UNCLASSIFIED

AD NUMBER

AD328876

CLASSIFICATION CHANGES

TO:

UNCLASSIFIED

FROM:

CONFIDENTIAL

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; APR 1962. Other requests shall be referred to Arnold Engineering Development Center, AFSC, Arnold AFB, TN.

AUTHORITY

AEDC ltr 4 Dec 1975 ; AEDC ltr 4 Dec 1975

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED AND CLEARED FOR PUBLIC RELEASE UNDER DOD DIRECTIVE 5200.20 AND NO RESTRICTIONS ARE IMPOSED UPON ITS USE AND DISCLOSURE,

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

UNCLASSIFIED

AD. 328 376

CLASSIFICATION CHANGED TO: UNCLASSIFIED_ FROM: CONFIDENTIAL AUTHORITY:

AEDC 1th, 4 Dec 75

UNCLASSIFIED

2)

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.



A O



ARO, INC. DOCUMENT CONTROL NO IG-223-343 COPY 444 OF 85 SERIES A PAGES 50

(TITLE UNCLASSIFIED)

ALTITUDE TESTING OF HERCULES POWDER COMPANY BE-3 ROCKET MOTORS

(Phase II-Qualification and Acceptance Testing)

By

A. L. Cannell and C. F. Nokes, Jr. Rocket Test Facility ARO, Inc.

TECHNICAL DOCUMENTARY REPORT NO. AEDC-TDR-62-63

April 1962

AFSC Program Area 921E, Project 9042

(Prepared under Contract No. AF 40(600)-800 S/A 24(61-73) by ARO, Inc., contract operator of AEDC, Arnold Air Force Station, Tennessee.)

ARNOLD ENGINEERING DEVELOPMENT CENTER AIR FORCE SYSTEMS COMMAND UNITED STATES AIR FORCE



CONFIDENTIAL

AEDC-TDR-62-63

.

(Title Unclassified) ALTITUDE TESTING OF HERCULES POWDER COMPANY BE-3 ROCKET MOTORS (Phase II - Qualification and Acceptance Testing)

By

A. L. Cannell and C. F. Nokes, Jr. Rocket Test Facility ARO, Inc.,

a subsidiary of Sverdrup and Parcel, Inc.

April 1962 ARO Project No. 134114

CONFIDENTIAL

(This abstract is classified CONFIDENTIAL.) ABSTRACT

Eight Hercules Powder Company, BE-3, solid-propellant rocket motors designed for application as a retrorocket for the lunar impact capsule of the Ranger series of spacecraft were tested at pressure altitudes in excess of 100, 000 ft as part of an acceptance and qualification program to determine ignition reliability and motor performance and to evaluate the erosion resistance of the inert components of the motors.

Seven motors were fired successfully. Vacuum total impulse varied from 52, 329 to 52, 736 lbf-sec. Specific impulse based on the vacuum total impulse and the manufacturer's stated propellant weight varied from 275.1 to 276.0 lbf-sec/lbm. The average ignition lag time was 8 millisec. During one firing, the motor forward closure burned through as a result of failure of the igniter support tube.

Considerable nozzle deterioration (also encountered during previous tests) was prevalent in the region of the exit plane. A nozzle modification, consisting of an aluminum stiffening ring bonded to the nozzle exit cone, was used on two firings to strengthen the nozzle and was successful for the one firing during which the ring stayed in place.

(Catalog cards with an unclassified abstract may be found in the back of this document.)

iii

Page

...]

CONTENTS

iii
1
2
4
5
10
11

TABLES

1.	Instrumentation	13
2.	Motor and Test Environment Variations	14
3.	Motor Performance Table	15
4.	Physical Data Table	16
5.	Performance Repeatability	17

ILLUSTRATIONS

Figure

٠

c

C

1.	Typical BE-3 Rocket Motor	
	a. Schematic of Motor	19
	b. Nozzle Wall Profile	20
	c. Schematic of Chamber Pressure	
	Adapter and Support Tube Assembly	21
	d. Photograph of Motor Assembly.	22
	e. Photograph of Nozzle Exit Region	22
	f. Nozzle Modification (Runs T3-41-09 and	
	T3-41-10)	23
2.	Schematic of Ranger Vehicle	24
3.	Installation of Motor in T-3 Test Cell	
•••	a. Schematic \ldots \ldots \ldots \ldots \ldots \ldots	25
	b. Photograph	26
4.	Typical Motor Firing	27
5.	Typical Thrust and Chamber Pressure	
~,	Buildup Characteristics	28

v

Ó

0

0

-

Page

Figure		Page
 6. Firing T3-41-08 (Motor Failure) a. Thrust, Chamber Pressure, 	and Cell	. 29
Pressure vs I line	Adenter	30
b. Damaged Chamber Pressure	Tall	31
c. Overall Photo of Motor and C		. 31
d. Front End Detail		
7. Vacuum Total Impulse vs Propellan	t Weight	. 32
8. Film Sequences of Firings		
a. Run Number T3-41-04		. 33
b. Run Number T3-41-07		. 34
c. Run Number T3-41-09		. 35
9. Post-Firing Inspection Photos of Mo	otors	
a. Run T3-41-03; Motor S/N 37	7	. 36
b Bun T3-41-04: Motor S/N 38	3	. 37
c Bun T3-41-05: Motor S/N 39)	. 38
d Bup T3-41-06; Motor S/N 42	2	. 39
a. Run T3-41-07; Motor $S/N 40$)	. 40
e. Run 13-41-07, Motor $S/N 43$	1	41
I. Run 13-41-00; Motor $S/N = 1$		42
g. Run T3-41-09; Motor S/N 43	J	. 12
h. Run T3-41-10; Motor S/N 43	5	. 40

ര

vi j

Ø

1.0 INTRODUCTION

The Hercules Powder Company (HPC), BE-3, solid-propellant rocket motor (Fig. 1) is to be used as the retro-rocket for the lunar impact capsule of the Ranger series of spacecraft (Fig. 2). The motor is designed to reduce the velocity of the capsule an incremental value of approximately 8660 fps prior to lunar impact.

Because of the necessity of knowing accurately the ballistic performance of these motors at near vacuum conditions, the final weight of the inert components, and also to establish motor reliability, a two-phase program was established at the Rocket Test Facility (RTF), Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC). Phase I of this program (Ref. 1) conducted during the period September 29 to October 6, 1961, consisted of development tests to determine performance of two motors and evaluate erosion resistance of the motor inert parts. The results of Phase II tests which consisted of qualification and acceptance tests of a series of similar motors are presented in this report. The Phase II tests were conducted during the period November 20-30, 1961.

The test was sponsored by AFSC and was conducted at the request of National Aeronautics and Space Administration. Personnel from Jet Propulsion Laboratory, Aeronutronics Division of Ford Motor Company, and Hercules Powder Company provided technical liaison for the test.

The primary objectives of the second phase of the test were to determine ignition capability; to accurately determine and evaluate repeatability of ballistic performance and to study erosion resistance of motor inert components (motor case, liner, nozzle, etc.).

The motors tested during Phase II differed from the Phase I motors (Ref. 1) in two respects. The nozzle wall thickness in the region of the exit plane (Fig. 1b) was doubled because of the deterioration experienced during Phase I testing. Also, the phenolic igniter support tube contained a steel sleeve (Fig. 1c) which was incorporated after difficulties were encountered during Phase I testing when one of the tubes was broken during connection of the CO₂ quench system (Ref. 1).

1

Manuscript released by authors February 1962.

2.0 APPARATUS

7

0

2.1 TEST ARTICLE

The HPC, BE-3, solid-propellant rocket motor (Fig. 1) is a fullscale flight weight motor. It has a spun fiberglass case with a Buna-N rubber insulator and contains a case-bonded propellant charge. The 16-deg conical nozzle (19:1 expansion ratio) has a graphite throat insert and a phenolic exit cone. The nozzle wall in the region of the exit plane was strengthened after Phase I testing by increasing the wall thickness as illustrated in Fig. 1b. For two firings (T3-41-09 and T3-41-10), an aluminum stiffening ring (Fig. 1f) was bonded on the nozzle exit cone to strengthen the nozzle in an attempt to prevent exit cone deterioration.

A modification of the igniter support tube was also incorporated which consisted of a steel sleeve in the phenolic tube (Fig. 1c).

Nominal design and performance characteristics are as	follows:
	32,6
Motor length, In.	18.18
Motor diameter, in.	100
Propellant weight, lb	100
Inert weight (including igniter and	•
nozzle closure). lb	24
mozzie eloparor,	214
Total motor weight, in	. 89
Mass fraction	6, 16
Throat area, in. ²	10 1
Nozzle expansion ratio	10.1
Average flow rate, 1b/sec	18
Motor chamber pressure. DSia	470
Wotor chamber problem, pro-	5000
Average thrust, in	

The motor propellant grain is cast in the configuration presented in Fig. 1a. The aluminized, double base propellant has the following composition:

o Incredient	Weight Percent
Ingredient	
Nitrocellulose (12.6-percent)	22.1
nitrogen content)	28.3
Ammonium perchlorate	20.7
Aluminum	21.4
Triacetin	1.5
Resorcinol 2 Nitrodiphenylamine	1.0

The BE-3 motor is equipped with a basket type igniter (Fig. 1a) containing 100 gm of BKNO3 pellets which are ignited with 2 U. S. Flare squibs. The nominal ignition current is 1.75 amp. The phenolic support tube for the basket igniter was utilized as a chamber pressure tap and also as a supply line for the CO₂ quench system provided for cooling the unit after burnout. For one firing (T3-41-09) a flight type igniter support tube which is filled with potting compound was used. Therefore no chamber pressure measurements were obtained for this firing.

The motors were equipped with a styrofoam throat closure. The closures were punctured prior to sealing the test cell; therefore the motor chamber pressure was equal to ambient pressure prior to ignition.

2.2 INSTALLATION

The aft end of the motor was installed in a mounting ring. This mounting ring rested on 4 roller bearings attached to a box frame structure. A steel plate attached to this box frame structure by tie rods was mounted on the front end of the motor. A thrust adapter was attached to this steel plate. The design of the harness allowed for longitudinal thermal expansion of the motor thus eliminating strain on the motor case. The firing harness was rigidly attached to a thrust cradle (Fig. 3) which was supported by three horizontal and two vertical flexure columns to permit a single degree of freedom. Load cells resisted and measured the axial thrust of the motor.

All motors were fired in Rocket Altitude Cell T-3 (Ref. 2). The pressure altitudes for these firings were established by using the RTF rotating exhaust machinery in conjunction with an auxiliary steam ejector. During the firings, the rocket motor exhaust was used as the driving gas for the ejector-diffuser system which maintained the simulated altitude in excess of 100,000 ft during the seven successful firings. During the first 5 firings, a 42-in.-diam, uncooled diffuser was used. A 48-in., water-cooled diffuser was used for the remaining three firings. A CO₂ quench system, exhausting through the igniter support tube, was installed to cool the motor after burnout in order to protect the motor case, case liner, and nozzle materials from the effects of residual heating, so that evaluation of the structural integrity of these components could be accomplished.

2.3 INSTRUMENTATION

Instrumentation (Table 1) was provided to measure four thrust signals, two chamber pressure signals, three cell pressure signals,

one cell temperature signal, one motor case temperature signal, and one ignition pulse signal. The four thrust measurements were obtained from two double-bridge, strain-gage-type load cells having a range of 0 to 10,000 lb. Chamber pressure was measured by two bonded straingage transducers, and the cell pressure was measured by unbonded strain-gage transducers. Iron-constantan (I-C) thermocouples were used to measure motor and cell temperatures.

The output signals from the load cells and transducers, were indicated in totalized digital form on a visual readout millivolt-to-frequency converter and also in analog form on a photographically recording, galvanometer-type oscillograph. A magnetic tape system recording in frequency form stored the signals from the converter. The signals stored on the magnetic tape system were reduced to engineering unit data by an ERA-1102 digital computer. The computer system provided data printouts of absolute values and accumulative integral values for all signals at 0. 1-sec intervals.

The printouts from the digital computer were considered to be primary data. Oscillograph records (trace speed of 25 in./sec) provided an independent backup for all data. Continuous recording nullbalance potentiometers recorded thrust, chamber pressure, cell pressure, and cell temperature to provide data for analysis immediately following the firings.

Visual observation of the motor firings was provided by a closed circuit television monitor. A visual record of the firings was provided by high speed (1000 frames per second) movie cameras.

3.0 PROCEDURE

After arrival at AEDC, the BE-3 rocket motors were radiographically inspected and then stored in a temperature-controlled storage area $(70^{\circ} \pm 1^{\circ}F)$ for a period of at least 72 hr prior to firing. Continuous temperature records were maintained for each motor on strip-type recorders. These recorders were regularly checked against a mercury bulb thermometer to document any drift in calibration. During storage, further visual and dimensional inspections of the motors were made including a fit check of the thrust adapter hardware, measurement of the igniter squib resistances, weighing and photographing the motor, and measurement of the nozzle exit plane diameters. The nozzle throat diameter measurements could not be obtained because of the nozzle throat closures. These measurements along with weights of all motor components were provided by the manufacturer.

After inspection and temperature conditioning were completed, the motor was transported to the cell in an insulated container. Temperatures were continuously monitored during this period with the same strip recorders used in the storage area. After the motor was installed in the test cell, all instrumentation connections were made, the circuits checked and the CO₂ quench system connected. The ignition circuit was continuity checked from the control room, and the sea-level calibrations were performed.

The pressure and temperature data systems were calibrated at sea level by a four-step electrical calibration system using known resistances to simulate known signal levels. The resistors were located in the test cell, and the systems were remotely energized from the control room.

The thrust measuring system was calibrated at sea level by a remotely operated dead weight calibrator at nominal thrust levels of 0, 2000, 4000, 4800, 5600, and 6400 lbf. The weights used on the calibrator had previously been compared with secondary standard weights whose error is 20 parts in a million. The thrust calibrator also was calibrated with a high accuracy load cell, (\pm 10 lb) prior to motor installation and system calibration.

The test cell was sealed, the pressure in the test cell was reduced to simulated altitude conditions, and the required checks and altitude calibrations were accomplished. The ignition circuit resistance was then adjusted to provide the proper firing current and the motor was then fired. Approximately 10 sec after motor burnout, the CO₂ quench system was actuated allowing approximately 50 lb of CO₂ to flow through the engine in a period of 15 min. After firing and while the test cell was still at simulated altitude conditions, the calibration procedures were repeated.

After removing the motor from the test cell, post-firing inspection was performed which consisted of weighing the motor assembly and measuring the nozzle throat diameter. The nozzle exit diameters were impossible to obtain to any degree of precision because of nozzle deterioration. Photographic documentation of the motor post-fire condition was also accomplished.

4.0 RESULTS AND DISCUSSION

4.1 GENERAL

Eight HPC, BE-3, solid-propellant rocket motors were fired at simulated altitudes in excess of 100,000 feet for qualification and

acceptance tests. The typical variation of axial thrust, chamber pressure, and test cell pressure throughout one of the firings is shown in Fig. 4. Typical build-up of thrust and chamber pressure immediately following ignition are shown in Fig. 5. The primary objectives were to determine ignition capability, to establish accurately and to determine the repeatability of motor performance. In addition, an evaluation of the erosion resistance of inert components including a strengthened nozzle exit cone was accomplished. The nozzles used on these motors were strengthened in the exit plane region by doubling the thickness of the nozzle wall at the exit plane (Fig. 1b) from that used on the motors tested during Phase I.

Seven motors were fired successfully. During the firing of one motor, the igniter support tube failed (Fig. 6) allowing hot gases to be expelled through the front end of the motor and finally resulting in burnthrough of the forward closure.

The igniter support tube as used during this firing did not simulate the flight application. For flight application, the tube is filled with potting compound which substantially increases its strength. The pressure adapter used for chamber pressure measurements and CO₂ quench system connections was not flight hardware.

The motors were essentially identical units except for variations in treatment during manufacture, such as prolonged vacuum conditioning, ethylene trioxide treatment, and sterilization. The difference in treatment is outlined in Table 2 along with variations in testing environment and nozzle modifications for each unit. The motor tested in run T3-41-09 had a flight type igniter support tube which is filled with potting compound. Therefore, no chamber pressure measurements were obtained for this firing.

4.2 IGNITION CAPABILITY

All motors ignited successfully at pressure altitudes above 100, 000 ft. The ignition lag time, defined as the time interval between the application of current to the igniter squibs and the first perceptible rise in thrust varied from 3 to 18 millisec, the average value being approximately 8 millisec (Table 3). A reproduction of a portion of the high-speed, oscillograph-type analog data showing thrust and chamber pressure build-up characteristics for a typical firing are presented in Fig. 5. The natural frequency of the thrust stand used for this test was approximately 40 cps.

4.3 VACUUM PERFORMANCE

4.3.1 Thrust and Impulse

Total impulse corrected to vacuum conditions for the seven successful firings varied from 52, 329 to 52, 736 lbf-sec. Total impulse as presented in this report is the average of 4 independent channels of thrust integral data. The vacuum correction based on prefire nozzle exit area is approximately 0.3 percent of the total measured values. The average total impulse, corrected to vacuum conditions, for seven firings was 52, 595 lbfsec. Propellant weights for the motors tested varied from 190.03 lb to 191. 26 lb (Table 4); this variation accounts in part for the difference in delivered total impulse.

Total impulse at vacuum conditions as a function of total propellant weight is shown in Fig. 7 for the seven successful firings. Also shown is the predicted variation of total impulse as a function of propellant weight based on the average specific impulse for seven firings. It is noted that all data fall within ± 0.25 percent of the predicted values based on the average specific impulse for the seven firings.

• Specific impulse for each motor is based on the average of the 4 channels of total impulse corrected to vacuum conditions. Specific impulse based on the manufacturer's stated propellant weight for the seven successful firings varied from 275.1 to 276.0 lbf-sec/lbm. The average value for the seven motors was 275.4 lbf-sec/lbm.

Specific impulse based on the pre- and post-firing weight difference is presented in Table 3 for comparison with values obtained using the stated propellant weights. The pre-firing weights used were supplied by HPC and are believed to be accurate within ± 0.01 lb. The post-firing weights were measured at AEDC and are believed to be accurate to ± 0.012 lb. Specific impulse calculated on this basis varied from 269.5 to 271.1. The average specific impulse for the seven successful firings was 270.4.

4.3.2 Thrust Coefficient

Average thrust coefficients for total propellant burning time were calculated for each motor by the following method

$$C_{f} = \frac{I_{v}}{A_{throat} \int_{0}^{t_{B}} P_{chamber} dt}$$

where

۲

Iv = Vacuum corrected total impulse

A_{throat} = Average of pre-firing and post-firing throat areas

 $\int_{P_{chamber}}^{P} dt = Integral of chamber pressure with respect to time for total burning time.$

The thrust coefficients calculated by this method varied from 1.82 to 1.86; an average value of 1.84 was obtained for the six firings. When an area ratio of 19:1 and a ratio of specific heats of 1.17 is assumed, the theoretical thrust coefficient for this nozzle would be 1.81.

4.3.3 Repeatability of Performance

Total and specific impulse were the performance parameters which were obtained with the greatest precision for these motors. Total impulse was obtained by averaging four channels of thrust integral data and correcting this average to vacuum conditions. Standard Deviation of the four channels of thrust integral data varied from 0.024 to 0.093 percent (Table 5). This is an indication of the precision of instrumentation used.

Specific Impulse was calculated for each motor based on the vacuum corrected total impulse and the manufacturer's stated propellant weights. These weights were stated to be accurate to ± 0.01 lb or approximately ± 0.005 percent of the total propellant weight.

It was decided to base repeatability of performance on specific impulse rather than total impulse because of the variation in propellant weights of the motors. While the variation in performance due to difference in propellant weights is of interest, it can be predicted from specific impulse. It is therefore of primary importance to know what variation in specific impulse can be expected for a group of motors because this value reflects performance variations due to slight differences in propellant composition, nozzle area ratio, nozzle misalignment, etc.

Maximum deviation of specific impulse from the average of the seven firings was 0.22 percent which is within the estimated maximum deviation of the instrumentation used to obtain the impulse data. Standard deviation of specific impulse for seven firings was 0.11 percent (Table 5).

4.4 INERT COMPONENTS EVALUATION

As in Phase I testing, the motor case and case liner material appeared to be satisfactory. However, additional strengthening of the nozzle exit cone to prevent deterioration may be necessary.

Film sequences of three firings considered typical are presented in Fig. 8. Post firing photographs of all motors are presented in Fig. 9. As can be seen, extensive nozzle deterioration was experienced during the first four firings. During the fifth firing a 2-in. strip of reflective aluminum tape was placed on the nozzle exit cone. No improvement in nozzle condition was noted. After the fifth firing the 42-in. uncooled diffuser was removed and replaced with a 48-in. water-cooled diffuser. This was done to determine if nozzle deterioration was being caused by radiation from the diffuser walls. During the first firing using this diffuser, the chamber pressure adapter failed; however, the nozzle deterioration still occurred during this firing which verified the existence of a nozzle problem rather than a testing environment problem.

The last two units were fired with an aluminum stiffening ring incorporated on the nozzle exit cone (Fig. 1f) as explained in Apparatus Section. This ring worked well on the first attempt (Fig. 9g) even though it became partially unbonded. On the second trial it became completely unbonded from the nozzle during firing and extensive deterioration was again experienced (Fig. 9h). It is believed that this ring would be sufficient as a fix if a sufficiently strong bonding agent is used and provided the weight penalty involved is not prohibitive.

Nozzle deterioration of this type could result in difficulties in using these motors because of the possibility of intolerable thrust vectors resulting from unsymmetrical deterioration.

The loss of motor inert component weight was obtained by comparing the manufacturer's stated inert components weight with the measured post-firing weight. This was done for runs T3-41-03 through T3-41-07. Run T3-41-08 was not used because of failure which occurred. Runs T3-41-09 and T3-41-10 were not used because the post firing weights included the aluminum ring and insulating material used in the nozzle modification. For the five firings considered, the loss in inert components averaged 3.67 lb. This value includes the nozzle closure (0.22 lb) and the igniter (0.82 lb). The remainder of the loss was case liner, nozzle material, potting compound, etc.

4.5 TEST FAILURE (FIRING T3-41-08)

During motor firing T3-41-08, a failure of the phenolic igniter support tube occurred and resulted in loss of the motor forward closure (Fig. 6d).

The motor ignited normally, but approximately 0.8 sec after ignition both chamber pressure signals were lost (Fig. 6a). The motor continued to burn at a slightly reduced thrust level until approximately 6.5 sec, and at this time thrust began to decay gradually; burning ceased at 11.25 sec.

From inspection of the motor condition, chamber pressure and thrust data, and movie film, the following sequence of events was surmised.

Since both chamber pressure signals were in phase and were lost simultaneously, it is believed that the igniter support tube failed at the threaded portion (Fig. 1c) during or shortly after ignition causing loss of chamber pressure signals and leaving the pressure adapter supported only by the CO₂ quench line and the pressure transducer sensing lines. The hot gases expelled through the 3/8-in. -diam hole in the phenolic tube caused the erosion of the pressure adapter (Fig. 6b) and also burned the CO₂ and pressure transducer lines.

The hot gases were deflected by the thrust pylon and adapter and recirculated around the motor until the forward closure separated. At this time (6.5 sec) axial thrust began to decay until burning ceased at 11.25 sec.

5.0 SUMMARY OF RESULTS

Eight BE-3, solid-propellant rocket motors were fired at simulated altitude conditions in excess of 100,000 ft. The results of the test may be summarized as follows:

- 1. All motors were ignited successfully, the average ignition lag time being 8 millisec.
- 2. The average total impulse corrected to vacuum for seven successful firings was 52, 595 lbf-sec.
- 3. The average specific impulse for seven firings was 275.4 lbfsec/lbm based on the manufacturer's stated propellant weight.

...

- 4. Repeatability of motor performance based on specific impulse using one sigma standard deviation was ±0.11 percent.
- 5. Extensive nozzle exit cone deterioration was experienced during the first six firings. For the seventh and eighth firings, an aluminum stiffening ring was bonded on the nozzle exit cone to prevent deterioration. This ring prevented the nozzle exit cone deterioration on the seventh firing and presumably would have worked on the eighth firing if it had remained bonded to the nozzle.
- 6. During one firing the motor forward closure burned through because of the failure of the igniter support tube at the forward end. This tube is used as a chamber pressure sensing line and a support for the chamber pressure adapter during static firings. For flight application the tube is used only as a conduit for ignition leads and is filled with potting compound.

REFERENCES

- Cannell, A. L. and Nokes, C. F., Jr. "Altitude Testing of Hercules Powder Company BE-3 Rocket Motors (Phase I)." AEDC-TDR-62-8, January 1962. (Confidential)
- 2. <u>Test Facilities Handbook (3rd Edition)</u>. "Rocket Test Facility, Vol. 2." Arnold Engineering Development Center, January 1961.

11

<u>ą.</u>

Estimated System Deviation at Operating Level	±1.00% ±0.25%	±3.00% ±1.00%	±5.00% ±2.00%	±3.00%	±0. 005%	±0.08%
Calibration Method	Dead Weight	Electrical	Electrical	Electrical	Dead Weight	:
Recording Method	Magnetic Tape	= =	= =	Null Balance Potentiometer	Visual	=
Range of Sensing Instrument	10, 000 lb	750 psia	1 psid	I- C (0-150°F)	Not Known	0 - 20 Ib
Units	lbf lbf-sec	psia-sec	psia-sec	년 o	lbm	lbm
Parameter	Axial Thrust Total Impulse	Chamber Pressure Integral	Cell Pressure Integral	Cell Temperature	Manufacturer's Stated Pre- Firing Motor Weight	Post-Firing Motor Weight

TABLE 1 INSTRUMENTATION

•

e. 0 13

AEDC-TDR-62-63

-

		-						
Parameter	T3-41-03 S/N 37	T3-41-04 S/N38	T3-41-05 S/N 39	T3-41-06 S/N 42	T3-41-07 S/N40	T3-41-08 S/N41	T3-41-09 S/N45	T3-41-10 S/N43
HPC Treatment	(2)	(2)	(2)	(3) and (4)	(1)	(1)	(3) and (4)	(3) and (4)
Temperature Conditioning at AEDC	*	*	*	*	*	*	*	*
Average Cell Pressure during Firing, psia	. 1313	. 1246	. 1225	. 1205	. 1310	. 3009	. 1098	. 1088
Type of Diffuser Installation	42 in. Uncooled	48 in. H2O Cooled	48 in. H2O Cooled	48 in. H2O Cooled				
Nozzle Shielding or Modification	None	None	None	None	2 in. Width Aluminum Reflective Tape	None	Aluminum Ring Stiffener	Aluminum Ring Stiffener

TABLE 2

MOTOR AND TEST ENVIRONMENT VARIATIONS

٩

No special treatment
 72 hr at vacuum
 Ethylene trioxide treatment
 Sterilize entire assembly
 * 72 hr at 70° ± 1°F

•

•

•

.

.

0

AEDC-TDR-62-63

...]

TABLE 3

MOTOR PERFORMANCE TABLE

		1						
Parameter	T3-41-03 S/N 37	T3-41-04 S/N 38	T3-41-05 S/N 39	T3-41-08 8/N 42	T3-41-07 S/N 40	T3-41-08 S/N 41	T3-41-09 S/N 45	T3-41-10 S/N 43
Total Mater								
Burning Time. sec	9.897	9,869	10.075	10.120	9.882	11,250	9.794	10.005
gnition Lag Time, sec	0, 007	0.003	0.018	0.005	0.005	0.010	0.012	0,005
Managered Impulse lb-sec								50 478
Sva. 1	52, 502	52, 537	52, 565	52, 640	52, 459	45, 121	52,220	52 485
Sva. 2	52, 482	52, 491	52, 540	52,617	52, 464	45, 190	55,113	52 434
Sve. 3	52, 451	52, 451	52, 472	52, 528	52,435	45,077	52 255	52,438
Sva. 4	52, 462	52, 482	52, 489	52, 577	52,454	40,121	52 204	52, 446
Average	52, 474	52, 490	52, 517	52, 591	52,453	40,161		
Chamber Pressure					i			
Integral, psia-sec				4940	4994		Not	4303
Sys. 1	4371	4304	4387	4426	4382		Measured	4310
Sys. 2	4442	4368	4401	4987	4353			4307
Average	4407	4336	4469	4001	1000			
tB Bahambar X dt X Athront.	28,835	28, 331	28, 888	28, 779	28, 599	-	Not	28 238
o lbf-sec							Measured	
Integral, DEIA-BCC					1	_	1 071	1.104
Sys. 1	1.30	1.21	1.23	1.21	1.29		1.080	1.075
Svs. 2	1.30	1,25	1.24	1.23	1.30	· ·	1.076	1,0895
Average	1.30	1.23	1,235	1.22	1.295			
tB C Beell x dt x Aerit							125 0	127.1
o lbr-sec	152.5	143.9	144.8	144.6	152.0		125.0	
I (Vacuum Corrected	<u> </u>						59 390	52 573
Total Impulse), lbf-sec	52, 626	52, 634	52, 662	52,736	52, 605		52, 525	
Specific Impulse,								
lbf-sec/lbm				1	1			
(1) Manufacturer's		975 9	275 3	276.0	275.1		275.4	275.6
Propellant Weight	275.5	215.2	210.5	2,0,0				270 3
(2) Measured Weight Difference	271.1	270.3	269, 9	269.5	270.6	-	271.4	210. 5
Iv	1 825	1,858	1.823	1,832	1.839		-	1.862
Pchamber x dt x Athroat	1, 625							1
	1	1						

15

Ť

٠

TABLE 4 PHYSICAL DATA TABLE

4

•

Parameter	T3-41-03 S/N 37	T3-41-04 S/N 38	T3-41-05 S/N 39	T3-41-06 S/N 42	T3-41-07 S/N 40	T3-41-08 S/N 41	T3-41-09 S/N 45	T3-41-10 S/N 43
Pre-Firing Weight (HPC)	213.90	214. 74	214. 19	214.70	213.90	213.75	212.97	214. 37
Post-Firing Weight (AEDC)	19.77	20.02	19.08	19.08	19, 34		20.15	19, 87
Manufacturer's Stated Inert Components Weight	22.862	23, 504	22, 934	23.640	22.701	22. 903	22.937	23. 598
Propellant Weight (1) HPC (Manufacturer) (2) Measured Weight Dif-	191.04	191. 24	191.26	191.06	191, 20	190. 84	190. 03	190. 78
ference Based on Pre- and Post-Fire Weights	194.13	194.72	195.11	195. 62	194.56		192.81	194.50
Mass Fraction								
(1) Based on Manufacturer's Stated Weights	0. 893	0. 891	0.893	0. 890	0, 895	0. 892	0, 892	0, 890
(2) Based on Weight Difference	0,908	0.907	0.911	0.911	0, 910		0.905	0, 907
Throat Area						e 200	6 290	6 290
(1) Pre-Fire	6.290	6,290	6.290	6.290	6.290	0.290	6.200 6.033	6.824
(2) Post-Fire	6.796	6.777	6,770	6.830	6,650	8 582	6 612	6,557
Average	6,543	6.534	6, 530	0.500	8.57	8.29	10.22	8, 49
Percent Change	8.04	1. (1	1,03	0. 40	0,01			
Svit Plane Area								
(1) Pre-Fire	117.302	117.014	117, 263	118.553	117.398	117, 321	117.129	115.688
(2) Post-Fire	•	+	+	*	*	•	115.352	
Average	•	*	•	*	*	•	116.241	
Pre-Firing Area Ratio	18, 649	18,603	18.643	18. 848	18.664	18.652	18. 621	18.551

*Not Available

16

.

	T3-41-03 S/N 37	T3-41-04 S/N 38	T3-41-05 S/N 39	T3-41-06 S/N 42	T3-41-07 S/N 40	T3-41-08 S/N 41	T3-41-09 S/N 45	T3-41-10 S/N 43
Measured Impulse, lbf-sec (1) (2)	52, 502 52, 482	52, 537 52, 491	52, 565 52, 540	52, 640 52, 617	52, 459 52, 464	45, 121 45, 190	52, 220 52, 173	52, 426 52, 485
(3) (4) Average	52, 451 52, 462 52, 474	52, 451 52, 482 52, 490	52, 472 52, 489 52, 517	52, 528 52, 577 52, 591	52, 435 52, 454 52, 453	45, 077 45, 121 45, 127	52, 169 52, 255 52, 204	52, 434 52, 438 52, 446
Standard Deviation, from Mean, of 4 Channels lib-sec percent	±1.71 1.0414	±35.57 ± 0678	±43.39 ± .0826	±49.10 ± .0934	±12.69 ± .0242	±46.69 ± .1035	1 41.00 ± 0785	±26.64 ± .0508
Specific Impulse Based on Average Total Impulse Corrected to Vacuum lbr-sec/lbm	275.5	275.2	275.3	276.0	275. 1	Not Applicable	275.4	275. 6
Average Specific Impulse = 27 Standard Deviation between F Secific Impulse Values Relative Standard Deviation.	75.4 lbf-sec/ irings Based = <u>-30 x 100</u>	$\frac{11}{10}$	1) ² + (. 2) ² + (.	. 1) ² + (. 6) ² +	+(. 3) 2 + (0) 2 +	(. 2) ² = ±. 30	lbrn 1brn	

TABLE 5 Performance repeatability

17

AEDC-TDR-62-63



4



AEDC-TDR-62-63

17.8

AEDC-TDR-62-63 0.020 in.-0.040 in. AREA 8-8 APPROXIMATELY EXIT PLANE OF NOZZLE CULTURE IN CREASE IN THICKNESS FOR PHASE UTITITI PHASE I NOZZLE WALL PROFILE b. Nozzle Wall Profile Fig. 1 Continued II NOZZLE ALL DAY 20

•



.



21

AEDC-TDR-62-63

Θ

....



d. Photograph of Motor Assembly



e. Photograph of Nozzle Exit Region Fig. 1 Continued



С

f. Nozzle Modification (Runs T3-41-09 and T3-41-10)

Fig. 1 Concluded





3 +

.

*







Fig. 3 Concluded

AEDC-TDR-62-63





.



Fig. 5 Typical Thrust and Chamber Pressure Buildup Characteristics

.

.

28



Fig. 6 Firing T3-41-08 (Motor Failure)

£4





b. Damaged Chamber Pressure Adapter

Fig. 6 Continued



c. Overall Photo of Motor and Cell



d. Front End Detail Fig. 6 Concluded



-

۲

Fig. 7 Vacuum Total Impulse vs Propellant Weight



1 (Ignition)



4 (5.0 sec)



2 (0.8 sec)



5 (6.8 sec)



3 (2.1 sec)



Ð

a. Run Number T3-41-04 Fig. 8 Film Sequences of Firings

33



l (Ignition)

4 (5.0sec)



2 (1.0 sec)

5 (7.0 sec)



These times are approximate

10



6 (9.0sec)

b. Run Number T3-41-07 Fig. 8 Continued







4 (7.6 sec)



2 (0.6 sec)



5 (Burnout)



3 (3.8 sec)

c. Run Number T3-41-09 Fig. 8 Concluded



a. Run T3-41-03; Motor 5/N 37 Fig. 9 Post-Firing Inspection Photos of Motors



b. Run T3-41-04; Motor S/N 38 Fig. 9 Continued



1 2 1

c. Run T3-41-05; Motor S/N 39 Fig. 9 Continued

38

de-



d. Run T3-41-06; Motor S/N 42 Fig. 9 Continued

39

.



e. Run T3-41-07; Motor S/N 40 Fig. 9 Continued



f. Run T3-41-08; Motor S/N 41 Fig. 9 Continued



ŧ

g. Run T3-41-09; Motor S/N 45 Fig. 9 Continued





h. Run T3-41-10; Motor S/N 43 Fig. 9 Concluded



 Rocket motors Tests Rocket motor nozzles Rocket motor nozzles Rocket propulsion Ignition Reprised from Area 921E, Project 9042 Aros Project 9042 Contract AF 40(600)-800 S/A 24(61-73) Contract AF 40(600)-800 N. Contract AF 40(500)-800 N. Contract AF 40(500)-800 N. STA 24(61-73) N. Contract AF 40(500)-800 N. STIA 20(500)-800 N. STIA collection 	
Arresid Engineering Development Center Arresid Engineering Development Center Arresid Air Pores Baltin Random Air Pores Baltin Frank (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1014 - J. 1014 (1996), 10 p. 1001 2 refs., 1001 2 refs., 1001 (1996), 10 p. 1001 2 refs., 1014 (1996), 10 p. 1001 2 refs., 1001 2 refs., 1014 (1996), 1001 2 refs.,	mentor, and repeatability of performance based on specific copular way determined. During any frame, the meter forgeties the entropied character burning as a result of fathere of the picture support take. Countérendies marie determination that entropert take. Countérendies marie determination that region of the still picture detail subpression to the still picture of the mark pression to the consis- tent term, was send on the take throug through the counte- station and was picture.
 Berkiet matters Tunis Tunis Tunis Berkint metter muties Berkint propolation Berkint metter Berkint metter Berkint metter Berkint Berkint metter Berkint Berkint APSC Program Area With Termina APSC Program Area With Dependent APSC Program Area AP	
Armold Engineering Development Center Armold Air Purses Station, Teuturene Res. Nat. Artic. 7108-01-0. ALLITIVOR TESTING OF BRANCILLS FOUNDER COMPARY IN: 2 ROUTER PENDER J. OLIALIZATION AND ACCENTRATE FORMATION Phase II OLIALIZATION AND ACCENTRATE TESTING (The State of the Least Links, 1604-000 Phase II OLIALIZATION AND ALLIAL FORMATION April 1801, 30 p. 1041 Z. Teña, 1604-000 Phase II OLIALIZATION AND ALLIAL FORMATION April 1801, 30 p. 1041 Z. Teña, 1604-000 Experimental Antonia Compary. BE: 3, 4014-proving land research and the approximation of the International Found for the approximation of the International Found to the approximation of the Interna- tion (600 ft as partit of an Application of the Interna- tion and the errorum relation of the Interna- tion evaluation for evaluation the errorum relation were from nuc- components of the Internation of the Interna- tion evaluation for evaluation the errorum relation were from nuc- evaluation. After motions and applications were from the evaluation that Impolate was obtained for each resented by Vacuum time Linpolate was obtained for each	motion, and repeatability of performance haved an specific reputate was determined. During one furing, the motion forward stimute homological through an extent of the printer equipment likes. Considerable much of the printer equipment factoring prevailant in the regime of the axid plane. A maniful modification, con- entiating of an alterning prevailant the modification, con- entiating of an alterning thermaphen the mode and one successful for the auto furing thermap which the rung stoped in place.

ł	1. Rocket were 2. Tests 3. Rocket were 4. Determine 6. Igniton 7. Spectration 1. APC Propriet 1. APC 1. APC	
	Arrold Engineering Development Center Arrold Air Porces Matter, Transactor Ret. No. AEDC 1700 (22) 33. ALTITUDE TRETING OF BEROVILES FOOTBERL COMPANY THE J MONCET MATTODS (FEROVILES FOOTBERL COMPANY THE J MONCET MATTODS (FEROVILES FOOTBERL COMPANY THE J MONCET MATTODS (FEROVILES FOOTBERL COMPANY, THE J MONCET MATTODS (FEROVILES FOOTBERL COMPANY, THE J MONCET MATTODS (FEROVILE) TRETING FOR A STRUCTURE AND A MATTODS (FEROVILE) TRETING A STRUCTURE AND A MATTODS (FEROVILE) TRETING A STRUCTURE AND A MATTODS (FEROVILE) TRETING A STRUCTURE AND A MATTOD (C. 600 It as part of an assessment and annular pre- ter the formation of the Matter Andrea and a (R. 600 It as part of an assessment and annular pre- ter and the second and the Matter Andrea and Annu- tion of the matter and a structure way detained for weak and annual pre- ter and the second and annular preference and the second and the second and the lastra- teredulity. Vermine and annular preference and the second and an annual second and a second and and a second and an annual second and annular preference and and a second and an annual second and an annual second and an and a second annual second and an annual second and and an annual second and annual second and an annual second and an annual second and annual second and an annual second and an annual second and annual second and an annual second and an and a second and annual second and annual second and and annual second and annual second and annual second and and annual second and an annual second and annual second and and annual second and an annual second and an annual second and and annual second and an annual second and an annual second and and annual second and an annual second and annual second and and annual second and annual second and annual second and and annual second and annual second and annual second and annual second and an annual second and annual second and annual second and an annual second and annual second and annual second and an annual second and annual second annual second and annual seco	entric, and repeatability of performance based on specific impulse was determined. During cas furing, the nation for entries exponent table. Considerable among a fractance of the quilter exponent table. Considerable among a service table semimined during previous natural was prevealent in the regulation, can stating of the and plane. A survey and the neutric end over seas used on two furings to attemption the result during in plane.
	 Restort matter Transa Partial Restriction matter master Restriction matter master Restriction matter <l< th=""><th></th></l<>	
	Areald Displacering Development Center Areald Air Porces Batton, Transace Areald Air Dores Batton, Transace Min. No. AIRC-TON-90-61. ALTITUDE TESTING OF MERCILLES PORTORY COMPARE IN: J MARCH (1984, U.D.). and Arconformer Testing (10) (Arial 1984, U.D.). and Arconformer Testing (10) (Arial 1984, U.D.). and Arconformer Testing (10) (Arial 1984, U.D.). area Arconformer Testing (10) (Arial 1984, U.D.). area Arconformer Testing (10) (Arial 1984, U.D.). area architecture (10) (Arial 1984, U.D.). area area area area area are present motors do algorit for any lighting are array of the formation transmission of the formation area of the formation area area are area are area are for the binder for area area area are are are area to the area of an area area area are are area to the area area area are are area are area are area to the area area area are are area are area are area to the area area area are are area are area are area to the area area area are area are area are area to the area area are are are area are area are area to the area area area are area are area are are	mind, and researching of performance human in spirific topular wave determined. Dering and hitting, the noture forward shower human intervals a strendt of different printer support take. Considerable isotoche determination take mocoulered aurung prevalues total possible to the mortle statistic of an aluminant stiffscing for direnging in the mortle statistic are sourcessful for the one firstly during which the result determine the first first are firstly during which the result state sourcessful for the one firstly during which the result determine the place.



.

1

•

 Rocket motors Tests Rocket motor nozzles Deterioration Rocket propulsion Rocket propulsion Rotting Specific impacts AFSC Programmers AFSC Programers AFSC Programers AFSC Programmer	
Areald Englancing Development Center Areald All Process Basin, Tomasa Rencill, All Process Basin, Tomasa Rencill, R. AEGC-TDR. 63-63. ALTITUDE TERTING OF HERECUL, R. POCC-TDR. 63-63. ALTITUDE TERTING OF HERECUL, R. AEGC-TDR. 63-63. ALTITUDE TERTING OF ALL OPENING CONTRACT IN. A MORE (Phase II - Qualification and Accordance Merican Orbane II - Qualification and Accordance Merican Development II Qualification ID. <i>Programmy</i> - Combony, EU-3. ability properties the transfer temport cargonics of the Hauger service of hysics creation are temport cargonics of the Hauger service of hysics creation are temport cargonics of the Hauger service of hysics creation are temport cargonics of the Hauger service of hysics creation are temport cargonics of the Hauger service of hysics creation are temport cargonics of the Hauger service of hysics creations in distribution residenticity and moletic perform- source and the arcticut. Forum anterne area fixed ante- composite of the methods was dataland for each composite of the methods was dataland for each	motion, and requestability of performance based on specific implates was determined. During new Lingur, the motion forwards information lumining in a rescaled of fadious of the guittee appoint table. Consider marks marked and allow encountereed during prevenue teach during the preventant in the region of the exit form. A moral model to the marks and the administry for the cost firing during shirth the rug depend in place.
 Rocket motors Rocket motor nozzles Rocket motor nozzles Bocket motor nozzles Rocket propulsion Rocket propulsin Rocket procket propulsion Rocket	
Arnold Engineering Development Center Arnold Air Force Station, Temessee Ru. No. AEDC-TDR-82-63. ALTITUDE FRULES POWDER COMPANY BE-3 KOTT HONE (Phase IP ² - Qualification and Acceptance (Phase IP ² - Qualification as a retro-rocket proprietary-tenter (Phase IP ² - Qualification as a retro-rocket for the lunar impact capsule of the Ranger series of space- craft were tested at pressure altitudes in access of 100,000 ft an acceptance and qualification pro- gram to determine ignition reliability and motor perform- ance and to evaluate the erosion resistance of the inert construity. Vacuum total impulse was obtained for each	motor, and repeatability of performance based on specific impulse was determined. During one firing, the motor forward closure burned through as a result of failure of the igniter support tube. Considerable nozzle deterioration (also encountered during previous tests) was prevalent in the region of the exf plane. A nozzle molification, con- sisting of an aluminum stiffening ring bonded to the nozzle and was successful for the one firing during which the ring stayed in place.

40----

•

3

i

t

,

 Monitor material Tests Tests Te	
Armeld Equivaring Development Context Armeld Algorithm Transmess For So. ALTC: TDR. 21. ALLYTTUDE TRETTING OF FORMEDLES FORMER COMPARING RECENTING (TRANSLIES FORMER) REC	multity, and representing of performance based on spendific transition was determined. To performance based on spendific transmission and the set of the set of the species of the guitar support take. Considerable mouth deterformation (also communicated during previous mails) was prevalent in the terragion of the set photo. A nuesda multification, que- taining of an abmenium attribution to a structure state attribution of the number of the number attribution of the terma during relation the number attributed in place.
 Recker matore treat nour master forter nour master betrierentim Detrierentim 	
Arnold Extineering Invelopment Cert Arnold Extineering Invelopment Cert Arnold All Force Station, Tennessee Arnold All Force Station, Tennessee EERCULATS POWDER COMPANY BE-3 ROCCOT MOTOR Phase II - Qualification and Acceptance Transfer Proprietation Acceptance T	moture, and representation of performance based on appeciate inputse was determined. Density one former, the motion forward closence burning through as a result of failure of the galaxies are considered for any previous twore) was prevention the region of the sent plane. A merida molification, non- stating of an simulation for the sent forming buring which the sent set ones, was seed in two forming through the former should be plane.

Surgery and

1

ι

UNCLASSIFIED

UNCLASSIFIED