FACILITY FORM 602

N66 22240
(ACCESSION NUMBER)

(THRU)

38
(PAGES)

1
(CODE)

TMX-56686
(NASA CR OR TMX OR AD NUMBER)

31
(CATEGORY)

# NASA LANGLEY SMALL METEOROLOGICAL SOUNDING ROCKET DEVELOPMENT PROGRAM

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Presented to Indian National Committee for Space Research
Seminar on Sounding Rocket Techniques and Experiments

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

Thumba, India
January 11, 1965

[redacted]

TMX 56686

NASA LANGLEY SMALL METEOROLOGICAL SOUNDING ROCKET

DEVELOPMENT PROGRAM*

Harold B. Tolefson**

## SUMMARY

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A program has been initiated at the NASA Langley Research Center to develop a small meteorological rocket system for atmospheric measurements in the altitude range from 30 km upwards to 70 km and possibly to 100 km. The objective is to provide a relatively inexpensive system for measuring the basic meteorological parameters of wind, temperature, density, and pressure with an overall reliability of 90 percent. Little or no restriction as to launch location or weather conditions and with direct short-time data availability are included. The paper discusses the work in progress and the achievements made to date. Future plans and the anticipated system progression are outlined.

author

## INTRODUCTION

The meteorological sounding rocket has been proven as a valuable tool for atmospheric research in the altitude region extending from about 30 km to 60-70 km. In order to increase the effectiveness of rocket probings of this portion of the atmosphere, programs are under way within the United States and elsewhere to develop a reliable and economical meteorological sounding rocket system. The Langley Research Center of the National Aeronautics and Space Administration is applying its background and experience with solid-propellant rockets and instrumentation systems to the meteorological rocket development problem. The ultimate goal of the NASA program is to provide a meteorological sounding rocket system for use in programs of repeated atmospheric samplings on a worldwide scale. The objectives of this program are reviewed in this paper, and the progress made to date, the research tools used in solving vehicle and payload problems, and future milestones are discussed.

## PROGRAM OBJECTIVES

In order to provide a brief background on the NASA sounding rocket development program, the objectives are summarized in figure 1 and will be discussed very briefly.

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*Presented to Indian National Committee for Space Research, Seminar on Sounding Rocket Techniques and Experiments, Thumba, India, January 11, 1965.

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The program objective is to provide a rocket system for obtaining measurements of the winds, temperatures, and densities to an altitude of about 65 km. Such measurements are of interest in connection with Atmospheric Research, Range Support, and Routine Meteorological Measurements.

First, in regard to Atmospheric Research, the vertical sounding type of measurement is one of the most powerful tools yet devised for studying the atmosphere and for developing weather forecasting methods. The conventional balloon sounding is limited to about 30 km, and although this altitude covers about 99 percent of the mass of the earth's atmosphere, research has shown that disturbances sometimes originate at altitudes much higher than 30 km, propagate downward, and influence the weather at the earth's surface. Meteorological rocket data are needed for research in these upper portions of the atmosphere to obtain a better understanding of events at the high altitudes, and to use this information to improve forecasting.

Secondly, such a rocket system is required for Range Support. Most launchings of space vehicles require atmospheric data for preflight and postflight studies and trajectory analysis problems. For example, unexpected high wind velocities might account for excessive drifts of a space vehicle from a desired trajectory, particularly during staging operations, if such winds were not accounted for in the guidance programing. As another example, all reentry studies require atmospheric density measurements at the point of reentry for a successful analysis of the heating history of the entering payload. Experiments such as project FIRE or the NASA Scout reentry series would not be controlled experiments without the best available information on the density of the atmosphere in which the experiment was conducted. A small rocket system for use at the range itself or one that can be used quite readily at downrange stations is thus needed for Range Support purposes.

A third objective of the program is to develop a rocket sounding system for Routine Meteorological Measurements. Reference is made here to synoptic or repeated types of measurements such as taken by the U.S. Weather Bureau or other agencies for use in meteorological studies. Such measurements also apply to the problem of establishing a set of launch vehicle design data. The beginning of a routine meteorological measurement program has been established through the informal joining of American range stations to form the so-called Meteorological Rocket Network. Cooperative programs have also been discussed with other countries for extending the Meteorological Rocket Network to a worldwide effort. A fully developed small meteorological sounding rocket system is needed for these meteorological purposes.

## SYSTEM REQUIREMENTS

A sounding rocket system which will serve the purposes outlined in figure 1 must meet a number of severe requirements. Some of the System Requirements are listed in figure 2.

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First, the system must provide accurate measurements of the wind, temperatures, and densities to altitudes of 65 km. These are needed to an accuracy of 1 to 5 percent depending on the element being measured.

Secondly, the measurements are to be provided with a reliability of at least 90 percent and with a minimum cost of expendables. The low-cost feature, of course, derives from the network type of application where large numbers of rockets are expended in routine observational programs.

Next, a worldwide operational capability with launchings from locations other than well-equipped ranges is necessary if the network concept is to be achieved. It should be possible, of course, to launch the rockets in bad weather as well as in good weather.

As a fourth requirement, provisions must be made for simple data readout and rapid transmission of data. For range support purposes, a near real-time readout system is needed as the value of an atmospheric measurement decreases rapidly with the passage of time.

Finally, minimum manpower and ground support is a desirable goal in any rocket launching and is especially important in the present case of repeated launchings from a number of locations.

## SMALL METEOROLOGICAL ROCKET CONFIGURATIONS AND OPERATIONAL EXPERIENCE

Several vehicle-payload combinations are under development and have been used in meteorological rocket sounding programs. Within the last 5 years, more than 4000 launches have been made in atmosphere data collection programs within the U.S. despite the fact that the vehicles were in the development stage during this time. This somewhat unusual situation of relying on not fully qualified vehicle systems for the operational collection of data has at times led to frustrating experiences for the users, but was the result of the requirement for a specialized meteorological sounding tool. Anxiety on the part of the user and the researcher to provide the needed atmospheric data tended to override the complete and systematic development of a meteorological sounding rocket system before it was placed in operational use. For these reasons, only few of the system requirements in figure 2 have been met.

The two general types of currently used rockets within the meteorological sounding rocket category are sketched in figure 3. The rocket in the left of the figure is a single-stage end-burning configuration and provides a thrust of 5g for about 28 seconds. Burnout occurs near 15 km, and the rocket then coasts to about 65 km. The nose cone separates from the motor case at that altitude and the payload is deployed. The payload may consist of an inflatable sphere which is tracked by radar for wind and density sensing, or it may consist of a telemetering package which is lowered by a parachute. Atmospheric temperature is ordinarily telemetered by the package and radar tracking of the parachute provides wind information.

The rocket in the right of figure 3 is of the boosted dart configuration and provides a thrust of about 50g for $2\frac{1}{2}$ seconds. The dart separates from the motor at burnout and coasts to about 65 km. The same sequence of events as noted for the end burner then occurs.

It is perhaps obvious that quite different philosophies have been followed in the development of the two sounding rocket configurations shown in figure 3. For the end burner on the left, the application of a long-burning propellant is advantageous because it may be possible to reduce peak g loading and also because more efficient conversion of thrust to vehicle velocity is realized based on the greater percentage of thrust time at the higher and more rarefied regions of the atmosphere. A greater ratio of propellant weight to inert components is also provided by the geometry of the end burning grain. The configuration shown in figure 3 provides a relatively large payload volume, the nominal volume being 300 cubic inches for instrumentation and parachute packaging. One of the principal weaknesses of this approach to an operational meteorological rocket vehicle is its inherent sensitivity to wind. Such wind sensitivity arises from its low acceleration (and velocity) during the early part of the flight and results in a requirement for precise ballistic analyses before each launching. These requirements are not in accord with the simple operational concept discussed earlier.

The boosted dart configuration is characterized by a high-g take-off, reaching a Mach number near 5.0 at the end of the 2-second burn period. Wind sensitivity is minimized, thus eliminating the complications of lengthy ballistic analysis. Its small payload volume, less than 30 cubic inches, and the high-g launch pulse, however, have led to instrumentation problems. The development of solid-state electronic devices and integrated microcircuitry hold considerable promise of alleviating these problems.

The optimum meteorological sounding rocket configuration perhaps lies somewhere between the two shown in figure 3. Efforts of the NASA Langley Research Center to define this configuration will be discussed later.

When viewed in the light of current thinking on rocket-propelled vehicles for other areas of research, meteorological sounding rockets are very small rockets indeed. Their small size, however, is by no means a basis for judging the amount of engineering involved in developing a satisfactory system. The remainder of this paper will discuss the engineering efforts currently under way at the Langley Research Center to develop a satisfactory meteorological sounding rocket system.

## APPROACH TO PROBLEM

The approach to the problem of developing a satisfactory meteorological sounding rocket system essentially consists of two parts: first, an effort to provide solutions to some of the problems encountered in the currently available systems; and, second, a study to determine the most feasible system for use in a program of frequent atmospheric measurements to 65 km. The altitude of 65 km is somewhat less than the ultimate objective of perhaps 100 km, but it covers the range where the synoptic requirement is best defined and can best be met.

## IMPROVEMENTS TO CURRENT ROCKET SYSTEMS

Considerable effort has been expended by the NASA Langley Research Center and other groups to provide solutions to problems which have arisen with the current end-burning type of meteorological rocket system. Some of the problem areas are shown in figure 4. These are rather broad areas and include the rocket motor, the complete flight vehicle, the means of separating the payload from the motor, the payloads themselves (inflatables, telemeters, sensors, and parachutes), and a definition of the onboard flight environment.

The research tools used to examine and define these problems are listed in figure 5. As noted in this figure, ground-based equipment available at the Langley Research Center and at the Wallops Range, and specially designed flight equipment are used. The majority of the ground-based equipment is available from other programs. The onboard equipment, however, is specialized for the meteorological rocket development program. The remaining paragraphs of this section will discuss the use of these tools in examining the problem areas noted in figure 4. A common format will be followed in discussing the different problem areas.

### Rocket Motors

Problem (see fig. 6).- One of the more important problems experienced with the rocket motor has been a catastrophic failure due to explosion soon after launch. Failures of this nature have not been limited to a particular motor, but needless to say, firings were halted when such failures did occur and an analysis was made of the failures.

Data.- Analysis of the failure mode was aided by high-speed film records from ground-based cameras and recovered motor case from firings conducted at the NASA Wallops Range. Conferences with the manufacturer and other users were also initiated to isolate the cause of failure.

Conclusion.- The conclusion was reached that premature burning of the forward grain was initiated by the gases and high pressures early in the flight.

Solution.- A modified method was developed for sealing the forward end of the rocket motor grain (application of inhibitor).

Result.- Motor failures from this cause have been essentially eliminated since this modification was made.

## Vehicle

Investigations of vehicle problems are outlined in figure 7. The high spin rate of the vehicle (ARCAS system) has caused problems in deployment of payloads. Both parachute and inflatable payloads tended to twist and tangle when separated from the spinning vehicle. Such twisting naturally led to difficulty in achieving proper deployment and operation. These problems were documented by radar tracking and signature data, onboard cameras, and simulation of spinning vehicle deployments in vacuum tank tests. One obvious quick fix for twisting of parachute suspension lines, a swivel, was applied with some beneficial effects. An attempt to reduce the spin rate from 20 cps to 8 cps introduced another problem. While this reduction in spin rate appeared to be reasonable from estimated aerodynamics, the flight-test results showed a pitch-up to high coning motions which resulted in unacceptable low apogee altitudes. Firings were halted at the 8-cps spin rate and an effort is under way to define the cause for this unexpected phenomenon. This investigation includes both analytical work and wind-tunnel testing and should provide data useful in estimation methods for many similar sounding rocket systems.

In another phase of this program, a technique of despinning a section or all of the vehicle just prior to payload deployment is under investigation. This approach should allow a more orderly parachute deployment and a less severe environment for ejection of inflatable spheres while still allowing the high vehicle spin rate as required by flight stability and dispersion requirements.

## Separation

High shock separation loads and hot sparks (fig. 8) from the firing of the pyrotechnic gas generator in the separation system were shown to be the cause of payload failures. The evidence of these failure modes was obtained through vacuum tank simulation, telemetry, and recovered parachutes which showed burn holes. It was concluded that the pyrotechnic charge was burning too fast with the generation of burning particles in the generated gases. A composition change was initiated and after minimum testing, the change was incorporated into the manufacturers assembly line production of the separation unit. Since this change was made, the separation loads have been reduced and the spark problem effectively eliminated.

## Inflatable Payloads

Improper inflation of inflatable meteorological spheres (see fig. 9) was observed from radar signature and tracking data and during vacuum tank simulation of full-scale deployments. It was verified that residual air in the loosely packed payloads and inconsistent release of the highly volatile inflation liquid (isopentane) were causing the improper operation of the inflatable payloads. These effects, as well as the effects of high spin rate on ejection of the payloads, were examined using vacuum tank testing techniques. In one such vacuum tank test, it was possible to simulate the pyrotechnic separation of a full-scale nose cone from a spinning booster in free fall (at altitudes above 65 km) with subsequent deployment of an inflatable payload.

Using data from such tests and continued development work, the inflatable payloads have been repackaged in a smaller volume within a clam-shell device similar to that used with the Echo balloons but in a simple mechanical form. The inflation capsule has been redesigned and testing is now under way to verify the operation. Successful deployments of the inflatable payloads have been made with the repackaged units.

## Parachutes

A parachute having slow and stable descent characteristics from altitudes upwards of 65 km is desirable for current wind- and temperature-sensing methods. High fall rates and unstable descents of the current standard meteorological parachute (fig. 10) were observed with radar tracking and long-range ground-based cameras. By the use of onboard cameras the deployment sequence of the standard parachutes was studied. New and stable parachute configurations have been designed with noticeable improvement in performance. Positive deployment techniques have also been incorporated. A number of free-flight tests have been made and additional tests are under way.

The type of parachute under development for high-altitude meteorological sensing is shown in figure 11. The parachute is designed on the basis of geometric porosity, that is, the effect of canopy porosity in achieving aerodynamic stability is obtained by allowing air to flow through the openings in the canopy. The parachute is referred to as the "disk-gap-band" configuration and for strength is made from reinforced mylar, the so-called "scrim" material. Rapid opening at the deployment altitude of 65 km is achieved through use of an inflatable torus on the lower inner edge of the band. Wind-tunnel and flight-test programs have been successfully completed as part of the development of the parachute. Qualification tests under operational conditions are being planned.

Experience in parachute development programs for high-altitude applications has shown that the most direct approach is to photograph the canopy during the deployment, inflation, and descent phases of flight. The camera package shown in figure 12 was developed for this purpose.

The photographic system basically involves a camera, power supply, and activation switch. The payload is housed in a fiber-glass shell and, due to uncertainty concerning the aerodynamic heating that would be experienced, a subliming material was applied as a protective coating to the entire package. The camera utilized is a NASA-modified Air Force N-9 type 16-mm gun camera. The major modifications included the removal of excess weight, modification of the drive mechanism to operate under high acceleration conditions, and rigidizing of the unit in general. Silver cell batteries were utilized for the power supply. The total weight of the assembled camera package is 9 pounds.

The system was tested for the anticipated rocket-borne environment, and each assembled unit was dynamically balanced at the approximate spin rate of the rocket. Wide-angle f/11 lenses, both 90° and 120° viewing angle, were employed so that the parachute canopy would remain in the field of view even while undergoing rather erratic motions.

Figure 13(a) shows sample frames from three flight films obtained with the camera package at an altitude of 55 km and also from reference films from helicopter drops at lower altitudes for the 90° and 120° lenses. On the first flight, a smudge appeared on the lens, probably caused by heating effects on the lens during ascent. For later flights, lens protection was provided during ascent. Also, the sun's reflection on the lens intermittently blanked out the image of the parachute canopy as the camera package experienced a coning motion while descending beneath the parachute.

On the second flight, the lens became coated with an oily residue. Fortunately the payload oscillated clockwise and then counterclockwise, such that periodically the shadow of the riser line fell across the lens. The shadow is the wide black band on the sample frame for flight 2 in figure 13(a) and permitted the canopy to become visible for short periods of time. For flight 3, two suspension lines became draped over the canopy during deployment and full inflation was never reached during descent.

A sample frame from a subsequent flight at an altitude of 65 km is given in figure 13(b). Also shown in figure 13(b) for reference is a frame showing a fully inflated canopy. The principal change to the design of the parachute shown in figure 13(b) was the addition of a swivel to the system between the riser line and the payload. The motion-picture sequences taken during these parachute tests provide considerable assistance in determining parachute operational characteristics and in solving operational problems.

## Environment

One of the problems in payload qualification has been the lack of accurate definitions of the vehicle-induced environment. A performance payload has been designed to define this environment and one flight test has been made with excellent results. In figure 14, the axial ($A_L$) accelerations measured during the launch, burn, and separation phases of the Arcas rocket are shown. The double-peaked launch acceleration history is due to the thrust buildup of the rocket itself to about 45g followed by the thrust of 60g provided by the gas generator for the particular closed-breech launcher used with this rocket. The steady in-flight thrust during burn phase increases from about 4g to 5g as weight is lost. The separation g loading is quite high. The peak shock which builds up to 75g within only a few milliseconds has caused a number of telemetering-payload failures. The cause of the double peaks at separation is not known, but the second peak might be due to the rivets which hold the nose cone being sheared during the separation sequence.

Additional performance payloads are being prepared and other flights are planned to document further the onboard flight environment of not only this particular rocket, but also other rockets as they are developed in the NASA meteorological sounding rocket program.

As a brief summation at this point, evaluation of future sounding rocket systems and payloads can be conducted with confidence with the equipment and techniques developed in this program. The field fixes as well as major modifications to present systems will be considered in planning and designing future small meteorological sounding rocket systems.

## PAYLOAD DEVELOPMENT

One of the most pressing problems concerning meteorological rocket payloads is that of reliability. The reliability of temperature-sensing payloads has been as low as 25 percent, and currently the reliability is not more than 50 percent for temperature measurements to 65 km. Increasing the measuring capability to 100 km will require extensive effort, since present state-of-the-art sensors for the higher altitudes do not lend themselves to a network type of operation.

Most tracking facilities use large expensive radars to provide slant range and altitude information, and a tracking receiver to provide meteorological data. It is perhaps desirable that future tracking systems include automatic data processing equipment to provide data in direct real-time read-out for better launch support as well as weather information. Improved accuracy can be achieved by general overall system improvement. The three-step program in figure 15 outlines the NASA development effort which is directed at achieving these goals of increased payload reliability, accuracy, and altitude performance.

The first step in the payload development program is to improve the reliability and accuracy of currently available sensors and payloads. Most of the current effort at the Langley Research Center has been centered around this improvement program. The second step is to design an interim system which will incorporate payload improvements found desirable from the current study. This procedure will result in an operational payload for wind, temperature, and pressure measurements to 65 km. The final development of a 100-km system will follow. Some current work involved in the first phase of the improvement program is discussed in the following section of this paper.

### Improvements to Present Systems

Figure 16 indicates the general areas in which improvements are being made to current telemetering payload systems.

Tube Ruggedization Program.- The transmitting tube developed originally for balloonsondes was suspected at the onset of the program as being one of the weak links contributing to poor payload reliability. The problems associated with the transmitting tube are:

(a) Life expectancy of the pencil tube of only 5 hours

(b) Stamped metal cavity that will distort under acceleration and shift the carrier frequency

(c) Poor temperature characteristics

An improvement program was undertaken to develop a ruggedized version of the pencil tube and cavity. The electrical characteristics and physical size were maintained to permit the incorporation of the tubes in the present payloads with no design changes. The tube development program has been completed, and prototype flight qualification tests are in progress.

Power supply.- A new battery pack has been designed at the Langley Research Center and is composed of 107 mercury cells welded together and encapsulated in Echo-foam. Life tests indicate that the new packs will last at least $6\frac{1}{2}$ hours. Shelf life will be increased by at least 6 to 8 times, or in in the neighborhood of 3 to 4 years. Initial flight tests of the battery pack have indicated complete reliability.

Range tracking.- Preliminary studies of tracking problems indicate that the so-called GMD-2 should perform adequately for the first phase of the meteorological rocket payload development program. One of the major areas of concern has been the range ambiguity problem in obtaining slant range information, but modifications are now being made to the equipment by the manufacturer to correct the ranging problem. Other developments based on X-band and S-band radar systems for tracking meteorological rocket payloads and acquiring and processing the meteorological data are being closely followed and will be incorporated into the small rocket system as necessary.

Thermistor mount.- Another problem area concerns the method of mounting the temperature-sensing thermistor to the sonde itself. A number of thermistor failures were experienced during laboratory vibration tests of telemetering payloads. The similarity of the thermistor mount to that of a tuning fork may be noted in the sketch included in figure 16, and at some point during the vibration test, the posts would resonate and deflect sufficiently to destroy the thermistor. Corrections are being made to prevent these failures.

RF heating.- An important problem associated with the thermistor mount is that of RF (radio-frequency energy) heating errors since the thermistor is normally located in a fairly strong radiation field. Studies have shown that the RF error can be as high as $10^{\circ}$ C under a simulated pressure altitude of 50 kilometers. Other temperature-sensing errors may arise due to heat conduction along the leads, and heating due to convection, radiation, and aerodynamic effects. A new thermistor mount has been fabricated to minimize these temperature measurement errors. Figure 17 is a photograph of the thermistor mount and assembly method.

The mount shown in the photograph consists basically of a 1-mil-thick Mylar film which is bonded to two upright phenolic posts. Onto this Mylar film is vacuum deposited (in opposed surfaces) two U-shaped films of silver of about

40,000 Å thickness. The metallic films form the electrical conduction paths for measuring the thermistors resistance. The thermistor itself is soldered between the opposed silver film at its top edge and at the center where two legs of the U's are exactly opposed. The two legs actually form a transmission line which is resonant at the transmitter frequency. The result is to provide an effective short circuit across the bead for any RF power absorbed by the electrical portion of the mount.

Recent flight tests have confirmed analytical and laboratory findings on the operational characteristics of the thermistor mount, and considerably improved response characteristics are indicated.

Figure 18 indicates the nature of the improved temperature data obtained with the use of the new mount. Of particular interest are the results in figure 18(a) of a flight with a dual-channel prototype payload launched at Wallops Island. The results indicate a decided improvement in the thermal time constant of the new mount as compared with the conventionally mounted thermistor. The 1962 reference atmosphere temperature profile is included in figure 18(a) for purposes of comparison. Figure 18(b) shows two separate temperature profiles obtained from meteorological rocket flights at the Eastern Test Range which indicate the improved thermal time constant of the sensor. The modified mount permits the thermistor record to follow the typical negative slope of the standard atmosphere at altitudes above about 15 km. The reversal in the slope of the temperature-altitude profile at these altitudes has not been indicated by previous thermistor rocket systems.

## Interim Payload

The elements of the interim payload for the meteorological sounding rocket system are given in figure 19. The payload will incorporate a new antenna design to give broad lobes of signal off the nose and tail to insure an adequate signal for tracking and data acquisition during both ascent and descent. The new payload will also have a new solid state transmitter capable of withstanding the higher accelerations experienced with most small rocket solid propellant systems. Much progress has been made in solid state circuitry and recently two 1750-Mc oscillators survived the 20,000g shock of a gun launch and operated for approximately 2 minutes before failure due to the high aerodynamic heating encountered in a gun probe launch.

Microcircuits will be used in designing the electronics to reduce the payload size and weight. Reductions in weight are desirable for maintaining a subsonic velocity during the parachute descent phase of flight. Since no major breakthroughs are anticipated in sensor design in the near future, the payload will probably use thin film type immersion temperature sensors. Thin film techniques appear to be the best method of improving the sensor time response as well as reducing conduction errors. Aerodynamic heating is one of the more predominant sources of error in temperature measurements at high altitude with contemplated meteorological rocket systems, and wind-tunnel tests will be run on the payload to determine the magnitude of these errors. It is anticipated that a pressure transducer will be included in the payload to provide some redundancy in measurements.

Tracking systems are being studied, and it has been noted that current improvements to the GMD-2 unit may prove satisfactory for the interim payload.

### Future Development

As was noted in connection with figure 15, future developments include payloads capable of extending atmospheric measurements to 100 kilometers. Continued research will be required in sensor development for the higher altitudes. The feasibility of taking the measurements during rocket ascent will be closely examined in order to decrease the overall sounding time. Extensions to the range of ground tracking and data acquisition equipment will be required to cover the higher altitudes.

## VEHICLE SYSTEM DEVELOPMENT

There is a great difference in range time and operational effort between launching a vehicle of low acceleration and one of high acceleration. Due to the high wind sensitivity of the low acceleration vehicle, it is necessary to determine wind data and compute launcher corrections even for relatively mild wind profiles. A prominent example of such a vehicle system is the end-burning configuration which was sketched in figure 3 and which has been in use for 5 years at Wallops Island for synoptic and research support measurement of wind, temperature, and density. Inherent with this system are large impact dispersions ($1\sigma$ = 12 n. mi.), thereby requiring large area surveillance by aircraft and radar. These are major operations using complex and costly equipment and requiring efforts comparable to those associated with the launching of large rocket systems. Most important of all, the low-g vehicle cannot be launched when wind conditions are more severe than moderate. Aside from certain exceptions, this type of vehicle is not launched at Wallops when surface winds exceed 22 ft/sec.

In late 1962 the Langley Research Center conducted a preliminary study to determine:

1. What modifications could be made to the low-g end-burning configuration vehicle to insure that it would meet the objectives of reliability, simplicity, and economy.

2. If these objectives could not be achieved with the existing vehicle, to determine the vehicle or "off-the-shelf" rocket motor around which such a vehicle could be designed. As has been implied, the economy consideration is not limited to purchase cost alone but also involves prelaunch operational costs.

In the course of this vehicle study, several potential "fixes" for the extreme wind sensitivity of the end-burning configuration were examined, such as:

1. Decreased static stability to make the vehicle less responsive to winds.

2. Prespinning the vehicle at a high rate to reduce dispersion.

3. Increased velocity of exit from the launch tube in order to traverse more rapidly the lower portion of the atmosphere.

The only significant improvement noted in the study was that associated with increased velocity of exit from the launch tube. However, the exit velocity required for any appreciable improvement was of such magnitude as to be impractical.

A follow-on study was also conducted to determine the acceleration required to reduce the wind sensitivity of a vehicle of this type to a tolerable level. Although optimum acceleration values were not established, the results from this investigation clearly showed the beneficial effects of high-g acceleration on reduction of dispersion due to wind.

These studies have not resulted in any modification to the current end-burning configuration which would reduce its wind sensitivity, nor has a survey of available rocket motors yielded any motor, within the economy consideration, that has propulsion characteristics required for low sensitivity to winds. These several short-term vehicle system studies have, nevertheless, provided helpful potential vehicles which may be proposed as meeting the requirements for a meteorological rocket vehicle for synoptic application.

A contractual study is currently being made to determine the most feasible vehicle for use in a program of frequent periodic atmospheric measurements to 65 km. Although this is somewhat less than the ultimate altitude objective, it covers the altitude range where the synoptic requirement is presently most definitive. The vehicle will be defined in terms of configuration (as to size, envelope, aerodynamic parameters) and propulsion (such as method, stages, motor performance and associated parameters) rather than by reference to trade names. This vehicle must satisfy, within the "state-of-the-art," the general requirements which were outlined earlier in figure 2.

## Vehicle System Approaches

Some of the possible types of vehicle systems which are being considered in the feasibility study are listed in figure 20. In general, the various propulsion systems are to be studied to arrive at a lightweight and simply launched vehicle. Successive launchings should result in a close matching of trajectories. It is desired that the vehicle be capable of routine nonwind-weighted launchings in surface winds up to 30 fps.

Following the vehicle feasibility study, specifications for the detail design and fabrication of the vehicle selected will be prepared. Meanwhile, the Langley Research Center of NASA is keeping abreast of any developments in sounding rockets which show promise of meeting the requirements of the meteorological rocket system development program.

## Falling Mass Hazard Criteria

Another problem area in the development of a Small Meteorological Sounding Rocket System is the long-range objective of making an "any location" firing feature possible. For this objective to come into being, a reliable technique must be established for reducing to a safe level the falling mass hazards associated with rocket vehicle inert components. At this point, it would perhaps be of interest to mention the guidelines on what constitutes a falling mass hazard as established by the U.S. Army Missile Command with whom NASA is cooperating in seeking a solution to the problem. Briefly, a falling mass hazard is considered to exist if a falling particle constitutes a fire hazard, or has a kinetic energy of 1 ft-lb or greater, or has a weight greater than 0.1 lb.

At present, the two leading potential techniques for elimination of falling mass hazards are explosive fragmentation and consumable. In a joint study of these techniques, the NASA is supporting an investigation and development of the explosive fragmentation technique. The Army Missile Command is supporting a contract for the consumable approach.

For the past several years approximately a half dozen firms have been working in this area. Previous work in this area has consisted of testing material samples and applying the particular destruct technique to the samples and components which simulated rocket motor parts. The current contractual effort will result in the design and fabrication of rocket-motor vehicle-systems for static firing and initiation of the destruct technique and for simulated altitude proof testing of the technique. Follow-on effort will include flight-test qualification of the technique selected for eliminating the falling mass hazard.

## Vehicle Progression

The anticipated vehicle progress with respect to time is shown in figure 21. Improvements to the current end-burning rocket configuration are expected to continue and this vehicle will remain in operation for another 1 to $1\frac{1}{2}$ years. The new 65-km vehicle just discussed is expected to be fully qualified and in operation by that time. A vehicle capable of operating to 100 km is the next step; some overlap with the 65-km vehicle is shown in figure 21 since the current study includes possible extension of altitude range to 100 km. Elimination of falling mass hazard and the application of mass production to achieve low unit cost will result in the final vehicle for "any location" operations to 100 km.

## CONCLUDING REMARKS

The preceding discussion has outlined efforts within the NASA Langley Research Center to develop a small meteorological sounding rocket system for use in repeated atmospheric measurements to altitudes of 65 km and ultimately to 100 km. A number of improvements have been made to available rocket-payload systems to increase the reliability and performance of present-day rocket equipment. The work currently in progress and that planned for the future is providing a step-by-step solution to the many problems involved in developing an optimum high-altitude meteorological sounding rocket system.

DEVELOP A SMALL ROCKET SOUNDING SYSTEM TO MEASURE WINDS, TEMPERATURES AND DENSITIES TO 65 KM FOR:

- ATMOSPHERIC RESEARCH
- RANGE SUPPORT
- METEOROLOGICAL MEASUREMENTS

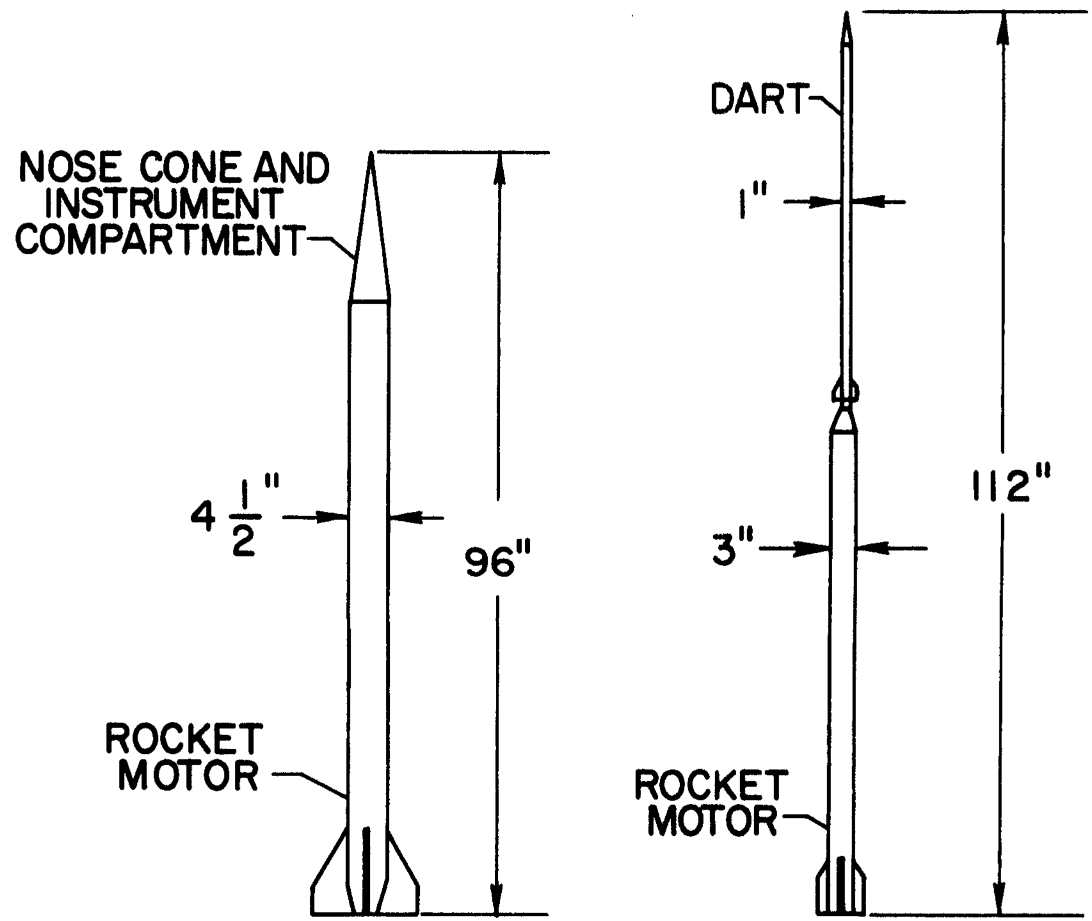
NASA

Figure 1.- Objectives of NASA Langley small meteorological sounding rocket development program.

- PROVIDE ACCURATE WIND, TEMPERATURE, DENSITY DATA
- HIGH RELIABILITY, LOW COST
- ALL-WEATHER, WORLD-WIDE OPERATIONAL CAPABILITY
- SIMPLE DATA READ OUT
- MINIMUM GROUND SUPPORT

NASA

Figure 2.- Requirements of small meteorological sounding rocket system.




NASA

Figure 3.- Current meteorological sounding rocket configurations.

- ROCKET MOTOR
- VEHICLE
- SEPARATION
- INFLATABLE PAYLOADS
- INSTRUMENTED PAYLOADS
- PARACHUTES
- FLIGHT ENVIRONMENT DEFINITION

NASA

Figure 4.- Problem areas of current flight systems.

GROUND BASED

- VACUUM TANKS
- CAMERAS
- ROCKET FACILITIES
- VIBRATION EQUIPMENT
- TELEMETRY STATIONS
- RADAR

ONBOARD

- CAMERAS
- DATA RECORDERS

NASA

Figure 5.- Research tools for studying flight vehicle problems.

| | |
|---|---|
| PROBLEM: | BLOWS UP |
| DATA: | GROUND CAMERAS<br>RECOVERED MOTOR<br>OTHER USERS |
| CONCLUSION: | PREMATURE BURNING |
| SOLUTION: | CHANGE INHIBITOR |
| RESULT: | MOTOR FAILURES ELIMINATED |

NASA

Figure 6.- Investigation of rocket motor problems.

HIGH SPIN RATE (20 CPS)

- RADAR
- ON BOARD CAMERAS
- VACUUM TANK TESTS

TWISTING PAYLOADS

- SWIVELS
- LOWER SPIN (8 CPS)
- DESPIN AT SEPARATION

NASA

Figure 7.- Investigation of vehicle problems.

HIGH LOADS

HOT SPARKS

- VACUUM TANK
- TELEMETRY
- RECOVERED PARACHUTES

PYROTECHNIC TOO FAST

- COMPOSITION CHANGE

LOADS REDUCED

SPARKS ELIMINATED

NASA

Figure 8.- Investigation of payload separation problems.

IMPROPER INFLATION

- RADAR SIGNATURE
- LOW FALL RATE
- VACUUM TANK

RESIDUAL AIR RUPTURE

CAPSULE FAILURE

- REPACKAGE
- REDESIGN CAPSULE

SUCCESSFUL DEPLOYMENT

NASA

Figure 9.- Investigation of inflatable payload problem.

HIGH FALL RATE

UNSTABLE DESCENT
- RADAR
- CAMERAS

IMPROPER DEPLOYMENT

PARACHUTE UNSTABLE
- STABLE DESIGNS
- POSITIVE DEPLOYMENT

TESTS UNDERWAY

NASA

Figure 10.- Investigation of parachute problems.

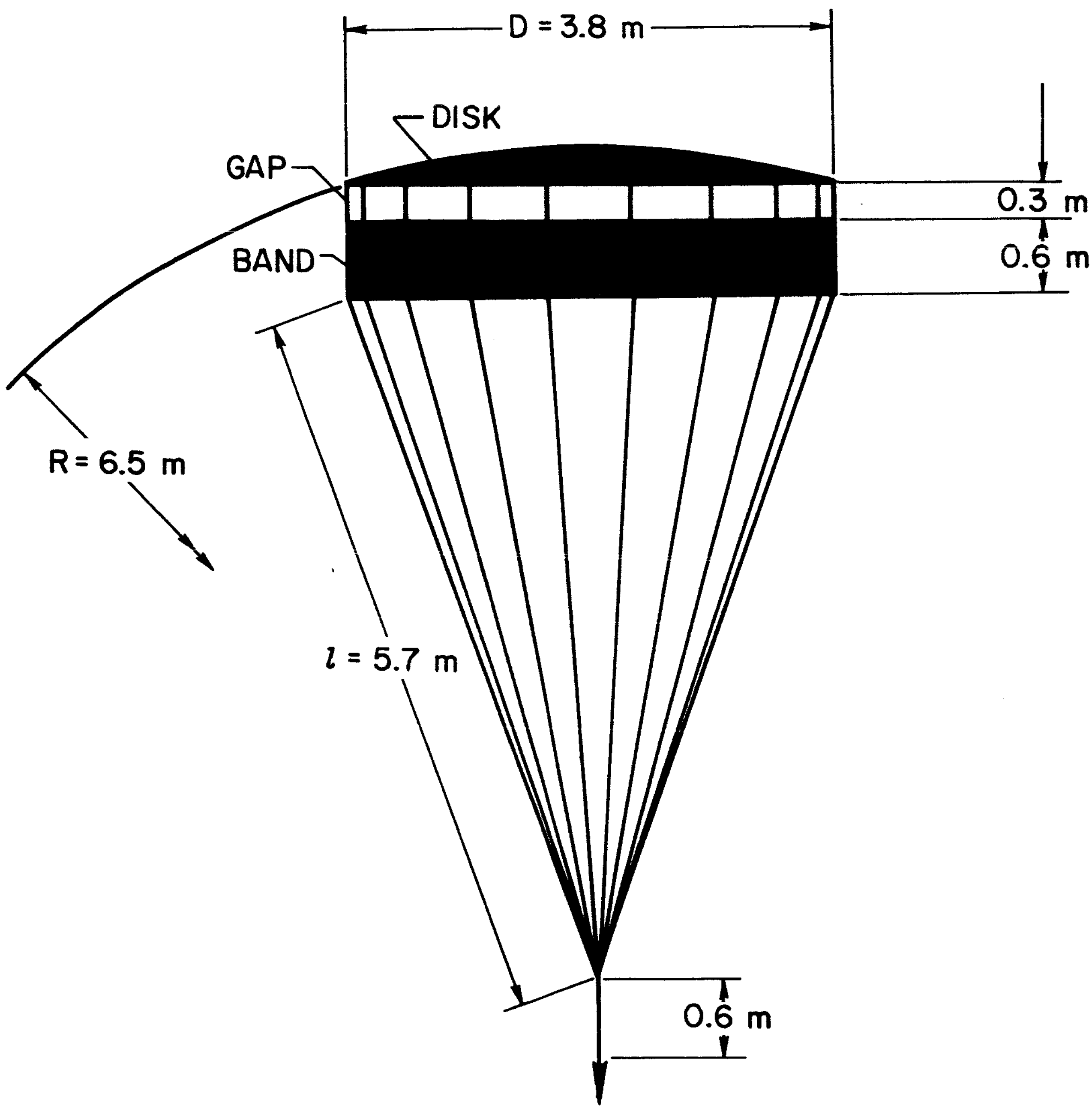



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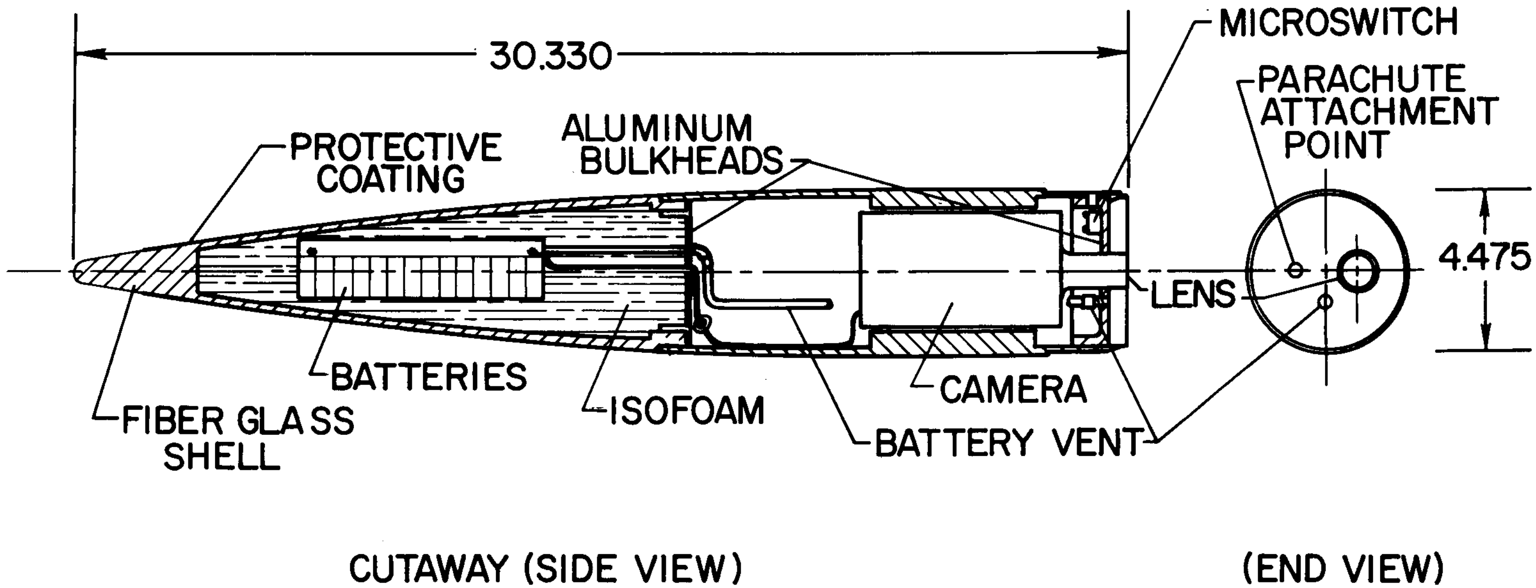
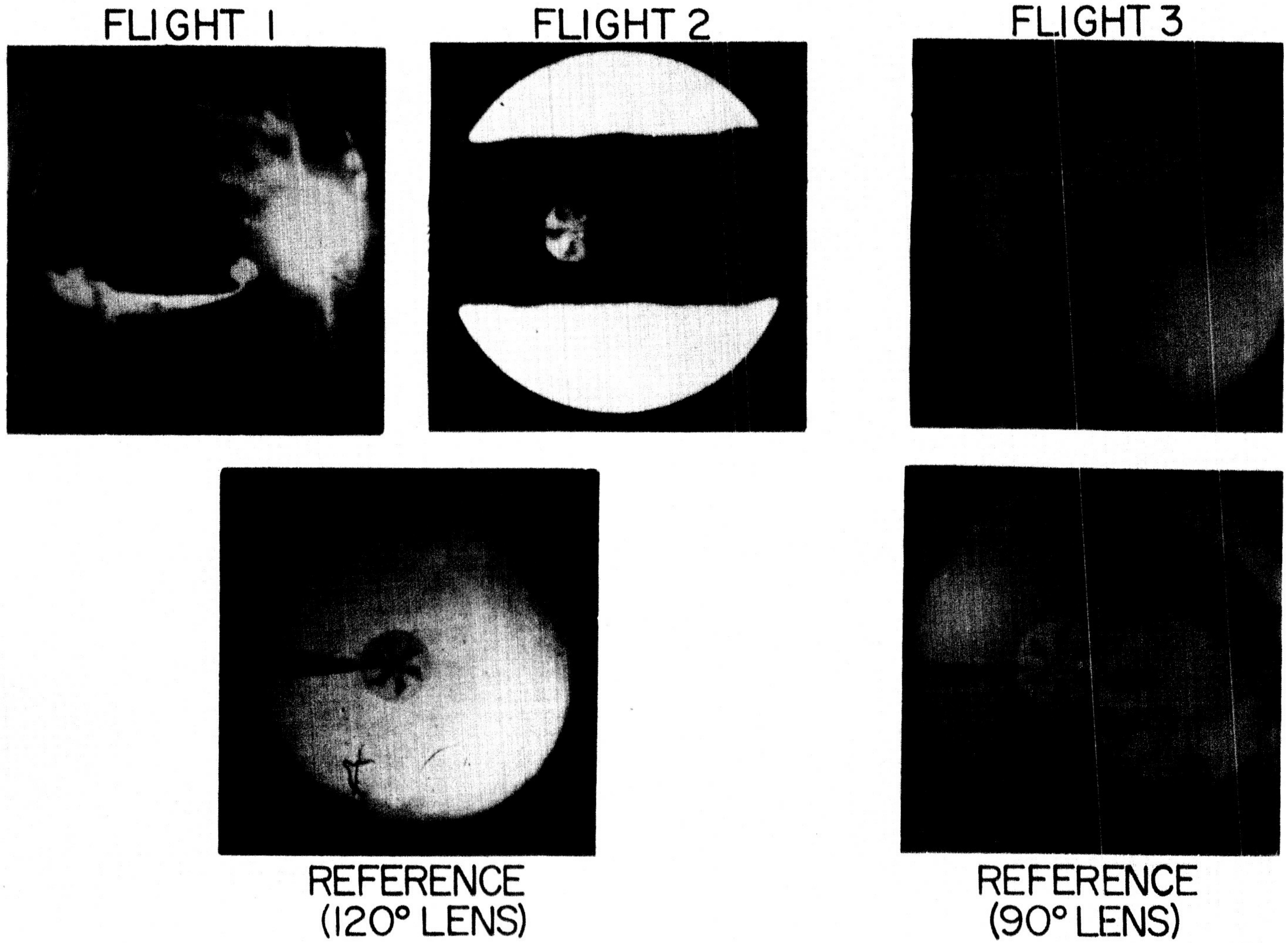
Figure 11.- High-altitude meteorological parachute configuration (all dimensions approximate).




NASA

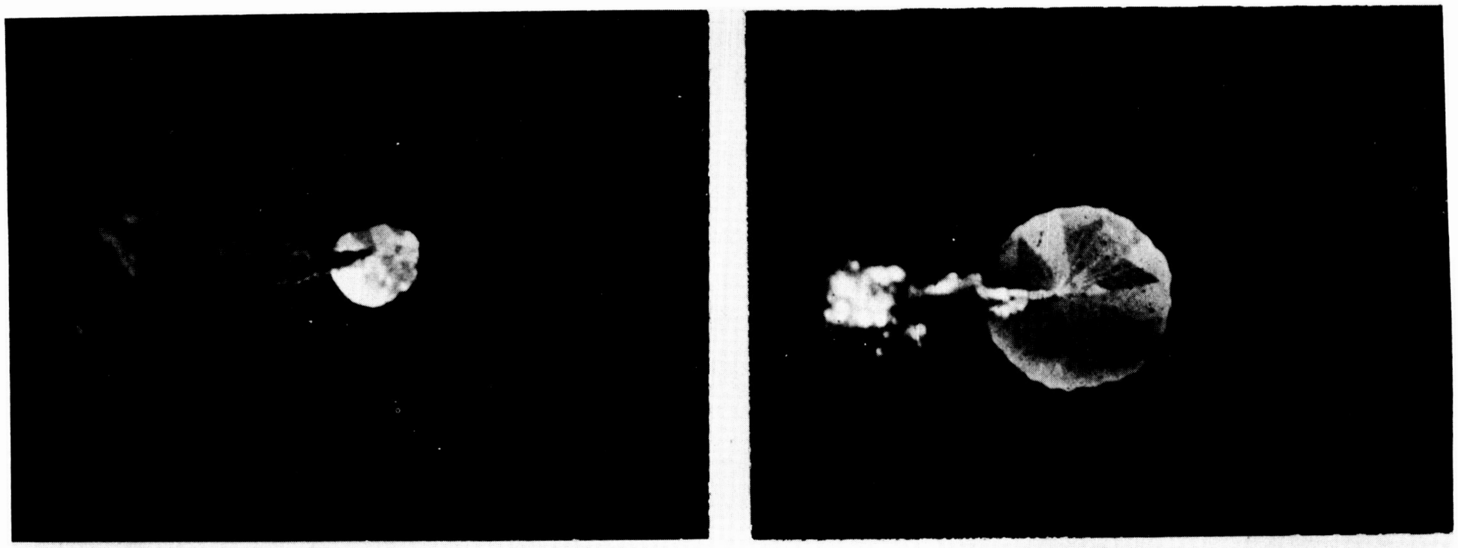
Figure 12.- Assembly drawing of in-flight camera package.




(a) Early flights, altitude 55 km.

NASA

Figure 13.- Sample photographs of parachute operation.



FLIGHT,
200,000 FT

REFERENCE

(b) Later flights, altitude 65 km.

Figure 13.- Concluded.

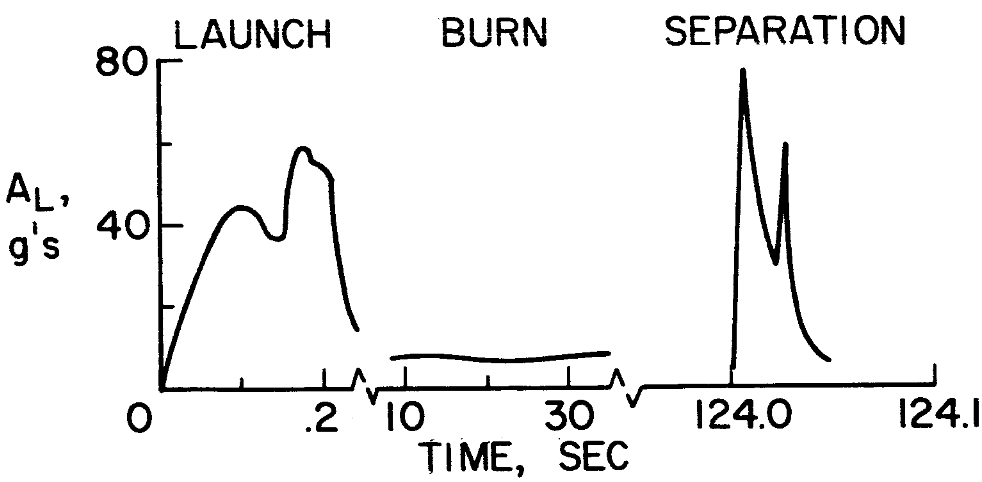
NASA

ENVIRONMENT NOT KNOWN

- LACK OF FLIGHT DATA
- INSTRUMENT FAILURES

PERFORMANCE PAYLOAD

ENVIRONMENT DEFINED




NASA

Figure 14.- Flight environmental measurements.

- IMPROVE RELIABILITY AND ACCURACY OF PRESENT SYSTEM
- DESIGN INTERIM SYSTEM – WINDS, TEMPERATURE (PRESSURE)
- DEVELOP FUTURE SYSTEM FOR MEASUREMENTS TO 100 KM

NASA

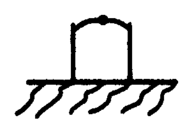
Figure 15.- Payload development program.

TUBE RUGGEDIZATION

POWER SUPPLY

RANGE TRACKING

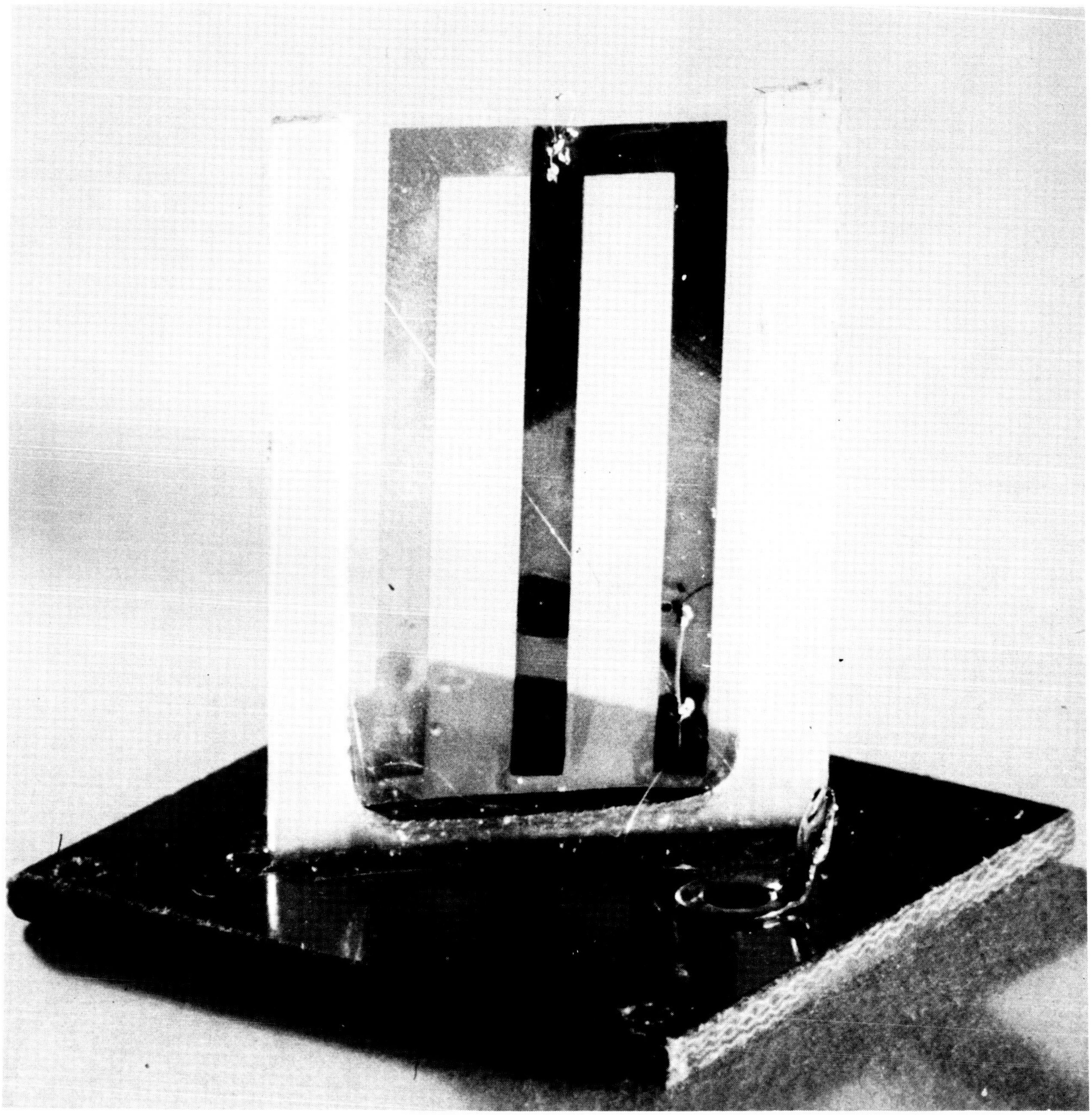
THERMISTOR MOUNT



RF HEATING ERRORS

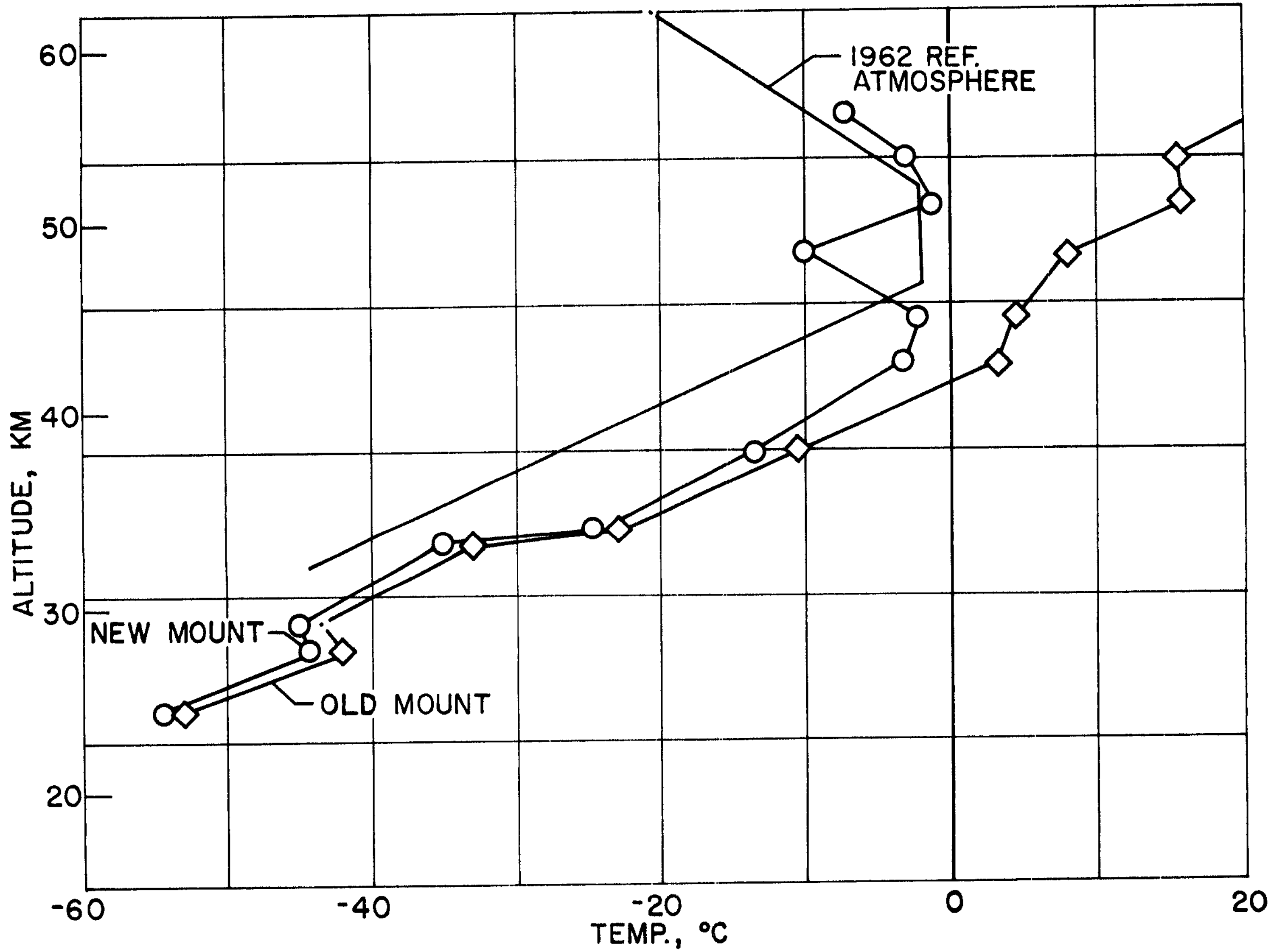
NASA

Figure 16.- Improvements to current meteorological telemetering payloads.



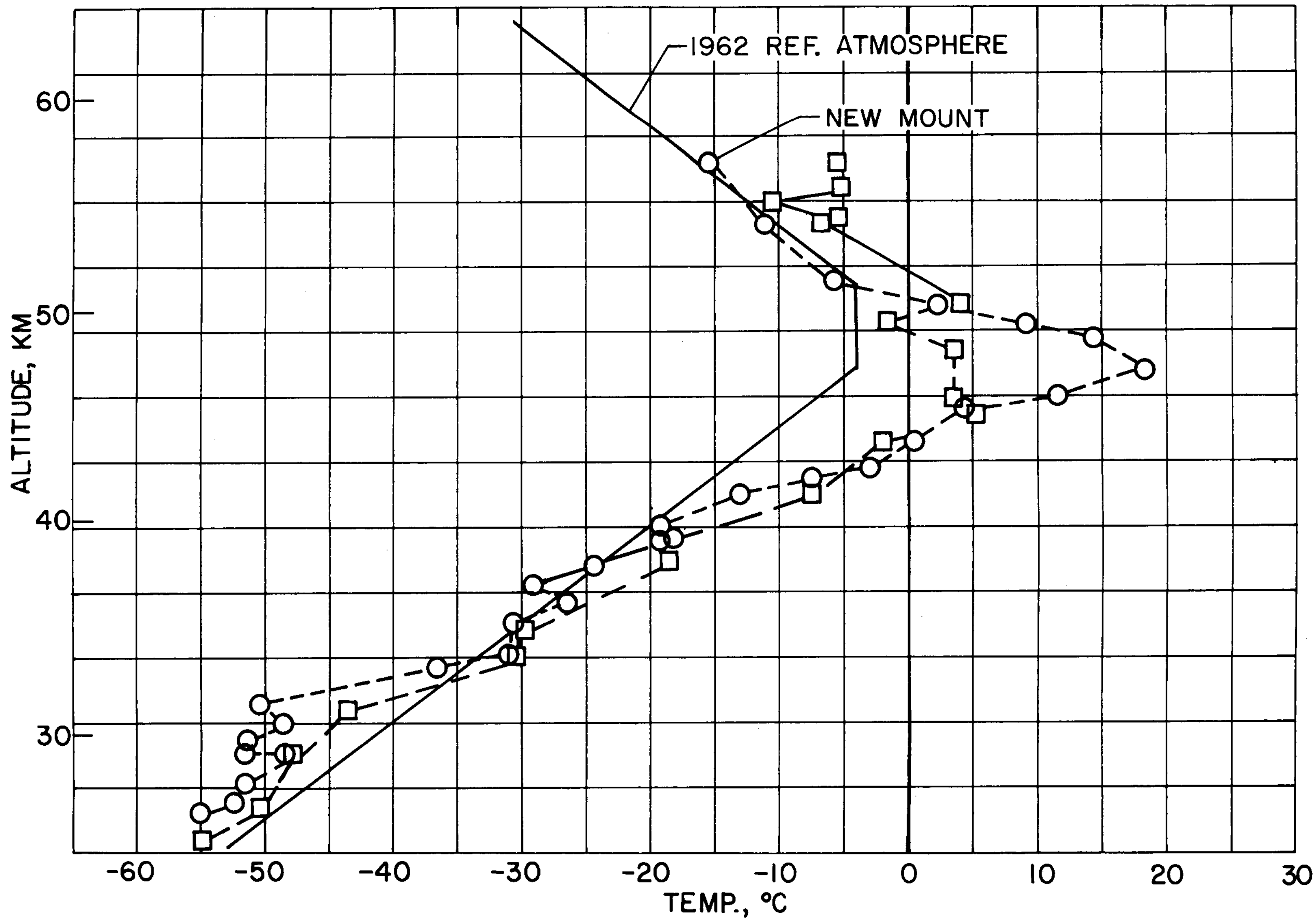
NASA

Figure 17.- Photograph of improved thermistor mount assembly.
(Approximately 4X enlargement.)




(a) Dual channel prototype payload measurements at Wallops Island. NASA

Figure 18.- Improvements in temperature measurements from meteorological rocket payloads.




(b) Measurements at Cape Kennedy, Florida.

NASA

Figure 18.- Concluded.

- NEW ANTENNA
- NEW SOLID-STATE TRANSMITTER
- IMPROVED ELECTRONICS
- IMPROVED SENSORS
- IMPROVED TRACKING

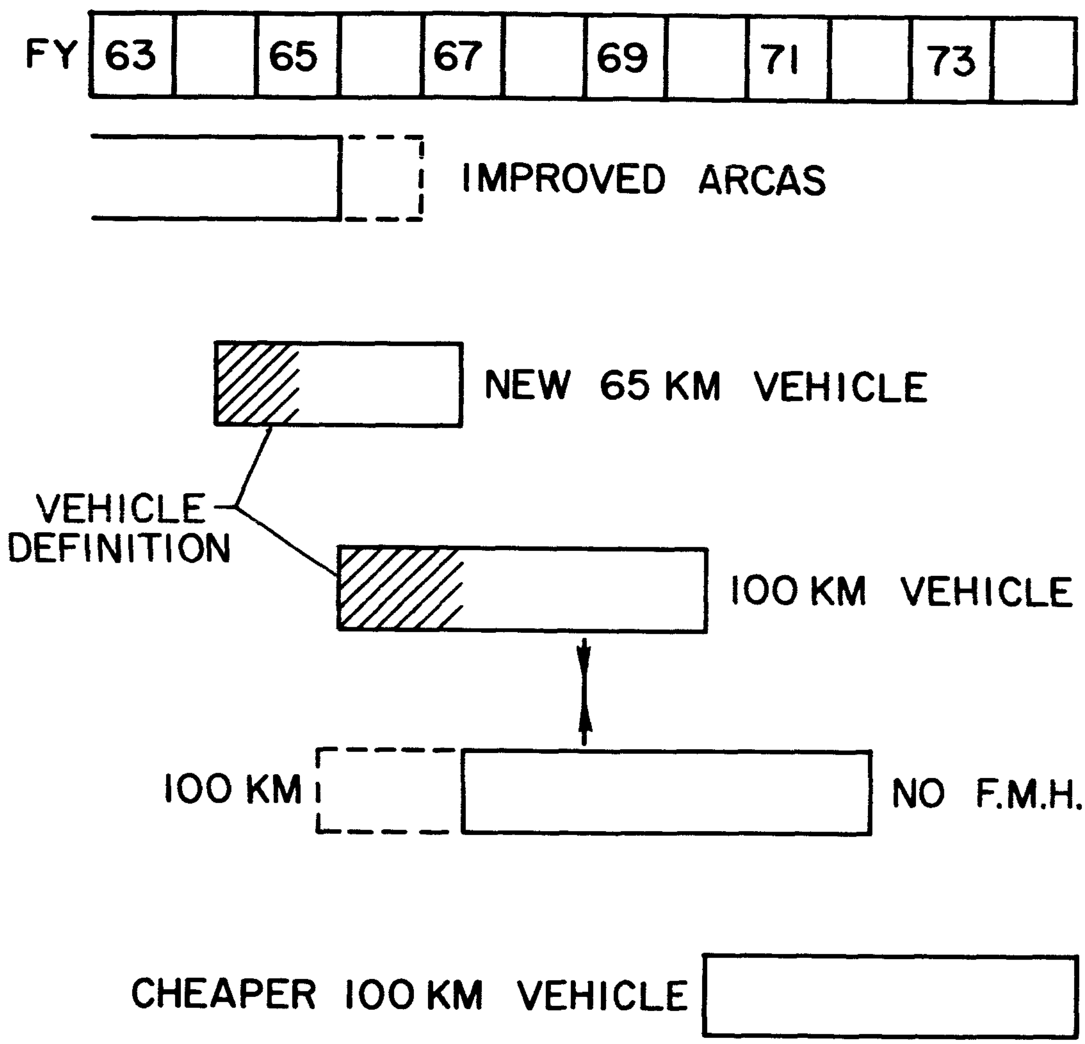
NASA

Figure 19.- Interim payload characteristics.

- SINGLE-STAGE SYSTEM
- SINGLE-STAGE/DUAL THRUST LEVEL
- SINGLE-THRUSTING STAGE/INERT "DART" TYPE STAGE
- TWO-STAGE SYSTEM

NASA

Figure 20.- Vehicle system approaches.




NASA

Figure 21.- Anticipated vehicle progression.

NASA-Langley, 1965