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RELIABILITY STUDY,

ATLAS

TANK FRAGMENTATION SYSTEM FOR

"F" R&D MISSILES

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INTRODUCTION

The purpose of this report, in accordance with the "Work Statement for Revision of Atlas Tank Fragmentation System for "F" R&D Missiles WAP No. 1798, Contract No. AF04(647)-507", is to present a reliability analysis based on the application of available data for the re-evaluation of critical reliabilities in the modified design of the tank fragmentation system for Atlas "F" R&D missiles. This covers reliability considerations of: (1) probability of retro-rockets firing, (2) probability of proper fragment detonation, (3) probability of inadvertent premature fragmentation detonation, (4) probability of no re-entry vehicle-fragment collision, and (5) reliability testing.

SUMMARY

Evaluation of the results of this study indicate that the inherent reliability of the retro-rockets is greater than 0.99. The intrinsic reliability of the control subsystem meets the design objectives, as shown in the following table:

Control Subsystem

Reliability of	Design Objective	Inherent Reliability
Detonation when required	$\geq$ 0.99	> 0.9986
No inadvertent detonation	$\geq$ 0.9999	0.99998

The probability that a mission failure will occur due to a fragment colliding with the re-entry vehicle was found to be less 0.001 which meets the design objectives. A mission failure occurs when a fragment collides with the re-entry vehicle and the fragment has enough impact energy to introduce > 5 nautical miles deflection from the unobstructed impact point of the re-entry vehicle.

DISCUSSION

1.0 Description of Tank Fragmentation System

1.1 The tank fragmentation system consists of a control subsystem and a destruct unit. The control subsystem is made up of portions of autopilot programmer (A/P), arming device, retro-rocket firing indication microswitches, re-entry vehicle separation switch, and the enable relay in the range safety control assembly (Refer to Fig. II).

1.1.1 The tank fragmentation is designed to operate only if the missile successfully completes its powered flight, separates the re-entry vehicle, fires the retro-rockets, and allows the re-entry vehicle to separate at least 1,000 ft from the missile. This is accomplished by generating a re-entry vehicle separation command in the A/P to disengage the re-entry vehicle from the missile. One second later the A/P generates a retro-rocket fire command through SW 14 and SW 18. SW 14 is used to fire the retro-rockets mounted on the vernier rocket housing, and SW 18 is used to fire the retro-rocket mounted in the B-2 pod. If both vernier retro-rockets and at least one B-2 pod retro-rocket fire, all four retro-rocket covers will be blown off causing four microswitches to close. Once the re-entry vehicle has separated from the missile, the re-entry vehicle separation switch closes causing the +28 VDC battery voltage to energize the enable relay (K3).

1.1.2 Once the enable relay is energized, it provides a path for the destruct signal, which will be generated in the A/P switch 15 approximately 200 seconds after re-entry vehicle separation. The destruct signal will trigger the destruct loops of command receivers 1 and 2 energizing relays k4 and k5 in the arming device closing the path for the destruct signal to trigger the primer in the destruct unit, thus causing the destructor to fragment the missile. The arm-safe contacts are shown in the arm condition in Figure II because this switch must be put in the armed condition before flight.

1.2 From the above description it can be determined that four conditional reliabilities must be analyzed. They are stated as follows:

(1) Reliability of the Separation Subsystem in Tank Fragmentation - The probability that proper re-entry vehicle separation is sensed.

(2) Reliability of Proper Detonation - The probability that if separation occurs the tank fragmentation system will detonate and fragment the missile.

(3) Reliability of the Tank Fragmentation System Preventing an Inadvertent Detonation - The probability that detonation will not occur when not commanded or desired.

(4) <u>Reliability of Proper Fragmentation</u> - The probability that if fragmentation occurs, no fragments will collide with the re-entry vehicle.

2.0 Reliability of the Separation Subsystem in Tank Fragmentation

2.1 Requirements and Operation

The separation subsystem must:

A. Provide sufficient separation distance between re-entry vehicle and missile at the time of fragmentation, such that fragments presumably will not collide with the re-entry vehicle (at least 1,000 ft for a 3,000 nautical mile flight, Reference 1).

B. Inhibit tank fragmentation if proper separation between missile and re-entry vehicle does not occur.

The reliability analysis is primarily based on the retro-rockets and their corresponding microswitch interlocks. Table I shows reliability estimates for single retro-rocket, based on flight and static test results. The data establishes a lower one-tailed 0.90 confidence estimate of 0.9871 for flight tests and 0.9962 for flight and static tests. The data permits the conclusion that the single retro-rocket reliability is at least 0.99 and may well be higher. Although one retro-rocket will produce some re-entry vehicle separation, sufficient separation can only occur when both retro-rockets mounted on the vernier engines and at least one retro-rocket located in the B-2 pod fire. Because each of the four retro-rockets has an interlocked cover and microswitch that closes when the retro-rocket fires, and all four microswitches are connected in series, the separation subsystem is dependent

TABLE I

RELIABILITY ESTIMATES FOR THOR AND ATLAS RETRO-ROCKETS

	Thor[a]	Atlas[a]	Both
Number of flights containing retro-rockets	49	88	137
Number of flights successful to retro-rockets activation (b)	34	55	89
Number of failures of retro-rockets to fire (c)	0	0	0
Total No. of retro-rockets succeeding (d)	68	110	178
Number of retro-rockets firing without failure (e)	230	200	430
Total Number of retro-rockets firing without failure	298	310	608
Estimates of single retro-rocket reliability:			
Point estimates	1.00	1.00	1.00
.90 Confidence estimates, flights only (f)			0.9871
.90 Confidence estimates, flights and static tests (f)			0.9962

Explanations of data:

(a) Flight data on retro-rockets are from the following sources:
Thor - Reference (7)
Atlas - Reference (8)

(b) The difference between row one and row two represent failures occurring in flight before intended separation time.

(c) Failures at or after the time of separation were all reported as other than failure of retro-rockets to ignite. One "E" series Atlas missile failed to separate due to failure of the retro-rockets to fire, but it was determined that the command from the autopilot

(c) **continued**

programmer was fired into a dead short in the cable harness. No retro-rocket ignition failures were reported.

(d) Two retro-rockets are installed in each missile of each type.

(e) Data on static firings are reported in Reference (9) Appendix A.

(f) The Thor and Atlas retro-rockets are similar and are manufactured by the same vendor, and the above data are similar for each type; therefore, confidence estimates can be expressed for the retro-rockets as a class, instead of for each type separately.

2.1 (Continued)

upon the reliability of the microswitch series string. (Either B-2 pod retro-rocket will trigger both B-2 pod covers and micro-switches,

2.2 **Conclusion**

Due to the micro-switches and retro-rocket covers, the separation subsystem's reliability with respect to tank fragmentation is dependent upon the control subsystem and the separation subsystem reliability becomes that of the microswitch string analyzed in paragraph 3.3 of this report. In turn the separation subsystem will become a factor in the analysis of the probability of fragment-re-entry vehicle collision analysis.

3.0 Reliability of Proper Detonation

The model shown in Figure 1, derived from the function schematic shown in Figure 2, can be used to calculate the system probability of detonation, which is the control subsystem reliability.

3.1 Autopilot Programmer (A/P) Analysis

3.1.1 Tank fragmentation is not required unless a successful mission culminating with the re-entry separation from the booster is accomplished. The analysis is, therefore, restricted to determining the probability of portions of the Autopilot Programmer (A/P) operating for approximately 200 seconds, after re-entry vehicle separation, and generating a destruct signal.

3.1.2 For this analysis only the circuitry in the A/P that is needed to generate the actual destruct signal is analyzed. All circuitry is assumed to be serially connected so that any mode of failure of any component would prevent the generation of the destruct signal. Conservatism is provided through the use of failure rates provided in reference 4. Reference A provides failure rates based upon the application and environment of the component, and therefore provides a more rigid analysis than the data used in reference 3. An ambient temperature of 75° C is estimated. Assuming that standard engineering design procedures were used, all capacitor data are taken at 75% maximum rated voltage and all resistor data are taken at 50% maximum rated power dissipation.

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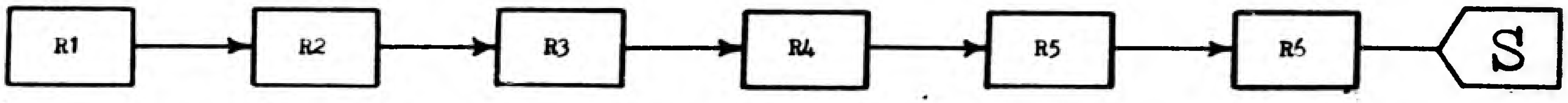
FIGURE I



$$R_S = \prod_{i=1}^{6} R_i$$

Reliability Model Key

R1 = Subsystem control generation
  a. Autopilot Programmer (A/P) and Alternator
  b. Missile Battery & Power Change-over Assembly
R2 = Re-entry vehicle (R/V) Separation Switch
R3 = Retro-rockets firing indication microswitches
R4 = Connector pins and solder connections external to the (A/P)
R5 = Destruct enable relay and Arming Device
R6 = Destructor Assembly

MODEL FOR CALCULATING SUBSYSTEM PROBABILITY OF DETONATION

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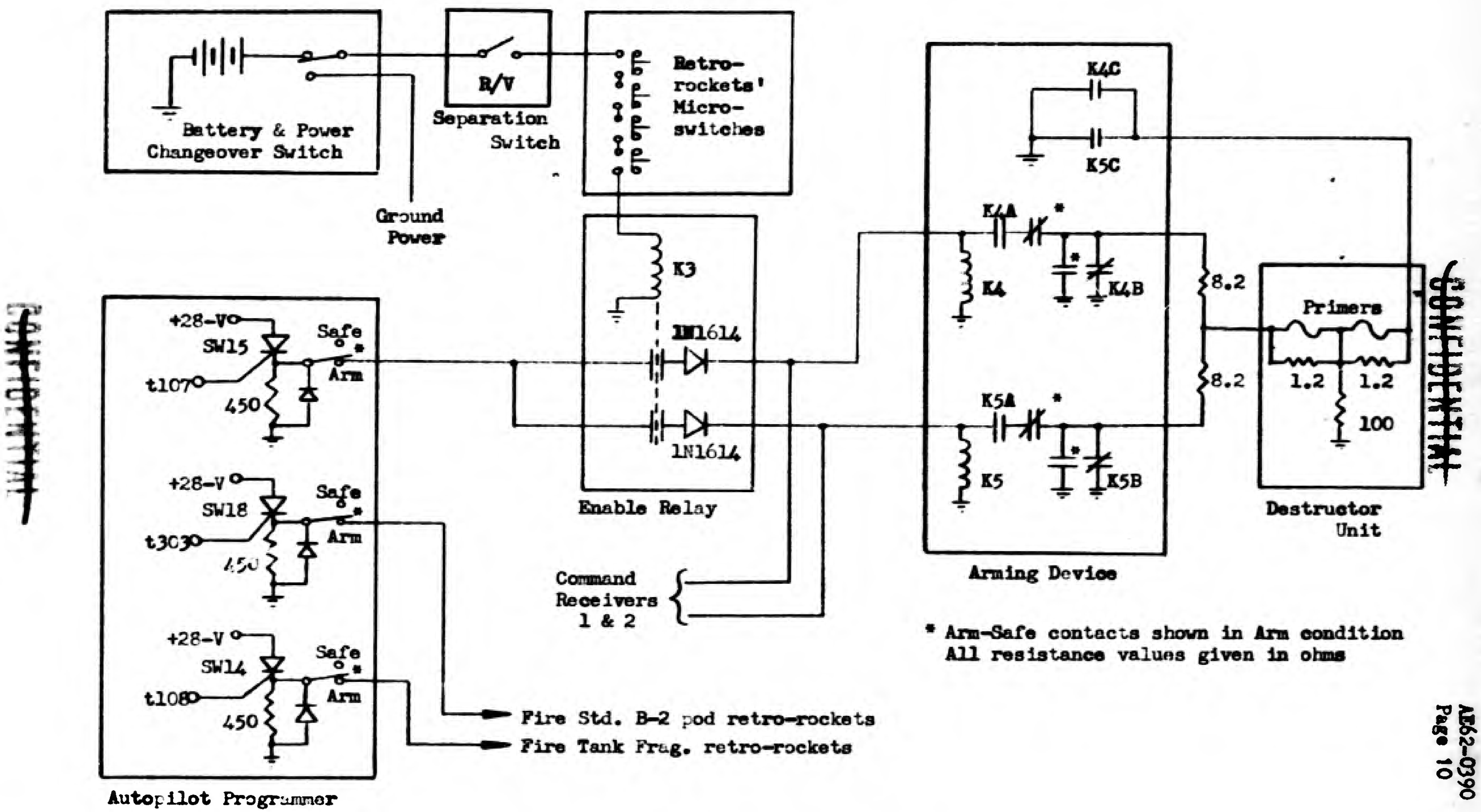
FIGURE II



CONTROL SUBSYSTEM FUNCTIONAL SCHEMATIC

3.1.3 The failure rates per assembly were established using the parts count obtained from the schematics applicable to the generation of the destruct signal and the part generic failure rates (GF_r) provided in reference 4. These failure rates have been tabulated in Appendix 4. The assembly generic failure rates, obtained from Appendix A are summed in Table II to determine the total A/P generic failure rate. The generic failure rate is that failure rate the A/P would have if operated under laboratory conditions at 75°C. To determine the flight failure rate, the generic failure rate is adjusted due to a operation factor (K_{op}). Reference 4 lists that a K_{op} of 100 must be used for hard mounted components in aircraft during flight and a K_{op} of 800 must be used for hard mounted components in missiles during flight. Because the A/P is enclosed and contains circuit boards, a K_{op} of 200 is assumed for this analysis which is about ¼ the hard mounted missile in flight case.

3.1.4 To find the total environmental failure rate of the A/P, the generic failure rate must be corrected with the K_{op} factor (200).

$$F_r\ (A/P) = (200)\ (69.035\ \text{failures}/10^6\ \text{HRS})$$

$$= 13{,}807\ \text{failures}/10^6\ \text{HRS}$$

TABLE II

SUMMARY OF AUTOPILOT PROGRAMMER ASSEMBLY FAILURE RATES

ASSEMBLY		REFERENCE PAGE	$GF_r/10^6$ HRS
Network Logic Assy #1	A1A1	A-2	15.914
Network Logic Assy #3	A2A1	A-3	4.014
Remote Set Programmer	A4	A-4	0.978
High Power Assy	A7A2	A-5	2.772
Counter Unit Sub-Assy	A10A1	A-6	17.248
Counter Assy.	A10A2	A-7	18.509
Diode Assy.	A12A1	A-8	2.170
Diode Assy.	A12A2	A-9	1.557
Programmer, Electronic, Autopilot		A-10	5.873
	Total (A/P) Generic failure rate		69.035

3.1.4 Continued

The alternator F_r (335 Per 10^6hr), obtained from reference C, and the power changeover switch contacts F_r(2 Per 10^6hr), obtained from reference 4, have been added to the (A/P)F_r and the reliability for the (A/P) calculated with the following equations:

$$R(A/P) = e^{-\Sigma\lambda t}$$

$\Sigma\lambda$ = sum of the part failure rates

$$\Sigma\lambda = 14144/10^6 HR = 3.92 \times 10^{-6}/SEC.$$

$$t = 200 \text{ SEC.}$$

3.1.5 The main missile battery has a point reliability of one for 92 flight tests. These tests consider only missile batteries that were flown. In one series "E" flight tests there was an erratic decay in voltage after 414 seconds. According to the flight test report, a marginal battery condition was indicated prior to launch. To estimate the battery failure rate, the following assumptions are made:

1. Detonation would not have occurred in 1 case out of 92.
2. The average battery load time was 500 seconds.
3. The total battery load time was (92x500) 46000 seconds.
4. The probability of battery failure during flight can be reduced by a factor of ten if the pre-launch marginal test tolerances are decreased.

The battery reliability can then be calculated with the following equation:

$$R_B = e^{-0.1\lambda_1 t}$$

$$\lambda_1 = \text{battery failure rate} = \frac{1\ \text{FAIL}}{46{,}000\ \text{SEC}}$$

$$\lambda_1 = 2.18 \times 10^{-5}/\text{SEC.}$$

$$t = 200\ \text{SEC}$$

3.1.6 The reliability of block R1 of Figure I can be calculated from the following equation:

$$R1 = R(A/P) \times R_B = e^{-(\Sigma\lambda + 0.1\lambda_1)t}$$

$$\Sigma\lambda + \lambda_1 = \text{failure rate of R1, Figure I}$$

$$\Sigma\lambda + \lambda_1 = 6.1 \times 10^{-6}/\text{SEC.}$$

$$\alpha_1 = (\Sigma\lambda + \lambda_1)t = 1.21 \times 10^{-3}$$

$$t = 200\ \text{SEC.}$$

3.2 <u>Re-entry Vehicle Separation Switch Analysis</u>

The separation switch is a one shot device that requires only one-half of one cycle of operation to perform its function. The reliability of block R2, Figure II is, therefore, calculated from the failures per cycle for typical microswitches obtained from reference 4.

$$R2 = e^{-\lambda_2 c}$$

$$\lambda_2 = 1.56 \times 10^{-5} \text{ FAILURES/CYCLE}$$

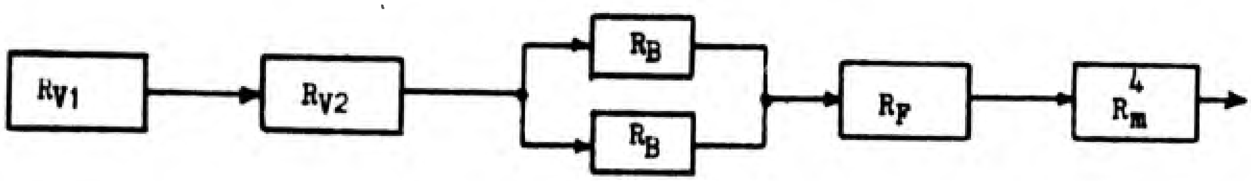
$$C = 0.5 \text{ CYCLE}$$

$$\alpha_2 = \lambda_2 C = 7.8 \times 10^{-6}$$

3.3 **Retro-Rocket Firing Indication Microswitches Analysis**

3.3.1 The retro-rocket firing indication microswitches are four one shot devices connected in series to prevent the enable relay from energizing unless proper re-entry vehicle separation occurs (refer to Figure II). The mathematic model for block R3, Figure I is shown in Figure III.

FIGURE III



$$R3 = R_{V1}\, R_{V2}\, R_F\, R_m^4 \left[1 - (1 - R_B)^2\right]$$

MODEL FOR CALCULATING R3 PROBABILITY OF SUCCESS

Reliability Model Key

$R_{V1} = R_{V2} =$ Vernier Engine Retro-rockets and Covers Reliability.
$R_B =$ B-2 Pod Retro-rockets and Covers Reliability.
$R_{F_4} =$ B-2 Pod Retro-rocket Covers Reliability.
$R_m =$ Series String of Microswitches Reliability.

3.3.2 The retro-rocket reliability for this analysis must be unity because the conditional reliability of proper detonation assumes that the re-entry vehicle separates properly from the tank section; therefore, the expression for R3 reduces to:

$$R3 = R_{VC}^{2} R_{F} R_{m}^{4}$$

where: R_{VC} is the reliability of the vernier engine retro-rocket cover.

3.3.3 The failure rate of the vernier engine retro-rocket covers is estimated to be zero, because each cover requires approximately 0.5 psi pressure difference blow off and if the retro-rocket fires it will apply a much greater pressure on the cover. The B-2 pod covers (2), because of their location with respect to the retro-rockets, summed failure rate is estimated to be 0.2 failures per million hours. These estimates are based on the simplicity of construction and inherent characteristics of the retro-rocket covers.

3.3.4 The reliability of each of the microswitches is calculated from the failures per cycle for typical microswitches obtained from Reference 4. The reliability of block R3 is calculated with the following equations:

$$R3 = R_F R_m^4 = e^{-\alpha_3}$$

$$\alpha_3 = 4\lambda_m c + \lambda_F t$$

$\lambda_m = 1.56 \times 10^{-5}$ FAILURES/CYCLE

$C = 0.5$ CYCLE

$\lambda_F = 5.56 \times 10^{-11}$ FAILURES/SEC.

$t = 200$ SEC.

$\alpha_3 = 3.121 \times 10^{-5}$

$R3 > 0.9995$

3.4 <u>Connector Pins and Solder Connections Analysis</u>

The connectors and solder connections in the A/P unit have been included in the analysis of paragraph 3.1. There are 25 additional connector pins and approximately 100 solder connections, some of which are redundant, but for this analysis they are assumed serially connected so that a failure of any connection would cause a subsystem failure. The Reliability of block R4 can then be calculated from the following equation the data from Reference 4:

$$R4 = e^{-\alpha_4}$$

where: $\alpha_4 = (\lambda_p + \lambda_s)t$

λ_p = connector failure rate

$\lambda_p = 3.48 \times 10^{-9}$ failures/sec

λ_s = solder connection failure rate

$\lambda_s = 5.56 \times 10^{-9}$ failures/sec

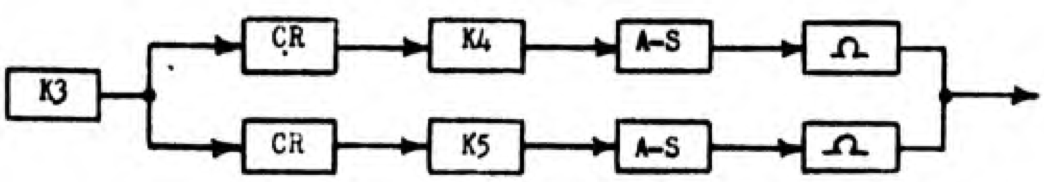
$t = 200$ sec

$\alpha_4 = 1.808 \times 10^{-6}$

3.5 **Destruct Enable Relay and Arming Device Analysis**

3.5.1 Proper tank fragmentation can only be accomplished if a destruct signal is sent to the Destructor Assembly at the proper time (approximately 200 seconds after re-entry vehicle separation). The enable relay (K3) in the Range Safety Control Assembly must be energized by +28V DC from the main missile battery to provide a path for the time slot output of the (A/P) to trigger the arming device relays K4 and K5. Due to these relays there are parallel paths for the destruct signal to reach the destruct unit. From Figure II the mathematical model shown in Figure IIIa can be derived to determine the reliability of the enable relay and the arming device (R5 in Figure I).

FIGURE IIIa



$$R5 = R_{K3}\left[1 - (1-R_{CR} R_K R_{A-S} R_{\Omega})^2\right]$$

MODEL FOR CALCULATING R5 PROBABILITY OF SUCCESS

Reliability Model Key

K3 = Enable Relay
CR = Diode (IN1614
K = K4 & K5 Relays in the Arming Device
A-S = Arm-safe switch contacts
Ω = 8.2 ohm Resistor

3.5.2 Table III lists the generic failure rates for each component operated at 75° C taken from reference 4.

TABLE III

ENABLE RELAY AND ARMING DEVICE FAILURE RATES (K_{op}=200)

Component	$GF_r/10^6$HRS
K3 (2 active contact sets)	0.06
CR (IN1614)	0.05
K(3 active contact sets)	0.045
A-S(2 active contact sets)	0.068
Ω (10 Watt resistor)	0.502

The reliability R5 can be calculated with the following equations:

$$R5 = e^{-\lambda_{K3}t}\left[1-\left(1-e^{-(\lambda_{CR}+\lambda_K+\lambda_{A-S}+\lambda_\Omega)t}\right)^2\right]$$

where: t = 200 seconds

For: $\lambda t \leq .001$; $e^{-\lambda t} \rightarrow 1-\lambda t$

Let $\lambda' = \lambda_{CR}+\lambda_K+\lambda_{A-S}+\lambda_\Omega$

If: $\lambda = K_{op}\ GF_r/10^6$HRS

Then: $R5 = [1-\lambda_{K3}t][1-(1-1+\lambda' t)^2]$

$R5 = [1-\lambda_{K3}t][1-(\lambda' t)^2]$

Therefore: $R5 = e^{-[\lambda_{K3}t+(\lambda' t)^2]} = e^{-\alpha_5}$

λ_{K3} = 12 failures/10^6HRS = 3.33×10^{-9} failures/sec

λ' = 132.6 failures/10^6HRS = 3.68×10^{-8} failures/sec

$\lambda_{K3}t+(\lambda' t)^2 = 6.67\times10^{-7} + 5.42\times10^{-11}$

$\alpha_5 = 6.67\times10^{-7}$

3.6 Destructor Unit Assembly Analysis

Reference 6 establishes a reliability of 0.9999 for this unit (block R6 at Figure II)

Therefore: $R6 = 0.9999$

where: $R6 = e^{-\alpha_6}$

$\alpha_6 = 1.0x10^{-4}$

3.7 Control Subsystem Reliability

The control subsystem reliability can be calculated from the model shown in Figure I.

$$R_s = \prod_{i=1}^{6} R_i = e^{-\alpha_s}$$

where: $$\alpha_s = \sum_{j=1}^{6} \alpha_j$$

$\alpha_1 = 1.22x10^{-3}$

$\alpha_2 = 7.8x10^{-6}$

$\alpha_3 = 3.121x10^{-5}$

$\alpha_4 = 1.808x10^{-6}$

$\alpha_5 = 6.67x10^{-7}$

$\alpha_6 = 1.0x10^{-4}$

$\alpha_s = 1.362x10^{-3}$

$R_s = e^{-(1.362)(10^{-3})} = 0.99864$

3.8 Conclusion

The control subsystem reliability was calculated using an (A/P) failure rate of 13,807 failures per million hours for that portion of the (A/P) that affected the tank fragmentation system. The Reliability Summary Reports give a failure rate of 2,602 failures per million hours for the whole (A/P). Therefore, the failure rate data for the (A/P) is conservative by a factor of at least 6 and probably the factor is closer to 10. It is, therefore, concluded that the control subsystem intrinsic reliability meets its design objective.

4.0 Reliability of the Tank Fragmentation System Preventing an Inadvertent Detonation.

The design modification of the Tank Fragmentation system includes all devices analyzed in Reference 3 plus the interlock micro-switch string in the retro-rocket subsystem (safing function). The arming device, retro-rocket firing subsystem (separation subsystem), and destructor unit are fail safe except for the receivers (See Figure II), in that detonation cannot occur unless the enable relay contacts are closed and a destruct signal is available from the autopilot programmer (A/P). The analysis is based on two conditions. (1) The (A/P) generates a premature destruct signal before completion of the 200 second interval after re-entry vehicle separation (R/V). (2) The (A/P) generates a premature destruct signal before re-entry vehicle separation and the enable relay (K3) contacts are in the destruct position (Refer to Figure II): where the time before separation is defined as mission time (t_m) and equals countdown time (t_c) plus tactical hold time (t_h), plus flight time (t_f).

$t_c = 0.25$ hr

$t_h = 1.00$ hr

$t_f = 0.08$ hr

$t_m = 1.33$ hr

4.1 **Inadvertent Detonation After (R/V) Separation**

This condition can occur with any one of the following modes of failure shown in Figure IV, which is a mathematical model of the unreliability of the destruct signal generation circuit (Figure V) with respect to false trigger generation. The enable relay (K3) has been energized due to (R/V) separation. The generic failure rates for all possible failures of the models in Figure IV are listed in Table IV. These failure rates (GF_r) when multiplied by K_{op} = 200 (refer to paragraph 3.1) will be the failure rate (λ) that causes improper circuit action. The failure rates (λ') are the rate of failures within λ that will cause a false trigger to cause inadvertent detonation. Transistors will be assumed to fail equally short-circuit and open-circuit; therefore, the failure rate for either case would be one-half the total failure rate. Diodes will be as described in Appendix A, page A-10. Resistors are assumed to fail in the open-circuit condition. The conditional failures of the circuits shown in Figure V are as follows:

1. Counter circuit will generate false count if:

   Transistors fail in short circuit condition

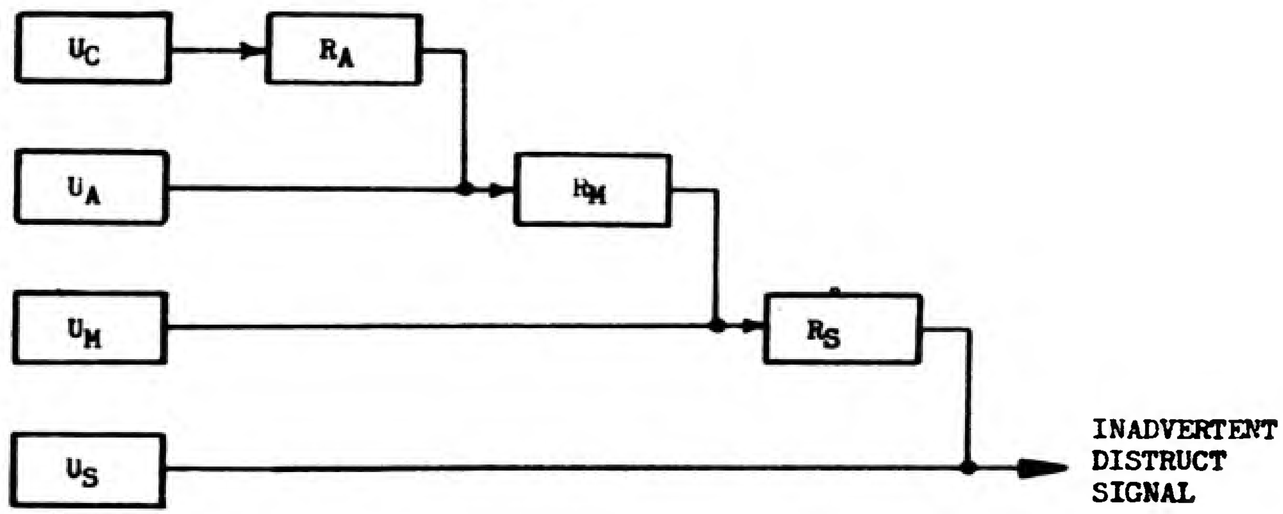
2. Amplifier circuits will generate false time counts if:

   Transistors Q1 through Q8 fail open-circuit

3. Diode Matrix will generate false t 107 if:

   a. R_1 fails open-circuit
   b. Any diodes CR1 through CR9 fails short-circuit

FIGURE IV



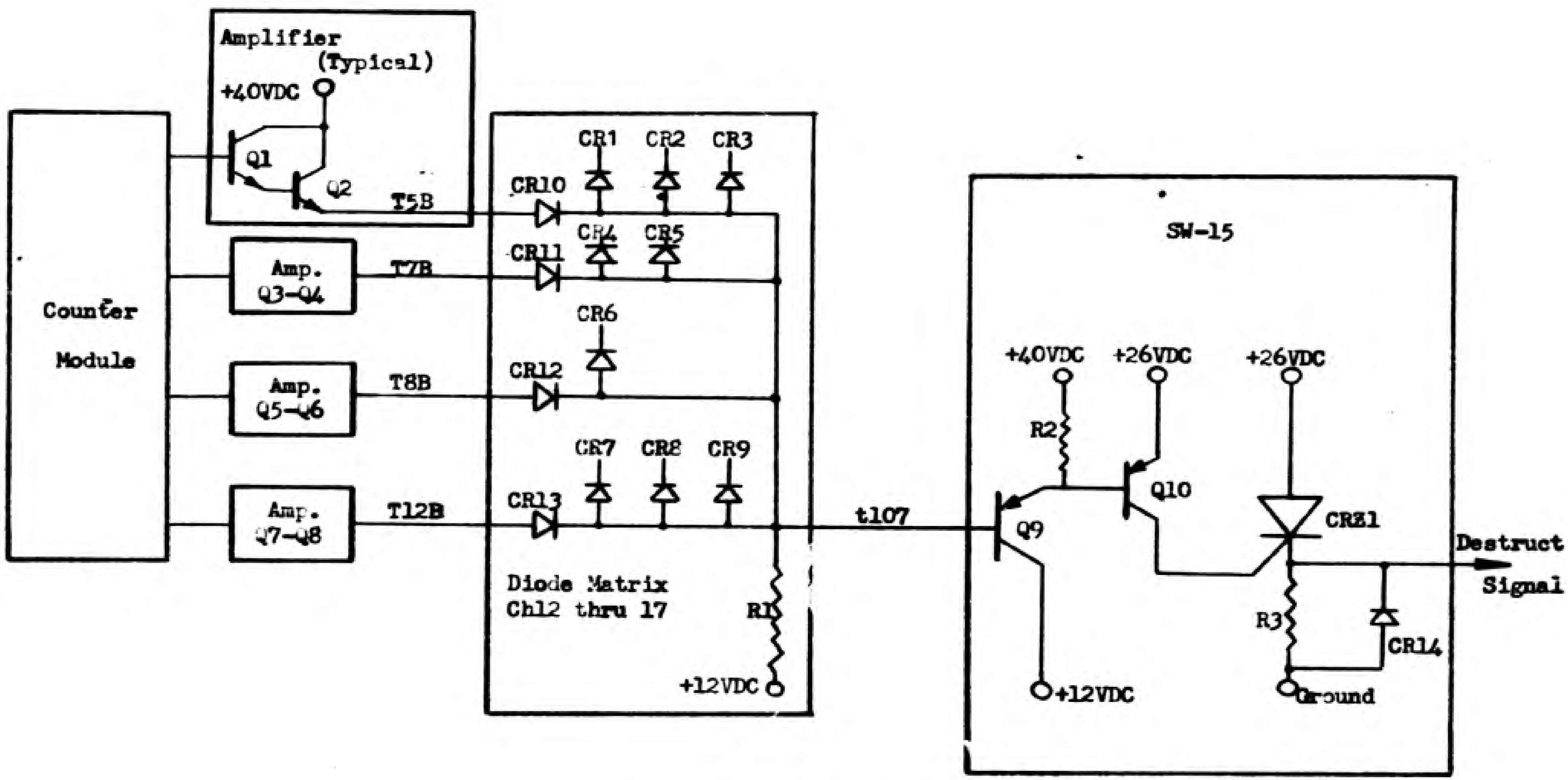
$$P_I = U_S + U_M R_S + U_A R_M R_S + U_C R_A R_M R_S$$

Unreliability Model Key

U_C = Probability of counter failure with outputs T5B, T7B, T8B, and T12B.
U_A = Probability of amplifiers Q1-2, Q3-4, Q5-6, and Q7-8 failure with output.
R_A = Probability of amplifiers Q1-2, Q3-4, Q5-6, and Q7-8 having no failure.
U_M = Probability of diode matrix failure with E107 output.
R_M = Probability of diode matrix having no failure.
U_S = Probability of SW15 failure with destruct signal output.
R_S = Probability of SW15 having no failure.

MODEL FOR CALCULATING PROBABILITY OF INADVERTENT DISTRUCT SIGNAL GENERATION

FIGURE V



DESTRUCT SIGNAL GENERATION FUNCTIONAL SCHEMATIC

TABLE IV

(A/P) DESTRUCT SIGNAL GENERATION GENERIC FAILURE RATES

Circuit	Quantity	$Gf_r/10^6$	Ka	$GF_r/10^6$
Counter	4	2.0	0.15	1.200
Amplifier	4	1.0	0.15	0.600
Diode Matrix				
Diode	13	0.2	0.25	0.650
Resistor	1	0.047	2.2	0.103
Total				0.753
SW 15				
Transistor	2	0.5	0.15	0.150
Diode	1	0.2	0.25	0.050
CRZ	1	0.4	0.25	0.100
Resistor	2	0.047	2.2	0.207
Total				0.507

Key

Gf_r = Generic failure rate at 25°C

k_a = Application factor

GF_r = Generic failure rate at 75°C ($K_A Gf_r$)

Data extracted from Reference 4

c. Any diode CR10 through CR13 fails open-circuit

4. SW15 circuit will generate false destruct signal if:

a. CR21 fails short-circuit

b. Q_9 or Q_{10} fails short-circuit

The probability of inadvertent detonation after re-entry vehicle separation (P_I) is calculated from the following expressions: (Refer to Figure IV)

$$P_I = U_S + U_M R_S + U_A R_M R_S + U_C R_A R_M R_S$$

$$P_I = 1 - \left(e^{-\lambda'_s t} + e^{-(\lambda_s + \lambda'_m)t} + e^{-(\lambda_s + \lambda_m + \lambda'_a)t} + e^{-(\lambda_s + \lambda_m + \lambda_a + \lambda'_c)t}\right) + \left(e^{-\lambda_s t} + e^{-(\lambda_s + \lambda_m)t} + e^{-(\lambda_s + \lambda_m + \lambda_a)t}\right)$$

where: $t = 200$ seconds $= 0.056$ hrs

$\lambda'_s t = 80 \times 10^{-6} \times .056 = 4.5 \times 10^{-6}$

$\lambda_s t = 101 \times 10^{-6} \times .056 = 5.7 \times 10^{-6}$

$\lambda'_m = 75 \times 10^{-6} \times .056 = 4.2 \times 10^{-6}$

$\lambda_m = 151 \times 10^{-6} \times .056 = 8.5 \times 10^{-6}$

$\lambda'_a = 60 \times 10^{-6} \times .056 = 3.9 \times 10^{-6}$

$\lambda_a = 120 \times 10^{-6} \times .056 = 6.7 \times 10^{-6}$

$\lambda'_c = 120 \times 10^{-6} \times .056 = 6.7 \times 10^{-6}$

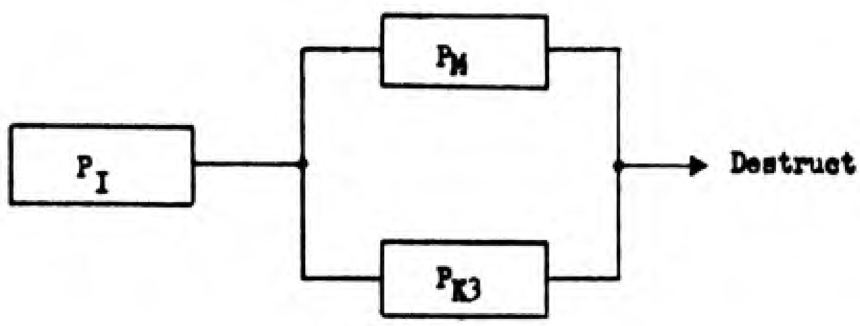
$P_I = 1 - .9999807$

$P_I = 1.93 \times 10^{-5}$

4.2 Inadvertent Detonation Before (R/V) Separation

This condition can occur when an inadvertent (A/P) destruct signal is present and the (R/V) separation switch and the retro-rocket microswitches fail short or the enable relay (K3) fails with contacts in the destruct position. This condition can be represented by the unreliability mathematical model in Figure VI.

FIGURE VI



P_I = Probability of inadvertent (A/P) destruct signal = 1.93×10^{-5}

P_M = Probability of separation switch and microswitch failure = $\alpha_2 + \alpha_3 = 3.90 \times 10^{-5}$ (Refer to paragraphs 3.2 and 3.3)

P_{K3} = Probability of enable relay failure $\approx \alpha_5$ = 6.67×10^{-7}

$$P_I = P_I \left[1 - (1 - P_M)(1 - P_{K3})\right]$$

MODEL FOR CALCULATION OF THE PROBABILITY OF INADVERTENT DETONATION BEFORE (R/V) SEPARATION

$$P_I \approx P_I \left[1 - e^{-(\alpha_2 + \alpha_3 + \alpha_5)\frac{t_m}{t}}\right]$$

$$P_I = (1.93 \times 10^{-5})(1 - e^{-9.45 \times 10^{-3}})$$

$$P_I = (1.93)(9.45)(10^{-8}) = 1.82 \times 10^{-7}$$

4.3 **Total Reliability of No Inadvertent Detonation**

The reliability of the Tank Fragmentation capabilities to prevent an inadvertent detonation (R_S') can be calculated as follows:

R_I = Reliability of no inadvertent detonation after re-entry vehicle separates.

R_I' = Reliability of no inadvertent detonation before re-entry vehicle separates.

$R_I = 1 - P_I \doteq 0.99998$

$R_I' = 1 - P_I' \gg R_I$

$R_I' \rightarrow$ Unity

R_S' = Probability of inadvertent detonation 2×10^{-5}

4.4 **Conclusion**

The preceding analysis indicates that the probability of inadvertent detonation is less than 0.0001 and it, therefore, can be concluded that the control subsystem meets its reliability design objective.

5.0 **Reliability of Proper Fragmentation**

To obtain the reliability of proper fragmentation (R_F) the probability of fragment-re-entry vehicle (R/V) collision (P_F) at proper separation time and distance must be calculated. ($R_F = 1 - P_F$) This analysis is based on a 4,000 nautical mile flight. It was considered that it would be the most severe case, because the tank section would have the greatest mass on a shorter mission causing the separation distance between the tank section and re-entry vehicle to be less. The results of this analysis are used to analyze the 5,000 and 6,000 nautical mile flights in paragraph 5.5 (Conclusion).

5.1 **Fragment-Re-entry Vehicle Collision Discussion**

Reference 13 is an analytical study of the probability of fragment - (R/V) collision. Certain assumptions were made in Reference 13 because there was no data from which any analysis could be made at that time. The assumptions and conclusion made in Reference 13 for the study are:

1. Separation time = 210 seconds
2. R/V separation velocity = 4 ft/sec.
3. Number of fragments in the dispersion pattern will be approximately 120.
4. The fragments will disperse in a spherical pattern and are distributed uniformly about a spherical surface.

Conclusion: The separation distance of (R/V) must be greater than 840 ft. for a probability of < 0.001 that a fragment will collide with the R/V.

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FIGURE VII

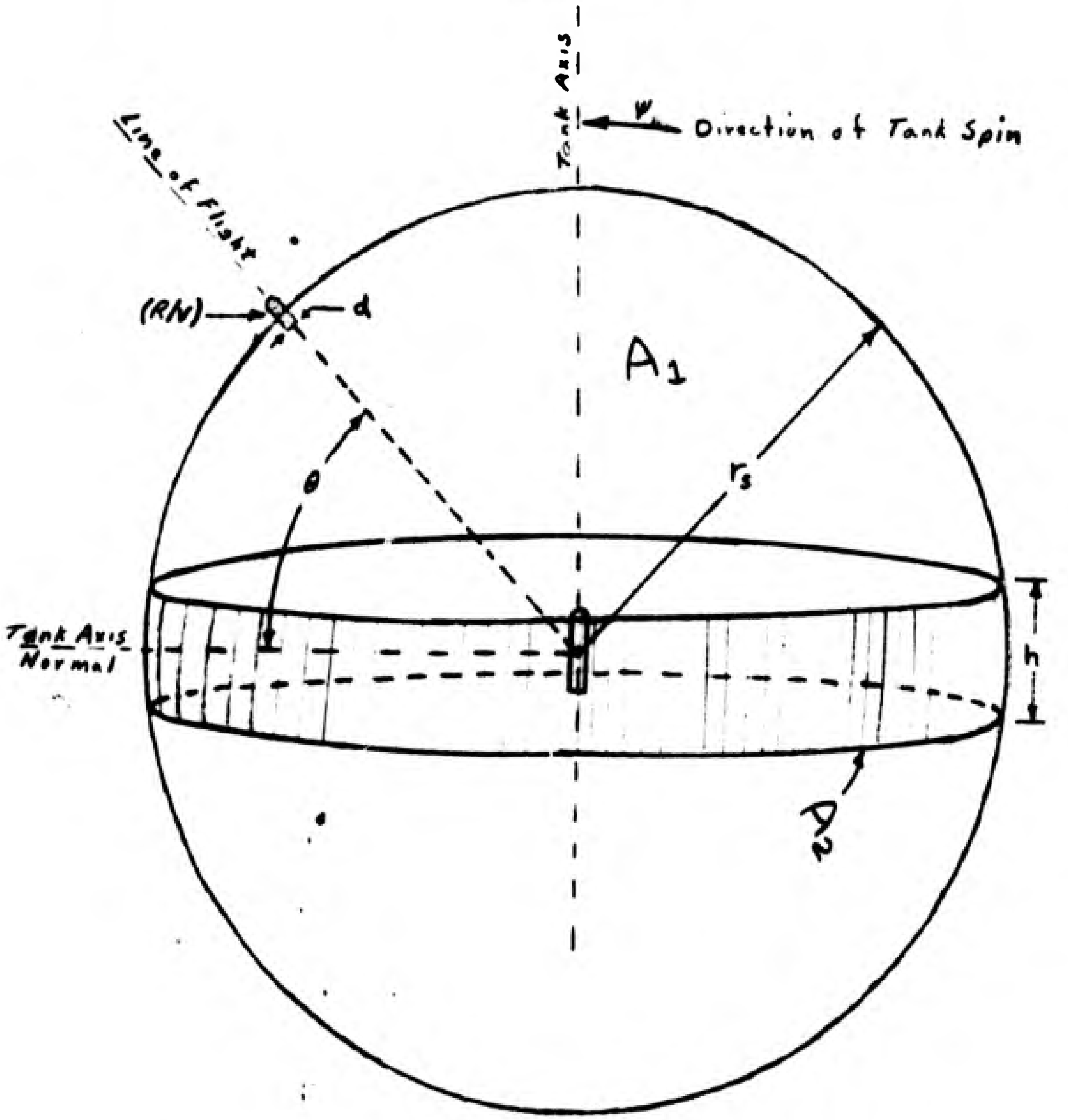

Diagram Key

A_1 = Total Spherical Area Excluding Fragment Dispersion Pattern
A_2 = Area of Dispersion Pattern for Fragments
r_s = Radius of Sphere (1000 Ft.)
d = Diameter of Re-entry Vehicle (R/V)
ψ = Rotational Displacement of Tank During Separation
θ = Angular Displacement of Tank Normal with respect to (R/V) Line of Flight.
h = Height of Dispersion Pattern for Fragments

TANK FRAGMENTATION DISPERSION PATTERN

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Since the time Reference 13 was written, an Atlas missile was pressurized, detonated, and the fragment pattern observed. This test is reported in Reference 12, and much of the data has been used in this analysis. Although this test was made on a static missile in the atmosphere, the fragment pattern was observed on high speed film. The film shows the pattern just after detonation and with Reference 12 indicates that the fragment pattern forms a cylindrical surface with the fragments velocity vectors basically in the direction of the normal surface to the tank center line axis. (See Figure VII)

Based on information presented in Reference 12, Reference 9, and the design specifications, revisions to the Reference 13 assumptions can be made as follows:

1. Separation time = 184.2 seconds.
2. Separation distance = 1000 ft.
3. Separation velocity = 5.4 ft/sec
4. Number of fragments in dispersion pattern will be approximately 800. (See Table V)
5. Dispersion pattern will be of random distribution in a spherical band as shown in Figure VII.
6. All hits (fragments - R/V collision) will not necessarily cause a mission failure.
7. The retro-rocket impulse will cause the tank section to rotate about its center of mass.

8. The retro-rocket impulse is not constant and will vary with a normal distribution.

9. (See Figure VII) Total tank rotation angle (ψ) will be proportional to the total retro-rocket impulse (time is constant).

10. The fragments kinetic energy will vary with a normal distribution. (Approximation of highly skewed distribution)

11. The dispersion band, based on Reference 12, will be an arc 130 ft in height (h) and 6280 ft ($2\pi r_3$) in length.

Explanations of the above assumptions will be made in the analysis as they are used. The probability of a fragment - (R/V) collision causing a mission failure can be computed by the following equation:

$$P_F = P_B \, P_H \, P_E$$

P_F = Probability of mission failure due to fragment-re-entry vehicle collision.

P_B = Probability that re-entry vehicle will lie in the fragment dispersion band.

P_H = Probability that a fragment will collide with the re-entry vehicle if re-entry vehicle is in the fragment pattern band.

P_E = Probability that a fragment will have enough kinetic energy to cause a mission failure if a fragment-re-entry vehicle collision occurs.

Figure VIII shows how the height of the fragment band is determined. The total height will be the length of an arc on the sphere of radius (r_s) defined by the angle ϕ. This arc (h) can be found by the following expression:

$$h = \phi \text{ (in radians) } \times r_s = 2(\delta + \gamma + L)$$

The L is one-half of the total tank section length and γ is the length of arc defined by the angular dispersion with respect to the normal equal to $r_s \sin\beta$. δ is the radius required for an exclusion area (A_e) for the maximum fragment size. (See Figure IX). The maximum fragment size as shown in Table V is 274 ft^2 with a δ = 9.3 ft. Therefore, the total exclusion area (A_E) for the fragment pattern is the ΣA_e's for each fragment or $\Sigma k A_e$.

5.2 Probability of Fragment - (R/V) Collision

The probability of a fragment - (R/V) collision is defined as $P_B P_H$. This means that before a hit can be scored the (R/V) must lie within the fragment dispersion band. There are three cases to consider when calculating P_B. They are:

1. The angle β (Figure VIII) approaches 90° causing the fragment dispersion band to occupy the whole surface of the sphere or ϕ = 180°.
2. The tank tumbles in a random manner and the dispersion band can occur any place on the surface of the sphere (See Figure VII).

FIGURE VIII

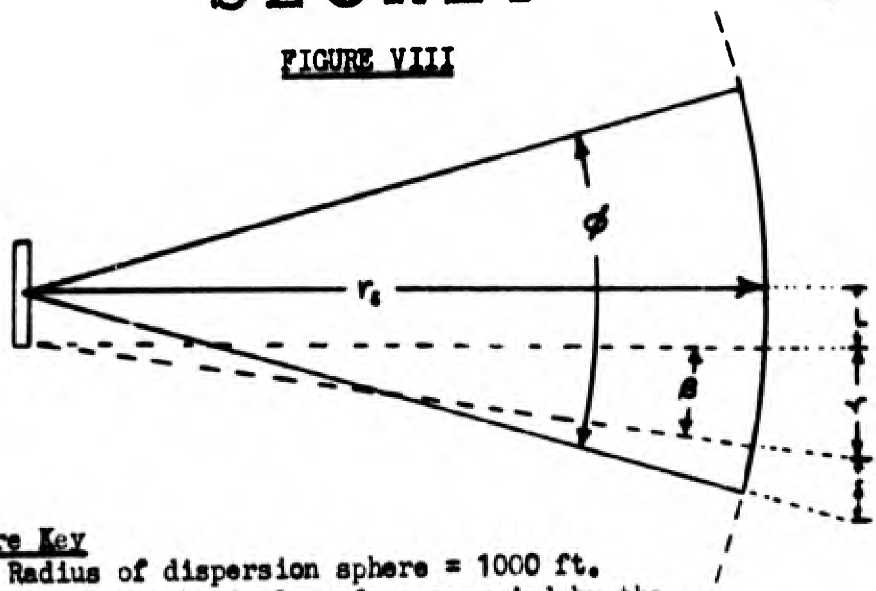


Figure Key

r_s = Radius of dispersion sphere = 1000 ft.

ϕ^s = Angle of spherical surface occupied by the fragment pattern.

δ = Exclusion area arc = radius of the R/V ($r_{R/V}$) plus the radius of the largest fragment (r_p).

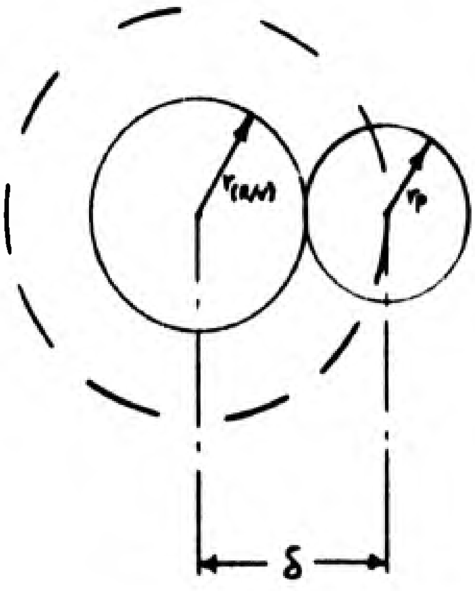
β = Angle of fragment dispersion with respect to the normal of the tank section centerline.

γ = Length of arc to account for fragments that do not disperse normal to the centerline of the tank section $\rightarrow r_s \sin\beta$.

L = One-half the length of the tank section = 32.5 ft.

HEIGHT OF FRAGMENT DISPERSION BAND

FIGURE IX



$r_{(R/V)}$ = Radius of (R/V)

r_p = Radius of fragment

$\delta = r_{(R/V)} + r_p$

$A_e = \pi \delta^2$

FRAGMENT EXCLUSION AREA (A_e)

3. The band will vary with a normal distribution about an average tank rotation deflection angle ψ with an angle of dispersion for the fragments $\beta \rightarrow$ Zero degrees. (See Figures VII and VIII)

5.2.1 Use Figures VII, VIII, IX, X and Table V as reference. In case 1 above, if the diperaion angle ϕ aproaches 180°, the probability of the re-entry vehicle (R/V) being in the path of the band (P_B) approaches unity and the dispersion area on the surface of the sphere appreaches the total area of the sphere if dispersion is uniformly distributed. Therefore, the probability of collision can be calculated from the following expression:

$$P_B\, P_H \rightarrow P_H = \frac{\Sigma A_e}{A_1 + A_2}$$

where: $\Sigma A_e = A_E$ Total exclusion area of all fragments dispersed.

$A_1 + A_2 = 4\pi r_s^2$ Total surface area of dispersion

$$P_B\, P_H = \frac{A_E}{4\pi r_s^2}$$

In case 2, if the tank section tumbles in a randum manner P_B can be calculated by the following expression: (See Figure VII)

$$P_B = \frac{A_2}{A_1 + A_2}$$

The probability of a hit P_H if P_B occurs can be calculated by the following expression:

$$P_H = \frac{\Sigma A_e}{A_2}$$

This expression can be true only if:

$\theta \leq \frac{1}{2}\phi$ (See Figures VII and VIII).

Therefore, the probability of fragment-re-entry vehicle collision is:

$$P_B\, P_H = \left(\frac{A_2}{A_1 + A_2}\right)\left(\frac{\Sigma A_e}{A_2}\right)$$

$$P_B\, P_H = \frac{\Sigma A_e}{A_1 + A_2}$$

This expression is the same as case 1 and therefore reduces to:

$$P_B\, P_H = \frac{A_E}{4\pi r_s^2}$$

Refering to Figure X and Table V, it can be seen that of the 799 active fragments, more than 1/3 are less than 0.2 square feet in area. Only a very few particles are greater than 20 square feet in area. This data was obtained from the fragmentation test report (Reference 9). The total exclusion area A_E of the 799 fragments is given in Table V. Therefore:

$$P_B\, P_H = \frac{28{,}700\ ft^2}{4(\pi)(1000)^2\ ft^2} = 0.00228$$

where: $A_E = \Sigma k A_e = 28{,}700\ ft^2$

$r_s = 1000\ ft.$

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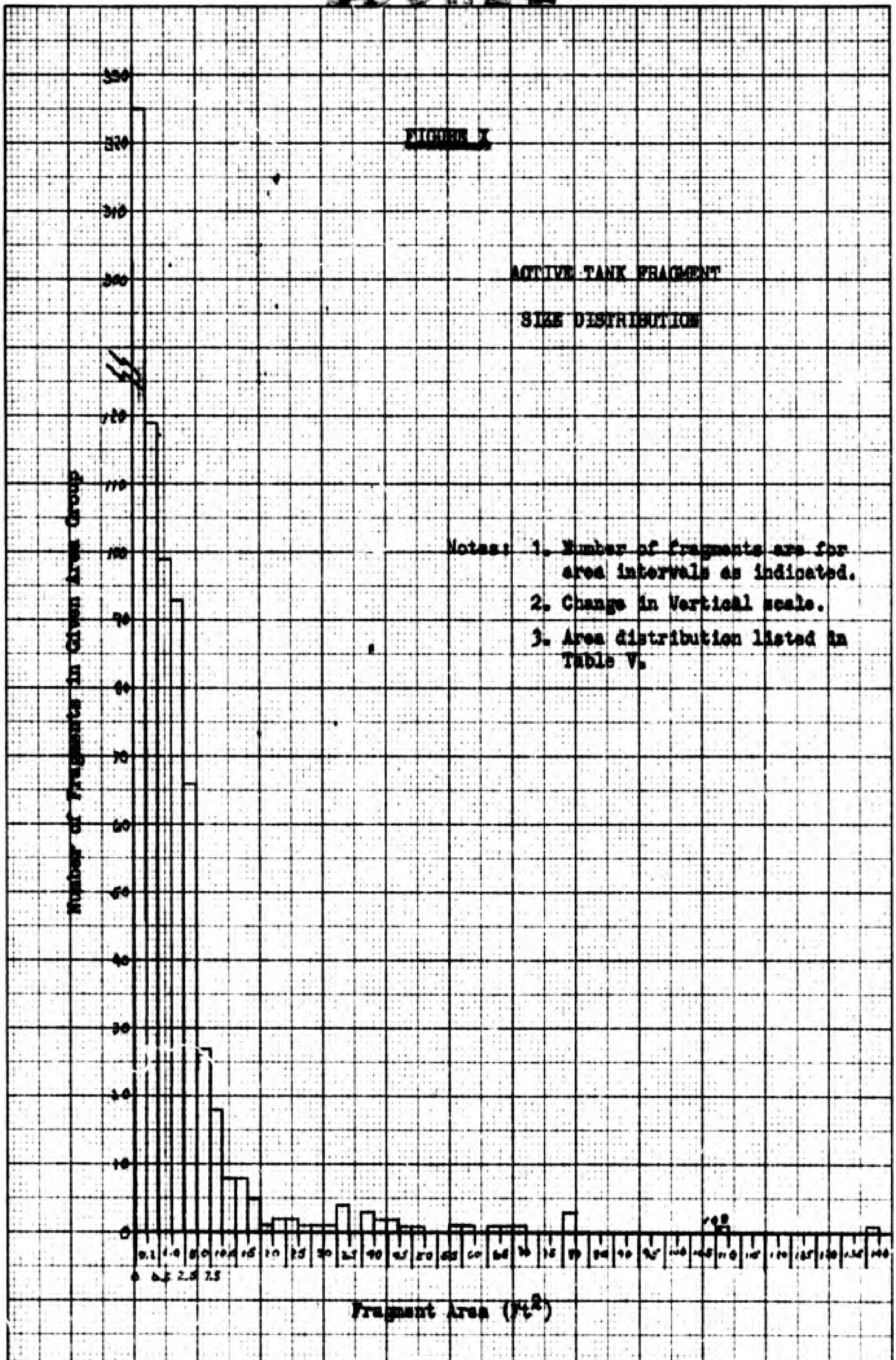

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TABLE V

FRAGMENT DISPERSION D

NUMBER (K)	AVE. SIZE $(Ft)^2$	FRAGMENT RADIUS r_p (Ft)	FRAGMENT RADIUS δ (Ft)	EXCLUSION AREA A_e $(Ft)^2$	EXCLUSION AREA KA_e $(Ft)^2$	FRAGMENT WEIGHT W (Lbs)	FRAGMENT WEIGHT KW (lbs)	FRAGMENT m_o (Slug)
325	0.1	0.18	2.82	25.2	8160	0.20	65.94	0.0063
119	0.35	0.33	2.98	27.9	3320	0.50	59.54	0.0156
99	0.75	0.49	3.14	31.2	3080	1.28	126.28	0.0396
93	1.75	0.84	3.49	36.2	3360	3.40	316.02	0.1055
66	3.75	1.09	3.74	44.0	2970	3.19	210.27	0.0991
27	6.25	1.41	4.06	51.9	1400	10.10	272.18	0.3130
18	8.75	1.60	4.25	55.8	1020	10.65	191.59	0.3310
8	11.25	1.90	4.55	66.0	520	6.29	50.30	0.1950
8	13.75	2.09	4.74	70.5	565	14.20	113.50	0.4400
5	16.25	2.27	4.92	76.0	381	17.00	85.00	0.5280
1	18.75	2.46	5.1	82	82	19.00	19.00	0.5900
1	21	2.58	5.23	86	86	3.00	3.00	0.0800
1	22	2.65	5.3	88	88	9.25	9.25	0.2900
1	24	2.76	5.41	92	92	12.00	12.00	0.3700
1	25	2.83	5.47	94	94	22.50	22.50	0.7000
1	26.4	2.85	5.5	94	94	19.25	19.25	0.6000
1	28	2.98	5.63	100	100	34.00	34.00	1.0600
1	32	3.17	5.84	108	108	2.52	2.52	0.0800
4	33.75	3.26	5.91	110	440	14.70	58.75	0.4550
3	38.75	3.51	6.16	119	357	39.50	118.50	1.2267
2	42	3.65	6.3	124.5	249	21.38	42.75	0.6650
1	42.7	3.69	6.34	126	126	45.00	45.00	1.4000
1	45	3.78	6.43	130	130	38.00	38.00	1.1800
1	46.5	3.85	6.5	133	133	25.25	25.25	0.7800
1	49	3.95	6.6	137	137	9.00	9.00	0.2800
1	55.3	4.20	6.85	148	148	64.00	64.00	1.9900
1	60	4.37	7.02	155	155	86.00	86.00	2.6800
1	63	4.48	7.13	160	160	29.25	29.25	0.9100
1	66	4.58	7.23	164	164	37.00	37.00	1.1500
1	70	4.73	7.38	171	171	73.00	73.00	2.2700
1	79.5	5.02	7.67	185	185	50.00	50.00	1.5500
1	79.5	5.02	7.67	185	185	16.00	16.00	0.5000
1	108	5.85	8.5	236	236	80.00	80.00	2.4800
1	140	6.65	9.3	274	274	82.00	82.00	2.5500

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BLE V

SPERSION DATA

WEIGHT KW(lbs)	FRAGMENT MASS m_o(Slug)	Km_o(Slug)	AVE. VELOCITY v_e (Ft/sec)	AVERAGE KINETIC ENERGY $\mathcal{E}_i$ (lb-Ft)
65.94	0.0063	2.05	206	134
59.54	0.0156	1.85	206	331
126.28	0.0396	3.92	210	875
316.02	0.1055	9.82	218	2510
210.27	0.0991	6.54	228	2580
272.18	0.3130	8.45	260	9800
191.59	0.3310	5.95	255	10780
50.30	0.1950	1.56	240	6050
113.50	0.4400	3.52	266	15550
85.00	0.5280	2.64	261	18000
19.00	0.5900	0.59	261	20100
3.00	0.0800	0.08	92	338
9.25	0.2900	0.29	80	928
12.00	0.3700	0.37	89	1465
22.50	0.7000	0.70	239	20000
19.25	0.6000	0.60	80	1920
34.00	1.0600	1.06	20	212
2.52	0.0800	0.08	25	25
58.75	0.4550	1.82	152	5250
118.50	1.2267	3.68	232	33000
42.75	0.6650	1.33	208	14400
45.00	1.4000	1.40	146	14900
38.00	1.1800	1.18	252	37400
25.25	0.7800	0.78	37	535
9.00	0.2800	0.28	187	5000
64.00	1.9900	1.99	203	41000
86.00	2.6800	2.68	108	15600
29.25	0.9100	0.91	130	7700
37.00	1.1500	1.15	244	34200
73.00	2.2700	2.27	434	214000
50.00	1.5500	1.55	151	17650
16.00	0.5000	0.50	220	12100
80.00	2.4800	2.48	570	403000
82.00	2.5500	2.55	115	16900

Notes:

K : Number of fragments in group

r_p : Ave fragment radius in group.

$\delta = r_{(R/V)} + r_p$ (See Figure IX)
where: $r_{(R/V)} = 2.65$ Ft.

A_e : Ave exclusion area in group

KA_e : Total exclusion area of group

W : Ave fragment weight in group.

KW : Total Weight of fragment group

$m_o = \frac{W}{g}$; Ave fragment mass in group.
where: $g = 32.2$ Ft/sec.

Km_o : Total mass of fragment group.

v_e : Ave fragment velocity in group greater than $v_{(R/V)}$

$\mathcal{E}_i$ = Ave. fragment kinetic energy in group. (Impact energy)
$K.E. = \frac{1}{2} m_o v_e^2$

Data Totals

$K_T = \Sigma K = 799$ Fragments

$A_E = \Sigma KA_e = 28,700$ Ft^2

$W_T = \Sigma KW = 2466.64$ Lbs.

$m_T = \Sigma Km_o = 76.62$ Slug.

$\mathcal{E}_A = \frac{\Sigma K \mathcal{E}_i}{K_T} = 3433$ Lb-Ft

B

5.2.2 Case 3 describes the probability of fragment-R/V collision as $\beta \rightarrow$ zero degrees (see Figure VIII) and the dispersion band varies about an average deflection angle (ψ_{AVE}) with a normal distribution which is proportional to the total retro-rocket impulse (I). From Reference 9 the turning rate of the tank section after separation is:

$$w_r = \frac{d\psi}{dt} = 4.73 \text{ degrees/second}$$

The initial deflection during retro-rocket thrust time is:

$$\psi_e = 3.3 \text{ degrees}$$

These values are at the rated impulse (I_T) of the retro-rockets which is:

$$I_T = 2920 \text{ lb-sec}$$

From ten Impulse samples taken during flight tests:

$$I_{AVE} = 1852 \text{ lb-sec}$$

Because: $w_r = \frac{I_t(1)}{M}$

$$w_r \sim I_T$$

$$W_{AVE} = \frac{1852}{2920} \times w_r = 3.01 \text{ degrees/second}$$

$$\psi_e' = \frac{1852}{2920} \psi_e = 2.1 \text{ degrees}$$

$$\psi_{AVE} = \psi_e' + W_{AVE} t = 547^\circ = 9.54 \text{ radians}$$

where: $t = 184.2$ seconds

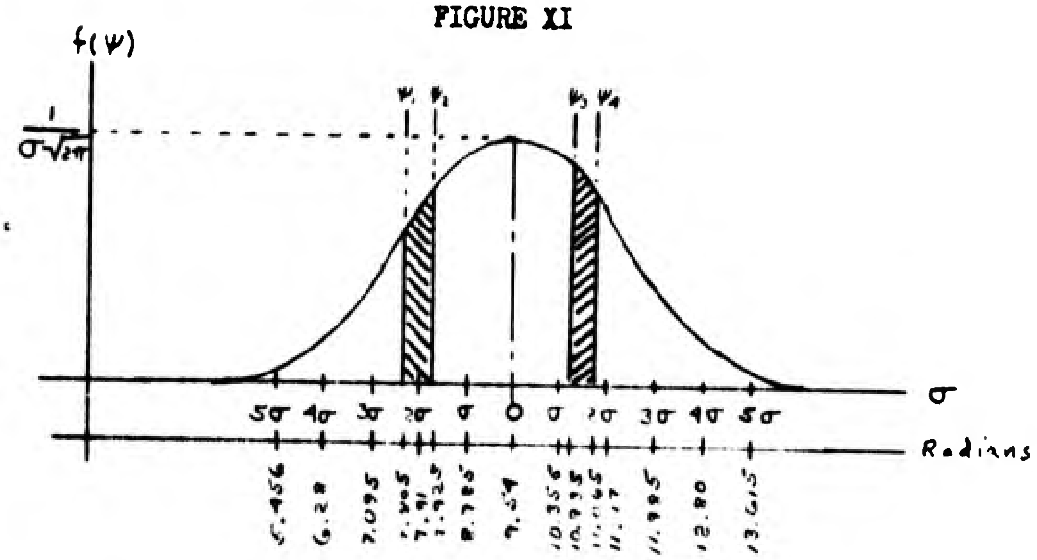
standard - deviation - from - mean; $\sigma = \left(\sqrt{\frac{\Sigma(\psi_i - \psi_{AVE})^2}{n}}\right)\left(\frac{1}{C_2}\right)$

where: n = 10 samples
ψ_i = Value of each sample = $(5.24 \times 10^{-3})(I \quad)$
ψ_{AVE} = 9.54 - 0.04 = 9.5 radians
$\Sigma(\psi_i - \psi_{AVE})$ = 5.654 (from 10 Impulse samples)
$C_2 = \bar{\sigma}/\sigma$ = .9227
σ = Sample standard deviation of normal universe

$\sigma = (.5654)^{\frac{1}{2}}(1.082) = (0.752)(1.082)$

$\sigma = 0.815$ {Assume 56 limit}

FIGURE XI



FRAGMENT BAND PATTERN DISTRIBUTION

Collision Band centering on re-entry vehicle will occur at intervals of $\psi = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \cdots$ etc.

Assume: Dispersion Band is an arc 130 ft long which is defined by $2(\delta + \gamma + L)$ and $\delta = 9.3$ ft and $L = 32.5$ ft with:

$\gamma = 22.5$ ft $= r_c \sin\beta$. (See Figures VII and VIII)

$\beta < 0.01$ radian

$\frac{1}{2}\phi = \frac{1}{2}\left(\frac{130}{2\pi(1000)}\right)2\pi = .065$ rad

ϕ = Circular Arc of Dispersion band.

Collision can then occur at:

$\psi = 1.57 \pm .065$ rad

$\psi = 4.72 \pm .065$ rad

$\psi = 7.86 \pm .065$ rad

$\psi = 11.00 \pm .065$ rad

$\psi = 14.15 \pm .065$ rad

The probability (P_B) is calculated for a deviation of 5σ. This includes greater than 0.99999 of all the possibilities that could cause the (R/V) to be in the dispersion band.

$$P_B = \int_{\psi_2}^{\psi_1} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\psi - \psi_{AVE}}{\sigma}\right)^2} d\psi + \int_{\psi_3}^{\psi_4} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\psi - \psi_{AVE}}{\sigma}\right)^2} d\psi$$

where: $\sigma = 0.815$

$\psi_{AVE} = 0$

$\psi_1 = |7.805 - 9.54| = 2.13\sigma = 1.735$ rad

$\psi_2 = |7.925 - 9.54| = 1.98\sigma = 1.615$ rad

$\psi_3 = |10.935 - 9.54| = 1.71\sigma = 1.395$ rad

$\psi_4 = |11.065 - 9.54| = 1.87\sigma = 1.515$ rad

$$P_B = \frac{1}{\sqrt{2\pi}}\left[\int_{1.98}^{2.13} e^{-\frac{\tau^2}{2}} d\tau + \int_{1.71}^{1.87} e^{-\frac{\tau^2}{2}} d\tau\right]$$

where: $\tau = \frac{\psi - \psi_{AVE}}{\sigma} = \psi/\sigma$

and: $\sigma\, d\tau = d\psi$

$P_B = 0.48341 - 0.47615 + 0.46926 - 0.45637$

$P_B = 0.02015$

From paragraph 5.2.1 P_H can be calculated from the following expression: (Refer to Figures VII and IX)

$$P_H = \frac{A_E}{A_2} = \frac{28700 \text{ ft}^2}{2\pi(130)(1004 \text{ ft}^2)} = .0315$$

where: $A_2 = 2(\delta + \gamma + L)\,2\pi r_s$

Therefore:

$P_E\, P_H = (.02015)(.0315) = 0.000634$

5.3 **Probability of Mission Failure Due to Fragment - R/V Collision**

5.3.1 If a fragment - (R/V) collision occurs (Paragraph 5.2) the probability of a mission failure due to a collision can be calculated. Reference 9 indicates that most series "E" and "F" reentry vehicles normally impact within a radius of three nautical miles from ground zero and a good hit is considered anywhere within an eight nautical mile radius. If the R/V would normally impact within three nautical miles of the target the least the colliding fragment can move the R/V off course is five nautical miles and still be within the eight nautical mile limit. Therefore, for this analysis any deflection greater than five nautical miles will be classified as a mission failure. This estimation offers conservatism inasmuch as the R/V could fall three nautical miles short of the target as well as long. It has been estimated by Aerophysics (595-1) that at R/V separation for a 4000 nautical mile flight a change in R/V velocity of one foot per-second will cause a 0.76 nautical mile error at the impact area. This error would be a little less at the time of tank fragmentation, but the above error ratio will be used in this analysis for further conservatism. The impact kinetic energy (ξ_m) required by a fragment to cause a mission failure is calculated by the following expression.

$$\mathcal{E}_m = \frac{1}{2}\left(\frac{S}{\Delta S}\right)^2\left(\frac{W_{(R/V)}}{g}\right) = \frac{1}{2}(\Delta v)^2 m_{(R/V)}$$

where: $S = 5$ n-mi

$\Delta S = 0.76$ n-mi/(ft/sec)

$W_{(R/V)}$ = Weight of Series "F" (R/V) = 4047 lbs

$g = 32.2$ ft/sec^2

$$\mathcal{E}_m = \frac{1}{2}\left(\frac{5}{0.76}\right)^2\left(\frac{4047}{32.2}\right) = 2740 \text{ lb-ft}$$

5.3.2 Table V lists the average impact kinetic energies ($\mathcal{E}_i$) of the fragments groups. This data was estimated from Reference 12. Because there were 799 total fragment samples, the individual fragment kinetic energies are estimated to follow the normal distribution. The average group velocities (V_e) are the average velocities of the fragments with respect to the (R/V). At the time of detonation (t = 184.2 seconds after t 108; t 103) the velocity of the R/V with respect to the tank section is:

$$V_{(R/V)} = \frac{r_s}{t} = 5.425 \text{ ft/sec}$$

where: r_s = separation distance $\approx$ 1000 ft

t = 184.2 seconds

For each fragment group, V_e (Table V) is calculated from the following expression to account for the separation velocity of the R/V.

$$V_e = V - V_{(R/V)} = V - 5.425 \text{ ft/sec.}$$

where: V = Total average dispersion velocity of fragment group

The average fragment velocity for each group (V_e) was estimated from the data presented in Reference 12. Although these velocities are very rough approximations because of the nature of the test presented in Reference 12, they compare readily with the theoritical estimations made in Reference 13.

The average kinetic energy of each fragment group ($\mathcal{E}_i$) is calculated from the expression given in the Notes of Table V.

The average fragment kinetic energy ($\mathcal{E}_A$) and its respective σ (Standard deviation $\mathcal{E}_i$ from $\mathcal{E}_A$) are calculated from the following expressions: (Reference 15)

$$\mathcal{E}_A = \frac{\Sigma k \mathcal{E}_i}{k_T} = 3433 \text{ Lb-ft}$$

$$\sigma = \frac{1}{C_2}\sqrt{\frac{\Sigma(\mathcal{E}_i - \mathcal{E}_A)^2 k}{k_T}} = 1.66 \times 10^4 \text{ Lb-ft}$$

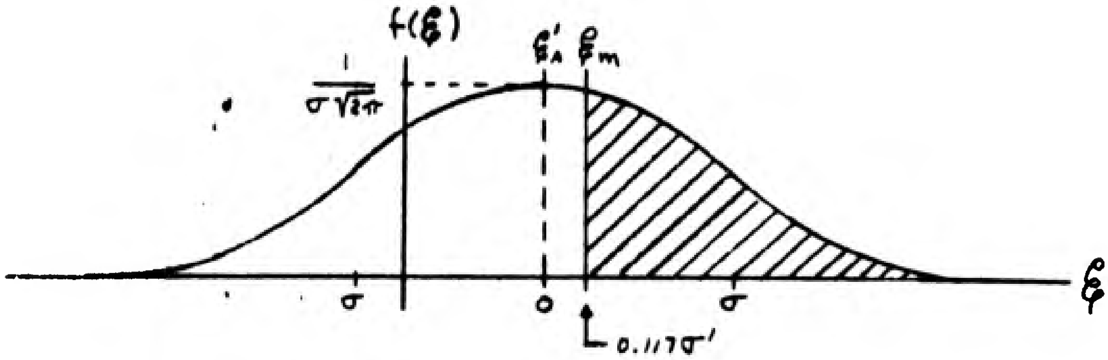
where: k = Number of particles in group

$k_T = 799$

$C_2 = \bar{\sigma}/\sigma \simeq 1$ (for $k_T = 799$; $\sigma \rightarrow \bar{\sigma}$)

These parameters give the maximum distribution for the energy transfer between the colliding fragment and the (R/V). For this distribution to be true the fragment center of mass would have to collide with the center of mass of the (R/V) or the energy transfer between the colliding fragment and (R/V) would have to approach 100 percent. Since the possibility of a collision (P_H, calculated in paragraph 5.2) was based on the exclusion area shown in Figure IX, the probability of total energy transfer is very small. For this

FIGURE XII



AVERAGE FRAGMENT KINETIC ENERGY DISTRIBUTION

analysis an average of 50 percent of the average energy is estimated transferred to the R/V by each fragment group. Therefore, the values for ξ_A and σ become:

$$\xi_A'' = \frac{\Sigma n k \xi_i}{k_T} = 1717 \text{ lb-ft}$$

$$\sigma' = \frac{a}{C_2}\sqrt{\frac{\Sigma(\xi_i - \xi_A)^2 k}{K_T}} = 8.75 \times 10^3 \text{ lb-ft.}$$

where: a = 0.50

This estimate could well be quite conservative, because the fragments would actually be tumbling and spinning, causing very little energy to be transferred to the (R/V).

Figure XII shows the normal distribution of the average fragment kinetic energies. To find the probability of a mission failure due to a fragment collision with the R/V, ξ_m is found in terms of σ'.

$$\mathcal{E}_m = 2740 \text{ Lb-Ft}$$

$$\sigma' = 8750 \text{ Lb-Ft}$$

$$\mathcal{E}_m = \frac{2740 \text{ Lb-Ft}}{8750 \text{ Lb-Ft}} \sigma' = 0.117(\sigma)'$$

P_E , the probability that the fragment, if it collides with the R/V, will have enough energy to cause a mission failure, can be found from the following expression:

$$P_E = 0.500 - \frac{1}{\sigma'\sqrt{2\pi}} \int_0^{\mathcal{E}_m} e^{-\frac{1}{2}\left(\frac{\mathcal{E}_i - \mathcal{E}_A}{\sigma'}\right)^2} d\mathcal{E}$$

$$P_E = 0.500 - \frac{1}{\sqrt{2\pi}} \int_0^{0.117} e^{-\frac{T^2}{2}} dT$$

$$\text{where: } T = \left(\frac{\mathcal{E}_i - \mathcal{E}_A}{\sigma}\right) = \mathcal{E}_i/\sigma$$

$$\sigma dT = d\mathcal{E}$$

$$P_E = 0.500 - .042 = 0.458$$

5.4 Probability of Mission Failure

Using the results obtained in paragraphs 5.1, 5.2 and 5.3, the probability of a mission failure can be calculated by the following expression:

$$P_F = P_B P_H P_E$$

Cases 1 and 2; $P_F = 0.00104$

Case 3; $P_F = 0.00029$

Because Case 1 and 2 assumes the most severe cases (random dispersion) of a hit and Case 3 limits the hit band to a normal distribution, the calculated probabilities form the upper and lower bounds of the actual probability at mission failure due to fragment - R/V collision. Therefore:

$$0.0003 < P_F < 0.001$$

5.5 Conclusion

5.5.1 The preceding analysis indicates that the chances for a mission failure due to a fragment-R/V collision is less than 0.001 for a 4000 nautical miles flight. Certain conditions are assumed to arrive at this conclusion. They are:

1. The least favorable orientation of the fragments (broadside collision).
2. Each fragment occupies a position in space with no over lapping of area. (Total surface area of all fragments was used in calculations.)
3. During any fragment - R/V collision the average energy transferred to the R/V is 50 percent the total kinetic energy of the fragment relative to the R.V.
4. All fragments attain enough velocity to collide with the R/V.

From the above assumptions a conservative estimate of the probability of no fragment-R/V collision could be made. Case 1 and 2 (paragraphs 5.2.1 and 5.4) show the limiting factors in the probability of fragment collision with the R/V. If the fragments disperse in a spherical pattern or the tank tumbles in a random fashion, the probability of a collision was shown to approach the $\Sigma k A_e$ divided by the total area of a sphere with radius (r_s) equal to the separation distance between the R/V and tank section. In the case of a 4000 nautical mile flight, the tank tumble approaches a spin with a total deflection about its center of mass (Ψ) that can be represented by a normal distribution. (Case 3; paragraph 5.2.2 and 5.4) In assuming 50 percent energy transfer at collision the probability of a damaging hit (P_E) was found to be 0.458. This assumption was made on the basis that most would not make a direct hit and [illegible] absorption, thus transfer only part of their collision energy to the R/V. If 100 percent energy transfer were assumed, P_E would only increase to 0.516.

5.5.2 From the results obtained in this analysis, estimations can be made on the effects of tank fragmentation on 5000 and 6000 nautical mile flights. In the longer flights the energy required to deflect the R/V off target will become somewhat less. Compared to the 4000 nautical mile flight where at separation a change in velocity of one foot per second will cause a 0.76 nautical mile error at the impact area; a one foot per second change in velocity will cause a 0.96 nautical mile error for the 5000 nautical mile flight and 1.2 nautical mile error for the 6000 nautical mile flight.

Therefore, the P_E for the longer flights will increase slightly, but not enough to affect the overall probability of mission failure due to collision appreciably. The longer the flight the more random the tank tumble will become because the inertial properties of the spinning tank changes as a function of the fuel left in the tank. Also, the mass becomes less because more fuel is used during powered flight. Thus, due to the tank decrease in mass the separation distance between R/V and tank section increases. As this distance increases, the probability of a collision decreases in proportion to the square of the increase because $P_B \cdot P_H$ approaches the fragment exclusion area divided by the area of the sphere formed by the separation distance. It can, therefore be concluded that it is less probable to have fragment-R/V collision on the longer range flights than the 4000 nautical mile flight.

5.5.3 Because the only data available for the writing of this report was the test made as reported in Reference 9, certain assumptions were made to try to use the data as it applies to the environmental conditions. If in the future actual environmental data becomes available, this analysis should be revised to reflect the actual conditions of the fragment dispersion pattern.

6.0 Reliability Testing

6.1 Reliability Testing and Selection of Components

The feasibility of performing reliability tests can be correlated to the minimum number of test cycles required to demonstrate a specified reliability on a given system or component. The minimum number of test cycles can be domonstrated by solving the equation

$R^N = (1-C)$ for N; where:

R = required reliability

N = minimum number of test cycles to demonstrate R

C = lower confidence limit.

Table VI and Figure XIII show N as a function of C for R = 0.99 and R = 0.9999. It can be seen from the plot for R = 0.99 that at least 230 test cycles are required for a 90% confidence level, while for R = 0.9999, at least 25,000 test cycles are required for a confidence level of 90%.

Reference 11 indicates that the proposed test plan for the system is to test three tank fragmentation systems, open loop, on "F" R&D missiles. From Figure XIII, it can be seen that with only three tests the reliability of the whole system cannot be verified with any appreciable degree of confidence. The control subsystem, which requires a reliability of 0.99, reliability could not be demonstrated adequately. The data gained

TABLE VI

MINIMUM NUMBER OF TEST CYCLES TO DEMONSTRATE A SPECIFIED RELIABILITY

Equation: $R^N = 1-C$

$$N = \frac{\text{Log}\ (1-C)}{\text{Log}\ R}$$

where: $\text{Log}\ R = -0.00436$; $R = 0.99$

$\text{Log}\ R = -0.00004$; $R = 0.9999$

C	Log (1-C)	N; (R=0.99)	N; (R=0.9999)
0.99	-2.00000	459	50,000
0.95	-1.30103	298	32,500
0.90	-1.00000	230	25,000
0.80	-0.69897	160	17,500
0.70	-0.52288	120	13,100
0.60	-0.39794	91.3	9,950
0.50	-0.30130	69.0	7,530
0.40	-0.22185	50.9	5,550
0.30	-0.15949	36.6	3,990
0.20	-0.09691	22.2	2,420
0.10	-0.04567	10.5	1,140

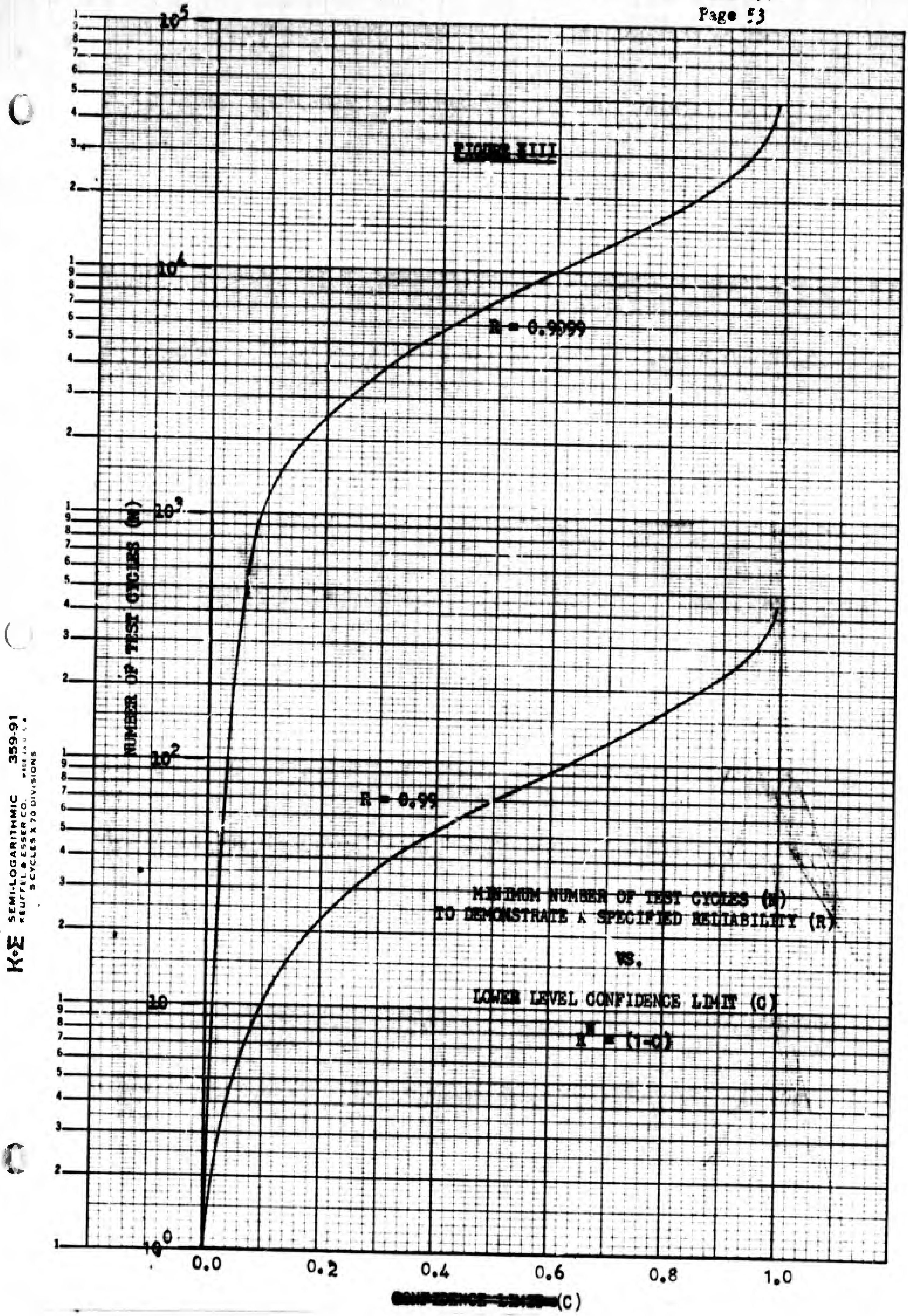


FIGURE XIII
R = 0.9999
R = 0.99
MINIMUM NUMBER OF TEST CYCLES (N)
TO DEMONSTRATE A SPECIFIED RELIABILITY (R)
VS.
LOWER LEVEL CONFIDENCE LIMIT (C)
R^N = (1-C)
NUMBER OF TEST CYCLES (N)
10^5
10^4
10^3
10^2
10
10^0
0.0
0.2
0.4
0.6
0.8
1.0
CONFIDENCE LIMIT (C)
K+E SEMI-LOGARITHMIC 359-91
KEUFFEL & ESSER CO.
5 CYCLES X 70 DIVISIONS

from these three tests will give engineering knowledge that can be used to determine areas of the tank fragmentation system that need testing and modification to increase the total reliability of the system.

6.2 Conclusion

It is considered feasible to perform a sequential life test on the control subsystem to demonstrate that the probability of detonation when required is not less than 0.99. Paragraph 3.7 indicates that the inherent reliability of the control subsystem is at least 0.998, and the most determining factor is α_1, the autopilot programmer (A/P) failure rate. If any failures were recorded during any of the three open loop flight test in the (A/P) a lift test program would be desirable on the (A/P). Likewise, if any of the other assemblies recorded failures during the flight test, a life test program should be set up for them. It is recommended that no less than 3 component assemblies of any type be used for the reliability study test. The test should be performed under mission conditions with respect to temperature and vibration. Allowances should be made for replacement of assembly parts reaching their design life during the test.

It is not considered feasible to perform a demonstration test to establish the probability of no inadvertent destruction is 0.9999 or greater. It is, however, recommended that a search for critical weakness test be performed to discover modes of failure that could cause inadvertent detonation.

If possible it is recommended that the three open loop tests be allowed to go through tank detonation (closed loop) to obtain a dispersion pattern for the fragments. This pattern can then be used to indicate the probability of no fragment collision with the re-entry vehicle as described in paragraph 5.0.

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APPENDIX A

Appendix A contains the generic failure rate data used to calculate the failure rate of the autopilot programmer (A/P). The total $GF_r/10^6$ HRS value for each part is determined by the following equation:

$$\text{TOTAL } GF_r/10^6 = (Gf_r/10^6)\,(K_a)\,(N)$$

where: K_a = Application factor which adjusts the generic failure rate for operating temperature (75°c) and part construction.

N = Quantity of parts of a type.

The total generic failure rate for each assembly is determined by summing the generic failure rates of each type of part in the assembly. The generic failure of a solder connection was estimated to be one per billion hours.

DRAWING NO. 27-41428-801 $GF_r/10^6$ HRS 15.914

ASSEMBLY NAME Network Logic Assy #1 A1A1

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Binary Assy	6	-	-	11.322
Transistor	17	0.5	0.15	1.275
Diode	6	0.2	0.25	0.300
Resistor	12	0.043	2.2	1.130
Capacitor	1	0.1	1.5	0.150
Transformer	1	1.04	0.18	0.187
Connector (17 active pins)	1	0.2	7	1.400
Solder Connections	150	0.001	1	0.150

DRAWING NO. 27-A1594-805 $GF_r/10^6$ HRS 4.014

ASSEMBLY NAME Logic Assy #3 A2A1

PART TYPE	QUANTITY	$GF_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Binary Assy	1	-	-	1.887
Transistor	4	0.5	0.15	0.300
Diode	2	0.2	0.25	0.100
Resistor	6	0.043	2.2	0.567
Capacitor	1	0.1	1.5	0.150
Connector (12 active pins)	1	0.2	4.8	0.960
Solder Connections	50	0.001	1	0.050

DRAWING NO. 27-45206-5 $GF_r/10^6$ HRS 0.978

ASSEMBLY NAME Remote Set Programmer A4

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Switch Contacts	3	0.05	.45	0.068
Resistor	1	0.043	2.2	0.094
Connectors (9 active pins)	1	0.2	4	0.800
Solder Connections	16	0.001	1	0.016

DRAWING NO. 27-41635-5 $GF_r/10^6$ HRS 2.772

ASSEMBLY NAME High Power Assy A7A2

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Transistor	8	0.5	0.15	0.600
Diode	3	0.2	0.15	0.150
SCR	3	0.4	0.25	0.300
Resistor	6	0.043	2.2	0.567
Connector (13 active pins)	1	0.2	5	1.000
Solder Connections	20	0.001	1	0.020

DRAWING NO. 27-40964-805 $GF_r/10^6$ HRS 17.248

ASSEMBLY NAME Counter Unit Sub. Assy T1-T6 and T14 A10A1

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Binary Assy	7	-	-	13.209
Transistor	42	0.5	0.15	3.150
Diode	5	0.2	0.25	0.250
Resistor	2	0.043	2.2	0.189
Connector (3 active pins)	1	0.2	1.5	0.300
Solder Connections	150	0.001	1	0.150

DRAWING NO. 27-41445-5 $GF_r/10^6$ HRS 18.509

ASSEMBLY NAME Counter Assy A10A2

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Binary Assy	7	-	-	13.209
Transistor	42	0.5	0.15	3.150
Diode	16	0.2	0.25	0.800
Connector (15 active pins)	1	0.2	6	1.200
Solder Connections	150	0.001	1	0.150

DRAWING NO. 27-40113-801 $GF_r/10^6$ HRS 2.170

ASSEMBLY NAME Diode Assy 12-17 A12A1

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Diode	17	0.2	0.25	0.850
Resistor	3	0.043	2.2	0.284
Connector (14 active pins)	1	0.2	5	1.000
Solder Connections	36	0.001	1	0.036

DRAWING NO. 27-41449-835 $GF_r/10^6$ HRS 1.557

ASSEMBLY NAME Diode Assy A12A2

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Diode	6	0.2	0.25	0.300
Resistor	1	0.43	2.2	0.945
Connector (3 active pins)	1	0.2	1.5	0.300
Solder Connections	12	0.001	1	0.012

DRAWING NO. 27-41001-989 $\quad GF_r/10^6$ HRS 5.873

ASSEMBLY NAME Programmer, Electronic, Autopilot

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Connector U3J1 (9 active pins)	1	0.2	4	0.800
Connector U3J2 (4 active pins)	1	0.2	2	0.400
Connector U3J3 (5 active pins)	1	0.2	2.5	0.500
Connector U3J4 (10 active pins)	1	0.2	4.2	0.840
Diode*	200	0.0667	0.25	3.333

* These diodes are located on circuit boards A11A1, A11A2, A13A1, and A13A2. Although they don't affect the tank fragmentation signal directly, if any failed with a short in the reverse-biased condition, they could cause a programmer failure that would inhibit the tank fragmentation signal. From knowledge of manufacturing defects resulting in failures, it can be assumed that one out of three diode failures will be a short. To account for this a generic failure rate of 0.0667 failures per million hours was used instead of the normal 0.2 failures per million hours.

[redacted]

DRAWING NO. 27-41498-1 $GF_r/10^6$ HRS 1.887

ASSEMBLY NAME Binary Assy

PART TYPE	QUANTITY	$Gf_r/10^6$HR	K_a	TOTAL $GF_r/10^6$HRS
Diode	3	0.2	0.25	0.150
Resistor	7	0.043	2.2	0.662
Capacitor	3	0.1	1.5	0.045
Connector (8 active pins)	1	0.2	3	0.600
Solder connections	25	0.001	1	0.025

[redacted]

FORM NO A-702-1