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CONVAIR DIVISION OF GENERAL DYNAMICS CORPORATION

DEVELOPMENT AND EVALUATION OF A SHAKE TEST PROCEDURE FOR MEASUREMENT OF RP-1 FUEL FOAM FORMATION

REPORT NO. 27E 1546

GENERAL DYNAMICS ASTRONAUTICS
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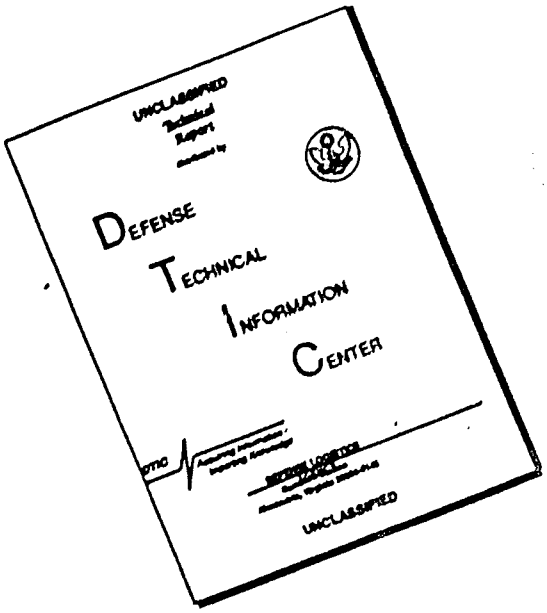

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INTRODUCTION:

Recent problems with undesirable foaming of RP-1 fuel at several missile bases have revealed a need for a rapid and simple test to measure the foam formation characteristics of the fuel. After taking into consideration the limited facilities and laboratory trained personnel available at "D" and "E" Series bases, the Propellant Utilization Group (P/U Group), Department 535-3, requested a study be made to determine if a simple but accurate shake test could be developed. A procedure was developed, followed by a revision, for testing the foam formation of RP-1 fuel by shaking a fuel sample in a container. The original procedure utilized an "unguided" shaking technique (ML-563-1-61-242) while the revision utilized a "guided" shaking technique (ML-563-1-62-40).

OBJECTIVES:

To develop and evaluate an RP-1 fuel shake test procedure (and any revisions) with respect to the following parameters:

1. It should correlate to the P/U Group's satisfaction with the results of the Materials Test Laboratory Nitrogen Diffusion Test (ML-563-1-62-90).

2. It should have a repeatability range limit of ± 20%.

3. It should be simple in scope such that an engineer or technician with no previous experience could learn to satisfactorily perform the test within a short period of time.

4. It should use test equipment which can be easily procurred or presently available at each "D" and "E" Series site.

CONCLUSIONS:

It is concluded that, at the present time, the reliable measurement of foam formation characteristics of RP-1 fuel by inducing foam through shaking a sample in a container, doesn't satisfactorily meet all parameters investigated, as detailed below.

A rough correlation with the Materials Test Laboratory Nitrogen Diffusion Test is possible, however, the 0.999 probability limits (with 90% confidence) are extremely high for many samples (Figure 2 and Table III).

The repeatability range (based on 0.999 probability with 90% confidence) exceeded the maximum limits by a significant degree (Figure 2 and Table III). Taken alone the shake test doesn't appear to be adequate as a basis for establishing an acceptance level of foam formation for RP-1 fuel at the present time.

The original procedure and its revision are relatively simple to perform without previous experience. The revised (or guided) shake test appeared to be the easiest for operators with no experience to learn in a short period of time.

The equipment required for both procedures is simple, inexpensive and easily procured, with one exception, from most laboratory equipment distributors. (Refer to Discussion of Results for details.)

RECOMMENDATIONS:

Although the use of the shake test procedures alone may not be feasible, it appears likely that the test may have some value as a guide. The shake tests could be used to determine the general foam formation level of RP-1 fuel at the sites. The definitely low - foaming and high - foaming fuels as determined by limits set by the P/U Group, could be identified without further testing. Those fuels within a marginal area could then be sent to a laboratory facility for testing by the Materials Test Laboratory Nitrogen Diffusion Test. The shake tests would also have value as a simple means of monitoring the foam formation level, to detect any sudden and unexpected large changes in the fuel, i.e., introduction of foam producing contamination.

SPECIMENS:

The material tested consisted of 75 available samples of RP-1 fuel, as received from 6 missile bases including Edwards Rocket Site, Fairchild AFB, Forbes AFB, Offutt AFB, Vandenberg AFB and Warren AFB.

PROCEDURE:

A. Establishment of an initial shake test procedure

1. The Materials Test Laboratory Nitrogen Diffusion Test (ML-563-1-62-80) was used as a guide to begin this study. The same volume (200 ml.) of RP-1 fuel, the same temperature (70 ± 1°F), and the same technique of measuring bridge retention were used initially. A preliminary shaking rate was established which produced a volume of foam equal to or greater than that produced by the Nitrogen Diffusion Test.

2. Each of these parameters was taken one at a time, holding the remaining parameters constant, and investigated to obtain the most consistent results. The volume of the fuel samples was varied from 150-350 ml. Glass and polyethylene containers of selected sized and configurations were tested. Tests were conducted at 45 ± 1°F. The shaking rate was increased and decreased. Holding the shaking rate constant, a) the length of time for shaking was varied from 2 to 30 seconds and b) the shaking force was increased and decreased. Measurements of surface retention (time interval from termination of shaking until the fuel surface is no longer completely covered by bubbles) and length of time for complete dissipation of bubbles were made. The number of foam formation measurements required for each sample was set. A satisfactory container cleaning procedure was developed and included in the test procedure.

B. Development of the shake test procedure

1. Preliminary test results were gathered using two technicians and 18 different fuels. The test procedure at this point was then conducted by seven laboratory personnel who had had no previous contact with the testing personnel and also one engineer with no laboratory experience. Observations were made as to points in the procedure which were unclear or easily misunderstood.

The procedure at this stage (ML-563-1-61-242, "Unguided" Shake Test) was sent to Warren AFB site as an experimental test in the field. The results of five on-site operators were reported back by L. McKee, GD/Astronautics Quality Control, shortly thereafter (Table I).

During a related fuel test study at Vandenberg AFB, OSTF #1, ca. 35 samples were tested by one operator using the Materials Test Laboratory Nitrogen Diffusion Test and the unguided shake test procedure. Additional data was collected from 3 on-site personnel who also conducted the shake test using selected samples (Table I).

2. The facilities available at each site for use in testing RP-1 fuel by the shake test procedure were studied. Discussions with the Propellant Loading and Propellant Utilization Groups, and a study of site facility schematics were made.

3. To more closely control the shake test and to enable personnel to more quickly learn and perform the test, a revision was made. This consisted, in the main, of controlling the guide path of the container with the aid of a container clamp and a guide rod (ML-563-1-62-49, Figure 1).

C. Evaluation of the shake test procedure

1. A comparison of the "Unguided" Shake Test Procedure (ML-563-1-61-242) and the "Guided" Shake Test Procedure (ML-563-1-62-49) was made, using the Materials Test Laboratory Nitrogen Diffusion Test as the reference value. The comparison was made and the repeatability limits were determined by the following tests:

   a. Five operators determined the Bridge Retention time with a fresh sample of the same fuel by both shake test procedures. This sequence was repeated three additional times, using three other fuels. This series was carried out to compare the results of the MTL Nitrogen Diffusion test and both shake test procedures as well as to determine the reproducibility of the tests.

b. One operator determined the Bridge Retention time for five (5) additional fuels by both shake tests to provide more complete coverage for correlation purposes.

c. One operator determined the Bridge Retention time three separate times by the guided shake test, using fresh samples of the same fuel. This sequence was repeated with two additional fuels. This series was carried out to determine repeatability of the procedure.

d. In all series, a reference Bridge Retention time was determined for each fuel by the Materials Test Laboratory Nitrogen Diffusion test. One value for each fuel sample was determined as per ML-563-1-62-90.

RESULTS:

1. The unguided shake test procedure (ML-563-1-61-242) contains the parameters which were developed initially, i.e. temperature, shaking rate and time, container used, etc.

2. The results of on-site and off-site testing are shown in Table I.

3. All "D" and "E" series sites concerned at present have a utility building, hot and cold running water and a sink for use as a water bath. Where ice isn't available to help control the bath temperature, adequate frost can be obtained from layers which form on the LOX lines.

4. Figure 1 is a summary of all test data correlating the Shake Test procedures and the Materials Test Laboratory Nitrogen Diffusion test. This graph includes the data from ML-563-1-61-242 (Unguided Shake Test Procedure), from 37 fuel samples taken at OSTF #1 during a fuel contamination test study and from ML-563-1-62-49 (Guided Shake Test Procedure).

Table II contains the test results for (a) fuels tested with both shake procedures by five operators and (b) fuels tested three times by one operator with the guided shake test procedure.

Table III contains test results and calculated probability limits for the seven (7) fuels tested in Table II. All bridge retention measurements for each fuel, guided and unguided, are recorded together in order to calculate the probability limits.

Figure 2 shows the relationship between the shake test values and the probability limits for the seven (7) fuels tested.

Figure 3 shows the correlation between the guided shake test and the MTL Nitrogen Diffusion Test with probability limits shown.

DISCUSSION OF RESULTS:

One piece of equipment (the container guide clamp), which consists of four (4) small parts, would have to be assembled by GD/Astronautics or off-site personnel for the revised (guided) shake test procedure (ML-563-1-62-49). Facility items such as present and pending sampling points, present hot and cold water sources, and any deep sink can be utilized as proper equipment.

A satisfactory RP-1 fuel sampling procedure is being prepared at the present time by Department 535-3 for site use. This procedure is to be used as soon as it is available at the sites.

Table 1 illustrates the spread of data when personnel of various occupations, with and without laboratory experience, conduct the shake test. This data emphasizes that the shake test could be used to determine the general foam formation level of RP-1. If more specific discrimination is necessary, the forwarding of a sample for testing by the Materials Test Laboratory Nitrogen Diffusion Test would follow.

Figure 1 illustrates the broad correlation that exists between the Nitrogen Diffusion test and the two shake test procedures. A definite trend is present. This data gives an extensive cross section of the shake test procedures.

Table II illustrates a) the close comparison between the unguided and guided shake test results for a given fuel, b) the absence of an operator characteristic trend for separate fuels and c) the general comparison between the shake tests and the MTL Nitrogen Diffusion Test.

Table III illustrates the high probability levels (those which exceed 20%) and standard deviations for the fuels tested. The data from all five (5) operators was taken together to absorb any inherent differences in technique.

Figure 2 illustrates a) the general, but somewhat erratic, increase in the probability limits which accompany an increase in Bridge Retention time for the unguided shake test and b) the systematic increase in probability limits with an increase in Bridge Retention time (with one exception) for the guided shake test. Because the guided shake test results were not scattered, as were unguided shake test procedure results, a further study of the guided shake test procedure was made as shown in Figure 3. This data illustrates the broad probability limits of the guided shake test procedure, when calculated as 0.999 probability with 90% confidence.

REFERENCES:

1. ML-563-1-61-242, "Shake Test Procedure for Measurement of RP-1 Fuel Foam Formation," Memo to R. J. Kreisler, 8 Sept. 61.

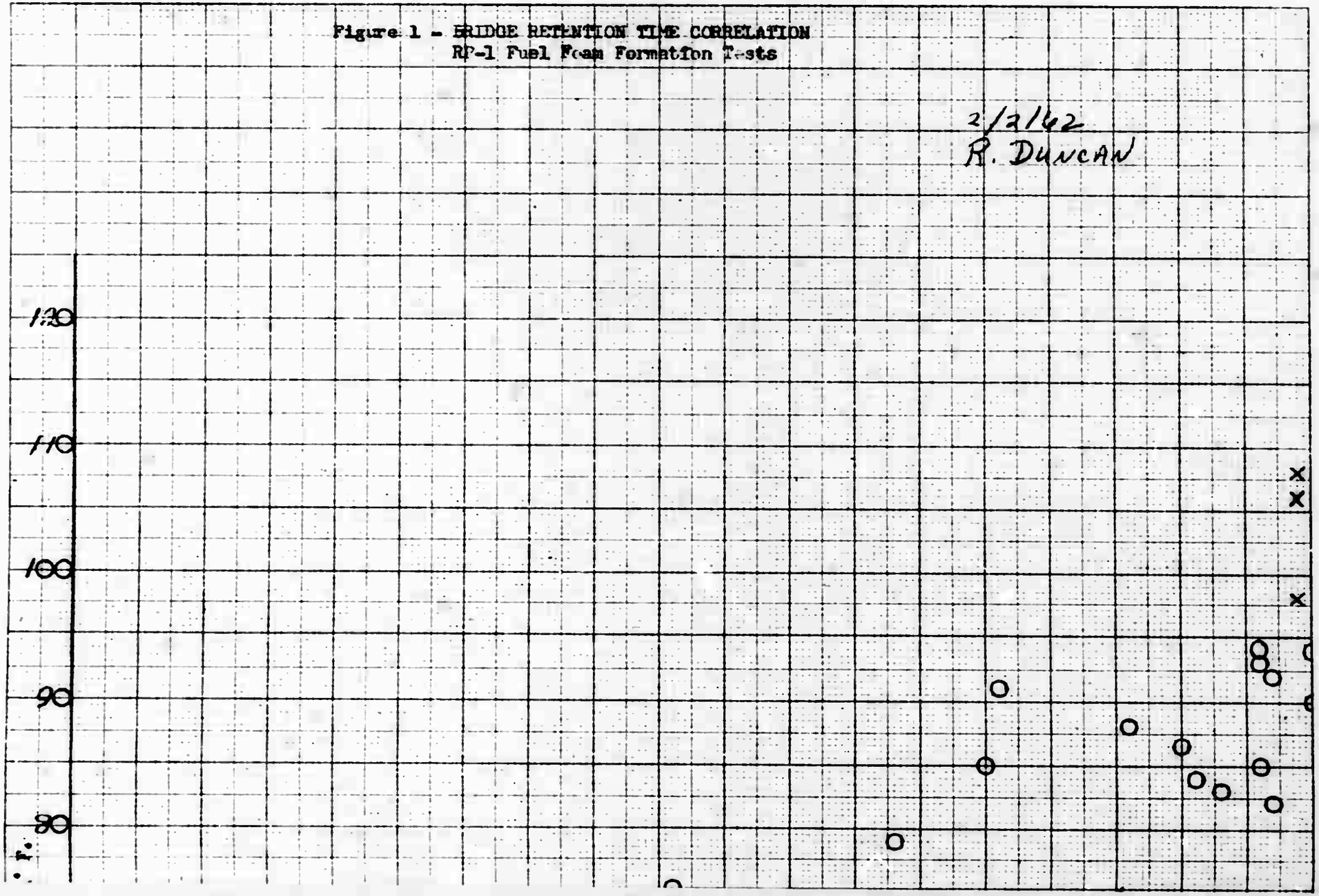
2. ML-563-1-62-19, "Guided Shake Test Procedure for Measurement of RP-1 Fuel Foam Formation", Memo to R. Kreisler, 5 Feb. 62.

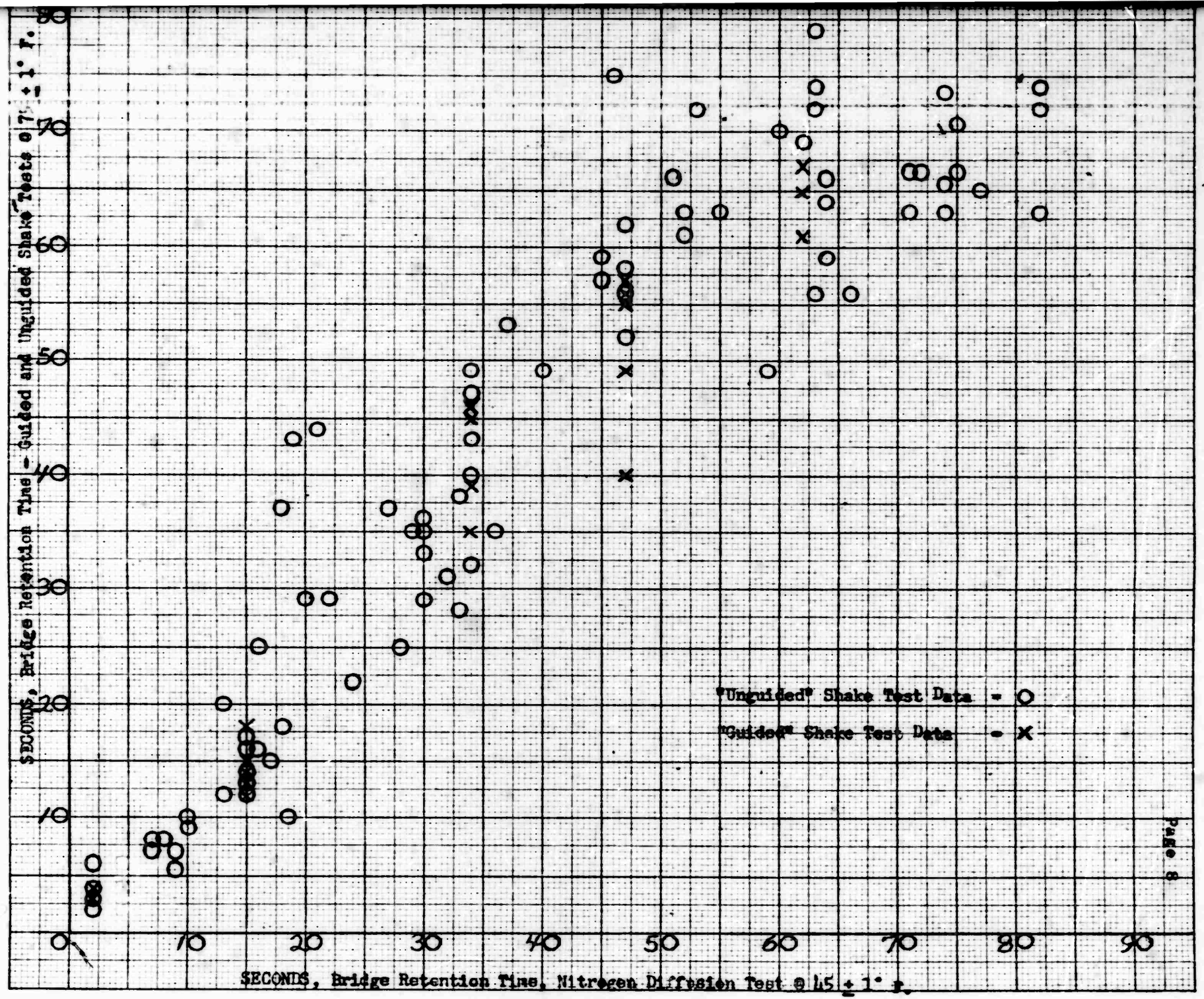
3. ML-563-1-62-90, "Materials Test Laboratory Nitrogen Diffusion Test Procedure for Measurement of RP-1 Foam Formation," 27 Feb. 62.

NOTE: The data from which this report was prepared is recorded in Astronautics Engineering Laboratory Notebook 7856, pp 55-70 and Notebook 7726, pp 31-33, 36-39, 71-73, 86-89 and 94-98.

10 X 10 TO THE INCH 359-11L
KEUFFEL & ESSER CO.

Figure 1 - BRIDGE RETENTION TIME CORRELATION
RP-1 Fuel Foam Formation Tests




SECONDS, Bridge Retention Time - Guided and Unguided Shake Tests @ 7° ± 1° F.
SECONDS, Bridge Retention Time, Nitrogen Diffusion Test @ 45 ± 1° F.
"Unguided" Shake Test Data - O
"Guided" Shake Test Data - X
0
10
20
30
40
50
60
70
80
90

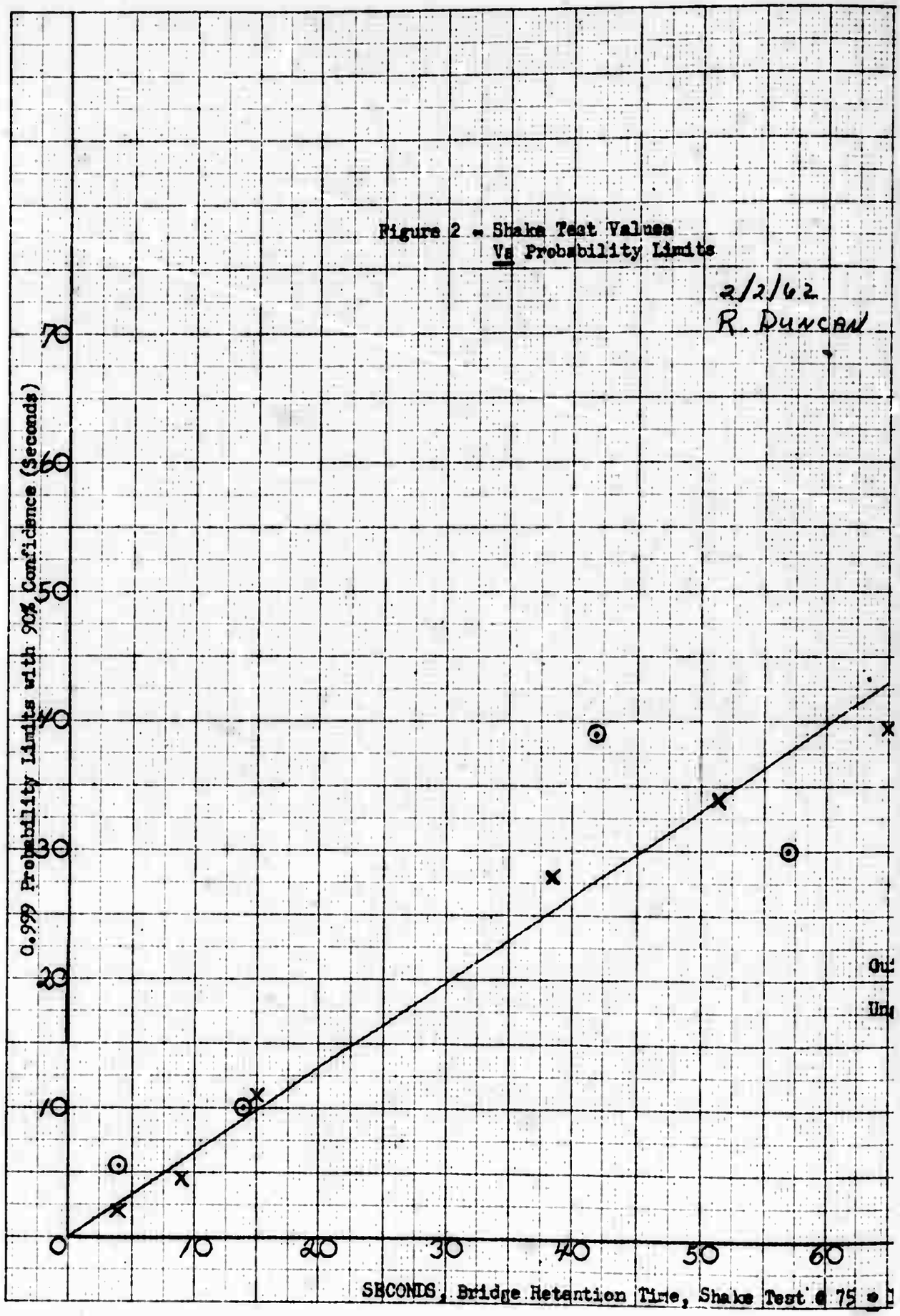


Figure 2 - Shake Test Values
Vs Probability Limits

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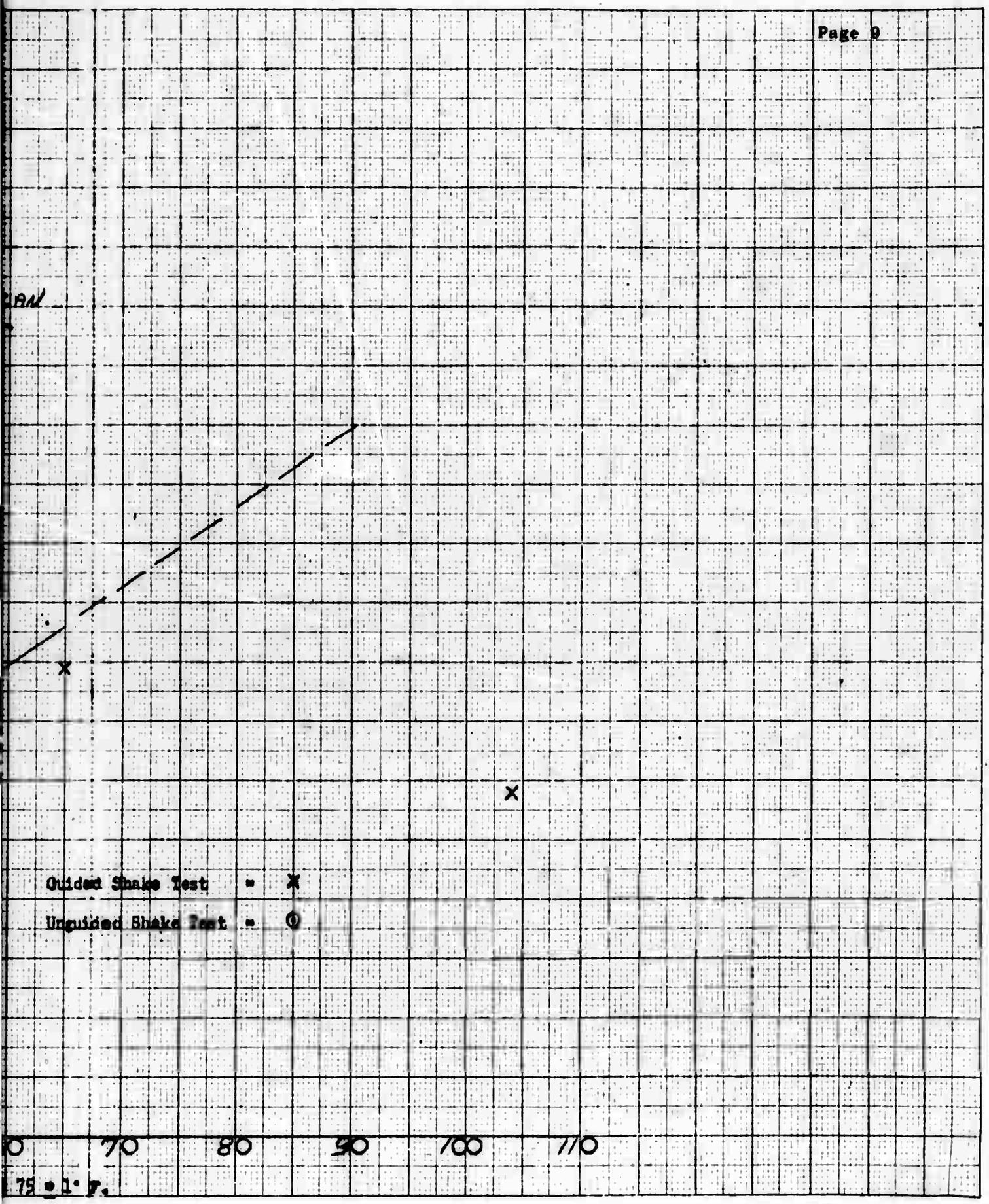
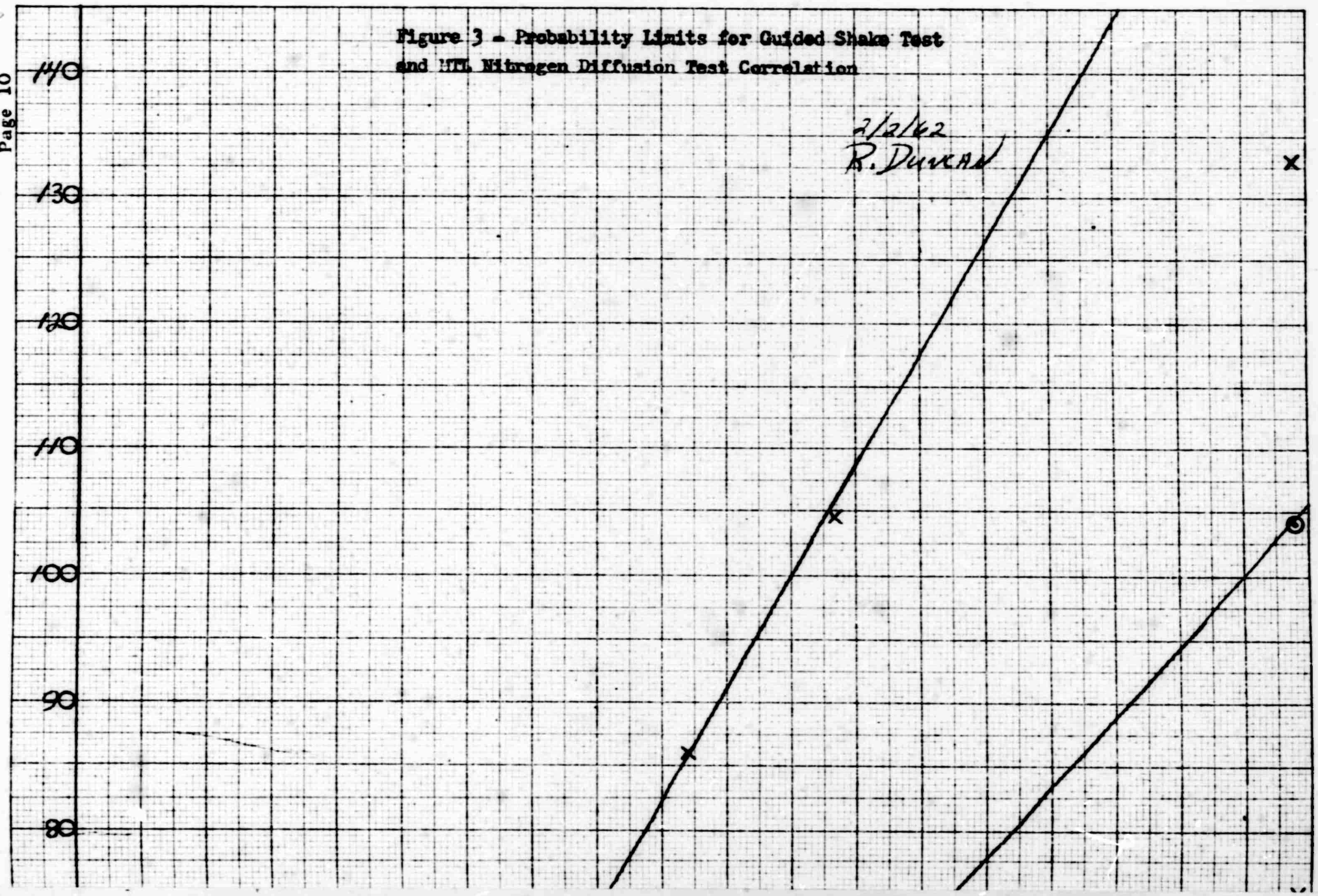

Guided Shake Test = X
Unguided Shake Test = O
70
80
90
100
110

K+E 10 X 10 TO THE ½ INCH 359-11L
KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 3 - Probability Limits for Guided Shake Test and HTL Nitrogen Diffusion Test Correlation



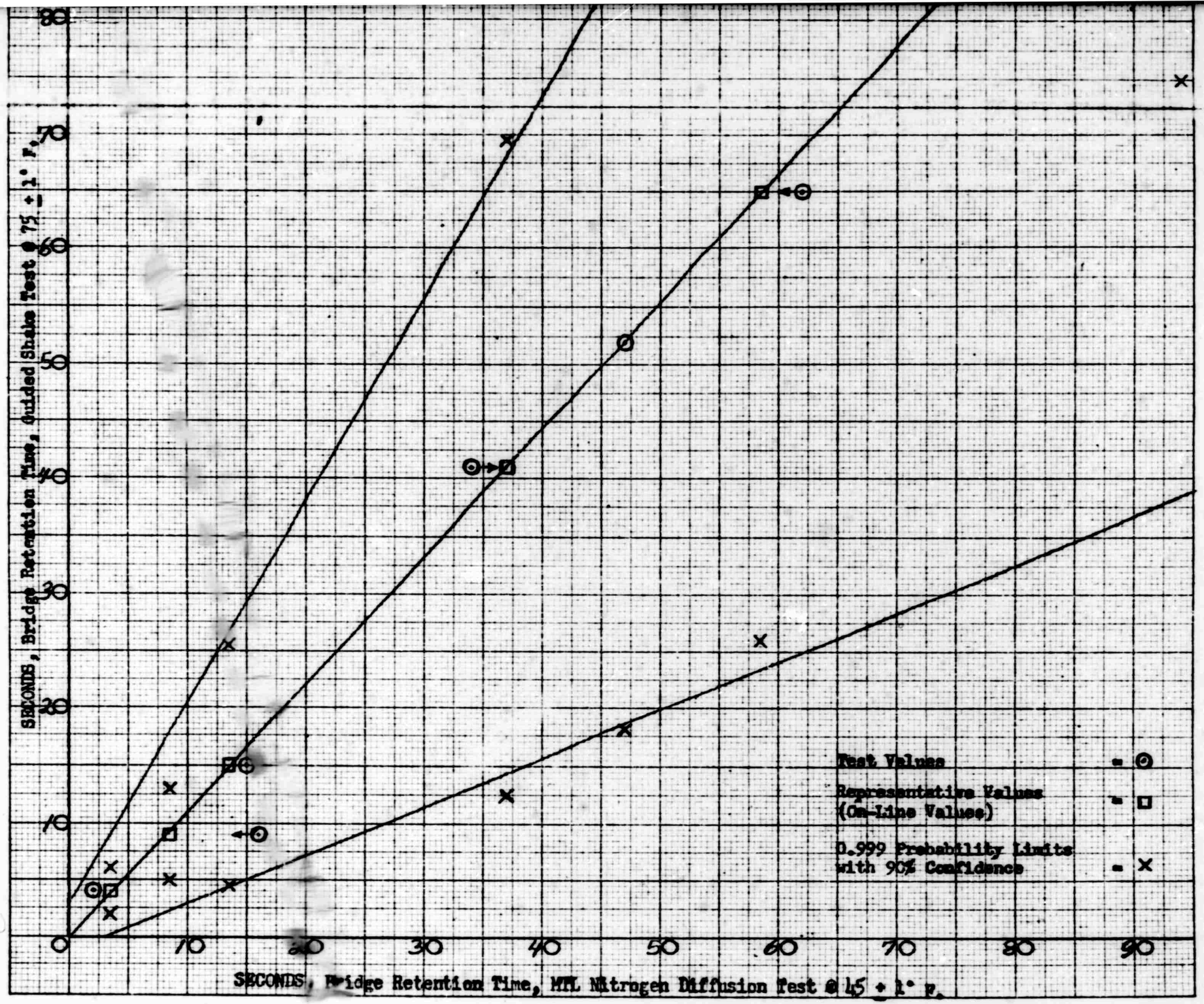

SECONDS, Bridge Retention Time, Guided Shake Test @ 75 ± 1° F.
SECONDS, Bridge Retention Time, MTL Nitrogen Diffusion Test @ 45 ± 1° F.
0
10
20
30
40
50
60
70
80
90
Test Values
Representative Values (On-Line Values)
0.999 Probability Limits with 90% Confidence

TABLE I - Summary of Test Results
From ON-Site and OFF-Site Personnel

SERIES A - ON-Site Personnel

Test Conductors	Fuel Sample 1 (CP2581)	2 (CP3005)	3 (CP3006)	4 (CP3181)	5 (CP3004)	6 (CP3184)
	Ave. Bridge Retention Time (as per ML-563-1-61-242) Sec.					
A. Laboratory Personnel	8				75	
B. " "	8				80	
C. " "		11		66		
D. " "			27			90
E. " "			33			91
F. " "		11		66		
G. " "		14		71		
H. Engineer		11		69		94
-Average of Above Values-	8	12	30	68	78	92
J. Lab Personnel w/ Shake Test Experience	8	10	38	69	75	93

SERIES B - OFF-Site Personnel

Test Conductors	Fuel Sample 1 (CP4159)	2 (O-2b)	3 (O-7d)	4 (O-9b)	5 (O-14a)	----
	Ave. Bridge Retention Time (as per ML-563-1-61-242) Sec.					
A. WAFB Site Personnel	8					
B. " " "	8					
C. " " "	8					
D. " " "	8					
E. " " "	9					
F. VAFB Site Personnel		35	78			
G. " " "		29	72	76	94	
H. " " "		33	74	79	93	
J. GD/A MTL Lab Personnel	10	--	63	74	85	

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TABLE II - Unguided and Guided Shake Test Results as Compared with MTL Nitrogen Diffusion Test Results

FUEL	A		B		C		D	
SHAKE TEST	Bridge Retention Time @ 75± 1° F. (Seconds)							
	Unguided	Guided	Unguided	Guided	Unguided	Guided	Unguided	Guided
Operator #1	4	4	16	14	49	39	64	56
#2	4	4	12	12	32	45	56	57
#3	2	4	13	15	40	46	52	49
#4	3	3	14	18	43	35	58	55
#5	6	4	17	15	47	39	62	40
Average	4	4	14	15	42	41	58	51
Nitrogen Diffusion Test	Bridge Retention Time (Seconds)							
	@75±1°F.	@45±1°F.	@75±1°F.	@45±1°F.	@75±1°F.	@45±1°F.	@75±1°F.	@45±1°F.
Operator #2	2	2	6	15	7	34	7	47

FUEL	E		F		G			
SHAKE TEST	Bridge Retention Time @ 75±1° F. (Seconds)							
	Guided		Guided		Guided			
Operator #2								
Test #1	106		65		8			
#2	108		67		10			
#3	98		61		8			
Average	104		64		9			
Nitrogen Diffusion Test	Bridge Retention Time (Seconds)							
	@75±1°F.	@45±1°F.	@75±1°F.	@45±1°F.	@75±1°F.	@45±1°F.	—	—
Operator #2	54	94	14	62	4	16		

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TABLE III - Unguided and Guided Shake Test Procedure Probability Levels*

		FUEL						FUEL							
		A	B	C	D			A	B	C	D	E	F	G	
UNGUIDED TEST	Average Value for Bridge Retention Time @ 75± 1° F. (Seconds)	4	14	42	57	GUIDED TEST	Average Value for Bridge Retention Time @ 75± 1° F. (Seconds)	4	15	41	52	104	65	9	
	Number of Operators	5	5	5	5		Number of Operators	5	5	5	5	1	1	1	
	Number of Test Values	20	24	40	36		Number of Test Values	20	36	36	36	16	24	16	
	Standard Deviation (Seconds)	1.3	2.4	10.0	7.5		Standard Deviation (Seconds)	0.5	2.8	7.2	8.6	6.5	9.5	1.0	
	0.999 Probability With 90% Confidence (Seconds)	5.6	10	39	30		0.999 Probability With 90% Confidence (Seconds)	2.1	11	29	34	29	40	4.5	
		Bridge Retention Time @ 45± 1° F. (Seconds)													
	TTL Nitrogen Diffusion Test	2	15	34	47			2	15	34	47	94	62	16	

*Technique of Statistical Analysis, Chapter 2, Eisenhart, Hastay & Wallis

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