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FLIGHT-TEST TEMPERATURE DATA FOR AN ALTAIR-IIC1 ROCKET MOTOR

by James L. Raper

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SUMMARY

Comparison of chamber-wall temperatures obtained from flight data and static tests at altitude shows some differences. The flight data indicate maximum chamber-wall temperatures of 800° F as compared with maximum temperatures of 400° F for static tests on the chamber wall at simulated altitude. Comparison of static data for a foil-wrapped and a nonwrapped chamber indicates foil wrapping causes an increase in temperature from 400° F to 700° F. Flight temperatures are sufficiently high to cause epoxy resin boiloff, charring of the chamber wall, and resultant loss of chamber structural strength.

INTRODUCTION

During the qualification testing program of the Altair-IIB1 rocket motor for NASA Scout spin rates, one motor failure occurred during thrusting due to chamber-wall burn-through. In addition to that catastrophic burn-through, there were several instances of chamber-wall charring indicating insufficient insulation in the cylindrical chamber region. As a result of this testing, the inhibitor tube around the igniter was shortened to permit more complete propellant burning, and additional side-wall insulation was added to the motor design. The resulting Altair-IIC1 motor has been extensively instrumented and tested twice in the Propulsion Engine Test Cell of the Rocket Test Facility, Arnold Engineering Development Center (AEDC) (ref. 1). It has also been tested once as the fourth stage of a standard Javelin research vehicle. A single sensor on another motor used as the fourth stage of the NASA Scout launch vehicle has provided additional flight verification data. It should be noted that the NASA is developing an Altair-IIE1 motor with the objective of reducing the chamber-wall temperatures obtained in the Altair-IIC1 version. Chamber-wall-temperature data for the Altair-IIC1 obtained from the aforementioned tests are the subject of this report.

It should be emphasized that the data in this report are not used to reflect upon the ballistic performance of the motor. A motor user who ejects the motor shortly after burnout is not concerned with the motor-case-temperature problem described herein. However, a user who builds a payload around the motor (for example, micrometeoroid satellite S-55) or retains the motor for an extended time after burnout must design his payload to accommodate the hot motor case.

ALTAIR IIC1 MOTOR DETAILS

The Altair IIC1 rocket motor consists basically of a fiber-glass pressure vessel lined with buna-S asbestos insulator, a propellant charge cast into the chamber, and a conical divergent nozzle. Figure 1(a) shows a schematic of the motor assembly. The detail at the top of figure 1(a) shows the location of the previously mentioned inhibitor tube. Figure 1(b) shows the propellant core geometry. Figure 1(c) shows details of the forward dome and cylinder insulator. Note the location on the side wall where boric-acid-loaded synthetic rubber insulation has been added to a previously uninsulated portion of the forward cylinder as previously mentioned. Figure 1(d) shows a cross section of the motor in the aft cylinder area. Note that the insulator is thickest at the points where the propellant first burns through to the chamber wall. The thinnest insulator location is opposite the thickest propellant section. Note also that two strips of boric-acid-loaded synthetic-rubber insulator have been added at the locations opposite minor grain slots to prevent previously experienced chamber-wall hot spots. Figure 1(e) shows details of one of 2 typical places or one of four typical places of the after-cylinder insulator as indicated by the two sections taken through figure 1(d).

TESTS

Flight Test

A modified Javelin vehicle was launched from Wallops Island, Virginia, on April 15, 1964, to flight test an Altair IIC1 (X-258) (S/N RH-65) rocket motor in a spinning environment similar to that of the Scout vehicle. The primary objective was to obtain flight-performance and temperature data to correlate with AEDC static tests. Modification of the basic Javelin vehicle consisted of substituting the Altair-IIC1 as the fourth stage in place of an Altair-IA6 with the other stages remaining the same (Honest John, Nike, Nike). Figure 2 shows the vehicle on the launcher.

Figure 3 shows a comparison of the actual and nominal altitude-range plot. Failure of the fourth-stage heat shield to eject at the proper time resulted in a performance level lower than expected. The heat shield did eject as noted in table I where actual flight events are compared with nominal event times.

Instrumentation in the payload for monitoring performance is listed with respective ranges in table II. Figure 4 shows schematically the location of the 10 thermistors which are of primary interest in this report. Figures 5 to 7 are photographs of the actual thermistor locations on the flight motor.

As previously mentioned, the motor has 10 thermistors attached to its external surface. In addition, a coat of silver conductive paint was applied to the forward dome; an expansion potentiometer was located at midcylinder which monitored the expansion of one-half of the cylinder; two radiometers were located at the forward thrust face on the cylinder wall.

A prime requirement for the flight test was to have a spin rate equal to or slightly greater than that of Scout during motor burning. The spin rate was produced by canting the first-stage fins 30 minutes and the third-stage fins 37 minutes. Since spin rate was deemed to be a primary measurement it was measured by several instruments and the results are shown in figure 8.

Static Altitude Test

Static tests of two Altair-IIC1 motors identical to the motor in the Javelin flight test are reported in detail in reference 1. Both motors (S/N RH-56 and S/N RH-58) had temperature-sensing instruments in locations identical to those on the flight motor. The primary objectives of the two static-test firings were to evaluate the structural integrity and the temperature effectiveness of the insulation modification on the Altair-IIC1 motor.

Both motors were placed in the rocket-motor spin-test apparatus at the Langley Research Center for testing. Motor RH-56 was tested at 192 rpm and motor RH-58, at 184 rpm. Motor RH-56 was ignited at a pressure altitude of 118,000 feet and RH-58, at 110,000 feet.

The first and third quadrants of the RH-56 motor case were painted with a silver conductive paint that is used to improve tracking during Scout flights. For qualification purposes, the motor case and forward dome of RH-58 were wrapped with aluminum foil to conform with the Delta flight configuration. The aluminum foil was provided to determine if the sensitive elements of a payload could be protected from the contaminants of the hot epoxy gases released from the fiber-glass motor case. Chromel-alumel thermocouples were used to determine temperature histories.

RESULTS AND DISCUSSION

Figures 9 to 13 compare the results of the flight test and of the static altitude tests. As indicated in the figures, the flight motor had silver conductive paint on the forward dome but was natural elsewhere. Examination of the data for thermocouple (TC) 4 in figure 11 indicates that the addition of an aluminum-foil wrapping to a natural case can increase the maximum temperature of the case from 400° F to 700° F. It should be noted that for TC 4 the maximum temperature for the foil-wrapped case occurs 150 seconds after that for the nonwrapped case. Similar results were observed during the static test of an Altair-IIB1 (S/N RH-47) motor tested at 200 rpm as indicated in reference 2. Examination of the Altair-IIB1 motor after testing showed a large deposit of resin on the aluminum foil. As a consequence of this resin boiloff, the fiber-glass filaments in the chamber midsection were left essentially unbonded. This condition resulted from a case surface temperature of 700° F measured over a grain slot (fig. 4).

Examination of RH-56 (silver paint on alternate quadrants) revealed the motor sustained only slight discoloration (in spots) and no external case deformation was evident. The maximum measured case temperature was 600° F.

Examination of RH-58 (covered with aluminum foil) revealed that approximately 20 inches of the after-chamber section and also the forward dome had turned a dark brown. The after section was charred and three small soft spots were evident. There was a light deposit of epoxy resin on the after-cylinder aluminum foil. As a result, the fiber-glass filaments in the soft spots were partially unbonded but not to the extent described in reference 2 for RH-47. The maximum measured temperature of case RH-58 was 700° F.

Based on the Javelin data, the temperatures measured in flight on the chamber side walls are significantly higher than for the static tests. For the unwrapped motor cases (RH-56 and RH-65), the chamber-wall temperature in the flight test was 400° F greater than in the static tests as shown in figures 10 and 11. Even though the heat shield did not eject as planned, it had no effect on the side-wall temperature histories since there was no indicated temperature increase prior to the time that the heat shield did eject. A possible reason for this difference between flight- and static-test data at simulated altitude is in the test environments. The static tests are generally performed at a simulated altitude of about 100,000 feet while the flight test of the Javelin vehicle extended up to 2.4×10^6 feet as shown in figure 3. The considerably lower density of the flight environment reduces the case heat transfer to the surrounding atmosphere compared with the transfer which occurs in the AEDC tunnel tests. In figure 14 temperature for the forward dome of Scout S-122 is compared with the temperature on the Javelin and AEDC motor tests. An Altair-IIB1 (RH-61) was used on Scout S-122, but dome temperatures would be the same as those from Altair-IIC1 motors since dome insulation is identical. The Scout S-122 motor had an aluminum-foil blanket over the forward dome and was spinning at approximately 160 rpm. Each flight test shows larger maximum temperatures - a maximum temperature which occurs much later than in the static tests - and a much lower rate of cooling after maximum temperature.

There are several other possible causes for the observed temperature differences. At the present time there is not enough directly comparative data to rule out completely any one possibility. Increase in spin rate has been shown to precipitate more aluminum oxide in the burned-out chamber which causes higher temperatures. References 3, 4, and 5 show the magnitude of this phenomena for several current solid-propellant rocket motors. The effects of longitudinal acceleration (none during static tests) on the motor during burning are unknown. It is, however, known that thermocouple installation does not account for any of the differences since the instruments were installed identically and with the same materials.

It is only possible to speculate as to the condition of the motor case during the flight test. The motor manufacturer indicates that boiloff of the case resin begins at 450° F and that progressively higher temperatures cause discoloration and result in char and filament unbonding at the higher temperatures. As a result of the char and the filament unbonding associated with the temperatures measured on the RH-58 (ref. 1) and RH-47 (ref. 2), it can be implied that the RH-65 test resulted in a considerable amount of char on the case and resin boiloff. A motor case charred to this extent is incapable of transmitting any significant bending or compressive loads. Reference to figure 11 indicates that the motor problems due to temperature become serious about 75 seconds after motor ignition.

It should be noted that in the Javelin flight test, examination of the vehicle-motion records showed no unusual motions until 904 seconds. At this time there was a dynamic pressure of approximately 0.4 pound per square foot, and the vehicle divergent rates encountered at this time were greater than those expected of a rigid vehicle and indicate vehicle breakup.

CONCLUDING REMARKS

Comparison of temperature data for the X-258-C1 (S/N RH-65) motor case spinning at 250 rpm with data from static tests at simulated altitude indicates some differences between flight-test results and results from static tests at simulated altitudes. Flight data indicate the maximum chamber-wall temperature was 800° F for an unwrapped case as compared with 400° F for a static test. The probable result of this higher temperature was a severely charred case. Comparison of static data for a nonwrapped and a foil-wrapped case indicates an increase in maximum case temperature from 400° F to 700° F due to the foil wrap. Temperatures in both instances are so high that epoxy resin boiloff occurs and results in a severely charred case which has little bending or compressive structural strength remaining.

Temperatures on the rocket motor case do not get high enough to cause case strength degradation until approximately 75 seconds after motor ignition. For the flight test of motor RH-65 the onboard instrumentation indicated an absence of any excessive vehicle motions until 904 seconds.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 12, 1965.

REFERENCES

1. White, D. W.; and Nelius, M. A.: Results of Testing Two HPC-ABL X-258 (S/N's RH-56 and RH-58) Solid-Propellant Rocket Motors Under the Combined Effects of Simulated Altitude and Rotational Spin. AEDC-TDR-64-97, U.S. Air Force, May 1964.

2. Nelius, M. A.; and White, D. W.: Results of Testing the HPC-ABL X-258 B-1 (S/N RH-47) Solid-Propellant Rocket Motor Under the Combined Effects of Simulated Altitude and Rotational Spin. AEDC-TDR-64-41, U.S. Air Force, Mar. 1964.

3. Lucy, Melvin H.; Northan, G. Burton; and Swain, Robert L.: Rocket Motor Spin Data Summary. NASA paper presented at Naval Ordnance Test Station Symposium on Behavior of Propellants Under Acceleration Fields (China Lake, Calif.), Nov. 18-19, 1964.

4. Anon.: Fourth-Stage Scout Rocket Motor Program Development Test Report. UTC 2100-DTR (Contract No. AF 04(695)-588), United Technol. Center, Mar. 16, 1965.

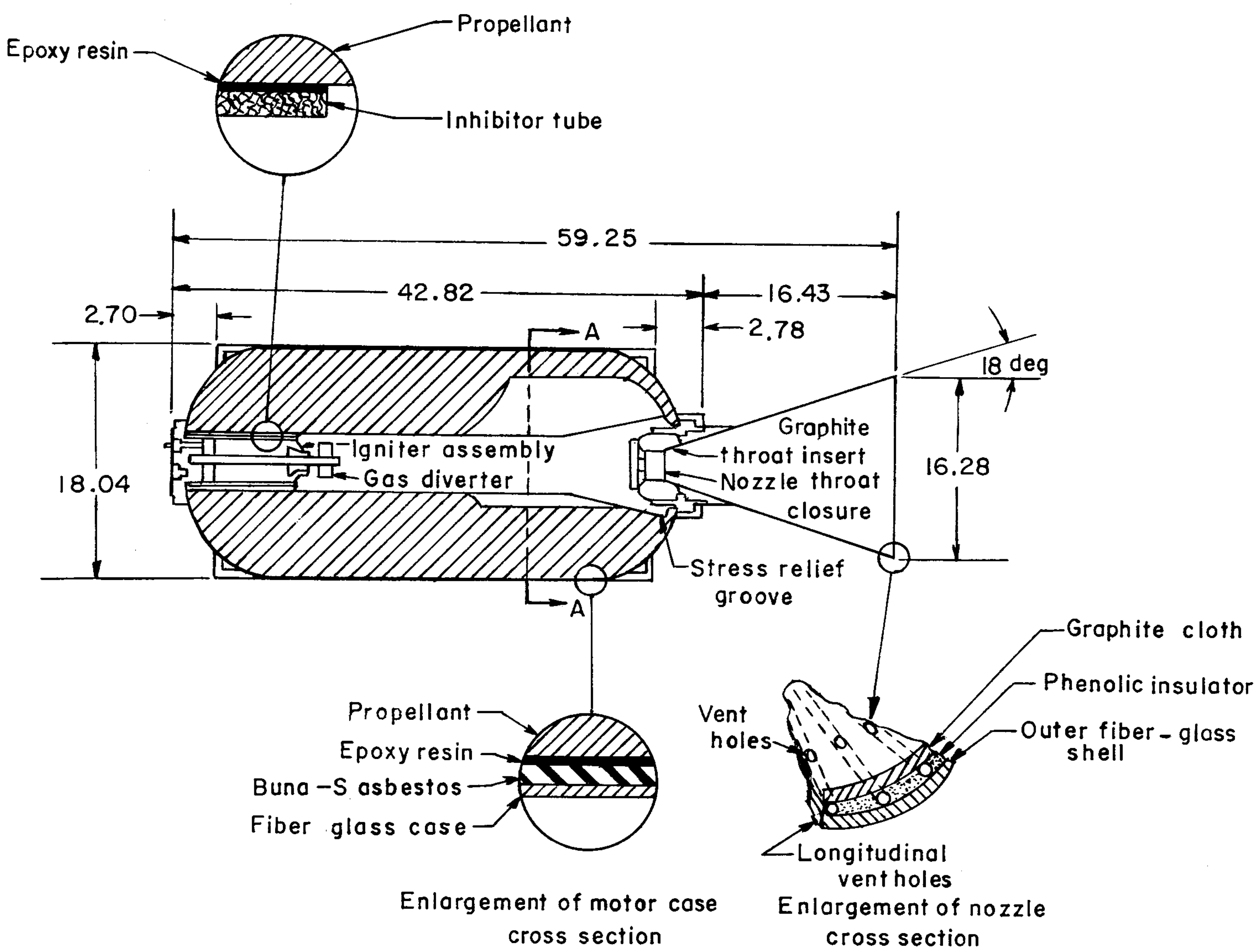
5. Harnett, Stephen; and Olstein, Myron: The Effect of Spin on the Internal Ballistics of End Burning Rocket Propellants. Tech. Mem. Rept. No. 1555, Picatinny Arsenal (Dover, N.J.), Oct. 1964.

TABLE I.- JAVELIN FLIGHT EVENTS

Event	Time, sec		Altitude, ft		Velocity, fps		Flight-path angle, deg	Range, ft
	Actual	Nominal	Actual	Nominal	Actual	Nominal	Actual	Actual
First-stage ignition	0.095	0	0	0	0	0	82	0
First-stage burnout	5.008	5.0		4 252		1 596		
Second-stage ignition	10.093	9.7		10 669		1 258		
Second-stage burnout	13.800	13.0		16 725		2 529		
Third-stage ignition	25.089	25		40 907		1 755		
Third-stage burnout	28.712	28.3		50 276		4 294		
Fourth-stage ignition	71.094	72	192 476	188 404	2 760	2 721	66.73	61 061
Heat-shield ejection	94.503	74	322 350		10 959		66.01	117 183
Fourth-stage burnout	96.059	96	337 714	326 580	11 260	13 334	65.99	124 509
Nose-cone ejection	119.227	120 ± 2	571 727		10 762		64.80	228 878
Despin	119.20	120 ± 2	571 727		10 762		64.80	228 878
Apogee	503	571	2 385 531	2 987 000				
Last radar data point	909		278 719					3 373 432

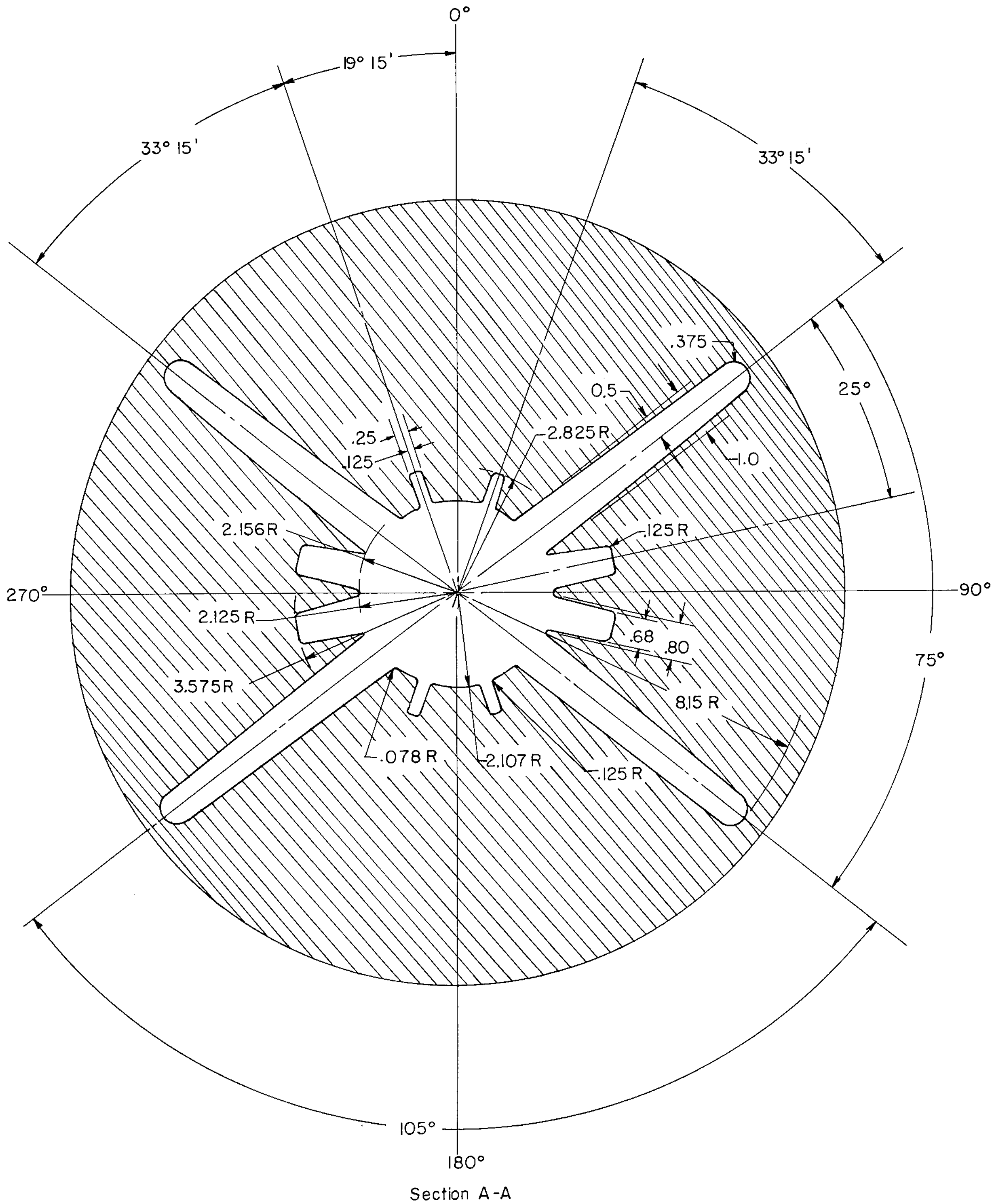
TABLE II.- JAVELIN FLIGHT INSTRUMENTATION

Instrument	Parameter measured	Range
Longitudinal accelerometer	Thrust, drag	-20g to 50g
Longitudinal accelerometer	Motor chuff	±0.5g
Pressure transducer	Thrust	0 to 800 psia
Pressure transducer	Thrust decay	0 to 4 psia
Radial accelerometer	Spin rate	-1.5g to 15g
Normal accelerometer	Tipoff	±1 g
Transverse accelerometer	Tipoff	±1 g
Orthogonal crystal accelerometers (3)	Vibration	±10g
Stablized gyro platform	Roll, pitch, and yaw	
	Position and rate	
Snap action switches	Monitor heat-shield ejection	
Thermistors (10)	External chamber temp.	0 to 1000° F
Longitudinal magnetometer	Tipoff	±600 mg
Transverse magnetometer	Tipoff and roll rate	±600 mg
Linear potentiometers (4)	Cylinder and dome expansion	



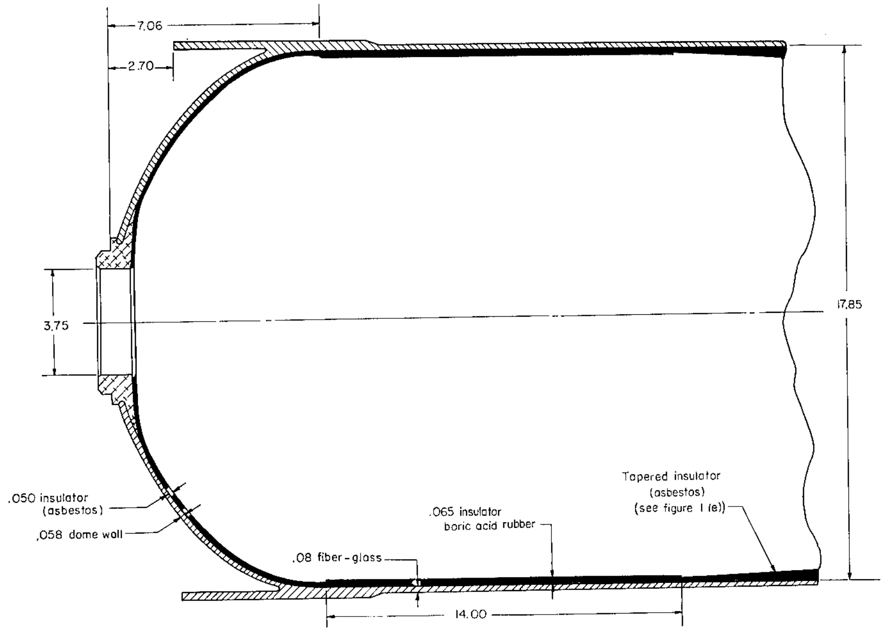
(a) Schematic. (See figure 1(b) for section A-A.)

Figure 1.- Altair-IIC1 motor. All linear dimensions are in inches.

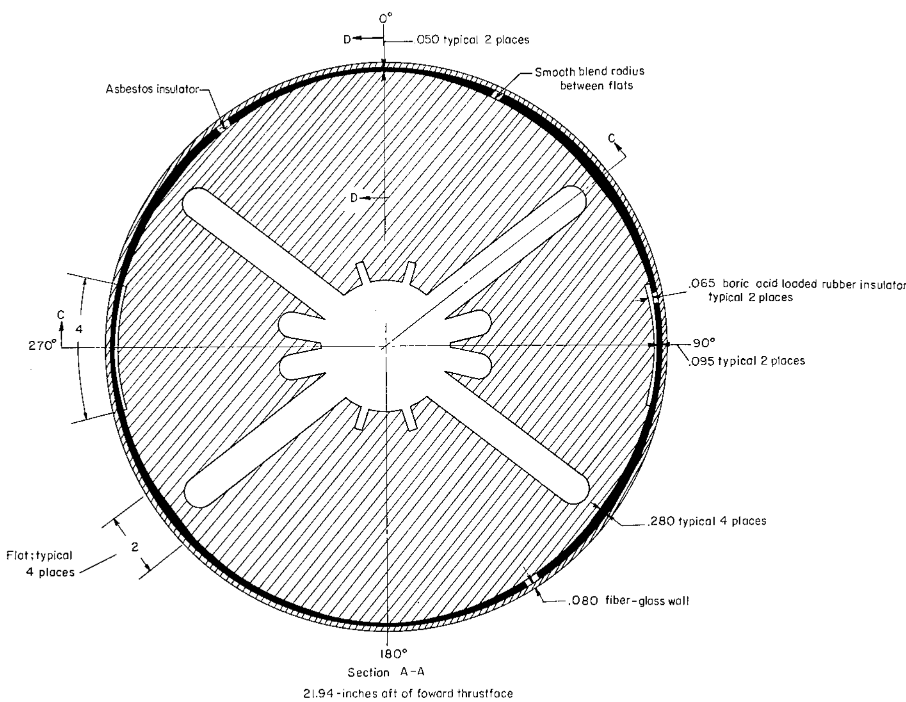


(b) Propellant core geometry.

Figure 1.- Continued.

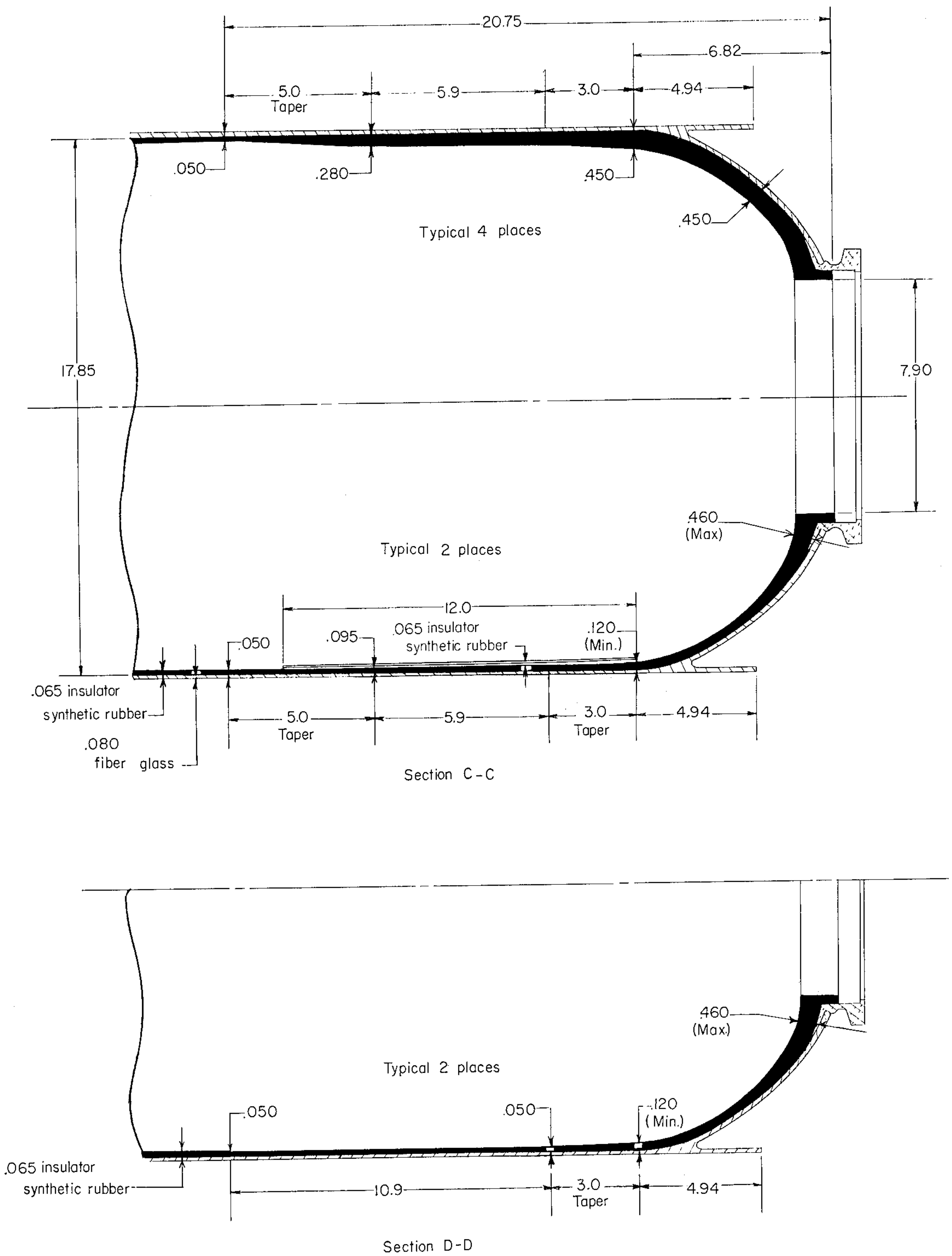


(c) Details of forward dome and cylinder insulator.



(d) Insulator cross section. (See figure 1(e) for sections C-C and D-D.) Cross section of motor in aft cylinder area.

Figure 1.- Continued.



(e) Aft-chamber asbestos insulator.

Figure 1.- Concluded.

Figure 2.- Modified Javelin on launcher. W-64-162

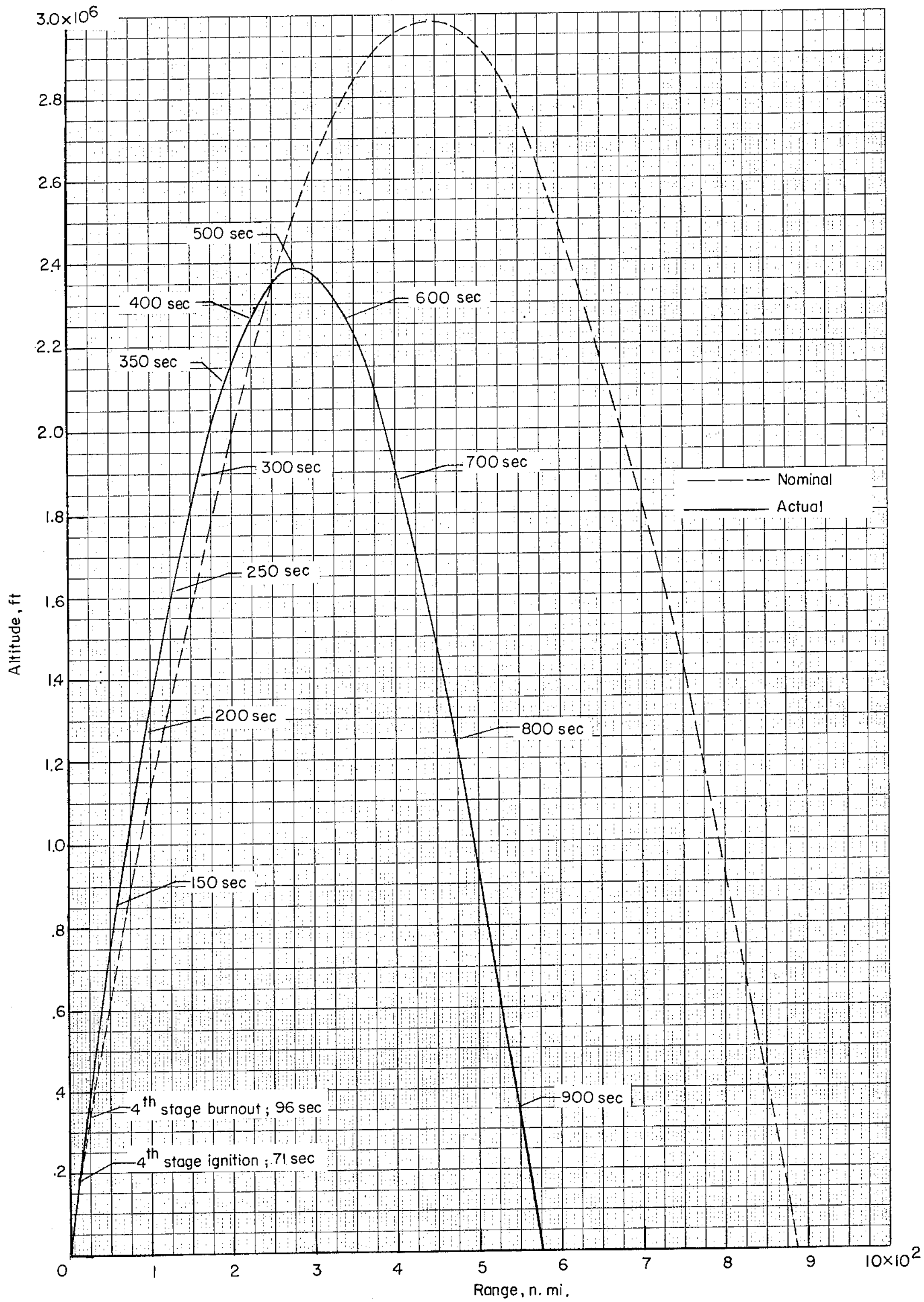


Figure 3.- Comparison of actual and nominal flight path.

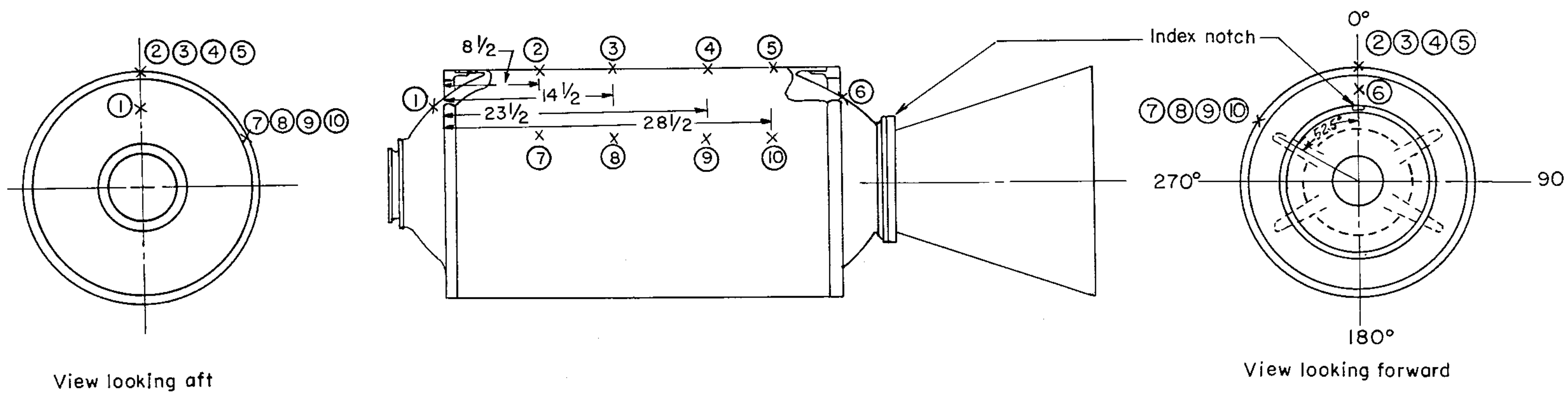


Figure 4.- Temperature-sensor locations. All dimensions are in inches.

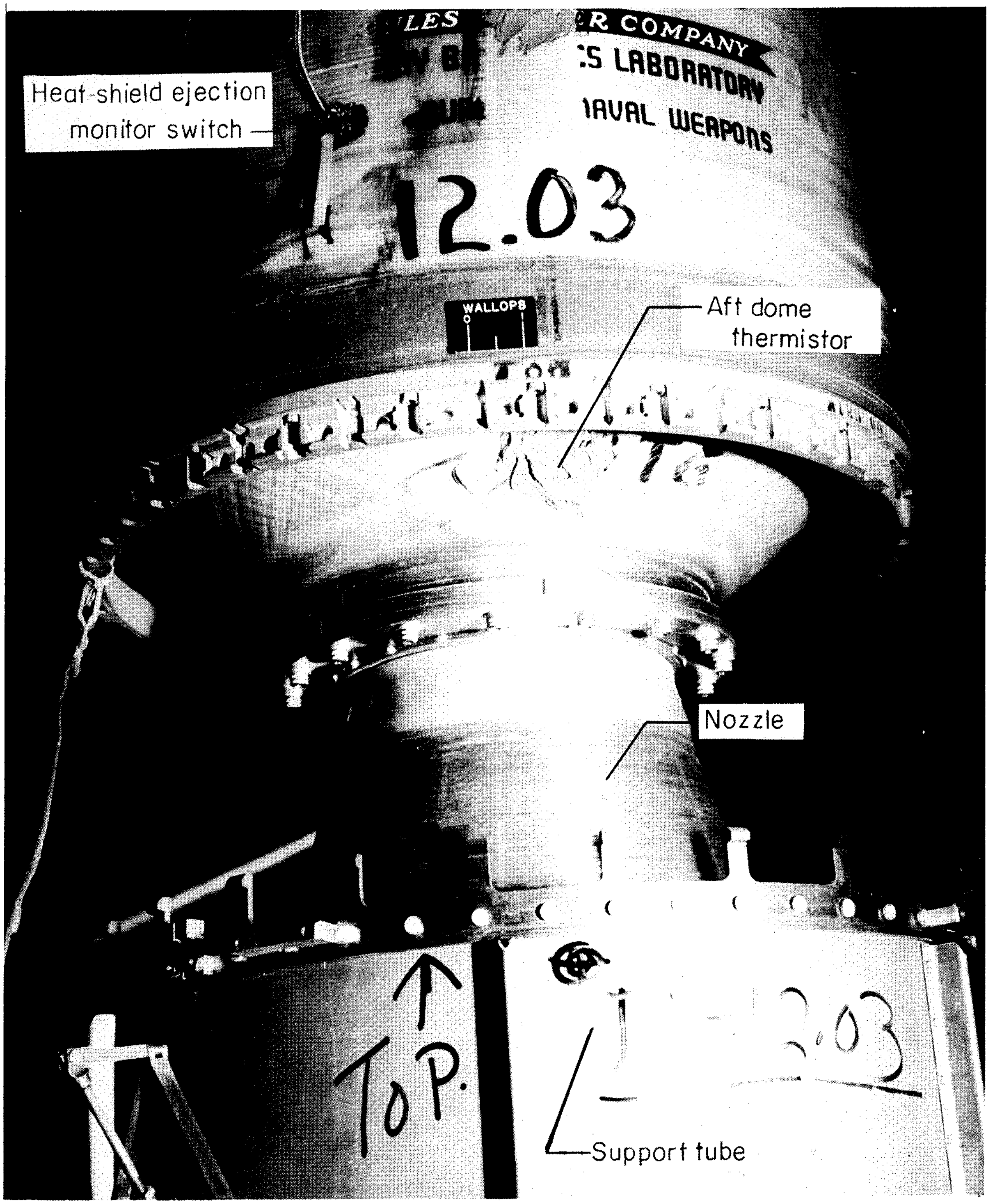


Figure 5.- Altair-IIC1 instrumentation (aft end).

L-65-116

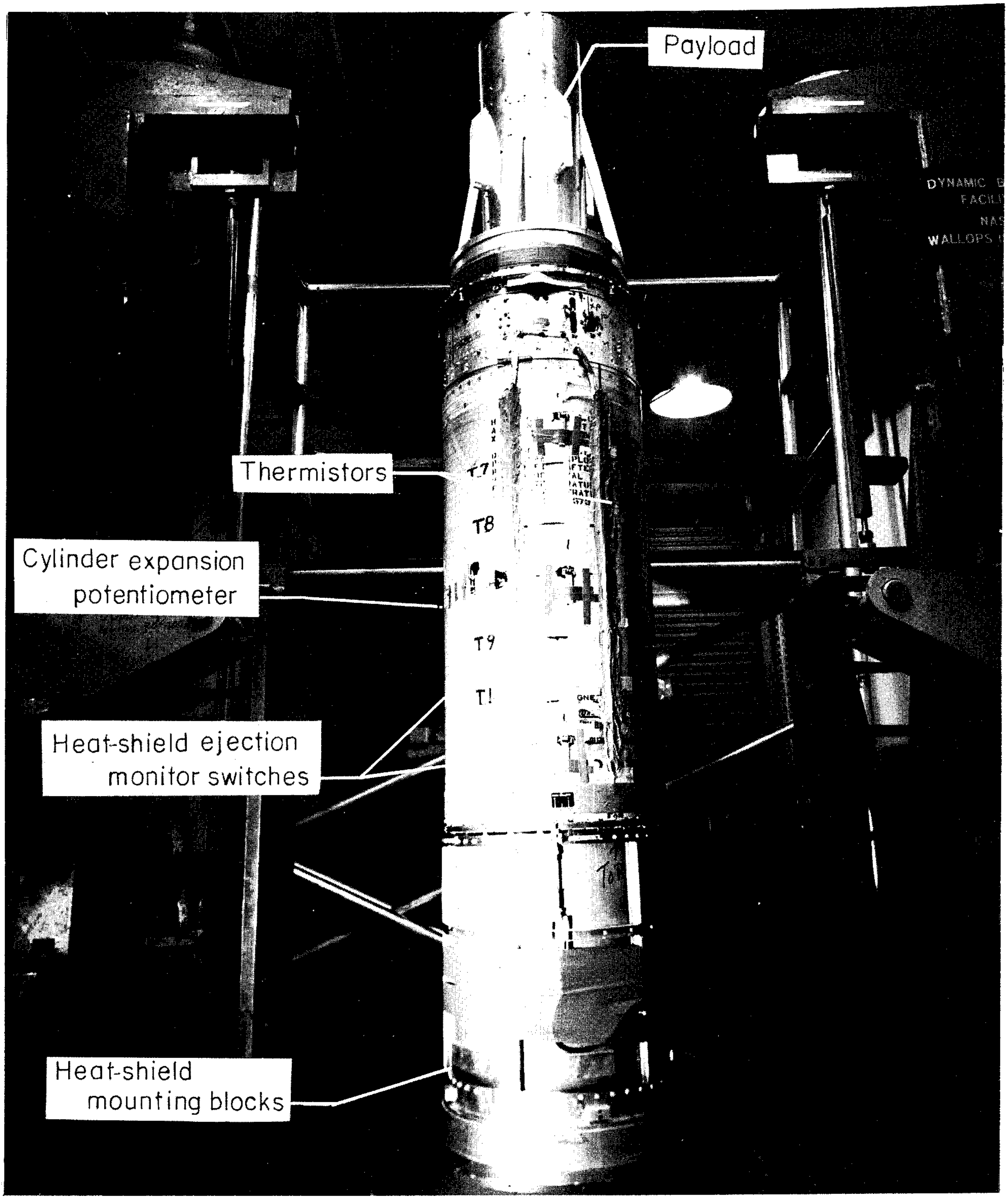


Figure 6.- Altair-IIC1 payload stage. L-65-117

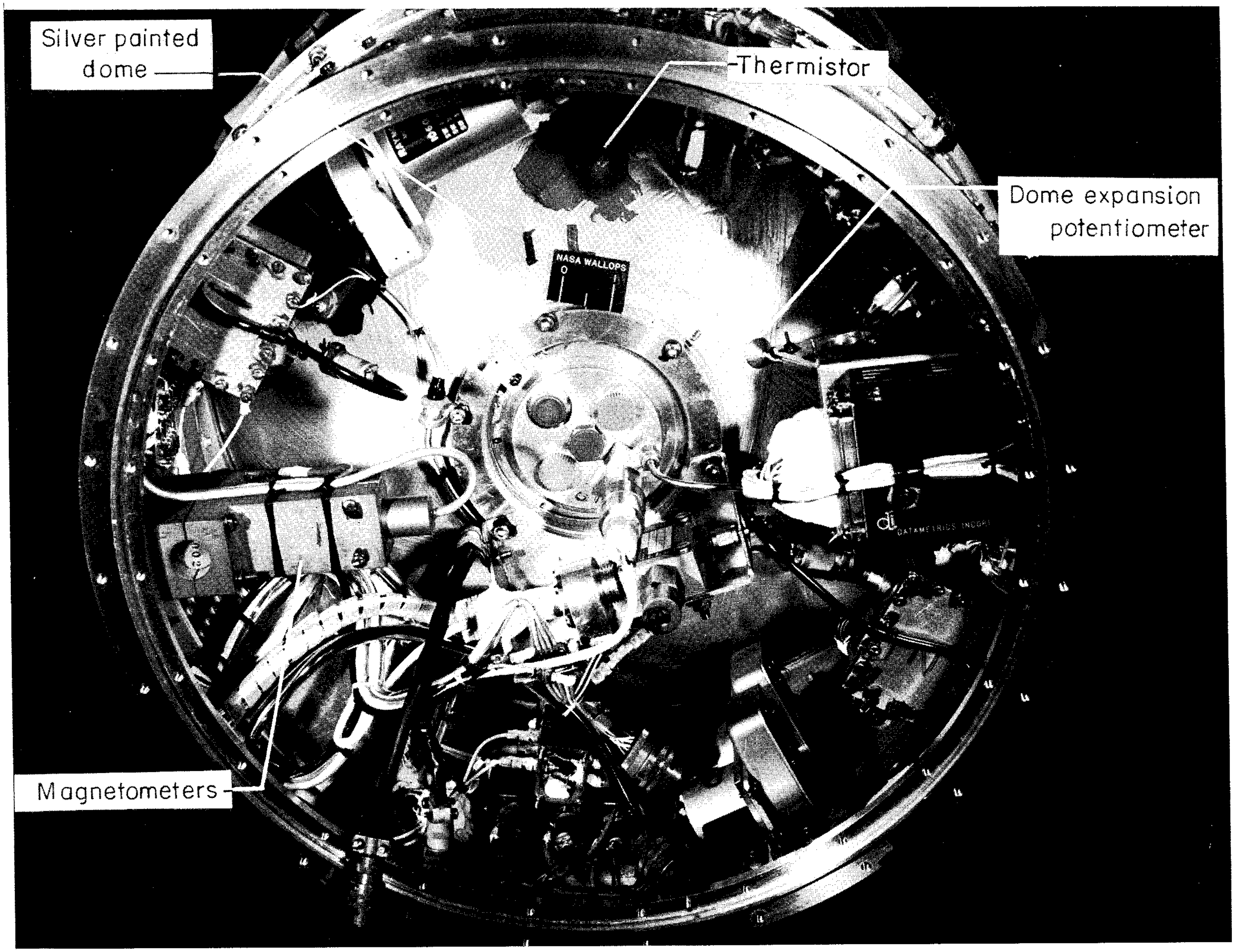


Figure 7.- Altair-IIC1 instrumentation (forward end). L-65-118

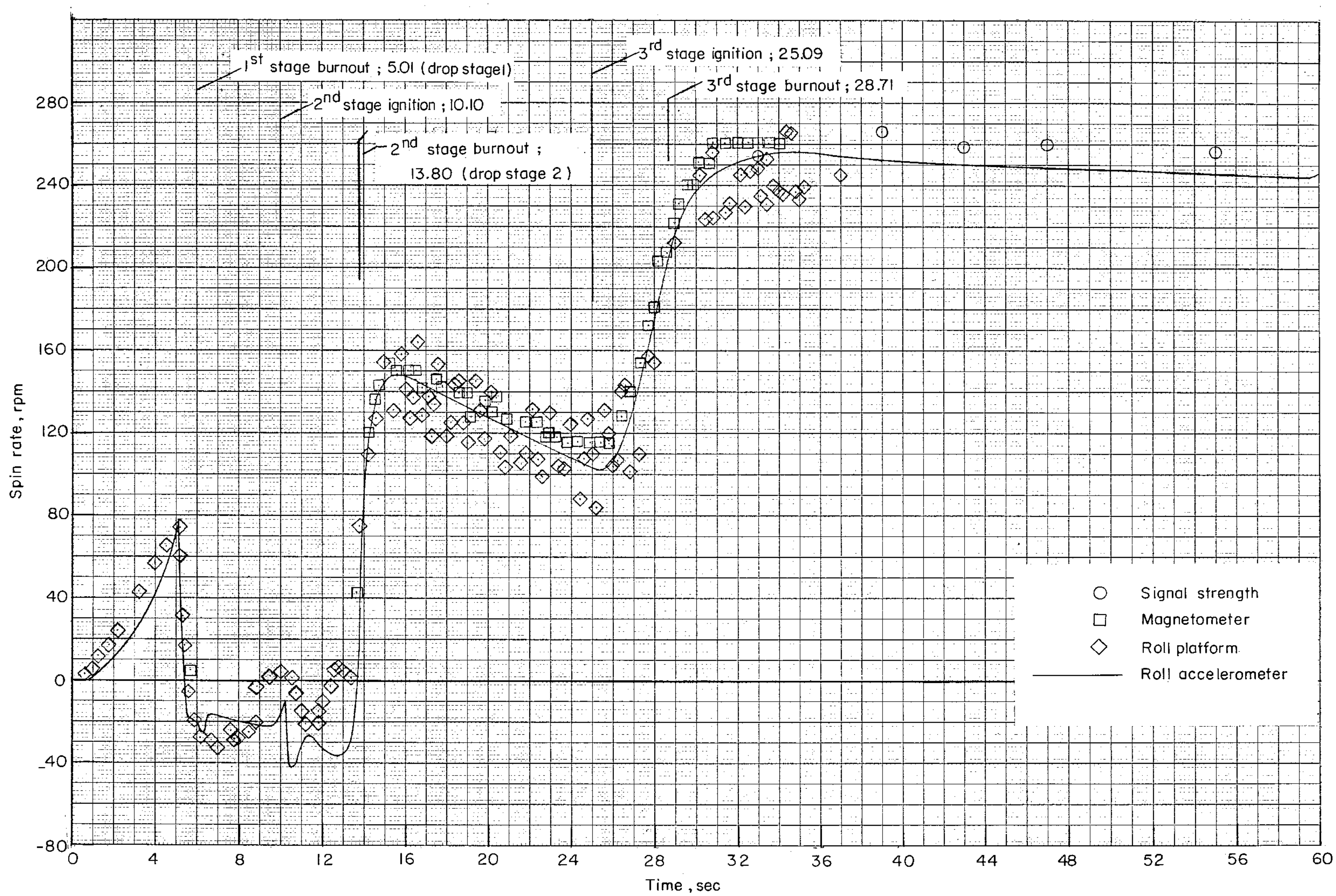


Figure 8.- Comparison of spin rate obtained from various sources.

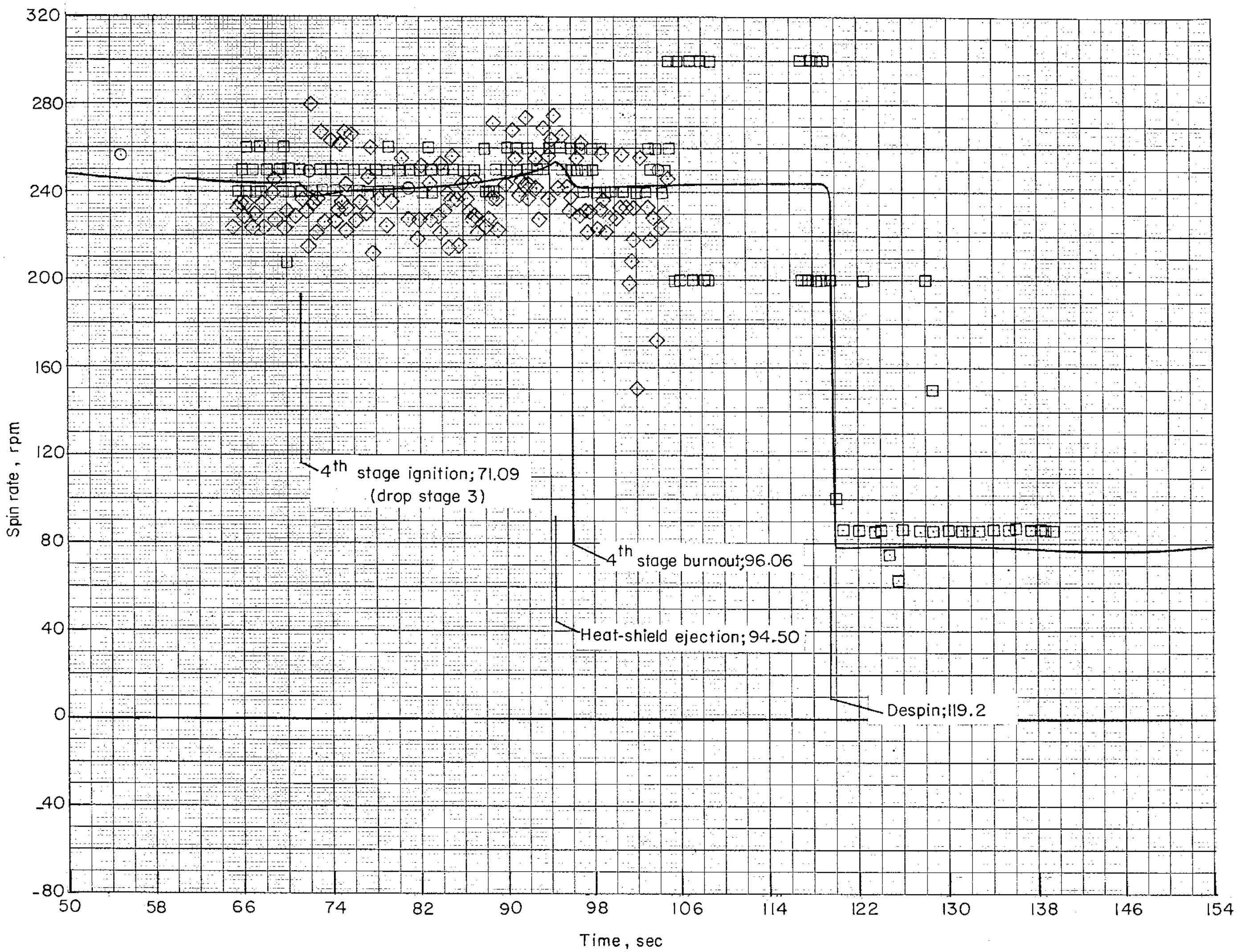


Figure 8.- Concluded.

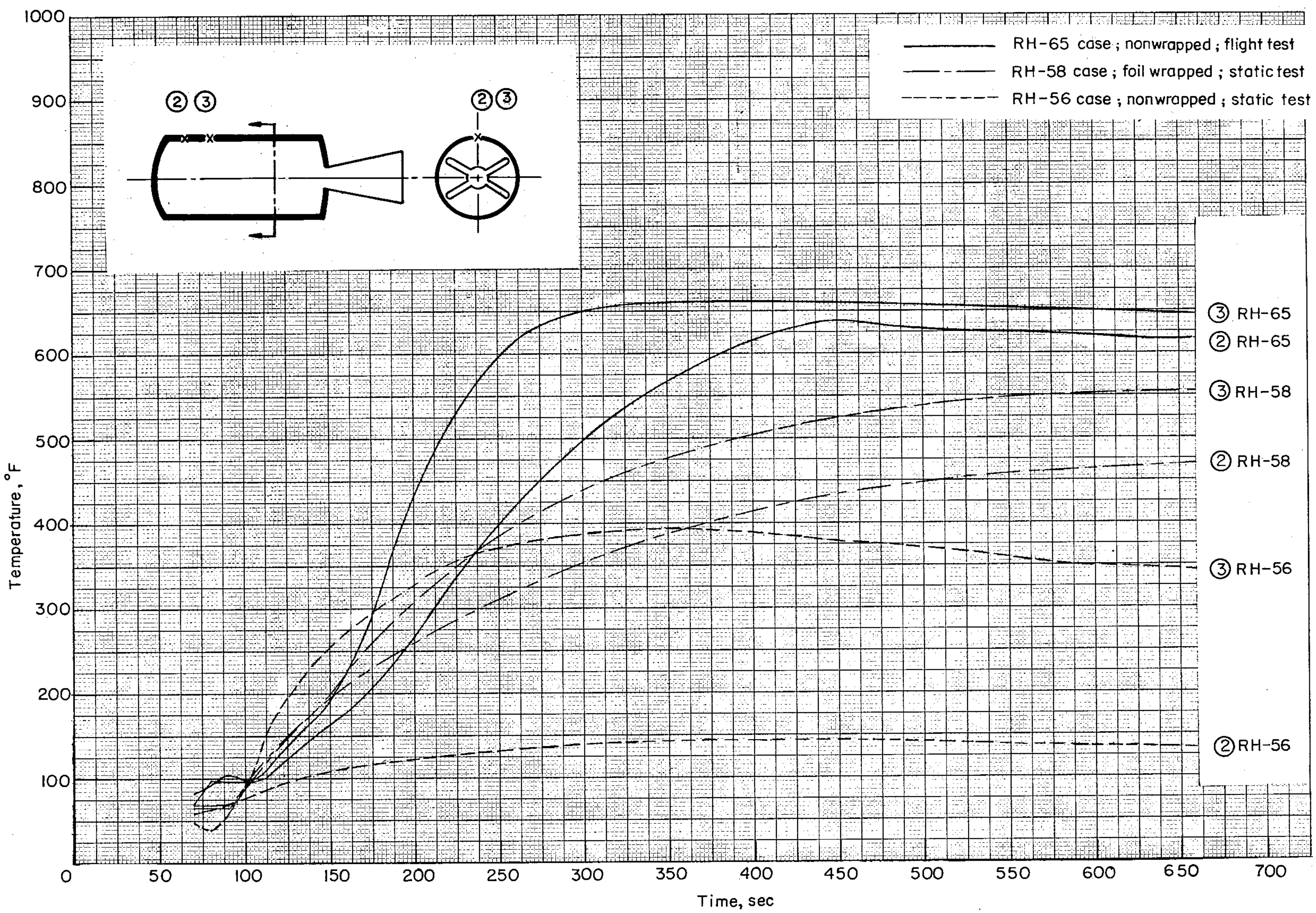


Figure 9.- Forward-cylinder temperatures measured at thermocouples 2 and 3.

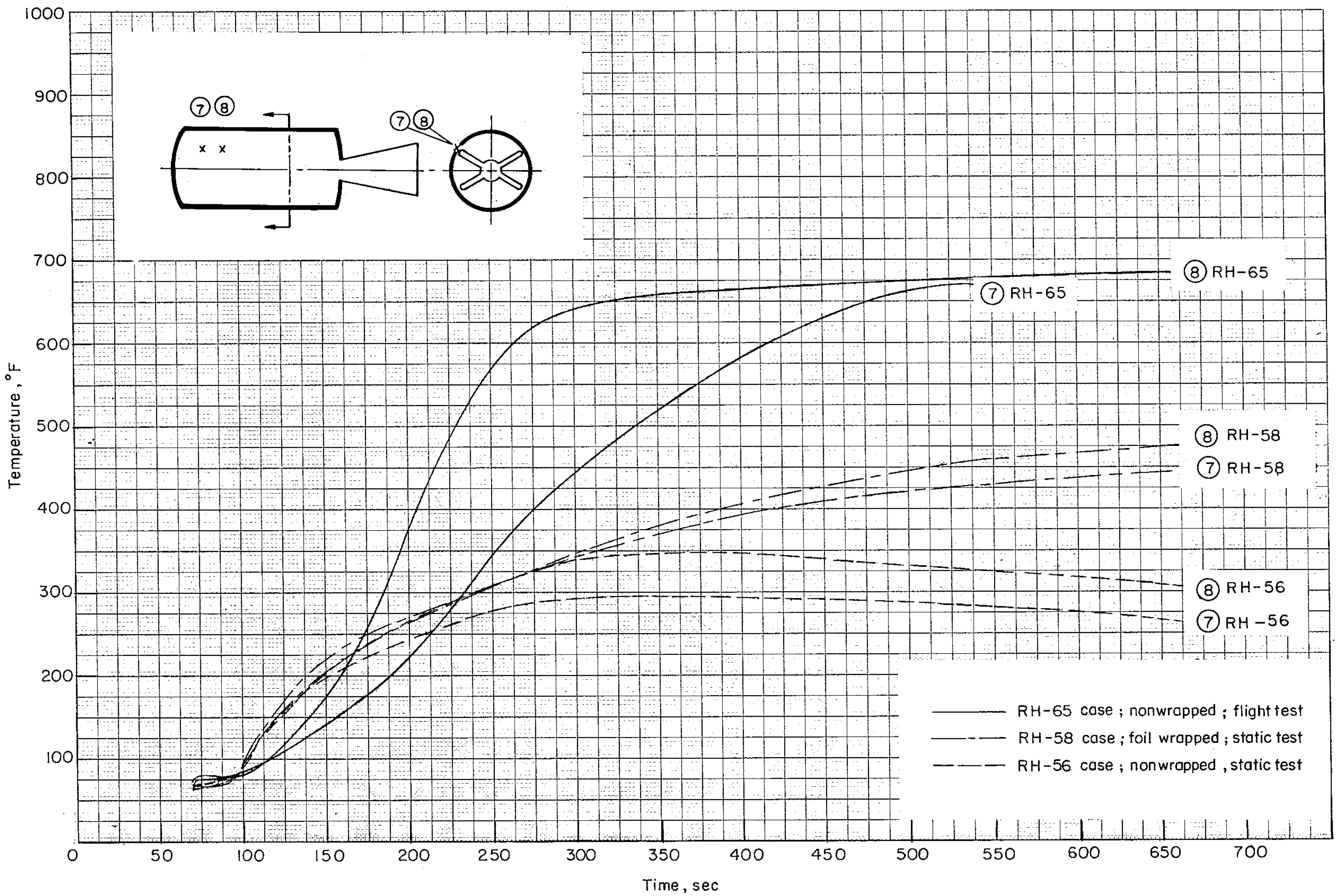


Figure 10.- Forward-cylinder temperatures measured at thermocouples 7 and 8.

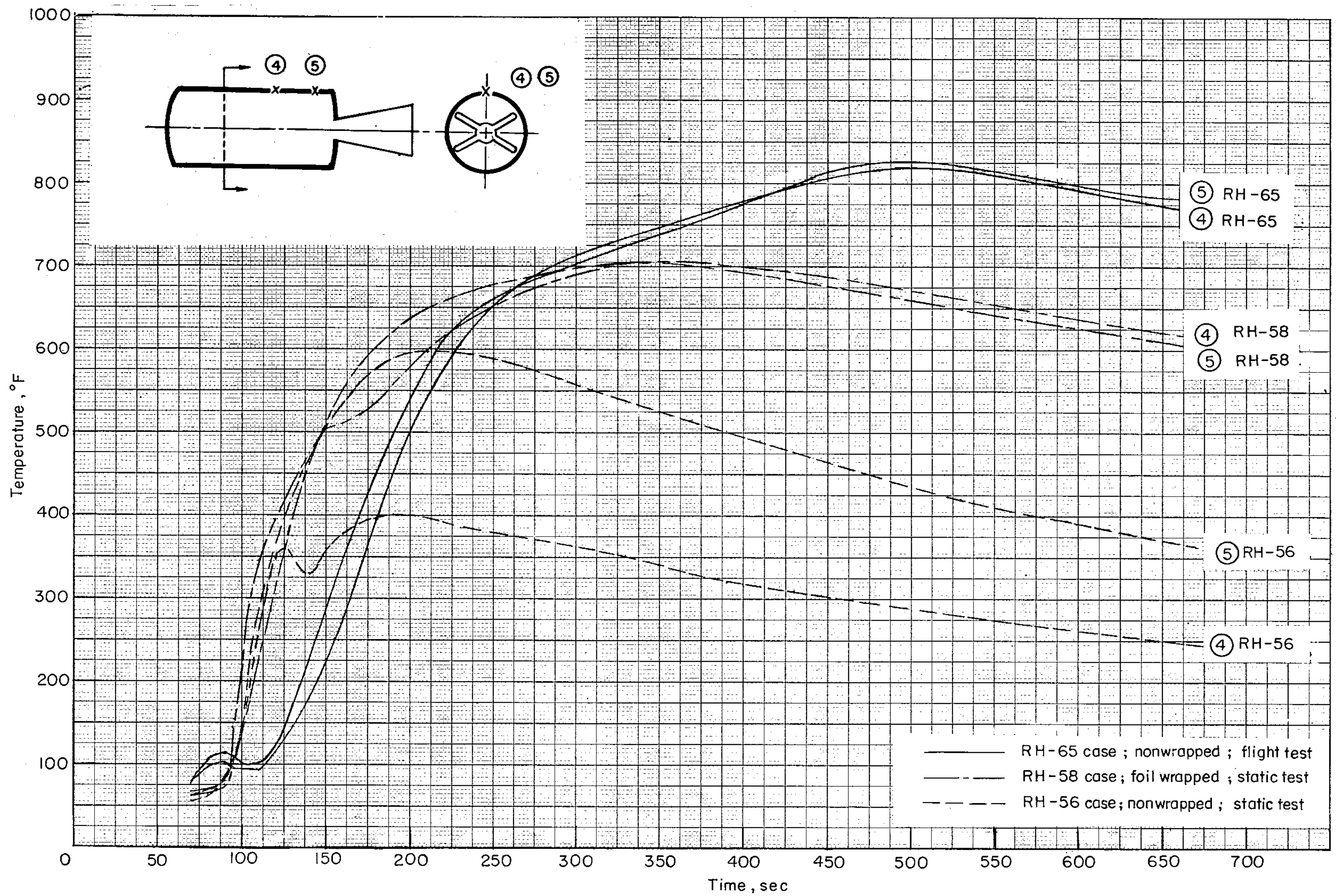


Figure 11.- After-cylinder temperatures measured at thermocouples 4 and 5.

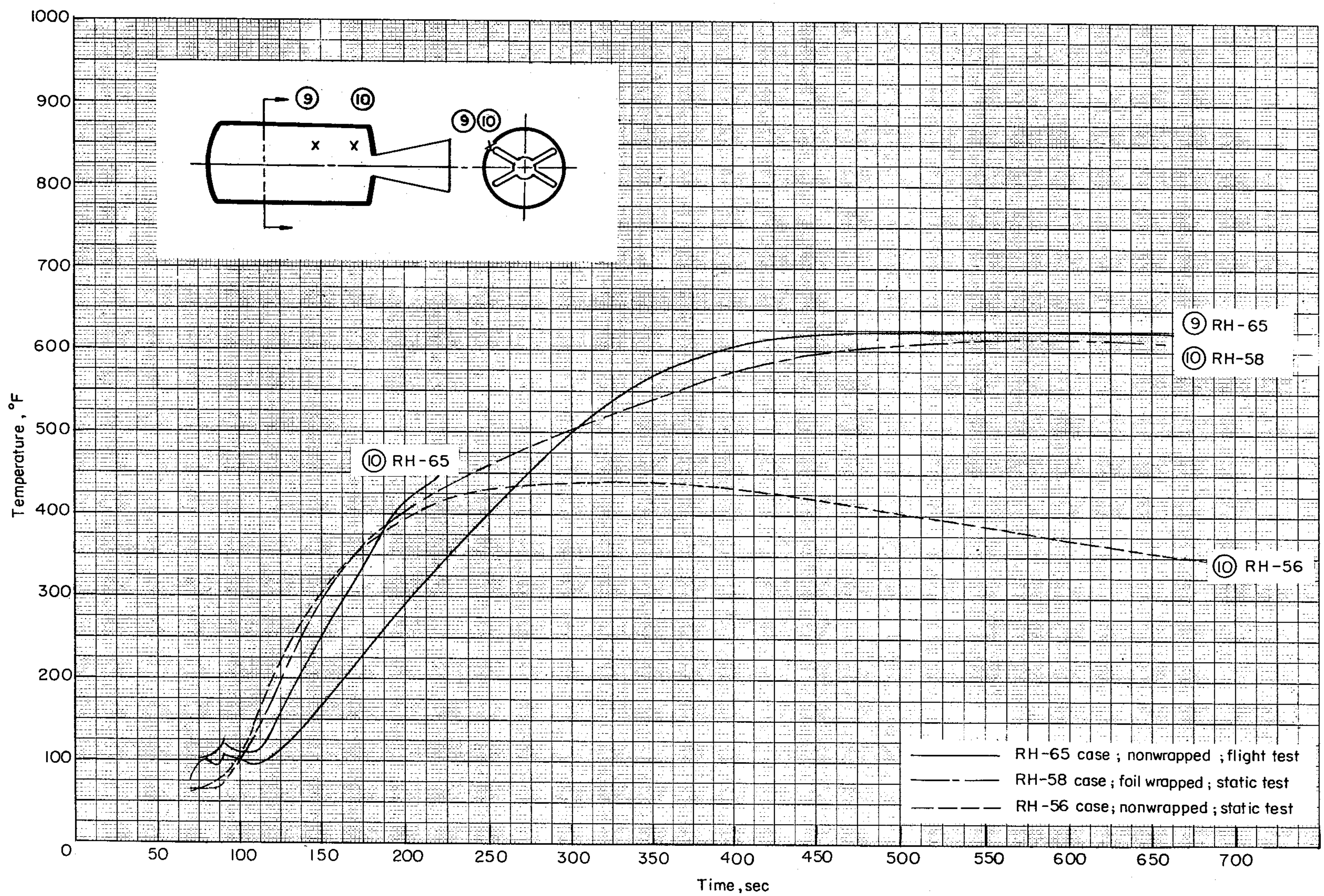


Figure 12.- After-cylinder temperatures measured at thermocouples 9 and 10.

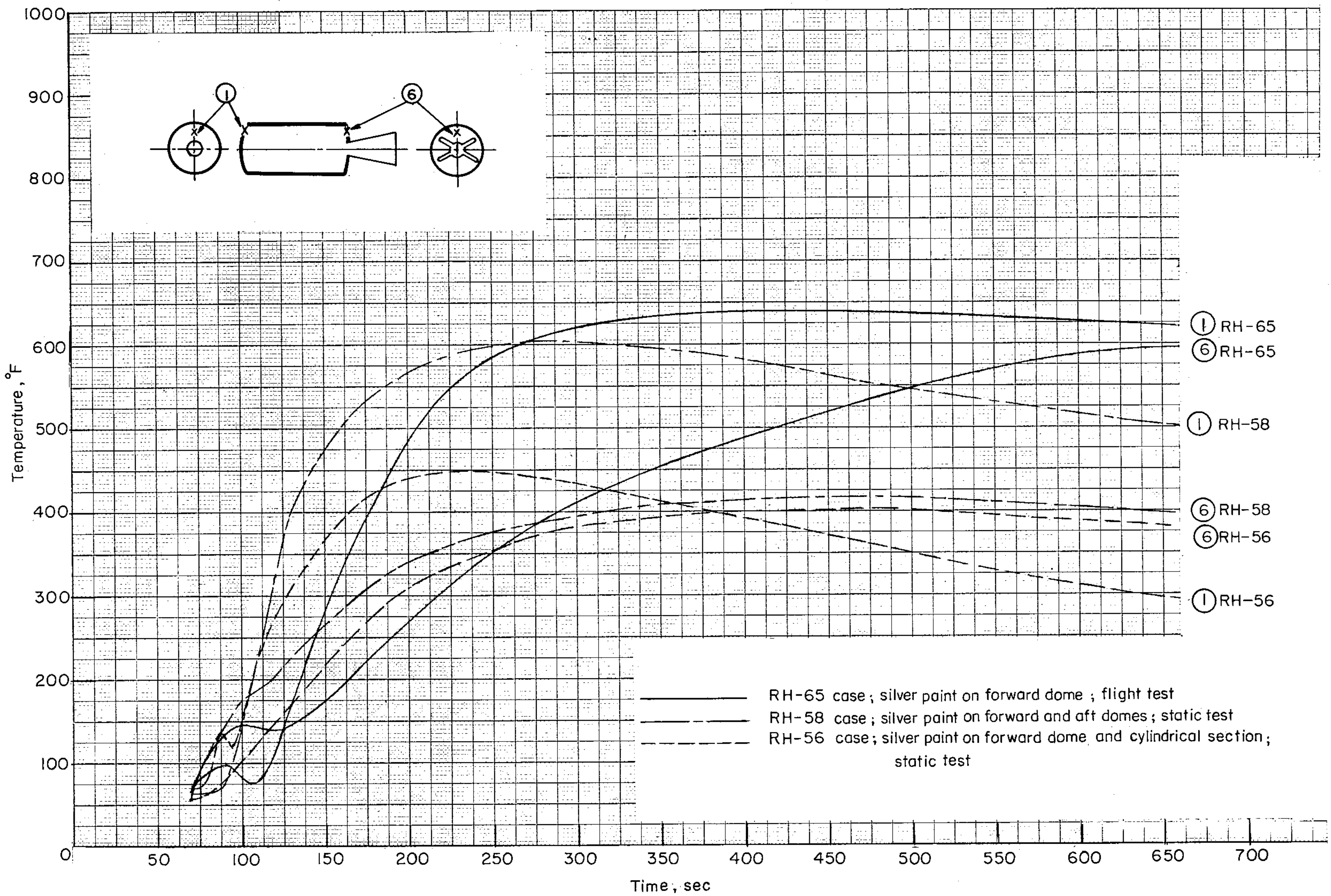


Figure 13.- Forward- and after-dome temperatures measured at thermocouples 1 and 6.

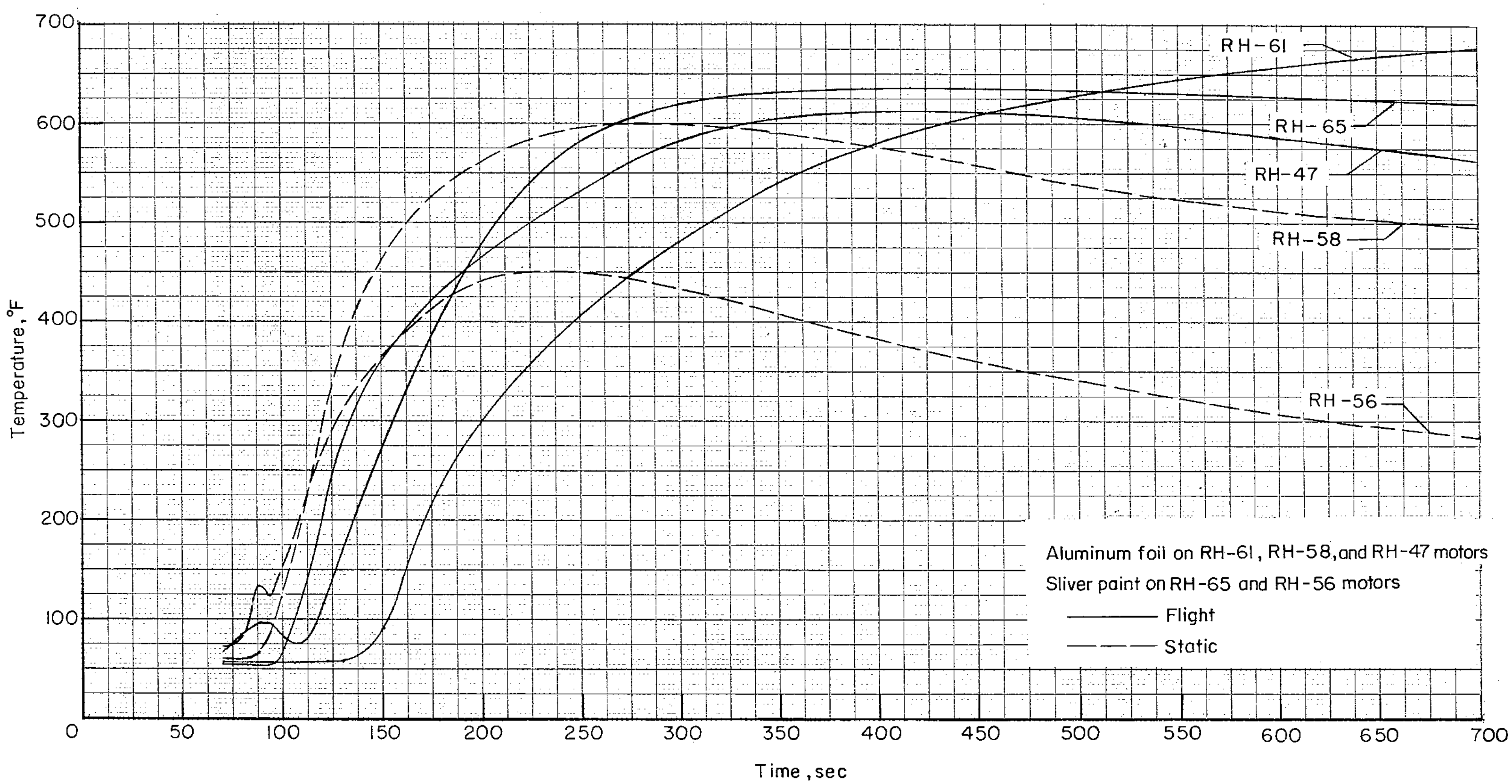


Figure 14.- Comparison of forward-dome temperatures from static and flight tests.

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