JOURNAL OF GEOPHYSICAL RESEARCH VOLUME 64, No. 11 NOVEMBER, 1959

Application of Meteorological Rocket Systems

WILLIS L. WEBB AND KENNETH R. JENKINS

U. S. Army Signal Missile Support Agency
White Sands Missile Range, New Mexico

Abstract—A series of test rocket firings has been conducted during the past 18 months to establish the operational feasibility of numerous rocket systems for meteorological observations. As might be expected, the most desirable systems from the point of view of instrumentation are generally not the most desirable from that of the rocket-firing problem. It has been demonstrated, however, that a reasonable observation schedule can be accomplished by the judicious application of currently available rockets and sensors. The most variable of high-atmosphere meteorological parameters is the flow. Chaff was used initially for rocket wind measurements because it could be expected to provide a suitable indication of the wind in the atmosphere above balloon sounding levels. It is easy to package and deploy. Most of the available high-atmosphere wind data have been obtained through use of a chaff sensor, and it is still most applicable for point measurements and at very high altitudes.

The need for a more coherent sensor and a vehicle capable of transporting a telemetry system to provide for the measurement of other parameters has resulted in the development of a parachute system. Although an altitude range problem will always be encountered, it is possible to obtain data from approximately 200,000 ft. to the surface through the application of a single parachute and balloon combination. Launch and flight characteristics of the tested rockets are presented for use in applying this new observational technique. Careful adherence to the design and operational restrictions indicated by these data will result in savings in the effort required for development of the various desirable measuring techniques. Experience to date indicates that it is possible, with available equipment and a reasonable expenditure of effort, to obtain profiles of several meteorological parameters from the surface to altitudes of the order of 200,000 ft.

Introduction—The lower reaches of the atmosphere have received a great deal of attention during the past 30 years as a result of exploration by balloon techniques. A large amount of data has been accumulated between the surface and 50,000 ft by these methods, but the data are usually more sparse at higher altitudes and are generally not considered satisfactory above 75,000 ft [*Mervill*, 1949]. It is possible to increase the maximum altitude obtained by balloons, but a significant amount of data will probably not be obtained above 100,000 ft through balloon systems.

The application of satellite vehicles to meteorological observation problems is opening a new era for meteorologists. Although the earth satellite performs a function of which no other system is capable, it is limited in that it cannot operate in the regions of the atmosphere below 100 miles. The interim region of the atmosphere is, therefore, largely unprobed by direct observation. Although observations from below or from above may produce significant information it is not likely that the necessity of direct observation can be avoided. The only available system for systematically probing the region from 20 miles to 100 miles is the meteorological rocket [*Stroud*, 1958; and *Spencer*, 1958]. A rocket technique is neither simple nor easy, but in view of the complete lack of other methods of obtaining data, the details of such an operation are presented for the edification of the profession.

The U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mexico, has initiated observational studies of the atmosphere by rocket systems to complement its activities in support of the missile program [*Jenkins and Webb*, 1958]. The effects of the atmosphere on the flight of a missile cover a wide range of physical phenomena. The ballistic effects of drag and wind must be considered, as well as the propagation effects involved in the transmission of various forms of energy that the missile communicates to the atmosphere, either

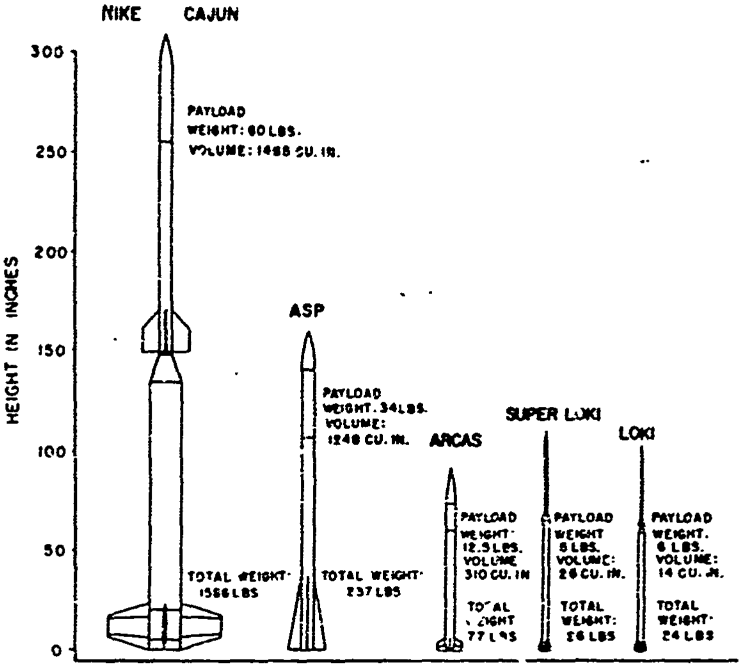

Fig. 1—Configurations and performance characteristics of tested meteorological rockets.

as desired or as inadvertent radiation. A meteorological rocket launching installation has been set up, and a total of 120 rounds has been fired in support of various experiments requiring information about the state of the upper atmosphere. The following data are presented to show the meteorologist the scope of problems encountered and to indicate the present state of the meteorological rocket art.

General performance characteristics of tested meteorological rockets—A large variety of rockets has been utilized in atmospheric studies in the past 10 years [*Haig and Lally*, 1958]. This discussion will be devoted to the smaller types useful in a synoptic system. They range from the small Loki rocket to the Nike Cajun configuration. The choice of a rocket for use in a particular case rests largely on the payload requirement and the peak altitude desired. The small rockets are more easily handled and are desirable wherever they can meet the experimental requirements.

As is indicated in the configuration and performance data (Figs. 1 and 2), the Loki Phase I can be fired with a total rocket weight of only 24 lb to carry a 2-lb payload to approximately 140,000 ft at White Sands Missile Range. The Loki Phase IIA can deliver the same payload to 280,000 ft. The stress on the Loki Phase IIA system is such that an alternative vehicle has been developed. The system consists of the Loki Phase I booster and an enlarged dart which carries a 2-lb Naka motor. This system is expected to provide adequate altitudes without the excessive speeds that result in gross aerodynamic heating. The Arcas rocket was developed by the U. S. Navy, Office of Naval Research, to meet the need for an economical, easily handled, meteorological rocket with an adequate payload [*Webb, Jenkins, and Clark*, 1959]. As can be seen from the performance characteristics, the Arcas delivers a 12½-lb payload to peak altitude with a total lift-off weight of 77 lb. It can also be classed as an easily handled vehicle.

If additional payload in weight or volume is required, the Asp offers a reasonable solution. Its total weight of 237 lb makes the launching operation more difficult. Although the Asp's payload capability is advantageous, its performance and cost rule out its application to synoptic observational programs.

The final meteorological rocket system dis-

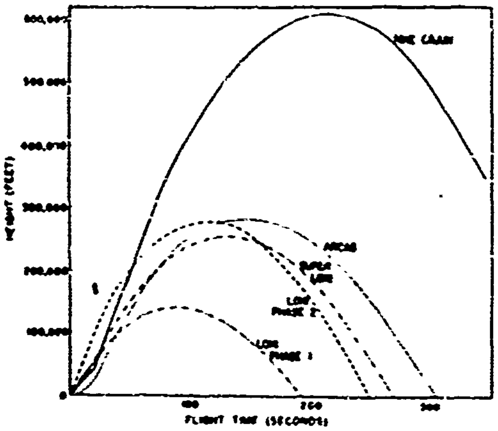

Fig. 2—Idealized trajectories of tested meteorological rockets.

cussed is the Nike Cajun configuration. This vehicle is composed of a Cajun motor and a Nike Ajax booster, provided with suitable fin modifications. The booster is used to propel the second-stage Cajun rocket to an altitude of approximately 50,000 ft, where the sustainer motor can operate efficiently. A payload of 60 lb contained in 465 cu in can be lifted to above 100 miles with the Nike Cajun. The rocket's total weight when ready to leave the rail is 1566 lb. The application of the Nike Cajun rocket is limited by the cost and the magnitude of the problems associated with preparation and firing.

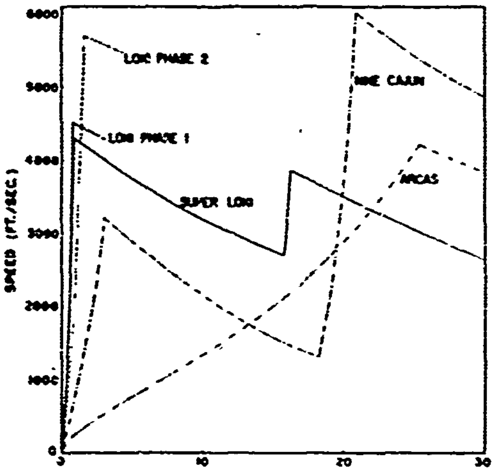

Fig. 3—Velocity distribution for selected meteorological rockets.

Idealized trajectories are presented, Figure 2, for the Loki Phase I, Loki Phase IIA, Super Loki, Arcas, and Nike Cajun. The Loki Phase I reaches a peak height of approximately 140,000 ft when fired from the 4000-ft altitude of the White Sands Missile Range. The Loki Phase IIA coasts to approximately 250,000 ft, which is similar to the planned performance of the Arcas. The Super Loki is designed for a peak altitude above 200,000 ft, and the Nike Cajun reaches well above 500,000 ft. As can be observed from these graphs, the time of sensor exposure on board the rocket is limited at any altitude with any of the vehicles. The maximum period of observation is obtained near peak and thus provides opportunity for more extended observations at that altitude.

Figure 3 indicates the velocity distribution expected during the burning phase, or phases, of the several vehicles. The Loki series is seen to experience large accelerations during the initial phase of the flight, and thus the structural stresses and thermal inputs are at a maximum. Accelerations are in excess of $200g$, requiring relatively rugged instrumentation. The Nike

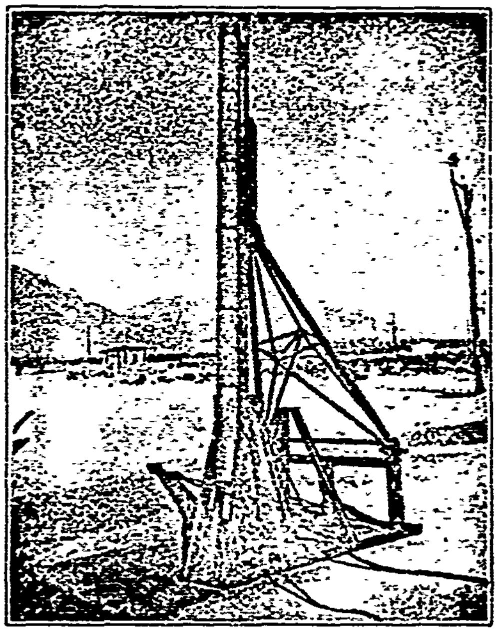

Fig. 4—The Loki launcher in firing position.

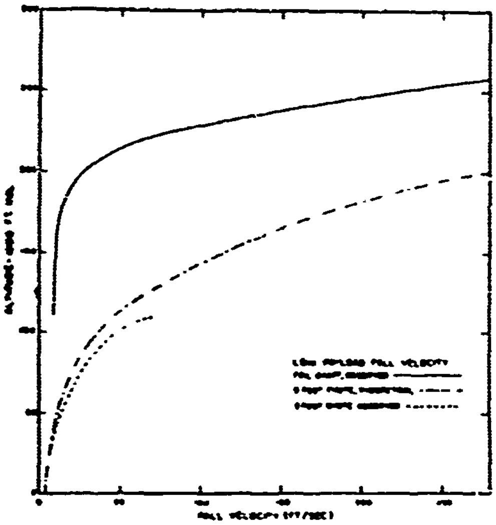

Fig. 5—Chaff and parachute wind sensor fall velocities.

Cajun is a short-burning rocket with accelerations of the order of 50*g* during boost phase and second-stage burning. The provision for an extended coast phase in the Super Loki and Nike Cajun permits second-stage ignition at a high altitude, taking advantage of the low drag at that stage of propulsion. The Arcas, on the other hand, uses a slow-burning motor which provides low acceleration over a long period of time to achieve a reasonable burnout velocity at an altitude where the drag is relatively low. Reliable instrumentation in this rocket is relatively easy to achieve, owing to the low accelerations involved.

The Loki system—The Loki meteorological rocket, a modification of the Loki tactical missile, is launched from the extruded-rail tubular launcher shown in Figure 4. Burning time for the Loki Phase I is 8/10 sec, at which time the dart is traveling in excess of 4400 ft sec. The Loki has two major components. The first stage contains solid propellant and provides the total thrust for the rocket flight. The initial acceleration causes the second-stage dart to turn in a J slot and free the locking pin. Separation is achieved at burnout through the force of a spring-loaded piston and differential drag. The initial acceleration causes a weight in the tip of the dart to shear a safety pin, igniting a percussion cap, and initiating a pyrotechnic train which is set for the desired time of payload expulsion. The dart coasts to peak altitude and the wind sensor is ejected. The sensors that have been tested extensively consist of an 8-ft mylar parachute, metalized for radar tracking, for use with the Loki Phase I vehicle, and radar reflective chaff [*Thaler and Masterson*, 1956; and *Vaughn*, 1957]. The parachute has provided an excellent point source in the region from 140,000 ft down to 75,000 ft. Chaff has been used extensively in the Loki Phase IIA to obtain wind measurements in the altitude range from 250,000 ft down to 140,000 ft. As can be observed in Figure 5, the fall rate of a sensor which is acceptable in one of these ranges will generally not be acceptable in the other. The parachute represents an excellent tracking target for the radar and provides a point source throughout its descent. Comparisons of the wind measurements with radiosonde values in balloon-attained levels indicate that the parachute provides a reasonable means for evaluating the winds. Conversely, the chaff load disperses with time after ejection and the wind determination becomes more difficult [*Anderson and Hoehne*, 1956; *Anderson*, 1957; *aufm Kampe*, 1957; *Batton*, 1958; *Cline*, 1957].

In addition, the strong winds frequently encountered aloft make it difficult to track one sensor through a 100,000-ft stratum. Considerable research will be necessary to achieve a suitable sensor for the entire wind profile.

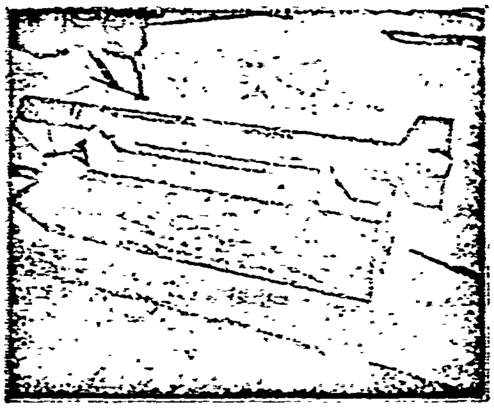

Fig. 6—Arcas meteorological rocket being prepared for beacon performance test.

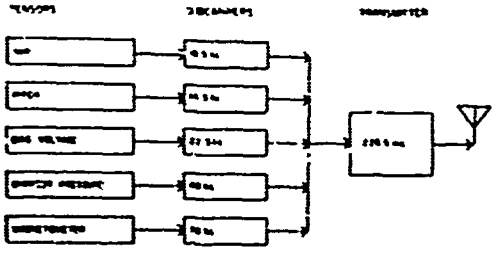

FIG. 7—Telemetry instrumentation for an Arcas performance test.

The Arcas system—The Arcas rocket was given initial flight testing at White Sands Missile Range, New Mexico, during the winter of 1958–1959. A series of 5 rounds was fired to establish the feasibility of the launching system and to determine the aerodynamic stability of the rocket. A view of the rocket during beacon checkout is shown in Figure 6. The initial firing incurred a structural failure which caused deviation from the planned trajectory at 15,000 ft. The nose cone was equipped with a DPN-43 radar beacon which failed at 15 sec, but skin tracking of the rocket by radar was possible. The second Arcas rocket was instrumented with a telemetry system in an attempt to establish the cause of the initial failure. The rocket was equipped with a 226.5-Mc/s 2-watt transmitter which was modulated by five subcarrier oscillators (Fig. 7). The subcarrier oscillators were in turn controlled by sensors which measured the pitch, yaw, combustion-chamber pressure, and a single component of the earth's magnetic field. The pitch and yaw were desired for evaluating aerodynamic stresses on the vehicle; the chamber pressure was needed to determine the thrust developed; and the magnetometer was included to measure the roll rate of the vehicle and to evaluate the attitude of the missile near peak where the parachute would be ejected. Figure 8 indicates the data obtained from the telemetry system during the burning phase. As can be observed, the combustion-chamber pressure behaved somewhat sporadically during the initial phases, operated smoothly through most of the burning phase, and was slightly unstable at burnout. The angle between the flow about the missile and the missile axis shows large deviations during the early phases which were probably due to the relatively small aerodynamic loads on the sensor at these speeds. The large excursions observed as the rocket approached the speed of sound were verified through reduction of ballistic camera data obtained in support of the firing. The large accelerations involved in the roll rate of the rocket as it became supersonic are not clearly understood.

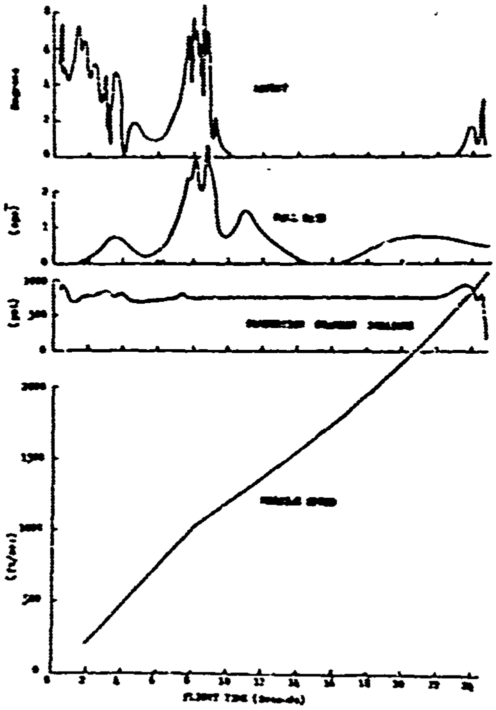

FIG. 8—Performance characteristics of an Arcas test round.

The third Arcas test round was fired, with an AMT-4 radiosonde transmitter as payload, to check the possibility that the extra drag resulting from the telemetry antennas and the performance sensors were the causes for the low peak latitude of 73,000 ft obtained with round 2. As round 3 reached a peak altitude of 93,000 ft, it was assumed that a further reduction in the drag was required. The roll rate of the rocket is presented in Figure 9. These data were obtained by recording the signal strength of the AMT-4 antenna located in the side of the nose cone. The signal strength was modulated as the rocket rolled and the antenna was turned toward and away from the receiver. The first few seconds of flight were unrecorded as a result of acquisition problems resulting from the GMD-1's failure to track in automatic position. The GMD-1 was 6 miles from the launch point. After manual acquisition at approximately 15 sec, automatic tracking was maintained throughout the flight.

The Arcas Launcher consists of an 11-ft tube which has a larger concentric chamber about its base. The rocket is mounted on a split piston and is held in alignment with the axis of the launcher by means of rigid foam blocks. This equipment falls away as the rocket leaves the launcher. Initially the exhaust gases are allowed to by-pass the piston to reduce lift-off accelerations. The pressure then builds up and assists in obtaining the desired exit velocity.

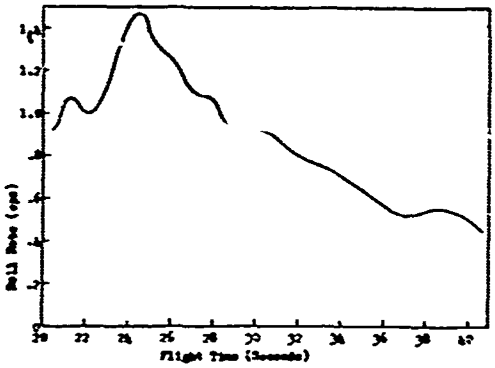

Fig. 9—Roll rate of the Arcas during test launching, obtained by using AMT-4 transmitter and GMD-1 ground equipment.

A redesign of the nose-cone configuration was incorporated in subsequent rockets, and the fourth round was fired with a dummy load to an altitude of 178,000 ft. The fifth flight, which achieved an altitude of 171,000 ft, included an AMT-4 radiosonde transmitter which operated only during the first 15 sec of flight.

The Nike Cajun System—A series of seven Nike Cajun firings was conducted at White Sands Missile Range by the U. S. Army Signal Missile Support Agency during the summer of 1958. Instrumentation in the Nike Cajun (Fig. 10) nose cones included a DPN-41 radar beacon, used in certain propagation studies, and a smoke generator, which was being tested as a wind measurement technique. The smoke trail did not prove satisfactory in this firing, owing to payload limitations and the high speeds involved in reaching a peak altitude in excess of 100 miles.

The Nike Cajun, a relatively large rocket, presents several problems in handling and preparation. Suitable equipment is required to place the various components on the launcher, and a great deal of care must be exercised to assure proper mating of the component parts. The Nike Cajun is launched from a standard Nike Ajax launcher. The booster is fitted with a set of four fins which are considerably strengthened to stand the increased acceleration resulting from the small load. The booster burns for 3 sec, attaining a speed of 3200 ft sec. After booster burnout, aerodynamic drag separates the stages, and the Cajun coasts for approximately 15 sec. The Cajun motor then ignites, burning for 3 sec and then coasting in a trajectory that carries it well above 100 miles. The record altitude attained with a 67-lb payload is 121 miles. Excellent trajectory data were obtained by radar tracking of the DPN-41 transponder.

Conclusions—The rocket firing crews of the U. S. Army Signal Missile Support Agency have fired a total of 120 meteorological rockets; 105 of them performed satisfactorily, and data were obtained from 73 of the firings. The rather low percentage of completely successful firings is partly due to testing of experimental components. Instances in which a series of firings

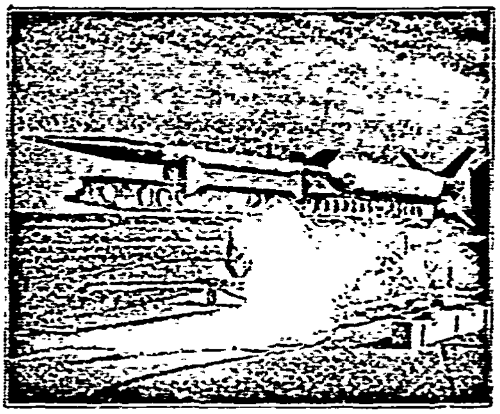

Fig. 10—The Nike Cajun rocket during launching preparations.

has been conducted with tested hardware has resulted in successful firings in excess of 75 per cent. Further improvement in rocket and sensor reliability can be expected as experience increases and production problems are minimized.

The training of rocket launching crews, construction of launchers, perfection of radar tracking techniques, and selection of data handling techniques have been pursued by personnel of the U. S. Army Signal Missile Support Agency with the intention of obtaining data at high altitudes on a systematic basis. This aim is now taking form in the planned six-station rocket network first proposed several years ago by Dr. Hans aufm Kampe of the U. S. Army Signal Research and Development Laboratories. This network is expected to be composed of stations at Wallops Island, Virginia; Patrick Air Force Base, Florida; White Sands Missile Range, New Mexico; Point Mugu, California; Fort Greely, Alaska; and Fort Churchill, Canada.

The initial test will involve daily firings from each of the six stations for a period of 1 month during each season of the year. The data obtained will provide information about the desirability of such measurements and will point out seasonal effects that might prove important to meteorologists. The data will be reduced in a form compatible with standard balloon observations and will be made available to all interested agencies.

Despite the many disadvantages of the rocket system, it can be expected to open new areas of interest for the meteorologist by obtaining measurements in this relatively unexplored region.

References

Anderson, A. D., and W. E. Hoehne, Experiments using window to measure high altitude winds. *Bull. Am. Meteorol. Soc.*, *37*, 454-457, 1956.

Anderson, A. D., Comments on upper air wind measurements with small rockets, *J. Meteorol.*, *14*, 473-474, 1957.

aufm Kampe, H. J., Upper air wind measurements with small rockets, *J. Meteorol.*, *13*, 601-602, 1956.

Battan, L. J., Use of chaff for wind measurements, *Bull. Am. Meteorol. Soc.*, *39*, 258-260, 1958.

Cline, D. E., Rocket beacon wind sensing system, *U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, Eng. Rept. E-1295*, 1957.

Haig, T. O., and Vincent E. Lally, Meteorological sounding systems, *Bull. Am. Meteorol. Soc.*, *39*, 401-409, 1958.

Jenkins, K. R., and W. L. Webb, Rocket wind measurements, *U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mexico, Tech. Memo. 531*, 1958.

Mervill, H. J., Structure of the wind, *U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, Tech. Memo. M-1135*, 1949.

Spencer, N. W., Forty-seven rocket firings at Fort Churchill, ARS preprint 635-58, 1958.

Stroud, W. G., Meteorological rocket soundings in the arctic, *Jet Propulsion* (American Rocket Society), *23*, 817-822, 1953.

Thaler, W. J., and J. E. Masterson, A rapid high altitude wind determining system, abstract in *Bull. Am. Meteorol. Soc.*, *37*, 177, 1956.

Vaughn, W. W., Use of chaff to determine wind velocity at aircraft altitude, *U. S. Air Force Armament Center, Eglin Air Force Base, Florida, Tech. Publ.*, 1957.

Webb, W. L., K. R. Jenkins, and G. Q. Clark, Flight testing of the Arcas, *U. S. Army Signal Missile Support Agency, White Sands Missile Range, New Mexico, Tech. Memo. 683*, 1959.