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DEVELOPMENT, ACCEPTANCE AND
QUALIFICATION TESTING OF THE
SNAP 10A EJECTABLE HEAT SHIELD

AEC Research and Development Report

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ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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QUALIFICATION TESTING OF THE
SNAP 10A EJECTABLE HEAT SHIELD

By
H. L. SPEROW

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

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ABSTRACT

The development, acceptance, and qualification tests performed on the SNAP 10A Ejectable Heat Shield and components, the results of those tests, and the conclusions drawn from the results are presented in this report.

The final conclusions made of the completion of the Qualification Program, December 23, 1964, were as follows:

- 1) The heat shield will maintain the heat exchange fluid within the prescribed limits of 50 to 250°F, thus preventing plugging of the NaK lines during the orbital period before startup of the nuclear reactor.
- 2) The heat shield will perform satisfactorily provided the outside shield temperatures do not exceed 375°F. The shield will eject from the nuclear power unit when the temperature of the heat exchange fluid at the reactor outlet approaches $275 \pm 25^\circ\text{F}$, and will clear all vehicle components.

The conclusions made in this report certifying the performance of the heat shield were justified April 3, 1965 when the heat shield performed its prescribed function after the launch of the SNAP 10A-FS-4 Nuclear Power System. The facts that there was no plugging of the NaK lines and that the shield cleared the vehicle upon ejection unequivocally qualified the heat shield both thermally and mechanically.

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I. INTRODUCTION

The SNAP 10A ejectable heat shield (EHS) is a lightweight conical structure, surrounding the major portion of the nuclear power unit (NPU), that is ejected from the vehicle after the nuclear reactor has been started and the action of the reactor has heated the heat exchange fluid to 275°F. The SNAP system is protected during ascent through the atmosphere by the Agena nose fairing which is ejected at approximately 100,000 ft. After nose fairing ejection, the system will be subjected to the full impact of the space environment. The side of the vehicle facing the sun is subjected to a high rate of solar radiation, the opposite side subjected to cold. Since the nuclear reactor will not be started until the vehicle has been verified to have attained the prescribed polar orbit. There is a period of time (estimated 17 hours maximum) during which the NaK (sodium-potassium) heat exchange fluid must be prevented from solidifying.

During the period of time between Agena nose fairing ejection and the startup of the nuclear reactor, the EHS must maintain the temperature of the NaK heat exchange fluid between 50 and 225°F. The vehicle will be in a polar orbit during this period and, dependent upon the time of launch, the EHS will be subjected to a sun-shade or constant-sun constant-shade condition, Figure 1. When the NaK temperature reaches 275°F following reactor startup the EHS will be automatically ejected from the SNAP 10A system.

The EHS acts as a passive thermal control surface utilizing solar radiation to keep the NaK in a fluid state. The command for ejection is generated by thermal switches immersed in the NaK at the outlet from the reactor. The development, acceptance, and qualification of the EHS are described and discussed herein.

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Figure 1. SNAP Unit Orbits

Experimental data obtained from a series of qualification, acceptance, and developmental tests have verified the ability of the EHS to maintain the NaK temperature as specified and have established that the shield will be ejected from the vehicle at sufficient velocity to clear all vehicle components, provided that the vehicle is in a stable orbit and the EHS surface temperature limitation of 375°F is not exceeded.

Development tests performed on components and assemblies of the original heat shield design

to determine design feasibility and develop design and installation criteria to produce a more efficient system were completed in January 1964. Analyses of test data proved that the original design was feasible but required further development. Although the heat shield had performed its function as a thermal barrier, the velocities at time of release were below those predicted. To improve this condition, design modifications were specified that would decrease the shield assembly weight by more than 20%, increase the available potential spring energy by 25%, and reduce the parting friction approximately 50%.

Two other significant facts were obtained from the analyses of development test data. First, it was evident that the heat shield ejection performance could be regulated by controlling certain static friction forces and that these forces were dependent upon the assembly techniques used during the mating of the EHS to the NPU. Secondly, since an energy balance could not be made using data obtained from these tests, it was necessary to determine the effect of each individual parameter that was used to predict shield performance.

In July 1964, an acceptance program was initiated with the primary objective to verify and document the conformity of components and

assemblies to modifications dictated by the development tests. The secondary program objective was to determine the value of each parameter used to predict heat shield performance. The results of these tests indicated that the modifications to the original design had produced a heat shield assembly that weighed less than 0.32 lb/ft^2 of surface area and that the efficiency of the ejection mechanism was greater than 80%. Also, the experimental test values obtained made possible an accurate evaluation of the individual effects of air drag, gravity, changes of weight, moment of inertia, spring energy, and vibration environment. The knowledge of these effects made possible accurate prediction of performance criteria for qualification tests, regardless of the test conditions.

In November 1964, a complete EHS assembly was subjected to a qualification test program which included tests at the most adverse environmental conditions predicted during the pre-startup orbits in space. The EHS assemblies were ejected, on every qualification test, at velocities that exceeded the minimum values specified, and the NPU was maintained within its specified temperature limits although the simulated thermal conditions were more severe than those predicted.

II. EHS DESIGN AND EJECTION OPERATION

A. EHS DESIGN

To perform the specified operations, the ejectable heat shield must be lightweight yet have sufficient strength to endure stresses imposed during launch, orbital temperature cycling, and ejection from the vehicle. The ejection mechanism must be highly efficient to produce a reliable system. The outside surface of the EHS must have the necessary average thermal emissivity and absorptivity values to collect the proper amount of solar radiation, and the inside surface must have a relatively low emissivity value to reduce thermal flow from the NPU.

The shield assembly developed to meet the criteria consists of a conical shell, the hardware necessary to retain the shell in position, the hardware to perform ejection, and flight diagnostic instrumentation. Figure 2 shows the design of the shield half and the positions of the components.

1. Conical Shell

When assembled on the vehicle, the EHS is concentric about the NPU with an annular clearance between the inside surface and the NPU of approximately 3/4 in. The EHS is approximately 98-1/4 in. long, the top diameter approximately 22 in., and the bottom diameter 53 in.

The shell structure is split lengthwise into two half sections. The shell halves will be referred to herein as the +Y shield half and the -Y shield half, attaining their identities from the position on assembly, Figure 3. Both shield halves are made of lightweight 5051 adhesive bonded aluminum honeycomb structure.

The core was fabricated by adhesive-bonding 0.0007-in. aluminum foil to form a honeycomb configuration 1/4 in. in height and with a 1/8 -in. size cell. The cell walls are perforated to allow for changes in external pressure. The face

skins were fabricated from sheets of 4-mil 5051 aluminum foil attached to each other by an adhesive bonded lap joint.

The shield halves are reinforced in critical stress areas by doublers bonded to the inside and outside surfaces. All major structural components are attached to the shield in the reinforced areas. The shield halves are additionally reinforced in the area of the retaining band by a retaining band guide.

The inside surface of the heat shield was polished to a highly reflective surface to attain a low thermal emissivity value. The outside surface was subjected to the same treatment and then stripped with a high emissivity coating. The width of the strips and spacing are dependent upon the average emissivity value desired.

2. Alignment Hardware

The alignment hardware consists of the shield edge alignment pins, the aft alignment pins, the pivot bracket assembly, the alignment tab, the retaining band, and miscellaneous attachment hardware.

The hardware is unique in that, although simple and lightweight, it performs a dual purpose. It maintains the shield halves in alignment with each other and with the vehicle and, after performing the alignment function, most of the hardware is utilized as part of the release and ejection mechanisms.

The hardware allows the shield halves to expand and contract in a longitudinal direction but partially fixes the shield against diametrical growth.

3. Ejection Mechanism

In addition to the alignment hardware items that become part of the ejection hardware upon

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Figure 2. SNAP 10A Ejectable Heat Shield

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Figure 3. Orientation of Shield Halves

release, there is an ejection spring assembly, a squib actuated pin puller, and a breakaway electrical connector. The ejection spring assembly includes an 11-in.-long steel compression type spring, an aluminum thrust tube, an aluminum housing, a retaining nut, and the necessary attachment hardware. The squib-actuated pin puller assembly includes two squibs, a plunger, the band retaining pin, and the attachment hardware. The male portion of the breakaway connector, two receptacle ejection springs, and the supporting hardware are included in the electrical assembly. All of the contact surfaces that must slide relative to each other during thermal growth or during the ejection operations were polished and treated to attain a low coefficient of friction.

4. Flight Diagnostic Instrumentation

The flight instrumentation consists of a total of 4 thermocouples mounted on the shield surfaces and components to monitor the temperatures encountered during orbit before the ejection operation.

B. EJECTION OPERATION AND EJECTION RATE PARAMETERS

1. Ejection Operation

The heat shield will be ejected from the vehicle after the vehicle has attained a stable

polar orbit and the guidance system has reduced rotation about the X, Y, and Z axes to a minimum. The ejection operation will be initiated by one or both of the thermal switches mounted in the NaK outlet lines from the reactor. The switches are actuated when the temperature of the NaK attains $275 \pm 25^\circ$. The action of these switches energizes a relay which closes the circuit between the Agena pyrotechnic battery and the squibs on the pin puller. The firing of one or both of the squibs retracts the pin through the retaining band, allowing the band to release. Upon retracting the pin, the retaining band, which, due to its corrugated configuration, is a tension spring, retracts from the band guides thus releasing the shields to rotate about their pivots. Upon release of the band, the energy stored in the two compressed ejection springs on each shield half accelerates the heat shield halves to rotational velocities ranging from $65^\circ/\text{sec}$ to $75^\circ/\text{sec}$, depending upon the properties of the shield half. The shields continue to rotate about the pivot after the springs have reached the end of their stroke, decelerating slightly due to the dissipation of energy caused by the friction at the pivot. After rotating 28 to 35° , the pivot shaft reaches a position where the pivot housing will not react the inertia forces and the forces imposed by the two receptacle ejection springs. Upon release of these forces, the shield is free of the vehicle.

2. Ejection Rate Parameters

The parameters that effect the ejection rates of the heat shield are environmental conditions, shield properties, friction forces, and available ejection energy. To reduce the number of variables and to make the evaluation of performance easier, the performance velocity data has been converted to kinetic energy and presented in percent of potential energy available from ejection springs. In the process of converting kinetic energy to percent potential energy, the

variables in shield properties and ejection energy are accounted for, leaving only friction and environmental conditions as variables.

The symbols used to designate the parameters are:

I_p = mass moment of inertia about pivot
(ft-lb/sec²)

I_o = mass moment of inertia about center
of gravity (ft-lb/sec²)

W = weight (lb)

$\bar{R}$ = distance from pivot to center of
gravity (ft)

f = frequency of oscillation (seconds)⁻¹

PE = potential energy available (spring
force) which is equal to area under
force vs displacement curve (ft lb)

F = force (lb)

KE = kinetic energy (ft/lb)

E = efficiency (%)

ω = rotational velocity (radians/sec)

ω_s = velocity at end of spring stroke
(radians/sec)

ω_R = velocity at time of release from
pivot (radians/sec)

$\bar{V}_R$ = linear velocity (ft/sec)

θ = degrees rotation (degrees)

t = time (sec)

d = distance traveled (ft)

M = mass = W/g (lb-sec²/ft)

g = acceleration due to gravity =
32.2 ft/sec²

K = spring constant (lb/in.)

Q = energy dissipated (ft lb)

The values used for W, $\bar{R}$, f, θ , t, and V were

obtained from experimental test data. These values were used to convert performance to energy as follows:

Mass moment
of inertia
about pivot $- I_p = \frac{W \bar{R}^2}{4\pi^2}$

Mass moment
of inertia
about c.g. $- I_o = I_p - M \bar{R}^2$

$$PE = d(F_{\min} + 1/2 K)$$

Spring energy
also equal to area under force-deflection
curve

$$\text{Rotational } KE = \frac{I_p \omega^2}{2} = \frac{I_o \omega^2}{2} + \frac{MV^2}{2}$$

$$\text{Linear } KE = 1/2 MV^2$$

The energy dissipated during an ejection is determined as follows:

$$Q = PE - KV_{\text{vacuum}}$$

$$= \frac{K^2 d}{2} - \frac{I_p \omega^2}{2}$$

The efficiency of the system is equal to the kinetic energy divided by the available potential spring energy,

$$\%E = \frac{KE}{PE} \times 100.$$

The tests conducted in a vacuum were considered to have zero air drag and the forces due to friction were the only restrictions to shield ejection; therefore, the difference between potential energy available and the kinetic energy is equivalent to the energy dissipated by friction.

$$Q_{(\text{friction})} = PE - \frac{I_p \omega^2}{2} (\text{In vacuum})$$

$$= PE - KE$$

The tests performed at ambient temperatures

and pressures were subjected to air drag and friction forces. The difference in potential energy converted to kinetic energy during test at ambient temperatures in a vacuum and at ambient pressures is equivalent to the energy dissipated by air.

$$Q_{\text{air}} = (KE)_{\text{vacuum}} - (KE)_{\text{ambient}}$$

$$= \frac{I_p}{2} \left(\underset{\substack{\uparrow \\ \text{vacuum}}}{\omega_R^2} - \underset{\substack{\uparrow \\ \text{ambient}}}{\omega_R^2} \right)$$

Likewise, the additional energy dissipated by thermal effect is equivalent to the difference in energy converted during tests conducted in vacuum at ambient temperatures and in a vacuum at environmental temperatures.

$$Q_{\text{thermal}} = (KE)_{\text{vacuum}} - (KE)_{\text{thermal}}$$

$$Q_{\text{thermal}} = \frac{I_p}{2} \left(\underset{\substack{\uparrow \\ \text{vacuum}}}{\omega_R^2} - \underset{\substack{\uparrow \\ \text{thermal}}}{\omega_R^2} \right)$$

C. SHIELD LIMITATION

The heat shield configuration is structurally adequate to perform all the specified functions provided the EHS surface temperature limitation of 375° is not exceeded. The structural integrity of the shield has been proven within these limits. Acceptance tests of the epoxy bond indicated that at temperatures of 400°F the bond strength becomes critical; therefore, it would be inadvisable to attempt an ejection when shield temperatures exceed the prescribed limitations.

III. EHS DEVELOPMENT TEST PROGRAM

The objectives of the development test program were to evaluate the performance of a heat shield designed, fabricated, and installed per the original concept, and to develop any new design criteria or installation techniques that were considered necessary to improve performance.

The two types of tests conducted to evaluate performance were (1) thermal emissivity tests to evaluate the thermal performance and (2) ejection tests to determine if the shield halves would eject and clear the vehicle.

A. EJECTION TESTS

The first development ejection test program was initiated September 28, 1962. The purpose of the tests was to demonstrate the functional reliability of the heat shield when tested in a vacuum and temperature environment approximating those expected in orbit. The shield tested, Serial Number 0001, was the first shield fabricated to the original design configuration. The 10-lb force springs in the ejection assembly were replaced with 16-lb springs to compensate for the effect of gravity, the difference in spring energy between a 10-lb spring and a 16-lb spring being approximately equal to the energy required to raise the 14-lb shield through the 15° arc to the vertical position (Figure 4).

The shield was subjected to what were considered the 3 worst conditions: maximum thermal gradient across parting plane, 45° from plane, and 90° from plane. It was concurrently subjected to temperature extremes of -298°F on the cold side and 295°F on the hot side. The maximum hot side temperature recorded was 336°F with a concurrent cold side temperature of -168°F. No evidence of damage to the shield material or surface coatings was apparent

after a total of 47 hr of testing at environmental temperatures and pressures. Upon ejection at these conditions, the shield was observed to open $6^\circ \pm 1.0^\circ$ representing an energy expenditure of 0.314 ft-lb or approximately 8% of the available energy, indicating that 92% of the energy was used to overcome friction.

Figure 4. Gravity Effect in Vertical Position

These tests proved the structural integrity of the heat shield but the high percentage of energy used to overcome friction indicated that further development tests were necessary to reduce friction forces and that an increase in the available spring energy might be required.

Analytical investigation of data developed on initial ejection test indicated that the design feasibility of the ejection system could be evaluated by tests conducted at ambient temperatures and pressures and at environmental

temperatures and ambient pressures but must be at a simulated zero gravity condition.

A test stand, Figure 5a, b, was designed and fabricated to impose the simulated zero gravity condition. The test assembly was mounted in the stand in a horizontal position with the parting edge of each shield half positioned on the vertical plane through the centerline of the system. The weight of the shield halves was supported by two booms that were free to rotate about the same vertical axis as their respective shield halves. The support simulated a gravity-free condition for the shield halves when considered as free bodies; that is, a summation of the vertical forces and moments was equal to zero. This method of simulating zero gravity was considered adequate although the imposed bending stresses on the shield were neglected.

Ejectable Heat Shield, Serial Number 0004, was subjected to the second series of development tests. The shield halves were installed per existing setup and installation specifications on a nuclear power mockup system.

The results of the first ten performance ejection tests were very unsatisfactory. The shield halves ejected at rates far below those predicted (see Figure 6a, b). The fact that the heat shield did eject proved the design was feasible, but the difference in predicted and actual values indicated that additional development work was required to determine the reasons for the low rates and to take corrective action. A 3-phase program was undertaken toward this goal.

1. Static Tests

The first step was a series of static tests to determine the potential spring energy available for ejection and the magnitude of the forces that were dissipating the spring energy. The static tests that were conducted to obtain this information are described below, and shown in Figure 7a, b, c, and d.

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a.

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b.

Figure 5. Test Stand for Simulated Zero Gravity Condition (Development Test)

a. Efficiency vs Angular Rotation Development Test Data

Figure 6. Effects of Angular Rotation

Separation Pull Test

Test conducted to determine magnitude of static friction forces imposed by components and effect of modifications.

Receptacle Test

Test conducted to determine static friction forces and develop criteria for ejection springs.

Spring Tests

Test conducted to determine spring forces and friction effects due to spring housing.

Pivot Force Test

Tests conducted to determine the static friction forces at the pivot.

The static test of the springs indicated there was a considerable difference between the force required to compress the spring when installed in the spring housing and when compressed when mounted on an alignment rod. The force

values obtained when mounted on the rod were within design specifications but were too high in the housing. This indicated that friction between the housing and the spring could be causing dissipations of energy although this was not conclusive since the ejection spring is extending during the operation.

The information gained from the force test on the pivot block assembly indicated that there were excessive forces due to friction in this area. The test consisted of measuring the force required to slide the shield pivot across the pivot support while the shield sections were mated. At the beginning the force averaged between 25 and 30 lb. This force was reduced to 5 lb by adjusting the centerline of the pivot to coincide with the center line of the support, alignment of the axis of the electrical connector, and removal of the corners on the pivot supports.

Figure 7. Static Force Tests

The separation pull tests were conducted with and without connector and connector springs. The forces averaged $6.4 \text{ lb} \pm 0.07 \text{ lb}$ indicating the effect of the springs was negligible. These tests were conducted before and after the pivot friction tests.

2. Property Tests

The second step was to conduct tests to determine the physical properties of the test shield and to compare these values against those for predicting the ejection rates. Tests were conducted at ambient temperatures and pressures to determine the weight, location of the center of gravity, and the mass moment of inertia, Figure 8. The results of this step are shown in the figure.

The results of the weight cg tests are shown in the table accompanying the setup sketches of Figure 8. The mass moment of inertia data obtained during these tests is not shown since the magnitude of the values was erroneous due to the effect of air drag.

3. Evaluation Tests

The third step of the program was to determine the effect of the adjustments and modifications made during the static test evaluation. Ejection tests were performed at ambient temperatures and at elevated temperatures under a simulated zero gravity condition.

The tests at ambient temperatures were performed with balanced and unbalanced spring

SHIELD SERIAL NUMBER	SHIELD HALF	L_x (in)	L_y (in)	L_z (in)	$\bar{R}$ (ft)	θ (deg)	WT (lb)
0004	+y	46.5	11.86	24.2	4.16	16° 26'	15.09
0004	-y	44.2	11.80	26.0	3.98	17° 17'	14.46
0005	+y	46.6	11.98	26.65	4.15	16° 17'	12.86
0005	-y	42.8	11.8	25.95	3.85	17° 49'	12.00

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Figure 8. Property Test

forces at the top and bottom of the heat shield. The change in ejection rates was not noticeable with a 6-lb force differential. The shields failed to eject with a 12-lb differential. It is unknown if ejection was prevented by binding caused by twisting of the shield or by the reduction of available spring energy. The shields ejected with balanced springs when subjected to ambient and elevated temperature conditions, but at about the same rates as when the shields were ejected on the initial performance tests. The logical conclusion after evaluation of the test data, was to increase the spring plunger to travel a greater distance and to reduce the weight of the heat shield, thus increasing the rate of ejection. The shield had to be refabricated to reduce weight but the spring energy could be increased by simply modifying the plunger. This modification was made, increasing the stroke from 2 to 2-3/4 in.

a. Evaluation Test After Extension of Thrust Tube

Ejection tests were again conducted to determine the gain in efficiency and reliability after the latest modifications had been made. Installation criteria that appeared to be beneficial were also used in the mating of the shield to the NPU. The most important of these were a 5-lb maximum separation force and a 7-lb maximum friction block force.

The results of evaluation tests are discussed in the following paragraphs.

The gain in rotation efficiency was only 4% at the end of the spring stroke and 1% at the time of release from the pivot support, but the increase in performance reliability was significant. Neither heat shield failed to eject on any test after the changes were made. Fifty-six

tests were performed without an ejection malfunction, and there was no apparent structural damage to the shield after being exposed to 104 ejection tests.

A motion study utilizing the experimental test data, extrapolating to attain the velocities within a vacuum, indicated that after release from the system the shield halves would continue to rotate about their center of gravity at an angular velocity of 20°/sec and would move away from the vehicle at a rate greater than 1 ft/sec. These values were based on the assumptions that the separation forces remained constant when the shield was subjected to the maximum temperature gradients imposed during space flight. The kinetic energy remaining at the time of ejection was equivalent to 28% of the potential spring energy, and was 38% less than initially predicted. The poor correlation of test values and analytical predictions and the questionable effect of friction under a true environment indicated that the acceptance and qualification ejection tests would have to be performed under a fully simulated space environment before a degree of confidence necessary to qualify the shield would be attained.

b. Ejection Tests at Ambient Condition of One-g Gravity

The object of this test was to develop ejection criteria for use during the acceptance test program when a zero gravity condition could not be simulated. The NPU was mounted in an upright position and the same shield installed per criteria developed during the horizontal, zero g, development program (Figure 9). The shield was released in the same manner and the resulting action recorded on slow motion film.

The +Y shield opened 5°; the -Y shield opened 8.60° from the closed position. These values were much lower than predicted. Predicted values indicate that the shield halves should have

rotated the full 35° and released from the NPU, decelerating up to 15° and accelerating from 15 to 35°. The difference in predicted and test values created reasonable doubt in the validity of the test data.

B. ACOUSTICAL TESTS

One of the original design shields, Serial No. 0002, Figure 10 was installed on the PSM-1A system and subjected to high intensity sinusoidal acoustic excitation for a period of approximately three hours. When evaluated, the data showed that no damaging modes occurred during the test. Although the acceleration response of the specimen could not be precisely determined as a function of frequency, the G response as measured was generally of a low order (Figure 11a, b)* and the indications are that most of the responses were of relatively high frequency. Because high frequency responses have low structural damage potential, the vibrations of the order measured during the acoustic test were not critical. Sustained vibrations at these levels could produce fatigue failure; however, the exposure time during test was approximately three hours which is considerably longer than the two or three minutes exposure to random noise expected during launch.

No modifications to the shield design were required as a result of this series of tests.

C. VIBRATION AND SHOCK TEST

The complete shield assembly (Serial No. 0002) was installed on an NPU (PSM-1) and mounted on a shake table for vibration and shock testing. The assembly was vibrated and shocked along each of the mutually perpendicular axes. The specimen was subjected to shocks along the X axis of +8 g to -2.5 g and along the Y and Z axes of ±5 g for a 6 msec period. The vibration test consisted of a single sweep along each axis from 5 to 3000 cps at a variable load level and a constant octave sweep rate of 3 min/octave. The magnitude of the input load levels varied as shown below.

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Figure 9. Vertical Ejection Test Setup

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Figure 10. Acoustical Test Setup

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7561-02391A

a.

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7561-02391B

b.

Figure 11. Shield Response Following High Intensity Sinusoidal Acoustical Excitation

Axis	Magnitude	Frequency (cps)
Longitudinal X-X	1/2 in. DA	5 to 9
	2.3 g	9 to 400
	7.5 g	400 to 3000
Lateral Y-Y and Z-Z	1/2 in. DA	5 to 8
	1.7 g	8 to 250
	4.5 g	250 to 400
	7.5 g	400 to 3000

Since the EHS was not instrumented, the response and the acceleration loads could not be determined; but, since inputs were measured, the test was considered valid.

A visual inspection of the shield and bracketry during and after test indicated the structure was structurally adequate although there had been some damage to the lower support bracket allowing the heat shield to separate and chatter during the vibration sweeps.

The only modification to the basic design that developed from the vibration tests was to increase the rigidity of this support bracket to prevent bending during installation and imposed vibrations during launch.

D. PRE-ORBITAL STARTUP TESTS

The effectiveness of the ejectable heat shield as a passive thermal barrier was demonstrated during the first stage of tests performed on SNAP 10A systems to obtain startup and performance data. This first stage of the tests is designated as pre-orbital startup. The objective of this test was to determine the capability of the NPU to operate after a period of 6 to 18 hours in a space environment. The NaK loading techniques require that the working fluid precipitate oxides at temperatures of $<20^{\circ}\text{F}$. The actual value is dependent upon the impurity content of the NaK. These oxides could cause plugging of

the converter tubes. Consequently, one of the objectives was to determine if the NaK temperature is maintained above the design limit of 50°F . In addition to the minimum temperature limitation it was necessary to verify that the NaK temperatures did not exceed $275 \pm 25^{\circ}\text{F}$ which is the temperature at which the heat shield is triggered for the ejection operation.

The design of the heat shield as a passive barrier to maintain the NaK within the above limits was based on a thermodynamic analysis which indicated that the inside surface should have a low thermal emissivity of about 0.08 and that the outside surface should have an overall average thermal emissivity of 0.18 and a solar absorptivity of 0.33. To accomplish these objectives the inside surface was anodized and the outside surface treated with three separate coatings, applied in alternating circumferential strips.

The function of the coating was as follows: the low value on the inside served to minimize heat loss from the radiator converter to space in the shaded portion of the system; the outside surface coating ensured that a sufficient amount of solar energy was absorbed to keep the NaK above the minimum temperature and also rejected energy when the temperature of the NaK approached the upper limit.

To provide a check on the assumptions used in modeling the system, the computer code was checked against the pre-startup orbital operation portion of the system test on flight mockup FSM-1 (Figure 12). This system was a duplication of the SNAP 10A flight system in all respects except that the nuclear core was replaced by an electrical heater. The shield used on this test was Serial No. 0003.

The tests were performed in a vacuum environment under simulated thermal inputs and the thermoelectric pump of the system was ex-

cited to produce a normal prestartup NaK flow of about 4% of the design point value. Radiant lamps were used to simulate the solar input. (See Figure 13.)

The test procedure allowed the system to reach thermal equilibrium, then the radiant heaters along one side of the vacuum vessel were energized to simulate a Constant Sun-Constant Shade environment. The lamps were left on for a period of 3.6 hours, corresponding to two orbits at a 600-mile orbital altitude.

A comparison of temperature histories of certain key variables obtained from the computer model and the data obtained from the ground test indicated substantial agreement between the computed results and the test data (Figure 12). The correlation of data and computed results obtained on this test provided adequate justification to use the computer model in predicting temperature for use during the acceptance and qualification test program on the ejectable heat shield.

The effectiveness of the shield appeared to be adequate but it was apparent that additional testing should be performed under a more complete simulation of environmental conditions.*

E. CHANGES RESULTING FROM DEVELOPMENT TESTS

Based upon the results of this test program, the following design changes were incorporated into the SNAP 10A ejectable heat shield design and installation specifications:

- 1) The depth of cut on the electrical plug bracket assembly was changed. Due to tolerance buildup, a possible interference fit between this part and the shield pivot arm existed.

- 2) The OD of the electrical plug bracket assembly pivot was reduced. This was necessary as the shield's entire weight was allowed to ride on the edges of the electrical plug

bracket assembly pivot causing a higher frictional resisting load during ejection.

- 3) The bottom width of the electrical plug bracket assembly pivot was decreased. The original fit was close (possible 0.001 in.).

- 4) All square and sharp corners on edges in the entire pivot area were rounded off to reduce any possibility of the shield sections binding upon ejection.

- 5) The slots on the top ears of the electrical plug assembly were located from the center of the bracket. This was to prevent the electrical connector from cocking the bracket pivot, thus causing it to bind in the pivot block.

- 6) The centerline of the electrical plug bracket assembly was located with respect to the center of the pivot arm for proper alignment of the plug bracket.

- 7) The centerline of the slots was aligned on the top ears of the electrical plug bracket assembly with the centerline of the holes in the electrical receptacle bracket. This alignment was necessary so the electrical connector would not cause the electrical plug bracket assembly to torque sideways, causing binding on the pivot block.

- 8) The bottom pivot surface of the pivot block was aligned parallel to the plane of the bottom of the NPU support legs with 0.002 total indicator reading.

- 9) The outside diameter of the thrust tube spring (ejection spring) was changed. This was to ensure proper clearance between spring and thrust tube.

- 10) The back side of the electrical connector that has the silicon insert (female half) was potted. Welds failed on several sleeves at the D pins on the connectors during the course of the ejection tests. Also,

*See NAA-SR-9720, "SNAP 10A Prestartup and Startup Performance," G. S. Drucker and T. J. Boyle, June 30, 1964, CRD, for a complete report.

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Figure 12. Comparison of Computer Model Results with Test Data

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Figure 13. Prestartup Thermal Simulation

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the D pins easily pulled out of their silicon retainers. The top part of the female half of the connector was designed to take a potting compound and its installation will aid in securing wire leads to the connector.

11) Proper sized D-shape sleeves on the wire terminal sleeves which connect to the

heat shield electrical connector pins were specified.

12) The distance over which the thrust tube plunger acts was increased. It was found during testing that an increase of 3/4 in. reduced the ejection time by about 25%.

IV. ACCEPTANCE AND QUALIFICATION PROGRAM

The modifications to design, installation, and checkout procedures generated by the information gained during the development program produced an EHS significantly different from the original design. The next series of tests was initiated to verify, document, and flight qualify the modified concept. It was necessary to redetermine the properties affecting ejection and thermal emissivity, to qualify the structural integrity, and to evaluate the effectiveness of the modification of design and installation procedures.

The unaccountable losses in potential energy which occurred during all of the development tests indicated that it was necessary to conduct the acceptance program tests to produce adequate information to determine (1) the amount of potential spring energy being converted to kinetic energy by the spring ejection assembly and (2) the percentage of the kinetic energy that was being dissipated by friction, air drag, strain energy (deflection of the shield), and gravity. The knowledge of these specific values would make possible a better correlation of test data and predicted values and the prediction of exact criteria for the qualification test program.

The acceptance and qualification test programs were performed concurrently on the same flight configuration ejectable heat shield assembly. It is difficult to classify these tests since many of the tests conducted for each program had dual objectives — first, to obtain acceptance data, and second, to qualify the assembly. For this reason the tests to meet the objectives are presented in chronological order insofar as possible and are listed below.

1) Component Tests

a) Available Energy Tests — Static and dynamic tests on the ejection spring assembly to determine efficiency.

b) Shield Property Tests — Tests to determine mass moment of inertia, weight, and center of gravity location.

c) Mass Moment of Inertia and Air Drag Effect — Tests to determine the effect of air by measuring the rotational velocity of the EHS about its pivot when the actuating force was gravity and the energy dissipation force was air.

d) Honeycomb Structure Decompression Test

e) Electrical Connectors Qualification Tests

f) M-130 Squib Qualification Tests

g) Pin Puller Assembly Qualification Tests

2) Ejection Tests

a) Space Simulated Environment Zero Gravity Conditions

1) Ambient Environment

2) Space Simulated Environment — Tests at simulated environmental conditions imposed during ascent and orbital flight to meet the following objectives: determine structural integrity of the shield, obtain formal data to assess the ability of the shield to conform to all design requirements and performance objectives, and determine effectiveness of the shield as a passive thermal control surface of a space environment.

3) Test Stand Effect — Test to determine drag of the support booms used for zero gravity simulation.

b) One-g Gravity Tests — Ejection tests were conducted with the heat shields rotating in a vertical plane under the influence of one-g gravity. These tests were performed to develop acceptance criteria for ejection

tests conducted before and after vibration and shake tests.

The component and ejection tests and their results are completely discussed in the following text.

A COMPONENTS TESTS

1. Available Energy Tests

a. Static Tests of Spring

To determine the energy available at ideal conditions, when the motion of the plunger and the direction of forces were coincidental, a static acceptance test was performed on each spring and plunger fabricated. Static tests were also performed to determine the effect of repeated loading, misalignment of the plunger motion and the line of force, and additional lubricant on the walls of the ejection tube.

The static tests were performed in an Instron Testing Machine. The spring and plunger were installed in a spring assembly test fixture and the fixture mounted between the compression heads of the machine (Figure 14).

Force vs displacement was automatically recorded on an X-Y recorder through the complete compression and extension cycle performed during the fitup and ejection operations. A typical recording is shown in Figure 15. The work available from the spring during extension is represented by the area below the extension recording. The work available or potential energy, the maximum force when the plunger is compressed to the working position, and the force at the end of the 2-3/4-in. extension are recorded in Table 1

The energy available from each spring based on design specifications should have been 3.78 ± 0.12 ft lb. As shown in the table, the developed spring energy at ideal conditions for 29 of the 30 springs tested was within the

Figure 14. Static Test of Spring

Figure 15. Shield Ejection Spring, Force vs Displacement

TABLE 1
STATIC SPRING TEST DATA
(See Figure 14)

Test Number	Plunger Number 0-2004-4	Spring Number 0-2008-3	F ₁ (lb)	F ₂ (lb)	Energy (ft lb)
1	1A	1A	10.5	22.5	3.80
2	2A	2A	11.0	22.6	3.77
3	1	1	11.0	22.5	3.83
4	2	2	10.9	22.5	3.78
5	7	3	11.1	22.0	3.86
6	4	4	11.0	22.1	3.81
7	5	5	10.9	22.4	3.79
8	6	6	11.0	23.0	3.85
9	8	8	10.9	22.0	3.82
10	9	9	11.0	22.3	3.86
11	10	10	11.0	23.0	3.81
12	11	11	10.8	23.0	3.74
13	12	12	11.0	23.0	3.81
14	13	13	10.9	21.1	3.76
15	14	14	11.0	22.3	3.82
16	15	15	10.8	22.6	3.79
17	16	16	11.0	22.4	3.82
18	18	18	11.0	21.7	3.79
19	17	19	10.6	21.7	3.85
20	20	20	10.7	22.0	3.74
21	21	21	10.9	22.4	3.78
22	24	22	11.2	22.3	3.76
23	23	23	10.7	22.0	3.71
24	29	25	10.8	22.5	3.70
25	26	26	10.7	22.6	3.76
26	27	27	10.4	21.3	3.64
27	28	28	10.7	21.7	3.66
28	30	30	10.6	22.0	3.74
29	31	31	10.6	21.7	3.73
30	32	32	10.5	22.3	3.74

specified limits. The changes in energy due to repeated loading, 1-1/2° misalignment, or additional lubrication were insignificant.

b. Dynamic Tests of Springs

The results of the static test indicated that 100% of the specified potential energy was being transmitted by the plunger when the plunger was moving at a rate of 2 in./min. The next series of tests was performed to determine the efficiency of the spring assembly under dynamic conditions. This was accomplished by equating the potential energy, determined by the static

test, against the work accomplished by the spring assembly on a compound pendulum. The spring assembly and the compound pendulum were mounted in a rigid frame with the assembly positioned in line with the center of gravity of the pendulum when the pendulum was in a vertical position. The force of the compressed spring and the vertical position of the pendulum were maintained by an 0.020-in. - diameter wire between the spring housing and the pendulum. The spring energy was released and the pendulum allowed to rotate by imposing 24-amp dc current on the wire, causing the wire to fail. The angular velocity attained by the pendulum and the height through which the center of gravity was raised after release were measured by a magnetic proximity pickup in conjunction with a visicorder. This data was converted to energy and the efficiency of the system determined. (See Figure 16 for test setup.)

Five springs were tested in this manner. A plot of velocity vs degrees rotation is shown in Figure 17a, and mark vs rotation is shown in 17b. The results of equating potential energy against work accomplished portrayed that 93% of energy was being converted to work and indicated that the spring assembly was not the main source of energy dissipation.

2. Shield Property Tests and CG and Weight Determination

The center of gravity and the weight of each shield half were determined by supporting the shield on knife edges resting on 2 sets of scales. The sum of the weights registered on the scales was equal to the total weight. The product of the distance between the knife edges and the weight measured at one of the knife edges divided by the total weight was equal to the distance from the other knife edge to the plane containing center of gravity.

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a.

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b.

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c.

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d.

Figure 16. Test Setup for Dynamic Spring Test

a. Velocity vs Degrees of Rotation

b. Work vs Degrees of Rotation

Figure 17. Dynamic Test of Spring

The test was performed with the knife edges perpendicular to the X, and Y, and the Z axes to obtain the distances to 3 planes containing the CG. The intersection of these planes located the exact position of the center of gravity. Figure 8 shows the values determined by the property tests.

3. Mass Moment of Inertia and Air Drag Tests

The mass moment of inertia tests were performed on the shield halves, the pendulum used for the dynamic spring energy test, and on the support boom assemblies. Since the test setup was identical to the air drag tests setup, both types of tests were conducted concurrently.

The mass moment of inertia is experimentally determined by measuring the time required for the body to make one complete oscillation through a small arc. The accuracy of the value obtained by using this time value, the distance from the point of rotation to the CG, and the

weight ($I_p = WR^2/4\pi^2$) are dependent on the two parameters of friction and air.

The effect of friction was reduced to a minimum by supporting the bodies on pivots that approached a knife edge configuration. The pendulum was supported by a wire and the heat shield was supported on jeweler's bearings.

The effect of air was significant on the shield but insignificant on the pendulum. The reason for this is the difference in the ratio of projected area to moment of inertia of the two items — the pendulum has a low ratio, the shield a high ratio. Although no analysis was made to indicate this effect, drop tests performed on the pendulum and shield proved the assumption to be true and made it mandatory that the shield tests be rerun under vacuum conditions (Figure 18) to attain a true value of I_p . The tests in a vacuum were performed with both test and flight instrumentation installed. The values obtained are shown in Table 2.

TABLE 2
EJECTABLE HEAT SHIELD PROPERTIES

Property	Units	EHS Serial Number 0005				EHS Serial Number 0004	
		+Y Shield		-Y Shield		+Y Shield	-Y Shield
		Shield	Shield +TC	Shield	Shield +TC		
Weight	lb	12.88	13.6	11.98	12.80	15.10	14.35
$\bar{R}$	ft	4.15	4.10	3.85	3.98	4.16	3.98
Period (T)	sec	2.66*	2.73	2.56*	2.64	2.88*	2.81*
I_p	ft-lb/sec ²	9.55	10.58	7.67	8.81	13.20	11.40
Spring	ft-lb	7.67	-	7.61	-	6	6
		2.75		2.75		(-2-in. stroke)	(2-in. stroke)
		in. stroke		in. stroke			
Energy	ft-lb/sec ²	-	-	-	-	7.6	7.6
						(2.75-in. stroke)	(2.75-in. stroke)

*Extrapolated values based on weight

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Figure 18. Mass Moment of Inertia
Test in Vacuum

The air drag effect was determined by comparing the energy available from the force of gravity on the body rotating through a given arc and the resultant change in kinetic energy during the test. Figure 19 shows the effect of air drag on the shield half.

The secondary objective of this test was to evaluate the instrumentation methods used and determine if this method could be used to measure the velocity of the shields and support booms during an ejection test of the shield halves. The results indicated that this method was satisfactory.

4. Honeycomb Structure Decompression Test

After surviving 26 ejection tests, 16 at ambient condition and 8 at a fully or partially simulated space thermal and pressure environment, the +Y shield half was subjected to a rapid decompression test to determine the structural integrity of the aluminum honeycomb structure. The shield half was placed in a space simulation chamber and the pressure reduced from ambient to a pressure equivalent to that encountered at 100,000 ft in a period of time that closely simulated the predicted flight conditions (see Figure 20). No major structural damage was apparent.

5. Electrical Connectors Qualification Tests

Two sets of heat shield connectors were subjected to tests under conditions simulating those encountered during flight to determine the effect of mechanical vibration and shock, thermal shock, and a combined thermal and vacuum environment. Tests were performed before and after exposure to the environment to determine unmating forces, electrical characteristics and degradation.

The first series of tests showed degradation in two areas, contact resistance and unmating force. The connections never failed to perform

as usable connectors but the degradation steadily grew worse or remained constant. Some of the brush assemblies appeared to loosen due to vibration and shock, causing variable resistance readings.

Modifications were performed on both of the connector assemblies and the tests were re-run. The modifications included relieving tolerances by milling 0.005 in. from the receptacle mating surfaces, strengthening the pins by potting the receptacle with Stycast 2651, and removing unneeded brush pin assemblies.

The test data from the second series of tests did not show the degradation attained previously. The unmating force was reduced below the specified limit of 3 lb and the electrical resistance was below the specified limit of 0.05 ohm when the gap between the receptacles was maintained at 0.035 ± 0.005 in.

Evaluation of the test data indicates that this shield component has qualified provided an 0.035 ± 0.005 -in. gap is maintained between the receptacles.

6. M-130 Squibs Qualification Tests

The purpose of this series of tests was to determine the performance of the squibs utilized to actuate the release mechanism of SNAP 10A components, one of which is the ejectable heat shield.

The squibs were subjected to environmental conditions simulating those that will be encountered during storage, assembly, shipment, and flight. The conditions simulated included temperature and humidity, shock and vibration, and thermal vacuum. The squibs were tested to determine the effect of each environmental condition on developed pressure continuity, resistance, spontaneous ignition, and no-fire ignition. The squibs qualified in every respect

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Figure 19. Influence of Air During Moment of Inertia Test

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Figure 20. Heat Shield Decompression Test, Pressure vs Time

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even after a storage life of eleven months. Performance tests were conducted after a shelf life of six, eight, and eleven months. There appeared to be no detrimental effects on the firing performance.

A comparison of qualifications and requirements is shown in Table 3 below:

A typical pressure vs time trace of the M130 squib is shown in Figure 21.

7. Pin Puller Assembly Qualification Test

A series of tests was performed to determine the structural integrity and the performance reliability of the pin puller assembly. Fourteen pin puller assemblies were subjected to tests during this program. Functional tests were conducted to qualify the performance after imposing the following environmental conditions.

- 1) Temperature and humidity
- 2) Shock and vibration
- 3) Thermal cycle in a vacuum environment.
- 4) Radiation

Figure 22 shows the test sequence and typical environmental conditions imposed. The pin puller assembly qualified on every test and was considered to be acceptable for use.

B. EJECTION TESTS

1. Zero Gravity Simulation

a. Test Setup

(1) Description

The zero gravity simulation test stand (Figure 23a, b) was redesigned for the acceptance and qualification test programs. Although the basic concept was used, the new design either eliminated the unknown parameters or made it possible to determine the magnitude of the parameters by adequate instrumentation. The zero simulation stand was fabricated to the criteria described below.

The stand, including the support booms, was built to operate within a 15-ft-diameter environmental test chamber at 10^{-6} torr pressure and temperatures ranging from -50 to 375°F.

The support booms were attached to the basic support structure (Figure 24). The boom supporting assembly was made with adjustments for locating the rotational axis of the boom in line with the rotational axis of its respective shield half. The boom assemblies were sufficiently rigid to support a roller that would allow the shield to translate after being rejected from pivot support. The drag of the booms on the shield halves during ejection was partially compensated for by the action of a leaf spring mounted at the pivot axis of the boom. The function of the spring was to accelerate the booms through the same arc as the shield half was accelerated by the ejection spring assembly. The springs were designed to accelerate the booms to a velocity of approximately 50% of that predicted for the EHS. The displacement and the amount of stored energy in the spring could be adjusted to requirements by changing the position of the reaction force and/or decreasing the thickness of the leaf spring used.

(2) Release System

Heat Shield

The heat shield was maintained in position against the ejection spring forces and released by two methods. The shields were held by a dummy retaining band during the preliminary tests to determine stand and shield performance at ambient conditions. The release of the dummy band was initiated by imposing sufficient voltage on a short section of wire to cause it to burn out. The release of the shield halves using the flight configuration retaining band was initiated by imposing a voltage on a squib mounted in the pin puller. The firing of the squib actuated the retaining pin through the band allowing the band to release.

TABLE 3
COMPARISON OF QUALIFICATION DATA AND REQUIREMENTS

Item	Data	Requirements
No Fire Current	0.5 amp max	0.5 amp max
Sure Fire Current	2.0 amp min.	2.0 amp min.
Resistance	0.65 ± 0.2 ohms	0.65 ± 0.2 ohms
Temperature and Humidity	MIL-ST-304	Not Required
Shock	40 g	20 g
Acceleration	12 g	9.4 g
Vibration	15 g	7.5 g
Random Vibration	$0.10 \text{ g}^2/\text{cps}$ max	Not Required
High temperature	500°F for 10 min	250°F for 48 hr
Low temperature	-65°F for 8 hr	30°F for 48 hr
Pressure (vacuum)	1×10^{-7} torr for 24 hr	10^{-6} torr for 48 hr
Water Immersion	MIL-E-5272B	Not Required
Spontaneous Ignition	Time vs Temperature Above 300°F	Not Required
Hydrostatic Test	After Firing 7500 psi for 10 sec	Not Required

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Figure 21. Typical Pressure-Time Trace

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Figure 22. Acceptance Test Sequence Pin Puller Test

Boom Attachment and Release

The support booms were maintained in the vertical plane through the shield center of gravity by induction magnets during the preenvironmental tests. These magnets were replaced with electrical solenoids for the simulated space environmental tests to prevent overheating of the magnetic coils.

The release was effected on the magnet system by removing the power from the magnets concurrently with the application of power to the shield release system. The release of the solenoid system was initiated by application of power to the solenoid and to the shield at the same instant.

(3) Simulated Environmental Space Conditions

The tests conducted to qualify the shield were performed at a vacuum of approximately 10^{-5} torr, simulated zero gravity, and a thermal environment simulating a Sun-Shade or a Constant Sun-Constant Shade orbit.

The test setup for the ejection tests in a space simulated environment was identical to that used for preenvironmental conditions tests with the additions of the application of a high emissivity coating to the surfaces of the NPU shell, the use of the cryogenic wall to simulate the shade side, and the use of radiation quartz lamps to simulate the sun side.

The NPU shell was coated with a high emissivity coating to simulate the thermal conditions created by NaK flow in the actual system. The NaK flow distributes absorbed heat over the entire area of the NPU, creating an isothermal condition. The coating allowed a large percentage of the radiant heat from the shield to be absorbed with a very small percentage being emitted back to the shield. The heat was then transferred from the hot to cold areas by conduction around the NPU thus partially simulating the same isothermal condition.

The Sun-Shade orbit thermal environment was simulated by applying radiant heat to the -Z portion of the shield surface and cooling the +Z portion of the shield surface with a cryogenic panel (Figure 25a, b). The heat was generated by eight T-4 (one kw) quartz lamps mounted in a 6 by 12-in. aluminum reflector assembly. Sixteen of the reflector assemblies were arranged in a flat plane encompassing the profile area of the EHS. This plane was located approximately 2 ft below and parallel to the parting edge of the shield. The shade condition was simulated by a cryogenic cold wall that was located 6-1/2 ft from and parallel to the centerline (X axis) of the NPU. The wall was cooled by circulating liquid nitrogen through the panel to temperatures approaching -300°F before heat was applied. The shield halves were ejected 1/2 hr after application of heat.

The Constant Sun-Constant Shade environmental condition was only partially simulated (Figure 26). The maximum temperature on the +Y portion of the shield was subjected to heat from the same bank of lamps located 6-1/2 ft from and parallel to the centerline of the NPU. The cryogenic panel was not used to cool the -Y portion of the shield. Consequently, this side of the shield did not meet simulated space conditions.

The bank of heat lamps was divided into three control zones. The rate of heat application was sensed by a calorimeter located near the surface of the shield and the center of each zone.

The temperature of the heat shield was limited to the maximum predicted temperatures by control thermocouples in conjunction with a temperature controller and power regulator. The control thermocouples were located on the shield surface in the area of maximum predicted temperatures and approximately above the center of each zone of lamps.

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a.

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b.

Figure 23. Zero Gravity Simulation Test Stand
(Qualification and Acceptance Test)

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Figure 24. Zero Gravity Simulation, Support Boom Structure

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NOTES

1. 8 LAMPS IN EACH REFLECTOR CONNECTED IN PARALLEL
2. EACH ROW OF REFLECTORS CONNECTED IN SERIES

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a. Sun Shade Condition Test Setup

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b. Reflector Arrangement

Figure 25. Sun-Shade Condition

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Figure 26. Constant Sun — Constant Shade
Condition Test Setup

b. Instrumentation

Instrumentation to measure the angular displacement of the support booms and their respective shield halves was integrated into the support stand. The booms were fabricated to accept a reluctance device, designated as a magnetic proximity transducer, and masses of steel were installed in a nonmagnetic support at the end of each shield and boom.

(1) Transducer

The angular motion of the booms and shield halves was measured and recorded by a magnetic proximity transducer in conjunction with a visicorder oscillograph.

The transducer was designed and fabricated for this test (Figure 27). The transducer is a reluctance type device that is affected by the close proximity of a mass of metal. The theory of operation is as follows: Masses of steel are placed along the arc of travel of the transducer with the first mass placed at start position and each successive mass positioned at the points

along the arc where displacement vs time is desired. The half bridge transducer is balanced on the recording oscillograph with the transducer in close proximity to the first steel mass. A motion occurs, the transducer moves off the steel mass causing an unbalance which is not regained until the center of the next steel mass is in line with the transducer. This period of unbalance is registered on the oscillograph record which is marked with respect to time, thus producing the displacement vs time record.

The secondary method of recording velocity data used high speed motion picture instrumentation. This data was required when a malfunction occurred in the primary system and during angular rotation after the transducer passed the last steel mass, which was positioned one to two degrees ahead of the release position.

Thermocouples were installed on the outside and inside surfaces of the shields and on the outside of the NPU. See Figure 28 for location. The test thermocouples were bonded to the surface of the unit with a high temperature epoxy

bond. Calibration of thermocouple wiring was made previous to installation.

(2) Calorimeters

In order to determine the quantity of heat imposed by the radiant heat lamp on the surface shield it was necessary to design and fabricate three calorimeters (see Figure 29). These devices operate on the principle that the temperature change of a perfect black body is a function of the amount of heat applied per unit area to the mass of the body and the coefficient of specific heat of the mass, as shown by the equation below.

$$Q = M C_p (\Delta t)$$

A check of one of the three units fabricated indicated that the design value of $0.012 (F^\circ / ft^2) / Btu$ was sufficiently accurate for test purposes.

c. Test Procedures

(1) Installation and Checkout

The NPU simulator was installed in the test stand with the two pivot supports and the center of the forward alignment brackets in the same horizontal plane. The support boom assemblies were installed and appropriate adjustments made to align the rotation axes of the booms with their respective pivot support. The boom velocity scales were then positioned in their appropriate positions, the boom ejecting springs adjusted to act through a $1^\circ 40'$ arc, and an

POSITION TRANSDUCERS

HALF BRIDGE TRANSDUCERS CIRCUIT

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Figure 27. Proximity Pickup and Schematic

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Figure 28. Environmental Test (EHS No. 0005), Thermocouple Location

ejection test conducted on each boom. The necessary spring size was determined from these tests. A spring thickness of 1/16 in. produced boom velocities of 15°/sec and a 1/8-in. spring thickness produced approximately 30°/sec.

The EHS was then installed using the recommended procedures developed during the development test program (Section III). Appropriate adjustments were made to ascertain that the reinforced area under the rollers on the support booms and the longitudinal center of the shield halves were maintained in their respective horizontal planes throughout the entire ejection operation.

The recommended static force tests were then performed to determine the effectiveness of the installation procedures. On the initial setup the separation pull test was performed using a strain gage dynamometer in conjunction with the magnetic proximity pickup and oscillograph. The force vs angular rotation information obtained from this data portrayed the combined effect of friction on the boom and shield.

The checks on shield and boom alignment were performed before and after installation of thermocouples and after any changes in test site.

(2) Shield Ejection Procedure

The procedures used to perfect an ejection were the same regardless of environment, although different hardware was used in the release of the booms and shields. The sequence of events was controlled by performing the manual operation on countdown. After the application of power to the shield release system, the operations were performed automatically by the shield and test stand mechanism.

The sequences were as follows: camera lights on; oscillograph on; motion picture camera on;

power to instrumentation on; apply power to the boom and the heat shield release systems. Upon application of power to the boom and shield release systems the energy from the ejection springs was released, rotating the shield and booms about their respective pivots. When each shield reached the position where its pivot support housing would not react the receptacle spring forces, linear motion was initiated. The force of receptacle springs combined with the linear momentum of the shield caused the receptacle, the pivot, and pivot support to separate. During this time period, and during the ensuing period after release, the booms continued to rotate while the boom roller translated along the boom. When the electrical contact between the two receptacle halves was broken, a command signal for release was imposed on a catcher mechanism and the EHS brought to rest in the confines of the catcher assembly.

(3) Space Environment

Space environment was simulated in a 15-ft-diameter by 21-ft-long environmental test chamber. Ejection tests were performed at ambient conditions before and after the series of severe environmental tests to determine detrimental effects on ejection.

The test stand containing the heat shield was installed in the chamber with the X-axis of the shield 4 in. below the centerline of the chamber and with the forward end approximately 4 ft from the forward end of the chamber.

The same procedures to attain boom alignment and shield fitup were used as during the preenvironmental tests, with the exception that the location of the velocity instrumentation had to be positioned to allow for the thermal expansion or contraction of the shield and booms.

The reduction of cold wall temperatures and chamber pressures were performed first and

concurrently since both required approximately the same period of time to reach specified conditions. Upon attaining a cold wall temperature of -280 to -300°F and a vacuum of 10^{-5} torr, heat was applied to the shield.

During the tests at a Sun-Shade condition, the amount of power applied to each of three zones was indicated by the output from the calorimeters. (Figure 29) A calibration of one of the calorimeters produced data indicating that the predicted design values for the calorimeter were valid within the temperature ranges from 70 to 150°F . The voltage required to produce the desired heat flux rate was determined before each test by preliminary trial runs. Predicted voltages were used for the first run. Adjustments to the voltage on each zone were made on each successive run until the slope of the calorimeter temperature data vs time matched the predicted slope.

The shield halves were ejected as soon as the maximum predicted temperature was attained. On three of the tests at a Sun-Shade environment, the ejection was initiated $1/2$ hr from the time that the heat was applied, and after a 25-hr period on the fourth test.

The power input to each zone, the heat flux sensed by the calorimeters, and the time period before maximum temperatures were attained are shown in Table 4. The power input was determined from data taken from a voltmeter on the thermac temperature controller and the resistance of the heaters at that voltage. The voltmeter was not a high accuracy instrument and the exact resistance at such a low current per lamp is uncertain; consequently, the power input should be used only as a reference value.

The calorimeters were not used during the Constant Sun-Constant Shade environment test nor was the cold wall simulation used. The heat was applied as rapidly as the lamp ar-

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Figure 29. Calorimeter

range would permit. Approximately four times the amount of power was required for this test than for the previous tests at the Sun-Shade condition due to the fact that the lamps were twice the distance away from the shield surface. See Figure 26.

The shield was ejected as soon as all zones had attained the maximum predicted temperature.

2. Vertical Ejection Tests – One-g Gravity

a. Discussion

A series of ejection tests was performed with shields oriented in a vertical position under the influence of gravity and at ambient temperatures and pressures.

These tests were performed on two shield assemblies, Serial Nos. 0005 and 0004. Serial No. 0005 shield assembly is the shield that was qualified during the qualification program at a zero gravity condition. Serial No. 0004 is one of the original heat shields that had been modified, where possible, to meet the latest specifications.

TABLE 4
POWER INPUTS TO HEAT LAMPS

Time (hr)	Test No.	Zone 1		Zone 2		Zone 3		Calori- Meter (watts/ft ²)
		V1 (volt)	I1 (amp)	V2 (volt)	I2 (amp)	V3 (volt)	I3 (amp)	
0.64	20	143	16.5	240	21	361	24	237
0.48	21	172	19	200	18	415	28	190
0.59	22	163	18	190	17	392	26	190
24	23	132	15	120	12.5	285	19.5	150
1.4	24	-	-	-	-	-	-	-

Previous tests had proven that the shield would eject with a considerable margin of safety under a thermal environment if the shield were mated according to the specification shown in the appendix. Since tests performed during the development phase had revealed that maladjustment of the shield could cause an abort, it was questionable if the vibration during the launch phase of the flight would have a significant effect on the initial alignment of the shield or would cause structural damage that would prevent ejection.

The tests of these two shields were conducted to obtain vertical ejection criteria from a shield that had qualified and to evaluate the performance of a second shield against that criteria before and after imposing a simulated vibration environment. See Figure 4.

The installation fitup and checkout procedures and test techniques used in the horizontal test ejection program (O-g simulation) were used for these tests with the exception that the magnetic proximity instrumentation was not used during the tests of shield Serial No. 0004.

b. Vertical Test EHS 0005

Shield, Serial No. 0005, was installed on the NPU simulator used during the horizontal ejection program. The release mechanism used to

initiate ejection conformed to flight specifications with the exception that one live squib and one dummy squib were installed in the pin puller assembly.

Two ejection tests were performed. The shield halves rotated approximately the same number of degrees on both tests before the influence of gravity, air, and friction dissipated the kinetic energy. Predictions made assuming that the energy dissipated by friction and air was the equivalent to that determined during ejection tests at zero gravity, indicated that the shields should rotate 8 degrees before the rotation velocity was reduced to zero. The shield halves rotated 8.5 to 9.5 degrees. This higher value is expected since there was no support boom drag and the position of the shield tends to produce lower friction values at the pivot and the alignment pins.

c. Vertical Test of EHS 0004 Before and After Vibration and Shock

The FSM-4 system was subjected to shock and vibrations along each mutually perpendicular axis. The system was subjected to shock and vibration levels specified for both acceptance and qualification of the vehicle. The acceptance level tests were conducted to develop criteria for acceptance tests of later flight vehicles, and

the qualification level tests were conducted to qualify the FSM-4 system. The acceptance and qualification levels of input to the shake table are shown in Table 5.

EHS No. 0004 was installed on the FSM-4 NPU per specifications (Appendix) and an ejection test performed before and after the qualification shock and vibration level test. The static pull tests, the critical measurement noted in the Appendix, and a visual inspection were performed on the shield and support bracketry before and after imposing qualification level shock and vibration along each axis.

The vehicle was mounted on the shake table in a vertical position. Consequently the ejection tests were by necessity conducted in a vertical plane under the influence of gravity. This heat shield was five to six pounds heavier than the flight heat shield configuration. Therefore, the loads imposed due to the acceleration during the vibration tests were considerably higher and the dissipation of energy was greater than if the same tests had been performed on a flight configuration shield. Since this test imposed more severe conditions, due to the heavier shield, qualification of the system using this shield was considered to be conservative.

3. Structural Behavior

Although EHS Nos. 0004 and 0005 were repeatedly subjected to conditions that imposed impact and thermal strains far more severe than will be encountered under actual conditions, there was no apparent damage that would adversely effect ejection or thermal performance. Tables 6, 7, and 8 summarize the tests performed on each shield.

There was visible distortion of the skin along the bonded joints after imposing a Constant Sun-Constant Shade thermal and pressure environment (375° maximum and 10^{-5} torr) on the EHS

Nos. 0004 and 0005. The magnitude of the "bubble-like" distortions increased during the rapid decompression test but returned to the post Constant Sun-Constant Shade condition upon returning to ambient pressures. Although this indication of structural damage is not considered critical, this information combined with peel tests performed on skin samples at temperatures between 350 and 400°F indicates that 375°F on the external surface is an absolute maximum temperature limitation at which ejection performance can be certified.

4. Ejection Performance — One-g and Zero Gravity Conditions

The ejection performance of the SNAP 10A EHS met the minimum requirements on every test conducted during the acceptance and qualification program. This was true of even those tests performed under the influence of air drag which dissipated 67 to 74% of the available spring energy. The specified minimum criteria at time of release were rotational velocities of 10°/sec and linear velocities of 1 ft/sec, or the dissipation of an energy equivalent to these velocities by test conditions not encountered in space, i.e., such effects as gravity, air friction, and boom drag.

The effect of each test parameter on the EHS performance was determined from the data taken from the acceptance program tests. The values are shown in Figure 30a, b, and c and are tabulated on Figure 30b. The data presented in the table are average values at the instant of release and are the values used for evaluation of EHS 0005. Since the effect of air drag is a function of velocity and position of shield relative to the NPU the values are presented in both forms.

The determination of the effect of air drag was the most significant revelation in the series of tests to determine effect of test parameters.

TABLE 5
VIBRATION AND SHOCK TEST LEVELS

VIBRATION TEST LEVELS (Acceptance Test)			
Description	Frequency Band (cps)	Input Level	Sweep Rate
100% Longitudinal (X)	5-8	3/8 in. DA	Constant octave sweep rate of 1 minute/octave
	8-160	1.5 g	
	160-400	1.5 g	
	400-2000	5 g	
100% Lateral (Y) and Normal (Z)	6-160	1 g	Constant octave sweep rate of 1 minute/octave
	160-250	1 g	
	250-400	3 g	
	400-2000	5 g	
VIBRATION TEST LEVELS (Qualification Test)			
100% Longitudinal (X-X)	5-9	1/2 in. DA	Constant octave sweep rate of 3 minutes/octave
	9-400	2.3 g	
	400-2000	7.5 g	
100% Lateral (Y-Y)	5-8	1/2 in. DA	Constant octave sweep rate of 3 minutes/octave
	8-250	1.7 g	
	250-400	4.5 g	
	400-2000	7.5 g	
SHOCK TEST INPUT VALUES			
Axis	Magnitude (g)	Duration (Millisecond)	
Longitudinal (X)	6.8	6	
	-2.5	6	
Lateral (Y) and Normal (Z)	+5	6	
	-5	6	

An examination of Figure 30c reveals that 70% of the energy is required to overcome air drag alone. This explains why considerable difficulty was encountered in obtaining acceptable performance data during the development phase of the program. During the initial phase when 10 and 16 lb force springs were being utilized, there was insufficient energy to overcome air drag. The 6.0 ft lb of energy developed when the 16-lb springs were replaced with 22-lb

springs, maintaining the same plunger stroke, was just sufficient to overcome air and friction if the dissipation by friction were maintained below a 30% ft lb energy level or 1.8 ft lb. The fact that the shields did eject on the last 56 tests under these conditions tends to prove that the methods used to check the fitup of an EHS (Serial No. 0004) to the NPU by measuring static friction forces (Appendix, Steps 8 and 12) is satisfactory.

a. Support Boom Effect

b. Energy Dissipation, -Y Shield Due to Air, Friction and Temperature

c. Energy Dissipation, +Y Shield Due to Air, Friction and Temperature

Figure 30. Effects of Boom, Air, Friction and Temperature

Ejectable Heat Shield																				Component Tests							
Shield Serial No.	Test Type	Ejection Tests						Vibration		Pre- Orbital Startup With Shield	Special Tests			Air Drag		Friction		Installed on NPU	Fabricate per Change	Ejection Springs		Squibs		Pin Puller		Electrical Connector	
		Zero Gravity			One "g" Gravity						C. G. Tests Ambient	Moment of Inertia Test				Pivot Force Test	Sep Force Test			Static	Dynamic	On Shield	Off Shield	On Shield	Off Shield	On Shield	Off Shield
		Ambient Temp & Press	Ambient Temp & Vacuum	Space Environ- ment	Ambient Temp & Press	Ambient Temp & Vacuum	Space Environ- ment	Accoust	Mech			Ambient	Ambient	Vacuum	Ambient												
0001	Dev Acc Qual									1								FSM-1	A	30	5						
0002	Dev Acc Qual						5	1	1									PSM1-A PSM1-A	A			7		7		5 2	
0003	Dev Acc Qual									1								PSM-1									
0004	Dev Acc Qual	105			2						1	2				15 5 5	43 5 5	FSEM-2 FS-3					3 2		3 2		107
0005	Dev Acc Qual	10 8	2	1 4	2						1	2		2	2	15	15	FSEM-2† FSEM-2 FSEM-2					3 12		3 12		11 12
0006	Dev Acc Qual								1							5	5	FS-4				8		4		4	
0007	Dev Acc Qual								1							5	5	FS-5									

*The number of tests shown are those that have been documented, actually the number of special tests conducted far exceed the numbers shown.
 Vibration Test Test includes vibration in all three axes
 Pre-orbital Start Test includes all space environment tests conducted
 †FSEM-2 Utilized previously for electrical tests

Table 6. Enumeration of Ejectable Heat Shield Tests and Components Tests*

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TABLE 7
VERTICAL EJECTION TESTS - ONE-g GRAVITY CONDITION AMBIENT TEMPERATURE
AND PRESSURE, RELEASED BY SQUIB AND PIN PULLER ACTION

Test No.	Shield Sr. No.	Ejection Spring Sr. No. and Energy		Test Conditions		Force Tests				Rotation (Degrees)		Comments
				Vibration		Separation Load (lb)		Pivot Friction Load (lb)				
		Axis	Level	+Y	-Y							
1	0005	031, 032 (See Table 7 for Energy)	023, 025	-	None	2.7	3.75	Less than Specified Maximum of 7 lb	Less than Specified Maximum of 7 lb	9.5	8.5	Predicted rotation using data from zero gravity test, +Y = 8.0°. Minimum acceptable = 4.5°.
2	0005	031, 032 (See Table 7 for energy)	023, 025	-	None	2.7	3.75	Less than Specified Maximum of 7 lb	Less than Specified Maximum of 7 lb	9.5	9.0	Predicted rotation using data from zero gravity test, +Y = 8.0°. Minimum acceptable = 4.5°.
3	0004	- 7.6 ft lb Energy 2 springs	-	-	None	3.6 [*]	4.0	3.2	3.2	9.25	9.0	Predicted rotation +Y = 7.4° -Y = 7.6° Minimum acceptable ~4.5°.
4	0004	- 7.6 ft lb Energy 2 springs	-	X - X Y - Y Z - Z	Qualifi- cation	3.7 [†] 2.8 [§] 4.0 ^{**}	3.8 4.3 4.0	3.6 6.0 4.4	3.2 3.0 4.2	No No 7.25	Test Test 7.0	Reduced angle of rotation 2° after vibration in three planes equivalent to 5.25% of available potential energy.

Notes: *Test 3 was conducted before imposing vibration and shock to system.

†Test 4 was conducted after imposing vibration and shock to system.

§Heat shield would have rotated to release position on all four tests had the tests been performed in a vacuum.

Predictions based on 62% dissipation of energy due to air pressure; ~15% dissipation of energy due to friction, 23% dissipated by gravity.

**Released by squib and pin-puller action.

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Velocity Data (Degrees/Sec.)																Test Conditions				Ejection Hardware				Comments												
Test Number/Position	+Y Shield Half							-Y Shield Half							Environment		Static Force lb (average)		Squibs		Pin Puller	Burn Out Wire Release	Shield Performance	Squib Performance	Ejection Springs											
															Temperature Profile	Pressure	Separation Test		Pivot Friction		Part S/N	Part Number			Part Number		Sr. Number Energy +Y	Sr. Number Energy -Y								
	+Y	-Y	+Y	-Y																																
1	36.2	27.7	25.0	20.0	19.6	18.7	-	38.8	-	No Data				Ambient	Ambient	2.0	2.0			None	None	None	Yes			Two dummy squibs installed	031, 032 7.47 ft lb	023, 025 7.41 ft lb								
2	38.6	27.2	25.7	20.4	20.0	20.0	-	39.2	27.5	27.3	17.8	15.8	13.7	14.0																						
3	38.2	27.8	24.4	20.9	20.6	18.6	-	37.8	25.0	18.9	16.7	14.7	13.1	11.2																						
4	35.8	26.3	21.2	19.8	19.2	17.1	-	No Data																												
5	33.6	27.0	25.0	20.5	19.7	19.6	-	37.9	27.0	20.4	15.8	13.7	12.9	11.2																						
6	37.5	26.4	25.2	20.8	19.5	19.1	-	36.6	27.8	19.6	15.4	13.1	11.5	-																						
7	37.6	26.8	24.0	19.9	-	-	-	36.2	26.5	20.5	16.3	15.2	-	-																						
8	36.5	26.3	23.8	17.9	18.0	17.3	-	37.6	27.8	22.2	17.5	15.4	15.5	15.1																						
9	38.0	26.7	23.4	19.9	18.3	17.5	16.7	38.5	27.9	23.1	19.0	16.6	15.6	14.2																						
10	33.3	24.4	21.3	17.3	15.0	13.6	13.9	37.9	32.3	25.5	19.9	18.3	15.8	14.6																						
11	35.2	26.4	21.7	17.3	18.2	13.8	13.1	-	No Data									2.0	2.0			-		022												
Average, Tests 1-10	36.5	26.7	23.9	19.7	18.9	17.9	15.3	37.8	27.7	22.2	17.3	15.4	14.0	13.3																						
12	Data Not Reduced, Documentary Film																																			
13	27.03							40.65	25.32	20.41	16.95	14.71	13.51	-	13.33																					
14	38.46	25.64	22.22	19.23	14.51	15.27	14.08	26.31	25.64	20.20	17.39	15.87	15.38	-	12.50																					
15	35.71	32.26	22.47	19.96	16.00	16.67	14.08	38.46	25.97	21.28	16.95	15.27	13.99	-	13.89																					
16	38.46	28.49	22.22	20.41	17.09	-	17.73	38.76	27.03	22.47	18.90	16.80	-	14.93	14.29																					
25	62.5	27.03	20.62	17.70	17.24	14.51	15.15	Not Reduced																												
17	65.8	62.5	61.7	61.7	63.0	61.7	62.7	67.6	64.1	67.6	64.1	66.7	64.1	62.7	64.1		Ambient																			
18	63.8	61.7	58.2	62.5	62.5	59.6	63.3	73.0	68.5	64.1	64.1	66.7	69.5	64.2	64.2		2×10^{-5} torr																			
Average, (17-18)	64.8	62.1	59.9	62.1	62.7	60.6	63.0	70.9	66.3	65.8	64.1	66.7	66.8	63.4	64.1		1×10^{-5} torr																			
19	66.67	60.60	57.1	60.6	64.5	63.7	69.4	71.43	71.43	71.43	71.43	71.43	-	-			Vacuum																			
20	62.5	60.2						71.4	66.7	68.5	66.7	64.9	64.1	65.8	65.8		8×10^{-6} torr																			
21	71.4	55.6	56.0	57.6	58.8			75.8	63.3	64.9	66.7	66.7	60.2	59.6	59.6		7×10^{-6} torr																			
22	67.7	58.8	58.8	59.6	64.1	58.8	62.5		64.9	63.3	66.7	64.1	61.0	62.5	61.7		7×10^{-6} torr																			
23	62.5	59.7	57.3	56.5	60.2	62.5	55.6	70.4	64.0	62.5	58.9	61.7	62.5	55.6	55.6		1.5×10^{-6} torr																			
24	No data from oscillograph. Both shield halves ejected at equivalent velocities as Test Number 23. Data taken from slow-motion film																Constant Sun Constant Shade																			
																	5×10^{-4} torr																			

NOTES: Tests 1 through 7 were conducted with flight thermocouples installed
Tests 8 through 25 were conducted with flight thermocouples plus test thermocouples
V_R = 1 ft/sec — Measured on test Number 10

Table 8. Horizontal Ejection Tests — Zero-g
Gravity Condition EHS Serial
Number 0005

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The acceptance tests performed at ambient conditions and the qualification tests performed at environmental conditions on EHS No. 0005 produced data that tended to increase the confidence in the methods being used to check fitup to an even higher level. (See Figure 31a,b.) The analysis of the data taken from the development and acceptance program indicated that the difference in energy dissipated due to friction and air drag on any two development tests or any two acceptance tests at ambient conditions was less than 0.3 of a ft lb. This indicates that the dissipation due to friction and air drag was maintained within a tolerance of less than 4% of the available energy. The correlation of predicted values and the test data are shown in Figure 32a and b. The correlation of the test data and predicted values is within $\pm 5\%$ for even those tests performed under the influence of gravity, which is within the limits of the test instrumentation.

An evaluation of the ejection performance data under environmental conditions revealed that only $30 \pm 10\%$ of the available spring energy was required to eject the heat shield at the minimum specified velocities. The additional energy available accelerated the shield halves to velocities nearly 4 times the minimums specified.

The vertical ejection conducted before and after vibration test on EHS No. 0004 indicated that a maximum energy loss of 5% could be expected due to conditions prevailing during the launch phase of the flight. This increases the energy requirement to $35 \pm 10\%$. Using the 45% as the minimum energy criteria, there is a margin of safety in the system of greater than 2.2.

The excellent correlation of test data on two different ejectable heat shields, the fact that the shields ejected on the last 82 tests - 56 on

a. EHS 0005, +Y Shield Half

b. EHS 0005, -Y Shield Half

Figure 31. Acceptance and Qualification Program, in Air, in Vacuum, at Sun Shade Conditions

SHIELD	θ DEGREES			
	PREDICTED	TEST	PREDICTED	TEST
NO	+Y	-Y	+Y	-Y
0004	6.6	6.7	*7.0	*6.0
0005	7.9	8.1	8.5	9.0

*EJECTION DATA
AFTER VIBRATION TESTS

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a. Zero Gravity Conditions

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7561-02410-2

b. One-g Gravity Condition

Figure 32. Correlation of Test Data and Predicted Values

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the development program and 26 on the acceptance and qualification program — under conditions far more severe than will be encountered in space, produces credulity that the heat shield will eject satisfactorily.

5. Thermal Performance

The temperatures imposed on the external shield surface on the shade side of the vehicle are generally higher than requested, due to the low capacity of the cryogenic wall or, as in the Constant Sun-Constant Shade condition, the elimination of the cryogenic panel. The temperatures attained on the sun side were very close to predicted values and can be seen in Figure 33 a, b, c, d, and e. The thermal gradient between the inside of the shield and the outside is considerably higher than predicted. This condition was first noticed during pre-startup tests performed on the FSM-4 system. At that time the indicated temperature difference was believed to be due to erroneous readings from the test thermocouples. However, this condition prevailed on a second shield under two different test conditions establishing that thermal gradients as much as 80°F difference do exist across the shield.

The most valuable information gained from the thermal study of the data is the fact that regardless of the test condition, the shield performed its function as a passive thermal barrier, maintaining the shell temperature below the specified maximum limit and within 10°F of the minimum limit. Since the test system did not contain the working NaK that will be circulated through the system during this phase, the test condition was considered far more severe than actual conditions; therefore, the shield was thermally qualified.

C. ACCEPTANCE AND QUALIFICATION WITH HEAT SHIELD INSTALLED ON FLIGHT MOCKUP

Heat Shield No. 0004, modified as nearly to flight design configuration as possible, was subjected to additional acceptance and qualification tests when installed on a SNAP 10A flight mockup system (FSM-4). The FSM-4 system was identical to a flight system with the exception that the nuclear power unit was replaced with electrical heaters. (Figure 33)

The objectives of these tests were to gather additional acceptance data and to further qualify the shield under conditions that could not be imposed during the previous tests. The previous shield tests were performed on an NPU simulator that did not contain the NaK working fluid or the power conversion system. Consequently, the effectiveness of the heat shield as a passive thermal barrier was questionable. The tests described in the following section produced data to qualify the shield in this questionable area.

1. Prestartup Orbital Test

The heat shield was installed per specifications of the appendix, and installed in a vacuum chamber as shown in Figure 13. The only difference between this test setup and that made for the development test of FSM-1 was the utilization of a cryogenic panel that completely encompassed the vehicle. The use of the panel produced a better simulation of a sun-shade condition than was attained on the FSM-1 test.

The shield was subjected to vacuum and thermal environments simulating the two possible conditions imposed by the relative positions of the vehicle, the earth and the sun, and the resulting data indicated that the shield would maintain the NPU within the prescribed temperature limits of +50 to 225°F. See Figure 34 for predicted thermal environment.

a. Sun-Shade Condition, Test 22, 1/2 hr, Section C

b. Sun-Shade Condition, Outside Shield Temperatures

c. Sun-Shade Condition, Test 23, 25 hr (Section C)

d. Constant Sun-Constant Shade Condition, Test 24, 1 hr, Without Cold Wall (Section C)

e. Constant Sun-Constant Shade Condition, Outside Shield Temperatures, Test 24, 1-hr

Figure 33. Heat Shield Ejection Thermal Data

Pre-tests were conducted primarily to meet the requirements and problems described below.

1) As was expected, the value of the constant sun-constant shade test in predicting space thermal behavior was lost due to gravity induced flow imbalances in the system. The test serves as experimental verification of this effect and indicates that future system tests of this type must include planning to minimize or eliminate the effect of convection currents. The test produced extreme heat shield temperatures slightly in excess of those expected in space (maximum measured value was 385°F). An unexpected result of importance was that a significant temperature drop through the shield was measured (about 50°F at highest heat flux conditions). It was believed that the temperature drop would be negligible, and the presence of a sizable drop probably indicated that the heat shield outer skin will be ~20°F higher than expected on the sun side. The maximum predicted heat shield temperature was 346°F and the upper design specification 350°F.

2) The sun shade transient test also suffered from the flow imbalance problem. However, thermal performance in this environment is much less sensitive to flow rate than in the Constant Sun-Constant Shade environment and the test results support previous analyses. Minimum NaK temperature was about 65°F during the 16-hr test. During this test the heat shield was cycled through the equivalent of eight orbits.

3) Tests up to this time had indicated that the vessel vacuum was not adequate to simulate space heat transfer. Only mechanical pumps had been used and the pressure was in excess of 10 microns. Several cool-down tests (no radiant heaters used) were performed at different vacuums. It was experimentally determined that a pressure of

0.1 microns or less must be reached to reduce gaseous conduction effects to a negligible level. The cool-down rate obtained under these conditions was about 15% slower than that predicted by prior analysis, indicating that the heat shield is a better radiation heat barrier than anticipated.

4) The low gradient tests were designed to permit simulation of minimum NaK temperatures without inducing buoyant forces on the fluid. Power was introduced into the core heater to simulate the solar heat picked up on the sun side and both sides of the system simulated the shade side in space. Due to a misunderstanding of certain test specifications, an abnormally long cool down preceded application of core heat. The minimum NaK temperature was 45°F after a 5-hr cool down. After application of core heat (300 watts), system temperatures rose over a 16-hr period to 120°F. With proper allowance for the procedural error, a minimum NaK temperature of 70°F would be predicted, below an ambient value of 75°F. Test results and analytic predictions agree within about 20%.

5) The results obtained in the low gradient sun shade transient test are also in good agreement with predicted performance and indicate system performance will easily meet NaK temperature requirements.

The heat shield was removed from FSM-4 on 10-27-64, and a cursory examination indicated that blistering had occurred on both shield halves. The shield half which had seen the maximum heat flux was most affected. The shield, however, was structurally sound.

The following conclusions were drawn.

1) The agreement between test results and prior computations was good, thus lending credence to the analytical prediction for the actual space conditions.

2) The SNAP 10A should easily meet the minimum NaK temperature specification.

2. Acceptance Test of Flight Vehicle Shields Serial No. 0006 and 0007

The ejectable heat shields that were installed on the flight vehicles FS-4 and FS-5 were acceptance tested in two ways. First, the static tests outlined in the Appendix, Steps 8 and 12, were performed. Secondly, the shields were subjected to shock and vibration acceptance level tests. These tests were considered adequate since the performance of a flight shield had fully qualified when installed and checked by the same specification.

D. MOTION STUDY

Motion studies were made to determine the trajectory of the shield halves after ejection. Studies were made utilizing the velocities of the shield halves measured during the qualification ejection tests. Both the shield halves cleared all vehicle components. See Figure 35.

The test data taken during the test of EHS No. 0005 was extrapolated from the release positions of the shield halves ($28 - 1/2^\circ$ for +Y, 32.0° for -Y) to 35° . The extrapolated data was used for the motion studies on FS-4 shield No. 0006 and FS-5 shield No. 0007. Since shield No. 0005, 0006, and 0007 were fabricated to the same specifications, the center of gravity location, weight, and moment of inertia values determined by test of shield No. 0005 were used for No. 0006 and 0007. See Figure 36a, b for extrapolated values.

Because the direction of EHS ejection is normal to the orbital direction, there is concern regarding the possibility of collision between the spacecraft and the ejected heat shield. The probability of this occurrence is discussed below.

When the heat shields are ejected in orbit, each shield has the original velocity of the orbiting spacecraft plus the additional velocity of

ejection. The shields will go into orbit about the earth; however, because they have velocities, differing from that of the spacecraft, the orbits will be different. That is, the heat shields will traverse a different path in space, and the period (the time required for one revolution about the earth) will be changed. While different, the orbits nevertheless have at least one point in common — the initial starting point. As shown in the diagram, both the spacecraft and the heat shields will pass through the same point in space, the point of ejection, once each revolution.

If the heat shield and the spacecraft have orbital periods which are almost equal after one orbit, the two objects will pass through essentially the same point within a very small time interval. Because of the high speeds at which these objects are moving ($\sim 23,600$ ft/sec), the difference in orbital period must be on the order of less than a millisecond for a possibility of collision to exist.

In the case of the SNAP 10A heat shield, the relatively small ejection velocity of about 4 ft/sec directed orthogonally with respect to the in-track velocity of the satellite, provides a very small change in the velocity vector of the heat shield relative to the spacecraft and, hence, a very small change in orbital period — on the order of a millisecond.

The factor complicating the exact determination of the change in period is the spacecraft attitude controller. This device maintains a programmed attitude within certain limits,

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DEFINITION OF PROPERTIES

- ω_f = FINAL ANGULAR VELOCITY OF THE EJECTED SHIELD HALF. THE DATA LISTED IS NOMINALLY EQUAL TO ω_R AS MEASURED IN EJECTION TESTS OF THE FS-3 SYSTEM
- ω_R = AVERAGE ANGULAR VELOCITY OF SHIELD HALF TO TRAVERSE $\angle \theta_R$
- R = DISTANCE FROM THE PIVOT POINT TO THE C.G. OF A SHIELD HALF
- V_t = TANGENTIAL VELOCITY OF THE EJECTED SHIELD HALF. $V_t = \omega_R \cdot R$
- V_R = RADIAL VELOCITY OF THE EJECTED SHIELD HALF RESULTING FROM SPRING FORCE F_R ACTING AT A RATE K AND THEN A DISTANCE S UPON THE MASS M OF THE SHIELD HALF SUCH THAT $V_R = \sqrt{\frac{KS}{M}}$
- V = VECTOR SUM OF V_t AND V_R THE DIRECTION OF THE VECTOR DEFINES THE INITIAL TRAJECTORY OF THE EJECTED SHIELD HALF RELATIVE TO THE NPU
- W = THE WEIGHT OF A SHIELD HALF CORRECTED FOR TEST THERMOCOUPLE WEIGHTS
- M = WEIGHT + ACCELERATION OF GRAVITY = MASS
- θ_R = THE ANGLE THRU WHICH A SHIELD HALF TRAVELS FROM THE INSTALLED POSITION TO THE POSITION OF RELEASE
- θ_{ca} = THE ANGLE SUBTENDED BY A VERTICAL LINE AND A LINE DRAWN FROM THE PIVOT POINT TO THE C.G. OF A SHIELD HALF

- ϕ = THE ANGLE SUBTENDED BY THE X AXIS AND THE LINE OF ACTION OF VECTOR V AS MEASURED IN THE Y-Y PLANE
- S = DISTANCE THRU WHICH SPRING FORCE F_R ACTS
- K = RATE AT WHICH SPRING FORCE F_R ACTS. DATA LISTED REPRESENTS TWO SPRINGS PER SHIELD HALF
- t = TIME SCALE OF VECTOR V
- t_1 = TIME OF TRAVERSE THRU $\angle \theta_R$
- I_p = MOMENT OF INERTIA OF A SHIELD HALF AT THE PIVOT POINT.

TABLE OF TEST DATA AND CALCULATED PROPERTIES

PROPERTY	FS-3 SYSTEM (8.1 WT SHIELD %4.0005)						FS-4 SYSTEM (8.1 WT SHIELD %4.0006)					
	MAX	NOM	MIN	MAX	NOM	MIN	MAX	NOM	MIN	MAX	NOM	MIN
ω_f (RAD/SEC)	1.06	1.02	0.96	1.12	1.01	0.90	1.08	1.01	0.94	1.12	1.00	0.88
R (IN)	4.15			3.85			4.15			3.85		
V_t (FT/SEC)	4.48	4.28	3.98	4.31	3.89	3.47	4.48	4.18	3.90	4.31	3.86	3.43
V_R (FT/SEC)	0.78	0.76	0.73	0.82	0.79	0.76	0.78	0.76	0.78	0.82	0.79	0.76
V (FT/SEC)	4.55	4.30	4.05	4.38	3.96	3.56	4.55	4.25	3.96	4.38	3.92	3.57
W (LBS)	12.88			11.88			12.88			11.88		
M (LBS)	0.40			0.37			0.40			0.37		
θ_R (DEGREES)	28.5			37.0			33.5			34.5		
θ_{ca} (DEGREES)	16.3			17.8			16.3			17.8		
ϕ (DEGREES)	NOT APPLICABLE						96.3	97.5	95.3	97.0	95.3	93.8
S (INCHES)	31			31			31			31		
K (LBS/IN)	30.8	28.8	26.8	30.8	28.8	26.8	30.8	28.8	26.8	30.8	28.8	26.8
t_1 (SEC)	0.57			0.63			0.58			0.64		
I_p (LBS/IN ²)	10.72			9.14			10.72			9.14		

NOTE 1 TEST VALUES ARE CORRECTED FOR TEST THERMOCOUPLE WEIGHTS
2 FS-4 SYSTEM DATA, WITH THE EXCEPTION OF θ_R , IS EXTRAPOLATED FROM FS-3 DATA

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a. +Y Shield Half, EHS 0005

b. -Y Shield Half, EHS 0005

Figure 36. Extrapolated Data for Motion Study, Angular Rotation vs Velocity

therefore, within these limits the actual attitude of the satellite at the instant of ejection can not be known in advance. The purpose of this analysis is to determine the conditions required for collisions between the heat shield and the satellite and to estimate the probability of these conditions being met within the known limits of controller variation.

It is assumed that the heat shield has the same initial tangential velocity as the satellite. The heat shield is then given a small change in velocity which causes it to change orbits.

The problem, then, becomes one of determining the change in tangential velocity experienced by the heat shield and its subsequent change of orbital period.

The change in velocity is composed of two components; the ejection velocity of the heat shield and the velocity component due to difference in CG location of the shield with respect to the satellite.

The ejection velocity of the heat shield is nominally 4 ft/sec normal to the plane of the orbit and directed 6° below the local horizontal plane. The satellite, however, will have some small deviations in its orbital attitude, thus changing the orientation of the heat shield ejection velocity. These deviations must be considered in determining the final change in tangential velocity.

The equation for the difference in orbital period of the spacecraft and the EHS is:

$$\Delta T = \frac{12\pi dR}{V_1} + \frac{6\pi R}{V_1^2} \left[\frac{V_a^2}{2V_1} \pm V_r \sin p \pm V_t \sin \Sigma \right],$$

where

ΔT = difference in orbital period between the spacecraft and the ejected heat shield,

dR = distance between the centers of gravity of the spacecraft and EHS,

V_1 = spacecraft velocity,

V_a = EHS velocity at ejection,

V_r = radial velocity component of EHS,

p = pitch angle of spacecraft at time of EHS ejection,

V_t = tangential component of EHS, and

Σ = yaw angle of spacecraft at time of EHS ejection.

The miss distance between the CG's is S and

$$S = V_1 (\Delta T)$$

Substitution yields:

$$S = 12\pi d R + \frac{6\pi R}{V_1} \left[\frac{V_a^2}{2V_1} \pm V_r \sin p \pm V_t \sin \Sigma \right] .$$

Because of the physical dimensions of the heat shield and the satellite, it can be assumed that $|S| \leq 20$ ft is tantamount to a collision.

Substitution of these values will result in a range of pitch and yaw angles for which a collision will occur for any given orbital radius.

Figure 37 is a plot of this equation for a 700-nautical-mile orbit. The shaded area represents the area of interaction between P and E wherein the miss distance S will be between $+20$ and -20 ft.

Because the attitude controller is a deadband device, the probability of being anywhere within the band is the same. Therefore, the ratio of the interaction area to the total area represents the probability that the miss distance of at least one heat shield half will be between ± 20 ft. Note that there is a small area wherein both heat shields will be within the 20-ft-limit.

The probability that one heat shield CG will pass within ± 20 ft is computed to be 0.972% for the orbital conditions given above, if the attitude

controller maintains roll, pitch, and yaw within $\pm 3^\circ$ (± 0.052 radians).

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Figure 37. Pitch and Yaw Interaction

E. CONCLUSIONS

The heat shield performed satisfactorily when exposed to a fully simulated space environment, at partially simulated environments and at an ambient condition that imposed more severe restrictions on ejection performance than the fully simulated condition. The shield was found to be structurally sound under all simulated conditions imposed from boost-off through ejection.

The data obtained from the numerous tests performed on the two heat shields and the components allowed the prediction that the heat shield would perform satisfactorily in space. The prediction was justified on April 3, 1965 when the heat shield was completely qualified following in-orbit verification of EHS ejection.

APPENDIX*

The following steps shall be taken for installing the heat shield on the NPU.

Step 1 Remove the spring 02008 and plunger 02004-4 from the thrust tube assembly 02004. Replace the nut 02004-3 on the thrust tube assembly.

Step 2 Back out the adjustment screws in pivot arm 02010-3 and support bracket 02012 to flush condition on inside surfaces.

Step 3 With the small end of the shield approximately 6 feet from the top of the NPU, mate the pivot arm 02010-3 of the shield with the pivot block 02010-1 on the structure and the electrical plug bracket 02021.

Step 4 Rotate the shield halves 02001-1 and 02001-2 into position so that the pinguides on the bottom corner of the shield enter the slots in the support bracket 02012. Make sure the tongue and grooves mate properly on the parting edge of the shield. Check alignment of shield halves with NPU. If either shield half does not center on NPU, make the following adjustments:

- (a) Loosen pivot shaft mounting screws.
- (b) Center shield half on NPU.

(c) Adjust shield height if necessary to assure mating of shield halves at top and to assure the adjusting screws of the 10FSM1-61045-6 bracket on the +Y and -Y axes have sufficient bearing area on the expansion guide, 02005.

(d) Tighten mounting screws on pivot shaft.

Step 5 Mount the receptacle 10FSM1-61048 to the receptacle bracket 02019 as shown in section A-A of 10FSM1-61042 and shim as re-

quired to obtain the 0.035 ± 0.005 gap between connector bodies.

Step 6 Remove shield halves from NPU, and install springs 10FS-14009 on head of studs on lower side of receptacle bracket 02019.

Step 7 Repeat step 3 and 4, making sure the pivot arm 02010-3 and receptacle bracket 02021 are fully engaged in the pivot block 02010-1 before rotating shield halves into position. Care must be taken to insert the springs 10FS-14009 properly between the connector brackets.

Step 8 With the shield halves mated (all pins engaged), check the force required to slide the pivot arm 02010-3 across the pivot block (approximately 1/8 in either direction). This test is performed with a force gauge and shall not exceed five pounds. If this force is exceeded, the place where the pivot is binding must be determined and corrected. The following places shall be checked:

(a) Cocking of the pivot arm assembly 02010-3 in the pivot block 02010-1. A uniform gap shall be present along the pivot arm (0.001 to 0.004 inch).

(b) Cocking of the electrical plug bracket 02021 in its cut out on the pivot arm 02010-3. This can be corrected by adjusting the electrical plug 10FSM1-61048 in its mounting slots on this electrical plug bracket 02021.

(c) Interference of the electrical plug bracket 02021 with the structure of the NPU (possible bent bracket).

(d) Interference of the top edge of the electrical plug bracket pivot 02021-2 and the pivot arm 02010-3.

*Taken from specification procedure for installation, adjustment and checkout of S10A EHS

(e) Possible interferences shall be checked throughout the central pivot area where the electrical plug bracket contacts the pivot arm.

Step 9 After meeting the force requirement of step 8, make the final adjustments required on the adjusting screws of the pivot arm 02010-3, support bracket 02012 and expansion guide 02005. Tighten the locknuts on the adjusting screws of the expansion guide (see section J-J of 10FSM1-61042) and lock wire.

Step 10 With both shield halves held together in secured position, adjust the nut 02004-3 of thrust tube assembly for contact with 10FSM1-61045-3 and mark location to permit reassembly to the same position.

Step 11 Recheck all adjustments to assure the shield assembly is centered functionally.

Step 12 With the complete assembly in the vertical position and each shield half mated (all pins engaged), separate one shield half at its top, with a force gage (tension). The required force for this operation shall not exceed 4 pounds. If the force is exceeded, the location of excessive binding or hang-up shall be located and corrected.

Step 13 Check the rotation of each shield half about its pivot and its release from the pivot housing. No binding or hang-up shall occur.

Step 14. Reinstall the springs 02008 and plunger 02004-4 in thrust tube assembly. Reinstall the nut 02004-3 to the position

established in step 10 and lock wire to prevent rotation.

Step 15 Install the retainer assemblies 02004-7 on the thrust tube nut 02004-3 to retain plunger for installation of shield halves.

Step 16 Fit-up pin puller assemblies 10FS-86009 per view E-E of 10FSM1-61042. Adjust pin puller bracket 02007-4 and -5, if necessary, to assure a free fit of the pin puller shaft in the bushing of the heat shield 02001-1 (re-safety wire mounting screws if adjustment is required). Insert ends of band assembly 02013-13 and 02013-15 in band guide of 02001-1 (bands to remain separated at turnbuckle) and install pin puller 10FS-86009 using appropriate fasteners per 10FSM1-61042 and lock wire. Install dummy squibs 10FS-86005 and connect appropriate cabling.

Step 17 For final installation of shield repeat step 3 and 4, making sure to align the springs 10FS-14009 and the electrical connector 10FSM1-61048. With both shield halves in position, assemble the turnbuckle of the 02013 band assembly and tighten nut until looseness is removed. Remove spring retainers 02004-7 and manually hold shield halves in secured position and tighten nut of band assembly until looseness is removed and band tension just increases from zero then tighten the nut an additional 0.6 inch of travel (use an AN315D3 nut in place of lock nut for fit-up and checkout). Install safety wire to band retainer as shown in view H-H of 10FSM1-61042.