NEWS RELEASE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
400 MARYLAND AVENUE, SW, WASHINGTON 25 D.C.
TELEPHONES WORTH 2-4155 — WORTH 3-1110

FOR RELEASE: UPON DELIVERY
ABOUT 9:00 AM (M.S.T.)
APRIL 3, 1962

Release No. 62-72

4 3 62

~~XI.11~~,

SATURN HISTORY DOCUMENT
University of Alabama Research Institute
History of Science & Technology Group
Date ---------- Doc. No. ----------

Keynote Address by Richard V. Rhode
Assistant Director, Space Vehicle Research
and Technology
National Aeronautics and Space Administration
to the
AMERICAN ROCKET SOCIETY
Conference on Launch Vehicle Structures and Materials

THE FIRST HUNDRED SECONDS

XI.11

INTRODUCTION

Those of you who have had the privilege of participating in a major space flight launching (Figure 1) will understand that the choice of title for this paper springs from the somewhat breath-taking drama of the first one to two minutes of flight, during which the major forces on the space vehicle are brought into play and the potentiality for structural failure is greatest. Although, traditionally, the lot of the structures engineer is a somewhat drab one and a dramatic title for a paper given at a meeting on launch vehicles structures may seem out of place, I make no apology. The fact of the matter is that the drama of the first hundred seconds is directly related to the state of launch vehicle structural technology and implies the necessity for improvement.

It is not my primary purpose, however, to dramatize. Rather, I should like to discuss a few aspects of launch vehicle structures and materials that appear to me to have a reasonably important bearing on prospects for improving the state of the art.

RESEARCH VS DEVELOPMENT

About four years ago, in another paper, I quoted a statement made by von Karman, which I should again like to repeat: "-- those who say that all that men teach and all that men investigate under the name aeronautical engineering is obsolete seem to assume that by some miracle the designers of space vehicles will not encounter problems involving such classical sciences as fluid mechanics, structures, materials and vibration. I am sure that this will not be the case." These words of von Karman probably were intended to do no more than emphasize the essentially similar nature of the technical problems involved in the design of space vehicles and aircraft. There seemed to have been an implication in them, however, that the technical environment of the space age would be found to remain similar to that of the aeronautical age. This has not been the case.

For example, twelve years after the Wright brothers' first flight, the U. S. Congress appropriated to the NACA, for aeronautical research, "-- the sum of $5000.00 a year, or so much thereof as may be necessary --". Five years after the first orbital flight of a spacecraft, the President requested that Congress appropriate to the NASA for FY 1963, the sum of $3.8 billion for space exploration -- largely to get on with manned space flight to the moon. It is worthwhile, I think, to observe that this original appropriation to the NACA was to be applied to research on how to improve the flying machine and that the smallness of the sum bespoke some misgivings as to the machine's future and the ability of the forthcoming state of technology to make much of it. In marked contrast, the requested appropriation for the NASA is to be applied primarily to the immediate development, for planned applications, of space flying machines, and the substantial size of the sum reflects an attitude of little or no doubt that the current state of our technology is or can readily be made adequate to the development and operational tasks planned.

This current situation seems, on the surface, therefore, to suggest that our current activity is only a multi-billion dollar sprint to overtake the Russian lead in big boosters and to beat them to the moon, or that we think we know it all and the future will take care of itself. Two questions are, in turn, suggested by these propositions: Is the space age here to stay? And, if it is, what is the best way to win the race?

In reference to this first question, there are many persons, including some eminent scientists, who sincerely believe that manned space flight to the moon or to the planets is not worth the cost and that the money could be much better spent for other more worthy purposes. Whether or not these persons are right, it should be easy enough now for all of us to see that there are at least many kinds of earth orbiting flights, civilian and military, manned and unmanned, that will have to be made more or less frequently into the indefinite future. The space age is clearly here to stay, and we would do well to make sure that the way is paved for a sound future and that we are prepared to win the long race as well as the sprint.

The answer to this second question -- how to win the race -- is suggested in the experience of long distance runners or rowing crews. Their object is simply to get from the starting line to the finish line in the least time. But they have many ways open to them -- many combinations of racing starts, steady long pulls and sprint finishes. They find that only one combination is best, and, if too much effort is spent on the racing start, and not enough on the long pull, the race will be lost. As applied to the space race, this simply means that we cannot afford to forget that through long range research programs, detached from immediate space vehicle developments and designed to yield a thorough understanding of the physical phenomena with which we are dealing, we must build a sound future for reliable, efficient and economical space operations.

I do not intend these words to imply that research is being neglected in favor of development. Nevertheless, some very considerable forces have been brought into play by the necessity for rapid progress in our space activities, and these forces have inevitably pushed in favor of development. For example, the recent NASA reorganization cleared the way for increased use of NASA in-house research personnel and facilities on development projects, at the potential expense of our research effort. It nevertheless remains a fact to this writing that responsible people in NASA headquarters as well as in the research centers recognize this difficulty and are making a determined effort to ensure continuation of adequate research programs. Aside from the momentary, if severe perturbations caused by the dumping of a multi-billion dollar rock into the mill-pond, it seems to me, therefore that our program, viewed as a long-range effort, is at the moment soundly based and operating on recognition of the importance of research to improve the reliability, efficiency and performance of space flight systems. Whether it will stay that way in the future depends on a number of factors, one of which is the ability of research minded people to convince non-research minded people of the merits of adequate long-range research programs competently executed by dedicated scientists working in a reasonably calm environment.

STRUCTURAL DYNAMICS

From a purely technical point of view, von Karman's words have been proved to be eminently correct, especially as applied to the so-called launch vehicle. While on the ground, the launch vehicle is subjected to repeated loads, shocks, and vibrations from many sources, and while in the air, as shown by figure 2, it is stressed by acoustic excitation, dynamic pressure, buffeting, panel flutter, wind shear, atmospheric turbulence, and loads and excitations caused by inter-actions between the control system, the flexible structure and the sloshing fuel. The disciplines are then, the same as in aeronautics, and the differences in the structural problem seemingly lie only in differences in structural configuration and environment. One might think, then, that with our extensive background in aeronautics we should be able quite readily to bring the structural efficiency and reliability of launch vehicles to the same sound position enjoyed by airplane structures.

But let us look a little closer. Or, perhaps I should say, let us first look at the picture as a whole from a distance and then come closer for more detailed examination.

System Dynamics

First of all, the title of this conference, in common with much similar terminology, is something of a misnomer. In a structural sense there is really no such thing as a "Launch Vehicle". The booster components of space machines are not in themselves separate truck-like vehicles upon which or in which cargo may be carried into space. Each component of the complete system that stands on the launching pad must be firmly secured to the adjoining parts. When this is done, the combination of shape, mass and flexibility that results is such that there is no escape from treating this combination as one integral structural system. Terminology such as "space truck", "building block concept," "interface problem" and even "launch vehicle" are at times useful words, but the erroneous implications of such terms should not be permitted to condition our technical and management thinking. Otherwise, management anomalies such as responsibilities divided at the junction between components, and technical anomalies, such as different factors of safety for different components of the same system in the same environment should not be unexpected.

Unfortunately, from a technical standpoint, the extensive and variegated nature of our national space program has prevented the creation of a tailor-made system for each application. Considerations of cost and time have forced the use of a limited stable of booster components with a large number of payload components and other upper stages having a variety of weights, sizes and shapes. Figure 3, which shows various Atlas-boosted combinations, conveys but a partial picture of this situation. The same factors of time and cost greatly deter adequate consideration of so many different combinations on a complete systems basis. The problem, then, is to circumvent the necessity of numerous elaborate full-scale tests, including flight tests, or the costly alternative of too frequent flight failures of operational systems. This can be done by the development, through research, of improved analytical and model testing technics for structural design. A great premium should, in fact, be placed on such research.

There are many aspects to this problem. First and last, structurally oriented measurements on appropriately instrumented flight systems are necessary; first, because experience with airplanes has shown that it is not generally possible to formulate the complete dynamics problem adequately in the absence of experience based on flight measurements, and last, because flight checks are always necessary to ensure the adequacy of the analytical and model technics finally developed. The current situation on structural flight measurements is not, I am sorry to say, satisfactory from a structures or dynamics point of view, and, with minor exceptions, the structures man has had to rely on indirect and limited information from measurements made for non-structural purposes. An example is the measurement of engine gimbal angle, from which the angle of attack and aerodynamic load may be deduced. Figure 4 shows a time history plot of a system response to wind shear and turbulence in terms of engine gimbal angle, both as measured and as computed from a balloon sounding of the wind profile. The vertical scale and other information have been purposely deleted, but it can be said that the maximum measured gimbal angle shown corresponds to a substantial fraction of the design load. Data such as these reflect both the unsatisfactory state of the art and the paucity of information regarding the loads on and the dynamic behavior of flight vehicles. An effort is, of course, being made to correct this situation.

It is not necessary to have the flight data in hand in order to know some of the other things that must be done. There is much yet to be learned about the aerodynamic loads, acoustic pressures and other forces that may excite the system. One of the most important of these "input" factors is the wind profile, including both wind shear and the finer grained atmospheric turbulence.

As will be discussed at greater length during this conference, most of the available data on vertical wind profiles have been obtained through the use of balloon sounding technics that are incapable of defining adequately the required fine detail of wind shear and turbulence. Accordingly, other methods have been or are under development. One of the simplest of the newer technics, developed by the NASA Langley Research Center, employs small sounding rockets that lay smoke trails which can be simultaneously photographed in clear weather by cameras stationed at opposite ends of a suitable long base line. Figure 5 shows the two photographs of a smoke trail obtained through this technic. Analysis of such photographs yields quite accurate results in more than sufficient detail for structural purposes.

Figure 6 shows a wind profile obtained with the smoke trail technic and, for comparison, a simulated balloon sounding obtained by averaging the smoke trail sounding over suitable intervals. Computed maximum bending moments on a Scout vehicle "flown" through these two profiles are shown plotted against altitude in figure 7. Most of the rather considerable differences between the two bending moment plots is attributable to dynamic effects caused by the finer grained shear and turbulence not detected by the usual balloon system. This point is evident from the inset figure, which shows a portion of the actual bending moment traces for the two profiles. Very likely, a large part of the difference between the computed and measured gimbal angles shown in figure 4 was caused by this lack of detail in wind profile used for the calculations.

It is evident, then, that the sounding balloon data obtained in the past do not provide an adequate basis for determination of the structural loads and responses of space vehicles during flight through the atmosphere. A great deal of additional and more accurate data will have to be obtained at various geographic locations to make good this deficiency. A start has been made with the smoke trail technic, but better methods will have to be developed to permit the obtaining of data at any time and in any weather.

In one method developed by the USAF Cambridge Research Laboratories, a pressurized balloon such as shown in figure 8 is employed. The balloon is tracked by FPS-16 radar. It retains its spherical shape at all times and is not encumbered with instrumentation. Thus, it has a more accurate response to wind shear and turbulence than the sounding balloon. Further development and employment of this or other suitable technics in sufficiently extensive wind shear measurement programs would provide the required basis for load determination.

Another aspect of the system dynamics problem is the determination of structural modes and frequencies and of the damping characteristics of the structural system in these modes. Calculated properties leave much to be desired, especially beyond the first mode, and full-scale tests are difficult and expensive to make. For these reasons and because configurations have to be established at an early stage, the development of model testing technics is an attractive approach to this problem. This approach is currently being made through the use of models large enough to permit the introduction of significant structural detail. Figure 9 is a photograph of such a model of the Saturn C-1 configuration mounted for vibration tests at the NASA Langley Research Center. In order to ensure that such models yield results applicable to the full-scale system, it is necessary, during the course of development of the model technics, that some results for comparison be available from full-scale tests, such as those shown in progress at the NASA Marshall Space Flight Center in figure 10.

That something remains to be accomplished in this area is evident from the first-mode deflection curves from the model and full-scale tests, as shown in figure 11. These curves represent the fully-loaded or lift-off condition. A complete explanation of the discrepancies between these two curves cannot be given at this time, although a substantial part is believed to have been caused by differences in the suspension systems used. Figure 12 shows similar curves for the more lightly loaded condition corresponding to maximum "q". Here the agreement is much better, although an indication of restraint near the base caused by the suspension rig in the full-scale tests is evident.

Buffeting

One of the most important as well as most difficult structural dynamics problem areas of space vehicles during launch is buffeting. Although it is possible, in principle, to shape the vehicle in such a way as to avoid buffeting (as in the case of airplanes at low angles of attack), the difficulties of tailoring the vehicle for each space flight mission, give rise, in general, to odd shapes such as these already shown in figure 3. The discontinuities and recurved lines of such configurations are rather obvious potential sources of buffeting.

Studies of the problem to date indicate that there are, in fact, two related problems -- one, the local buffeting of structure in the turbulent wake, and, two, the general response of the system to the unsteady airflow. In reference to this latter point, figure 13 shows test data from two dynamic models of relatively clean and so-called "Hammerhead" configuration at M=0.90. The power spectra of bending moment response are obviously of entirely different order for the two cases. Results such as these sharply point up the fact that buffeting is more than a localized problem, and at the same time clearly suggest that, even with respect to local buffeting, reliance cannot be placed on rigid models.

The results shown on figure 13 also suggest that in some cases aeroelastic instabilities may occur, and this has, in fact, been found to be the case. Figure 14, for example, shows that the aerodynamic damping may decrease at transonic speeds to the point where the total damping can become negative, in which case a one-degree-of-freedom form of flutter occurs. Results such as these place a new and higher premium on the necessity for developing aeroelastic model technics in which not only the overall elastic properties but also the local structure is adequately represented.

There are, of course, many other structural dynamic problems of importance. Among them are panel flutter, response to acoustic excitation, wind and gust loads and responses while on the launch pad, and shock and vibration during transportation of large components. Most of these problems are common to both liquid and solid fueled rockets, but a few of them are peculiar to the liquid-fueled types. For the sake of rounding out the picture to a degree, it should perhaps to be said that solid-fueled rockets also have their own peculiar problems in structural dynamics, among which are the starting transient, especially in the large sizes and for multiple configurations such as clustered arrangements. Although none of these problems can be neglected, the more important requirements at the moment seem to lie in the areas of dynamic responses to wind shear, gusts and unsteady airflows, as discussed.

STRENGTH AND EFFICIENCY

The design of space vehicles also involves many considerations other than loads and dynamic response. There are closely interwoven relationships between the loading conditions and strength requirements on the one hand and the determination of an adequate combination of geometry and material to meet these requirements on the other. As we all know, there is nothing static about the flight of a space vehicle through the atmosphere. Even the quasi-static phenomena have superimposed upon them at all times more or less rapidly changing forces and temperatures from many sources. It thus becomes necessary to acquire an understanding of strength properties under a wide variety of complex dynamic situations. As new knowledge is gained of the dynamic environment, new requirements are introduced for understanding of the detailed stress and buckling behavior of the structure.

Although much remains to be learned about the static strength and efficiency of low-density structures, some investigators have recently turned their attention to strength properties under these more realistic dynamic situations. Results to date indicate that the strength generally increases over the static case when the load is suddenly applied. There has been some apprehension, however, that the strength capability for some of the principal loads may be reduced by the superposition of dynamic phenomena, such as acoustic excitation. The limited investigations conducted to date of this type of problem have not clearly shown the degree to which the apprehension is justified, if at all. It is, nevertheless, necessary that these investigations be further pursued as well as investigations of strength when the principal loads are applied at different rates.

Although there exists some doubt as to the possibility of dynamically applied loads decreasing the basic strength, some recent tests made at the NASA Langley Research Center have shown that rapid heating does adversely affect the strength, especially when the heating is unsymmetrical. Some results of these tests, as yet unpublished, are shown in figure 15. Here, the curve shown for the case of uniform temperature simply indicates the degradation in buckling strength caused by reduction in modulus of elasticity with increasing temperature. The experimental points were obtained by applying a stress through bending and then heating rapidly until buckling occurred. The square points represent the case of rapid, but uniform heating. In this case the additional degradation in strength is caused by circumferential thermal stress, since the bulkhead rings remained cooler than the skin. The circular points represent the case of rapid heating over only a part of the circumference. In this case longitudinal as well as circumferential stresses are introduced, and the strength is further degraded.

Cases such as these simply point up the need for a great deal of research to achieve a thorough understanding of strength properties under the complex dynamic situations of flight. These properties must be understood not only to ensure reliability, but also to permit design for minimum weight or maximum efficiency.

MATERIALS

Somewhat in contrast to structures research, the importance of materials research has enjoyed considerable recognition in recent years. Partly for this reason, and also because, superficially, the structural integrity of launch vehicles does not seem to be crucially dependent on materials research, it would be easy to pass over materials problems for launch vehicles too lightly. That to do so in a keynote talk would be something of a mistake is, perhaps, sufficiently evident from the titles and abstracts of the papers to be given at this conference, one of which, in particular, shows that the basic strengths of metallic materials are adversely affected by sonic and ultrasonic vibrations.

The facts of the matter are that, even in the seemingly mundane case of launch vehicles, the materials of construction find themselves in strange, new environments and that considerable research is still required to solve the many materials problems related to the strength, reliability and efficiency of the machine. Among the environmental aspects of the problem are shock, vibration and temperature, and, for the upper stages, hard vacuum, meteoroid impact and other space phenomena normally associated with space craft.

Under these conditions the selection of suitable materials and the devising of appropriate tests to ensure their suitability become difficult procedures. For example, it has been customary for many years to evaluate the suitability of sheet material to withstand stress concentrations, such as those produced by welds, on the basis of notch tensile tests of one kind or another. There is, as yet, no rational technical basis for selecting one type of test in favor of another, even at room temperature. Now we are faced with the reductions in toughness of tank materials at cryogenic temperatures, and the type of test required to evaluate the notch sensitivity of the material has become of increasing importance. In particular, we need to establish correlations between the strength of notched specimens and the strength of welded tanks under a variety of temperature conditions.

Although much remains to be done, some progress has recently been made on this important problem at the NASA Lewis Research Center. Cylinders machined from extruded aluminum tubing and containing notches of several radii were subjected to burst tests at a temperature of - 423°F.

A sketch of the type of cylinder and notches used, together with some results of these tests, are shown in figure 16.

In these tests both the two-to-one biaxial stress field of the cylindrical tank and the low temperature of liquid hydrogen were represented. Such tests of notch sensitivity are, of course, not only more realistic and informative than the usual uniaxial type of test, but they afford an opportunity for correlation of results from the two types of test, thus paving the way for more useful application of the large existing body of test data. In addition, the tank burst test obviously affords an opportunity for evaluation of welded seams and other types of joint in terms of definable notch sensitivity.

Another illustration of the many-faceted problem of materials lies toward the other end of the temperature scale. Liquid propellant rocket engines for the larger boosters are now all regeneratively cooled. Properly shaped tubes are brazed together to give the proper configuration and to channel the flow of coolant along the combustion chamber and nozzle walls. Aluminum tubes were employed on early engines, because of the high thermal conductivity of this metal. More recent engines have forced the use of materials with higher melting points. These materials pose difficult new problems. If we go to a material like stainless steel, we have good strength and embrittlement resistance. However, the thermal conductivity is so low that hot spots and high thermal stresses are generated.

An additional complication is introduced by brazing. Some of the more ductile brazes melt at engine operating temperatures. Others braze well and yield smoothly filleted joints, uniform in appearance. Unfortunately, they are both brittle and aggressive -- that is, they vigorously attack and alloy with the base metal. A micrograph of a brazed joint prepared with such an alloy is shown in figure 17. In this photograph the lighter area is a section of the tube wall and the darker area in one corner is the braze material. In between, and penetrating into the tube wall, is an alloy of the braze material and the tube material. The quality of the brazed joint and, therefore, of the entire structure obviously now depends on a new, non-uniform, uncharacterized alloy of the tube material and the braze metal, and no amount of data on the properties of the tube material will tell us what to expect.

There are, of course, innumerable other materials problems of importance, most of which are peculiar, in some degree, to the space age and launch vehicles. Truly, there is much room for materials research in any long-range effort to develop the full potential of space vehicles with respect to reliability, efficiency and performance.

CRITERIA

Although the program of this conference places the session on Criteria first, I have chosen to place my comments on this subject last. Perhaps this is because, as may now be evident, I regard myself as belonging to one of the research-minded segments of our technological society. To such a person, criteria necessarily follow after development of the state of the art, although from the designer's point of view, criteria come first.

We might do well at this point to consider for a moment what we mean by "criteria". In general, criteria are the stipulated or agreed upon conditions which the design must meet. They range widely therefore, over all aspects of the design, and the stipulation of the loads and of methods for determination of strength or materials properties are but a part of the over-all field. In any well-ordered society, criteria should continuously reflect the most advanced state of the art, while at the same time constituting a uniform and practicable foundation for design.

The present state of affairs respecting criteria for space vehicle design can best be described as anarchic. This statement is made in no critical vein, but only to emphasize the great need for a strong attack on the problem. Perhaps one illustration will suffice.

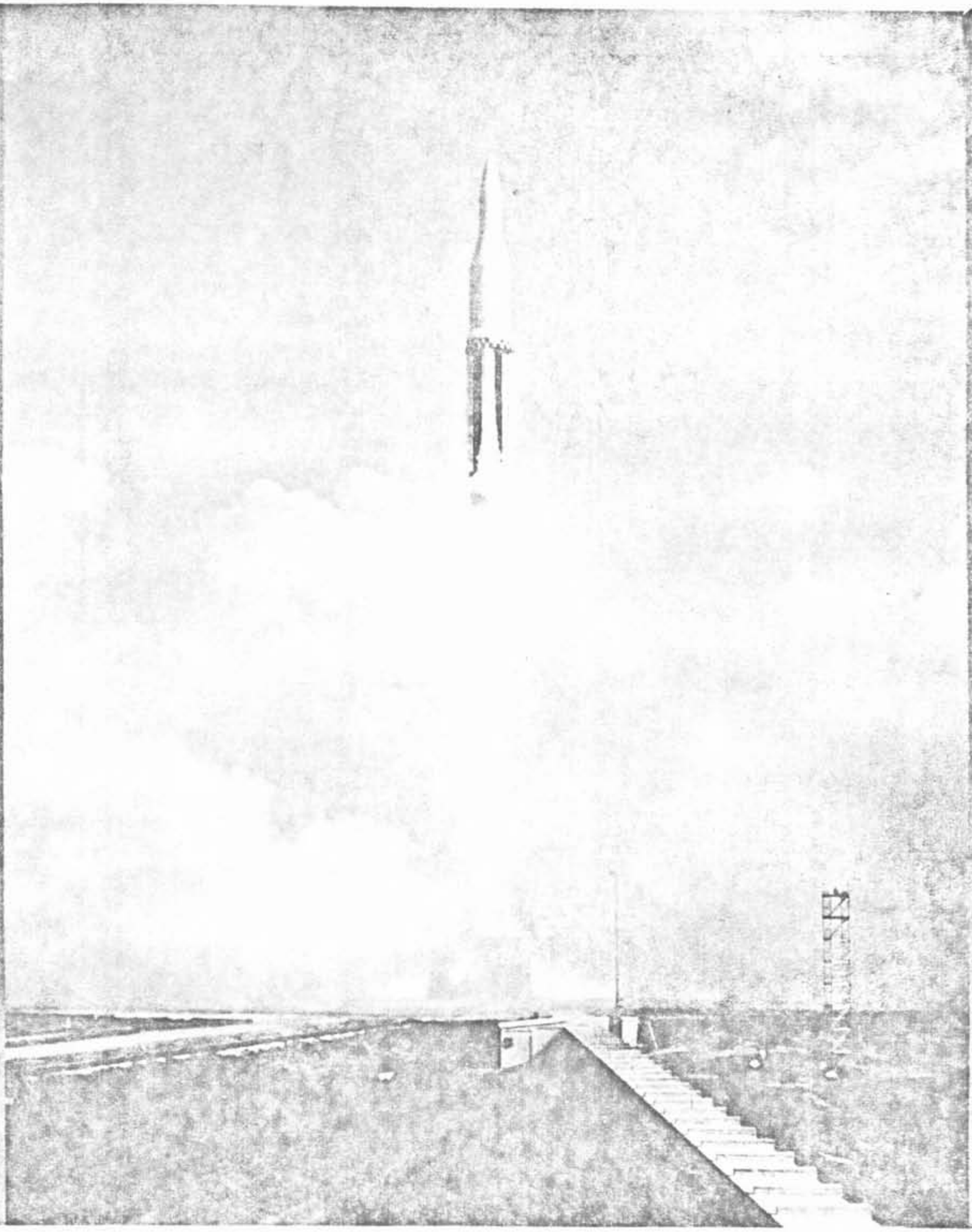
Allusion has already been made to the need for better data on wind shear and atmospheric turbulence. The need for better data on this and other subjects will undoubtedly continue for a long time. Meanwhile, data exist. There is a current state of the art. But no standards have yet been established on the basis of existing data, as a consequence of which fact various project and design groups interpret the data in their own different ways to arrive at wind profiles for design. Figure 18 shows a band of wind speed against height which describes the limits of some of these individual curves.

There is probably no need for further comment, other than to say that the problem is widely recognized and that efforts are being made, if slowly, to overcome the deficiencies evident in this one example. The task is, however, a very considerable one and will require application of the talents and capabilities of a great many persons representing many scientific and engineering disciplines.

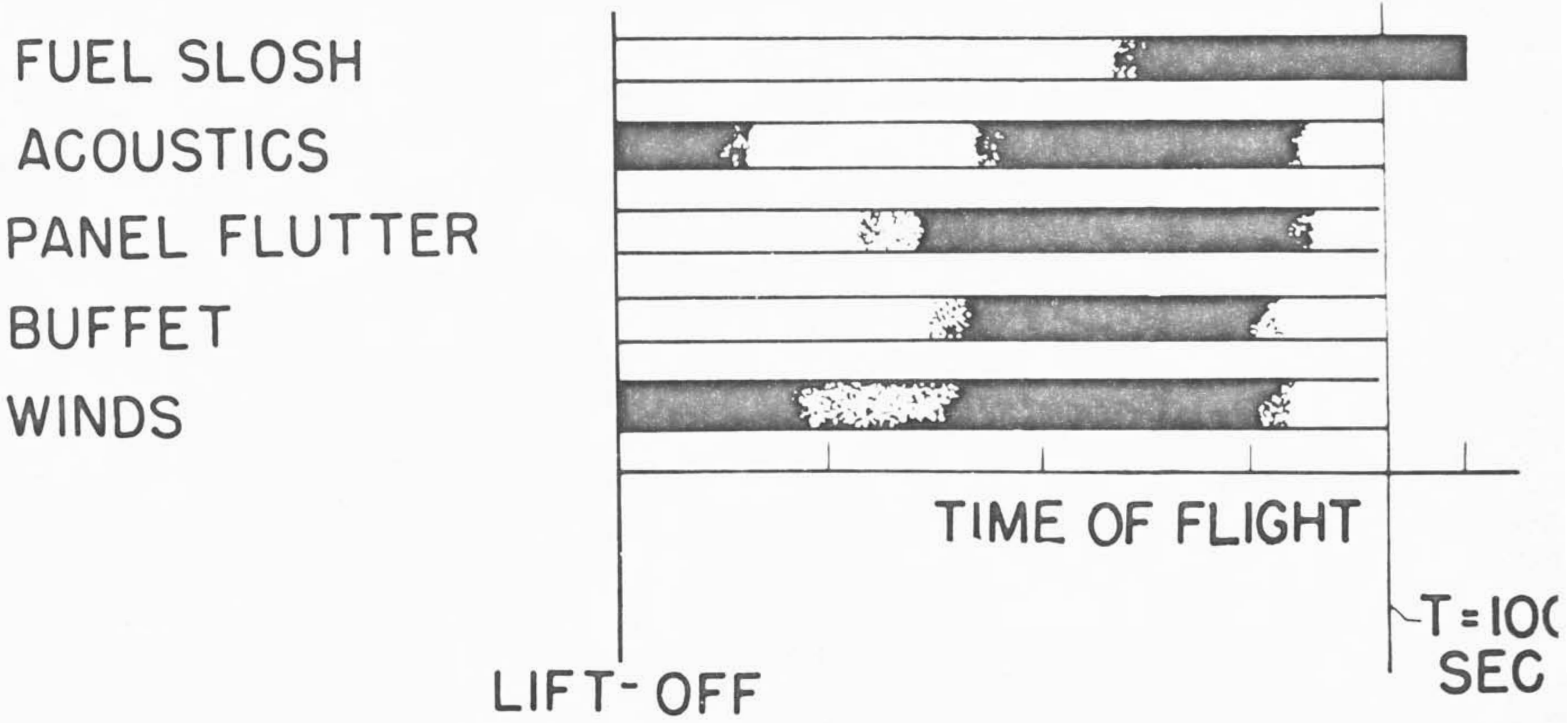
CONCLUSION

Thus, the drama of the first hundred seconds points up the need for improvement in the technology of launch vehicle structures and materials. Many of the required improvements, especially in the areas of loads and structural dynamics, are badly needed to ensure the structural integrity and reliability of currently planned space flights and missions. Other less pressing, but nevertheless important, improvements are required to ensure efficient and economical space operations in the future. Let us not forget that only through adequate research programs, detached from immediate development activities and designed to yield a thorough understanding of the physical phenomena with which we are dealing, can we build a sound future for reliable, efficient, and economical space operations. Only in this way can we win the long race.

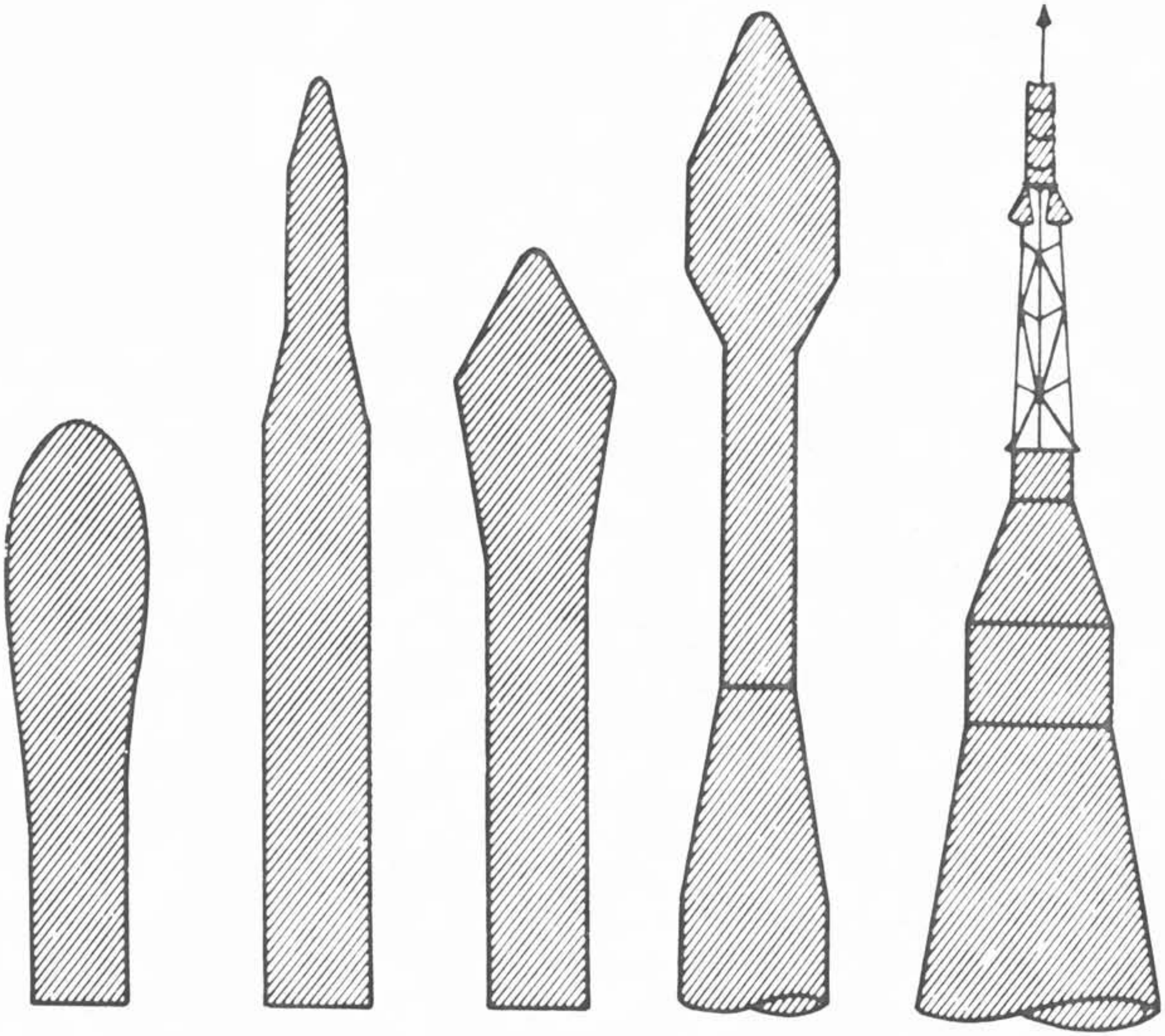
FIGURES



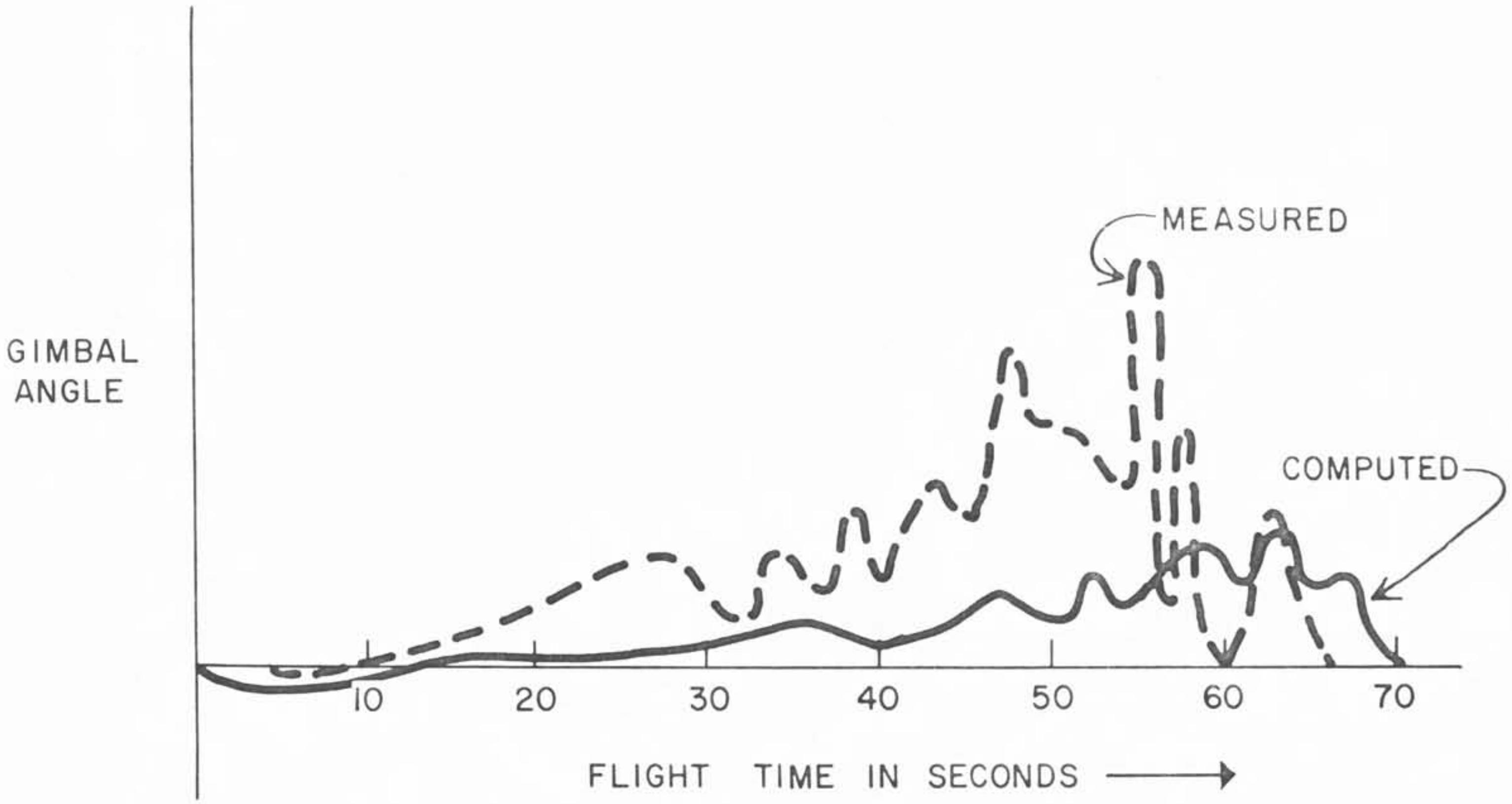
THE FIRST HUNDRED SECONDS



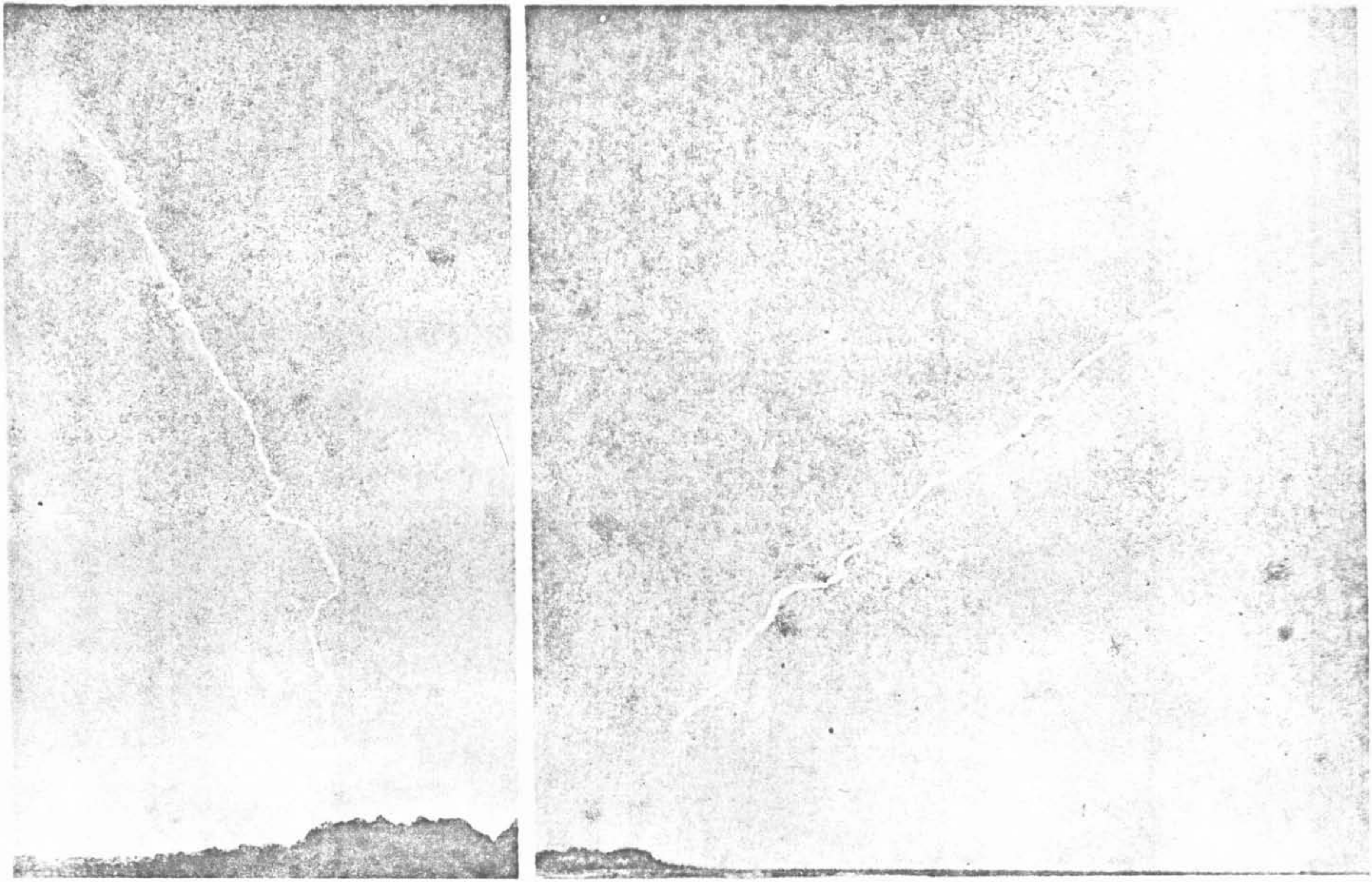
SOME TYPICAL SPACE VEHICLE CONFIGURATIONS



COMPUTED AND MEASURED VEHICLE RESPONSE



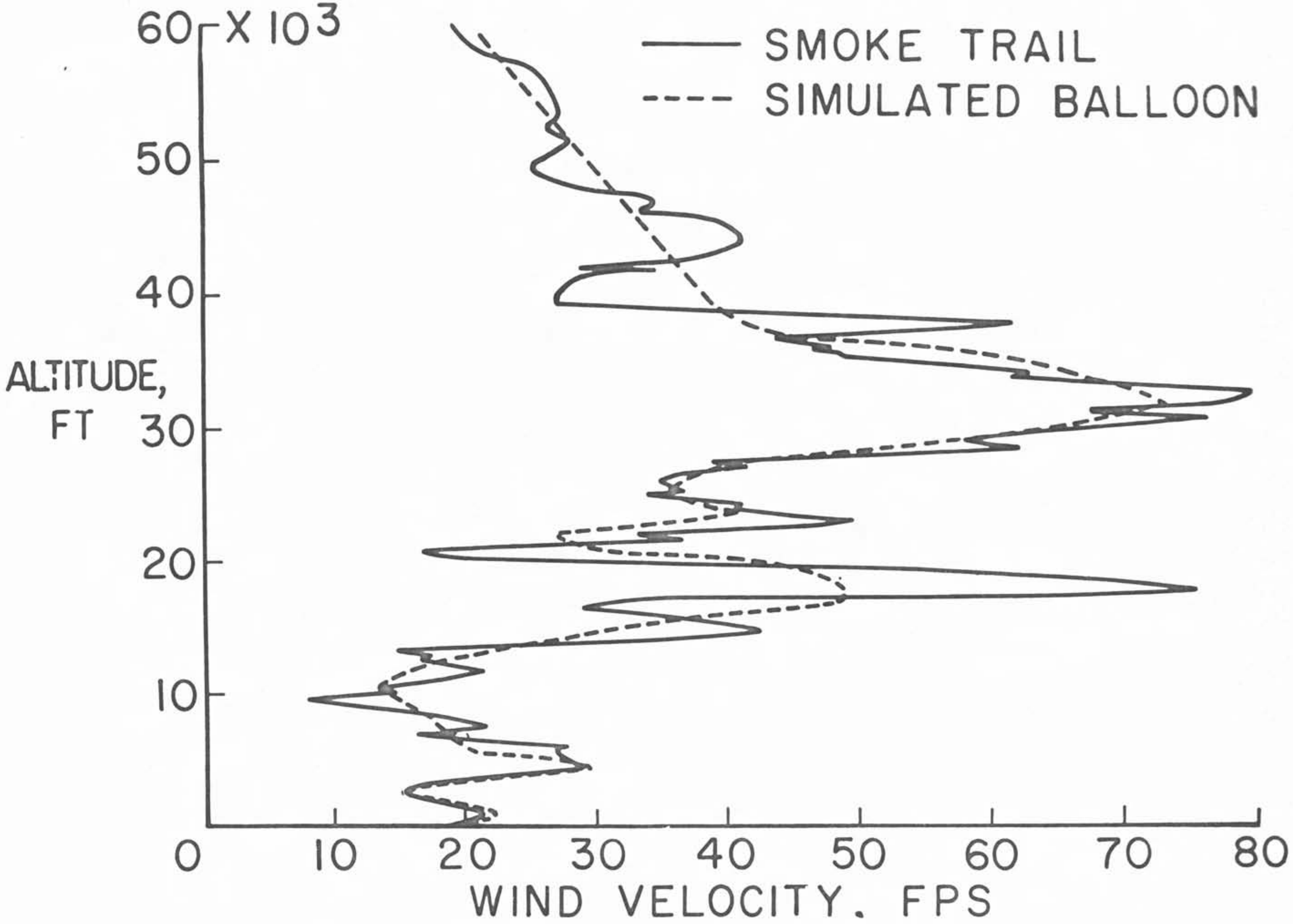
SMOKE TRAIL PHOTOGRAPHS



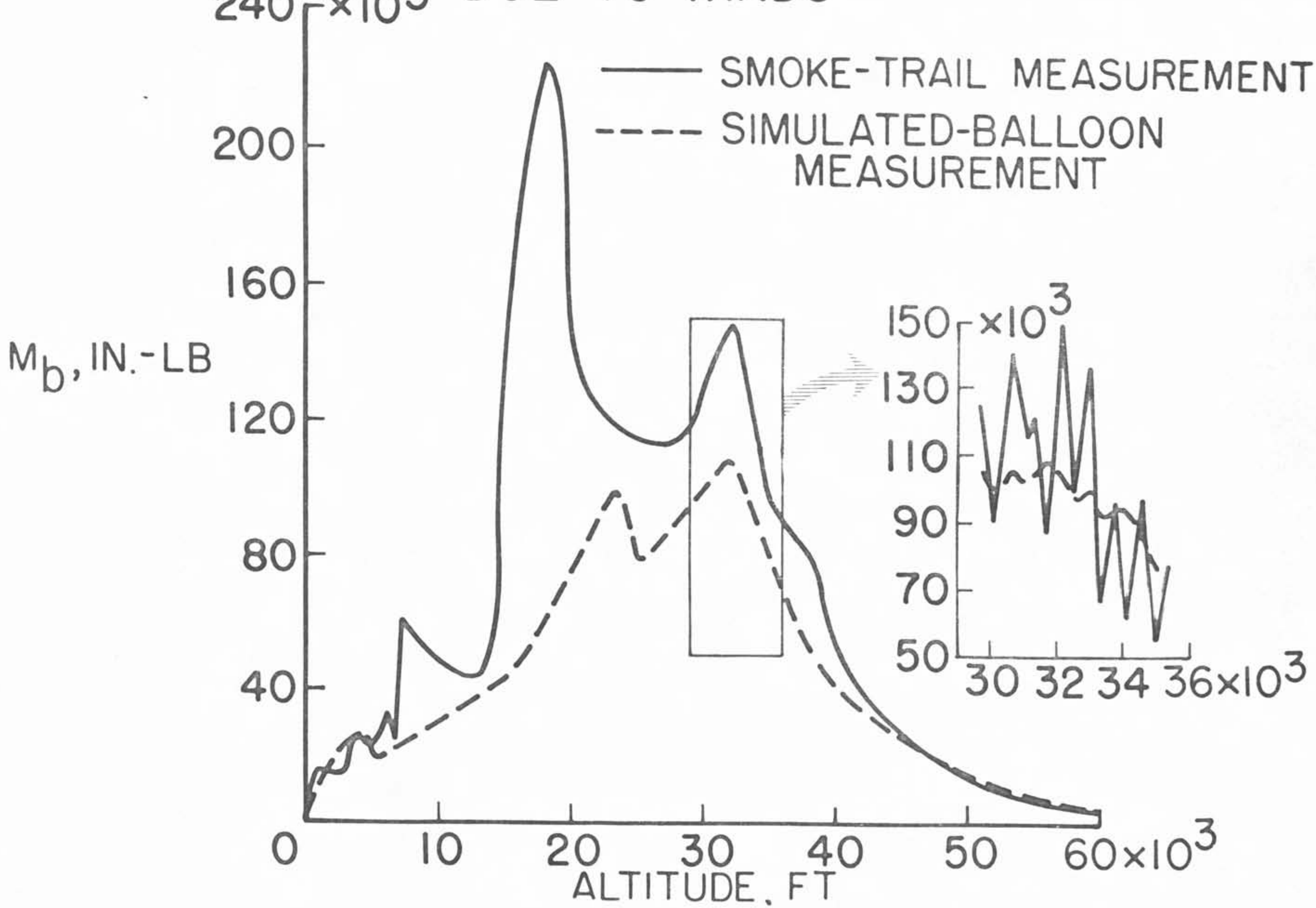
CAMERA I

CAMERA II

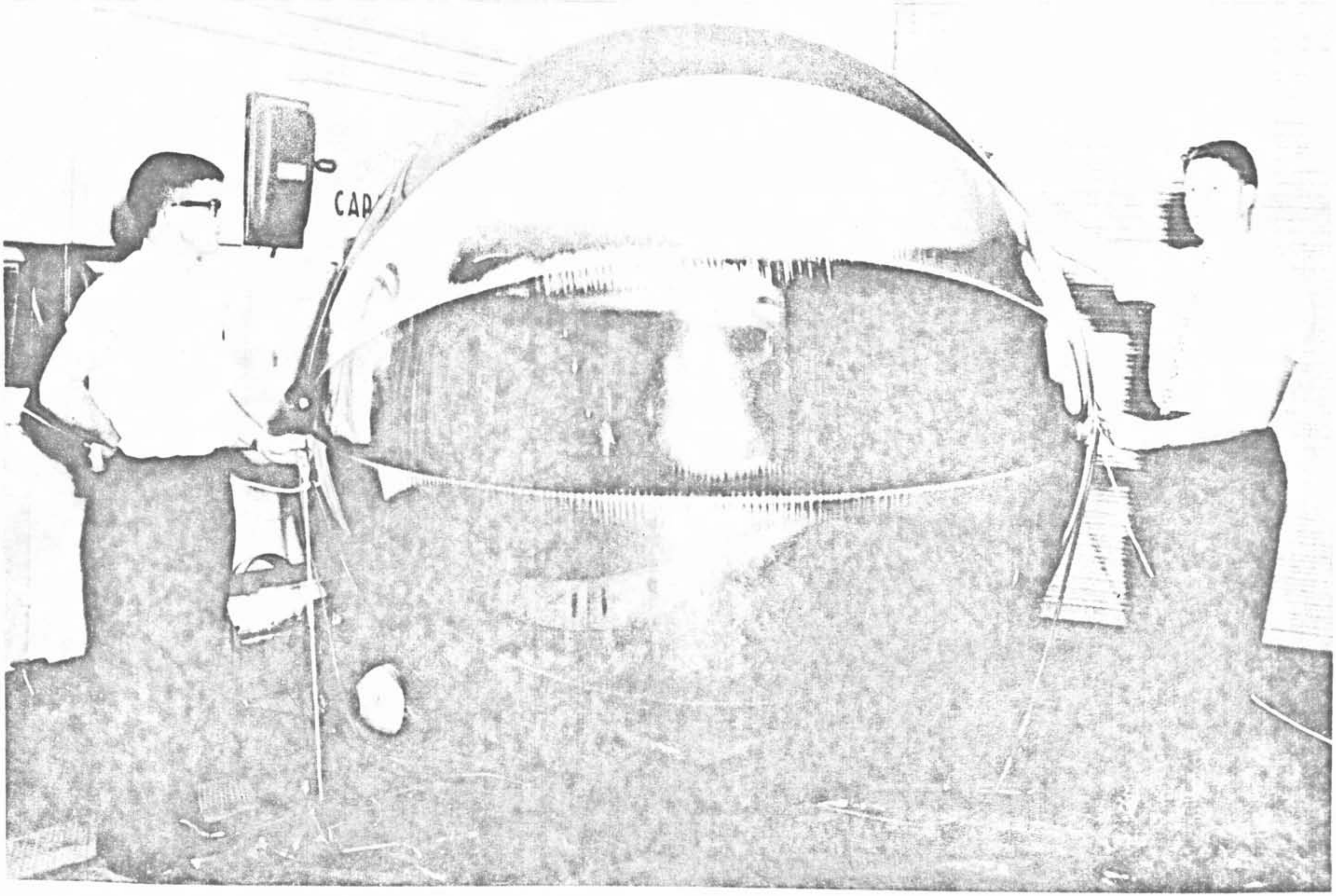
WIND-VELOCITY MEASUREMENTS

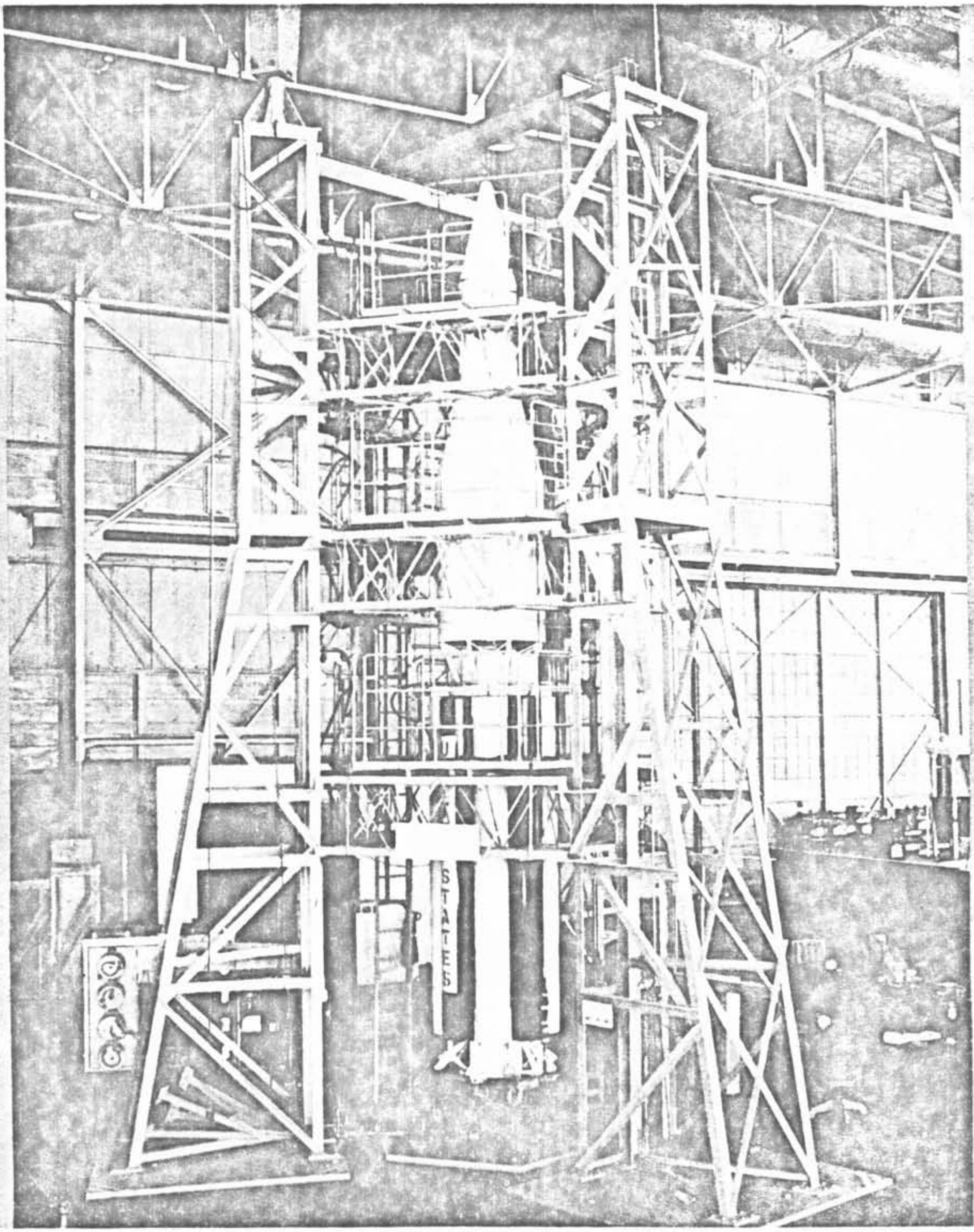


BENDING-MOMENT ENVELOPE DUE TO WINDS

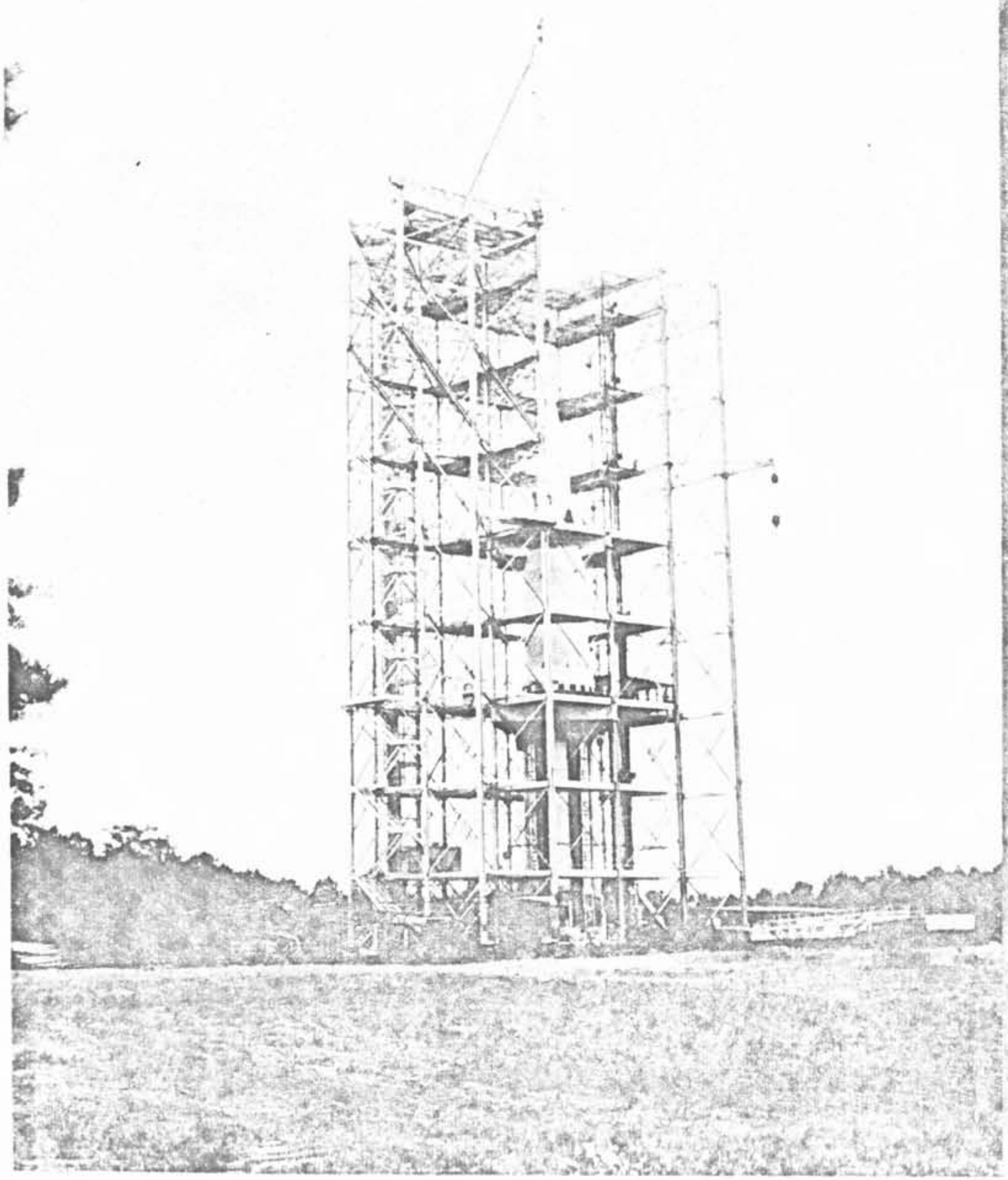


PRESSURIZED BALLOON FOR WIND PROFILE MEASUREMENTS



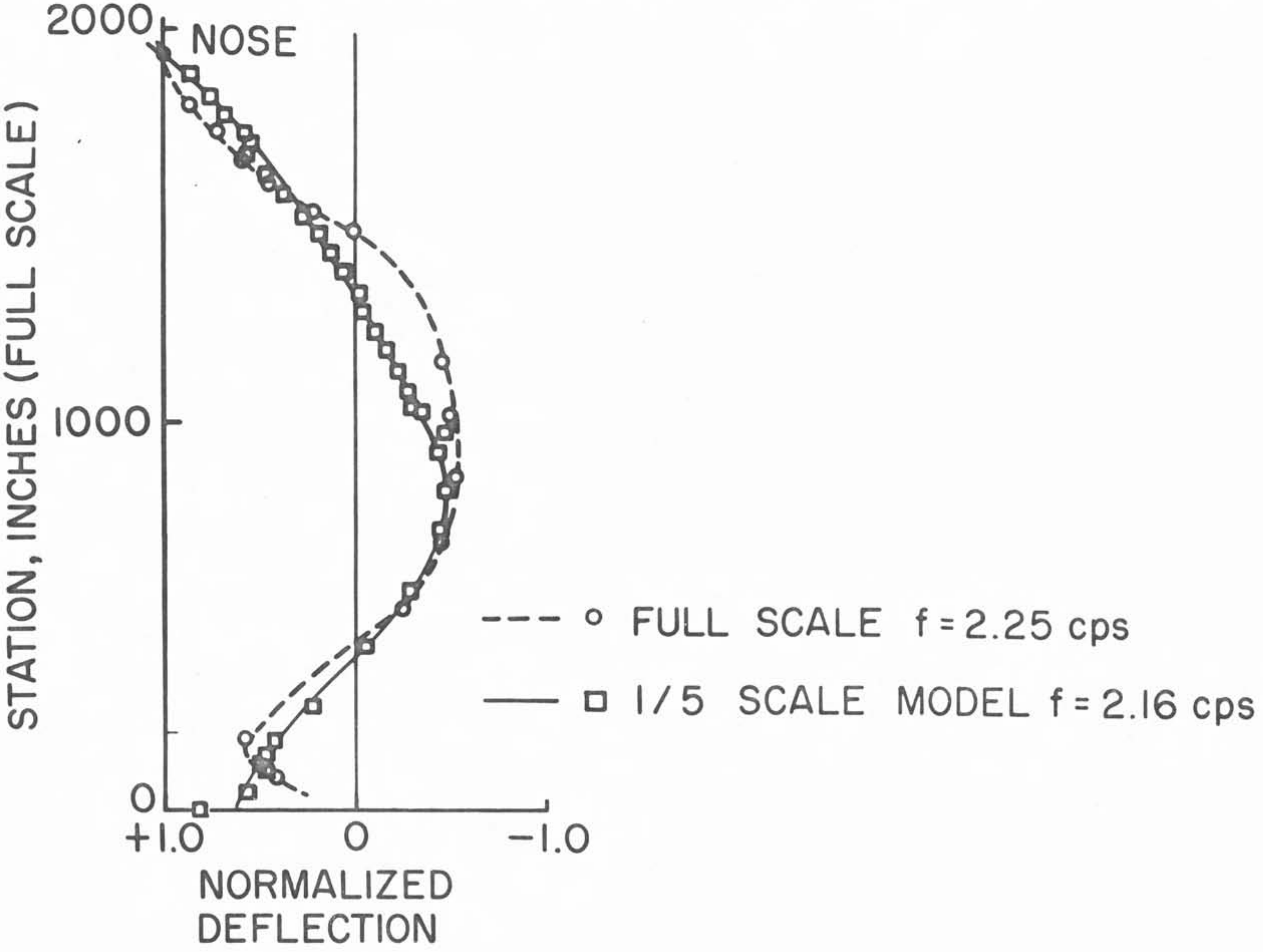

STATES

FULL SCALE SATURN VIBRATION TEST



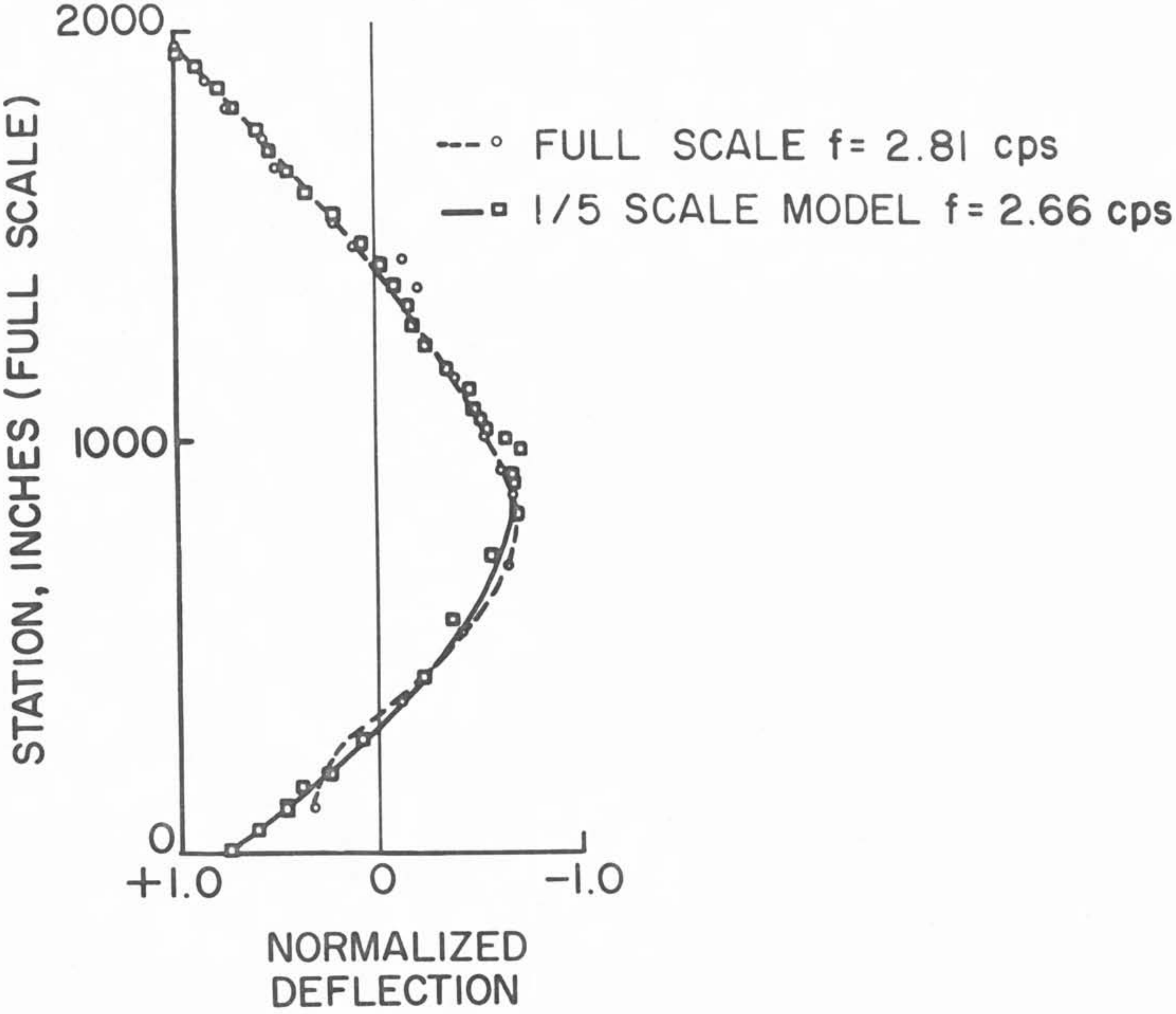
SATURN FIRST BENDING MODE DEFLECTION CURVES

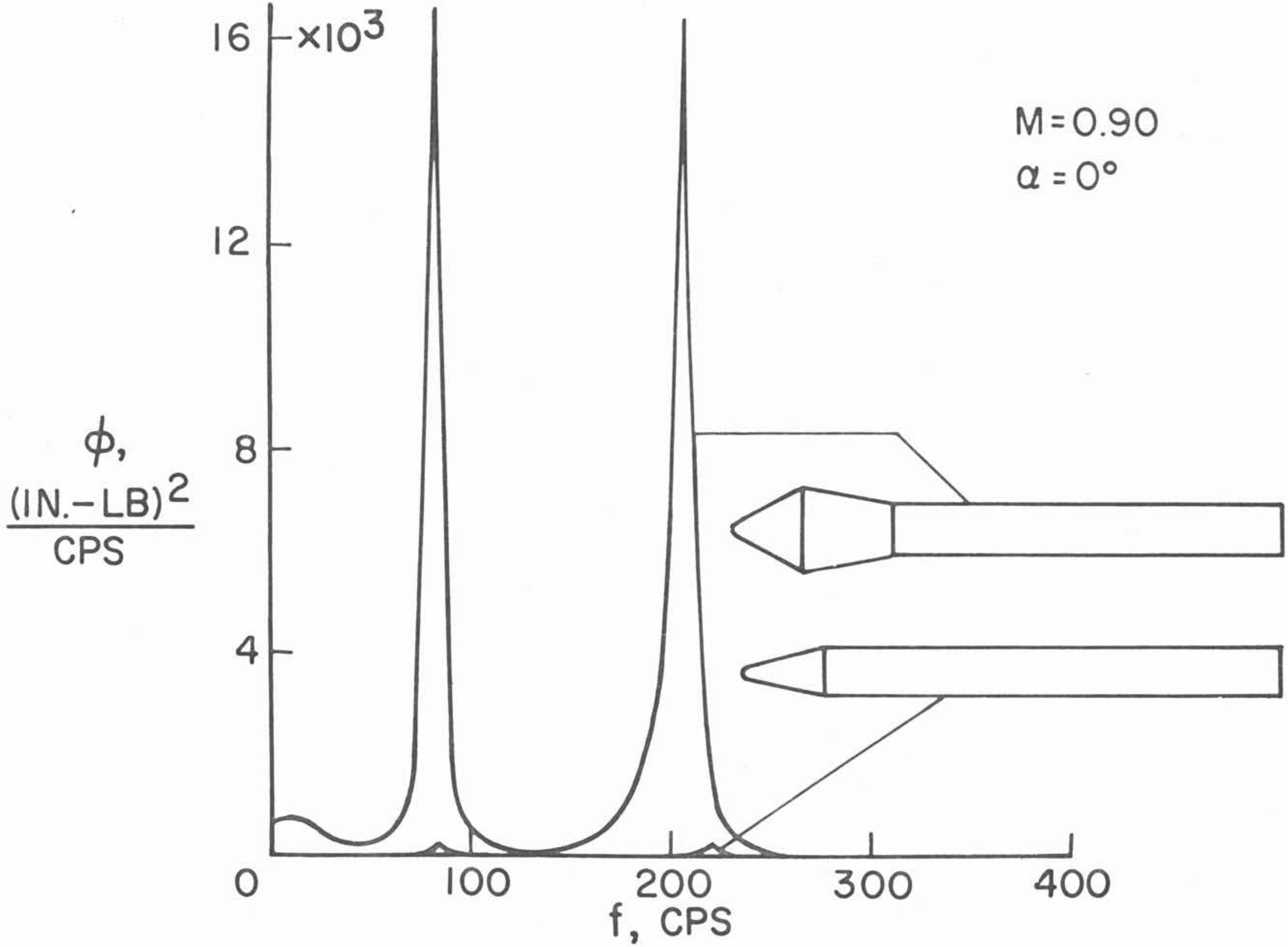
LIFT-OFF CONFIGURATION



SATURN FIRST BENDING MODE DEFLECTION CURVES

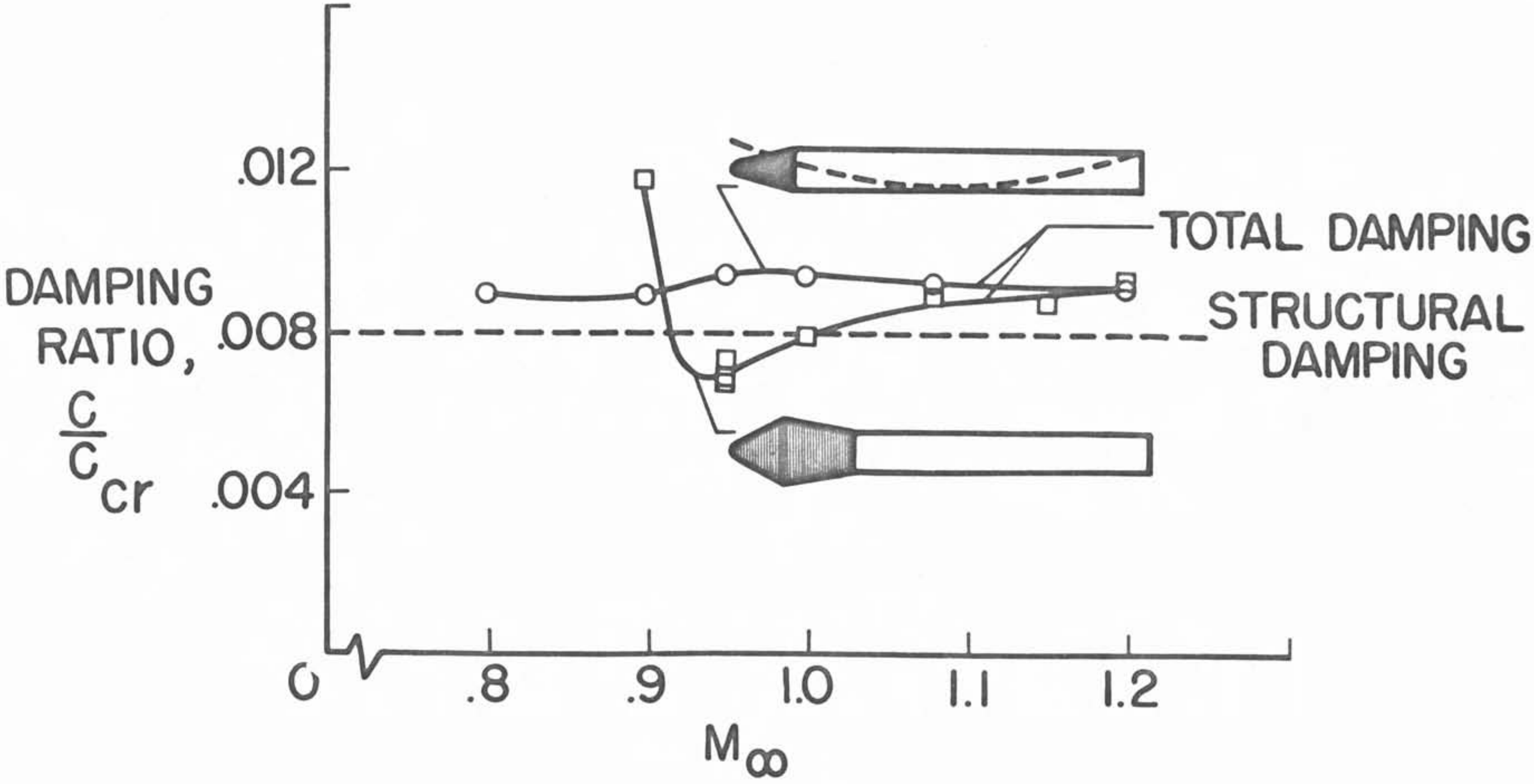
MAXIMUM q CONFIGURATION

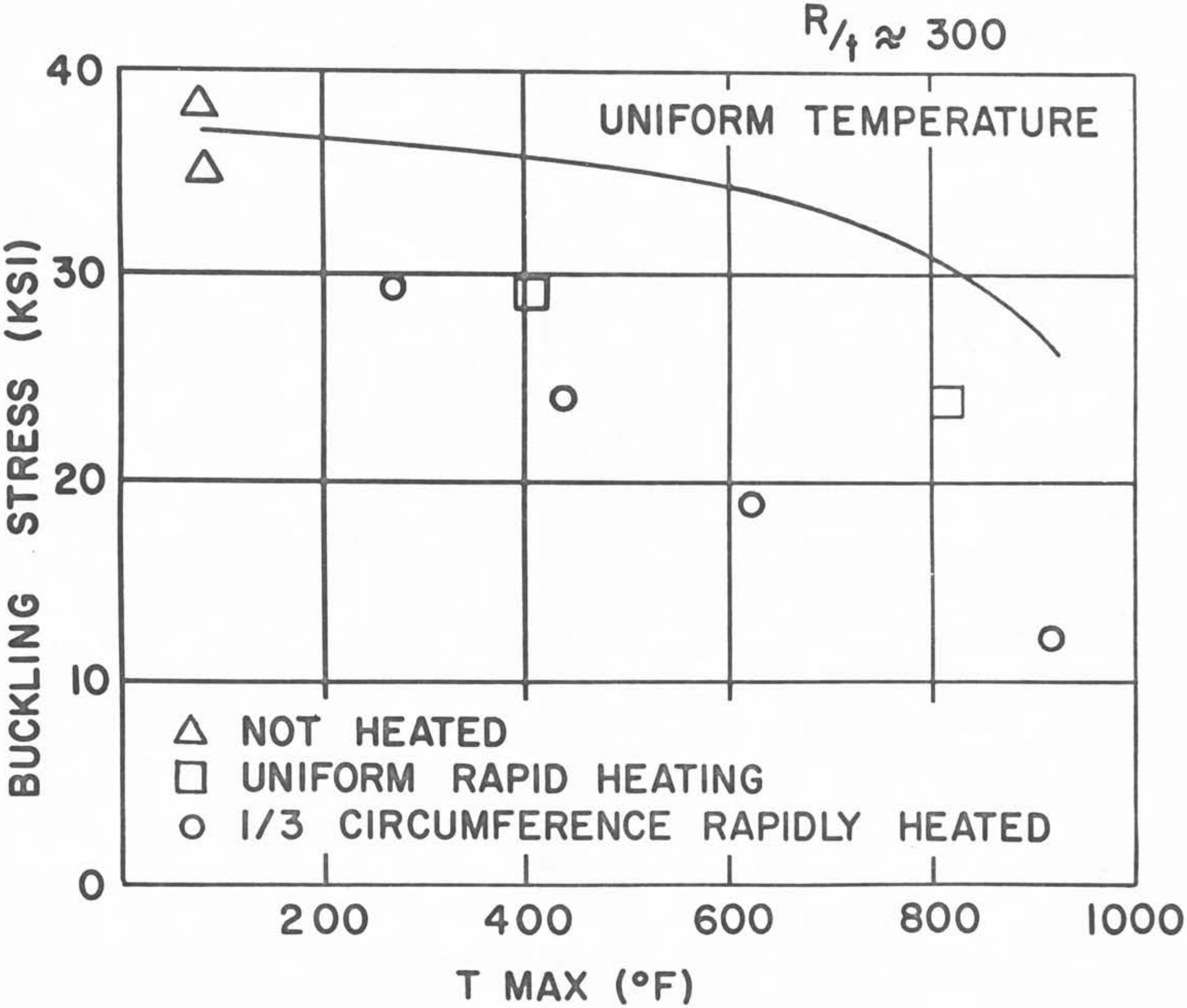




SPECTRUM OF BENDING MOMENT RESPONSE

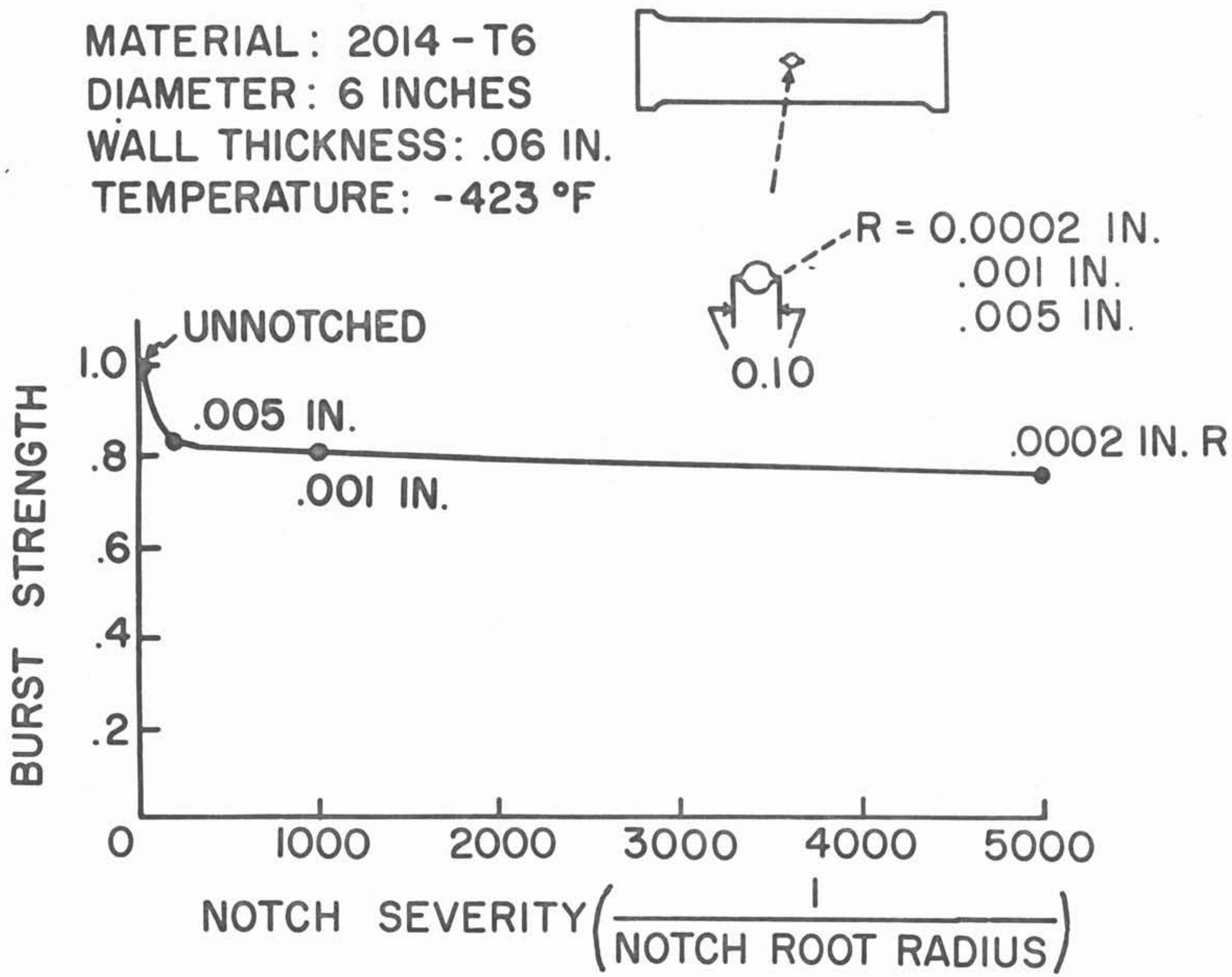
EFFECT OF NOSE SHAPE ON AERODYNAMIC DAMPING OF FIRST ELASTIC MODE





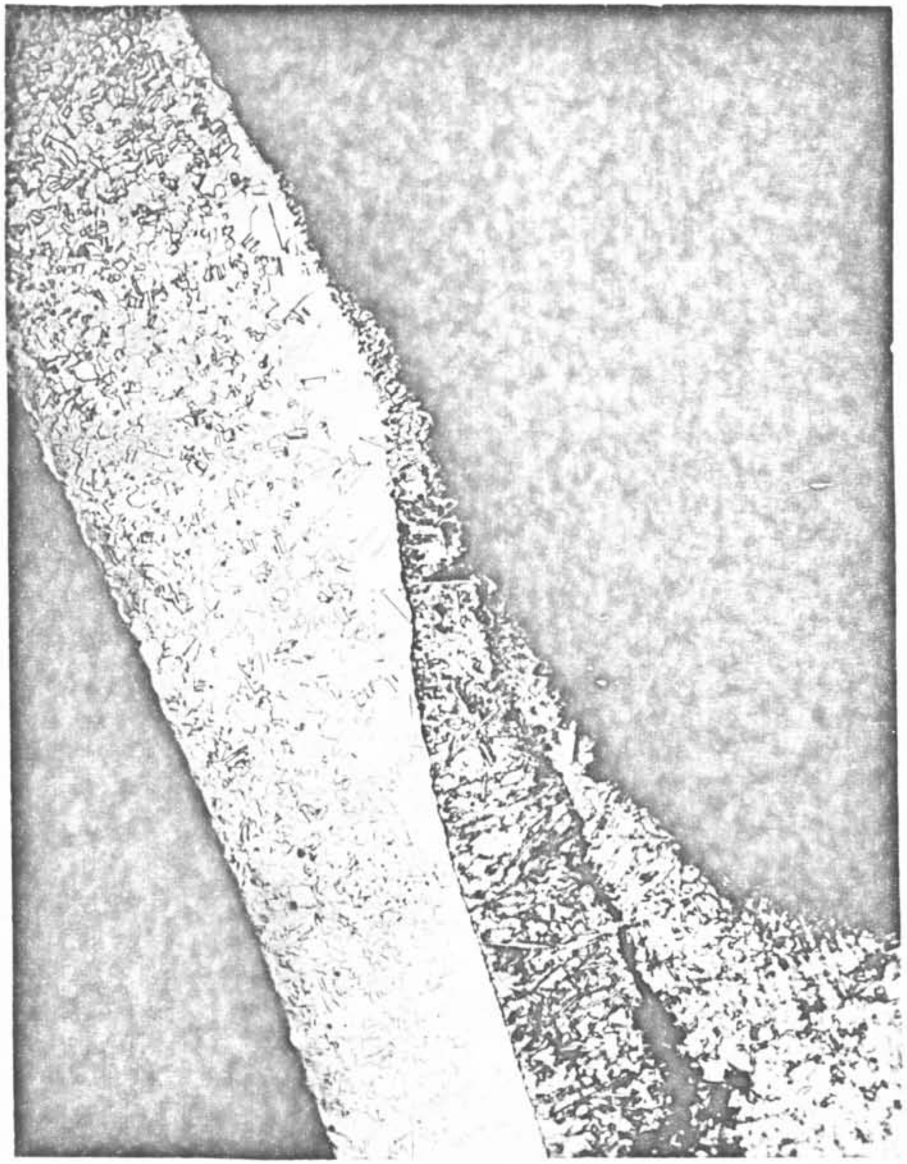
BENDING STRENGTH OF RAPIDLY HEATED STAINLESS STEEL CYLINDERS

BURST HOOP STRESS FOR NOTCHED ALUMINUM CYLINDERS



MATERIAL: 2014 - T6
DIAMETER: 6 INCHES
WALL THICKNESS: .06 IN.
TEMPERATURE: -423 °F

MICROGRAPH OF BRAZED TUBING



ENVELOPE OF DESIGN WIND PROFILES