UNCLASSIFIED

AD NUMBER
AD326784
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1961. Other requests shall be referred to Naval Ordnance Test Station, China Lake, CA.
AUTHORITY
30 Nov 1973 per Group-4, DoDD 5200.10 document marking; USNWC ltr, 2 Jun 1975

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AD 326 784

NAVWEPS REPORT 7745
NOTS TP 2712
COPY 45

SIDEWINDER 1C PROPULSION SYSTEM (MARK 24 MOD 0) QUALIFICATION PROGRAM AND EXPERIMENTAL TEST RESULTS

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ABSTRACT. Qualification evaluation of the Sidewinder 1C propulsion system, designated as the Mk 24 Mod 0, is detailed in this report. Included are the various treatments to which the rounds were subjected and the resultant internal ballistic characteristics obtained during static-testing. The results define the operational limits of the Sidewinder 1C propulsion system. (UNCLASSIFIED)

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U.S. NAVAL ORDNANCE TEST STATION
China Lake, California
November 1961

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FOREWORD

Qualification evaluation of the Sidewinder 1C propulsion system (Mk 24 Mod 0) was completed during December 1960. Ninety-six rounds were consumed in the course of these studies. Results obtained define performance limits before and after subjecting the rounds to simulated fleet handling conditions.

This study was conducted on BuWeps Task Assignment NO 520-236-63052-01060. This report is transmitted for information purposes only and is subject to revision and change as later data become available.

Released by
R. P. LUCAS, Head,
Propulsion Systems Div.
19 June 1961

Under authority of
J. T. BARTLING, Head,
Propulsion Development Dept.

NOTS Technical Publication 2712
NAVWEPS Report 7745

Published by . . . . Publishing Division
Technical Information Department
Collation . . . . Cover, 15 leaves, abstract cards
First printing . . . . 140 numbered copies
Security classification . . . . CONFIDENTIAL
Abstract alone . . . . UNCLASSIFIED
Title alone . . . . UNCLASSIFIED

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ACKNOWLEDGMENT

The authors acknowledge the assistance of I. S. Kurotori of the Test and Evaluation Division, Propulsion Development Department, for the statistical analyses conducted on various phases of the qualification program.

INTRODUCTION

During October, November, and December 1960, the Sidewinder 1C propulsion system (Mk 24 Mod 0) was subjected to qualification testing. A detailed statistical program was designed to evaluate the effect that various treatments, simulating Fleet service conditions, have on motor performance. Ninety-six rounds were consumed in the course of this intensive investigation to determine operation limitations.

The propulsion system consists of a booster and a sustainer motor in tandem contained in a single 5.0-inch steel tube. The two motors are separated by a bulkhead and seal plate to prevent the hot booster exhaust gases from prematurely igniting the sustainer propellant grain. At sustainer ignition, the seal plate shears a thin ring and moves aft to allow sustainer gases to exhaust through the expended booster chamber and nozzle.

The booster propellant grain is an internal-burning, five-point-star configuration extruded from standard X-12 sheet stock. The sustainer utilizes the same general geometry but is formed from standard X-14 propellant. Both motors are ignited by tubular-shaped igniters containing boron—potassium nitrate pellets. Hot igniter gases and burning particles are discharged through radial holes drilled through the igniter tube to initiate motor operation.

The operating sequence consists of (1) the booster firing for about 1.5 seconds, (2) a time lag of 1.0 second, and (3) sustainer operation for 1.5 seconds. The round develops a total impulse of about 11,227 lb-sec during the 3.0-second operating period.

Component arrangement is reproduced in Fig. 1. Thrust—time records from the booster and sustainer motors are shown in Fig. 2 and 3, respectively. A round that is ready for range-testing is shown in Fig. 4.

EXPERIMENTAL TESTS AND RESULTS

STATISTICAL TESTS

Purpose. This study was performed to obtain reference ballistics to determine the effect of various sequential treatments on motor characteristics.

Procedure. Eighteen rounds were loaded in flight hardware using standard loading techniques. All propellant grains were X-rayed, dimensionally inspected, and approved before loading.

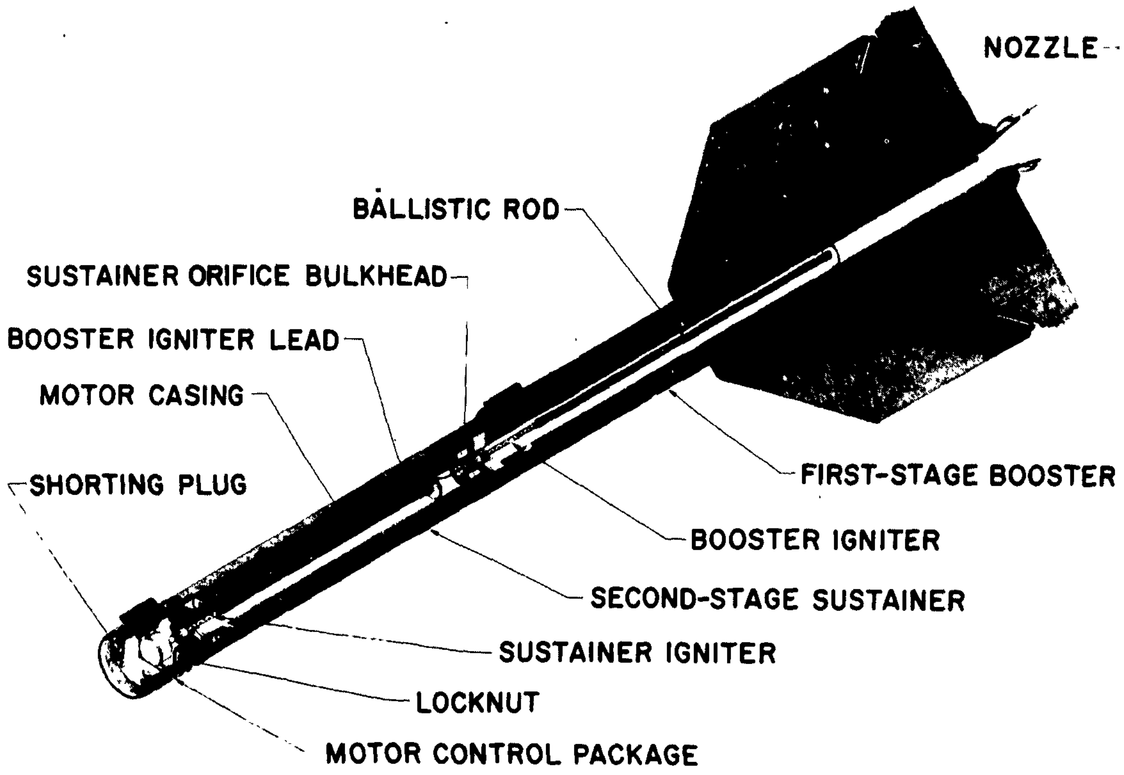

FIG. 1. Sidewinder 1C Rocket Motor Mk 24 Mod 0.

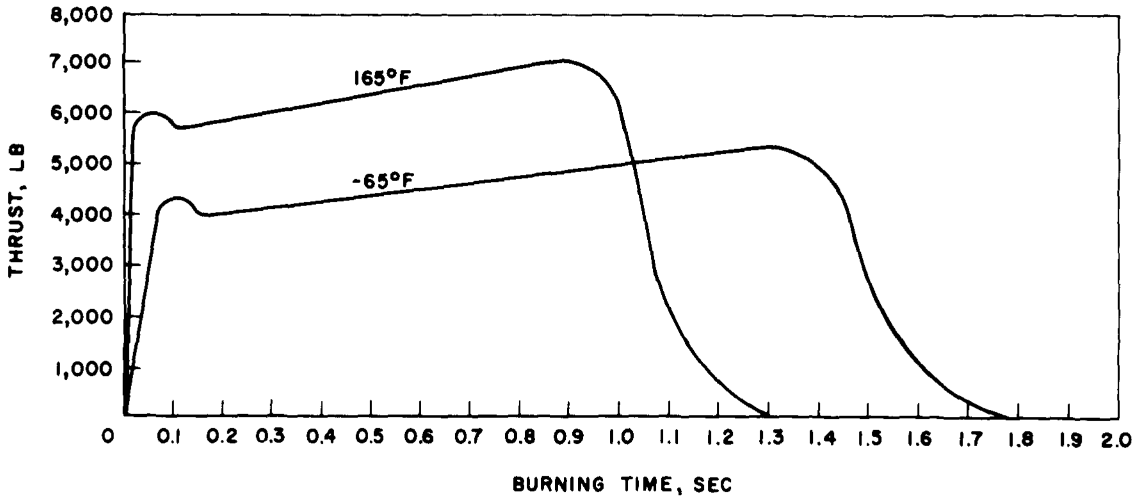

FIG. 2. Thrust–Time Record of a Sidewinder 1C Booster Motor.

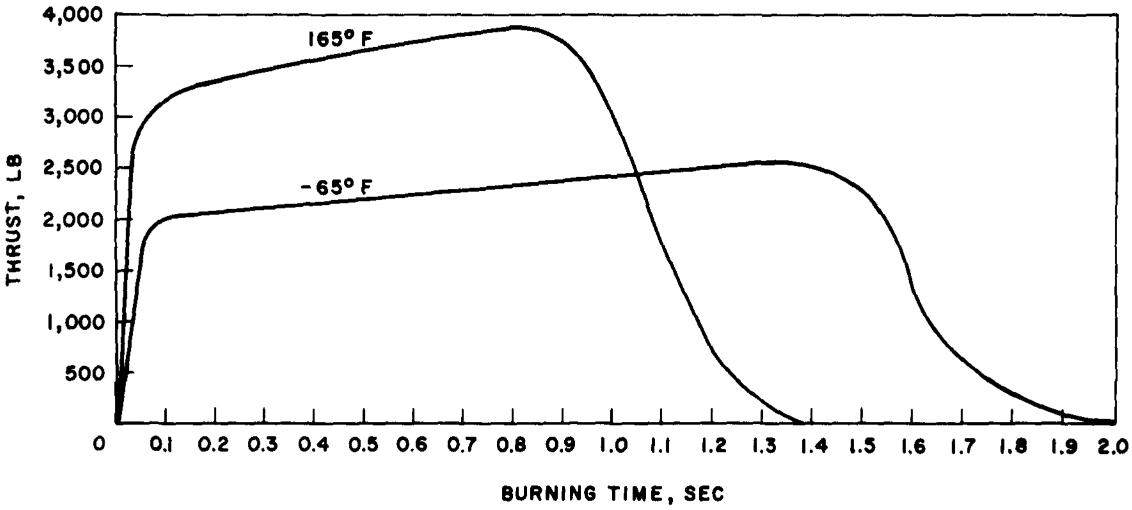

FIG. 3. Thrust–Time Record of a Sidewinder 1C Sustainer Motor.

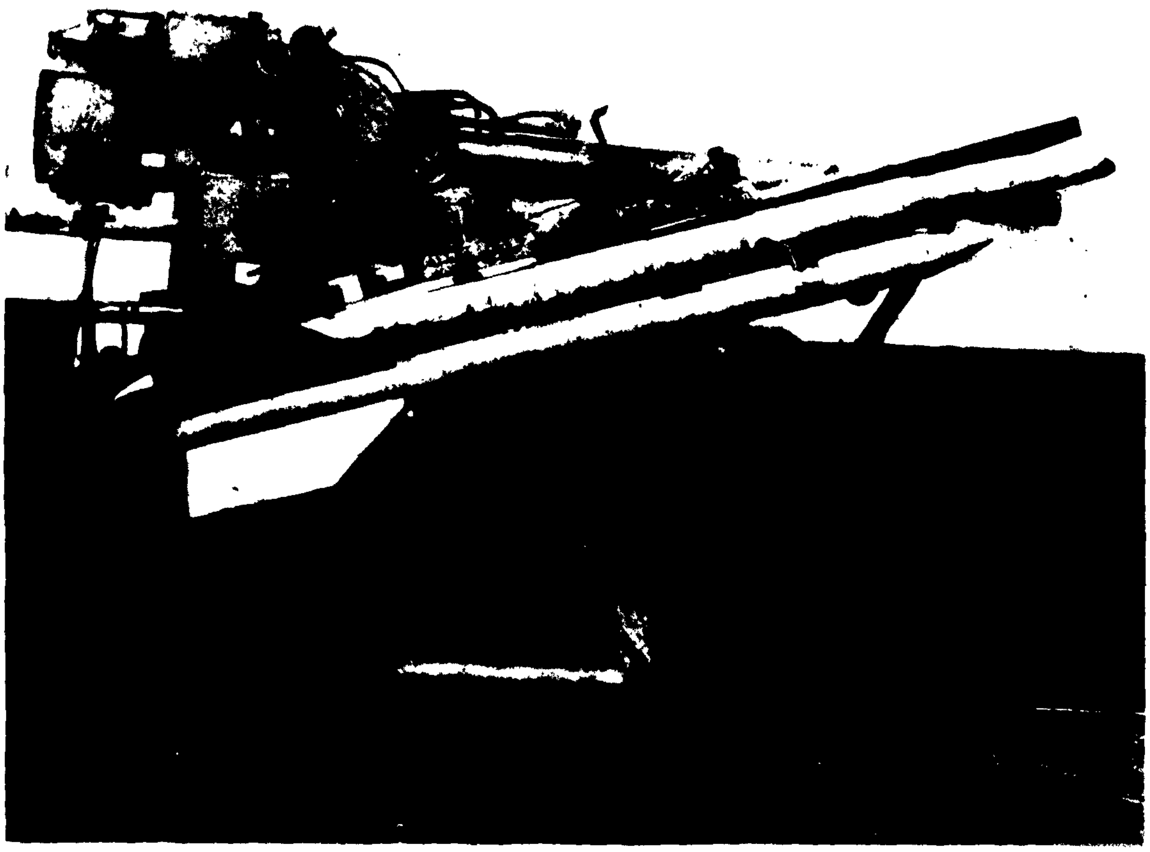

FIG. 4. Sidewinder 1C Ready for Range Testing.

Continuity measurements were made on both igniters and the igniter control unit to ensure successful operation of the electrical system. A jumper was required to bypass the inertia switch for static-testing. Eighteen rounds were conditioned for 8 hours; six each at 165, 70, and −65°F.

Motor performance was measured as thrust–time histories because pressure taps are not available when flight hardware is loaded with igniter control units. A consolidated oscillograph operated at a chart speed of 8 in/sec recorded motor performance.

Results. All 18 motors evaluated in this phase fired successfully. Post-firing inspection of the spent rounds indicated that neither tube bulges nor hot spots developed during motor firing.

The propulsion system delivered total average impulse values of 11,333, 11,227, and 10,967 lb-sec at temperatures of 165, 70, and −65°F, respectively. This represents an impulse variation of about 3.2% over the extreme temperature limits tested.

Confidence limits for motor performance characteristics and igniter control-unit operation obtained at 165, 70, and −65°F are shown in Appendix A. Three limits were placed on each performance characteristic. These represent 95% confidence limits on the mean, and limits for 95 and 99% of the population at the 95% confidence level.

Average motor performance characteristics and standard deviations obtained are summarized in Table 1. The average and standard deviation values calculated are based on a sample size of six rounds at each temperature investigated.

TABLE 1. AVERAGE AND STANDARD DEVIATION RESULTS OBTAINED FROM SIDEWINDER 1C STATIC EVALUATION

Parameter	Test temperature		
	165°F	70°F	-65°F
Booster			
Ignition delay, ms	14 ± 2	16 ± 3	35 ± 3
Thrust (early max.), lb	5,945 ± 144	5,058 ± 167	3,858 ± 87
Thrust (late max.), lb	7,525 ± 33	6,979 ± 53	5,730 ± 170
Impulse, lb-sec	6,984 ± 41	6,954 ± 51	6,792 ± 41
Burning time, sec[a]	1.192 ± 0.007	1.314 ± 0.010	1.586 ± 0.027
Sustainer			
Ignition delay, ms	23 ± 4	29 ± 1	38 ± 3
Thrust (early max.), lb	3,843 ± 421	3,418 ± 170	3,029 ± 303
Thrust (late max.), lb	5,258 ± 412	3,928 ± 233	3,093 ± 200
Impulse, lb-sec	4,349 ± 63	4,273 ± 27	4,175 ± 105
Burning time, sec[a]	1.124 ± 0.066	1.405 ± 0.083	1.689 ± 0.101
Total impulse, lb-sec	11,333	11,227	10,967

[a] Measured from 500 pounds initial thrust to 500 pounds final thrust.

These experimental results, from the limited number of statistical tests, indicate a reliability of at least 60.7% at a confidence level of 95% at the individual temperatures tested. However, by combining all statistical tests and assuming an equal chance of firing at any of the specified temperatures, the over-all reliability of a successful firing is at least 84.7% at the 95% confidence level. Statistically, the best estimate is the value found.

SEQUENTIAL I TREATMENT

Purpose. This phase was conducted to study the effect that various weathering and handling conditions, expected in service operations, have on motor performance characteristics.

Procedure. Twelve rounds were loaded to initiate the Sequential I phase. A second series of four rounds was loaded to conduct a concurrent study on performance of dropped rounds at low temperatures. The following treatments were investigated in the course of this study.

1. Humidity
2. Salt spray
3. Aircraft vibration
4. Aerodynamic heating
5. Two-foot drop
6. Static-firing

Sixteen motors were loaded in flight-weight hardware with previously inspected and accepted propellant grains. Twelve rounds received sequential treatment, and four rounds received all treatments in addition to the 2-foot drop at −65°F.

The experimental plan is detailed in Table 2 and was statistically analyzed as a full replicate of a $2^2 \times 3^1$ factorial program. Individual motor numbers are shown in order to visualize treatments to which each round was subjected.

Grains used in the course of this study were X-rayed, dimensionally inspected, and approved before loading. The booster–sustainer motor tubes were sonically inspected for liner unbondedness and pressure-tested for bulkhead seal leaks before using. All igniter control units and igniters were inspected for continuity and resistivity after loading to ensure successful operation of the electrical system. The rounds were subdivided as detailed in Table 2 to initiate the Sequential I program.

Humidity treatment consisted of 100% relative humidity at 120°F for 10 days. The motors were then subjected to 96 hours of salt-spray weathering conditions at 95°F. Two motors, no. 101 and 102, were subjected to additional salt spray for a total time of 168 hours.

The aircraft vibration test was conducted according to MIL-E-5272-C Procedure XII. In general, vibration was applied along three axes at −65°F. Total vibration time for each motor was 9 hours, and the vibratory range spanned 0 to 500 cps.

TABLE 2. EXPERIMENTAL PLAN OF THE SEQUENTIAL I PHASE OF THE SIDEWINDER 1C PROPULSION SYSTEM QUALIFICATION PROGRAM

Motor no.	Treatment		
	Humidity and salt spray	Aircraft vibration	Static-firing after temp.-conditioning, °F
19	no	yes	-65
20	no	yes	165
21	no	no	-65
22	yes	yes	aero-heat
23	yes	no	-65
24	yes	yes	-65
25	yes	yes	165
26	no	no	165
27	yes	no	165
28	no	yes	aero-heat
29	yes	no	aero-heat
30	no	no	aero-heat
101[a]	yes	yes	165
102[a,b]	yes	yes	-65
103[a,c]	yes	yes	165
104[a,d]	yes	yes	......

[a] Subjected also to a 2-foot drop test.

[b] Booster fired successfully; sustainer blew up after a 0.9-second burning time.

[c] Booster blew up immediately upon ignition.

[d] Sustainer grain fractured circumferentially during 2-foot drop, round not fired.

The dropped rounds were not part of the Sequential I study as detailed in Table 2. These rounds were dropped 2 feet from a horizontal position at -65°F.

Upon completion of the various treatments, the rounds were temperature-conditioned and fired.

Results. Eight rounds sequentially treated were successfully fired without an excessive shift of performance characteristics in relation to the reference ballistics. The remaining four rounds are presently being held in the ambient-temperature ovens for completion of the radiant heating facility to simulate aerodynamic heating conditions. (The results of these tests will be the subject of a future report.)

Blowups resulted from rounds statically fired after being dropped 2 feet from a horizontal position at -65°F. One booster motor blew up immediately upon ignition, and the other blowup occurred after the sustainer operated approximately 0.9 second.

Table 3 summarizes the average internal-ballistic results obtained in relation to the statistical reference values. These values represent

TABLE 3. PERFORMANCE OF SEQUENTIAL I TREATED ROUNDS IN COMPARISON TO THE STATISTICAL REFERENCE BALLISTICS

Parameter	Firing temp., -65°F		Firing temp., 165°F	
	Reference	Treated	Reference	Treated
Booster				
Ignition delay, ms	31.85–38.15	40[a]	11.90–16.10	21[a]
Thrust (early max.), lb	3,767–3,949	3,765[a]	5,794–6,096	6,063
Thrust (late max.), lb	5,552–5,908	5,809	7,490–7,560	7,559
Impulse, lb-sec	6,749–6,835	6,740[a]	6,941–7,027	7,004
Burning time, sec	1.558–1.614	1.587	1.185–1.199	1.193
Sustainer				
Ignition delay, ms	34.85–41.15	35	18.80–27.20	24
Thrust (early max.), lb	2,711–3,347	3,144	4,501–4,285	3,639[a]
Thrust (late max.), lb	2,883–3,303	2,958	4,826–5,690	4,947
Impulse, lb-sec	4,065–4,285	4,113	4,283–4,415	4,265[a]
Burning time, sec	1.583–1.795	1.671	1.055–1.193	1.147
Igniter-control unit				
Thermal relay delay, ms	0.379–0.539	0.472	0.243–0.287	0.306[a]
Voltage at delay break, v	6.680–7.520	6.900	7.480–8.320	7.400[a]
Squib switch delay, sec	2.054–2.312	2.167	1.708–1.842	1.756
Battery max. output, v	30.89–31.51	29.90[a]	31.18–32.02	31.40
Time to max., sec	0.655–0.741	0.828[a]	0.459–0.569	0.677[a]
Sustainer ignition, sec	2.492–2.794	2.641	1.988–2.095	2.063

[a] Values shifted outside reference limits.

limits calculated for 95% confidence level on the mean. Eleven values flanked the reference limits but the shift was not so excessive that the round could not perform its intended mission.

The effect that humidity and salt-spray environmental conditions have on total impulse delivered is of interest. The reference average total impulse was 11,091 lb-sec; whereas, after humidity and salt spray, the total average impulse delivered was 11,051 lb-sec. This represents a decrease of approximately 0.36%. Rounds removed from the salt-spray cabinet are shown in Fig. 5.

FIG. 5. Motors Subjected to the Salt-Spray Test.

Aircraft vibration had no significant effect on motor performance. Resistance measurements made on the igniter-control-unit subcomponents and motor igniters remained within acceptable limits. Resonance frequencies were not detected in motors subjected to vibratory accelerations through the range from 0 to 500 cps. The test-fixture arrangement for the vibration study is shown in Fig. 6.

FIG. 6. Arrangement of Fixtures for the Vibration Test.

Rounds subjected to the 2-foot drop from a horizontal position at −65°F produced the only motor blowups in the course of the study. Visual inspection of the dropped rounds showed that one sustainer grain was circumferentially fractured, and this round was not fired. The remaining three sustainer grains appeared undamaged after dropping. Two booster-igniter lead wires were severed and had to be replaced. (Booster grains were not inspected, as rounds previously dropped 4 feet at −65°F from a horizontal position were X-ray inspected and found to be undamaged.) Three rounds were fired after dropping. One round fired successfully at 165°F; the second blew up immediately upon booster-motor ignition as shown in Fig. 7. The third round was fired at −65°F and failed after the sustainer operated for 0.9 second (Fig. 8).

FIG. 7. Results of Booster-Motor Blowup Immediately After Ignition.

FIG. 8. Failure of Motor After 0.9-Second Sustainer Operation.

The results do not indicate a need to modify the present propulsion system design. The tests do dictate that any motors that are dropped either be discarded or returned to a loading facility for complete disassembly and inspection.

SEQUENTIAL II TREATMENT

Purpose. This study was conducted to investigate first- and second-order effects that various sequential treatments have on motor performance characteristics.

Procedure. Forty-eight motors were subjected to the following sequential treatments.

1. Accelerated aging
2. Temperature-cycling
3. Truck vibration
4. Static-firing

Forty-eight rounds were loaded in flight-weight hardware with accepted grains. The experimental plan is detailed in Table 4 and was statistically analyzed as a full replicate of a $3^1 \times 4^1 \times 2^2$ factorial program. Individual motor numbers are shown so that the treatment of each motor can be followed.

All propellant grains were X-rayed and dimensionally inspected before loading; and the motor tubes were sonically inspected and pressure-tested before loading. Continuity and resistance measurements were made on the igniters and control units after loading to ensure proper operation of the electrical system before sequential treatment. The rounds were randomly divided into three groups of 16 each to initiate the accelerated aging. All rounds were subjected to 30 days of accelerated aging; 16 rounds each at 95, 115, and 130°F.

Each of the subgroups was further divided, and half was subjected to temperature-cycling. This treatment consisted of subjecting the rounds to 4 hours at −65°F followed by 4 hours in the 165°F oven. The rounds were stored at −65°F, overnight, to eliminate or minimize the possibility of additional accelerated aging. Five cycles were required to complete the study.

The rounds were again divided, and half of the motors, in shipping containers, were subjected to truck vibration by transporting them 200 miles over secondary roads. An impactograph measured vibratory accelerations to which the rounds were subjected in the course of the study. This phase required approximately 10 hours to complete.

Forty-eight rounds were static-fired at four temperature conditions. The rounds were divided into lots of 12 and given the following treatments:

TABLE 4. EXPERIMENTAL PLAN FOR THE SEQUENTIAL II PHASE OF THE SIDEWINDER 1C PROPULSION SYSTEM QUALIFICATION PROGRAM

Motor no.	Treatment			
	Accelerated aging (30 days), °F	Temp.-cycling (5 cycles), −65 to 165°F	Truck vibration, 200 mi over secondary roads	Static-firing after temp.-conditioning, °F
31	130	yes	no	165
32	95	no	no	165
33	95	no	no	−65 to 165
34[a]	130	no	yes	165 to −65
35	130	yes	yes	165
36	95	yes	yes	165
37	115	yes	no	−65
38	95	no	yes	165 to −65
39	130	no	no	−65 to 165
40	115	yes	yes	−65
41	115	no	no	−65
42	115	yes	no	−65 to 165
43	130	no	yes	165
44[a]	130	no	no	−65
45	130	no	yes	−65
46	115	yes	yes	−65 to 165
47	95	yes	no	−65 to 165
48	95	yes	yes	165 to −65
49	130	yes	yes	−65 to 165
50	130	yes	no	−65
51	115	no	yes	−65 to 165
52	95	no	yes	165
53	130	yes	no	−65 to 165
54	95	no	yes	−65 to 165
55	115	no	no	−65 to 165
56	130	no	yes	−65 to 165
57	95	no	no	−65
58	95	no	no	165 to −65
59	130	yes	yes	−65
60	95	yes	no	165
61	115	no	no	165 to −65
62	115	yes	yes	165 to −65
63	115	yes	no	165
64	130	yes	no	165 to −65
65	115	no	yes	165 to −65
66	130	yes	yes	165 to −65
67	130	no	no	165 to −65
68	115	yes	yes	165
69	115	no	yes	−65
70	95	yes	yes	−65 to 165
71	95	yes	no	165 to −65
72	115	no	yes	165
73	130	no	no	165
74	115	no	no	165
75	95	yes	no	−65
76	95	yes	yes	−65
77	115	yes	no	165 to −65
78	95	no	yes	−65

[a] Igniter-control units failed to operate.

1. Temperature-conditioned at −65°F
2. Temperature-conditioned at 165°F
3. Thermally stressed from −65 to 165°F
4. Thermally stressed from 165 to −65°F

The rounds were then fired at −65, 165, 165, and −65°F, respectively. Straight temperatures required a minimum of 8 hours in the conditioning ovens. If thermally stressed, the rounds were initially conditioned for at least 8 hours, followed by 2 1/2 hours of conditioning at the other temperature extreme. Such conditioning ensured development of extreme thermal gradients across the web of the grains.

Results. Motor blowups were not encountered in the course of these studies. Two malperformances occurred when the igniter control units failed to operate. Both sustainer motors were successfully ignited by manually applying a firing pulse to the igniters. Post-firing inspection of the igniter control units indicated that the 2-second pyrotechnic delay train failed to function properly. Both units had previously been subjected to accelerated aging for 30 days at 130°F. Statistical analysis failed to indicate any significant correlation between malperformance and previous treatment.

Nine performance values, measured after sequential treatment, flanked the reference limits determined from the untreated statistical study rounds.

Accelerated aging produced a general degradation of the total delivered impulse, but the effect was minor.

Statistical significances correlating first- and second-order effects on motor-performance characteristics are reproduced in Appendix B.

A general understanding of sequential-treatment effect on motor performance can be obtained from Table 5. This summarization compares the results of untreated statistical rounds (95% confidence limits on the mean) with the average values found for sequentially treated rounds. Effect of individual treatments are not shown in Table 5 but can be determined by referring to Appendix B.

In general, the sequentially treated rounds did not show any severe shift of performance values. The only consistent effect found was a minor degradation of thermal battery voltage output. Voltage output was reduced approximately 0.9% after sequential treatment.

Another general trend was found upon comparing the total impulse values measured for rounds subjected to accelerated aging in relation to the average reference value when test-fired at 165°F. The average total impulse measured for the reference ballistics was 11,333 lb-sec. After accelerated aging at 95°F for 30 days, the total measured impulse was 11,298 lb-sec; when aged at 115°F for 30 days, the impulse decreased to 11,260 lb-sec; and after aging at 130°F for 30 days, the impulse decreased to 11,223 lb-sec. These values indicate a propellant degradation of 0.31, 0.64, and 0.97% total impulse at 95, 115, and

TABLE 5. PERFORMANCE OF SEQUENTIAL II TREATED ROUNDS IN COMPARISON WITH THE STATISTICAL REFERENCE BALLISTICS

Performance characteristics	Firing temp., -65°F		Firing temp., 165°F	
	Reference	Treated	Reference	Treated
Booster				
Ignition delay, ms	31.85–38.15	35	11.90–16.10	15
Thrust (early max.), lb	3,767–3,949	3,931	5,794–6,096	5,890
Thrust (late max.), lb	5,552–5,908	5,767	7,490–7,560	7,526
Impulse, lb-sec	6,749–6,835	6,715[a]	6,941–7,027	6,979
Burning time, sec	1.558–1.614	1.580	1.185–1.199	1.200[a]
Sustainer				
Ignition delay, ms	34.85–41.15	34[a]	18.80–27.20	27
Thrust (early max.), lb	2,711–3,347	3,072	4,285–4,501	3,838[a]
Thrust (late max.), lb	2,883–3,303	3,387[a]	4,826–5,690	4,951
Impulse, lb-sec	4,065–4,285	4,118	4,283–4,415	4,280[a]
Burning time, sec	1.583–1.795	1.593	1.055–1.193	1.166
Igniter-control unit				
Thermal relay delay, sec	0.379–0.539	0.458	0.243–0.287	0.284
Voltage at delay break, v	6.680–7.520	6.800	7.480–8.320	7.100[a]
Squib switch delay, sec	2.054–2.312	2.196	1.708–1.842	1.764
Battery output max., v	30.89–31.51	30.600[a]	31.18–32.02	30.900[a]
Time to max., sec	0.655–0.741	0.657	0.459–0.569	0.477
Sustainer ignition, sec	2.492–2.794	2.655	1.988–2.095	2.050

[a] Values shifted outside tolerance limits.

130°F, respectively. Statistical significance cannot be attached to these values, but the trend is apparent.

Throughout the truck-vibration test, the rounds were subjected to a maximum vibratory acceleration of 2.0 g and an average acceleration of 0.65 g. Continuity measurements on the igniters and igniter-control units failed to indicate that defects developed in the electrical system during truck vibration.

The propulsion system, as presently designed, appears to fulfill performance requirements after being subjected to simulated service environmental conditions. Modifications to the present system are not anticipated.

INDEPENDENT STUDIES

Forty-Foot Drop Test. Two motors were loaded using clip-seal-type tubes, previously developed, which differed from the regular flight hardware only in that a clip seal maintained the position of the bulkhead seal plate. The two rounds were loaded in shipping containers and temperature-conditioned at −65°F for approximately 20 hours before testing.

The crated rounds were oriented in a horizontal position, elevated 40 feet, and dropped on a 6-inch-thick steel plate. Each motor was subjected to one drop, isolated for approximately 15 minutes, and then returned to the motor-loading facility for disassembly and inspection.

Removal of the nozzle and igniter control unit showed both booster and sustainer grains were severely fractured, although the metal components were undamaged. Figure 9 shows the booster grain, and Fig. 10 shows the sustainer grain after being dropped 40 feet. Neither round was detonated by impact shock under test conditions. Continuity measurements on the igniters and igniter-control units failed to detect damage to these components after dropping.

FIG. 9. Booster Grain After 40-Foot Drop.

FIG. 10. Sustainer Grain After 40-Foot Drop.

Four-Foot Drop Test. Two rounds were loaded in flight weight hardware for the 4-foot drop. Regular tubes were specified, as the rounds were intended to be fired after the drop and inspection. Propellant grains used were X-rayed, dimensionally inspected, and accepted before loading.

The rounds were conditioned at −65°F for a minimum time of 8 hours before dropping. The motors were dropped once, isolated for 15 minutes, and returned to the motor-loading facility for disassembly and inspection.

The sustainer grain in both motors was severely fractured upon impact (Fig. 11). Neither booster grain appeared damaged; X-ray results confirmed the visual inspection. Continuity measurements failed to indicate damage to either the igniters or igniter-control units. These rounds were not fired after damage to the sustainer grains was noted.

Fire Sensitivity. The fire-sensitivity test was conducted on two rounds, one temperature-conditioned at −65 and the other at 165°F. Twelve thermocouples were attached to the exterior surface of the motor wall to determine the blowup temperature. The general test arrangement is shown in Fig. 12. The motors were suspended above a water-filled container having a layer of gasoline on the surface. Burning of the gasoline was initiated remotely by an electrical squib.

The first round, preconditioned to −65°F, blew up approximately 32 seconds after burning of the gasoline was initiated. The sustainer motor appeared to explode first, causing the entire booster section to be blown about 200 yards from the test site. At the time of explo-

FIG. 11. Sustainer Grain After 4-Foot Drop.

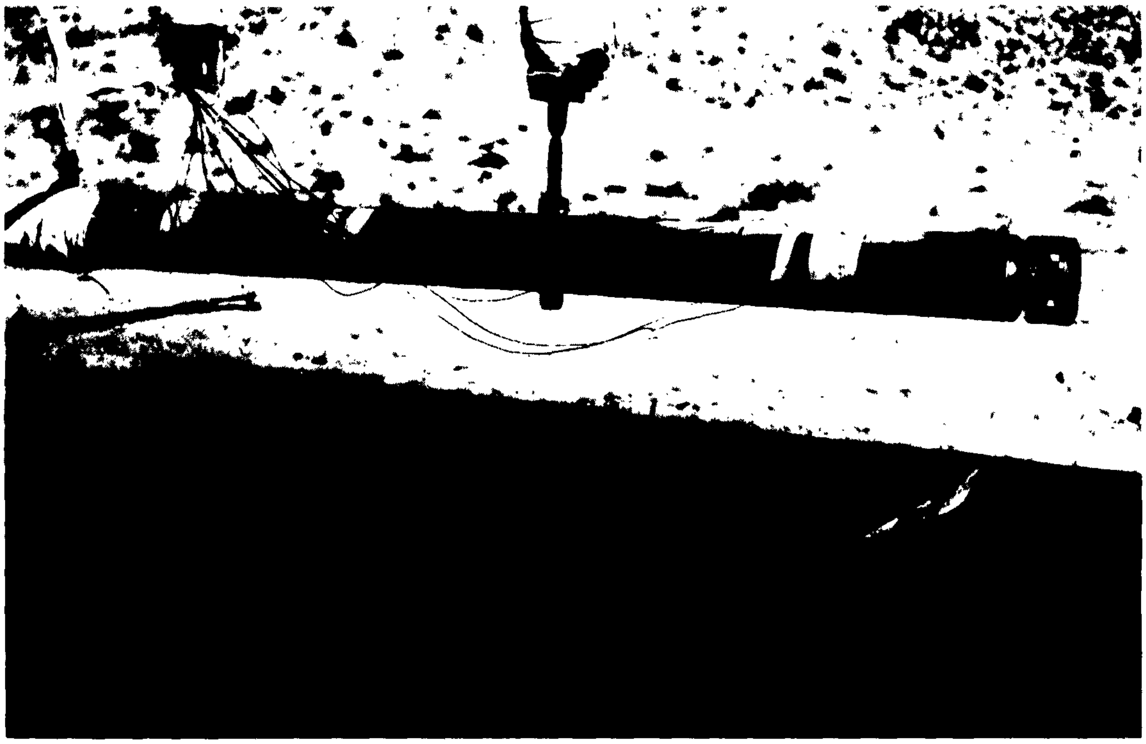

FIG. 12. Arrangement for the Fire-Sensitivity Test.

sion, the head end of the sustainer motor reached a maximum temperature of 1450°F.

The round preconditioned to 165°F blew up approximately 29 seconds after burning of the gasoline was initiated. The booster motor appeared to blow up first, scattering debris throughout the area. Various fragments were found 200 yards from the test site. A temperature of 1950°F was measured on the booster section, and a temperature of 1500°F was measured on the sustainer portion of the motor tube.

Bullet-Impact Tests. Four motors were used to conduct this test; three were conditioned at 165 and one at −65°F. The rounds were positioned on the ground, and a 50-caliber shell was fired into the motor from about 200 feet. The shells penetrated the booster chamber of the first two motors temperature-conditioned at 165°F. In the second test series, one round was conditioned to 165 and the second to −65°F, and the shells were fired into the sustainer chamber. Figure 13 shows the result of one test.

When the shell penetrated the booster chamber, the booster grain ignited and continued to burn at low pressures. Rupture of the motor tubes at shell impact prevented build-up of any appreciable chamber pressures. The sustainer grain from both motors ignited, either from heat transfer through the motor tube or from hot exhaust gases pass-

FIG. 13. Result of a Bullet-Impact Test.

ing into the sustainer motor; the rounds became propulsive, with bulkhead orifices serving as nozzles. The booster section separated from the sustainer.

Bullets fired into the sustainer chamber caused one motor to blow up immediately upon shell impact, scattering debris throughout the test area. Some fragments were found approximately 100 yards from the test site. When the shell was fired into the second sustainer chamber, the grain ignited and continued to burn to completion at low chamber pressures. The gases exhausted through a split in the motor-tube wall. Sustainer burning did not initiate burning of the booster grain.

Simulated Altitude. Four booster motors and four sustainer motors were loaded into individual motor tubes to investigate the effect of firing under simulated altitude conditions at −65°F. The booster and sustainer motors were not fired in sequence from one motor tube, because of the time required to obtain the desired vacuum and the heat transfer within the motor tube during this period. Under such conditions, neither the temperature of the sustainer motor nor the simulated altitude of the vacuum chamber would be known. Two booster and two sustainer motors were evaluated at a simulated 80,000 feet, and two booster and two sustainer motors were tested at 100,000 feet altitude.

Booster motors were loaded using standard procedures, but the sustainer sections were not loaded. Sustainer motors were loaded without boosters, but seal plates and adapters were used to seal off the sustainer chamber. Neither booster ballistic rod nor igniter tube was loaded into the booster section, but an inert squib body sealed the sustainer section.

A summary of the results is given in Table 6.

All motors were successfully fired at the simulated altitude conditions. The booster-motor ignition delay varied considerably, with measured values from 9 to 185 ms. Results did indicate that the ignition system operated successfully up to simulated altitudes of 100,000 feet.

TABLE 6. PERFORMANCE CHARACTERISTICS OF THE SIDEWINDER 1C FIRED AT -65°F UNDER SIMULATED ALTITUDE CONDITIONS

Motor	Simulated alt., ft	Ignition delay, ms	Thrust (early max.), lb	Thrust (late max.), lb	Impulse, lb-sec	Burning time, sec
Booster						
1	80,000	9	4,225	6,560	7,274	2.300
2	80,000	146	4,035	5,950	7,370	2.475
3	100,000	35	3,950	6,105	7,318	2.4534
4	100,000	185	3,985	6,360	7,316	2.463
Sustainer						
1	80,000	12	2,370	3,555	4,763	1.724
2	80,000	17	2,500	3,740	4,802	1.642
3	100,000	14	2,440	3,555	4,637	1.750
4	100,000	19	2,440	3,305	4,625	1.695

Appendix A

CONFIDENCE LIMITS FOR MOTOR PERFORMANCE CHARACTERISTICS

TABLE 7. PERFORMANCE LIMITS OF THE SIDEWINDER 1C AT −65°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Booster			
Ignition delay, ms	$21.76 < x < 48.24$	$17.68 < x < 52.33$	$31.85 < \mu < 38.15$
Thrust (early max.), lb	$3{,}474 < x < 4{,}242$	$3{,}356 < x < 4{,}360$	$3{,}767 < \mu < 3{,}949$
Thrust (late max.), lb	$4{,}980 < x < 6{,}480$	$4{,}748 < x < 6{,}712$	$5{,}552 < \mu < 5{,}908$
Impulse, lb-sec	$6{,}611 < x < 6{,}973$	$6{,}555 < x < 7{,}029$	$6{,}749 < \mu < 6{,}835$
Burning time, sec	$1.467 < x < 1.705$	$1.430 < x < 1.742$	$1.558 < \mu < 1.614$
Sustainer			
Ignition delay, ms	$24.76 < x < 51.24$	$20.68 < x < 55.33$	$34.85 < \mu < 41.15$
Thrust (early max.), lb	$1{,}692 < x < 4{,}366$	$1{,}279 < x < 4{,}779$	$2{,}711 < \mu < 3{,}347$
Thrust (late max.), lb	$2{,}210 < x < 3{,}976$	$1{,}938 < x < 4{,}248$	$2{,}883 < \mu < 3{,}303$
Impulse, lb-sec	$3{,}712 < x < 4{,}638$	$3{,}569 < x < 4{,}781$	$4{,}065 < \mu < 4{,}285$
Burning time, sec	$1.243 < x < 2.135$	$1.106 < x < 2.272$	$1.583 < \mu < 1.795$

TABLE 8. PERFORMANCE LIMITS OF THE SIDEWINDER 1C AT 70°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Booster			
Ignition delay, ms	$2.758 < x < 29.24$	$0 < x < 33.33$	$12.85 < \mu < 19.15$
Thrust (early max.), lb	$4{,}321 < x < 5{,}795$	$4{,}094 < x < 6{,}022$	$4{,}883 < \mu < 5{,}233$
Thrust (late max.), lb	$6{,}745 < x < 7{,}213$	$6{,}673 < x < 7{,}285$	$6{,}923 < \mu < 7{,}035$
Impulse, lb-sec	$6{,}729 < x < 7{,}179$	$6{,}659 < x < 7{,}249$	$6{,}900 < \mu < 7{,}008$
Burning time, sec	$1.270 < x < 1.358$	$1.256 < x < 1.372$	$1.304 < \mu < 1.325$
Sustainer			
Ignition delay, ms	$24.59 < x < 33.41$	$23.23 < x < 34.78$	$27.95 < \mu < 30.05$
Thrust (early max.), lb	$2{,}668 < x < 4{,}168$	$2{,}436 < x < 4{,}400$	$3{,}240 < \mu < 3{,}596$
Thrust (late max.), lb	$2{,}900 < x < 4{,}956$	$2{,}582 < x < 5{,}274$	$3{,}683 < \mu < 4{,}173$
Impulse, lb-sec	$4{,}154 < x < 4{,}392$	$4{,}117 < x < 4{,}429$	$4{,}245 < \mu < 4{,}301$
Burning time, sec	$1.039 < x < 1.771$	$0.926 < x < 1.884$	$1.318 < \mu < 1.492$

TABLE 9. PERFORMANCE LIMITS OF THE SIDEWINDER 1C AT 165°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Booster			
Ignition delay, ms	$5.172 < x < 22.83$	$2.450 < x < 25.55$	$11.90 < \mu < 16.10$
Thrust (early max.), lb	$5,309 < x < 6,581$	$5,113 < x < 6,777$	$5,794 < \mu < 6,096$
Thrust (late max.), lb	$7,379 < x < 7,671$	$7,334 < x < 7,716$	$7,490 < \mu < 7,560$
Impulse, lb-sec	$6,803 < x < 7,165$	$6,747 < x < 7,221$	$6,941 < \mu < 7,027$
Burning time, sec	$1.161 < x < 1.223$	$1.152 < x < 1.232$	$1.185 < \mu < 1.199$
Sustainer			
Ignition delay, ms	$5.344 < x < 40.66$	$0 < x < 46.10$	$18.80 < \mu < 27.20$
Thrust (early max.), lb	$1,985 < x < 5,701$	$1,412 < x < 6,274$	$3,401 < \mu < 4,285$
Thrust (late max.), lb	$3,439 < x < 7,077$	$2,879 < x < 7,637$	$4,826 < \mu < 5,690$
Impulse, lb-sec	$4,071 < x < 4,627$	$3,985 < x < 4,713$	$4,283 < \mu < 4,415$
Burning time, sec	$0.833 < x < 1.415$	$0.743 < x < 1.505$	$1.055 < \mu < 1.193$

TABLE 10. PERFORMANCE LIMITS ON THE IGNITER CONTROL BOX AT -65°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Thermal relay delay, sec	$0.124 < x < 0.795$	$0.020 < x < 0.898$	$0.379 < \mu < 0.539$
Voltage at delay break, v	$5.334 < x < 8.866$	$4.790 < x < 9.410$	$6.680 < \mu < 7.520$
Squib switch delay, sec	$1.640 < x < 2.726$	$1.473 < x < 2.893$	$2.054 < \mu < 2.312$
Battery max. output, v	$29.88 < x < 32.52$	$29.47 < x < 32.93$	$30.89 < \mu < 31.51$
Time to max., sec	$0.517 < x < 0.879$	$0.461 < x < 0.935$	$0.655 < \mu < 0.741$
Sustainer ignition, sec	$2.007 < x < 3.279$	$1.811 < x < 3.474$	$2.492 < \mu < 2.794$

TABLE 11. PERFORMANCE LIMITS ON THE IGNITER CONTROL BOX AT 70°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Thermal relay delay, sec	$0.027 < x < 0.653$	$0 < x < 0.750$	$0.266 < \mu < 0.415$
Voltage at delay break, v	$4.993 < x < 9.407$	$4.313 < x < 10.09$	$6.675 < \mu < 7.725$
Squib switch delay, sec	$1.289 < x < 2.419$	$1.115 < x < 2.593$	$1.720 < \mu < 1.988$
Battery max. output, v	$29.83 < x < 33.37$	$29.29 < x < 33.91$	$31.18 < \mu < 32.02$
Time to max., sec	$0.386 < x < 0.854$	$0.314 < x < 0.926$	$0.564 < \mu < 0.676$
Sustainer ignition, sec	$1.488 < x < 2.900$	$1.270 < x < 3.118$	$2.026 < \mu < 2.362$

TABLE 12. Performance Limits on the Igniter Control Box at 165°F

x indicates an individual value, and μ indicates an average value.

Motor characteristics	95% population covered within limits. 95% confidence level	99% population covered within limits. 95% confidence level	95% confidence limits on the mean
Thermal relay delay, sec	$0.172 < x < 0.358$	$0.144 < x < 0.386$	$0.243 < \mu < 0.287$
Voltage at delay break, v	$6.134 < x < 9.666$	$5.590 < x < 10.21$	$7.480 < \mu < 8.320$
Squib switch delay, sec	$1.493 < x < 2.058$	$1.405 < x < 2.145$	$1.708 < \mu < 1.842$
Battery max. output, v	$29.83 < x < 33.37$	$29.29 < x < 33.91$	$31.18 < \mu < 32.02$
Time to max., sec	$0.285 < x < 0.744$	$0.214 < x < 0.814$	$0.459 < \mu < 0.569$
Sustainer ignition, sec	$1.816 < x < 2.266$	$1.747 < x < 2.336$	$1.988 < \mu < 2.095$

Appendix B

STATISTICAL ANALYSES OF THE SEQUENTIAL II TREATMENT

TERMINOLOGY OF TEST RESULTS

- A temperature-cycling treatment
  - $\bar{A}_1$ average of treated rounds tested
  - $\bar{A}_2$ average of untreated rounds tested
- B truck-vibration test
  - $\bar{B}_1$ average of treated rounds tested
  - $\bar{B}_2$ average of untreated rounds tested
- C accelerated aging for 30 days
  - $\bar{C}_1$ average of rounds aged at 95°F
  - $\bar{C}_2$ average of rounds aged at 115°F
  - $\bar{C}_3$ average of rounds aged at 130°F
- D static-firing
  - $\bar{D}_1$ average of rounds stressed at 165°F for 8 hours and at −65°F for 2 1/2 hours, then fired at −65°F
  - $\bar{D}_2$ average of rounds stressed at −65°F for 8 hours and at 165°F for 2 1/2 hours, then fired at 165°F
  - $\bar{D}_3$ average of rounds treated at 165°F for 8 hours and then fired at that temperature
  - $\bar{D}_4$ average of rounds treated at −65°F for 8 hours and then fired at that temperature

The statistical significance is designated by plus one (+), plus two (++), and plus three (+++) and is shown for each first- and second-order effect on motor performance. A + significance indicates that one out of 20 times this effect could happen by chance; ++ indicates that one out of 100 times this effect could happen by chance; and a +++ significance level indicates that one out of 1,000 times this effect could happen by chance.

Results of these statistical analyses were obtained using Tukey's gap and straggler test.[1]

MATHEMATICAL MODEL

The mathematical model for the Sequential II treatment is given as follows:

$$\begin{Bmatrix} i = 1,2 \\ j = 1,2 \\ k = 1,2,3 \end{Bmatrix}$$

$$y = \mu = A_i + B_j + (AB)_j + C_k + (AC)_{ik} + (BC)_{jk} + \varepsilon_{ijk}$$

completely randomized, where A_i, B_j, and C_k are fixed so that

$$\sum_i A_i = \sum_j B_j = \sum_k C_k = 0$$

and all variables are quantitative.

The sum of squares (SS) of C has been partitioned into two sums of squares, namely the SS of C linear (C_l) and SS of C quadratic (C_q).

TABLE 13. STATISTICAL ANALYSIS OF THE IGNITION DELAY OF THE BOOSTER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	2.5	......	......	......
B	1	3.5	......	......	......
C_l	1	32.0	......	5.84	+
C_q	1	20.2	......	......	......
D	3	2,608.6	869.5	158.85	+++
AB	1	0.2	......	......	......
AC	2	0.7	0.3	......	... ..
AD	3	12.2	4.1	......	......
BC	2	0.2	0.1	......	......
BD	3	114.6	38.2	6.98	++
CD	6	15.0	2.5	......	......
Error	23	125.9	5.5	......	......
Total....	47	2,935.6	......	......	......

The ignition-delay results, in milliseconds, of the above treatments are compared as follows:

$\bar{A}_1 = 23.5$ and $\bar{A}_2 = 23.0$
$\bar{B}_1 = 23.5$ and $\bar{B}_2 = 23.0$
$\bar{C}_1 = 21.8$, $\bar{C}_2 = 24.2$, and $\bar{C}_3 = 23.8$
$\bar{D}_1 = 23.5$, $\bar{D}_2 = 20.3$, $\bar{D}_3 = 14.5$, and $\bar{D}_4 = 34.6$

Therefore, C_1 shows a significant separation (at the 95% confidence level) from C_3. C_3 and C_2 show no significant separation. There are significant separations between D_3 and $\bar{D}_2$, D_2 and $\bar{D}_1$, and $\bar{D}_1$ and $\bar{D}_4$. The error standard deviation is 2.338.

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[1] Tukey, J. W. Comparing Individual Means in the Analysis of Variance, BIOMETRICS BULL, Vol. 5 (1949), pp. 99–114.

TABLE 14. STATISTICAL ANALYSIS OF THE THRUST (EARLY MAX.) OF THE BOOSTER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	60,826	......	5.60	+
B	1	2,151	......	......	......
C_l	1	26,238	......	......	......
C_q	1	1,456	......	......	......
D	3	23,158,963	7,719,654	710.74	+++
AB	1	5,391	......	......	......
AC	2	3,690	1,845	......	......
AD	3	46,193	15,398	......	......
BC	2	22,318	11,159	......	......
BD	3	167,317	55,772	5.13	++
CD	6	163,878	27,313	......	......
Error	22	238,951	10,861	......	......
Total....	46	23,897,372	......	......	......

The early maximum thrust results, in pounds, of the above treatments are compared as follows:

$\bar{A}_1$ = 4,907 and $\bar{A}_2$ = 4,836
$\bar{B}_1$ = 4,865 and $\bar{B}_2$ = 4,878
$\bar{C}_1$ = 4,896, $\bar{C}_2$ = 4,879, and $\bar{C}_3$ = 4,839
$\bar{D}_1$ = 4,884, $\bar{D}_2$ = 4,780, $\bar{D}_3$ = 5,890, and $\bar{D}_4$ = 3,931

Therefore, there is a significant separation between $\bar{A}_2$ and $\bar{A}_1$, and there are significant separations between $\bar{D}_4$ and $\bar{D}_2$, $\bar{D}_2$ and $\bar{D}_1$, and $\bar{D}_1$ and $\bar{D}_3$. The error standard deviation is 104.4.

TABLE 15. STATISTICAL ANALYSIS OF THE THRUST (LATE MAX.) OF THE BOOSTER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	10,747.9	......	......	......
B	1	1,896.8	......	......	......
C_l	1	88,382.9	......	9.10	++
C_q	1	1,683.4	......	......	......
D	3	20,002,201	6,667,403	686.34	+++
AB	1	738.4	......	......	......
AC	2	22,822.4	11,411.2	......	......
AD	3	51,713.0	17,237.7	......	......
BC	2	20,889.9	10,445.0	......	......
BD	3	31,042.1	10,347.4	......	......
CD	6	56,079.9	9,346.7	......	......
Error	22	213,709.1	9,714.1	......	......
Total....	46	20,501,916.8	......	......	......

The late maximum thrust results, in pounds, of the above treatments are compared as follows:

A_1 = 6,679 lb and A_2 = 6,708 lb
B_1 = 6,700 lb and B_2 = 6,687 lb
C_1 = 6,637 lb, C_2 = 6,702 lb, and C_3 = 6,742
D_1 = 6,504 lb, D_2 = 6,979 lb, D_3 =7,525 lb, and D_4 = 5,767 lb

Therefore, C_1 and C_2 have a significant separation at the 95% confidence level, and C_2 and C_3 show no significant separation. D_4 and D_1 have a significant separation at the 95% confidence level, as do D_1 and D_2, and D_2 and D_3. The error standard deviation is 98.6.

TABLE 16. STATISTICAL ANALYSIS OF THE IMPULSE OF THE BOOSTER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	1,867.4	......	1.16	......
B	1	181.7	......	0.11	......
C_l	1	33,113.9	......	20.53	+++
C_q	1	68.1	......	0.04	......
D	3	451,605.1	150,535.0	93.35	+++
AB	1	2,739.3	......	1.70	......
AC	2	2,408.6	1,204.3	0.75	......
AD	3	2,601.1	2,067.0	1.28	......
BC	2	4,209.7	2,104.9	1.30	......
BD	3	1,937.2	645.7	0.40	......
CD	6	6,954.6	1,159.1	0.72	......
Error	22	35,478.3	1,612.6	......	......
Total	46	543,165.0	......	......	......

The impulse results, in pound-seconds, of the above treatments are compared as follows:

$\bar{A}_1 = 6{,}847$ and $\bar{A}_2 = 6{,}859$
$\bar{B}_1 = 6{,}851$ and $\bar{B}_2 = 6{,}855$
$\bar{C}_1 = 6{,}884$, $\bar{C}_2 = 6{,}855$, and $\bar{C}_3 = 6{,}820$
$\bar{D}_1 = 6{,}823$, $\bar{D}_2 = 6{,}895$, $\bar{D}_3 = 6{,}979$, and $\bar{D}_4 = 6{,}715$

Therefore, there are significant separations at the 95% confidence level between $\bar{C}_3$ and $\bar{C}_2$, and $\bar{C}_2$ and $\bar{C}_1$. There are significant separations at the 95% confidence level between $\bar{D}_4$ and $\bar{D}_1$, $\bar{D}_1$ and $\bar{D}_2$, and $\bar{D}_2$ and $\bar{D}_3$. The error standard deviation is 40.2.

TABLE 17. STATISTICAL ANALYSIS OF THE BURNING TIME OF THE BOOSTER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	0.0002	......	......	......
B	1	.0003	......	......	......
C_l	1	.0021	......	......	......
C_q	1	.0	......	......	......
D	3	.8974	0.2991	392.58	+++
AB	1	.0014	......	......	......
AC	2	.0019	0.0009	......	......
AD	3	.0010	0.0005	......	......
BC	2	.0005	0.0002	......	......
BD	3	.0038	0.0013	......	......
CD	6	.0042	0.0007	......	......
Error	22	.0168	0.0008	......	......
Total	46	0.9296	......	......	......

The burning-time results, in seconds, of the above treatments are compared as follows:

$\bar{A}_1 = 1.3725$ and $\bar{A}_2 = 1.3761$
$\bar{B}_1 = 1.3720$ and $\bar{B}_2 = 1.3766$
$\bar{C}_1 = 1.3826$, $\bar{C}_2 = 1.3738$, and $\bar{C}_3 = 1.3665$
$\bar{D}_1 = 1.3845$, $\bar{D}_2 = 1.3329$, $\bar{D}_3 = 1.1995$, and $\bar{D}_4 = 1.5803$

Therefore, there are significant separations at the 95% confidence level between $\bar{D}_3$ and $\bar{D}_2$, $\bar{D}_2$ and $\bar{D}_1$, and $\bar{D}_1$ and $\bar{D}_4$. The error standard deviation is 0.0276.

TABLE 18. STATISTICAL ANALYSIS OF THE IGNITION DELAY OF THE SUSTAINER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	174.4	......	8.70	++
B	1	78.7	......	......	......
C_l	1	27.2	......	......	......
C_q	1	44.7	......	......	......
D	3	740.4	246.8	12.31	+++
AB	1	0.4	......	......	......
AC	2	126.2	63.1	......	......
AD	3	241.4	80.5	4.01	+
BC	2	103.4	51.7	......	......
BD	3	398.1	132.7	6.62	++
CD	6	394.3	65.7	3.28	+
Error	21	420.9	20.0	......	......
Total	45	2,750.1	......	......	......

The ignition-delay results, in milliseconds, of the above treatments are compared as follows:

$\bar{A}_1 = 26.5$ and $\bar{A}_2 = 30.3$
$\bar{B}_1 = 27.1$ and $\bar{B}_2 = 29.6$
$\bar{C}_1 = 28.1$, $\bar{C}_2 = 27.0$, and $\bar{C}_3 = 30.0$
$\bar{D}_1 = 25.7$, $\bar{D}_2 = 25.8$, $\bar{D}_3 = 26.8$, and $\bar{D}_4 = 35.1$

Therefore, $\bar{A}_1$ and $\bar{A}_2$ show a significant separation at the 95% confidence level. There are no significant separations between $\bar{D}_1$, $\bar{D}_2$, and $\bar{D}_3$, but there is a significant separation (at the 95% confidence level) between $\bar{D}_3$ and $\bar{D}_4$. The error standard deviation is 4.47.

TABLE 19. STATISTICAL ANALYSIS OF THE THRUST (EARLY MAX.) OF THE SUSTAINER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	168,625	......	......	......
B	1	19,400	......	......	......
C_l	1	3,200	......	......	......
C_q	1	10,212	......	......	......
D	3	3,998,047	1,332,682	14.76	+++
AB	1	15,950	......	......	......
AC	2	44,388	22,194	......	......
AD	3	35,355	11,785	......	......
BC	2	4,101	1,367	......	......
BD	3	13,455	4,485	......	......
CD	6	63,838	10,639	......	......
Error	23	2,076,442	90,280	......	......
Total	47	6,453,013	......	......	......

The early maximum thrust results, in pounds, of the above treatments are compared as follows:

$\bar{A}_1 = 3,465$ and $\bar{A}_2 = 3,346$
$\bar{B}_1 = 3,385$ and $\bar{B}_2 = 3,425$
$\bar{C}_1 = 3,405$, $\bar{C}_2 = 3,426$, and $\bar{C}_3 = 3,385$
$\bar{D}_1 = 3,478$, $\bar{D}_2 = 3,234$, $\bar{D}_3 = 3,838$, and $\bar{D}_4 = 3,072$

Therefore, between D_4 and D_2 there is no significant separation, But D_2, D_1, and D_3 show significant separations at the 95% confidence level. The error standard deviation is 300.5.

TABLE 20. STATISTICAL ANALYSIS OF THE THRUST (LATE MAX.) OF THE SUSTAINER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	2,241	......	......	......
B	1	68,856	......	......	......
C_l	1	3,785	......	......	......
C_q	1	58,897	......	......	......
D	3	16,699,541	5,566,514	47.59	+++
AB	1	81,016	......	......	......
AC	2	468,864	234,432	......	......
AD	3	407,633	135,878	......	......
BC	2	76,745	38,373	......	......
BD	3	638,764	212,921	......	......
CD	6	238,989	39,831	......	......
Error	23	2,690,917	116,996	......	......
Total....	47	21,436,248	......	......	......

The late maximum thrust results, in pounds, of the above treatments are compared as follows:

$\bar{A}_1$ = 4,040 and $\bar{A}_2$ = 4,054
$\bar{B}_1$ = 4,085 and $\bar{B}_2$ = 4,009
$\bar{C}_1$ = 4,061, $\bar{C}_2$ = 3,998, and $\bar{C}_3$ = 4,083
$\bar{D}_1$ = 3,692, $\bar{D}_2$ = 4,159, $\bar{D}_3$ = 4,951, and $\bar{D}_4$ = 3,387

Therefore, $\bar{D}_4$, $\bar{D}_1$, $\bar{D}_2$, and $\bar{D}_3$ show significant separations at the 95% confidence level. The error standard deviation is 342.

TABLE 21. STATISTICAL ANALYSIS OF THE IMPULSE OF THE SUSTAINER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	479.7	......	......	......
B	1	1,903.4	......	......	......
C_l	1	4,553.9	......	......	......
C_q	1	1,833.8	......	......	......
D	3	165,409.6	55,136.3	24.89	+++
AB	1	1,803.9	......	......	......
AC	2	3,677.2	1,838.6	......	......
AD	3	17,683.8	5,894.6	......	......
BC	2	3,086.4	1,543.2	......	......
BD	3	2,677.5	892.5	......	......
CD	6	7,887.2	1,314.5	......	......
Error	22	48,736.2	2,215.3	......	......
Total....	46	259,732.6	......	......	......

The impulse results, in pound-seconds, of the above treatments are compared as follows:

$\bar{A}_1$ = 4,207 lb-sec and $\bar{A}_2$ = 4,201 lb-sec
$\bar{B}_1$ = 4,210 lb-sec and $\bar{B}_2$ = 4,197 lb-sec
$\bar{C}_1$ = 4,220 lb-sec, $\bar{C}_2$ = 4,195 lb-sec, and $\bar{C}_3$ = 4,196 lb-sec
$\bar{D}_1$ = 4,192 lb-sec, $\bar{D}_2$ = 4,225 lb-sec, $\bar{D}_3$ = 4,280 lb-sec, and $\bar{D}_4$ = 4,118 lb-sec

Therefore, $\bar{D}_4$ has a significant separation at the 95% confidence level from $\bar{D}_1$, $\bar{D}_1$ shows no significant separation from $\bar{D}_2$, and $\bar{D}_2$ and $\bar{D}_3$ show a significant separation at the 95% confidence level. The error standard deviation is 47.0.

TABLE 22. STATISTICAL ANALYSIS OF THE BURNING TIME OF THE SUSTAINER MOTOR

Treatment	Degree of freedom	Sum of the squares	Mean square	F ratio	Degree of signif. at 95% confidence level
A	1	0.0222	......	......	......
B	1	0.0	......	......	......
C_l	1	0.0015	......	......	......
C_q	1	0.0049	......	......	......
D	3	1.1364	0.3788	63.77	+++
AB	1	0.0043	......	......	......
AC	2	0.0318	0.0159	......	......
AD	3	0.5290	0.0176	......	......
BC	2	0.0030	0.0015	......	......
BD	3	0.0156	0.0052	......	......
CD	6	0.0126	0.0021	......	......
Error	22	0.1308	0.0059	......	......
Total......	46	1.8921	......	......	......

The burning-time results, in seconds, of the above treatments are compared as follows:

$\bar{A}_1 = 1.4085$ and $\bar{A}_2 = 1.3655$
$\bar{B}_1 = 1.3874$ and $\bar{B}_2 = 1.3866$
$\bar{C}_1 = 1.3867$, $\bar{C}_2 = 1.4013$, and $\bar{C}_3 = 1.3731$
$\bar{D}_1 = 1.4362$, $\bar{D}_2 = 1.3526$, $\bar{D}_3 = 1.1663$, and $\bar{D}_4 = 1.5929$

Therefore, $\bar{D}_3$, $\bar{D}_2$, $\bar{D}_1$, and $\bar{D}_4$ show significant separations at the 95% confidence level. The error standard deviation is 0.077.

NEGATIVE NUMBERS OF ILLUSTRATIONS

Fig. 1, L055334 (C); Fig. 2 and 3, none; Fig. 4, L056371 (U); Fig. 5, L060097 (U); Fig. 6, L061482 (U); Fig. 7, L061481 (U); Fig. 8, L061484 (U); Fig. 9, L058767 (U); Fig. 10, L058768 (U); Fig. 11, L058772 (U); Fig. 12, L059414 (U); Fig. 13, L059191 (U).

ABSTRACT CARD

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