ADVANCED UPRATED MODEL ROCKET SOUNDING SYSTEMS

by

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A Research and Development Paper
presented to the

1973 Model Rocket Science and Engineering Symposium
October 1973
United States Air Force Academy
Colorado

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Following the avialability of reliable model rocket motors in the total impulse range of about 50 nt-sec and over, much speculation arose concerning the practicability of uprated model rocket systems as vehicles for serious scientific research and similar professional applications. The few actual sounding rocket systems which were developed, however, were usually marginal in reliability, performance, payload capabilities, or other important specifications. Notably absent was a well-integrated system with multi-payload capabilities, reliable ground support equipment, high performance, and state-of-the-art reliability. The aim of a research and development program undertaken over the past three years by the author has been to develop such systems. These systems now include operational uprated model rocket vehicles capable of carrying a full temperaturesonde system to 10,000 feet using a single model rocket-type motor, operational two-stage vehicles with similar altitude capabilities and increased payload mass-volume product, an advanced ignition system, a precisely--aimable dual launcher system, experimentally-verified computer programs for performance optimization and prediction including time-and velocity-dependent forces, programmable onboard electronic sequencing and actuation of vital vehicle functions, and prototype sensor, telemetry, and data aquisition-and-storage systems.

Theoretical Investigations

A. Iterative Computer Simulation of Free-Ballistic Rocket Trajectories

Since uprated model rocket systems can attain velocities and altitudes far in excess of those usually encountered in conventional model rocket practice, accurate and sophisticated theoretical models are a necessity for performance prediction and optimization. An earilier paper (Schwede, 1971) first described a version of the iterative computer program, 'IRTC', used in this capacity. Improvements in the computer simulation since the writing of the 1971 paper include a variable-interval scheme for numerical integration of the equation of motion, which increases accuracy and decreases computer time used; and the capability to simulate flights of multi-staged

rockets or rockets with unpowered 'dart' or 'flechette' stages. Additional experimental verification of the accuracy of these programs has also been gathered since that time by the use of flight data on vehicles ranging from subsonic model rockets to twenty-pound instrumented electric-field measuring rockets wich attain velocities of Mach 2.

B. Measurements of Drag Co-efficients in Flight

Data from actual firings of Enerjet F52 powered rockets in late 1971 and in 1972 using IRTCV simulation yielded evidence that subsonic v^2 drag co-efficients for cleanly designed and carefully built model rockets could be appreciably lower than popular published values around 0.7 and 0.6 . These measurements were foreshadowed by earlier experimental work by the author (Schwede, 1969) which also yielded low drag co-efficients.

C. Computer-aided Design

In May and June 1972, the first numerical simulations of dart-type model rockets were run to optimize mass distribution between stages and sequencer intervals for desired performance. This use of the computer model constitutes the first serious instance of computer aided design of a model rocket, and resulted in the GDR series of uprated model rockets.

Samples of computer simulations of uprated model rocket flights constitute Appendix 1.

Operational Uprated Model Rocket Sounding Rockets: GDR and GSR Series

Experience in low-drag design of competition model rockets (flown at SWMRC's in 1969, 1970, and 1971) was extremely valauble in the process of development of high-performance uprated model rocket systems. Subsonic drag co-efficients of 0.35 ± 0.05 for such rockets were demonstrated at these times to be within the state of the art. Construction and finishing techniques were developed which allows extreme performance but maintain the structural integrity of the uprated vehicles.

A. GDR Series

A relatively novel concept in design of model rockets led to the GDR series of sounding rockets. In many instances, a payload

can be constructed so that it will fit into a housing whose diameter is significantly smaller than that of available motors and boosters. Good examples are most radio transmitters, silver iodide flares, and certain types of velocity measurement sensor/telemetry systems (such a system was described in the winning entry for November, 1971, Estes Industries' Design-of-the-Month competition, and is reproduced in Appendix 2).

In this case a significant performance advantage can be realized by designing the vehicle so that the large diameter, high drag booster separates from the dense, streamlined, smaller diameter instrument package at burnout. The instrument package, or 'dart' then coasts to peak altitude very much above the equivalent single-stage rocket peak altitude, deploys a recovery system at any appropriate time, and descends sensing properties of the surrounding atmosphere or performing another function as the mission requires. Another advantage of this system is the physical separation of the hot, polluting rocket motor from the experimental regions.

The author first flew such a vehicle on 12 June 1972 in Socorro, New Mexico. This rocket was named GDR-1 (for G-powered Dart Rocket; or in the appropriate vernacular, as G__ D___ Rocket). This first test launch was modestly spectacular in that the booster burn and subsequent clean separation were loud, fast, and as planned, but no trace of the dart was ever seen after burnout. Intensive searches of the recovery/impact area uncovered nothing, so that the best hypothesis seems to be that the dart recovery system did deploy and the dart drifted away.

Another test launch using a new mk. 2 dart and the same booster was conducted at the 1972 Southwestern Model Rocketry Conference in Albuquerque on 27 June 1972. This dart carried an operating radio transmitter. Unfortunately, separation of booster and dart was delayed until booster-motor ejection at T+ 9. seconds. The dart trajectory intersected the ground at about T+ 22. seconds with about one second left to planned chute deployment. This test did, however, prove the tremendous structural integrity of the dart fin/pressure bulkhead system which survived intact.

On 31 August 1972 a further improved mk. 3 dart with calibrated thermistor/telemetry system was flown in Phoenix, Arizona at a test session for Enerjet, Inc. rocket vehicles. The flight was an

unqualified success, with a measured peak altitude of 1.03 $\pm$ 0.10 kilometers (about 3400 feet). Power was a single Enerjet F 52-8 rocket motor.. Recored data from the temperaturesonde are sufficiently clean to allow reconstruction of the temperature vs. altitude profile. Postflight computer simulations fit the measured peak altitude and recovery-system deployment time simultaneously when the drag co-efficient values are:

$$C_{d\ boost} = 0.35$$

$$C_{d\ dart} = 0.10 \quad .$$

A scale drawing of this flight is shown in Figure 1.

The current version of GDR is the mk. 3 dart/mk. 2 booster combination, shown in the temperaturesonde confuguration on the cover photograph of the Proceedings. Scale drawings and specifications are shown in Figures 2 and 3. The vehicle features low-drag aerodynamics, adequate supersonic stability margin, provision for internal stowage of the telemetry antenna until recovery system deployment, and a convenient and proven sequencer-actuator and recovery system.

Recovery deployment is performed by an electronic sequencer-actuator developed over a two year period by the author. Current versions of this unit can be built for about seven dollars in small quantities, and feature extreme reliability and a safe standby time in excess of 72 hours. Timing intervals are programmable before flight and can range from 0. to over 250. seconds. The entire system fits into a 0.950 inch ID tube and weights less than 65. grams including a 6 volt, 0.180 ampere-hour rechargeable nickel-cadmium battery.

Also developed for the GDR program was a sensitive low energy squib which reliably and positively ejects parachutes, antennae, etc. from volumes up to about 150. cm^3 .

B. GSR Program

The development of the elctronic sequencer made practical a two-stage uprated model rocket, which is designated GSR (for G-powered Staged Rocket or G _____ Super Rocket). Designed and built in late 1972 and January of 1973, two prototype GSR's are extant at this writing (9 July 1973). A scale drawing of GSR mk. 1 and a specification sheet comprise Figures 4 and 5. This

vehicle features programmable sustainer ignition and recovery system deployment, dual antenna system for low drag and increased telemetry signal before recovery system and main antenna deployment, a recoverable booster which separates at BECO, increased payload mass and volume capability, and altitude capabilities with a 150. gram 150 cm^3 payload in excess of 9000 feet.

The GSR sequencer-actuator system independently ingites the sustainer engine and deploys the sustainer recovery system automatically at any programmed times after liftoff. The unit's safe standby time is in excess of 36 hours, and it weighs less than 75. grams. Its reliability and range of available delay times are comparable to those of the GDR timer.

It is planned to test launch GSR flight 001 at the 1973 Southwestern Model Rocketry Conference, with an operating temperature-sonde aboard to measure the atmospheric temperature-altitude profile at the launch site.

Computer simulations indicate that GSR is capable of sustainer burnout velocities in excess of Mach 1.2 and peak altitudes with an optimum payload of almost 12,000 feet using two Enerjet 30 126. nt-sec motors.

Ground Support

A. Launch Support

The performance capabilities and requirements for trajectory control of high performance UMR's made it necessary that some improvment be made upon the inadequate rod-type launchers now in use for many large model rockets and UMR's (e.g. Enerjet 1340, 1340-20, 2250). A dual-rail, independent Q.E., extended length launcher was built in 1972 and used on all GDR flights. This unit provides much improved trajectory control and higher velocity as the vehicle exits the rail, resulting in higher perfornace due to reduced yawing.

A low impendance solid-state ignition system was built in 1971 and used in numerous tests and launches since that time. This system provides immediate actuation of common bridgewire-type igniters, singly or in parallel clusters of up to ten (depending upon specific ingiter characteristics). This control of ignition times is a necessity in schemes requiring sequential firing of

parallel booster-sustainer combinations and similar advanced systems.

B. Checkout of Payloads and Sequencer Systems

Procedures have been developed for the calibration and checkout of a temperaturesonde system now used as a 'standard' test payload and for the onboard electronic sequencing systems to ensure safety, reliability, and accuracy. These procedures are sufficiently simple to be performed by one person, and require no specialized equipment.

C. Telemetry Systems

The current 'standard' test payload for the GDR and GSR programs is a modified Estes Transroc with thermistor system. The transmitter pulse rate has been increased to allow easier automatic data reduction, which is included in future development plans. The aim of this development is the real-time analog and digital recording and readout of temperature vs. altitude profiles.

At the time of this writing, raw magnetic-tape recorded data from a calibrated temperaturesonde flight are under analysis, as time permits, but use of an oscilloscope and camera data reduction system, which will yield temperature data atdiscrete time intervals during the flight record.

Conclusion and Overview

This report has summarized the main features of a research and development program undertaken as an amateur, spare-time activity by the author during the past three years. This program has resulted in operational uprated model rocket sounding systems which, to the author's knowledge, are the most sophisticated yet realized in model rocket technology. An integrated, working system including versatile sounding rocket vehicles, complete ground support systems, and a practicable temperaturesonde system has been developed. Advances in altitude and payload carrying capabilities have been achieved. Perhaps most importantly, a significant marriage of theoretical models and actual flight hardware and data has ocurred.

The author's hope is that this demonstration of potential and development work will result in wider use of uprated model rocket sounding systems for serious scientific and professional programs.

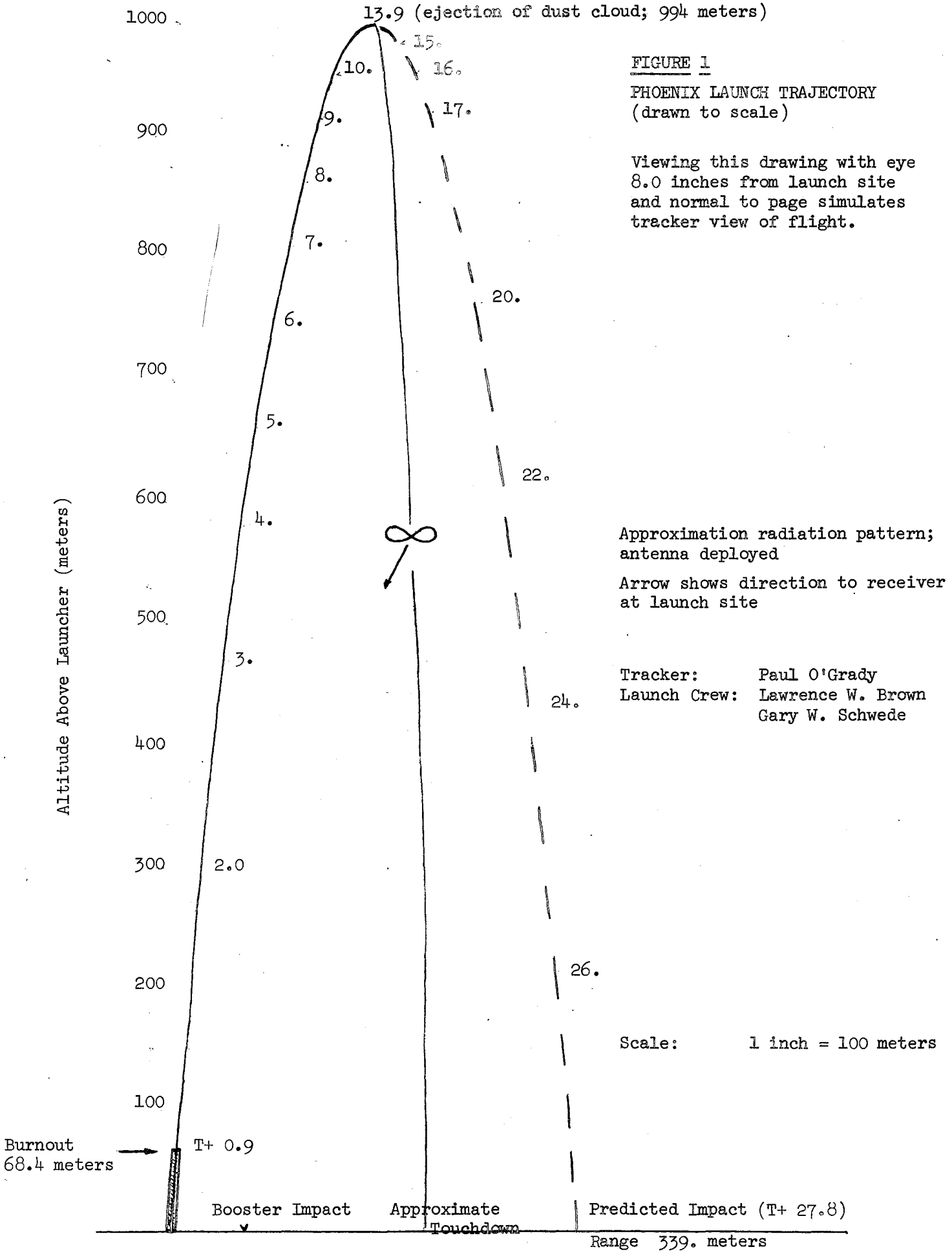


FIGURE 1

PHOENIX LAUNCH TRAJECTORY
(drawn to scale)

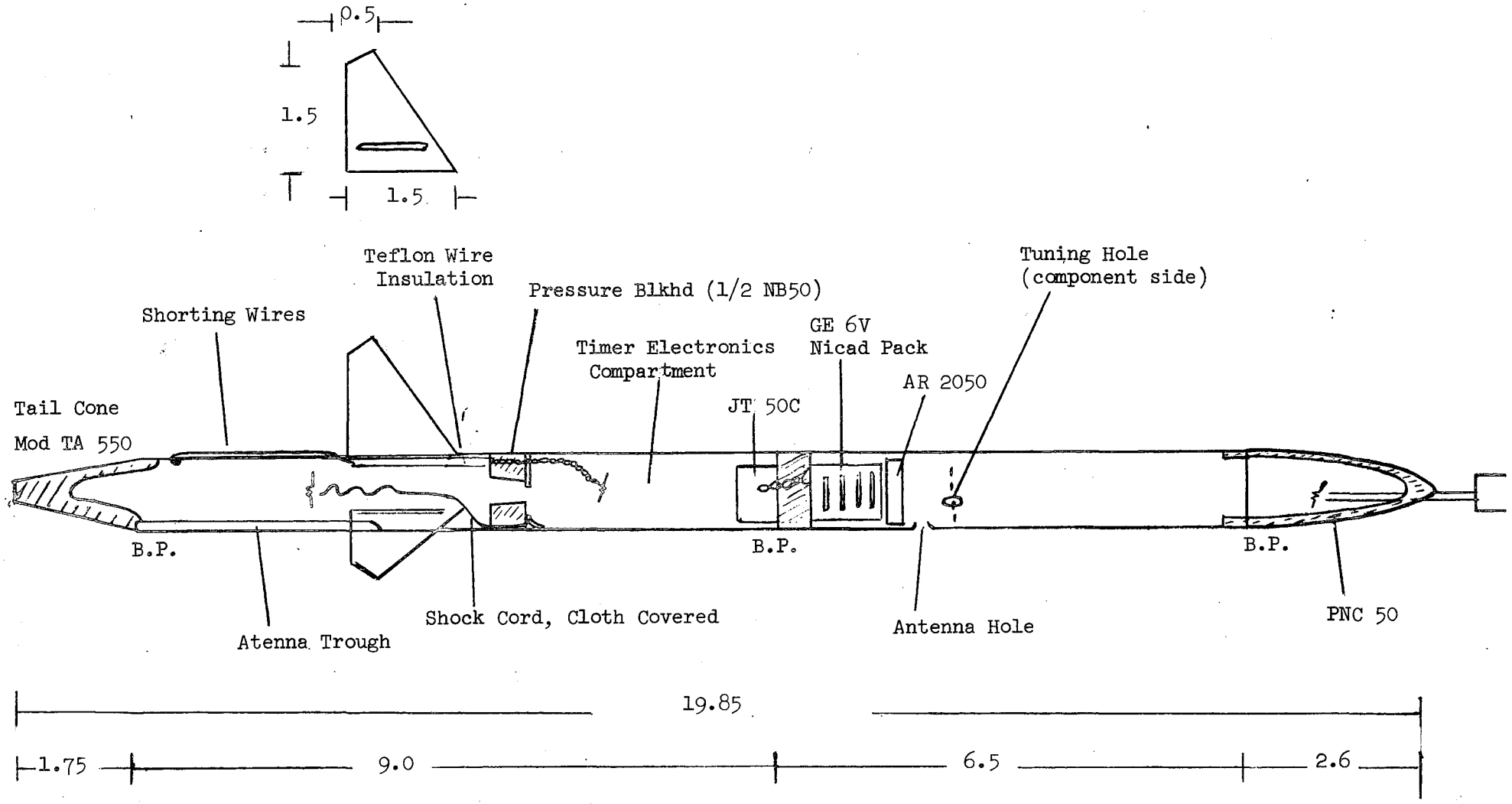
Viewing this drawing with eye 8.0 inches from launch site and normal to page simulates tracker view of flight.

Approximation radiation pattern; antenna deployed

Arrow shows direction to receiver at launch site

Tracker: Paul O'Grady
Launch Crew: Lawrence W. Brown
Gary W. Schwede

Scale: 1 inch = 100 meters



Notes:

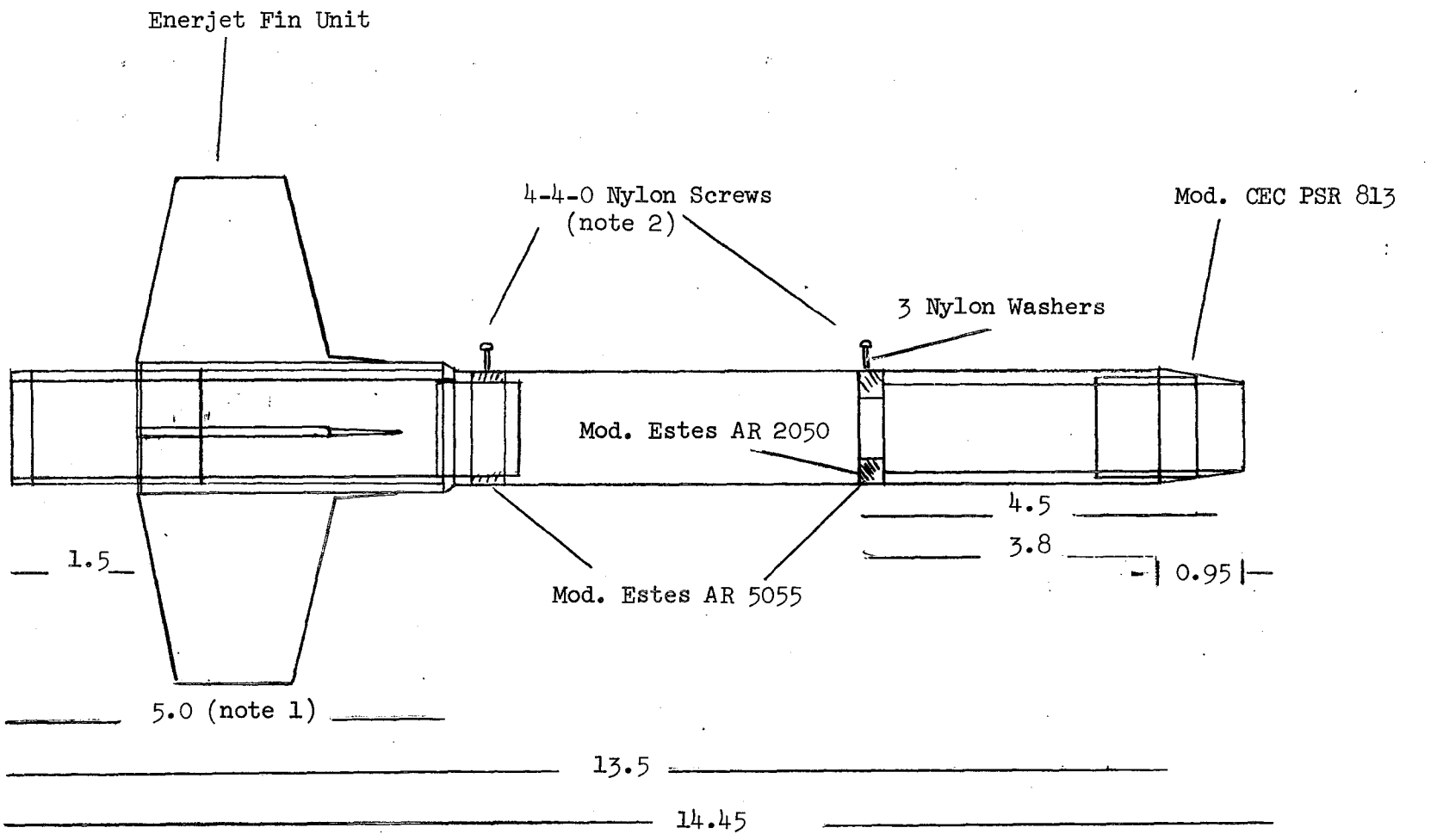
B.P. = Tube Break Points
Tinned Shorting Wires Used
Fins 1/32 birch plywood, epoxied to tube after tube cross-scratched with sharp X-Acto blade. Epoxy fillets.

FIGURE 2

GDR DART MK. 3

Scale 1:4 One Inch ⟷

Dimensions in inches.



Notes:

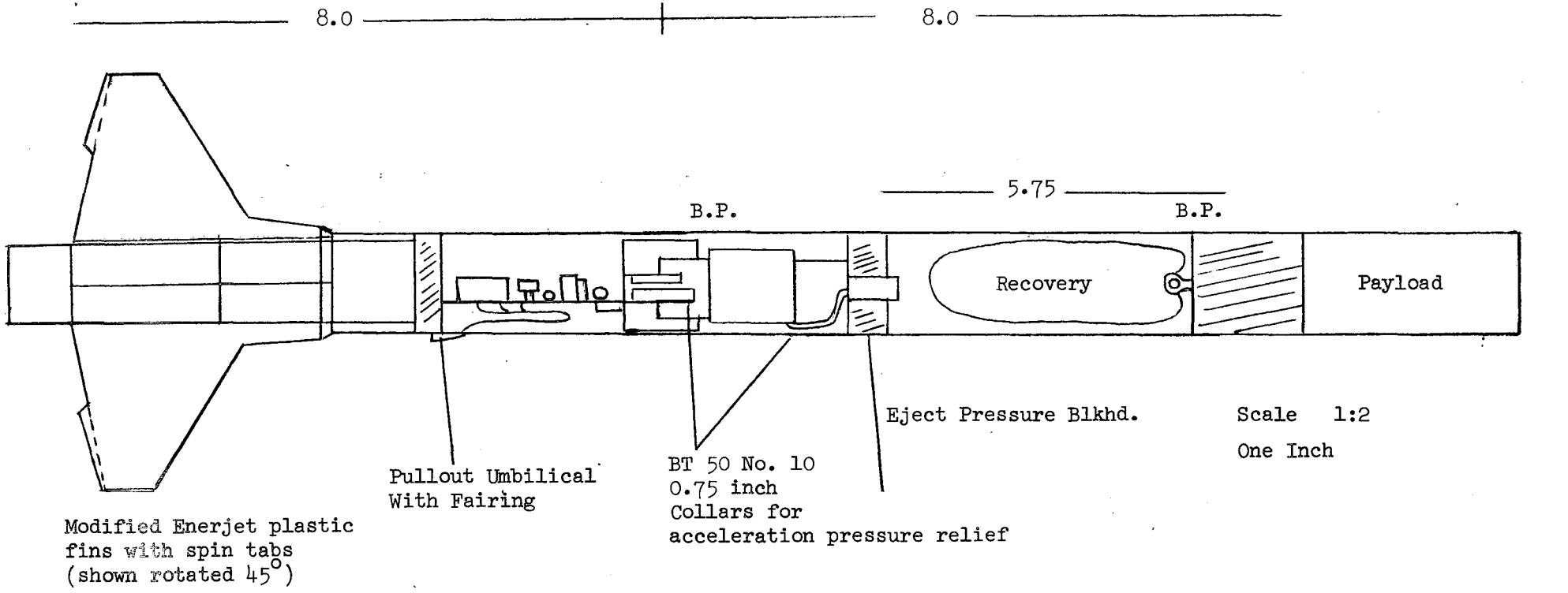
1. Increase to 5.625 for Enerjet-30.
2. Shown rotated 45° for clarity.

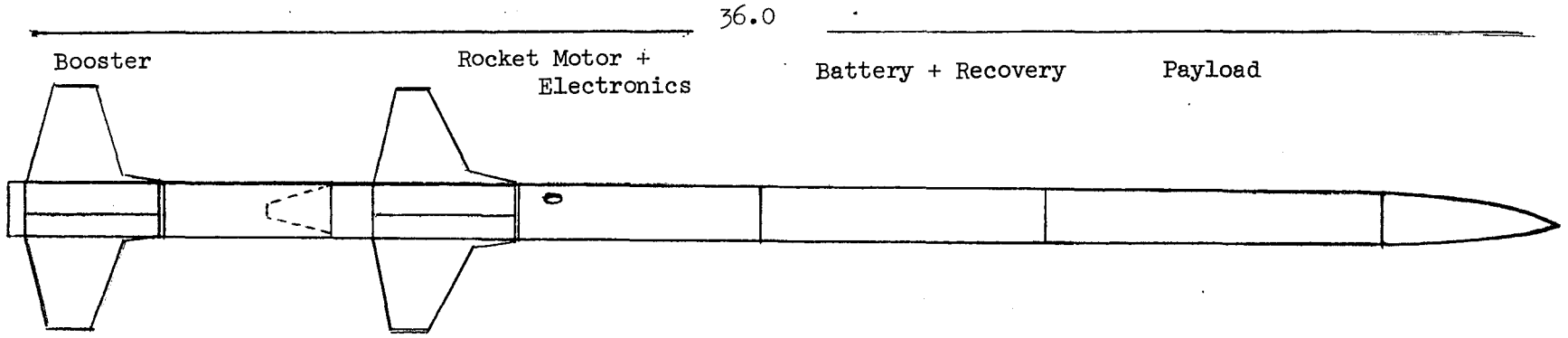
FIGURE 3

GDR BOOSTER MK. 2

Scale 1:4 One Inch ⟷

Dimension in inches.





Scale 1:4

One Inch

FIGURE 4

GSR MK. 1 TWO-STAGED ENERJET POWERED ROCKET with programmable sustainer ignition and recovery.

APPENDIX 2

Modifications of Estes Transroc For Stagnation Temperature and Velocity Measurements

With the introduction by Estes of the TRANSROC and temperature sensor TXA-3, much interest has arisen in the possibilities of measuring a model rocket's velocity by determining the rise of stagnation-point air temperature due to adiabatic compression. The scheme suggest in the TXA-3 manual, however, is not the optimum configuration for the temperature sensor.

Figure 5 depicts stagnation regions (areas where the relative air velocity in the direction of the rocket's motion has been reduced to some small fraction of the free stream velocity) in front of a flat plate and a sphere. When the 'outrigger' mount is used as suggested in the manual, the resulting airflow pattern corresponds to the spherical case, with the sphere being the thermistor bead. This results in an exceedingly small stagnation region (smaller than the volume of the bead) which, because of the low heat capacity per unit volume of air compared to that of glass (the termistor bead material) simply cannot heat up the bead to the stagnation temperature. (The heat capacity per unit volume of glass is about 2000 times that for air). A much more satisfactory scheme is shown in Figure 6. In effect we have created a larger stagnation region similar to the flat-plate case by flattening the tip of the nose cone. Thus the thermistor will be more completely heated to the stagnation temperature, giving more accurate results. A BT-50 sized tube may be used as shown, or a nose probe of BT-5 with a flattened cone and the small tube mount supplied with the TXA-3 kit could be used. The former method is recommeded since it is more easily contructed, and a larger stagnation region may be obtained.

The increase in drag due to this sensor configuration is no more than that due to mounting the thermistor and shade off center as suggested in the manual and thereby causing a permanent yaw.

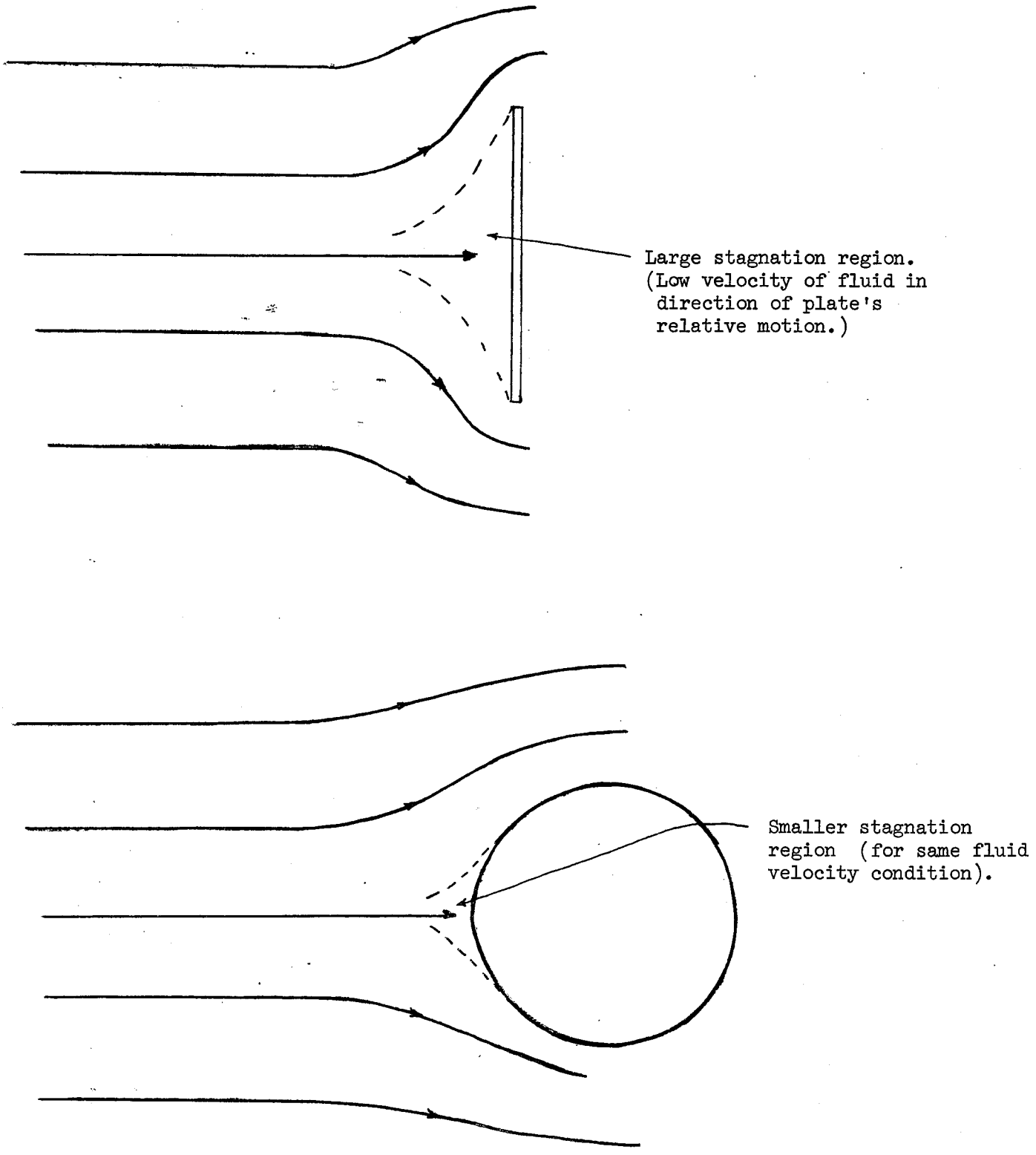
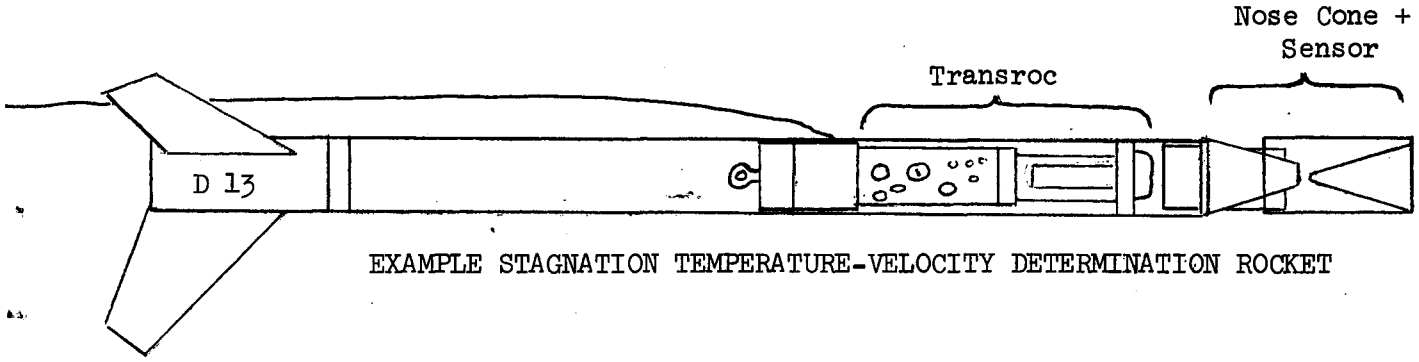


FIGURE 5

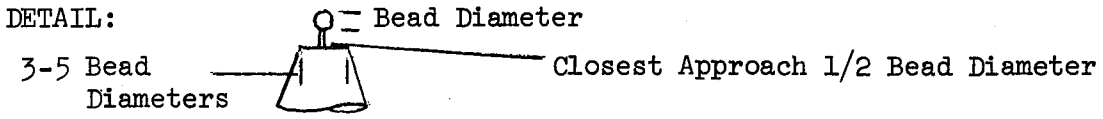
STEADY FLOW AROUND A FLAT PLATE AND A SPHERE

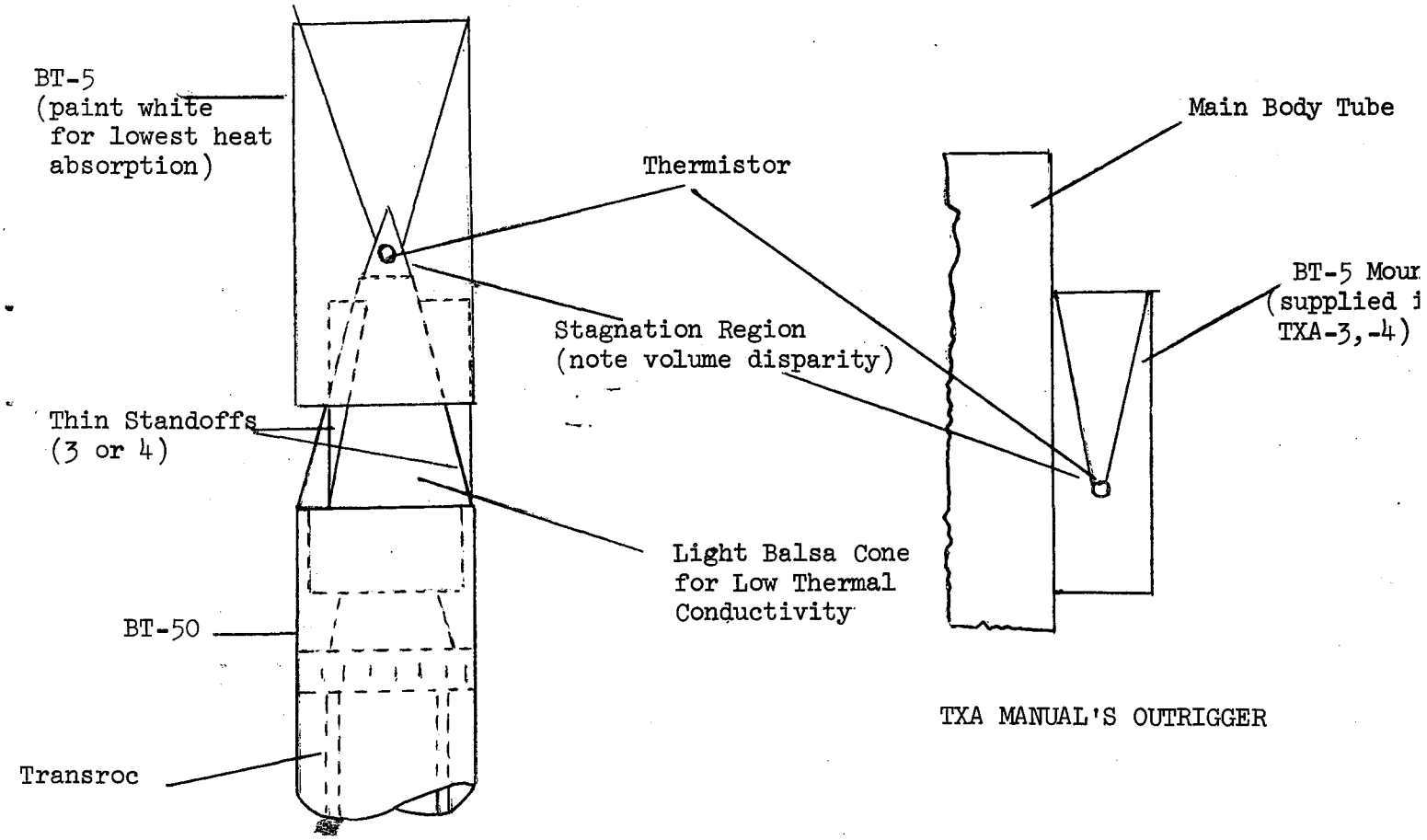
FIGURE 6

NOSE-MOUNTED THERMISTOR FOR STAGNATION TEMPERATURE MEASUREMENT



EXAMPLE STAGNATION TEMPERATURE-VELOCITY DETERMINATION ROCKET





PROPOSED CONFIGURATION

TXA MANUAL'S OUTRIGGER

APPENDIX 3

GSR Flight 001
17 July 1973

The first flight test in the GSR two-staged uprated model rocket program ocurred at the fifth Southwestern Model Rocketry Conference on 17 July 1973, at a site a few miles west of Albuquerque, New Mexico. GSR-1 was equipped with an operating temperaturesonde/telemetry package, dual antenna system, and programmed electronic sequencer system, and was powered by an Enerjet F52 booster motor and E24 sustainer motor. The flight was witnessed by about 50 rocketeers, newspeople, and interested spectators.

Liftoff is shown in Figure A3-1. Boost was fast and straight, with the vehicle disappearing from the sight of most observers. Sustainer ignition occurred at T+ 4. seconds as planned, and the vehicle was lost from sight for some minutes thereafter. At approximately T+ 300. seconds the recovery parachute was sighted drifting slowly down at an estimated altitude of one kilometer. As the parachute neared the ground it became apparent that it had separated from the sustainer, as was confirmed upon examination of its tattered remains. The descent telemetry antenna had also been torn from the payload, but telemetry signals were still being received some minutes later. As the final RF stage transistor absorbed energy reflected from the now-badly mismatched antenna stub, it heated, signals weakened and finally ceased.

The sustainer and payload were later recovered, and it was determined that the recovery system had been ejected as planned at T+ 22. seconds and that failure of the shock cord mount was solely responsible for the mishap. Overnight thunderstorms had caused water damage to the sustainer airframe, but the electronic sequencer and temperature-sonde systems were undamaged, save for the expected thermal damage to the transmitter output transistor.

The telemetry record from the flight clearly shows sensor heating during the booster and sustainer burns but is, of course, of little value after recovery system deployment due to the destruction of the descent antenna and resulting poor signal-to-noise ratio.

The flight was considered as 90 percent successful.