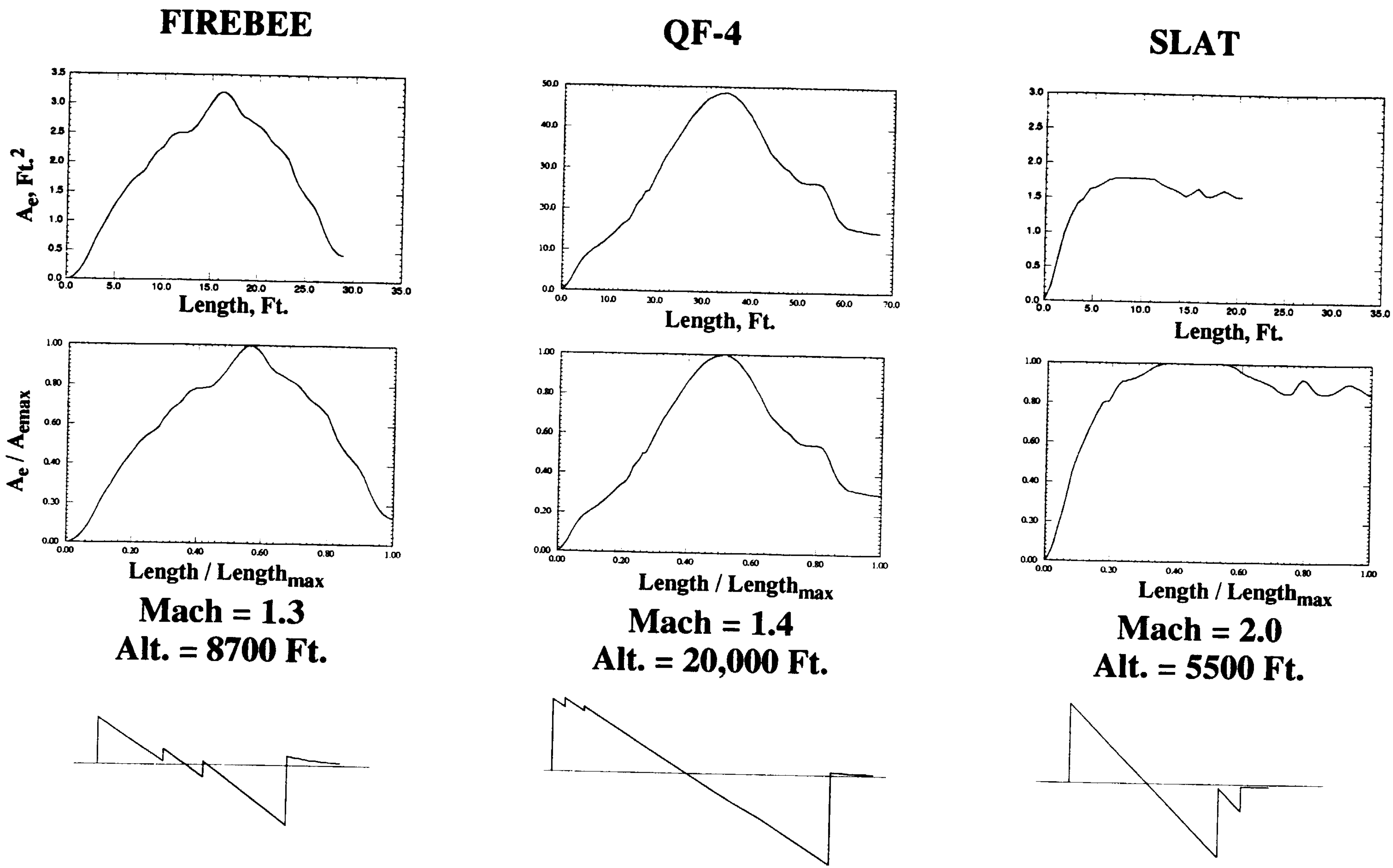


Figure 21.- Area distributions and signatures of basic recoverable vehicles.

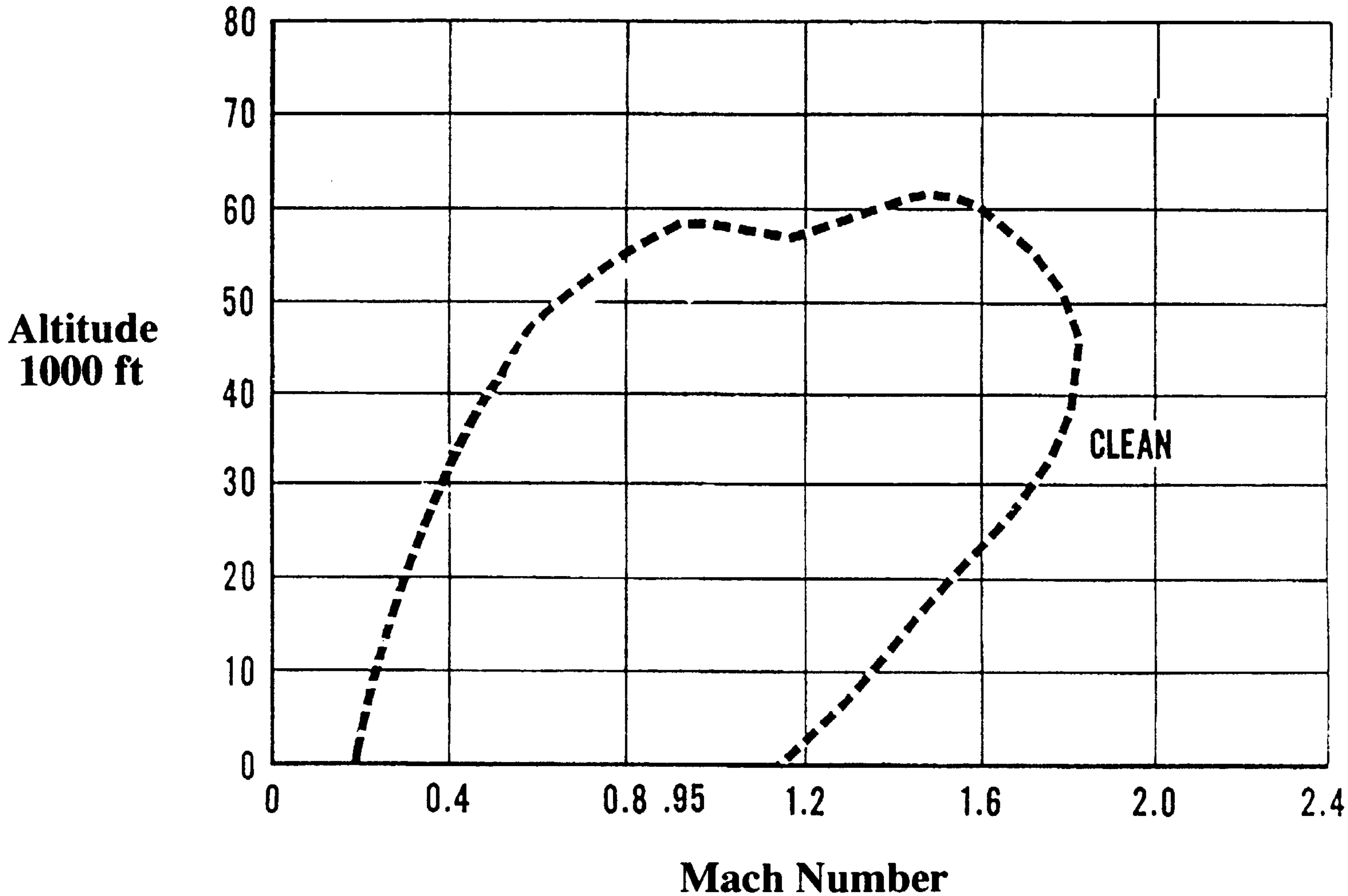


Figure 22.- Speed / altitude envelope of Firebee BQM-34E in clean configuration mode (no belly tank).

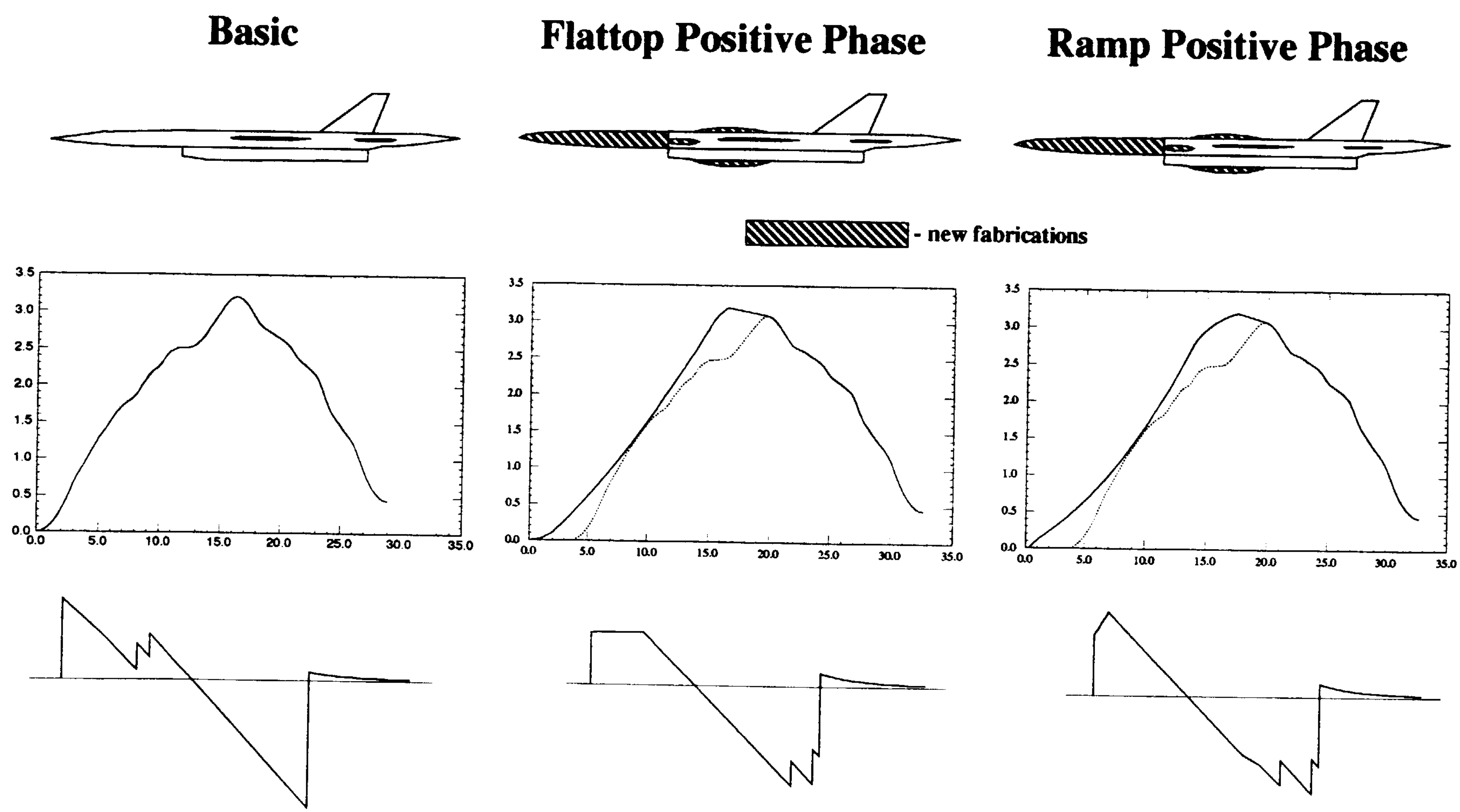


Figure 23.- Area distributions and signature characteristics of basic Firebee configuration and those designed to provide flattop and ramp type positive phase signature at Mach 1.3 and an altitude of 8700 feet.

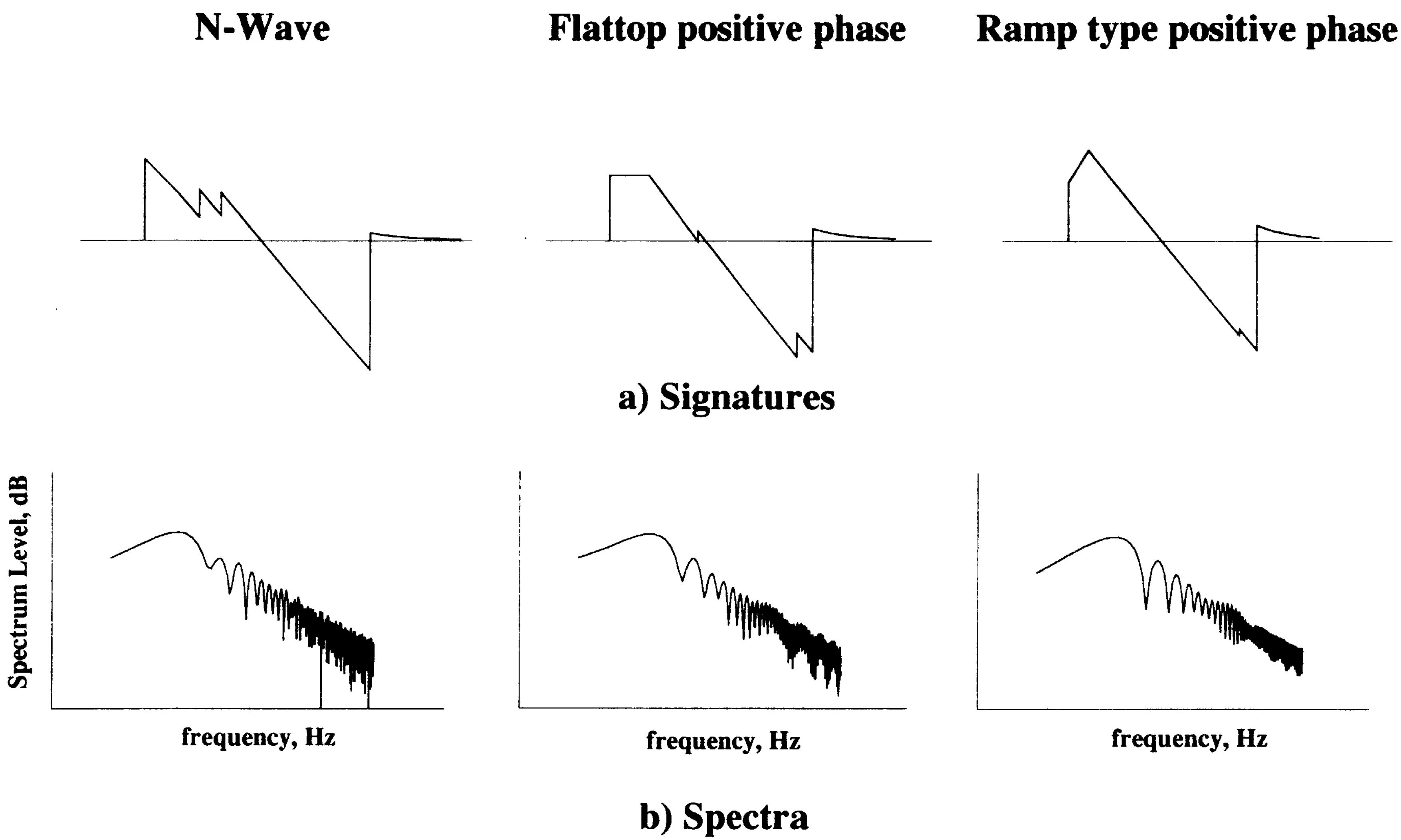


Figure 24.- Spectral characteristics of basic and modified Firebee sonic boom signatures.

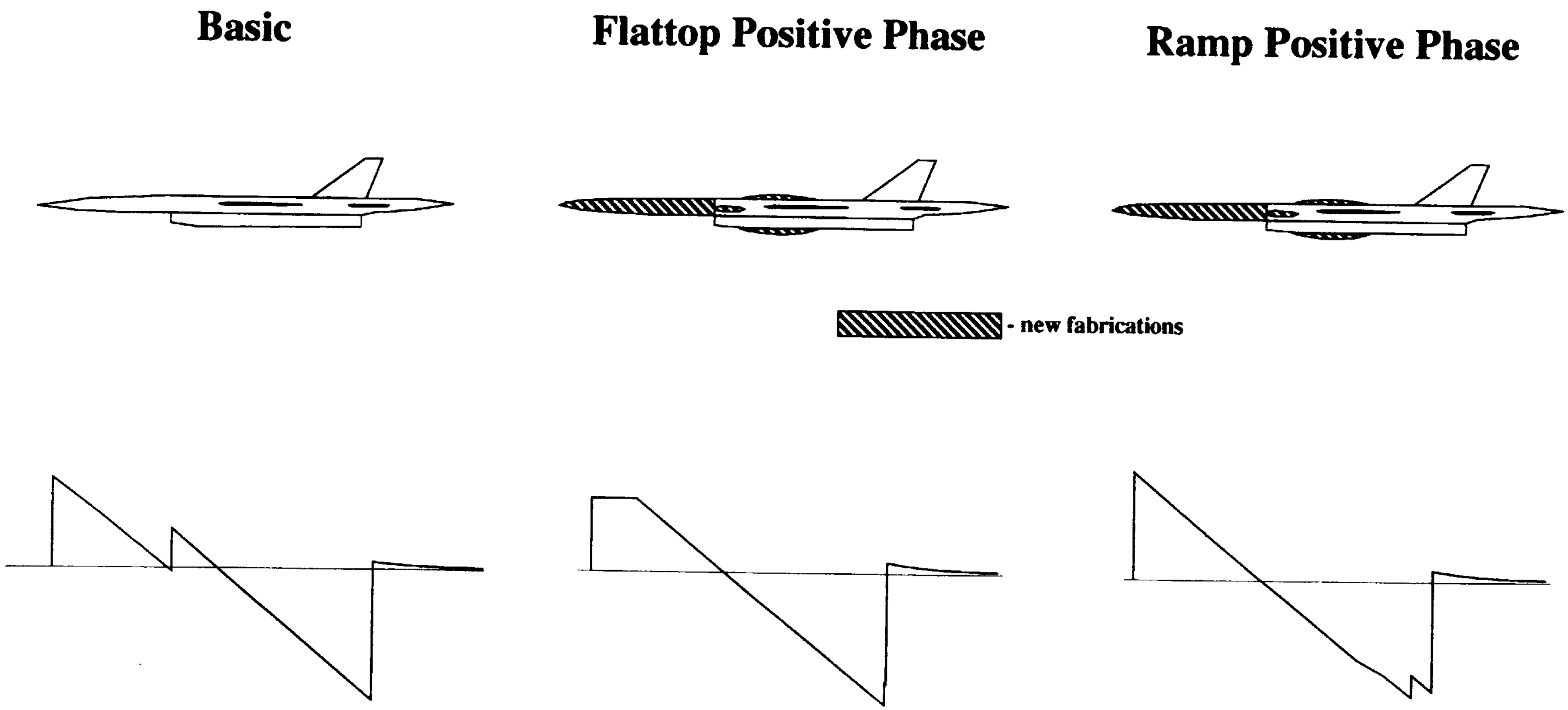


Figure 25.- Signature characteristics of the basic and two modified Firebee configurations when flown at off-design conditions of M=1.5 and at an altitude of 20,000 feet.

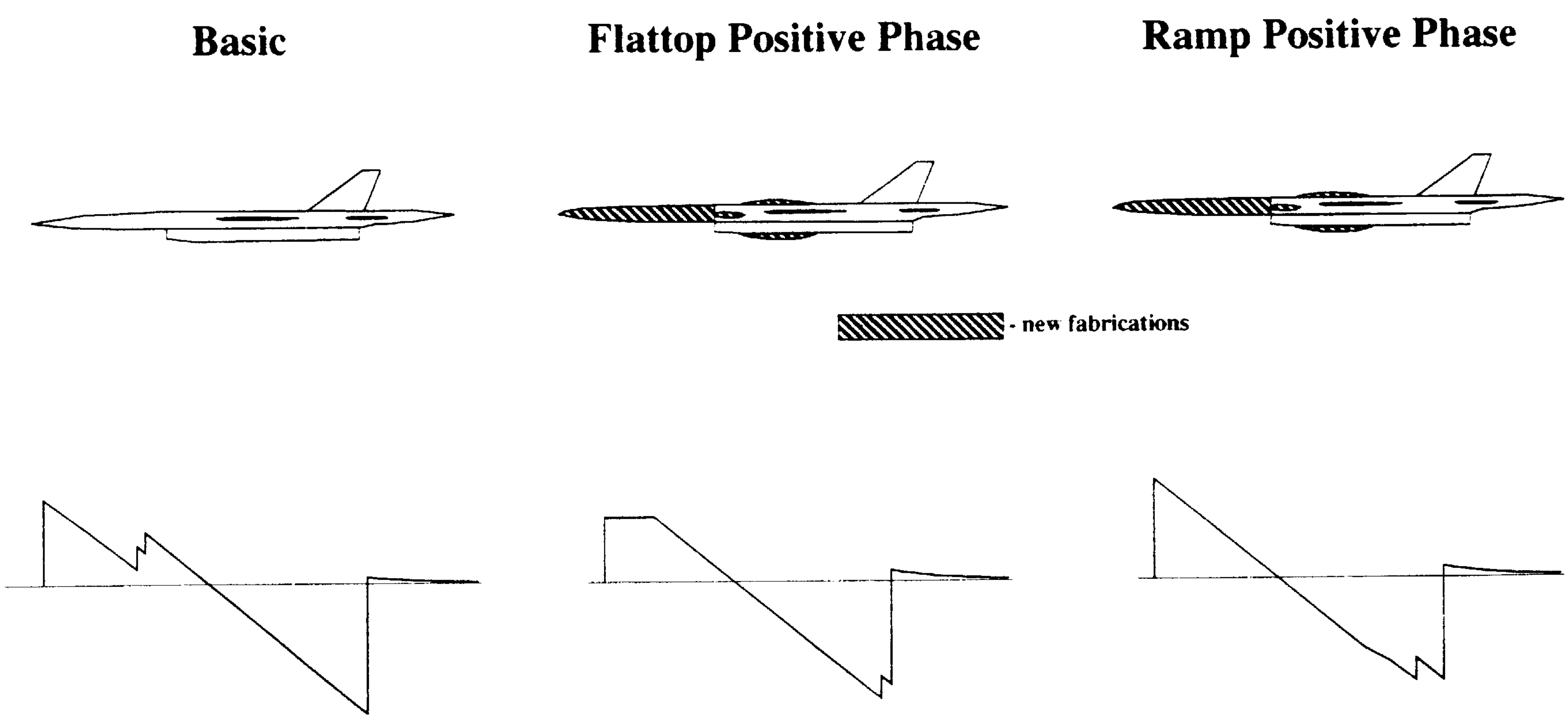


Figure 26.- Signature characteristics of the basic and two modified Firebee configurations when flown at off-design conditions of Mach 1.3 and at an altitude of 20,000 feet.

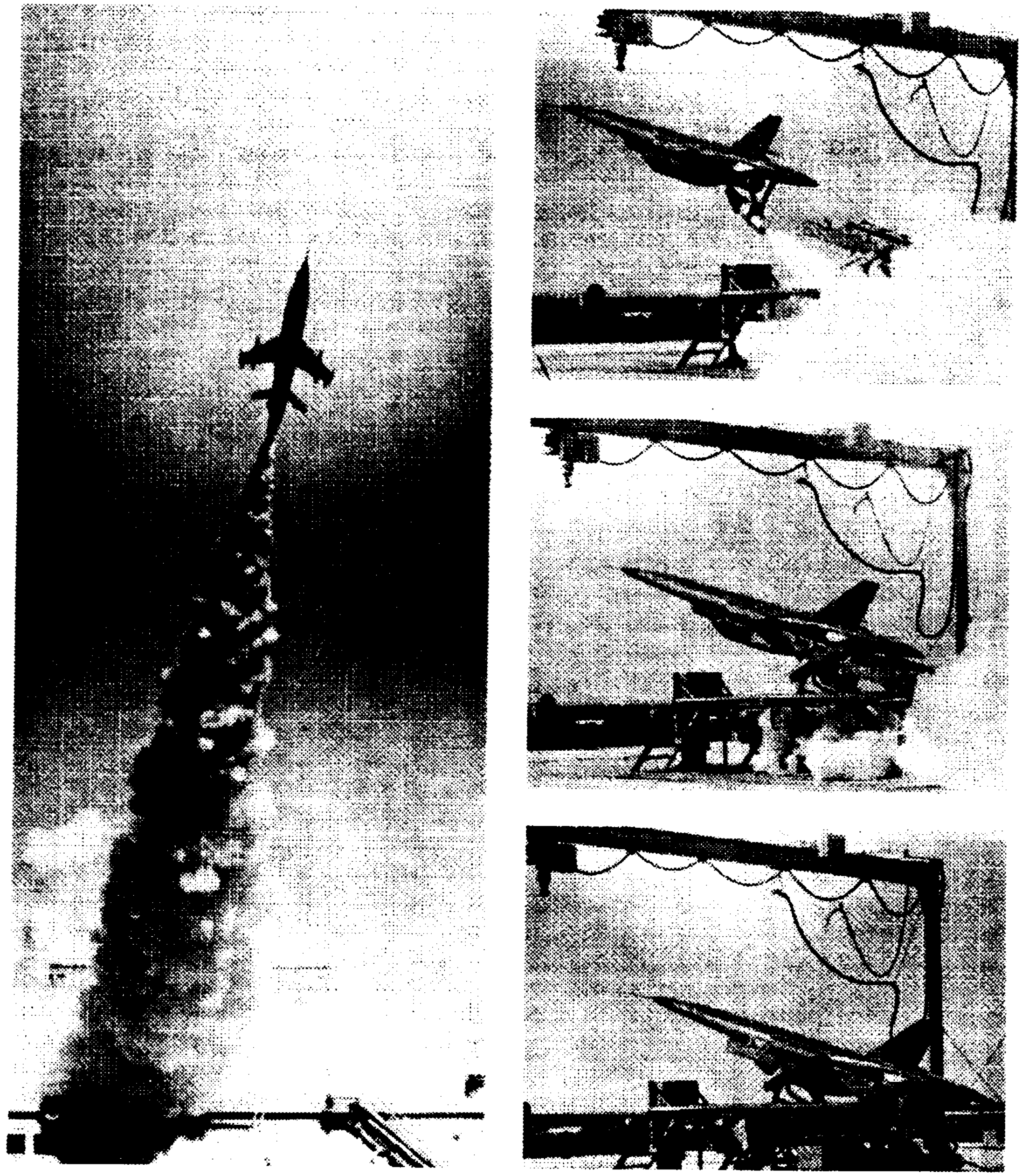


Figure 27.- Photograph illustrating Firebee BQM-34E ground launch sequences.

Figure 28.- Photograph illustrating Firebee BQM-34E air launch arrangement under left wing of aircraft.

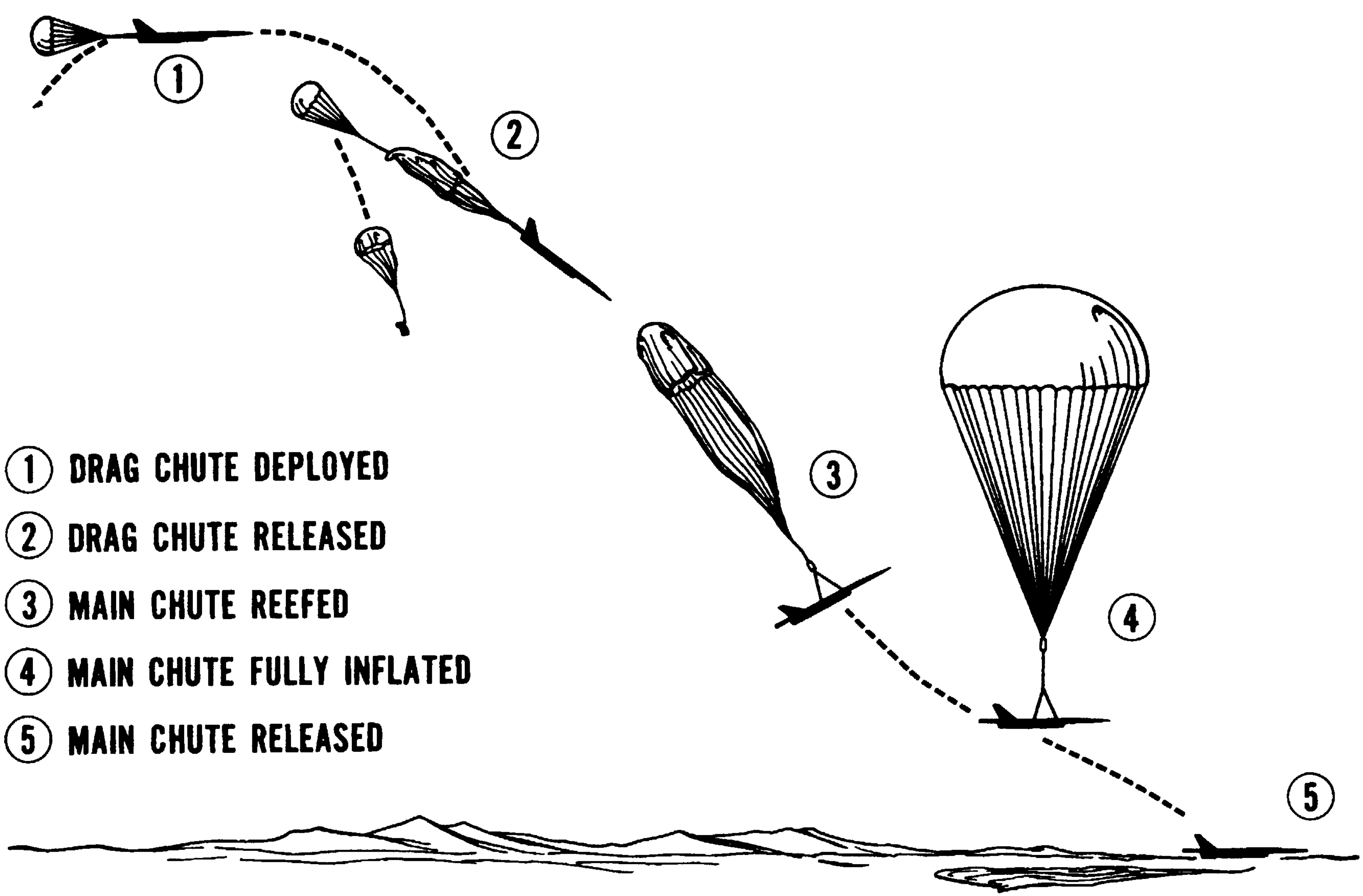


Figure 29.- Schematic illustration of Firebee BQM-34E recovery sequence.

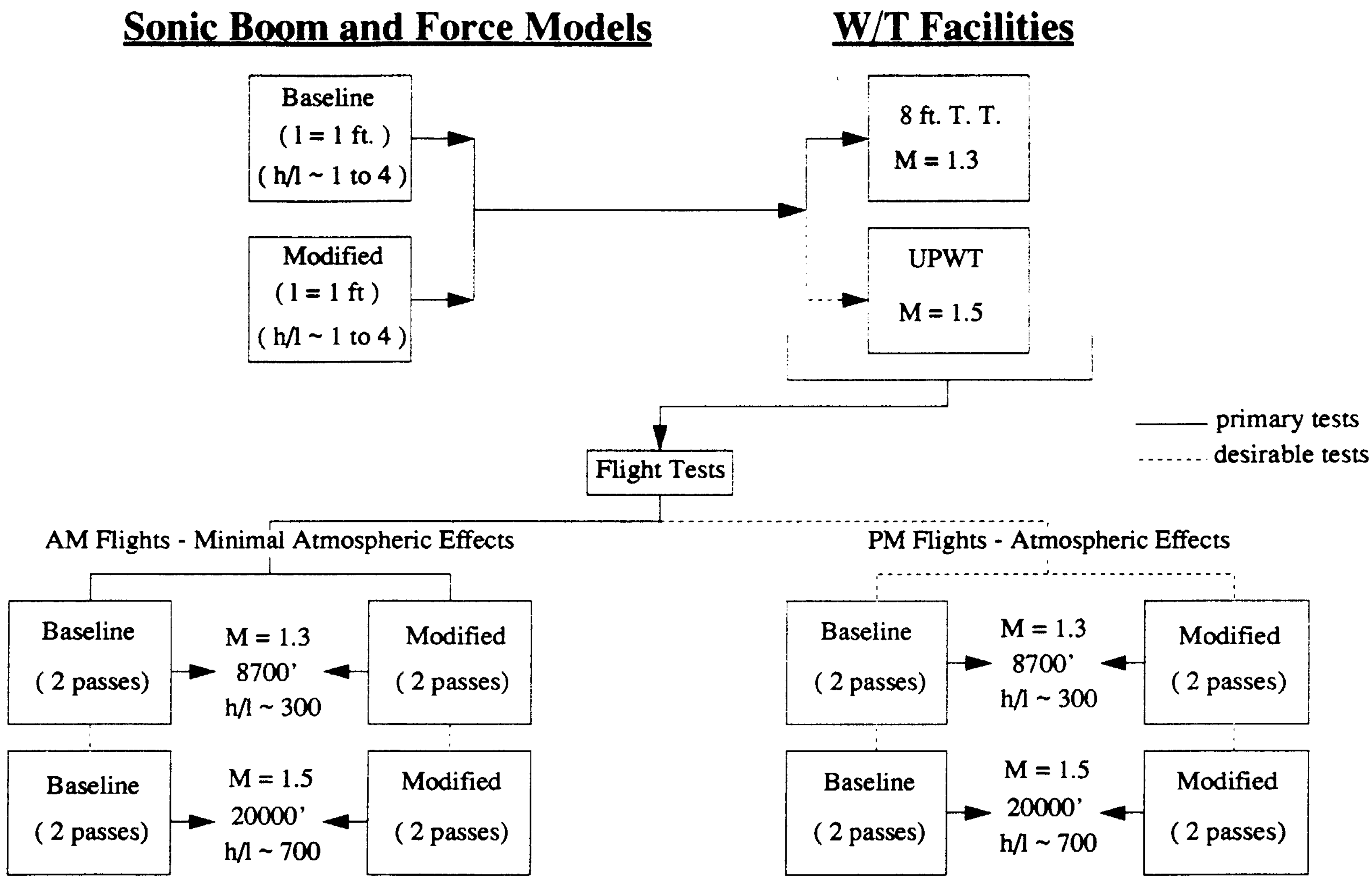


Figure 30.- Flow diagram illustrating scope of proposed Firebee wind-tunnel and flight tests.

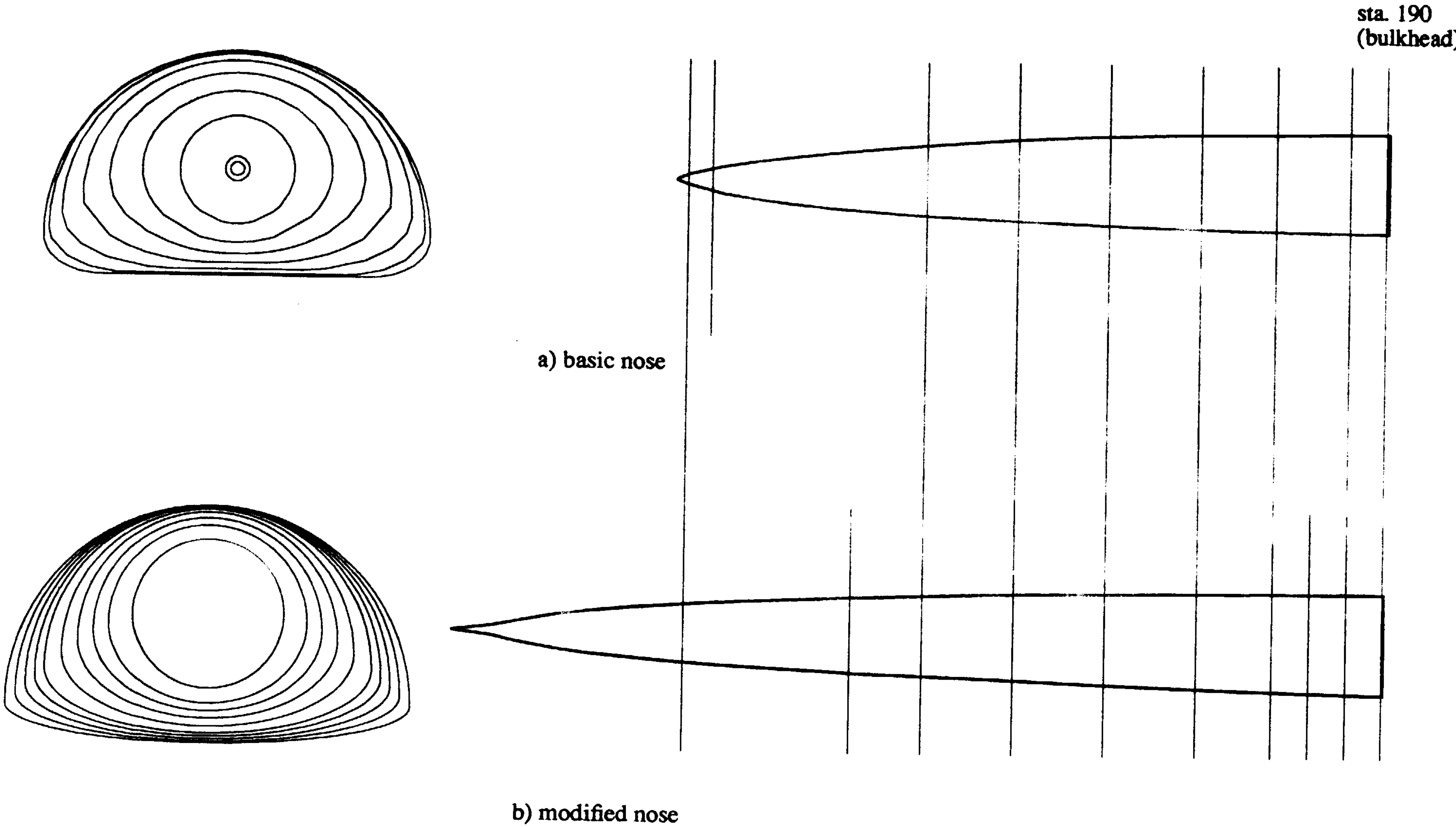


Figure 31.- Schematic defining changes to basic BQM-34E nose section to provide for a flattop positive phase sonic boom signature.

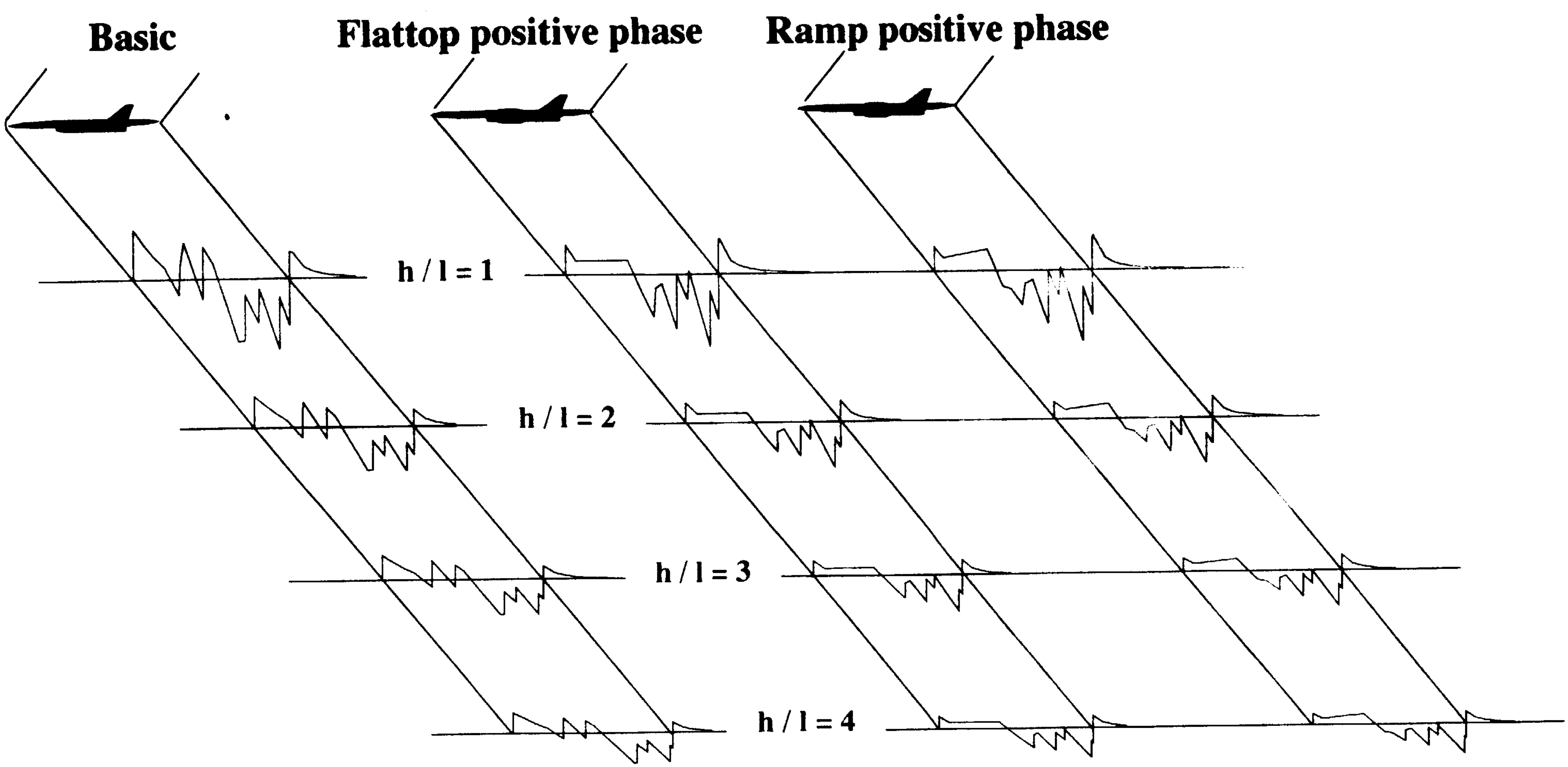


Figure 32.- Predicted sonic boom signatures for wind-tunnel tests of 1-foot long basic and two modified Firebee models 'LARC' 8'TT at Mach 1.3.

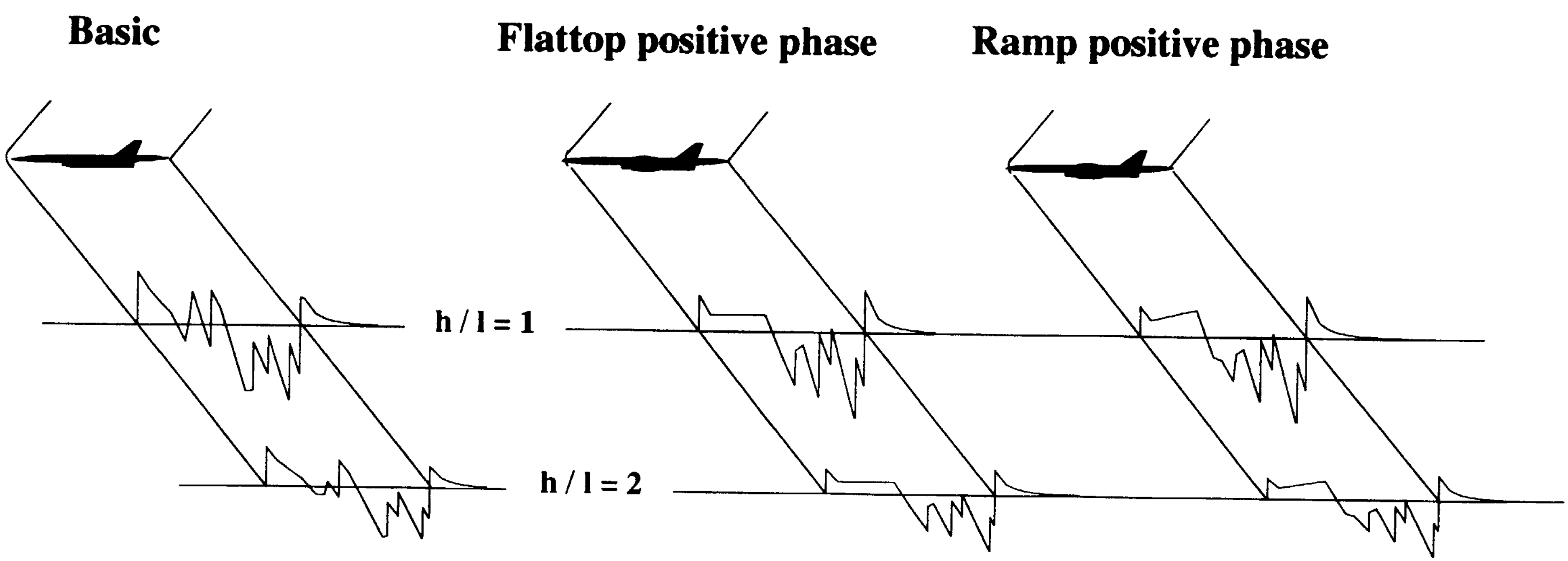


Figure 33.- Predicted sonic boom signatures for wind-tunnel tests of 1-foot long basic and two modified Firebee models in LARC UPWT at Mach 1.5

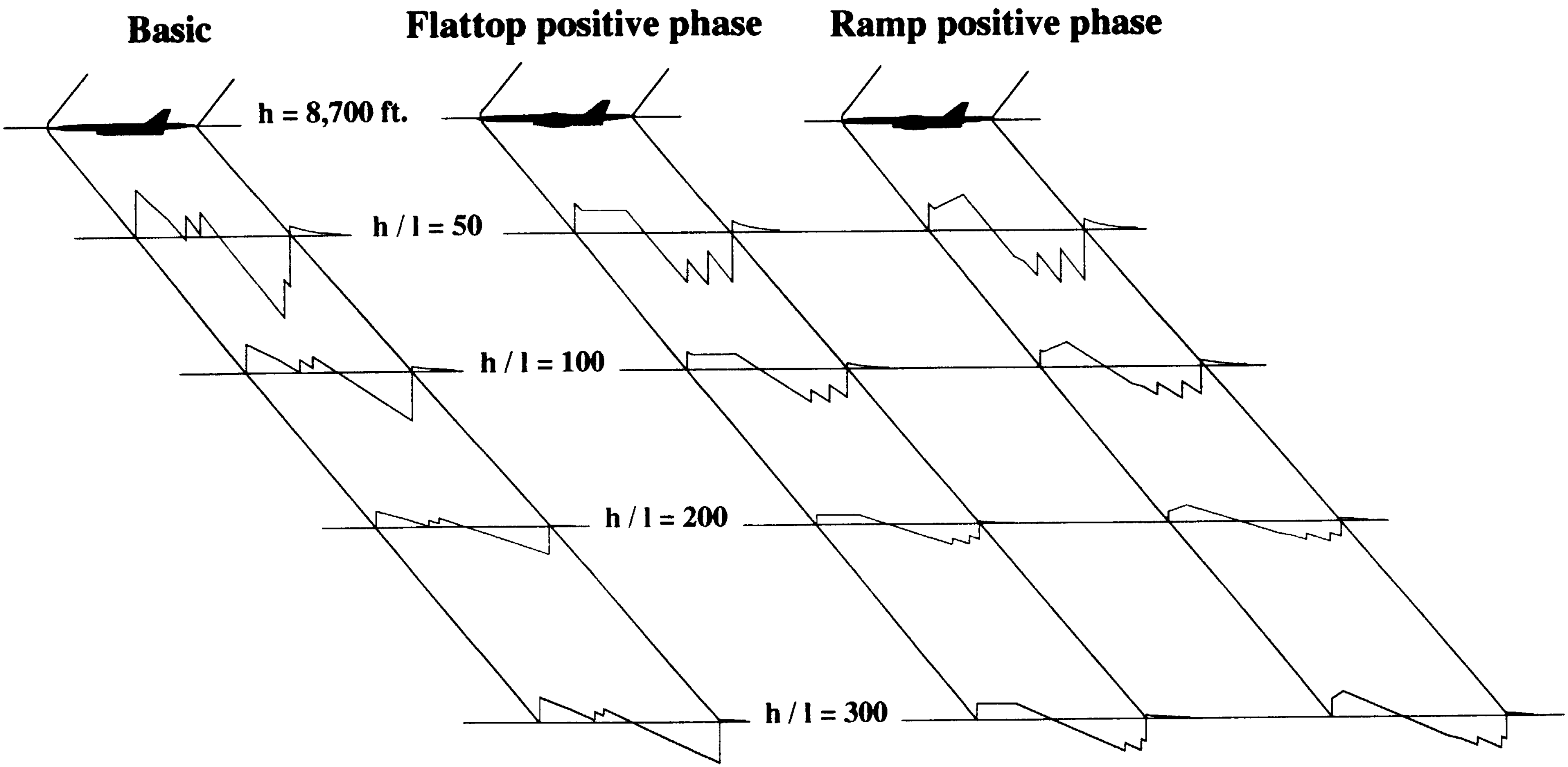


Figure 34.- Predicted sonic boom signatures for flights of full-scale basic and two modified Firebee vehicles at Mach 1.3 and at an altitude of 8,700 feet.

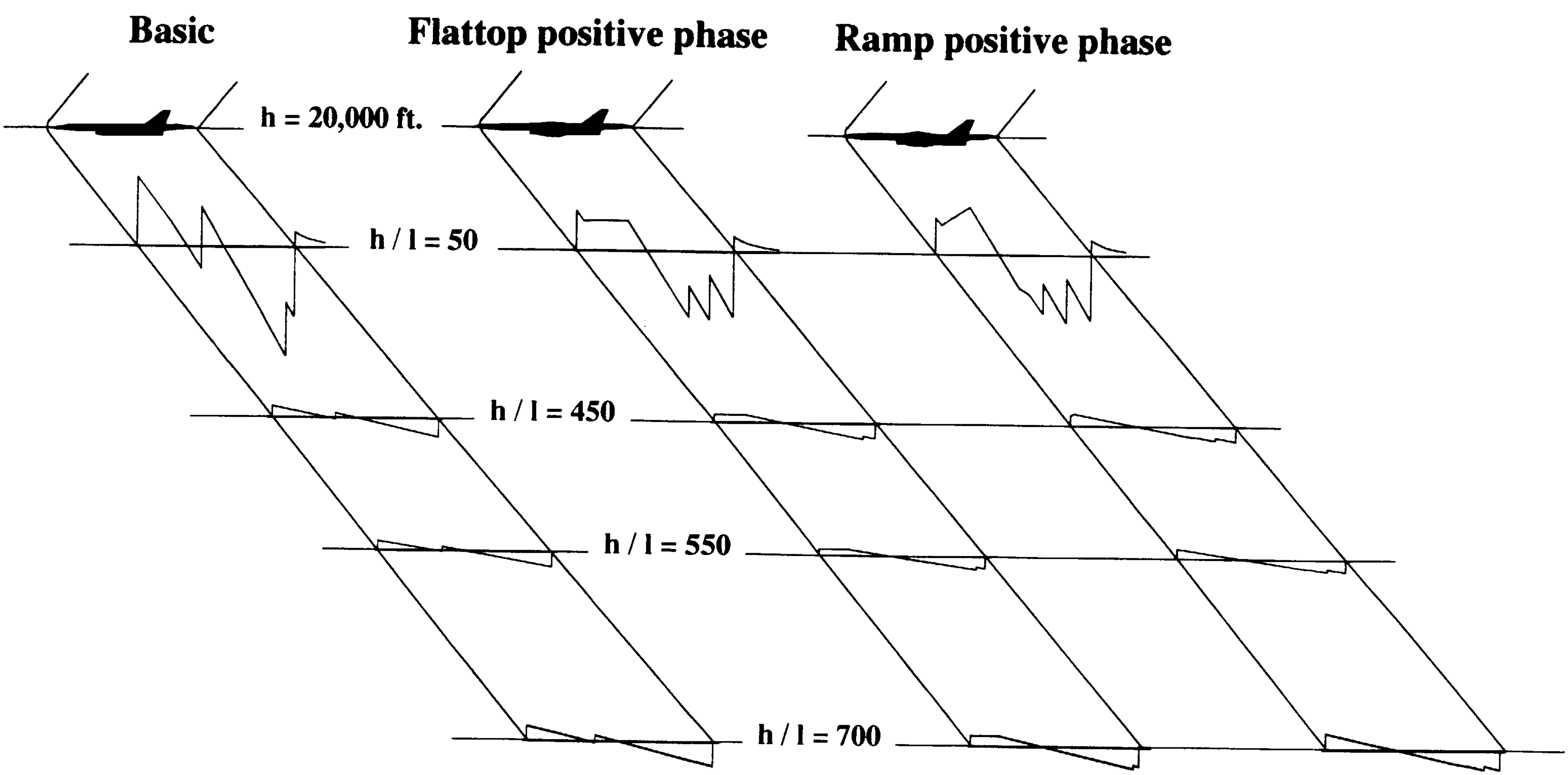


Figure 35.- Predicted sonic boom signatures for flights of full-scale basic and two modified Firebee vehicles at Mach 1.25 and at an altitude of 20,000 feet.

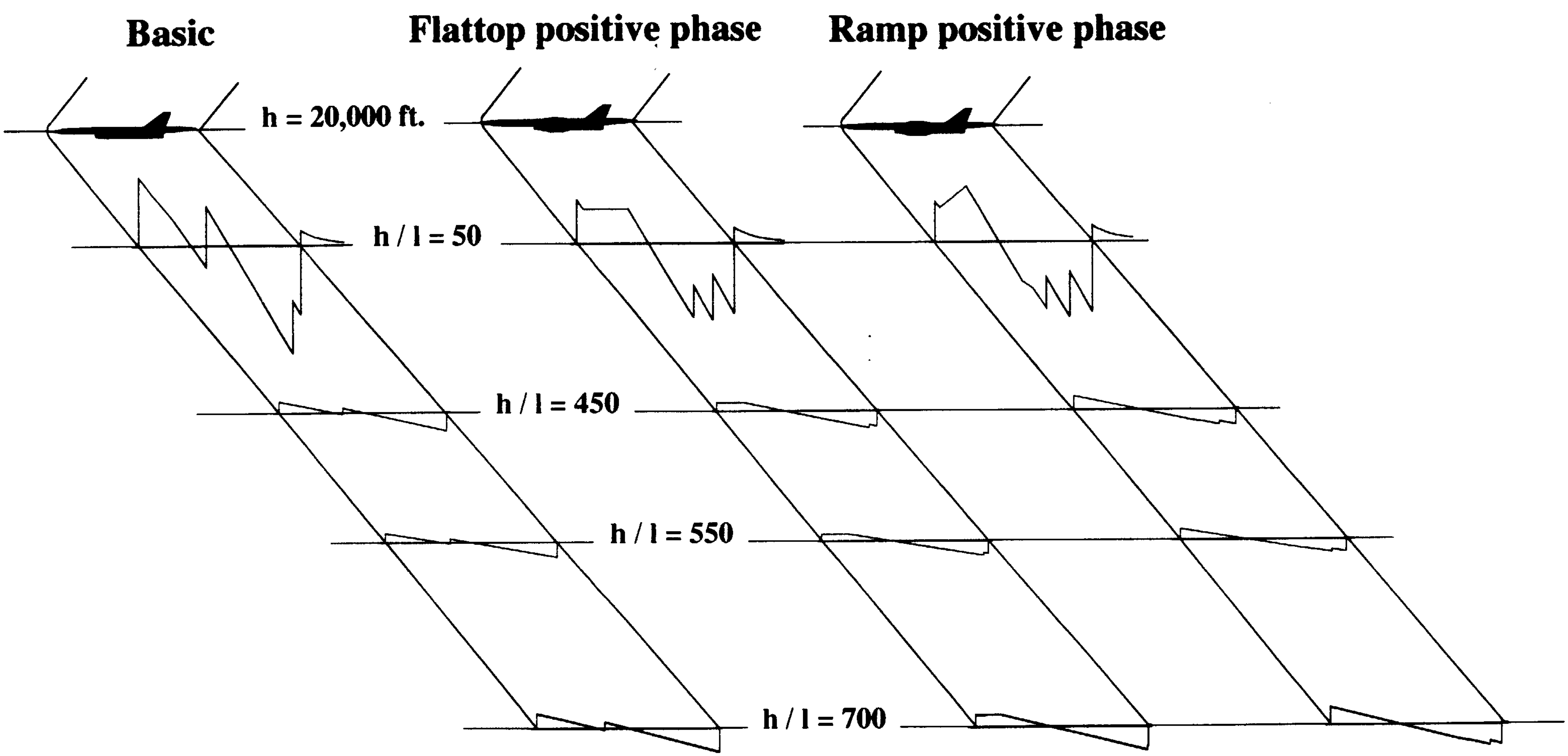
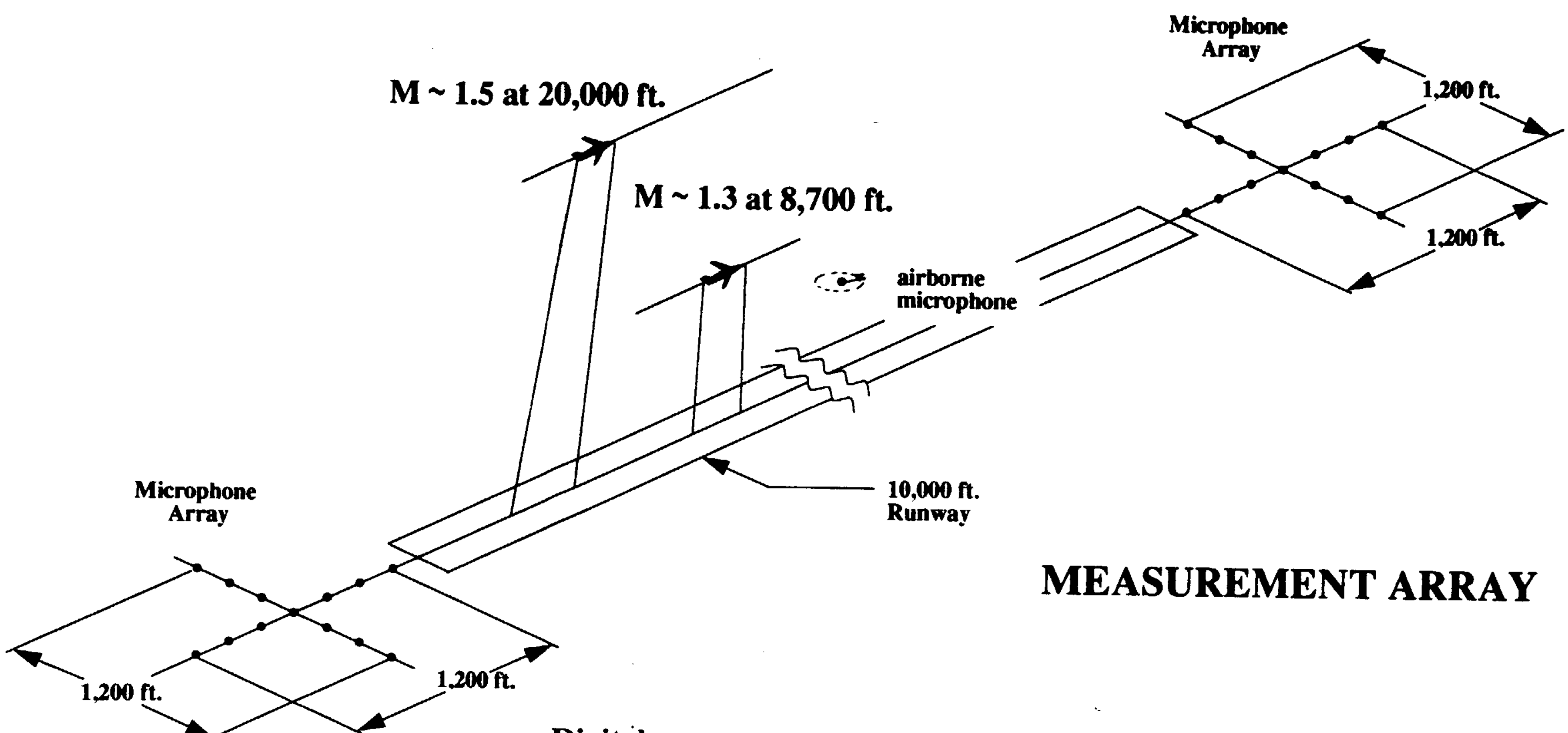
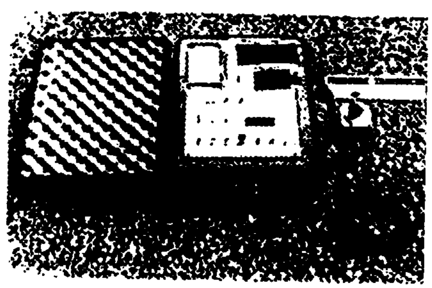


Figure 36.- Predicted sonic boom signatures for flights of full-scale basic and two modified Firebee vehicles at Mach 1.3 and at an altitude of 20,000 feet.



Digital-remote measurement systems



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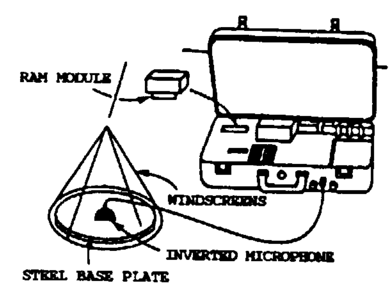

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Figure 37.- Schematic of sonic boom measurement arrangement and units for Firebee BQM-34E sonic boom flight test setup.

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A study has been made to determine the feasibility of experimentally establishing whether a "shaped" sonic boom signature, shown to be "do-able" on wind tunnel models out to about 10 body lengths, will persist out to representative flight conditions of from 200 to 300 body lengths. The study focuses on the use of a relatively large supersonic remotely-piloted and recoverable vehicle. Other simulation methods that may accomplish the objective are also addressed and include the use of nonrecoverable target drones, missiles, full-scale drones, very large wind tunnels, ballistic facilities, whirling-arm techniques, rocket sled tracks, and airplane nose probes. In addition, this report will also present a background on the origin of the feasibility study including a brief review of the equivalent body concept, a listing of the basic sonic boom signature characteristics and requirements, identification of candidate vehicles in terms of desirable features/availability, vehicle characteristics including geometries, area distributions, and resulting sonic boom signatures. A program is developed that includes wind tunnel sonic boom and force models and tests for both a basic and modified vehicles and full-scale flight tests.

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