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RESEARCH MEMORANDUM

AGE AND USAGE FACTORS AFFECTING MISSILE RELIABILITY: A STUDY BASED ON NIKE-AJAX EXPERIENCE (U)

William H. McGlothlin
David S. Stoller

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SUMMARY

This study examines the relationship between environmental history and missile firing success, based on a sample of 2585 NIKE-AJAX firings. The NIKE-AJAX was chosen because the data comprised the only available sample on U.S. missiles large enough to permit the kind of analysis done in this study. The primary data came from the historical logbooks which accompany each missile throughout its life. The major variables were: (1) date of manufacture and rebuilding (if any) for both the missile and the missile guidance unit, (2) time missile was on a NIKE battery site, (3) time missile guidance unit was operated both before and after rebuild, and (4) outcome of firing. Supplemental data were gotten from the NIKE firing summaries maintained by the Douglas Aircraft Company. They covered (1) malfunctions listed by system, and (2) the type of crew conducting the firing.

The split-sample technique was used in the analysis, with the 2585 firings divided into two approximately equal samples by odd and even serial numbers. The first half-sample was used for formulating hypotheses about relationships between firing reliability and the other variables. The second half-sample was used to test the statistical significance of these hypothetical relations.

The results of the study were that:

(1) Even after field-level overhaul of the missiles immediately before firing, missile usage on tactical sites, particularly as measured by the guidance-unit operating-time, lowers firing reliability.

(2) After a field-level overhaul, missile age factors have a negligible effect on firing reliability, if any; particularly, there appears to be no post-overhaul effect of prior time in depot storage.

(3) Except for missile-guidance malfunctions, the reliability of rebuilt missiles compares favorably with the reliability of those not rebuilt.

These results should be interpreted in the light of maintenance policies which provide a field-level maintenance inspection and repair-as-necessary immediately before the firings. It is probable that missile age and usage have greater unfavorable effects on combat reliability than those assessed in this study; but the field-level overhaul intervening between removal from the site and firing allows us to measure only the residual effects subsequent to this maintenance action. Test firings are normally conducted only after very thorough checkout and maintenance procedures. Tactical missiles, of course, would not have the benefit of this sort of maintenance immediately before firing.

This points up a problem that is common to most missile programs. The use of test firing results can lead to unrealistic estimates of combat capability, and can tend to obscure empirical measures of the effects of age and usage on firing reliability which, in turn, would be useful in determining preferred maintenance procedures for combat missiles. At the time a missile weapon system is considered operational, it would seem advisable to initiate test firings under conditions (1) which more closely simulate those of a combat environment, and (2) such that the effects of pre-launch environments on missile reliability can be more accurately assessed.

ACKNOWLEDGMENTS

The authors wish to express their indebtedness to the Field Service Division of Redstone Arsenal who extracted, and made available to us, the major portion of the data used in this study. A. A. Stewart and Paul Kane were especially helpful in this connection. In addition, the Douglas Aircraft Company make available some useful supplemental data. W. P. Anderson, Sadako Hayase, and Claire Buccella capably handled the numerical analysis of the data.

CONTENTS

I. INTRODUCTION

One of the major problems in determining a preferred policy for ICBM and other missile operation and maintenance is the difficulty of estimating the effects of age and usage on firing reliability. There have been some efforts to measure these effects on failure rates at missile checkout,* but the typically small number of firings has yielded very little information concerning the effect on firing reliability.** The NIKE-AJAX program, however, did encompass a large number of firings and thus yielded a large sample of environmental histories and firing outcomes. This study uses 2585 of these firings to explore the relationship between pre-launch environments and missile firing success.

The age effect examined here will be limited to "permanent" changes in missile firing reliability as a function of age, as opposed to "temporary" changes which may be detected and corrected by routine checkout procedures. Since all of the NIKE missiles received a thorough checkout immediately prior to firing, any detectable age effect would be a residual, or "permanent" effect.

The term "usage" in this paper will mean the maintaining of the missile in a ready or alert state, the operation of certain portions of the missile for checkout purposes, and its use for simulated combat exercises. The effect of usage on firing reliability is vitally important in determining missile

*C. E. Parker, "Some Effects of the Logistics Environment of an Air-to-Air Missile," Proceedings of the Symposium on Guided Missile Reliability, Part I, December, 1958, Dept. of Defense, pp. 111-116. W. H. McGlothlin and P. R. Yorshis, Measuring Missile Checkout Reliability Over Time (U), The RAND Corporation, Research Memorandum RM-2243, August 15, 1958 (Secret).

**P. J. Doyle and W. W. Szkil, Effects of Storage and Testing on Terrier Success Rates, U. S. Naval Ordnance Laboratory, Corona, Calif., May, 1956 (Confidential).

maintenance policies. If operating the missile for checkout purposes tends to reduce firing reliability, then this loss must be balanced against gains in overall combat capability resulting from the prompt detection of temporary age effects, i.e., changes affecting reliability which occur while the missile is standing in a ready, but inert state. Similarly, if using the missile for crew training reduces reliability, then this loss should be evaluated against possible gains in combat effectiveness resulting from training personnel on tactical missiles.

Because of limitations in the kinds of data recorded in the histories,* and the absence of experimental control in the samples, particularly with respect to maintenance policies (see p. 35), this study does not yield sufficiently complete planning information on the factors affecting missile combat capability to permit an assessment of the optimal use of the missile for checkout and training purposes. However, the measures of the effect of age and usage factors on firing reliability should prove generally useful in this area. This is particularly true in view of the unusually large sample studied here.

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*See D. S. Stoller and R. L. Van Horn, Management Information for the Maintenance and Operation of the Strategic Missile Force, The RAND Corporation, Research Memorandum RM-2131, April 30, 1958.

II. DATA

The majority of the data were extracted from the NIKE-AJAX logbooks by the Field Service Division at Redstone Arsenal. A logbook accompanies each missile throughout its life and provides a history of the environment to which the missile is exposed from manufacture to firing. Supplemental data were obtained from the firing summaries maintained by the Douglas Aircraft Company. The following are the data variables:

I. Redstone logbooks

1. Missile manufacturing date
2. Missile guidance unit manufacturing date*
3. Missile rebuild date (if any)
4. Missile guidance unit rebuild date (if any)
5. Time on tactical site before rebuild, or since new if no rebuild occurred
6. Time missile guidance unit was operated before rebuild (if any)
7. Time missile guidance was operated after rebuild, or since manufacture if no rebuild occurred
8. Date of firing
9. Location of firing
10. Outcome of test.

II. Douglas data

1. Missile and missile guidance unit serial numbers at the time of manufacture
2. Type of crew conducting firing
3. Malfunctioning system when known.

The completeness of the logbook entries for the above variables ranged from 100 per cent for date of manufacture and outcome of test, to approximately 80 per cent for time-on-site and time the missile guidance unit was operated. We had no means of assessing the accuracy of the entries.

Table 1 gives the total population of NIKE-AJAX firings for the period from January, 1953 to December, 1958, the number included in the Redstone sample, and the number for which both Redstone and Douglas data were available.

*The missile guidance unit is contained in the missile and should not be confused with the ground guidance radars and computer.

Table 1

TOTAL AND SAMPLE NIKE-AJAX FIRINGS:
JANUARY, 1953 - DECEMBER, 1958

Year	Total[a]	Redstone Sample	Both Redstone and Douglas Samples
1953	79	0	0
1954	297	20	2
1955	568	374	367
1956	711	600	592
1957	794	771	657
1958	874	713	391
Data Missing	–	107	104
Total	3323	2585	2113

[a]The total population of firings was obtained from the quarterly Project NIKE Firing Tests Summary, Bell Telephone Laboratories, December, 1954 to Fourth Quarter, 1958 (Confidential).

Both the Redstone and the Douglas data include firing outcomes. Redstone scored 74 per cent of the total firings as successful, while Douglas listed 68 per cent successful. The following table shows the extent of agreement between the Redstone and Douglas scorings:

SCORING COMPARISON

Douglas Scoring	Redstone Scoring		
	Successful	Unsuccessful	Total
Successful	1407	39	1446
Unsuccessful	140	527	667
Data Missing	353	119	472
Total	1900	685	2585

The Redstone data were given preference when the two scorings were discrepant, primarily so that we might use the total sample of 2585 firings rather than the 2113 for which both Redstone and Douglas data were available.*

The Douglas data identified malfunctioning systems as shown in the following table. The Redstone data did not include system malfunctions in firings which were scored successful.

System	
Armament	55
Booster	12
Flight Coverage	1
Ground Guidance	48
Missile Guidance Unit	127
Hydraulic	13
Launcher	3
Propulsion	82
Missile (general)[a]	297
Total[b]	638

[a]These malfunctions are attributed to the missile rather than the ground equipment, but the specific system is unknown.

[b]Includes multiple system malfunctions in a single firing. All the malfunctions listed here were considered to have contributed to the failure of the mission.

Since this study is primarily concerned with relating missile history to the firing outcome, the question arises as to whether the sample should include firings which were scored unsuccessful because of ground-system malfunctions. It was decided to retain these firings because (1) there may

*The Redstone criterion of a successful test was "a missile released within launching time (on or before the scheduled launch time) that bursts within 225 feet of the target." The Douglas criterion was more stringent.

have been an interaction between the performance of the missile and the failure attributed to the ground system, and (2) there was no way to determine the malfunctioning systems in the 472 firings for which the Douglas data were missing.

III. NIKE OPERATION AND MAINTENANCE

The NIKE-AJAX is a ground-to-air missile approximately 33 feet long, including the booster section, and weighs about 2400 pounds. It has four components: missile guidance, hydraulic, propulsion, and warhead. The propulsion system is composed of a solid-propellant booster and a liquid-fuel rocket motor. The ground system is composed of a target-acquisition radar, a target-tracking radar, a missile-tracking radar, and a computer. The computer receives target-location information from the target-track radar and transmits instructions to the missile guidance unit via the missile-track radar.*

Since one of the two main variables studied here is the effect of missile usage on firing reliability, it is pertinent to describe briefly the NIKE's operational environment. When a missile is received on a tactical site, the battery, warheads, detonating cords, and fuel are installed to make it a "ready missile." There are normally about 30 ready missiles and one training missile on a tactical site. Missiles on a site are given daily, weekly, and monthly checkouts, and are also used in simulated combat exercises for crew training. The daily checkout is a visual check. The weekly one provides certain tolerance checks which require the guidance and hydraulic units to operate for 5 to 10 minutes, while the monthly checkout operates the same systems 15 to 20 minutes. The combat exercises require elevation and handling of the missile, plus operation of the guidance and hydraulic units for about 5 minutes. On a training missile, these units may be operated as much as

*For a more complete exposition on the NIKE history, description, and operation see Bell Telephone Laboratories, Inc., Guided Missile System, XSAM-A-7, Over-all System Operation, December 8, 1952, Revised May 8, 1954 (Confidential); Bell Telephone Laboratories, Inc., and Douglas Aircraft Company, Inc., Project NIKE, History of Development, April 1, 1954 (Confidential).

15 hours a month. In this study, usage is measured by the number of months on site and the number of hours the guidance unit is operated.

There are the usual three levels of maintenance — organizational, field, and depot. Organizational maintenance consists primarily of tolerance adjustments and the replacement of major components. A depot-rebuild was required after two years on a site during the period of this study; the current limit is 30 months. Also, the rebuilt missiles included in this study were seldom returned to a site prior to firing at Ft. Bliss. Currently, however, a substantial number of rebuilt missiles are placed on tactical sites prior to return to Ft. Bliss for firing.

IV. MISSILE CONTINUITY

The missile does not necessarily keep the same components throughout its history. Guidance units, especially, are often replaced. Of those missiles which were fired without a rebuild, only 43 per cent still contained their original guidance units, and of those which were rebuilt only 23 per cent contained their original guidance units. However, there was 95-per-cent overall agreement between the rebuild status of the missile* and of the guidance unit, as can be seen in the following table.

Missile Guidance Unit	Missile			
	Non-rebuilt	Rebuilt	Data Missing	Total
Non-rebuilt	1139	67	76	1282
Rebuilt	34	953	21	1008
Data Missing	147	50	98	295
Total	1320	1070	195	2585

Similarly, the difference between the manufacturing dates for the missile and for its guidance unit was generally small: less than 150 days in 93 per cent of the cases. The rebuild dates were also within 150 days of each other in 93 per cent of the cases. For these reasons we have used single variables to define the age and rebuild status of the missile, rather than using one for the guidance unit and one for the missile. It should be pointed out, however, that since guidance units often become separated from missiles, the "time-on-site" measure does not necessarily apply to the guidance unit at the time of firing; and similarly, the measure of its usage does not necessarily apply to the rest of the missile.

*Excluding the guidance unit, in this discussion.

V. METHOD OF ANALYSIS

The 2585 firings were divided into two approximately equal samples, called Samples I and II, on the basis of odd and even serial numbers. Sample I was used in an exploratory manner to form hypotheses on what variables or combination of variables were related to firing reliability. Sample II was not inspected until this step was complete, after which it was used to provide statistical tests of the hypotheses formed from Sample I. This procedure allowed us to examine many possible relationships in Sample I without impairing the validity of the statistical significance tests which were performed on selected relationships in Sample II.

The relations in both samples were examined through grouping the firing results according to both controlled variables and the variable of interest. The success ratios observed in the cells of the tables thus formed were converted into Chi-square statistics. These statistics are derived by comparing observed frequencies with those frequencies expected under the hypothesis that the variable of interest has not affected the data.* Since the data in the tables are success ratios, the particular form of the Chi-square statistic known as the binomial index of dispersion is required.**

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*See, for example, W. J. Dixon and F. J. Massey, Introduction to Statistical Analysis, 2d ed., McGraw-Hill, New York, 1957, pp. 221-227.

**P. G. Hoel, Introduction to Mathematical Statistics, 1st ed., John Wiley and Sons, New York, 1947, pp. 196-197.

VI. RELATION OF DATE OF FIRING, DATE OF MANUFACTURE, FIRING CREW, AND REBUILD STATUS TO FIRING RELIABILITY

Figure 1 gives the proportion of successes in groups of 100 firings as a function of date of firing. Figure 2 provides the same presentation as a function of date of manufacture. Missiles manufactured after about December, 1954 (Missile Serial No. 4193) included a major modification, particularly in the guidance unit. The curves drawn in Figs. 1 and 2 were fitted to the data by an adjusted least-squares method described in Appendix A.

The preliminary analysis of the data (see p. 11) revealed a tendency for firing reliability to rise for later dates of firing; this tendency could not be accounted for by the intercorrelation of firing dates with other variables, such as dates of manufacture.* In searching for an explanation, we found that around July, 1956, missiles began receiving a special painting which greatly reduced the propulsion failures caused by "burn-throughs" in the earlier firings. The following table provides the distribution of critical failures attributed to malfunctions in the propulsion system, as a function of date of manufacture and date of firing:

	Date of Firing									
	Apr '54 – Aug '56		Aug '56 – Oct '57		Oct '57 – Nov '58		Data Missing		Total	
Date of Manufacture	N	Propuls. Failure	N	Propuls. Failure	N	Propuls. Failure	N	Propuls. Failure	N	Propuls. Failure
Aug '52 – Apr '54	460	31	329	12	147	4	7	1	943	48
Apr '54 – Dec '54	297	9	362	13	275	4	9	1	943	27
Dec '54 – Feb '58	69	2	133	1	405	1	92	3	699	7
Total	826	42	824	26	827	9	108	5	2585	82

*See Appendix B for a detailed presentation of the interrelations between date of firing and other variables.

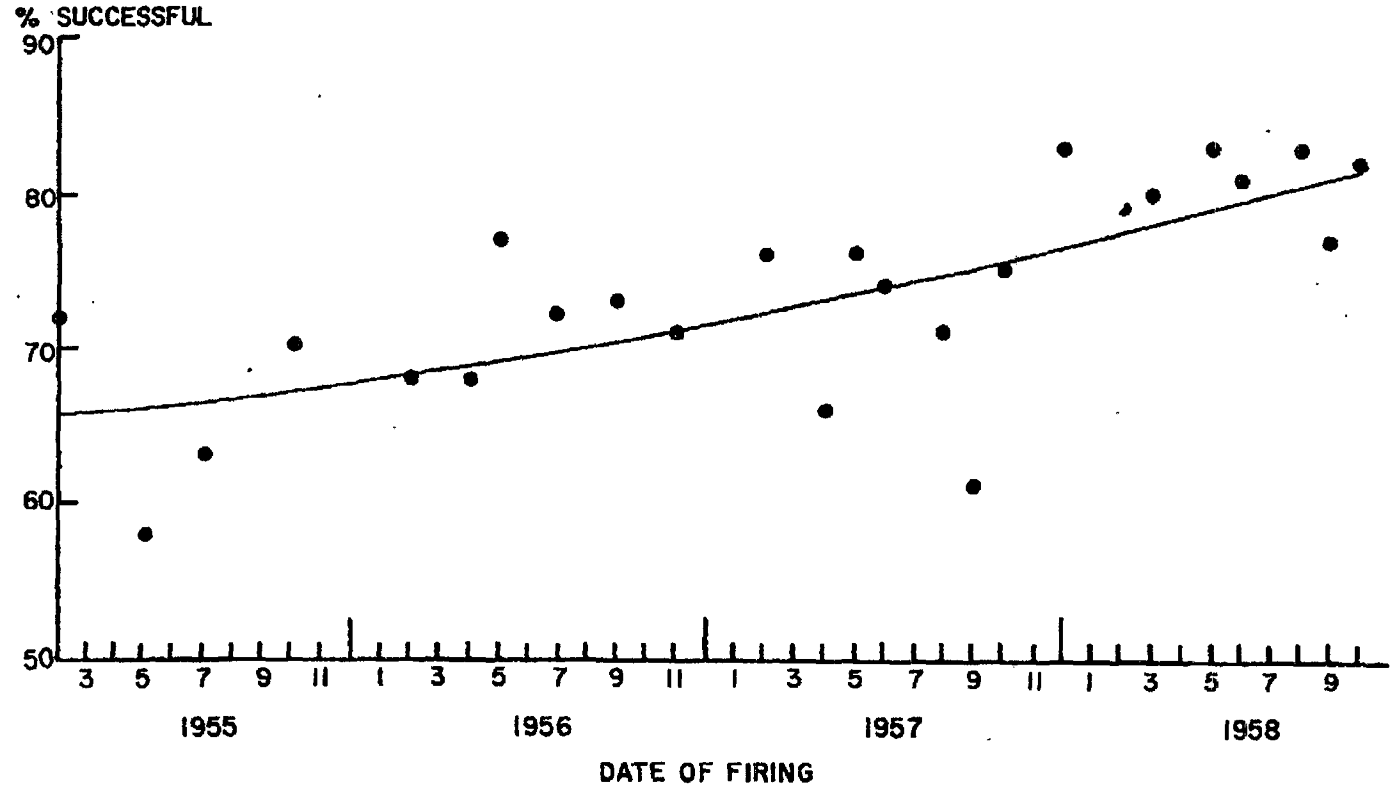

FIG. 1—RELIABILITY AS A FUNCTION OF DATE OF FIRING; DATA GROUPED IN SAMPLES OF 100 FIRINGS

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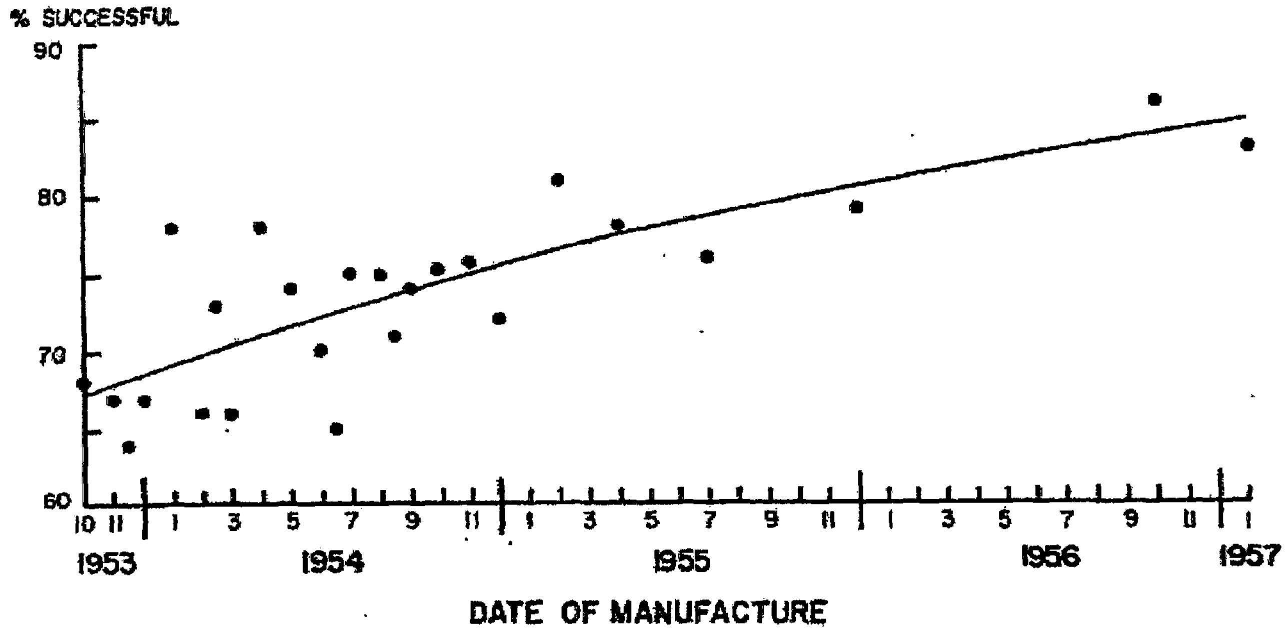


FIG. 2 — RELIABILITY AS A FUNCTION OF DATE OF MANUFACTURE; DATA GROUPED IN SAMPLES OF 100 FIRINGS

Since the purpose of this analysis is to study the effects of age and usage, it is useful to control or eliminate secular trends which are due primarily to the date of firing. For this reason, the firings whose failures were attributed to propulsion malfunctions were eliminated from the sample, leaving a total of 2503 firings. Since we did not have information on system malfunctions for the 472 firings for which the Douglas data were not available, we did not eliminate propulsion malfunctions from this group. This creates some bias in the data, because as can be seen in Table 1, the firings for which the Douglas data are missing were primarily during the years 1957-1958. Thus, some missile failures due to propulsion malfunctions are probably included during this period. However, as can be seen from the above table on propulsion malfunctions, the rate of this kind of failure is so small for the later firings that the bias should be negligible. The remainder of this paper will be concerned with the sample of 2503 firings, i.e., those remaining after removal of the 82 missile failures attributable to known propulsion-system malfunctions.

Next, the effect of the type of crew conducting the firing was examined. Experienced Army crews from tactical sites fired approximately 58 per cent of the sample. These firings were called "annual service program rounds." Another 18 per cent were fired in training programs by inexperienced Army crews generally receiving their first experience in actual firings. Another 5 per cent were fired by contractor or Army Ordnance crews, and for 19 per cent the crew information was missing. The following table gives the success rate by crew type after removal of propulsion failures:

	Firings	% Successful
Annual service crew	1452	78.6
Training program	458	68.6
Contractor and Army Ordnance ..	121	76.0
Data missing	472	74.8
	2503	75.9

The training-program firings represented only a very small proportion of the total firings during the later firing dates, a fact which tended to raise the estimate of reliability as a function of firing date. In the remainder of this paper we shall treat the firing-crew variable in three groups: annual service, training program, and a combined group made up of the contractor, Army Ordnance, and firings for which the crew data were missing. Only the annual service group will usually be presented in tabular form, but when statistical significance tests are cited they are a result of all three groups in Sample II. The complete set of results is given in Appendix C.

Another variable closely related to date of firing is the rebuild status of the missile. Only 9 per cent of missiles fired before May, 1957, were rebuilt, while about 81 per cent fired after this date were rebuilt before firing. Table 2 presents the relation between date of firing and success rate for missiles fired by annual service crews, with date of manufacture and rebuild status controlled. There is no longer a consistent trend in reliability as a function of date of firing, and the χ^2 value for Sample II was not significant. Reading across the rows under the corresponding rebuild statuses of Table 2, one can still see evidence of increasing reliability as a function of later manufacture-dates for non-rebuilt missiles, while the reliability of rebuilt missiles rises only slightly. When date of firing

Table 2

RELIABILITY FOR ANNUAL SERVICE CREWS AS A FUNCTION OF DATE OF FIRING; DATE OF MANUFACTURE AND REBUILD STATUS CONTROLLED[a]

Date of Firing	Date of Manufacture											
	Aug 52 - Apr 54				Apr 54 - Dec 54				Dec 54 - Feb 58			
	Non-Rebuilt		Rebuilt		Non-Rebuilt		Rebuilt		Non-Rebuilt		Rebuilt	
	N	%S	N	%S	N	%S	N	%S	N	%S	N	%S
Apr 54 - Aug 56	224 (162)[b]	72.3	3 (1)	—[c]	212 (170)	80.2	1 (1)	—	31 (28)	90.3	0 (0)	—
Aug 56 - Oct 57	64 (51)	79.7	119 (91)	76.5	91 (69)	75.8	91 (76)	83.5	75 (57)	76.0	10 (6)	—
Oct 57 - Nov 58	0 (0)	—	109 (90)	82.6	1 (1)	—	125 (95)	76.0	131 (110)	84.0	102 (86)	84.3
Data Missing	1 (0)	—	0 (0)	—	1 (1)	—	0 (0)	—	1 (1)	—	0 (0)	
Total	289 (213)	73.7	231 (182)	78.8	305 (241)	79.0	217 (172)	79.3	238 (196)	82.4	112 (92)	82.1

[a]Firings with missing data concerning rebuild status are not included in any of the tables throughout the remainder of the paper. As previously mentioned, failures attributed to propulsion malfunctions are excluded.

[b]The number in parenthesis indicates the number of successes.

[c]Percentages are not shown when N is less than 25.

is not controlled (total in Table 2), and all three groups of crews for Sample II are considered, missiles manufactured after December, 1954, were significantly more reliable (at the 95th percentile) than those manufactured prior to this date. The group manufactured between August, 1952, and April, 1954, did not prove significantly different from the April, 1954 - December, 1954 group in Sample II; the two are combined as a single group in the remainder of the analysis, and labeled the "old model." The "new model" comprises missiles manufactured after December, 1954 (after the major modification).

In Table 2, we may also examine the effect of rebuild status on reliability, with crew, date of manufacture, and date of firing controlled. The rebuilt missiles show a somewhat higher reliability here, and also for the other two crew types (not shown), but the difference did not prove to be significant in Sample II. It should be pointed out that the large majority of the rebuilt missiles in this sample experience only a storage environment between rebuild and firing, while the majority of the non-rebuilt missiles have some tactical-site environment between manufacture and firing.

VII. RELATION OF THE MISSILE AGE FACTOR TO RELIABILITY

Table 3 presents reliability as a function of age at firing, with crew, model, and rebuild status controlled. The age referred to here is that from manufacture to firing, regardless of intervening rebuild. For non-rebuilt missiles, there is no difference in reliability as a function of missile age for the old model, and an apparent decrement for older missiles of the new model. However, the sample size for the latter is small, and the age-reliability relationship did not prove significant in Sample II. Similarly, no significant relationship was found between the age factor and reliability when both rebuilt and non-rebuilt statuses were examined. In view of the fact that the missiles were given a thorough field-level overhaul immediately before firing, the lack of statistical significance between the age factor and firing reliability is interpreted as follows: The effect, if any, that the age factor has on the missile reliability is negligible after a field-level overhaul.

Table 3

RELIABILITY FOR ANNUAL SERVICE CREWS AS A FUNCTION OF AGE OF MISSILE; MODEL AND REBUILD STATUS CONTROLLED

Missile Age (Days)	Old Model						New Model					
	Non-Rebuilt			Rebuilt			Non-Rebuilt			Rebuilt		
	N	S	%S	N	S	%S	N	S	%S	N	S	%S
7 - 702	293	226	77.1	2	2	--	182	156	85.7	21	18	--
702 - 1109	283	215	76.0	96	74	77.1	55	39	70.9	35	28	80.0
1110 - 2002	16	12	--	350	278	79.4	0	0	--	56	46	82.1
Data Missing	2	1	--	0	0	--	1	1	--	0	0	--
Total	594	454	76.4	448	354	79.0	238	196	82.4	112	92	82.1

It is interesting to examine the effects of the missile age factor on reliability, independent of the usage factor. We attempted to investigate the age-reliability relationship for non-rebuilt missiles which experienced only a storage environment between manufacture and firing, but the sample size and spread in age were not sufficient to measure any possible effect. In the rebuilt portion of the sample the effect of age may be examined independently of usage because only a small portion of these missiles experienced a site environment between rebuild and firing. The range in age from rebuild to firing is fairly small, however. Table 4 presents the reliability of rebuilt missiles as a function of date of rebuild, with crew and model controlled. Table 5 provides the reliability of rebuilt missiles as a function of age since rebuild at firing, with crew and model controlled. There was a slight trend for missiles with later rebuild dates to have a higher reliability, but this did not prove significant. There was no evident relationship between reliability and age of missile since rebuild. This was true even though there is a positive correlation between early rebuild date and age of missile since it was rebuilt (see Appendix B) which, in view of the slightly lower reliability for missiles with early rebuild dates, would tend to favor lower reliability as a function of missile age since rebuild.* Since the missiles received a thorough field-level maintenance inspection and repair as necessary immediately before firing, we may conclude that the effect, if any, between reliability and the missile age factor is negligible after a field-level overhaul.

*White Sands Proving Ground disassembled, thoroughly inspected, and fired four missiles which had been in depot storage for from 27 to 46 months in order to examine the effect of storing missiles for long periods. Two of the four failed in flight, but it was concluded that the causes were not necessarily due to storage effects. Systems Test Div., White Sands Proving Ground, New Mexico, Shelf and Service Life of NIKE-AJAX Missiles, Test Plan 70, Technical Memo. 515, March, 1958 (Confidential).

Table 4

RELIABILITY FOR REBUILT MISSILES WITH ANNUAL SERVICE CREWS AS A FUNCTION OF DATE OF REBUILD; MODEL CONTROLLED

Missile Rebuild Date	Old Model			New Model		
	N	S	%S	N	S	%S
Mar. 12, 1954 - Mar. 14, 1957	193	148	76.7	8	5	—
Mar. 14, 1957 - Sept. 20, 1957	189	153	81.0	15	13	—
Sept. 20, 1957 - July 2, 1958	70	57	81.4	92	76	82.6
Data Missing	25	18	—	28	21	—
Total	477	376	78.8	143	115	80.4

Table 5

RELIABILITY FOR REBUILT MISSILES WITH ANNUAL SERVICE CREWS AS A FUNCTION OF AGE SINCE REBUILD; MODEL CONTROLLED

Missile Age Since Rebuild (Days)	Old Model			New Model		
	N	S	%S	N	S	%S
8 - 144	128	102	79.7	64	56	87.5
144 - 255	175	136	77.7	37	26	70.3
255 - 1467	145	116	80.0	11	10	—
Data Missing	29	22	—	31	23	—
Total	477	376	78.8	143	115	80.4

VIII. RELATION OF MISSILE USAGE TO RELIABILITY

Table 6 presents reliability as a function of number of months the missile was located on a tactical site, with crew, model, and rebuild status controlled. The data gave the time-on-site prior to rebuild, or since new if no rebuild occurred, but since only a small portion of the missiles in this sample were on a site subsequent to a rebuild, the variable includes essentially all the site-time experienced. If we assume that a rebuild eliminates any deterioration in reliability due to site environment, then we would expect to find the firing-success rate related to site-time in only the non-rebuilt portion of the sample. Table 6 shows a weak negative correlation between site-time and reliability. The χ^2 value for Sample II was significant at the 86th percentile. As expected, there was no relationship between site-time and reliability for rebuilt missiles.

Table 6

RELIABILITY FOR ANNUAL SERVICE CREWS AS A FUNCTION OF TIME-ON-TACTICAL-SITE; MODEL AND REBUILD STATUS CONTROLLED

Time Missile Was on Site (Months)	Old Model						New Model					
	Non-Rebuilt			Rebuilt			Non-Rebuilt			Rebuilt		
	N	S	%S	N	S	%S	N	S	%S	N	S	%S
0 - 0.8	147	122	83.0	52	42	80.8	150	129	86.0	14	11	--
0.8 - 13.0	248	186	75.0	130	102	78.5	28	21	75.0	13	11	--
13.0 - 48.0	81	62	76.5	198	160	80.8	49	39	79.6	71	57	80.3
Data Missing	118	84	--	68	50	--	11	7	--	14	13	--
Total	594	454	76.4	448	354	79.0	238	196	82.4	112	92	82.1

Table 7 presents reliability as a function of the amount of time recorded on the missile guidance unit since rebuild, or since new if no rebuild has occurred, with crew, model, and rebuild status controlled. There appears to be a negative correlation between reliability and the amount of time the guidance was used. The χ^2 value for Sample II was significant at the 85th percentile. On examining Table 7, we see that there is little spread in time-on-the-guidance-unit for rebuilt missiles. If we obtain a χ^2 value for only the non-rebuilt portion of the sample, the significance level rises to the 96th percentile.

Table 7

RELIABILITY FOR ANNUAL SERVICE CREWS AS A FUNCTION OF TIME MISSILE GUIDANCE UNIT WAS OPERATED SUBSEQUENT TO REBUILD, OR SINCE NEW IF NO REBUILD OCCURRED; MODEL AND GUIDANCE UNIT REBUILD STATUS CONTROLLED

Time Missile Guidance Unit Was Operated (Hours)	Old Model						New Model					
	Non-Rebuilt[a]			Rebuilt			Non-Rebuilt			Rebuilt		
	N	S	%S	N	S	%S	N	S	%S	N	S	%S
0.4 – 3.2	69	54	78.3	258	204	79.1	91	77	84.6	65	52	80.0
3.2 – 7.0	155	123	79.4	116	91	78.4	97	84	86.6	30	26	86.7
7.0 – 257.9[b]	297	220	74.1	22	16	—	77	55	71.4	6	4	—
Data Missing	25	20	—	25	21	—	2	2	—	2	2	—
Total	546	417	76.4	421	332	78.9	267	218	81.6	103	84	81.6

[a] In Tables 7, 8, and 9 the rebuild status refers to the missile guidance unit. In previous tables it referred to the rebuild status of the remainder of the missile.

[b] 92 per cent of this group is between 7.0 – 30 hours.

Table 8 presents reliability as a function of total time the guidance unit was operated, both before and after rebuild for rebuilt missiles only, with crew and model controlled. No significant relationship is observed.

As mentioned earlier, only 43 per cent of non-rebuilt missiles and 23 per cent of those rebuilt contained their original guidance units at the time of firing. The time the guidance unit is operated, therefore, does not necessarily indicate the amount of usage the remainder of the missile has experienced in an appreciable portion of the sample. We attempted to examine the relationship between reliability and the amount of time recorded on the guidance unit for non-rebuilt missiles which retained their original guidance units. The results were of the same direction as for the total sample, but the sample size was too small to determine whether there was a stronger relationship under these conditions.

Table 8

RELIABILITY FOR MISSILES WITH REBUILT GUIDANCE UNITS AND ANNUAL SERVICE CREWS AS A FUNCTION OF TOTAL TIME THE MISSILE GUIDANCE UNIT WAS OPERATED, BOTH PRIOR AND SUBSEQUENT TO REBUILD; MODEL CONTROLLED

Total Time Missile Guidance Unit Was Operated (Hours)	Old Model			New Model		
	N	S	%S	N	S	%S
0.7 - 6.6	70	51	72.9	12	9	—
6.6 - 14.3	156	125	80.1	33	25	75.8
14.3 - 245.5[a]	122	97	79.5	51	44	86.3
Data Missing	73	59	—	7	6	—
Total	421	332	78.9	103	84	81.6

[a]88% of this group is between 14.3 - 40 hours.

Table 9 presents the missile failures attributable to the guidance unit as a function of the amount of time recorded on the unit since rebuild, or since new if no rebuild has occurred, with rebuild status controlled. The data cover all three crew-types and both models. The percentages given in this table should not necessarily be interpreted as direct reflections of guidance-unit reliability, since the system causing the failure was listed as unknown in approximately 45 per cent of the cases. The trend is for the number of failures attributed to guidance-unit malfunctions in non-rebuilt missiles to be positively correlated with the amount of time the unit was operated. The relationship did not, however, test significant in Sample II. There is no relationship evident between the number of guidance-unit malfunctions and operating time since rebuild. It should be observed that this table is not strictly comparable with previous results, since crew type and model have not been controlled. The total time registered on the guidance unit on rebuilt missiles (not shown) showed no relationship to the number of guidance-unit malfunctions.

It is interesting to note in Table 9 that while the overall reliability of rebuilt missiles is generally as high or higher than that of non-rebuilt missiles, the reliability of the guidance unit appears to be appreciably lower in the rebuilt missiles. This difference is significant at the 96th percentile in Sample II. As mentioned before, this apparent decrement in the guidance-unit performance does not show evidence of being related to the time the unit was operated prior to rebuild.

Table 9

THE RELATION OF KNOWN MISSILE GUIDANCE UNIT FAILURES TO THE AMOUNT OF OPERATING TIME ON THE GUIDANCE UNIT SUBSEQUENT TO REBUILD OR SINCE NEW IF NO REBUILD OCCURRED; GUIDANCE UNIT REBUILD STATUS CONTROLLED[a]

Time Guidance Unit Was Operated (Hours)	Non-Rebuilt			Rebuilt		
	N[b]	S	%S	N[b]	S	%S
0.4 - 3.2	146	141	96.6	295	269	91.2
3.2 - 7.0	269	256	95.2	167	152	91.0
7.0 - 257.9[c]	428	402	93.9	38	36	94.7
Data Missing	66	61	—	30	29	--
Total	909	860	94.6	530	486	91.7

[a]Includes all three types of crews. Does not include firings for which rebuild-status data were missing.

[b]Excludes firings which failed because of non-guidance-system malfunctions; also excludes firings for which the Douglas data (system-malfunction information) were not available.

[c]86% of this group is between 7.0-30 hours.

Finally, an effort was made to examine, over the total sample, the reliability of non-rebuilt missiles which had more than 30 hours of operating time on the guidance unit. The 53 missiles in this category had a success rate of 67.9 per cent, as compared to 75.0 per cent for the 1182 non-rebuilt missiles with less than 30 hours of guidance operation. While this result is in the expected direction, the difference was not significant for this size of sample. Rebuilt missiles which had more than 40 hours of total guidance operating time were similarly examined. The 46 missiles in this category had a success rate of 76.1 per cent, as compared to 77.9 per cent for the 928 rebuilt missiles with less than 40 hours total guidance operating time. The difference is clearly insignificant.

In summary, the results of this study appear to support the hypothesis that even after a field-level overhaul, prior missile usage, as measured here, is generally negatively correlated with firing reliability. The number of months the non-rebuilt missile was on a tactical site showed a weak negative correlation, and the number of operational hours on non-rebuilt missiles evidenced a somewhat stronger negative relationship. Because of the divorce rate between the guidance unit and the remainder of the missile, the time-on-site measure is strictly applicable to only 43 per cent of the non-rebuilt guidance units. On the other hand, while the operational time on the guidance unit probably gives a good measure of the usage of the guidance unit, it is indicative of usage of the remainder of the non-rebuilt missile in only 43 per cent of the cases. If we eliminate both ground- and propulsion-system failures, the guidance unit accounts for approximately 61 per cent of the remaining known causes of failures. This fact, together with the relationship to reliability found in this paper, indicates that the time the guidance unit is operated may be a better measure of usage than the time-on-site.

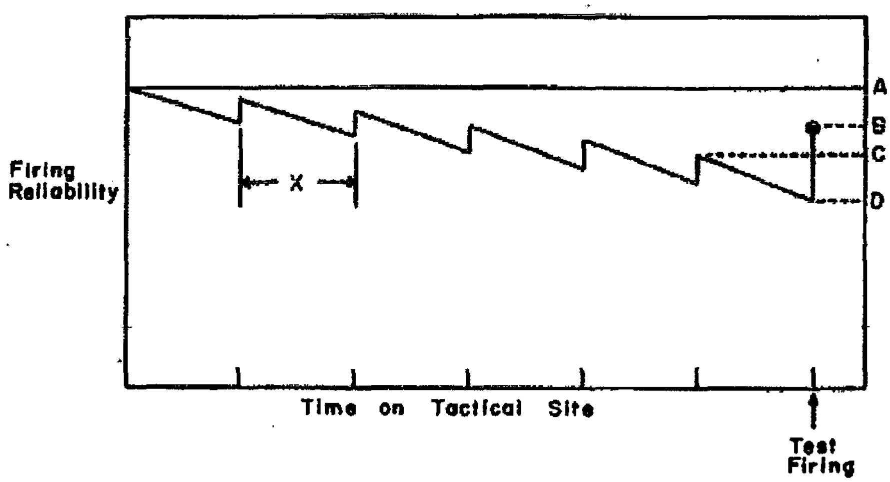
An alternative hypothesis to explain the negative correlation between guidance-unit operating time and reliability is that inherently inferior missiles require more time for the guidance unit to be calibrated, and this inferior quality is still present when the missiles are fired. We attempted to check this possibility at a NIKE site. One of the findings was that the frequency with which tolerance adjustments were required at checkout increased as a function of the number of checkouts undergone. This tends to support the conclusion that the guidance-unit operating-time is a valid measure of missile usage.

IX. RELIABILITY AS A FUNCTION OF CHECKOUT FREQUENCY

As mentioned in the Introduction, we do not have enough information from the historical summaries to determine optimal missile checkout frequencies in this study. However, it may prove useful to present a simplified model of how one would use such information to develop preferred maintenance policies. When a checkout is performed on a tactical missile, it is implicitly assumed that there is some chance of a failure occurring during the standing period since last checkout. If we make the usual assumption that the time-to-failure is defined by the negative exponential distribution, the probability of surviving t hours of standing time may be expressed by $e^{-t/\bar{t}}$, where $\bar{t}$ represents the mean-standing-time-to-failure. In this study, we could not assess this "temporary" effect of standing time on tactical missiles. The effect of standing time on checkout reliability has been experimentally measured on other missiles, however.*

This study found that use of the missile, as defined by operation of the guidance unit for checkout and other purposes, was negatively correlated with firing reliability even after the performance of a field-level overhaul. When we introduce this factor, along with an assumption about the probability of surviving the standing time between checkouts, we may draw the hypothetical diagram seen on the next page.

*See, for example, Final Report on the Employment and Suitability Test of the GAR-1 (Falcon) Missile, Hq. Air Proving Grounds, Eglin AFB, Florida, January, 1957, p. 15; and A. L. Story, "Military Implications of Guided Weapons Reliability" (U), Proceedings of the Joint Military-Industry Guided Missile Reliability Symposium, Redstone Arsenal, Huntsville, Alabama, Vol. 1, October, 1956 (Secret).



The missile is assumed to have reliability A when delivered to the site. The time between checkouts is X and reliability is assumed to fall by an amount, C-D, during X hours of standing in a ready state. During the time from delivery to the test firing, the reliability drop due to usage is A-C. We will assume that the effect of age independent of usage is negligible here. The reliability increase represented by B-C is intended to represent the effect of the field-level maintenance the missiles in this sample receive prior to firing. The value A-B represents the usage effect remaining after the field maintenance, which was the quantity measured on the NIKE sample.

If we adopt this very simple model of reliability of the tactical missile, and assume that the missile remains on a site for a fixed period without receiving a depot-rebuild, we may solve for an optimal checkout frequency. Such a policy would simply maximize the area under the reliability function.

In actuality, the factors affecting missile combat reliability are much more complicated than as outlined here. The reduction in firing reliability as a function of usage may not be linear,* and three other factors which are important are not considered: the cost of maintenance, missile time off alert due to checkouts and resulting maintenance, and use of the missile for training.**

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*McGlothlin and Yorshis, op. cit. (Cf. footnote, p. 1.)

**For a model which considers some of these factors, see Eloise E. Bean and W. H. McGlothlin, A Model for Assessing the Effect of Maintenance on Missile Reliability, The RAND Corporation, Research Memorandum RM-2451, September 23, 1959. See also R. S. LaVallee and D. S. Stoller, The Effect of Maintenance and Reliability on the Operational Effectiveness of an Interceptor Squadron: A Case Study (Project LOCK-ON) (U), The RAND Corporation, Research Memorandum RM-1499, June 8, 1955 (Secret — Limited Distribution).

X. CONCLUSIONS

The primary conclusions of this study are that within the range of age and usage factors studied here, (1) there is evidence that, even after a field-level overhaul, prior missile usage on tactical sites, particularly as measured by the guidance-unit operating-time, reduces firing reliability; (2) the effect, if any, of missile age factors on reliabilit is negligible after a field-level overhaul, and particularly, there appears to be no post-overhaul effect of prior time in depot storage; and (3) with the exception of missile-guidance malfunctions, the reliability of rebuilt missiles compares quite favorably with those not rebuilt.

These results should be interpreted in the light of maintenance policies which provide a field-level maintenance inspection and repair-as-necessary on the NIKE immediately prior to firing. It is probable that the unfavorable effects of missile age and usage on combat reliability are greater than those measured here; but the intervening field-level overhaul between removal from site and firing allows us to measure only the residual effects subsequent to this maintenance action. Test firings are normally conducted only after very thorough checkout and maintenance procedures. Tactical missiles, of course, would not have the benefit of this sort of maintenance immediately before firing.

This points up a problem that is common to most missile programs. The use of test firing results can lead to unrealistic estimates of combat capability, and can tend to obscure empirical measures of the effects of age and usage on firing reliability which, in turn, would be useful in determining preferred maintenance procedures for combat missiles. At the time a missile weapon system is considered operational, it would seem advisable to initiate test firings under conditions (1) which more closely simulate those of a combat environment, and (2) such that the effects of pre-launch environments on missile reliability can be more accurately assessed.*

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*See D. S. Stoller, The Measurement of Missile Reliability in Pre-Launch Operating Environments, The RAND Corporation, Research Memorandum RM-2508, January 1, 1960.

Appendix A

METHOD OF DETERMINING RELIABILITY TREND

In Figs. 1 and 2, the firing success rates are plotted by groups of 100 firings against the date of firing and the date of manufacture, respectively. It is evident by inspection that a secular trend exists in the data. A function of the form

$$Y = A + BX + CX^2 ,$$

where

$$Y = \text{success rate}$$

$$X = \text{date}$$

$$A, B, C = \text{fitted constants},$$

was considered adequate to represent the trend within the range of the data for each figure. Since the success rates observed in the data are not random observations from homogeneous binomial populations, the least-squares method for calculating fitted constants was adjusted to account for the heterogeneity. The adjustment was made by (1) estimating the standard deviation of each group, (2) weighting each observed-success rate by dividing by the estimated standard deviation, (3) obtaining a least-squares fit on the weighted success rates, and using step (3) to form a new estimate of the standard deviation for each group and reiterating a suitable number of times. The calculating procedure is given below:

Let: $Y_o(X)$ = observed success rate for date group X;

$Y_c^{(i)}(x)$ = calculated success rate for date group X, i-th iteration;

$A^{(i)}, B^{(i)}, C^{(i)}$ = least-squares coefficients, i-th iteration; and

$Z_o^{(i)}(X)$ = weighted observed success rate for date group X, i-th iteration.

(1) Calculate least-squares coefficients A_o, B_o, C_o with $Y_o(X)$ and X.

(2) $Y_C^{(1)}(X) = A_o + B_oX + C_oX^2$

(3) $Z_o^{(1)}(X) = Y_o(X) \Big/ \sqrt{Y_C^{(1)}(X) \left[1 - Y_C^{(1)}(X)\right]}$

(Since the groups are equal in size, the factor for the number of observations in the group may be dropped without affecting the results.)

(4) Calculate least-squares coefficients A_1, B_1, C_1 with $Z_o^{(1)}(X)$ and X.

(5) $Z_C^{(1)}(X) = A_1 + B_1X + C_1X^2$

(6) $Y_C^{(2)}(X) = Z_C^{(1)}(X) \sqrt{Y_C^{(1)}(X) \left[1 - Y_C^{(1)}(X)\right]}$

(7) $Z_o^{(2)}(X) = Y_o(X) \Big/ \sqrt{Y_C^{(2)}(X) \left[1 - Y_C^{(2)}(X)\right]}$

(8) Calculate least-squares coefficients A_2, B_2, C_2 with $Z_o^{(2)}(X)$ and X.

(9) $Z_C^{(2)}(X) = A_2 + B_2X + C_2X^2$,

etc.

The iteration is terminated when

$$\max_X \left| Y_C^{(i)}(X) - Y_C^{(i-1)}(X) \right| \leq \text{desired accuracy.}$$

Appendix B

INTERRELATIONS OF AGE AND USAGE VARIABLES

Table 10 provides the interrelations of the variables studied in this paper. Propulsion malfunctions are included. The following is the code to the column headings:

A. Number of missiles in group

B. Percentage of successful firings

C. Percentage manufactured from August, 1952 to August, 1954

D. Percentage fired from April 27, 1954 to August 5, 1957

E. Average age of missile at firing in days (firing date minus manufacturing date)

F. Percentage of missiles that were rebuilt

G. Percentage of missiles that were rebuilt from December 3, 1954 to June 7, 1957

H. Average age of missile subsequent to rebuild in days (firing date minus rebuild date)

I. Time missile was on tactical site in months

J. Total time missile guidance unit was operated in hours since manufacture

K. Time missile guidance unit was operated since rebuild, or since manufacture if no rebuild occurred

L. Percentage of missiles fired by annual service crews

M. Percentage of missiles fired by Army Ordnance crews

N. Percentage of missiles fired by field training program crews

O. Percentage of missiles fired by contractor crews

P. Percentage of missiles for which crew data were missing

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Table 10

INTERRELATION AMONG VARIABLES[a]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Date of Manufacture																
Aug 52 - Dec 53	471	.68	1.00	.76	888	.33	.21	244	6.7	14.4	8.6	.56	.00	.39	.00	.04
Dec 53 - Apr 54	472	.72	1.00	.62	1032	.44	.33	233	10.3	15.0	9.2	.63	.01	.25	.00	.11
Apr 54 - Aug 54	472	.71	1.00	.64	881	.32	.28	256	8.6	12.6	9.7	.64	.00	.23	.01	.13
Aug 54 - Dec 54	471	.75	.00	.29	1045	.69	.27	254	10.8	13.3	6.3	.52	.00	.13	.00	.35
Dec 54 - Sept 55	350	.77	.00	.32	969	.70	.08	164	18.1	20.8	12.7	.50	.01	.01	.01	.48
Sept 55 - Feb 58	349	.81	.00	.19	383	.20	.04	165	1.7	7.0	5.2	.60	.00	.05	.17	.18
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Date of Firing																
4-27-54 to 1-12-56	413	.66	.86	1.00	501	.01	.01	54	1.9	7.6	7.4	.51	.01	.38	.03	.06
1-18-56 to 8-23-56	413	.71	.75	1.00	652	.01	.01	110	5.2	10.0	10.0	.71	.00	.26	.01	.02
8-23-56 to 5-08-57	412	.71	.67	1.00	930	.25	.25	247	11.1	15.7	12.6	.66	.00	.31	.01	.01
5-08-57 to 10-24-57	413	.72	.62	.00	1098	.83	.76	215	10.2	17.7	12.9	.53	.00	.22	.00	.25
10-30-57 to 5-03-58	413	.80	.28	.00	931	.65	.25	216	10.0	11.4	3.7	.90	.00	.03	.00	.07
5-03-58 to 11-07-58	413	.81	.20	.00	1252	.94	.10	244	16.4	19.2	4.9	.28	.00	.00	.00	.72
Data Missing	108	.72	.15	—	—	.67	.17	—	14.9	17.3	8.2	.11	.01	.01	.08	.79
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Missile Age (Days)																
7-494	412	.80	.29	.58	316	.01	.01	206	0.6	5.6	5.5	.63	.00	.16	.06	.15
494-702	412	.68	.75	.91	607	.06	.03	199	3.7	9.3	9.0	.68	.01	.29	.00	.02
702-896	413	.67	.72	.93	793	.08	.04	174	9.1	13.6	13.9	.65	.00	.30	.00	.04
897-1109	412	.72	.49	.41	1019	.58	.37	172	12.3	17.2	12.6	.55	.00	.24	.00	.21
1110-1278	412	.76	.52	.12	1186	.94	.53	208	15.3	18.3	5.7	.57	.00	.15	.00	.28
1278-2002	413	.79	.63	.05	1441	.98	.36	285	14.7	18.1	4.5	.51	.00	.06	.00	.43
Data Missing	111	.72	.17	—	—	.71	.21	—	14.1	16.7	7.4	.12	.01	.01	.82	.05
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18

For footnotes, see p. 42.

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Table 10 — continued

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Missile Rebuild Date																
No Rebuild	1320	.71	.66	.83	641	.00	—	—	5.7	10.3	10.2	.65	.00	.28	.01	.06
03-12-54 to 10-30-56	178	.74	.91	.48	1179	1.00	1.00	345	8.6	23.2	11.7	.62	.00	.26	.00	.12
10-31-56 to 03-14-57	178	.73	.67	.12	1145	1.00	1.00	212	8.7	15.5	6.4	.55	.00	.23	.00	.22
03-14-57 to 06-07-57	178	.72	.52	.00	1217	1.00	1.00	245	13.6	14.7	5.7	.63	.00	.06	.00	.30
06-07-57 to 09-20-57	178	.79	.27	.00	1334	1.00	.00	272	15.1	17.4	3.7	.54	.00	.04	.00	.42
09-20-57 to 01-15-58	178	.81	.25	.00	1237	1.00	.00	181	17.8	16.9	3.2	.62	.00	.00	.00	.38
01-15-58 to 07-02-58	179	.82	.17	.00	1231	1.00	.00	113	19.8	22.4	4.6	.29	.01	.00	.00	.70
Data Missing	196	.74	.24	.43	718	—	—	—	80.8	14.5	23.3	.28	.01	.09	.55	.07
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Age Since Rebuild (Days)																
No Rebuild	1320	.71	.66	.83	641	.00	—	—	5.7	10.3	10.3	.65	.00	.28	.01	.06
8 - 105	177	.78	.34	.08	1139	1.00	.20	79	16.4	19.8	4.2	.53	.00	.04	.00	.43
105 - 144	177	.75	.45	.11	1151	1.00	.47	125	15.3	16.4	5.4	.59	.01	.14	.00	.27
144 - 194	177	.77	.39	.09	1193	1.00	.47	169	13.9	17.9	4.3	.57	.00	.07	.00	.36
194 - 255	176	.75	.45	.10	1213	1.00	.52	222	14.5	15.5	4.9	.66	.00	.08	.00	.26
255 - 373	177	.79	.72	.16	1306	1.00	.71	307	11.5	17.6	6.0	.63	.00	.14	.00	.23
373 - 1467	177	.77	.44	.07	1341	1.00	.63	465	13.4	21.6	9.6	.27	.00	.13	.00	.60
Data Missing	204	.74	.25	.43	718	—	—	—	9.3	15.4	21.6	.30	.01	.09	.09	.51
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Time on Site (Months)																
0	250	.73	.56	.88	487	.08	.02	214	.8	6.8	6.1	.53	.00	.36	.02	.09
0.1 - 0.8	365	.79	.32	.34	659	.31	.22	194	.3	7.6	6.1	.70	.00	.12	.01	.17
0.8 - 7.0	365	.73	.74	.64	859	.34	.24	259	3.8	12.9	10.8	.61	.01	.25	.00	.13
7.0 - 13.0	366	.71	.72	.56	987	.40	.27	247	10.3	15.5	12.8	.61	.00	.24	.00	.15
13.0 - 19.0	366	.73	.49	.43	1084	.57	.28	249	15.8	14.5	8.5	.68	.00	.13	.00	.19
19.0 - 48.0	365	.78	.31	.08	1228	.93	.20	193	24.1	22.4	6.1	.48	.00	.07	.00	.45
Data Missing	508	.69	.66	.66	834	.39	.28	261	—	13.6	8.5	.47	.00	.21	.04	.28
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18

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Table 10 — continued

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Total Guidance Unit Operating Time (Hrs)[b]																
.7 - 4.3	337	.77	.37	.54	585	.18	.11	215	2.6	2.9	2.7	.75	.00	.11	.01	.12
4.3 - 6.6	337	.74	.52	.55	751	.29	.16	232	6.4	5.5	4.7	.67	.01	.16	.01	.16
6.6 - 9.9	337	.73	.56	.56	883	.42	.26	223	9.2	8.2	5.9	.62	.00	.19	.01	.18
9.9 - 14.3	337	.73	.65	.49	1020	.52	.24	243	12.1	11.9	7.6	.64	.00	.18	.00	.18
14.3 - 21.2	337	.70	.56	.47	1033	.55	.21	207	13.5	17.5	10.3	.51	.01	.24	.00	.24
21.2 - 245.5[c]	337	.75	.48	.28	1119	.69	.23	222	15.0	36.9	16.7	.50	.00	.17	.00	.33
Data Missing	563	.72	.63	.58	877	.47	.33	247	7.5	-	14.8	.44	.003	.25	.03	.28
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Guidance Unit Operating Time (Hrs)[d]																
0.4 - 2.4	368	.75	.40	.19	985	.74	.39	186	11.2	11.3	1.8	.75	.00	.04	.00	.22
2.4 - 3.2	368	.80	.38	.20	1041	.74	.25	204	11.9	12.7	2.8	.64	.00	.07	.00	.29
3.2 - 4.5	368	.74	.49	.33	1011	.65	.27	245	10.4	12.1	3.8	.57	.00	.11	.01	.31
4.5 - 7.0	367	.77	.52	.53	798	.32	.17	270	7.3	9.6	5.6	.58	.01	.20	.01	.20
7.0 - 13.2	367	.72	.66	.78	783	.16	.09	271	8.7	11.5	9.6	.59	.00	.28	.01	.12
13.2 - 257.9[e]	367	.65	.72	.74	878	.19	.16	296	10.0	25.8	27.8	.56	.01	.34	.00	.09
Data Missing	380	.71	.65	.80	720	.27	.23	250	4.7	-	-	.37	.01	.29	.05	.29
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18
Crew Type																
Annual Service	1493	.76	.58	.52	870	.40	.22	209	9.1	12.1	7.4	1.00	.00	.00	.00	.00
Army Ordnance	9	.78	.78	.88	726	.14	.00	139	8.6	11.7	11.7	.00	1.00	.00	.00	.00
Field Training Prog.	494	.64	.83	.80	801	.22	.21	258	6.8	14.9	13.5	.00	.00	1.00	.00	.00
Contractor	117	.73	.07	.92	237	.00	.00	-	0.3	11.1	11.1	.00	.00	.00	1.00	.00
Crew Data Missing	472	.75	.26	.08	1105	.83	.25	248	13.7	18.1	7.8	.00	.00	.00	.00	1.00
Total	2585	.74	.55	.50	894	.45	.22	228	9.6	13.8	8.6	.58	.00	.19	.05	.18

[a]See p.39 for key to boxheads.
[b]Total time since manufacture.
[c]86 per cent of this group is between 21 and 40 hours.
[d]Time since rebuild or since manufacture if no rebuild occurred.
[e]84 per cent of this group is between 13 and 30 hours.

Appendix C

SUPPLEMENTARY TABLES

Tables 11-17 correspond to Tables 2-8 in the text and provide complete data for the three crew groupings: Annual Service, Training Program, and others. The last group comprises Contractor and Army Ordnance crews, and covers those firings for which crew data were missing. These tables include the data for firings with unknown rebuild status, which were omitted in Table 2-8. Missile firings which failed because of malfunctions in the propulsion system have been deleted from these tables.

Table 11

RELIABILITY AS A FUNCTION OF DATE OF FIRING: CREW, DATE OF MANUFACTURE, AND REBUILD STATUS CONTROLLED

		Aug 52-Apr 54						Apr 54-Dec 54						Dec 54-Feb 58					
		Non-rebuilt		Rebuilt		Rebuild Status Missing		Non-rebuilt		Rebuilt		Rebuild Status Missing		Non-Rebuilt		Rebuilt		Rebuild Status Missing	
Crew Type	Date of Firing	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
Annual Service	Apr 54-Aug 56	224	162	3	1	8	6	212	170	1	1	0	0	31	28	0	0	0	0
	Aug 56-Oct 57	64	51	119	91	2	1	91	69	91	76	12	8	75	57	10	6	17	12
	Oct 57-Nov 58	0	0	109	90	2	2	1	1	125	95	0	0	131	110	102	86	10	9
	Data Missing	1	0	0	0	3	3	1	1	0	0	2	2	1	1	0	0	4	2
	Total	289	213	231	182	15	12	305	241	217	172	14	10	238	196	112	92	31	23
Training Program	Apr 54-Aug 56	165	102	2	0	3	3	61	40	0	0	0	0	17	15	0	0	0	0
	Aug 56-Oct 57	51	35	54	47	5	4	46	28	35	25	4	3	0	0	0	0	5	4
	Oct 57-Nov 58	0	0	3	2	0	0	0	0	7	6	0	0	0	0	0	0	0	0
	Data Missing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	216	137	59	49	8	7	107	68	42	31	4	3	17	15	0	0	5	4
Contractor, Army Ordnance, and Crew Data Missing	Apr 54-Aug 56	21	16	0	0	3	2	14	7	0	0	0	0	6	3	0	0	13	12
	Aug 56-Oct 57	3	1	19	13	0	0	5	2	63	38	3	3	11	8	7	5	7	3
	Oct 57-Nov 58	1	0	28	23	0	0	1	1	135	108	1	1	30	25	128	102	3	3
	Data Missing	0	0	0	0	2	2	0	0	0	0	5	3	0	0	0	0	84	64
	Total	25	17	47	36	5	4	20	10	198	146	9	7	47	36	135	107	107	82

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Table 12

RELIABILITY AS A FUNCTION OF AGE OF MISSILE; CREW, MODEL, AND REBUILD STATUS CONTROLLED

Crew Type	Missile Age (Days)	Old Model: Non-Rebuilt N	Old Model: Non-Rebuilt S	Old Model: Rebuilt N	Old Model: Rebuilt S	Old Model: Rebuild Status Missing N	Old Model: Rebuild Status Missing S	New Model: Non-Rebuilt N	New Model: Non-Rebuilt S	New Model: Rebuilt N	New Model: Rebuilt S	New Model: Rebuild Status Missing N	New Model: Rebuild Status Missing S
Annual Service	7- 702	293	226	2	2	5	4	182	156	21	18	19	14
	702-1109	283	215	96	74	9	5	55	39	35	28	8	7
	1110-2002	16	12	350	278	9	8	0	0	56	46	0	0
	Data Missing	2	1	0	0	6	5	1	1	0	0	4	2
	Total	594	454	448	354	29	22	238	196	112	92	31	23
Training Program	7- 702	147	95	1	0	3	3	17	15	0	0	0	0
	702-1109	165	104	33	22	5	4	0	0	0	0	5	4
	1102-2002	11	6	67	58	4	3	0	0	0	0	0	0
	Data Missing	0	0	0	0	0	0	0	0	0	0	0	0
	Total	323	205	101	80	12	10	17	15	0	0	5	4
Contractor, Army Ordnance, and Crew Data Missing	7- 702	30	19	0	0	3	2	43	34	4	4	19	16
	702-1109	10	6	41	25	2	2	4	2	47	35	3	2
	1110-2002	5	2	202	155	2	2	0	0	84	68	1	0
	Data Missing	0	0	2	2	7	5	0	0	0	0	84	64
	Total	45	27	245	182	14	11	47	36	135	107	107	82

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Table 13

RELIABILITY FOR REBUILT MISSILES AS A FUNCTION OF DATE OF REBUILD: CREW AND MODEL CONTROLLED

Crew Type	Missile Rebuild Date	Old Model N	Old Model S	New Model N	New Model S
Annual Service	Mar 12, 1954 - Mar 14, 1957	193	148	8	5
	Mar 14, 1957 - Sep 20, 1957	189	153	15	13
	Sep 20, 1957 - July 2, 1958	70	57	92	76
	Data Missing	25	18	28	21
	Total	477	376	143	115
Training Program	Mar 12, 1954 - Mar 14, 1957	83	65	0	0
	Mar 14, 1957 - Sep 20, 1957	18	15	0	0
	Sep 20, 1957 - July 2, 1958	0	0	0	0
	Data Missing	12	10	5	4
	Total	113	90	5	4
Contractor, Army Ordnance, and Crew Data Missing	Mar 12, 1954 - Mar 14, 1957	47	33	13	11
	Mar 14, 1957 - Sep 20, 1957	123	85	5	2
	Sep 20, 1957 - July 2, 1958	75	64	118	95
	Data Missing	14	11	106	81
	Total	259	193	242	189

Table 14

RELIABILITY FOR REBUILT MISSILES AS A FUNCTION OF AGE SINCE REBUILD: CREW AND MODEL CONTROLLED

Crew Type	Missile Age Since Rebuild (Days)	Old Model N	Old Model S	New Model N	New Model S
Annual Service	8 - 144	128	102	64	56
	144 - 255	175	136	37	26
	255 - 1467	145	116	11	10
	Data Missing	29	22	31	23
	Total	477	376	143	115
Training Program	8 - 144	31	23	0	0
	144 - 255	24	19	0	0
	255 - 1467	46	38	0	0
	Data Missing	12	10	5	4
	Total	113	90	5	4
Contractor, Army Ordnance, and Crew Data Missing	8 - 144	42	27	82	63
	144 - 255	77	61	32	26
	255 - 1467	126	94	21	18
	Data Missing	14	11	107	82
	Total	259	193	242	189

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[redacted]

Table 15

RELIABILITY AS A FUNCTION OF TIME ON TACTICAL SITE;
CREW, MODEL, AND REBUILD STATUS CONTROLLED

Crew Type	Time Missile Was On Site (Months)	Old Model						New Model					
		Non-rebuilt		Rebuilt		Rebuild Status Missing		Non-rebuilt		Rebuilt		Rebuild Status Missing	
		N	S	N	S	N	S	N	S	N	S	N	S
Annual Service	0 - 0.8	147	122	52	42	0	0	150	129	14	11	13	10
	0.8 - 13.0	248	186	130	102	8	6	28	21	13	11	7	5
	13.0 - 48.0	81	62	198	160	5	5	49	39	71	57	7	7
	Data Missing	118	104	68	50	16	11	11	7	14	13	4	1
	Total	594	454	448	354	29	22	238	196	112	92	31	23
Training Program	0 - 0.8	81	54	22	17	1	1	16	14	0	0	0	0
	0.8 - 13.0	130	84	34	26	1	1	1	1	0	0	4	4
	13.0 - 48.0	39	23	25	21	4	2	0	0	0	0	1	0
	Data Missing	73	44	20	16	6	6	0	0	0	0	0	0
	Total	323	205	101	80	12	10	17	15	0	0	5	4
Contractor, Army Ordnance, and Crew Data Missing	0 - 0.8	15	10	23	15	2	2	39	31	10	9	3	2
	0.8 - 13.0	21	12	65	50	0	0	5	2	16	14	0	0
	13.0 - 48.0	5	2	126	95	0	0	0	0	104	79	2	1
	Data Missing	4	3	31	22	12	9	3	3	5	5	102	79
	Total	45	27	245	182	14	11	47	36	135	107	107	82

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UNCLASSIFIED/LIMITED [redacted]

Table 16

RELIABILITY AS A FUNCTION OF TIME MISSILE GUIDANCE UNIT WAS OPERATED SUBSEQUENT TO REBUILD, OR SINCE NEW IF NO REBUILD OCCURRED; CREW, MODEL, AND GUIDANCE-UNIT REBUILD STATUS CONTROLLED

Crew Type	Time Guidance Unit Was Operated (Hours)	Old Model						New Model					
		Non-rebuilt		Rebuilt		Rebuild Status Missing		Non-rebuilt		Rebuilt		Rebuild Status Missing	
		N	S	N	S	N	S	N	S	N	S	N	S
Annual Service	0.4 - 3.2	69	54	258	104	11	11	91	77	65	52	2	1
	3.2 - 7.0	155	123	116	91	10	9	97	84	30	26	1	1
	7.0 - 257.9[a]	297	220	22	16	6	4	77	55	6	4	1	1
	Data Missing	25	20	25	21	77	57	2	2	2	2	7	6
	Total	546	417	421	332	104	81	267	218	103	84	11	9
Training Program	0.4 - 3.2	13	9	20	12	0	0	1	1	0	0	0	0
	3.2 - 7.0	55	39	44	35	4	4	5	5	0	0	1	1
	7.0 - 257.9[a]	175	113	21	16	1	1	13	10	0	0	1	1
	Data Missing	20	12	7	6	76	48	0	0	0	0	1	1
	Total	263	173	92	69	81	53	19	16	0	0	3	3
Contractor, Army Ordnance, and Crew Data Missing	0.4 - 3.2	4	2	107	84	2	2	7	6	66	55	1	1
	3.2 - 7.0	18	14	105	68	0	0	30	24	42	31	2	2
	7.0 - 257.9[a]	30	18	18	17	1	0	17	9	16	14	2	2
	Data Missing	1	0	4	4	14	11	33	27	0	0	73	54
	Total	53	34	234	173	17	13	87	66	124	100	78	59

[a]Approximately 92 per cent of these groups are between 7 and 30 hours.

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Table 17

RELIABILITY FOR MISSILES WITH REBUILT GUIDANCE UNITS, AS A FUNCTION OF TOTAL TIME GUIDANCE UNIT WAS OPERATED BOTH BEFORE AND AFTER REBUILD; CREW AND MODEL CONTROLLED

Crew Type	Total Time Guidance Unit Was Operated (Hours)	Old Model						New Model					
		Non-rebuilt		Rebuilt		Rebuild Status Missing		Non-rebuilt		Rebuilt		Rebuild Status Missing	
		N	S	N	S	N	S	N	S	N	S	N	S
Annual Service	0.7 - 6.6	211	165	70	51	1	1	174	151	12	9	0	0
	6.6 - 14.3	161	118	156	125	5	5	58	44	33	25	1	1
	14.3 - 245.5[a]	135	103	122	97	8	7	16	9	51	44	1	1
	Data Missing	39	31	73	59	90	68	19	14	7	6	9	7
	Total	546	417	421	332	104	81	267	218	103	84	11	9
Training Program	0.7 - 6.6	62	43	14	7	0	0	5	5	0	0	1	1
	6.6 - 14.3	84	59	19	13	1	1	10	8	0	0	0	0
	14.3 - 245.5[a]	66	51	38	29	2	2	0	0	0	0	0	0
	Data Missing	31	20	21	20	78	50	4	3	0	0	2	2
	Total	263	173	92	69	81	53	19	16	0	0	3	3
Contractor, Army Ordnance, and Crew Data Missing	0.7 - 6.6	20	15	42	27	0	0	25	20	14	13	1	1
	6.6 - 14.3	16	11	77	57	1	1	12	9	19	17	0	0
	14.3 - 245.5[a]	15	7	83	70	0	0	6	3	85	65	1	1
	Data Missing	2	1	27	19	16	12	44	34	6	5	76	57
	Total	53	34	234	173	17	13	87	66	124	100	78	59

[a]Approximately 88 per cent of these groups are between 14 and 40 hours.

[redacted]