MIL-HDBK-336-1
25 October 1982

MILITARY HANDBOOK

SURVIVABILITY, AIRCRAFT, NONNUCLEAR,
GENERAL CRITERIA-VOLUME 1

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

NO DELIVERABLE DATA REQUIRED
BY THIS DOCUMENT

FSC MISC

DEPARTMENT OF DEFENSE
WASHINGTON 25, DC

MIL-HDBK-336-1
Military Handbook for Aircraft Nonnuclear Survivability.

1. This standardization handbook was developed by the Department of Defense with the assistance of the Air Force Wright Aeronautical Laboratories (AFWAL/FIE) in accordance with established procedure.

2. This publication was approved on 26 October 1982 for printing and inclusion in the military standardization handbook series.

3. This document provides basic and fundamental information on military aircraft survivability design requirements and assessment methodology. It will provide valuable information and guidance to personnel concerned with the design and assessment of military aircraft. The handbook is not intended to be referenced in purchase specifications except for informal purposes, nor shall it supersede any specification requirements.

4. Every effort has been made to reflect the latest information on military aircraft design techniques and assessment methodology. It is the intent to review this handbook periodically to insure its completeness and currency. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: (Air Force Systems Command, Attn: ASD/ENESS, Wright-Patterson Air Force Base, Ohio 45433) by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

1. This is a four volume Military Handbook. The titles of the four volumes are:

   a. Volume 1 - Survivability, Aircraft, Nonnuclear, General Criteria

   b. Volume 2 - Survivability, Aircraft, Nonnuclear, Airframe

   c. Volume 3 - Survivability, Aircraft, Nonnuclear, Engine

   d. Volume 4 - Survivability, Aircraft, Nonnuclear, Classified, General Criteria

The information contained in volumes 1, 2, and 3 is unclassified to permit greater utilization and accessibility to the user. In areas where classified data is applicable, it has been incorporated into volume 4, and is referenced as such in the text of each volume.

2. This handbook has been prepared to provide military planners and industry with the information and guidance needed for the conceptual and detail design of the new aircraft where nonnuclear-survivability enhancement is to be integrated into the system. It is also structured to provide data and guidance for the incorporation of survivability-enhancement features into existing aircraft systems as a retrofit modification. Both fixed and rotary wing aircraft design information are contained in this publication. Figure 1 illustrates the role of this handbook in the design process. It is a task-flow diagram of the major elements involved in the development of new aircraft. The system requirements are initiated by the using command that defines the operational requirements and capabilities desired to perform specific combat missions. These requirements are studied by the appropriate service agencies in the form of conceptual (Phase 0) design analyses. The optimum mission and performance parameters are defined, along with system/cost effectiveness comparisons of candidate conceptual design candidates. This is accomplished through an analysis to identify the mission-essential functions that must be performed in order to accomplish the specific mission objectives. With these functions defined, an analysis is conducted to identify the subsystem-essential functions that must be provided to perform the mission-essential functions. At the same time, an analysis is conducted to identify the hostile threat systems to which the aircraft system may be expected during the conduct of its operational mission. The results of these analyses are then used by the S/V engineer to conduct an evaluation of the various candidate survivability-enhancement techniques that may be used in the design concepts. This design handbook will be the basic source for identification of the basic principles and techniques that may be employed. It will also provide references to other information sources for more detailed and/or specialized data. The results of this analysis are summarized into recommendations for the development of candidate conceptual aircraft designs. As each candidate system is evolved, vulnerability and survivability assessment are conducted to evaluate the effectiveness of their individual S/V design features. As shown, this design handbook is used directly by the conceptual designers, vulnerability assessment analysts, and survivability assessment analysts in the design process. At the same time, design trade-off studies are conducted that evaluate the benefits and penalties associated with candidate system and subsystem elements. The results of vulnerability, survivability, and design tradeoff

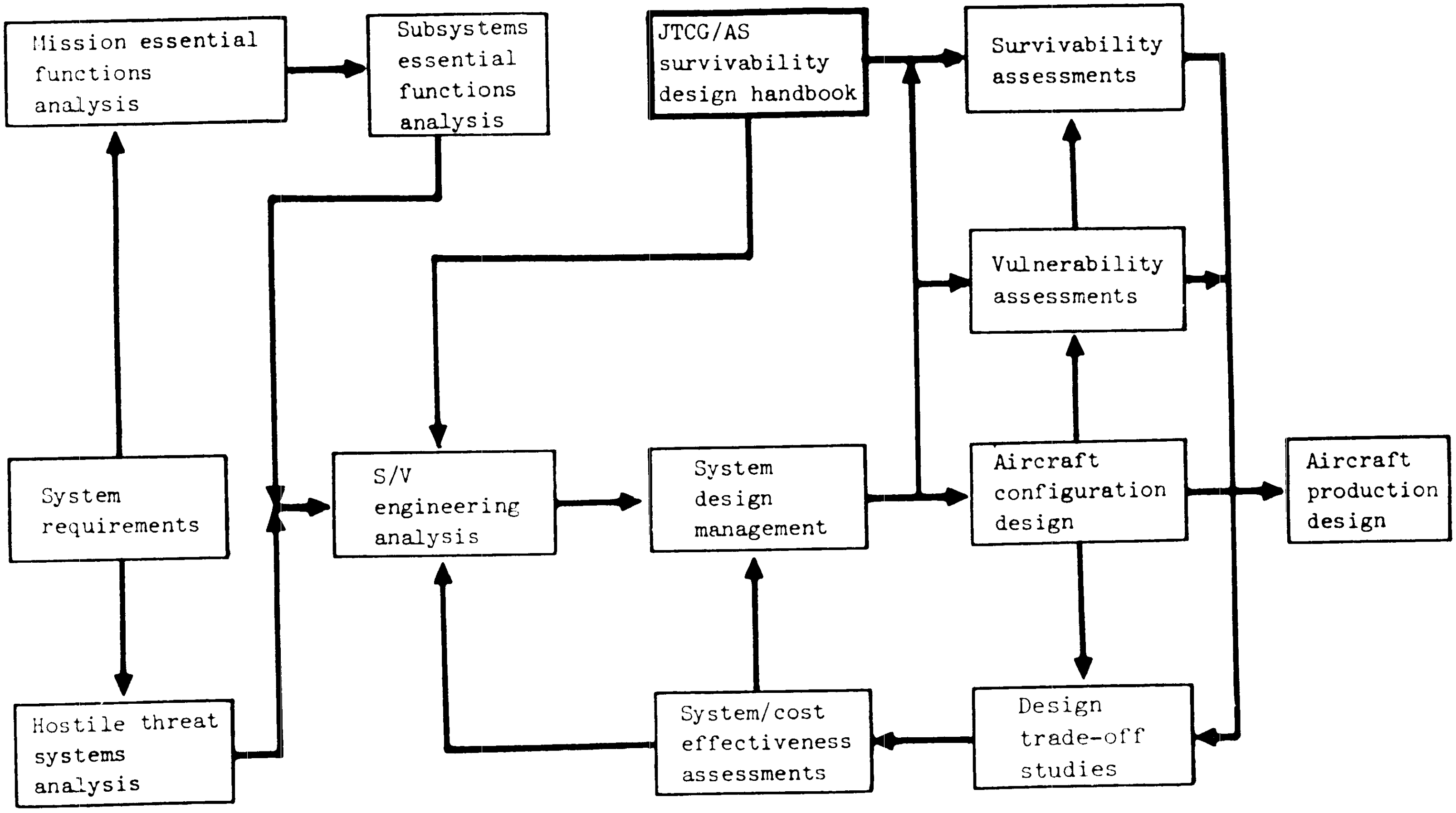

FIGURE 1. Handbook use in design process.

studies are used as input data for system/cost effectiveness analyses. This evaluation provides the system design management and the S/V engineer with the overall system benefits and penalties for the various design concepts. It permits selection of the most effective combinations of survivability-enhancement features for the specific system applications, and identifies areas of deficiencies or over design that may be improved. The process is iterative, and is continued until the most cost effective design concept is developed. It then becomes the baseline design for the production aircraft. The same process is repeated through the validation, full-scale development, production, and operational phases of the aircraft system.

3. Military aircraft survivability enhancement began in World War I with makeshift efforts by the pilots to provide themselves with some form of ballistic armor protection. This progressed from steel infantry helmets and stove lids fastened to the pilot seats to all-steel pilot seats 0.3-inch thick. In 1917, Germany designed an armored, twin-engine bomber, with 880 pounds of 0.29-inch steel plate armor located in sensitive areas. The British countered by installing steel seats and 0.50- to 0.625-inch nickelchrome steel armor around radiators, gas tanks, and the aircrew in some of their aircraft. In the late 1930's, the United States began to install armor in some of their fighter aircraft. In World War II, the greatest threat against aircrews was fragments for antiaircraft artillery shells. The available body armor in 1942 was awkward and heavy and thus rejected. The need for lightweight armor led to the development in 1943 of fiberglass bonded into a laminate and called Doron, after Col. G.F. Doriot. Most of the body armor of WW II was Doron Type 2. The introduction and use of flak suits reduced casualties from 6.58 wounds per 1,000-man sorties to 2.29 wounds per 1,000-man sorties in 1943-44. None of the armor of this period was effective against API bullets, however. The aluminum nylon M12 vest was developed as an improvement over Doron and was field-tested in Korea. An all-nylon vest consisting of 12 layers of 2 x 2-inch basketweave nylon also developed was attractive because of its flexibility and effectiveness against mortar and shell fragments. Flat plate armored glass was incorporated into the windshields of combat aircraft as an added protection for the crew. Self-sealing fuel bladders and lines were developed for bomber and fighter aircraft during World War II and were credited with saving many of these systems. Some attention was also directed to the suppression of fuel fires in bomber aircraft. Balsa wood was installed around some of the voids in wing fuel tanks to prevent fuel leakage fires in those areas. The British experimented with fire extinguishing systems in the fuel tank areas of some of their multiengine aircraft. Considerable research on specific problems of aircraft protection and vulnerability was conducted during the war, with particular attention being directed to penetration of materials by bullets and fragments, and the effect of blast on aircraft structures. In 1948, the First Working Conference on Aircraft Vulnerability was held at the U.S. Army Ballistic Research Laboratory at the Aberdeen Proving Grounds, Maryland. The participants were recognized experts from the Air Force Air Material Command, the Army Ballistic Research Laboratory, Johns Hopkins University Applied Physics Laboratory, University of Chicago Ordnance Research, General Electric Engine Company, New Mexico School of Mines, the Navy Ordnance Explosive Group, and the Rand Corporation. The purpose of this meeting was to define the problem of military aircraft vulnerability and to identify the technology required to develop design improvements. Unfortunately, the excellent beginning initiated by this group was curtailed by the philosophy that all future wars would be fought with nuclear weapons. This idea continued through the 1950's and early 1960's where little attention was

paid to nonnuclear survivability of military aircraft. During the Korean conflict, a limited revival of interest in nonnuclear survivability was experienced. The emphasis was primarily directed to fighter and attack aircraft. The major survivability enhancement techniques were mainly improvements in armor and self-sealing fuel tank designs. The use of coordinated tactics in air-to-air combat with fighter aircraft became an area of interest to the Air Force and Navy that proved to be an important factor in the one-sided kill ratios enjoyed by the United States. Again, after this conflict, the emphasis of military aircraft design was directed to general nuclear war considerations that hampered research on non-nuclear survivability considerations.

The Army recognized the threat of small arms and light AA weapons to aircraft operating in direct support of forward area units, and in the late 1950's initiated action to develop protective measures for the aircrew and critical aircraft components against these threats. The Air Vehicle Environmental Research Team, consisting of technical representatives from the user and the appropriate technical service laboratories was formed, and they developed the original concepts for ballistic protection systems that were later employed in all Army combat aircraft. These concepts were also used in varying degrees by the USAF and Navy. These efforts led to the development of a new family of lightweight armor materials, damage tolerant components, and major advances in fuel protection.

The employment of large numbers of U.S. aircraft in Southeast Asia, in the mid-1960's, resulted in an awareness of their susceptibility to hostile non-nuclear weapon systems. Helicopters were used for the first time in combat roles where exposure to enemy gunfire was commonplace. The large numbers of rotary-wing aircraft shot down or critically damaged by small-caliber weapons provided the motivation to conduct research and testing geared to providing improved survivability for these systems. Many of the design improvements were pioneered by this effort. The Air Force and Navy were also experiencing unacceptable aircraft losses and embarked on programs to analyze the problems and develop new means to modify the existing aircraft to make them more survivable. The use of reticulated foam inside fuel cells was one of the major improvements developed. Considerable advances were made in the field of armor materials. Ceramic composite armors were developed for protection against armor-piercing projectiles in an effort to obtain higher levels of ballistic protection with smaller weight penalties. Later in this conflict, when the sophistication of hostile weapon systems was raised to a level never before experienced, many new survivability enhancement methods were developed and employed. These included radar homing and warning systems (RHWS), electronic warfare countermeasures, infrared emission suppression methods for aircraft engines, evasive tactics against surface-to-air missiles, improved weapon delivery systems (missiles, smart bombs, etc), visual and aural signature reductions, tactics, and many other techniques.

The analytical capabilities for survivability assessment programs were expanded tremendously through the use of high-capacity, high-speed electronic computers, providing military and industry with valuable new tools. There occurred a rapid proliferation of computer models by each of the services and most of the airframe manufacturers. The military services recognized the need for an integrated effort to standardize the growing methodology and research and test programs. An organization was developed through triservice efforts to accomplish these objectives. It was designated as the Joint Technical Coordinating

Group on Aircraft Survivability (JTCG/AS), with the charter signed by the Joint Commanders on 25 June 1971. Since that time, considerable progress has been made to implement interservice efforts to develop more effective and efficient methods to enhance aircraft nonnuclear survivability. The organization has maintained close liaison with each service activity to ensure that all survivability and vulnerability data and systems criteria are made available to developers of new aircraft. The JTCG/AS has accepted the responsibility for coordinating the aircraft survivability technology for high-energy laser weapons that are projected as the next major threat system in potential future conflicts. This activity has been pursued for the past several years. Rapid advances in survivability enhancement methods are being accomplished through numerous research programs. Considerable savings in manpower and resources are expected to be realized through the coordination of this new technology through the efforts of the JTCG/AS in the future. This publication will serve as the vehicle by which the analytical and design data will be dispersed to the S/V community. The fruits of the coordinated efforts are currently being enjoyed, as is evidenced by the significantly higher levels of survivability that have been incorporated into new military aircraft systems now entering service or in current development.

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1. SCOPE

1.1 General. This is the first volume in a four-volume design handbook for nonnuclear survivability of military aircraft. Each volume is structured to be used in conjunction with the other three volumes, as needed, in the design process. This volume contains general information pertaining to vulnerability and survivability analysis techniques, weapon terminal effects, computer program descriptions, and basic subsystem conceptual design concepts. Volume 1 is arranged in a manner that allows the user to easily identify the specific information of interest.

1.2 Application. The data contained in this design handbook have been arranged to support the development of both fixed and rotary wing military aircraft. Each has unique mission and performance characteristics that require specialized attention and design solutions. The subystem design categories have been established with these considerations in mind. For example, the power train and rotor blade subsystems deal primarily with military helicopter applications, while the launch/recovery systems deal with those subsystem elements for both fixed and rotary wing aircraft landing gear systems and for those systems related to the assisted takeoff (launching) and deceleration (recovery) methods most used by the Air Force and Navy fixed-wing aircraft.

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2. REFERENCED DOCUMENTS

2.1 General. The documents in this section form a part of this handbook to the extent specified herein. This section contains a complete list of all references specifically referred to in these four volumes and those where additional information can be obtained.

2.2 Reference by volume. Table 2-I lists the reference by Volume number. Parentheses ( ) around a number indicates that the reference has been deleted.

TABLE 2-I. References by volume no.

Ref. No.	Volume Number			
	1	2	3	4
1	X			
2	X	X		
(3)				
4	X			
5	X	X		X
6	X			
7	X			
8	X			
9	X			
10	X			
11	X			
12	X			
13	X			
14	X			
15	X			
16	X			
17	X			
18	X			
19	X			
20	X			
21	X			
22	X	X		
23	X	X		
24	X			
25			X	
26			X	
27			X	
(28)				
29			X	
30		X	X	
31			X	
32		X	X	
33			X	
34			X	
35			X	
36			X	
37			X	
38			X	
39			X	
40			X	
41			X	
42			X	
43			X	
44			X	
45			X	
46			X	
47			X	
48			X	
49			X	
50			X	
51			X	
52			X	
(53)				
54			X	
55		X	X	
56			X	

the production contract deliverables which are not a part of the

TABLE 2-I. References by volume no. (continued)

Ref. No.	Volume Number			
	1	2	3	4
(57)				
58			X	
59			X	
(60)				
61		X		
62		X		
63		X		
64		X		
65		X		
66		X		
67		X		
68		X		
69		X		
70		X		
71		X		
72		X		
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74		X		
75		X		
76		X		
77		X		
78		X		
79		X		
80		X		
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84		X		
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87		X		
88		X		
89		X		
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92		X		
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109		X		
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118		X		
119		X		
120		X		
121		X		
122		X		
123		X		
124	X			
125		X		
126		X		
127		X		
128		X		
129		X		
130		X		

TABLE 2-I. References by volume no. (continued)

Ref. No.	Volume Number			
	1	2	3	4
131		X		
132				X
(133)				
(134)				
135		X		
136		X		
137		X		
138		X		
139		X		
140		X		
141		X		
142		X		
143		X		
144		X		
(145)				
146		X		
147			X	
148			X	
149			X	
150			X	
151			X	
152			X	
153			X	
154			X	
155		X		
156				X
157				X
(158)				
(159)				
160		X		
161	X	X		
162		X		
163	X	X		
164	X	X		
165	X	X		
166	X			
167		X		
168		X		
169		X		
170			X	
171		X		
172		X		
173	X	X		
174		X		
175		X		
176		X		
177		X		
178		X		
179		X		
180		X		
181	X			
182		X		
183	X			
184	X			X
185	X			
186	X			
187	X			
188	X			
189				X
190				X
191				X
192	X			
193	X			
194	X			
195	X			
196	X			
197	X			
198	X			
199		X		
200		X		
201		X		
202		X		

TABLE 2-I. References by volume no. (continued)

Ref. No.	Volume Number 1	2	3	4
203		X		
204		X		
205		X		
206		X		
207		X		
208		X		
209		X		
210		X		
211		X		
212		X		
213		X		
214		X		
215		X		
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221		X		
222		X		
223		X		
224		X		
225		X		
226		X		
227		X		
228		X		
229		X		
230		X		
231		X		
232		X		
233		X		
234		X		
235		X		
236		X		
237		X		
238		X		
239		X		
240		X		
241		X		
242		X		
243		X		
244		X		
245		X		
246		X		
247		X		
248		X		
249		X		
250		X		
251		X		
252		X		
253		X		
254		X		
255		X		
256		X		
257		X		
258		X		
259		X		
260		X		
261		X		
262		X		
263		X		
264		X		
265		X		
266		X		

2.3 Reference by subject. Table 2-II lists the References by subject matter.

TABLE 2-II. References by subject matter

Category / Ref. No.	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
1	X																	
2	X																	
(3)	O																	
4	X																X	
5	X																X	
6	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
7	X																X	
8																	X	
9																	X	
10																	X	
11																	X	
12																	X	
13																	X	
14																	X	
(15)																		O
16																	X	
17																	X	
18																	X	
19																	X	
20																	X	
21																	X	
22	X																	
23	X	X	X	X	X	X		X	X	X	X	X	X	X		X		X
24	X																X	
25					X													

TABLE 2-II. References by subject matter (continued)

Category / Ref. No.	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
26					X													
27					X													
(28)																		
29	X													X				
30				X	X													
31														X			X	
32					X			X	X				X					
33					X													
34					X													
35	X				X									X				
36					X													
37					X													
38					X													
39	X				X									X				
40	X													X				
41	X													X			X	
42	X													X				
43	X																	
44	X				X													
45	X				X													X
46					X													
47					X													
48					X													
49					X													
50					X													

TABLE 2-II. References by subject matter (continued)

Category / Ref. No.	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
51					X													
52					X													
(53)																		
54					X													
55					X													
56				X	X													
(57)																		
58				X	X													
59				X	X													
(60)																		
61	X	X																
62								X									X	
63								X										
64								X										
65								X										
66								X										
67								X										
68								X										
69								X										
70								X										
71								X										
72								X										
73	X							X									X	
74																X		
75	X						X	X					X					X

TABLE 2-II. References by subject matter (continued)

Ref. No. \ Category	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
76					X													
77					X		X											
78					X		X											
79					X		X											
80					X		X											
81					X		X											
82					X		X											
83	X		X															X
84									X							X		
85								X	X									
86								X	X									X
87	X																	X
88	X																	X
89	X																	X
90	X																	X
91	X																	X
92	X																	X
93	X																	X
94	X																	X
95	X																	X
96	X																	X
97	X																	X
98	X	X				X												X
99			X															
100	X		X															X

TABLE 2-II. References by subject matter (continued)

Category / Ref. No.	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
101			X													X		
102																X		
103																X		
104																X		
105																X		
106																X		
107																X		
108																X		
109																X		
110	X				X							X		X				X
111																X		
112																X		
113																X		
114	X		X													X		
115				X													X	X
116				X				X										
117								X										
118												X				X		X
119												X						X
120												X						X
121												X						
122	X	X																
123		X														X		
124	X																	
125		X																

TABLE 2-II. References by subject matter (continued)

Ref. No. \ Category	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov	Armor	Computer Prog.	Threat Data
126		X																
127								X									X	
128	X																	
129	X	X																
130		X																
131		X		X													X	
132	X	X																
(133)																		
(134)																		
135					X	X												
136								X										
137								X										
138																X		
139	X																X	
140	X																X	
141	X																X	
142	X																X	
143	X																X	
144													X	X				
(145)																		
146														X				
147					X													
148					X													
149					X			X	X							X		
150					X													

TABLE 2-II. References by subject matter (continued)

Category / Ref. No.	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
151					X													
152					X													
153					X													
154					X													
155	X	X																
156	X				X	X	X											
157	X				X	X	X											
(158)																		
(159)																		
160								X										
161								X										
162		X	X	X						X							X	
163								X										
164	X							X									X	
165	X							X									X	
166																		X
167								X										
168								X										
169				X														
170					X									X				
171											X							
172				X														
173				X														
174				X														
175				X														

TABLE 2-II. References by subject matter (continued)

Ref. No. \ Category	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
176				X														
177				X														
178				X														
179										X								
180										X								
181	X																	
182		X		X												X		
183												X						X
184	X											X						
185	X																	X
186	X						X											X
187	X						X											
188												X					X	X
189		X														X		
190												X						X
191	X	X														X		X
192	X																	
193	X																	
194	X																	
195																	X	
196				X														
197			X															
198				X														
199												X						
200	X																	

TABLE 2-II. References by subject matter (continued)

Ref. No. \ Category	General	Structures	Personnel (Crew)	Fuel	Propulsion	Power Train	Rotor Blades	Flight Cont.	Fluid Power	Envir. Cont.	Oxygen	Armament	Elect. Power	Avionics	Launch/Recov.	Armor	Computer Prog.	Threat Data
201												X						
202				X					X			X				X		
203					X							X						
204																X		
205																		
206	X	X																
207																X		
208									X									
209																X		
210				X														
211									X									
212				X														
213		X		X														
214				X														
215																X		
216																X		
217			X															
218				X														
219																X		
220	X							X										
221		X																
222		X																
223		X																
224		X																
225		X																

TABLE 2-II. References by subject matter (continued)

Category / Ref. No.	General Structures Personnel (Crew)	Fuel Propulsion Power Train	Rotor Blades Flight Cont. Fluid Power	Envir. Cont. Oxygen Armament	Elect. Power Avionics Launch/Recov.	Armor Computer Prog. Threat Data
226	X					
227	X					
228	X					
229	X					
230	X					
231	X					
232	X					
233	X					
234	X					
235	X					
236	X					
237	X					
238	X					
239			X			
240			X			
241				X		
242						X
243						X
244					X	
245	X			X		
246	X		X			
247		X				X
248				X		
249						X
250						

TABLE 2-II. References by subject matter (continued)

Category Ref. No.	General Structures Personnel (Crew)	Fuel Propulsion Power Train	Rotor Blades Flight Cont. Fluid Power	Envir. Cont. Oxygen Armament	Elect. Power Avionics Launch/Recov.	Armor Computer Prog. Threat Data
251						X
252						X
253						X
254						X
255						X
256						X
257		X				
258	X		X			
259				X		
260						X
261		X				
262		X				
263					X	
264			X			
265		X				
266						X

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(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer).

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3. DEFINITIONS

3.1 Terms and definitions. Aircraft nonnuclear S/V discipline covers many diverse activities and elements. These activities and elements range from analyses of the inherent capability of enemy threats to the effectiveness of those threats in particular environments; from analyses of inherent aircraft damage susceptibility to the response of materials from threat impact; from the development of analytical assessment procedures to the analyses of combat data; and from the development of vulnerability-reduction techniques to aircraft trade-offs, that include and interface with other disciplines, such as maintainability, reliability, etc. The S/V discipline, therefore, is multidimensional, as practiced at a variety of government agencies and industry groups. The close technical working relationship, with interchanges of data, methodology, etc. between these diverse activities, requires a precise understanding of the terminology used. To insure that such understanding is achieved the definitions for Aircraft Non-Nuclear survivability are as specified in MIL-STD-2089.

The terms are listed in six topical fields as shown in Table 3-I.

TABLE 3-I. Nonnuclear survivability definitions topical fields.

Topical Field	Associated Activities/Elements
Threats	Threat analysis, threat characteristics data, threat inherent lethality assessment
Assessment methodology	Computational methods and measures of aircraft survivability/vulnerability
System response	System/Subsystem response to threat impact; lethal criteria data; kill levels; kill mechanisms
Trade-offs	Benefits and penalties from survivability enhancement; trade-offs
Survivability enhancement	Vulnerability reduction; hardening; self defense; electronic countermeasures
S/V test and combat data	Test data, experimental methods; combat data analysis

Some of the most used and important definitions relevant to nonnuclear survivability are listed alphabetically in this section for the guidance of the user. Definitions are provided only for those terms which are not included in MIL-STD-2089.

a. Aircraft Probability of Kill - The probability that an aircraft will not survive a defined damage level in specified threat engagements.

b. Aircraft Survivability Assessment - Systematic description, delineation, quantification, and statistical characterization of the survivability of an aircraft in encounters with hostile defenses.

c. Aircraft Vulnerability Assessment - Systematic description, delineation, and quantification of the vulnerability of an aircraft when subjected to threat mechanisms.

d. Survivability - The capability of an aircraft to avoid and or withstand a man-made hostile environment without sustaining and impairment of its ability to accomplish its designated mission.

e. Vulnerability - The characteristics of a system that cause it to suffer a finite level of degradation in performing its mission as a result of having been subjected to a certain level of threat mechanisms in a man-made hostile environment.

4. GENERAL REQUIREMENTS

4.1 Management. Survivability (S/V) Engineering has been firmly established as a system engineering speciality. It has been integrated into the system engineering process as defined in MIL-STD-499(USAF) (Reference 192), "Engineering Management." This places the S/V engineering into a position of primary consideration in aircraft system development. Management of S/V engineering programs must conform to the objectives required by MIL-STD-499(USAF) which defines engineering management as:

> "The management of the engineering and technical effort required to transform a military requirement into an operational system. It includes the system engineering required to define the system performance parameters and preferred system configuration to satisfy the requirement, the planning and control of technical program tasks, integration of the engineering specialties, and the management of a totally integrated effort of design engineering, specialty engineering, test engineering, logistics engineering, and production engineering to meet cost, technical performance, and schedule objectives."

4.1.1 Life Cycle. Management of a military aircraft's survivability capability must be conducted throughout its life cycle process by both the government and the manufacturer. This involvement is required in all phases of the life-cycle process as shown in Figure 4-1. The government (DoD) has the major responsibility in the conceptual and validation phases where the basic requirements for the aircraft system are established. The contractor has the major task responsibility in the full-scale development and production phases. The using service has the major responsibility for the survivability enhancement capabilities of the system in the operational employment phase.

4.2 Military Coordination. Requirements for the conduct of S/V engineering programs have been established by each of the three major military services for application to their specific types of aircraft systems. The U.S. Army Aviation Research and Development Command (AVRADCOM) has published an Army "Aeronautical Design Standard Survivability Program" ADS-11A (Reference 2), which defines the general and detailed requirements for the contractor to develop and implement a survivability program for their specific aircraft systems. The Naval Air Systems Command has published MIL-STD 2072 "Establishment and Conduct of programs for Aircraft Survivability" (Reference 193), which defines the S/V engineering program requirements for Navy aircraft system development. The Air Force Systems Command has published a Design Handbook AFSC DH 2-7, "Systems Survivability" (Reference 5) which contains both Nuclear and Non-Nuclear Sections.

A triservice military standard is currently being prepared by the JTCG/AS entitled "Requirements for Establishment of Aircraft Nonnuclear Survivability Program". This document will contain detailed information and guidance for the development and conduct of a nonnuclear survivability program to be performed by industry. The basic elements of each of the individual service programs and the proposed military standard are the objectives, organization, plans, requirements, and verification procedures. Each of these items are discussed in subsequent paragraphs of this section.

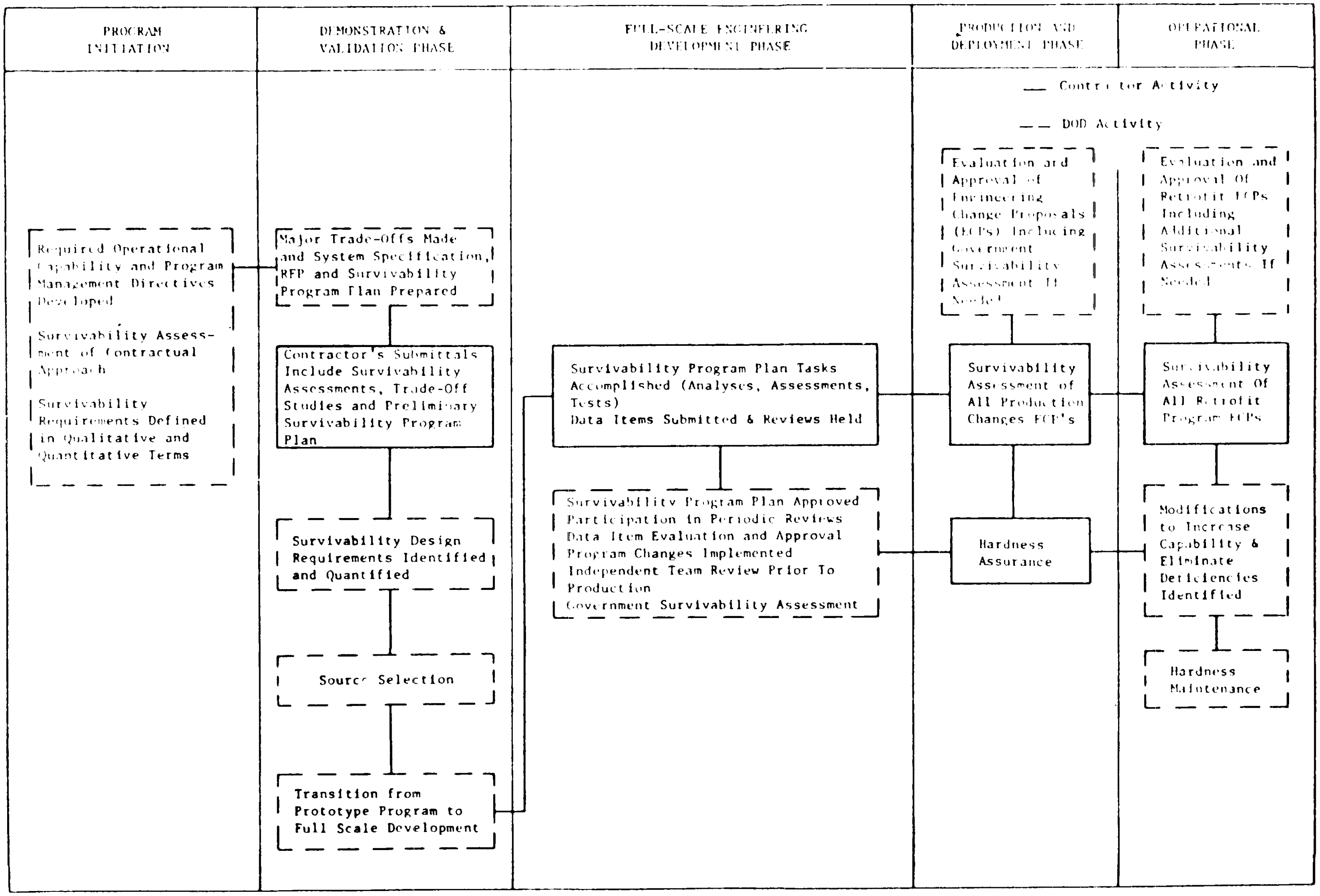

FIGURE 4-1. Life cycle survivability

4.3 Program objectives. The objectives (purpose) of S/V engineering programs are to provide uniform requirements and criteria for the establishment and conduct of aircraft survivability programs and provide guidelines for the preparation of survivability program plans. In all of the S/V program documents the primary purpose is to require that a thorough and systematic program is conducted to ensure that effective survivability features are incorporated into all future weapon systems. To accomplish this objective, certain basic program elements are specified. These include development of S/V engineering program plans by the contractor, the establishment of adequate management organizations, identification of required program tasks, establishment of S/V program procedures, establishment of program reporting criteria, and identification of quality assurance (verification) methods and procedures.

4.4 Organization. The implementation and conduct of an effective S/V program for an aircraft system dictates the need for an S/V engineering organization that is properly integrated into a contractor's management system. It must have the capability to perform the functions required to support the design process, conduct analyses and trade-off studies, conduct development programs and tests, and conduct verification programs. The S/V engineering organization must also be in a position to provide system design management with the necessary information and recommendations to influence the proper recognition and acceptance of S/V requirements. It is also needed to identify effective survivability enhancement methods for implementation into the design concept. An example of a typical contractor organization is shown in Figure 4-2. The S/V engineering function is under the system engineering manager who in turn reports directly to the program directors office. The S/V engineering group is on the same management level as producibility, maintainability, safety, reliability, human factors, integrated logistics, and value engineering. This arrangement also permits effective interface and cooperation with all of the system engineering disciplines.

4.5 Plans. The development of a survivability program plan is essential to the successful conduct of a nonnuclear S/V engineering program. It must adequately define the specific tasks that must be accomplished and indicate their interrelationships. The tasks may be depicted by a task flow diagram, such as the one shown in Figure 4-3. This example is for a rotary wing aircraft where the S/V engineering program requirements had been dictated by AVSCOM document ADS-11A (Reference 2). It illustrates the systematic means by which an aircraft manufacturer's S/V engineering organization would conduct the tasks necessary to develop and incorporate the most effective survivability features into the aircraft system. It represents the effort for research, development, test and evaluation (RDT&E) after a baseline design has been established. A similar, higher-level effort would have been utilized in the design concept.

4.6 Requirements. The definitive requirements for survivability levels of an aircraft system provide the design-to criteria that have been established by the system manager. These are usually defined as detailed requirements. They include both the qualitative and quantitative features desired for the particular system. The qualitative features are those that would be subjected to trade studies and system/cost-effectiveness analyses to determine optimum solutions and to establish quantitative requirements. The quantitative survivability features are those specified in terms of measurable values for specific items.

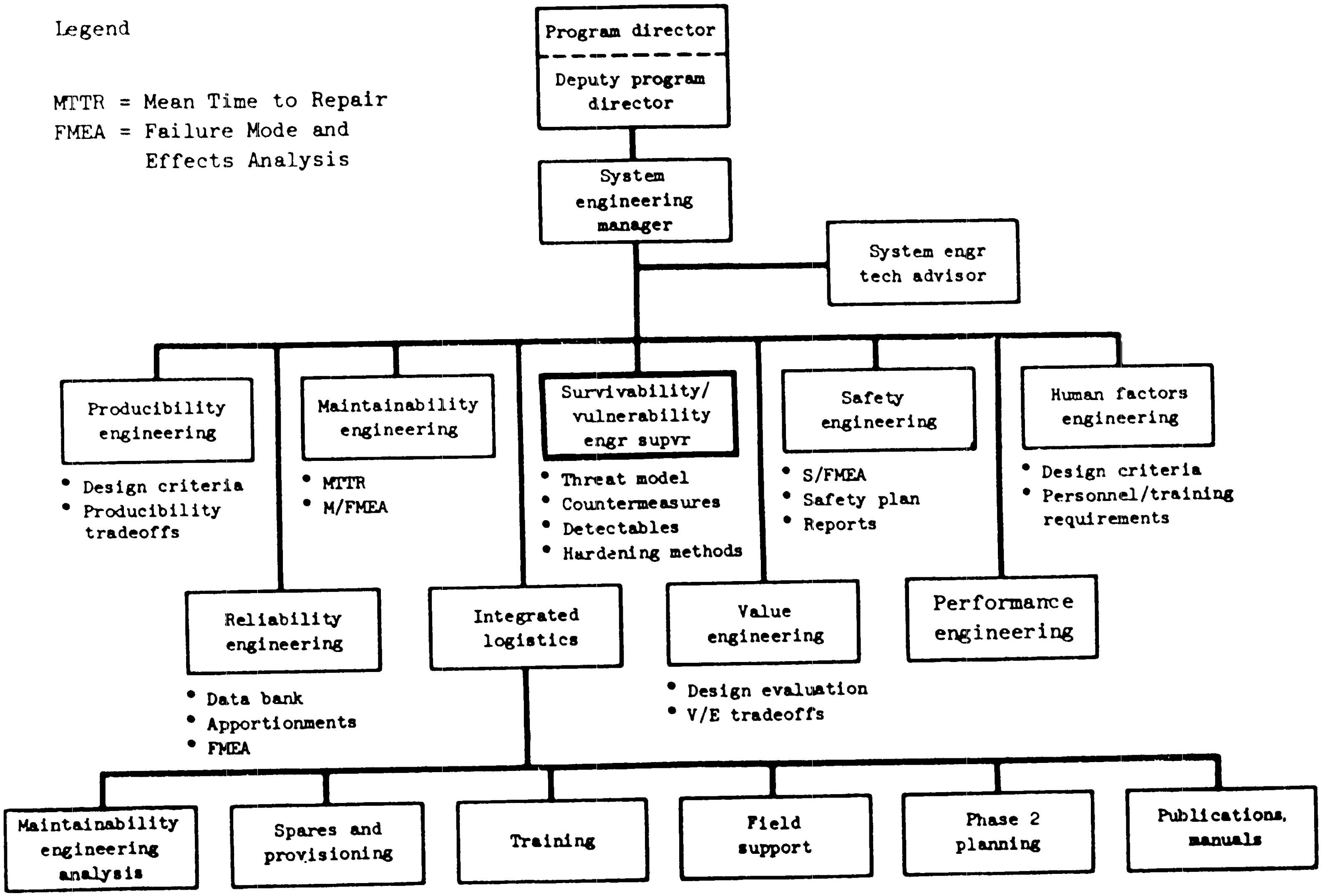

FIGURE 4-2. System integration organization.

4.6.1 Survivability enhancement. Requirements for a system may be specified for all or some of the following categories, as applicable:

a. Detection avoidance
   (1) Radar Cross-Section
   (2) IR Signature
   (3) Aural Signature
   (4) Visual Signature
   (5) Smoke
   (6) Electronic Countermeasures
   (7) Expendables
   (8) Decoys

b. Threat avoidance
   (1) Radar Warning
   (2) IR Sensing

c. Threat suppression
   (1) Countermeasures
   (2) Lethal Defense
   (3) Counter-Countermeasures

d. Threat effects tolerance (Subsystem Protection Levels) for:
   (1) Armor Piercing Projectiles
   (2) Incendiary Projectiles
   (3) High Velocity Fragments
   (4) Blast Overpressure
   (5) Other Threats (e.g., Laser, BW, CW)

e. Multiple exposures (Cumulative Effects)

f. Synergistic effects

g. Target threat orientation (Attack Aspects)

h. Verification

i. Hardware assurance

j. Other requirements (As necessary)

4.7 Verification Procedures. Requirements for survivability in a military aircraft system are contained in Part 3 of the aircraft system specification. For each specific requirement, a verification procedure is required in Part 4, Quality Assurance Section, of the specification. The method may be by test and/or by analysis as established by the contracting agency. This requires that the contractor either conduct the required analyses and/or tests to demonstrate compliance with the survivability requirements or to provide the necessary support for those tests to be conducted by designated government agencies, Verification plans and procedures are generally developed by the contractor and negotiated with the contracting agency. It is also the responsibility of the contractor to incorporate S/V requirements and verification methods into the specifications for subcontractors. This is required to ensure that the desired survivability enhancement level has been achieved in the end product and has been demonstrated in accordance with the requirements set forth in the aircraft system specification. For some items, the verification requirements and procedures are defined in existing military specifications and standards. These include such components as self sealing fuel cell bladders, pressure vessels, hydraulic reservoirs, personnel body armor, etc.

4.7.1 Coordination effort. It is the responsibility of the S/V activity to coordinate all of the verification effort, both test and analysis, into a program that produces the necessary data in an effective manner. To accomplish this task, the types of tests to be conducted, the quantity and quality of instrumentation and the test conditions must be established that realistically represent the operational employment of the aircraft system and the threat-encounter parameters.

5. VULNERABILITY ASSESSMENT

5.1 General. This section contains detailed descriptions of system kill level definitions, critical component identification processes, conditional kill probability criteria, and vulnerability assessment methods and procedures. The definition of vulnerability (see 3.1) excludes the probability that a specific hostile weapon effect (environment) occurs, and thereby is restricted to an evaluation of the response of the aircraft system or component in question to the specified weapon effect level.

5.1.1 Parameter variance. Due to the diverse nature of the hostile environments to which military aircraft may be subjected, the parameters employed to measure vulnerability vary in accordance with the type of damaging agent encountered. For example, if a projectile impact will cause a level of damage to be sustained, the vulnerability is best measured as a basis of a hit on the aircraft. The same analogy is valid for the impingement of a high-energy laser beam on an aircraft. By contrast, where damage is effected by the fragmentation and/or blast effects of a nearby exploding missile warhead or high-explosive projectile, vulnerability is best expressed in terms of the results per shot at the aircraft. Thus, one measure of vulnerability is the conditional probability of achieving a specified level of aircraft kill (or survival), given an exposure to a specified level of hostile effects; i.e., a hit by an impacting penetrator or the detonation by a proximity-fuzed projectile. The most commonly used measurement is termed "vulnerable area."

5.1.2 Vulnerable area. For a given threat and set of encounter conditions, the vulnerable area (A_V) of a component is the mathematical product of the presented area (Ap) of the component and the probability of killing the component given a hit ($P_{K/H}$), and is expressed symbolically as:

$$A_V = A_p \cdot P_{K/H}$$

Aircraft total vulnerable area (A_V) is the sum of the (A_V) for its components after allowing for functional redundancy (see Multiply Vulnerable) and overlay or superposition.

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5.2 Target kill categories/level of kill. To assess the vulnerability of both fixed wing (F/W) and rotary wing (R/W) aircraft in-flight, four kill categories have been defined and adopted by the Vulnerability Assessment Quantification Panel of the Aerial Target Vulnerability Sub-Group for the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) Target Vulnerability Group. These kill categories, Attrition, Forced Landing, Mission, and Mission Available, are defined along with the different levels of kill within each category, where applicable.

5.2.1 Attrition. This category covers those aircraft with combat damage so extensive that it is neither reasonable nor economical to repair. The attrition category is divided into six levels of kill. The first four are sequentially inclusive (i.e., "B" includes "A", "K", and "KK"; "A" includes "K" and "KK"; and "K" includes "KK") and time dependent. These kill levels are:

a. "KK" Kill (also referred to as "catastrophic"): Level of kill associated with damage that will cause the aircraft to disintegrate immediately upon being hit. Damage to the structures of either fixed wing (F/W) or rotary (R/W) aircraft could result in "KK" kill. Structural disintegration is usually caused by blast from internally or externally detonated projectiles or missile warheads, fuel tank explosions, high areal density fragment impacts from fragmentation/blast (FB) missile warheads, blast/fragmentation from engine blow-up, or detonation of stored ordnance.

b. "K" Kill: Level of kill associated with damage that will cause an aircraft to fall out of manned control within 30 seconds after being hit. Damage to the following components could result in "K" kill:
  (1) F/W: Pilot (single), structure, engine (single), flight controls, ammunition
  (2) R/W: Pilot (single), structure, main rotor group, ammunition

c. "A" Kill: Level of kill associated with damage that will cause an aircraft to fall out of manned control within five minutes after being hit. Damage to the following components could result in "A" kill:
  (1) F/W: Engine, fuel, controls (mechanical and/or hydraulic).
  (2) R/W: Engine, fuel, controls (mechanical and/or hydraulic).

d. "B" Kill: Level of kill associated with damage that will cause an aircraft to fall out of manned control within 30 minutes after being hit. Damage to the following components could result in "B" kill:
  (1) F/W: Same as for "A" kill plus other engine and fuel system components.
  (2) R/W: Same as for "A" kill plus other engine and fuel system components.

e. "C" Kill: Level of kill associated with damage that will cause an aircraft to fall out of manned control before completing its mission.

f. "E" Kill: Level of kill associated with damage that will cause an aircraft to sustain additional levels of damage upon landing and makes it uneconomical to repair as specified by the applicable Technical Orders (TO's), Technical Bulletins (TB's), and regulations. Damage to the landing gear, controls, or control surfaces of aircraft could result in "E" kill.

g. "V" Kill: Damage that will cause the aircraft to be incapable of vertical flight and/or vertical takeoff and landing (VTOL).

5.2.2 Forced landing. This category covers those aircraft with combat damage that forces the crew to execute a controlled landing (powered or unpowered). This category includes aircraft with damage which will require repairs for flight to another area and aircraft with damage which cannot be repaired on site but which can be recovered by a special team. Damage to the following components could result in forced landing:

a. F/W: Hydraulics, fuel lines, electrical system, engine.

b. R/W: Engines (single), main transmission lubrication, tail rotor drive (includes gearboxes), tail rotor control systems.

5.2.3 Mission (mission abort). This category covers any aircraft with combat damage that prevents the aircraft from completing the designated mission but permits it to return to base.

5.2.4 Mission available. This category covers those aircraft that have landed with combat damage and will require repair before returning to mission ready status. There are different levels (intervals) of mission availability which are expressed as MA_X. The subscript X is the interval of time required to accomplish repairs. This interval is expressed in elapsed time, total man-hours, or combinations thereof. This category assumes that the necessary personnel, equipment, and supplies are available.

5.2.5 Special note on kill categories. For rotary wing aircraft two flight modes are considered; namely, forward flight and hover. The critical components listed as examples in the above definitions are for forward flight. Some of these critical components for forced landing in forward flight mode may become critical for attrition in a hover mode (e.g., tail rotor drive). Hover mode does not necessarily mean zero velocity but that the helicopter is operating in a hazardous region of the height-velocity diagram (Dead-Man's Curve). It should be noted that application of the forced landing kill category in vulnerability studies has been restricted mainly to rotary wing aircraft which can land nearly anywhere either powered or by auto-rotation. Many of the crews of these aircraft can then make minor repairs on the ground and takeoff again either to return to their base or perhaps continue on the mission. It of course much more difficult for a damaged fixed wing aircraft to successfully execute a forced landing (and/or subsequent takeoff) since some prepared landing site is generally required. For rotary wing aircraft, until recently there has been insufficient test and combat data to enable the vulnerability analyst to separate the attrition category into time-dependent levels. However, sufficient data now exist so that future vulnerability studies of rotary wing aircraft can provide the attrition kill vulnerability in the "KK", "K", and "A" kill levels previously defined. The "B" kill level has not been applied in vulnerability studies of rotary wing aircraft since within 30 minutes the helicopter can usually be landed with autorotational capability. Furthermore, in studies of rotary wing aircraft, attrition, forced landing, and mission abort have been considered as mutually exclusive events. For fixed-wing vertical and short takeoff and landing (VSTOL) aircraft, the following kill level may also be used:

> "V" Kill: Damage that will cause the aircraft to be incapable of vertical flight and/or take-off or landing.

5.2.6 Nuclear mission. The preceding definitions are applicable for conventional "tactical" conflicts where recovery of the aircraft and crew is of primary importance and achievement of the mission objective is accomplished by repeated attacks by many aircraft. In a strategic conflict, where delivery of a nuclear weapon upon an enemy target to ensure its destruction is of primary importance, the delivery aircraft will be required to withstand hostile non-nuclear threats in its mission. The kill levels for these type missions, usually referred to as "nuclear mission," are as follows:

a. Sure Safe: That level of response to hostile weapon effects where no appreciable damage is sustained, and the aircraft is capable of being refueled and reloaded within the normal turnaround period for operational flight.

b. Mission Kill: That level of damage to the aircraft that results in conditions that prevent the mission objectives to be attained, but allows continued flight.

c. Sure Kill: That level of damage to the aircraft that causes it to immediately fall out of control. This corresponds to the "KK" kill level definition.

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5.3 Critical component identification. The definition for a critical component, as related to nonnuclear vulnerability assessment processes, is "an aircraft component which, if damaged or destroyed, would yield a defined or definable aircraft kill level." At present, there is no single JTCG/AS endorsed method that is specified to perform the identification effort. There are similar methods being used by the three major branches of the military for the identification of "critical components." A composite procedure is presented in this section that incorporates the basic elements of each of these methods. It is presented in this fashion to acquaint the reader with an overall understanding of the procedure. Until a standard triservice method is developed, the exact procedure to be used will be directed by the procuring activity for each aircraft system. A systematic and thorough process is essential for the proper identification of critical components. The first step in the procedure is to conduct an analysis to determine the flight and mission-essential functions that each aircraft system must perform to accomplish the mission objectives. This analysis should consider each phase of the combat mission(s) for which the aircraft is designed. Figure 5-1 shows an example of a typical combat mission with its major phases identified. The second step is the identification of system functions required for each mission phase. Next, aircraft subsystem functions are identified that are necessary to perform the system-essential functions. Thirdly, a failure mode and effects analysis (FMEA) is conducted to identify the specific components and failure modes related to loss of the subsystem-essential functions. Each of these steps is described in the following paragraphs.

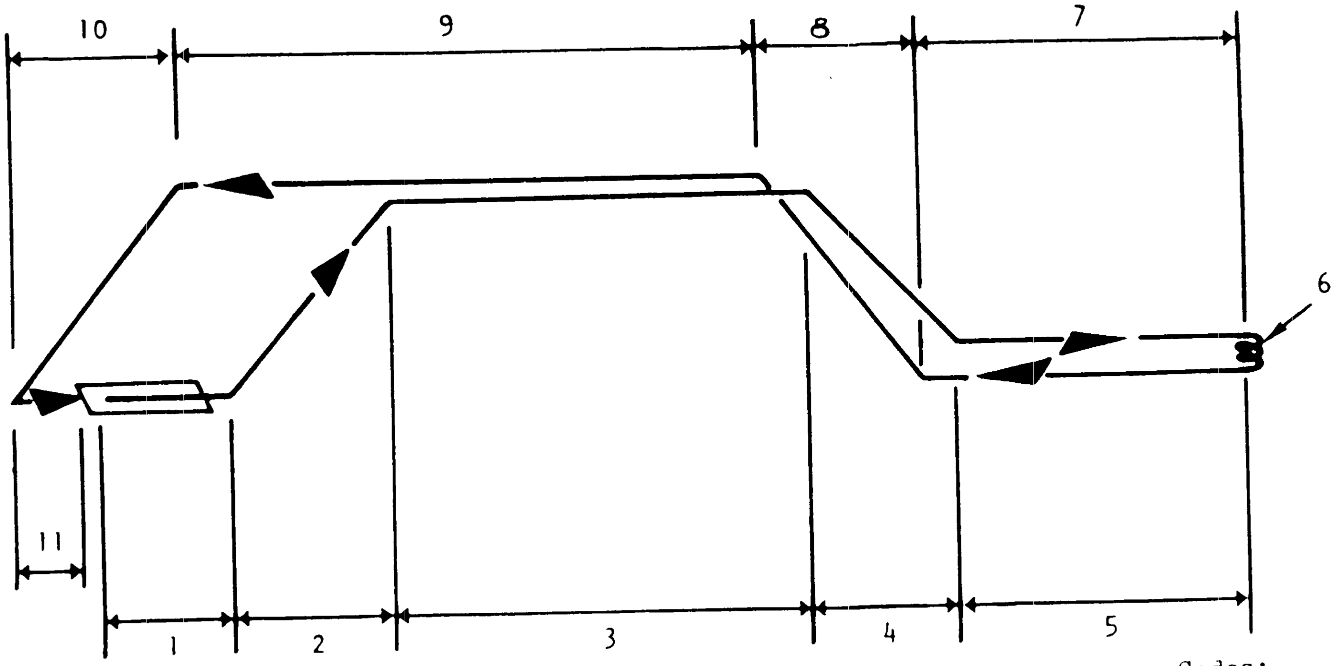
5.3.1 System-essential functions. The system-essential functions are those identified as being required to maintain flight or for mission completion, or both. Figure 5-2 shows an example of the mission phases of a rotary-wing aircraft and the system level S/V mission-essential functions required in each phase. The objective of this analysis is to identify those functions for which the priorities of protection may be established and to ensure that no subsystem components are overlooked in a vulnerability assessment.

5.3.2 Subsystem-essential function identification. The system-essential functions are next used for an analysis to identify the related subsystem(s). An example of a summary of mission-essential system functions and related subsystem identification is shown in Figure 5-3. This approach permits systematic evaluation and documentation of the process used for the analysis.

5.3.3 System/subsystem-essential functions relationships. An analysis of each subsystem is conducted to identify each subsystem function and its relationship to the mission-essential functions. Figure 5-4 shows an example of a summary of the analysis results for an electrical power subsystem. The degree of component essentiallity may also be necessary for consideration of degraded modes of subsystem operation and/or response of nonessential components. For example, three categories may be applicable for a given aircraft as follows:

a. Category I - Mission-Essential - Primary: The normal or preferred mode of performing a mission-essential function

b. Category II - Mission-Essential - Backup: An alternate mode of performing a mission-essential function in the event of loss of the primary mode



Codes:

1 - Takeoff/launch
2 - Climbout
3 - Cruise (outbound)
4 - Descent
5 - Penetration
6 - Combat or mission objectives
7 - Withdrawal
8 - Climbout
9 - Cruise (inbound)
10 - Descent
11 - Landing/recovery

FIGURE 5-1. Example of a combat mission profile.

Item	System-level S/V Mission-essential functions	MISSION PHASES							
		Alert	Takeoff	Cruise to larger area	Cruise to holding position	Cruise to assault position	Engage targets	Return cruise to FEBA*	Land
1	Communications • secured voice • unsecured voice • ICS								
2	Start systems								
3	Monitor systems								
4	Provide lift								
5	Provide controlled flight								
6	Provide air data intelligence								
7	Maintain terrain clearance								
8	Employ IFF/EW								
9	Navigate								
10	Locate/identify targets								
11	Employ weapons								

*FEBA = Forward Edge of the Battle Area
**IFF = Identification Friend or Foe
**EW = Electronic Warfare

FIGURE 5-2. Mission-essential functions - system level.

Item	System-Level S/V Mission-Essential Functions	Related subsystem								
		Electrical power	Hydraulic power	Engine/engine installation	Crew/crew station	Fuel system	Flight control	Avionics/ electrical installation	Armament	Basic structure
1	Communications	X			X			X		
2	Start system	X	X	X	X	X		X		
3	Monitor system	X			X			X		
4	Provide lift	X	X	X	X	X	X	X		X
5	Provide controlled flight	X	X	X	X	X	X	X		X
6	Provide air data intelligence	X			X			X		
7	Maintain terrain clearance	X	X	X	X	X	X	X		X
8	Employ IFF/EW	X			X			X		
9	Navigate	X			X		X	X		
10	Locate/identify targets	X			X			X		
11	Employ weapons	X	X		X		X	X	X	X

FIGURE 5-3. Mission-essential system function/subsystem relation.

Subsystem function ID letter	Essential subsystems functions	Essential system functions										
		Communications	Start systems	Monitor systems	Provide lift	Provide controlled flight	Provide air data intelligence	Maintain terrain clearance	Employ IFF/EW	Navigate	Locate/identify targets	Employ weapons
a	Generate electrical power	X	X	X	X	X	X	X	X	X	X	X
b	Provide automatic control and protection of power generation	X	X	X	X	X	X	X	X	X	X	X
c	Distribute electrical power	X	X	X	X	X	X	X	X	X	X	X
d	Provide automatic protection of power distribution	X	X	X	X	X	X	X	X	X	X	X
e	Provide power conversion (dc and low-voltage ac)	X	X	X	X	X	X	X	X	X	X	X
f	Provide battery power	X	X	X	X	X	X	X	X	X	X	X
g	Control subsystem loads	X	X	X	X	X	X	X	X	X	X	X
h	Process and transmit subsystem data and power control signals	X	X	X	X	X	X	X	X	X	X	X
i	Provide automatic electrical load management			X								
j	Provide controls and displays		X	X								
k	Provide illumination	X	X	X	X	X	X	X	X	X	X	X

FIGURE 5-4. System/subsystem function relationships, electrical power subsystem example.

c. Category III - Not Mission-Essential, But Enhances Survivability or Could Cause Secondary Hazards: An equipment/component whose loss would not prevent mission completion, but could significantly degrade the performance capabilities of the aircraft, or could result in secondary hazards to mission-essential equipment

Figure 5-5 shows an example of components of an electrical system listed together with the identification of the category to which they belong and the essential functions they perform.

5.3.4 Failure mode and effects analysis. A failure mode and effects analysis (FMEA) may be used to systematically determine the consequences of individual component failure or malfunction upon the capability of a subsystem to perform its designated functions. All possible failure modes should be developed for each component so that the information will be available for system vulnerability assessments. A recommended approach for conducting FMEA is the development of a schematic of each system/subsystem to provide a visual representation of all the components within each subsystem. The schematics should show all inter-connections, redundancies, and/or dependencies with components or elements in other subsystems. These diagrams are to provide the basic data base for conducting the failure mode analysis. Figure 5-6 shows a simplified example of a subsystem schematic. By this means, each component and/or element may be systematically identified for analysis. The analysis will then determine the contribution of each component to the accomplishment of each flight and mission-essential function. Those components which contribute to the accomplishment of these essential functions then become the set of critical components. A failure modes and effects analysis shall be conducted in accordance with MIL-STD-785 "Reliability Program for Systems and Equipment Development and Production", (Reference 194). The latest revision of MIL-STD-785, currently being prepared, will contain the failure modes and effects analysis requirements for the survivability program.

5.3.4.1 Identification system. An identification system may be developed to identify each component within each subsystem. The identification system shall be compatible, whenever possible, with an existing identification system such as the work unit codes of the services maintenance system or the work breakdown structure for the aircraft. The identification system should accommodate additions or deletions to the system as the design progresses.

5.3.4.2 Subsystem component analysis. An analysis of each subsystem component is conducted to determine all of the possible failure modes that can occur to that specific item. This should include malfunctions as well as failure-to-operate conditions. Figure 5-7 illustrates a type of format that may be used to document the results of the analysis (reference 186).

5.3.4.3 Component failure. The failure mode data may be used to conduct an analysis to determine the effects of each component failure mode on the subsystem of which it is an element or on other components and subsystems with which it has a functional or physical interface. The analysis must also determine the effects of the component failures on the total aircraft system, either directly or through an intermediate subsystem level. The analysis should also identify potential conditions where the failure of one component results in a conditional failure probability or effect for a second component which differs from the failure probability or affect of the second component when considered independently.

5.3.4.3.1 Component failure example. In a four-engine aircraft, the progressive loss of individual engines would incrementally degrade the flying level qualities of the total aircraft system and degrade the generation of secondary power for other subsystem operations. Figure 5-8 is provided as an example of a format that may be used to document the failure effects analysis (reference 181).

5.3.4.4 Additional formats. Additional (JTCG approved) formats used to document/summarize the results of critical component/subsystem analyses, failure mode identification analyses and FMEA analyses are illustrated in references 181, 187, and 186 respectively.

Item	Equipment nomenclature	Category	Essential function letters*
a	Electrical power generation		
a(1)	Generator primary ac 3-phase	I	a
a(2)	Control - generator primary ac	I	e
a(3)	Control - load	I	e
a(4)	Contactor - generator line	I	e
a(5)	Contactor - bus tie	I	f
a(6)	Contactor - load	I	f
a(7)	Panel - system integration	I	e,f
a(8)	Xfmr - cur - generator	I	e
a(9)	Xfmr - diff cur	I	f
a(10)	Xfmr - diff cur (bus tie)	I	f
a(11)	Xfmr - diff cur (ext pwr)	III	
b	Emergency power		
b(1)	Generator - emergency	III	
b(2)	Contactor - emer gen	III	
b(3)	Control unit - emer gen	III	
c	DC subsystems:		
c(1)	Battery - 5.7 amp-hr	I	d
c(2)	Charger-battery	III	
c(3)	Xfmr - rectifier 20-amp	I	c
c(4)	Xfmr - elect msl dc power	I	c
c(5)	Xfmr - msl htr power	I	c
c(6)	Xfmr - msl htr power (pylons)	I	c
c(7)	Xfmr - diff cur	I	f
	etc		

*See figure 5-4 for essential function definitions.

FIGURE 5-5. Electrical power essential equipment essentiality summary example.

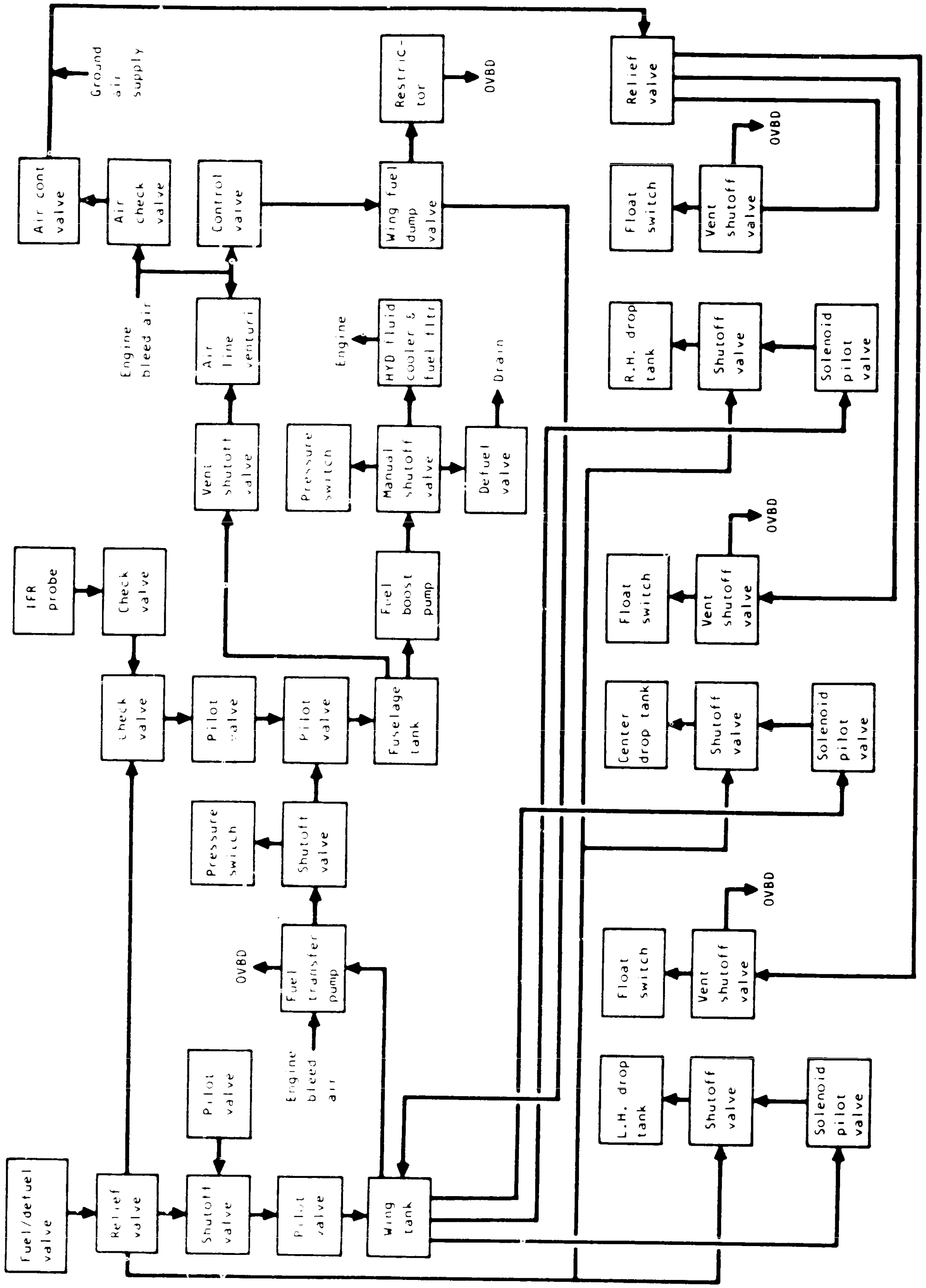


FIGURE 5-6. Example of subsystem schematic.

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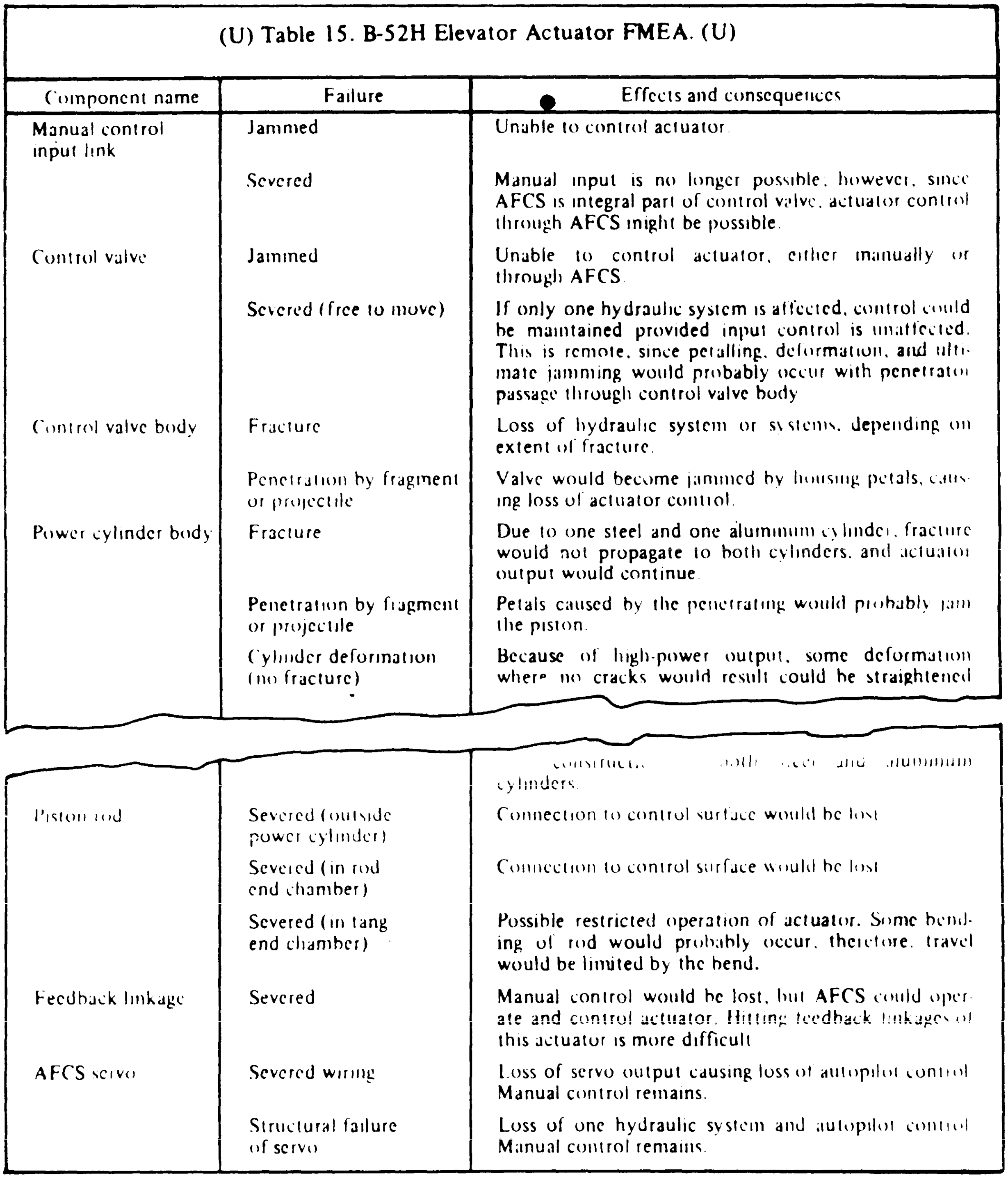
5.4 Conditional kill probabilities. The capability of a specific level of hostile weapons effect to inflict a level of damage on a given critical component to satisfy the failure of malfunction criteria for that component is determined in terms of conditional probability of kill given a hostile weapon effects exposure. For a projectile or fragment impact, the conditional kill probability is expressed as the probability of kill given a hit ($P_{K/H}$). For a component exposed to a given level and duration of a high energy laser beam, the probability of kill given an exposure may be expressed as ($P_{K/E}$). For blast overpressure, the probability of kill given a specified effective overpressure level may be expressed as ($P_{K/P}$). The determination of the actual numerical values for each probability must be accomplished through analysis and/or test of the specific physical characteristics of the component and the damage-producing mechanisms of the hostile weapon effect. Where sufficient data for such determination are not available, estimates may be made by use of data on similar items. For example, the Army Ballistic Research Laboratory is compiling a 12-volume set of data on aircraft component conditional kill probabilities. (Reference 6.) The titles for these volumes are:

Volume I - General
Volume II - Fuel Systems
Volume III - Crew
Volume IV - Propulsion
Volume V - Controls/Hydraulics
Volume VI - Rotor Blades
Volume VII - Transmission/Drive Train
Volume VIII - Armament
Volume IX - Structures
Volume X - Electrical/Avionics
Volume XI - Other (Oxygen, Tires, and Accessories)
Volume XII - Bibliography



(U) Table 15. B-52H Elevator Actuator FMEA. (U)

Component name	Failure	Effects and consequences
Manual control input link	Jammed	Unable to control actuator.
	Severed	Manual input is no longer possible; however, since AFCS is integral part of control valve, actuator control through AFCS might be possible.
Control valve	Jammed	Unable to control actuator, either manually or through AFCS.
	Severed (free to move)	If only one hydraulic system is affected, control could be maintained provided input control is unaffected. This is remote, since petalling, deformation, and ultimate jamming would probably occur with penetrator passage through control valve body.
Control valve body	Fracture	Loss of hydraulic system or systems, depending on extent of fracture.
	Penetration by fragment or projectile	Valve would become jammed by housing petals, causing loss of actuator control.
Power cylinder body	Fracture	Due to one steel and one aluminum cylinder, fracture would not propagate to both cylinders, and actuator output would continue.
	Penetration by fragment or projectile	Petals caused by the penetrating would probably jam the piston.
	Cylinder deformation (no fracture)	Because of high-power output, some deformation where no cracks would result could be straightened
		construct [illegible] oth eel and aluminum cylinders.
Piston rod	Severed (outside power cylinder)	Connection to control surface would be lost.
	Severed (in rod end chamber)	Connection to control surface would be lost.
	Severed (in tang end chamber)	Possible restricted operation of actuator. Some bending of rod would probably occur, therefore, travel would be limited by the bend.
Feedback linkage	Severed	Manual control would be lost, but AFCS could operate and control actuator. Hitting feedback linkages of this actuator is more difficult.
AFCS servo	Severed wiring	Loss of servo output causing loss of autopilot control. Manual control remains.
	Structural failure of servo	Loss of one hydraulic system and autopilot control. Manual control remains.

FIGURE 5-7. Format example for failure mode identification.

Aircraft subsystem	Subsystem		Failure mode	Effect on subsystem	Effect of degraded subsystem on aircraft	Aircraft kill category	Supporting references	Comments
	Component	Location						

FIGURE 5-8. Example of failure mode and effects summary format.

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5.5 Vulnerability assessments/procedures. A vulnerability assessment is a study made to determine quantitatively the vulnerability of a specific system to a hostile environment. With regard to aircraft systems, such a study can fulfill several needs: (1) it can help the designer in his decision making relative to design of the aircraft, (2) it can assist the military in their evaluation of competitive designs, and (3) it can aid the field commander in making tactical decisions relative to the employment of the final product. Appropriate techniques and analytical tools must be selected in order to perform a vulnerability assessment. In general, the assessment involves quantitative determination of the appropriate vulnerability measures for several specified weapon effects and for several levels of aircraft kill. For impacting and externally fragmenting rounds, the methodology includes computation of vulnerable areas for each expected direction of attack. For external blast effects, vulnerable volumes about the aircraft must be determined. It is necessary to compute both vulnerable areas and volumes for externally detonated rounds, the lethal mechanisms of which include both blast and fragments. The methodology for computing these vulnerability measures is presented in subsequent paragraphs. The calculations may be carried out manually using layout drawings, or by using scaled models of the aircraft coupled with photographic measurements, or they may be programmed for computation utilizing a digital computer. Manual calculations using actual component drawings permit the greatest accuracy; however, they require an extremely experienced analyst and can only be done for a limited number of combinations of viewing aspects, kill categories, and threats. The use of a digital computer speeds the computations; however, the accuracy of the results depends critically on the accuracy of the inputs to the program and the sophistication of the modeling employed, both of which are also time-consuming tasks. The selection of a manual or computer technique for computing aircraft vulnerability depends on the availability of computerized assessment procedures as well as a number of other factors, including the required available accurate resources, and the expected vulnerability assessment workload. Having defined the study inputs, selected the appropriate analytical techniques, and computed aircraft vulnerability, the remaining task is to present the results in a meaningful manner. The format for presentation of results will depend on the purpose of the study and the needs of the organization for whom the study is performed. If the objective of the study is to provide inputs to a survival analysis of competing aircraft designs, then the most meaningful results are vulnerable areas (or volumes) and the conditional probabilities of a hit or burst killing the aircraft, since these quantities can be used directly as inputs to the survival analysis. However, if the purpose is to provide a basis for evaluating different hardening "fixes" against a specific threat, then the contributions of the different critical components to overall aircraft vulnerability may provide the most meaningful data. Further discussion of the various graphical and tabular methods for meaningful data presentation are provided in subsequent paragraphs.

5.5.1 Vulnerability to impacting rounds. The vulnerability of an aircraft to an impacting round may be expressed as the probability of achieving a specified level of aircraft kill given a random hit by a prescribed damaging mechanism ($P_{K/H}$). The probability of aircraft kill therefore depends on the likelihood of a random hit killing a critical component. That is, a component whose defeat will result in the specified level of aircraft kill. If we assume that a kill of any one of these critical components (P_{K_i}) will result in a kill of the aircraft, then

$$P_{K/H} = P_{K_1} + P_{K_2} \ . \ . \ . + P_{K_n} = \sum_{i=1}^{n} P_{K_i}$$

Note: $0 \leq P_{K/H} \leq 1$

where:

P_{K_i} = Probability of defeating the i^{th} component given a hit on the aircraft; each P_{K_i} is in turn the product of two probabilities

and

$$P_{K_i} = P_{K/H_i} \ P_{Hi/_H}$$

P_{K/H_i} = Probability of defeating the i^{th} component given a hit on the component

$P_{Hi/_H} = \frac{A_{P_i}}{A_P}$ = Probability of hitting the i^{th} component given a random hit on the aircraft

A_{P_i} = Presented area of the i^{th} component at the aspect under consideration

A_P = The aircraft total presented area at the aspect under consideration

n = The number of critical components, any one of which if hit will result in a specified kill level of the aircraft.

By substituting the preceding quantities and defining two new quantities (A_{V_i} and A_V), the equation can be rewritten as follows:

$$P_{K/H} = \sum_{i=1}^{n} P_{K_i} = \sum_{i=1}^{n} P_{K/H_i} \ P_{Hi/_H} = \sum_{i=1}^{n} \frac{P_{K/H_i} \ A_{P_i}}{A_P}$$

$$= \frac{P_{K/H_i} \; A_{P_i}}{A_P} + \frac{P_{K/H_2} \; A_{P_2}}{A_P} + \ldots + \frac{P_{K/H_n} \; A_{P_N}}{A_P}$$

$$= \frac{A_{V_1} + A_{V_2} + \ldots + A_{V_n}}{A_P} = \frac{\sum A_{V_1}}{A_P} = \frac{A_V}{A_P}$$

where:

$A_{V_i} = P_{K/H_i} \; A_{P_i}$ = Vulnerable area of the i^{th} component

and

$A_V = \sum A_{V_i}$ = Total aircraft vulnerable area

Implicit in this derivation is the assumption that any one hit is taken from a uniform distribution; i.e., a hit is equally likely anywhere on the aircraft presented area. This assumption is usually valid if the aircraft is small with respect to the firing range of the weapon; or stated another way, if the weapon trajectory dispersion pattern is large compared with the size of the target aircraft. In such a case, the projectiles can also be assumed to travel in parallel paths so that it is possible to refer to a single direction of attack (or aspect) for all elements of the aircraft. Explicit in the derivation is the assumption that a defeat of any one of the critical components will result in a specified level of kill for the aircraft. This condition is satisfied only if the critical components are singly vulnerable. If any of the critical components are multiply vulnerable (i.e., redundant components), requiring two or more of them to be defeated for a kill on the aircraft (such as three out of four engines, both of two pilots, etc), then the contribution of these components to aircraft kill must be modified, as discussed in later sections. The vulnerable area of an item to the specified impacting round can be interpreted as an equivalent area which, if hit, will result in a specified level of kill to the item. Mathematically, vulnerable area (A_V) is a weighted value of the presented area (A_P) where the weighting factor is the probability of a random hit killing the item ($P_{K/H}$), and the presented area (A_P) is the projected area of the item in a plane normal to the trajectory of the impacting round. That is,

$$A_V = A_P \, P_{K/H}$$

From this expression it can be seen that the probability of a random hit killing and aircraft (comprised of singly vulnerable components) is equal to the ratio of its vulnerable area to presented area. The general problem in a vulnerability analysis is to compute these two areas for an aircraft so that the probability of a random hit killing the aircraft can be obtained.

5.5.1.1 Singly vulnerable component aircraft. When an aircraft is comprised only of components that are: (1) singly vulnerable, (2) not shielded, (3) nonoverlapping, and (4) commutative compounding of damage is excluded, then the aircraft total vulnerable area can be obtained by simply summing the component vulnerable areas. The concept of component presented area must be modified to account for an area effect of impacting rounds. This modification is presented in paragraph 5.5.2. The concept of aircraft vulnerable area is then defined and followed by a general method of removing the restrictions concerning shielded and overlapping component contributions to aircraft total vulnerable area. The application of these methods for specific damage mechanisms, encounter conditions, aircraft characteristics, and kill levels should be made within the framework of the general assessment methodology previously outlined.

5.5.2 Component vulnerable area. The calculation of aircraft vulnerable area begins with the determination of the respective vulnerable areas of the several aircraft components which have been identified as critical to the level of aircraft kill under consideration. The vulnerable area of a critical component (A_V) to a particular damaging agent is rigorously defined mathematically as:

$$A_V = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_{K/H} (x, y) \, dx \, dy$$

where:

$P_{K/H}$ (x, y) is the probability of component defeat for the impacting round striking the point, the coordinates of which are (x,y), and the integration is carried out over the entire region in a plane normal to the attack trajectory wherein the impacting round will effect damage to the component.

When the impacting round is a bullet or fragment, the area of effect being a point, then $\bar{P}_{K/H} = 0$ outside the physically presented area of the component (A_p) so that the vulnerable area becomes $A_V = \bar{P}_{K/H} A_p$. This is illustrated in the two examples of Figure 5-9, where $\bar{P}_{K/H}$ is the average probability that a single random hit on the presented area by a point effect damage mechanism will result in a component defeat.

5.5.2.1 Area of effect. When the impacting round has an area effect, as in a contact fuzed HEI shell, then a near miss is also capable of damaging the component so that the integration must be carried out over an "effective" presented area which may be larger than the physically presented area of the component at the aspect under consideration, as illustrated in Figure 5-10.

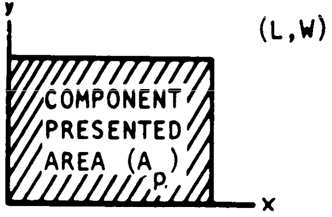
In general, the vulnerable area of a component can be expressed as shown above:

$$A_V = \bar{P}_{K/H} A_P$$

where:

$\bar{P}_{K/H}$ = Probability that a single random hit on A_P will produce the required kill level

Example I (Constant $P_{K/H}$)

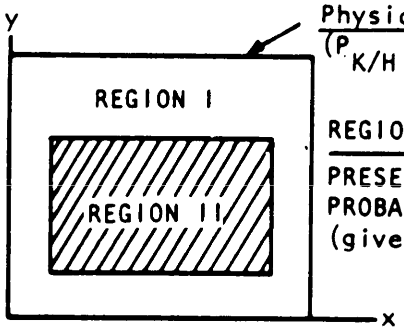


$P_{K/H}$ = 0 outside component limits

$P_{K/H} = \bar{P}_{K/H}$ = constant over A_p

$$A_V = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_{K/H}(x,y)\,dx\,dy = \int_{-\infty}^{L}\int_{-\infty}^{W} P_{K/H}(x,y)\,dx\,dy = \bar{P}_{K/H}\iint_{A_p} dx\,dy = \bar{P}_{K/H}\,A_p$$

Example II (Variable $P_{K/H}$)



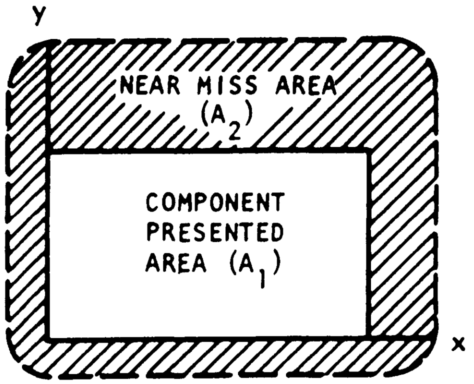
Physical outline of component ($P_{K/H}$ = 0 outside component limits)

REGION	I	II	TOTAL
PRESENTED AREA	A_1	A_2	A_p
PROBABILITY OF DEFEAT (given a hit within region)	P_1	P_2	$\bar{P}_{K/H}$

$$A_V = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_{K/H}(x,y)\,dx\,dy = \iint_{A_1} P_1(x,y)\,dx\,dy + \iint_{A_2} P_2(x,y)\,dx\,dy = \bar{P}_1A_1 + \bar{P}_2A_2$$

$$A_V = (\bar{P}_1A_1 + \bar{P}_2A_2)\frac{A_p}{A_p} = \left(\bar{P}_1\frac{A_1}{A_p} + \bar{P}_2\frac{A_2}{A_p}\right)A_p = \bar{P}_{K/H}\,A_p$$

FIGURE 5-9. Component Vulnerability to point effect damage mechanisms.



$$A_V = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_{K/H}(x,y)\,dx\,dy = \iint_{A_1} P_{K/H_1}(x,y)\,dx\,dy + \iint_{A_2} P_{K/H_2}(x,y)\,dx\,dy$$

$$= \bar{P}_{K/H_1} A_1 + \bar{P}_{K/H_2} A_2 = \bar{P}_{K/H} A_p$$

where $\bar{P}_{K/H} = \bar{P}_{K/H1} \frac{A_1}{A_p} + \bar{P}_{K/H_2} \frac{A_2}{A_p}$

and $A_p = A_1 + A_2$

$\bar{P}_{K/H_1}$ = average probability that a single hit by an area effect damage mechanism in the i^{th} region $(i = 1,2)$ will produce the required level of "kill"

A_i = presented area of the i^{th} region at the aspect under consideration

FIGURE 5-10. Component vulnerability to area effect damage mechanisms.

A_P = "Effective" presented area of the component at the attack aspect being considered (i.e., the total projected area in a plane normal to the attack trajectory wherein the impacting round will effect damage to the component).

5.5.2.2 Impacting projectile larger than critical component. There are some cases where the impacting projectile or fragment is larger than the critical component. See Figure 5-11. In these cases, the "area" within which an impacting threat can cause damage is larger than the component presented area. The following equation for $P_{K/H}$ should be used for cables, small diameter rods, fuel lines, hydraulic lines, oil lines, small diameter control tubes, and other such items.

$$P_{K/H} = \frac{D + d - 2\theta d}{d}$$

where:

D = cutting length of projectile (or diameter if untumbled)

d = diameter of critical component (tube, line, rod, etc)

θ = amount of tubular element that can be lost without loss of function (% of the circumference)

It is implicitly assumed in this expression that no sequential compounding of damage occurs. That is, the damage resulting from one hit is independent of damage resulting from any other hit. Otherwise, $\overline{P}_{K/H}$ could not be considered a constant, but would vary with each hit and the amount of damage caused by any previous hits. In view of the exclusion of sequential compounding and the fact that a component is "killed" or "not killed" by any particular hit on its presented area, the individual hit situations may be viewed as Bernoulli trials, and the value of $P_{K/H}$ is seen (conceptually) to be independent of the number of hits. As a consequence, the vulnerable area of a component is independent (by definition) of the number of hits on the component. Thus, the concept of vulnerable area may, with consistency, be applied to situations wherein there may be more than one hit on the component being considered. This does not mean that the vulnerability of a component is, in fact, independent of the number of hits. This convenient definition or "artifice" does, however, permit the extension of the vulnerable area concept to multiple-hit situations wherein the resulting damage can be considered to be nonsynergistic. The extension to the case of multiple hits and externally fragmenting rounds is considered in subsequent paragraphs. The assumption of single hit damage has a sound basis founded upon combat experience. Approximately 85% of all ground based AAA and small arms damage to aircraft was from single hits. Air-to-air combat data indicates that the average number of aircraft hits is not much greater than 1. The emergence of the quad-23 and other effective high rate of fire guns in enemy air defense systems may drastically change the percentage of aircraft damage from single hits.

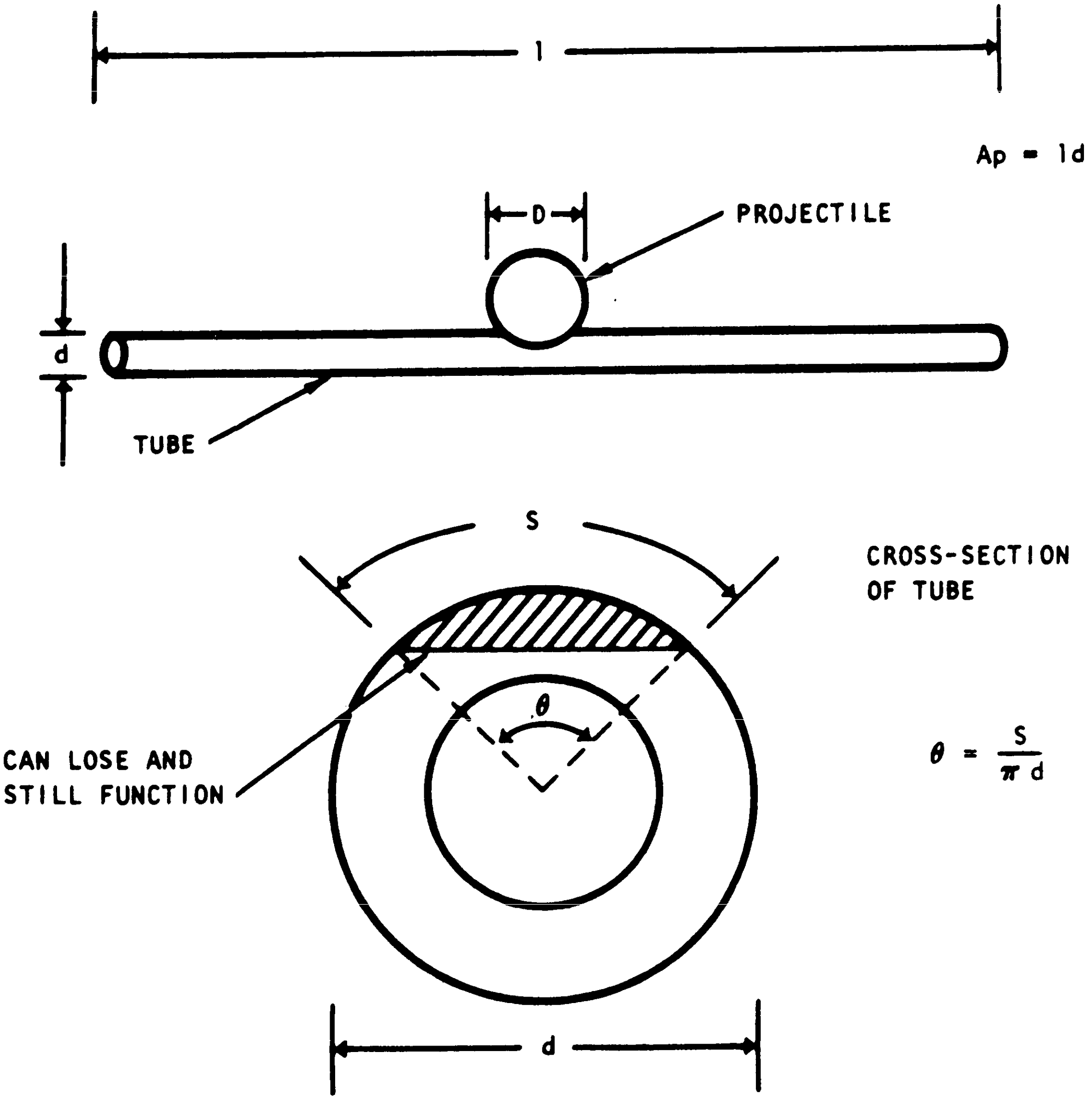


FIGURE 5-11. Projectile larger than component.

5.5.3 Aircraft vulnerable area. Once the respective vulnerable areas of the critical components have been obtained, these values are employed to calculate the vulnerable area of the entire aircraft. If (a) no "shielding" or overlapping of component presented area exists, (b) no commutative compound damage occurs, and (c) no multiply-vulnerable components are present, then the vulnerable area of the aircraft (A_{V_t}) is the sum of the vulnerable areas of its components. That is,

$$A_{V_t} = \sum_{i=1}^{n} \bar{P}_{K/H_i} A_{P_i} = \sum_{i=1}^{n} A_{V_i}$$

where:

N = Total number of singly vulnerable critical components, each capable of producing the required kill level.

a. The first restriction concerning shielding or "masking" of component presented areas, due to the physical location of other components, can be partially removed by reducing each term representing component presented areas (Ap_i) in the preceding expression by the amount of the component presented area that is perfectly shielded from a hit at the particular aspect being considered. It is also possible for imperfect or partial shielding to exist, in the sense that the shield attenuates the kinetic energy of the bullet or fragment but does not stop it. A method for handling this situation is discussed in this section. The case in which the presented areas of certain critical components "overlap" (i.e., a hit in the overlap region can damage (or kill) more than one component) can be handled for the case in which the overlapping components are each singly vulnerable by synthesizing homogenous areas from the overlapping components according to the rules provided in Section 5.1.5.4 of this volume. The vulnerable areas of these homogenous areas can then be summed in the preceding expression in place of the vulnerable areas of the overlapping components to obtain aircraft total vulnerable area.

b. No analytic techniques are presently available for adequately treating commutative compound damage. This type of damage is the synergistic compounding of damage due to multiple hits in which the independence of the damage done to each component by each hit cannot be assumed. Only if the failure mechanisms of different components can be considered to result in independent levels of damage and not to combine so as to result in synergistic damage levels to the aircraft, can the preceding expression be extended to cover the case of multiple hits. This restriction is a serious limitation to the validity of the vulnerable area concept in its application to the case of multiple hits or externally fragmenting rounds, and caution must be exercised in interpreting the results of such application.

c. The case in which the aircraft contains multiply vulnerable components in addition to a set of singly vulnerable components can be handled by the methods outlined in Section 5.1.5.5 of this volume. In these cases, the concept of an equivalent singly vulnerable area is introduced and employed to obtain an "equivalent" or average probability of a hit, resulting in a specified level of aircraft kill. Other alternatives are also presented.

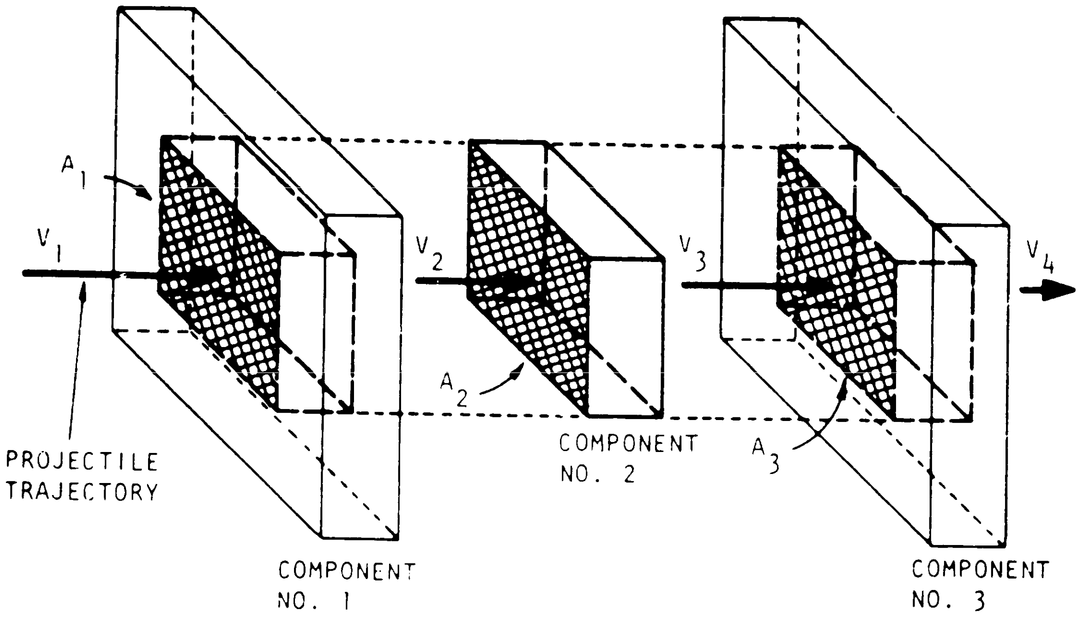
5.5.4 Component shielding and overlap. The contribution of component vulnerable areas (A_{V_i}) to aircraft vulnerable area (A_{V_t}) for the case in which the components are (1) singly vulnerable, (2) not shielded, (3) non-overlapping, and (4) commutative compound damage is excluded, is given by:

$$A_{V_t} = \sum_{i=1}^{n} A_{V_i} = \sum_{i=1}^{n} P_{K/H_i} \ A_{P_i}$$

where:

n = number of critical components capable of producing the required level of kill.

The restriction concerning shielded areas can be removed for the case in which a noncritical aircraft component provides perfect shielding of all or part of the presented area of a critical component. In this case, the presented area of the shielded component (A_{P_i}) entering into the preceding expression is reduced by the amount of presented area that is perfectly shielded from a hit at the aspect being considered. The more general case in which all restrictions concerning shielding and overlap of component presented areas are removed is discussed next. The concept is to partition the aircraft presented area at the aspect being considered into small nonoverlapping homogenous areas which have the characteristic that any parallel projectile trajectory penetrating the given homogenous area will encounter the same conditions with respect to components, thickness of plates, obliquities, etc. The total vulnerable area of the aircraft is then obtained by summing the vulnerable areas for each of the many homogenous areas. Nonshielded and nonoverlapping critical component presented areas are treated as homogenous areas for the aspect under consideration. Hence, the only new consideration to this point concerns the method for combining the vulnerable areas of the components comprising a homogenous area, which includes shielding or overlapping of critical components. Given a region of the aircraft presented area that includes several layers of overlapping components, each of which may or may not be critical to the level of kill under consideration, it is possible to partition the region into a number of homogenous areas. An example of one such homogeneous area is illustrated in Figure 5-12. The presented area of such a homogeneous area (A_{P_H}) is equal to the projection onto a plane normal to the projectile trajectory of the smallest component area comprising the homogeneous grouping (in Figure 16, this is A_2). The probability of a hit killing the first component penetrated is denoted by P_1, where $P_1 = 0$ for a noncritical component and $0 < P_i \leqslant 1$ for a critical



$A_{PH} = A_1 = A_2 = A_3$ = Homogeneous presented area

P_i = Average probability of the given projectile killing the i^{th} component with striking velocity V_i (for noncritical components $P_i = 0$, for critical components, $0 < P_i \leq 1$)

$P_{K/H}$ = Conditional probability of aircraft kill given a random hit on the homogenous area under consideration

$$P_{K/H} = P_1 + \sum_{K=2}^{n} \left[P_K \prod_{j=1}^{K-1} (1 - P_j) \right] = P_1 + P_2(1 - P_1) + P_3(1 - P_2)(1 - P_1)$$

n = Number of components penetrated = 3

A_{VH} = Total vulnerable area of the homogeneous area

$A_{VH} = P_{K/H} A_{P/H}$

FIGURE 5-12. Example of vulnerable area computation for a homogeneous area.

component. Assuming this component is penetrated by a projectile having a striking velocity V_1, the value of P_1 is assigned and the residual velocity of the projectile as it leaves the component (V_2) is computed. The same procedure is repeated for each successive component penetrated until the residual velocity is zero or all components comprising the homogeneous grouping have been perforated. The probability of a hit killing the homogeneous area is then obtained from the relation

$$P_{K/H} = P_1 + P_2 (1-P_1) + P_3 (1-P_1)(1-P_2) + \ldots$$

$$P_n (1-P_{n-1}) \ldots (1-P_1)$$

where:

n = number of components penetrated, and the total homogeneous vulnerable area is obtained from:

$$A_{VH} = P_{K/H} A_{PH}$$

Aircraft total vulnerable area is then obtained by summing the vulnerable areas of the many homogeneous areas, that is:

$$A_{V_t} = \sum_{i=1}^{n} A_{VH_i}$$

where:

n = number of homogeneous areas for the aspect and level of kill under consideration.

5.5.5 Procedures for high explosive projectiles and missiles. A manual technique has been used by the Vulnerability Laboratory and other Army Agencies for the analysis of the vulnerability of target aircraft to small caliber high explosive projectiles. This procedure involves superimposing a grid of points on drawings of the target aircraft to represent the impact points of the projectiles. Each projectile is assumed to strike normal to the view represented by the drawings and to detonate at a fixed distance within the surface of the target. If a grid point (more specifically, a detonation location) is in a lethal region of the aircraft for internal blast damage from the threat as shown on the internal blast drawings, then an aircraft kill in the appropriate kill category is recorded. If the detonation location is not within a lethal internal blast region for a given kill category, then the potential damage from fragmentation of the threat is considered. Information concerning the number of fragments, spatial distribution of the fragments (sidespray), and sizes and speeds of the fragments is required. For each detonation point corresponding to the grid points, the critical aircraft components in the fragment sidespray from the exploding round are determined and any shielding for these components is noted. The effects of the shielding, if any, in retarding or defeating the fragments are determined (see Section 5.1.5.8.2 for discussion of fragment penetration). Based on this shielding analysis and the fragmentation characteristics of the projectile, an average weight and striking speed for the fragments impacting each critical component in the sidespray from a given detonation are determined. Maximum (cut-off) distances from the detonation point to the center of the component entry area are established for potential lethality of these average fragments against the component. For each detonation point for which the distances to critical components are within the lethal range of these average fragments, an estimate of the probability of aircraft kill given the detonation is made and this probability is multiplied by the grid area associated with the detonation point to produce a vulnerable area increment. A summation of all these grid vulnerable areas yields the target vulnerable area for the attack aspect. It should be observed that a single small caliber high explosive projectile may have the capability of defeating a multiple vulnerable system (e.g., engines on a multi-engine aircraft).

5.5.5.1 Computer programs. Several "point-burst" computer programs have been generated for evaluation of the vulnerability of target aircraft to small caliber high explosive projectiles. Considerable effort under the auspices of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) is being expended to develop satisfactory computer methodology compatible with both MAGIC and SHOTGEN target descriptive programs for such evaluations. These developed or projected programs are not discussed in this report.

5.5.6 Extension to multiply vulnerable component aircraft. If it is assumed that a single hit can damage, at the most, one component, then the first hit upon a multiply vulnerable component aircraft cannot kill the aircraft by defeating one of the multiply vulnerable components. The first hit is therefore not a reliable criterion as to the vulnerability of the aircraft. It is for this reason that an "equivalent" vulnerable area concept based on the expected number of hits required to kill an aircraft has been devised for comparing the vulnerability of multiply vulnerable component aircraft to impacting rounds. As a special case, the "equivalent" vulnerable area reduces to the sum of the component vulnerable areas for an aircraft consisting only of singly vulnerable components. The concept is applicable only to impacting rounds, and sequential compound damage is excluded. A large number of hits is assumed, and the respective locations of the various hits on the target are assumed to be taken from a uniform population.

5.5.6.1 Effects of hits on multiple vulnerable components. Care must be exercised to identify all critical components, and whether they are multiply or singly vulnerable. All critical components have some level of vulnerabililty. It is their relationship with the other system components that determine the level of redundancy, if any. An example of the methodology used to determine the effects of hits on multiply vulnerable components is available in appendix A of reference 185.

5.5.6.2 Equivalent singly vulnerable area. The equivalent singly vulnerable area (A_s) for an aircraft consisting of one or more singly vulnerable components and the v_ith set of identical multiply vulnerable components is given by:

$$A_{s_i} = \frac{A_{v_i}}{E(\alpha,n,k)_i}$$

where:

A_{v_i} = Summed vulnerable area of the aircraft

$$A_{V_i} = A_{V_{s_i}} + n\,A_{V_{m_i}}$$

$A_{V_{s_i}}$ = Sum of the singly vulnerable aircraft component vulnerable areas obtained as in 3.1

$A_{V_{m_i}}$ = Vulnerable area of each multiply vulnerable component obtained as though the item were a singly vulnerable component

n = Number of identical components constituting the set of multiply vulnerable components

and:

$E(\alpha,n,k)_i$ = Expected number of hits on A_V required to kill the aircraft

$$E(\alpha,n,k)_i = 1 + \frac{n}{\left(\frac{n}{\alpha} - 1\right)} + \frac{n(n-1)}{\left(\frac{n}{\alpha} - 1\right)\left(\frac{n}{\alpha} - 2\right)} + \dots$$

$$+ \frac{n(n-1)\dots(n-k+2)}{\left(\frac{n}{\alpha} - 1\right)\left(\frac{n}{\alpha} - 2\right)\dots\left(\frac{n}{\alpha} - k+1\right)}$$

where:

K = Number of items in the multiply vulnerable set which must be defeated to result in the specified level of aircraft kill

$\alpha = \frac{n\,A_{V_m}}{A_V}$ = Fraction of the summed vulnerable area represented by the set of multiply vulnerable components

The quantity (α) can also be interpreted as the fraction of the lethal hits on the summed vulnerable area (A_V) which comprise lethal hits on the set of multiply vulnerable components. A sample calculation of A_{V_s} is illustrated in Figure 5-13. However, the concept of equivalent singly vulnerable area should be used cautiously, especially when the multiply vulnerable components do not have the same vulnerable area. In this case, the concept is not rigorously valid. It will be noted that the equivalent singly-vulnerable area (A_s) differs only slightly from the sum of the singly vulnerable component vulnerable area (A_{V_s}) when the multiply vulnerable components are small. Hence, in practice and depending on the objectives of the analysis, it is frequently possible to ignore all or all but the most significant multiply vulnerable components. A basis for deciding whether or not to include the contribution of a set of multiply vulnerable components to total aircraft vulnerable area is discussed next.

5.5.6.3 The contributions of a set of multiply vulnerable components. If the vulnerability of the set of multiply vulnerable components is ignored, the expected number of hits required to score a kill on the target is $E(\alpha,n,k) = 1/(1-\alpha)$. If the quantity $1/(1-\alpha)$ and $E(\alpha,n,k)$ are plotted for various combinations of n and k, as functions of α, it can be seen that the difference in their values varies. (For the case where n=1 and k=1, refer to Section 5.5.1.1 on singly vulnerable component aircraft). For convenience, the reciprocals of $E(\alpha,n,k)$ and $1/(1-\alpha)$ is plotted against α in Figure 5-14. In those cases wherein the difference is acceptably small, the contribution of the multiply vulnerable set to total aircraft vulnerability may be ignored.

The concept of an equivalent singly vulnerable area (A_s) can be generalized to apply to an aircraft having more than one set of multiply vulnerable components. The procedure is to consider each set, one at a time, with the remaining sets considered invulnerable for the time being. The procedure is illustrated mathematically as follows:

$$A_{s_1} = \frac{A_{V_s} + N_1 A_{V_{m_1}}}{E(\alpha_1, N_1, k_1)} \text{ for the 1st set}$$

where:

A_{s_1} = Equivalent singly vulnerable area of the singly vulnerable components and the first set of multiply vulnerable components with all other sets of multiply vulnerable components considered invulnerable.

The second set of multiply vulnerable components is then introduced to obtain a new equivalent singly vulnerable area (A_{s_2}) where:

$$A_{s_2} = \frac{A_{s_1} + N_2 A_{V_{m_2}}}{E(\alpha_2, N_2, k_2)} \text{ for the second set}$$

Given a single-place twin-engine fighter in which the engines are considered to be the only set of multiply redundant components and both engines must be killed to result in a kill of the aircraft.

$\hat{A}_P = 400\ \text{ft}^2$ = Total presented area of aircraft at the aspect under consideration

$A_{V_m} = 10\ \text{ft}^2$ = Singly vulnerable area of either engine

$n = 2$ = Number of redundant components

$k = 2$ = Number of redundant components which must be killed to result in a kill of the aircraft

$A_{V_s} = 40\ \text{ft}^2$ = Total vulnerable area for a singly-vulnerable component

$A_V = A_{V_s} + nA_{V_m} = 40 + (2)(10) = 60\ \text{ft}^2$ = Summed vulnerable area

$$\alpha = \frac{nA_{V_m}}{A_V} = \frac{20}{60} = 0.333$$

$$E(\alpha,n,k) = 1 + \frac{n}{\left(\frac{n}{\alpha} - 1\right)} = 1 + \frac{2}{6 - 1} = 1.4$$

$A_s = \frac{A_V}{E(\alpha,n,k)} = \frac{60}{1.4} = 42.85^{+}\ \text{ft}^2$ = Equivalent singly-vulnerable vulnerable area

$P_{K/H} = \frac{\hat{A}_s}{\hat{A}_p} = \frac{42.85^{+}}{400} = 0.1071^{+}$ = Average or "equivalent" single shot probability of kill given a hit

FIGURE 5-13. Equivalent singly-vulnerable vulnerable area example.

Given a single-place twin-engine fighter in which the engines are considered to be the only set of multiply redundant components and both engines must be killed to result in a kill of the aircraft.

$A_P = 400\ \text{ft}^2$ = Total presented area of aircraft at the aspect under consideration

$A_{V_m} = 10\ \text{ft}^2$ = Singly vulnerable area of either engine

$n = 2$ = Number of redundant components

$k = 2$ = Number of redundant components which must be killed to result in a kill of the aircraft

$A_{V_s} = 40\ \text{ft}^2$ = Total vulnerable area for a singly-vulnerable component

$A_V = A_{V_s} + nA_{V_m} = 40 + (2)(10) = 60\ \text{ft}^2$ = Summed vulnerable area

$$\alpha = \frac{nA_{V_m}}{A_V} = \frac{20}{60} = 0.333$$

$$E(\alpha,n,k) = 1 + \frac{n}{\left(\frac{n}{\alpha} - 1\right)} = 1 + \frac{2}{6 - 1} = 1.4$$

$A_s = \dfrac{A_V}{E(\alpha,n,k)} = \dfrac{60}{1.4} = 42.85^+\ \text{ft}^2$ = Equivalent singly-vulnerable vulnerable area

$P_{K/H} = \dfrac{A_s}{A_p} = \dfrac{42.85^+}{400} = 0.1071^+$ = Average or "equivalent" single shot probability of kill given a hit

FIGURE 5-13. Equivalent singly-vulnerable vulnerable area example.

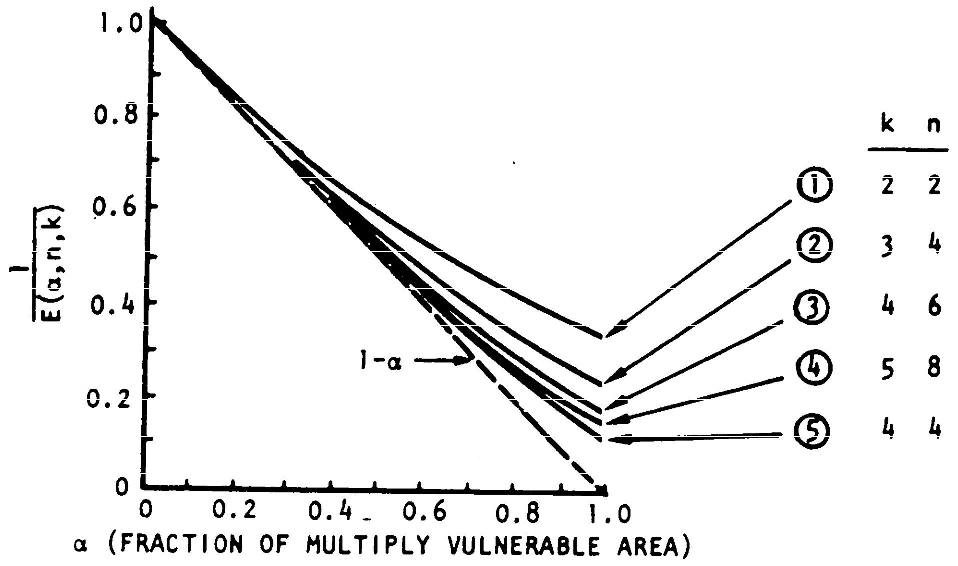


FIGURE 5-14. Relationship between expected number of hits required to kill target and α for various values of n and k.

and any remaining sets of multiply vulnerable components are considered invulnerable. The procedure is similarly repeated until all significant sets of multiply vulnerable components have been considered. The average probability of aircraft kill given a hit can then be obtained from the ratio of A_{s_j} and A_p, where j denotes the number of sets of multiply vulnerable components considered. That is,

$$P_{K/H} = \frac{A_{s_j}}{A_P}$$

An example illustrating the computation of A_s and $P_{K/H}$ for a four-engine bomber with two pilots, in which both the engines and the pilots are considered as sets of multiply vulnerable components, is presented in Figure 5-15.

5.5.7 Summarizing results. The result of a vulnerability assessment to impacting rounds consists of computed values of vulnerable areas for each aircraft design, kill level, and hostile environment considered. The number of different aircraft designs, kill levels, and hostile environments considered and the level of detail for which the results are presented will depend on the objectives of the analysis and the requirements of the organization for whom the study is performed.

5.5.7.1 Valid basis for aircraft design comparison. Vulnerable areas provide a measure of aircraft terminal vulnerability on the assumption that a hit has occurred. No consideration is given to the likelihood of a hit occurring. It is for this reason that vulnerability measures alone do not provide a valid basis for comparing different aircraft designs when overall survivability is at issue.

5.5.7.2 Overall survival. Overall survival of an aircraft depends not only on the probability of a hit killing an aircraft but also on the probability of a hit occurring. This latter quantity also depends on additional factors which affect (1) the number of weapons that engage the aircraft (e.g., terrain and vegetation, fire suppression, decision to engage, etc.) and (2) the accuracy of those weapons which do engage the aircraft (e.g., weapon range, aircraft speed, maneuvers, ECM, etc.).

5.5.7.3 Vulnerable areas summary. Vulnerable areas provide a basis for comparing the contribution of different components to aircraft vulnerability and are therefore useful in aircraft design, modification, and utilization studies. Knowledge of the respective contributions by critical components to aircraft vulnerability is essential for optimizing aircraft design and modification and is of value in determining the reasons for differences in survival on one aircraft compared with another. Knowledge of the most vulnerable components can also be of assistance in determining the optimum tactical employment of a given aircraft design. In view of the significance of critical component contributions to aircraft vulnerability, it is common practice to include vulnerable area data for critical components as well as for the aircraft in the results of a vulnerability assessment. Vulnerable areas of multiply vulnerable components are frequently presented separately to facilitate the computation of equivalent singly vulnerable areas, or for use in Survival studies. Meaningful presentation of computed vulnerable areas for an aircraft and its critical components to a spectrum of projectile types for a range of encounter conditions and kill levels can be a formidable task because of the large volume of data generated and the need for an orderly presentation to facilitate its interpretation and usefulness. To indicate the nature of the problem, vulnerable area can be considered mathematically as a function of the many parameters constituting the study inputs:

$$A_V = f(p, e, c, a)$$

where:

p = Projectile characteristics (size and type of ammunition such as ball, AP, API, HE, HEI, HEI-T).

e = Encounter conditions (attack directions, striking velocity, etc.)

c = Criterion levels for aircraft kill or damage (KK, K, A, B, C, E, etc.)

a = Aircraft characteristics (such as fuel load and distribution at time of encounter, munitions loading, critical components, and aircraft design)

Given a four-engine bomber with two pilots in which both the engines and the pilots are considered as mutliply vulnerable sets of components. Both pilots must be killed to result in an aircraft kill. The kill of any two engines will also result in a kill of the aircraft. The problem is to calculate the total singly-vulnerable vulnerable area for this aircraft.

GIVEN:

$$A_p = 1000 \text{ ft}^2$$

$$A_{V_s} = 100 \text{ ft}^2$$

ENGINES

$$A_{V_{m_1}} = 25 \text{ ft}^2$$

$$k_1 = 2$$

$$n_1 = 4$$

PILOTS

$$A_{V_{m_2}} = 2 \text{ ft}^2$$

$$k_2 = 2$$

$$n_2 = 2$$

SOLUTION

$$A_V = A_{V_s} + n_1 A_{V_{m_1}} = 100 + (4)(25) = 200 \text{ ft}^2$$

$$\alpha_1 = \frac{n_1 A_{V_{m_1}}}{A_V} = \frac{100}{200} = 0.5$$

$$E(\alpha_1, n_1, k_1) = 1 + \frac{n_1}{\left(\frac{n_1}{\alpha_1} - 1\right)} = 1 + \frac{4}{(8-1)} = 1.572$$

$$A_{s_1} = \frac{A_V}{E(\alpha_1, n_1, k_1)} = \frac{200}{1.572} = 127.2 \text{ ft}^2$$

$$\alpha_2 = \frac{n_2 A_{V_{m_2}}}{A_V} = \frac{(2)(2)}{200} = 0.02^{*}$$

$$E(\alpha_2, n_2, k_2) = 1 + \frac{n_2}{\left(\frac{n_2}{\alpha_2} - 1\right)} = 1 + \frac{2}{100-1} = 1.022$$

$$A_{s_2} = \frac{A_{s_1} + n_2 A_{V_{m_2}}}{E(\alpha_2, n_2, k_2)} = \frac{127.2 + (2)(2)}{1.022} = 126.4 \text{ ft}^2$$

$$P_{K/H} = \frac{A_s}{A_p} = \frac{126.4}{1000} = 0.1264$$

*For most purposes, the contribution of the pilots to total aircraft vulnerability could be ignored in this case

FIGURE 5-15. Equivalent singly-vulnerable vulnerable area example for multiple sets of multiply vulnerable components.

For each increment in each parameter, a new set of vulnerability data is generated. Hence, it is essential to determine beforehand those parameter variations which must be considered so as to minimize not only the computation workload, but also the problem of providing a meaningful presentation of the results of the computations. Both tabular and graphical formats are commonly employed to provide a summary of vulnerability assessment results.

5.5.7.4 Tabular formats. There are many ways to tabulate the results of vulnerability assessments. Figures 5-16 through 5-19 illustrate the preferred formats contained in reference 181 for nonexplosive projectiles, fragments, and high explosive projectiles and contact fuzed missile warheads.

a. Figure 5-16 is the format for a typical singly vulnerable area summary for listed subsystems at various projectile impact velocities. The kill category, specific threat, and aspect direction must be specified.

b. Figure 5-17 is a summary format for the total aircraft vulnerable area listing for projectile striking velocities from the six cardinal aspect directions. The kill category and threat must be specified.

c. Figure 5-18 shows the format for the vulnerable area listing of aircraft subsystem components for fragment striking velocities from 1000 to 10,000 feet per second. The impact direction, fragment mass, and fragment densities per square unit of area must specified. The form also has a column for the probability of kill, given a hit, ($P_{K/H}$) for each component.

d. Figure 5-19 is the format for summarizing the vulnerable area estimates for high explosive (HE) projectiles and contact fuzed missile warheads. The aircraft is divided into regions of kill probabilities ($P_{K/H}$) for the specified threat, kill category, and aspect direction. The areas for each region are then multiplied by the $P_{K/H}$ to obtain the vulnerable area.

5.5.7.5 Graphical formats. The results of a vulnerability assessment can also be presented graphically in a number of ways, depending on which parameters are held constant and which are varied. To illustrate the possibilities, consider the following expression for aircraft vulnerable area in terms of some of the more significant parameters:

$$A_V = f(x_1, x_2, x_3, x_4, x_5, x_6)$$

where:

x_1 = Projectile/fragment size and type

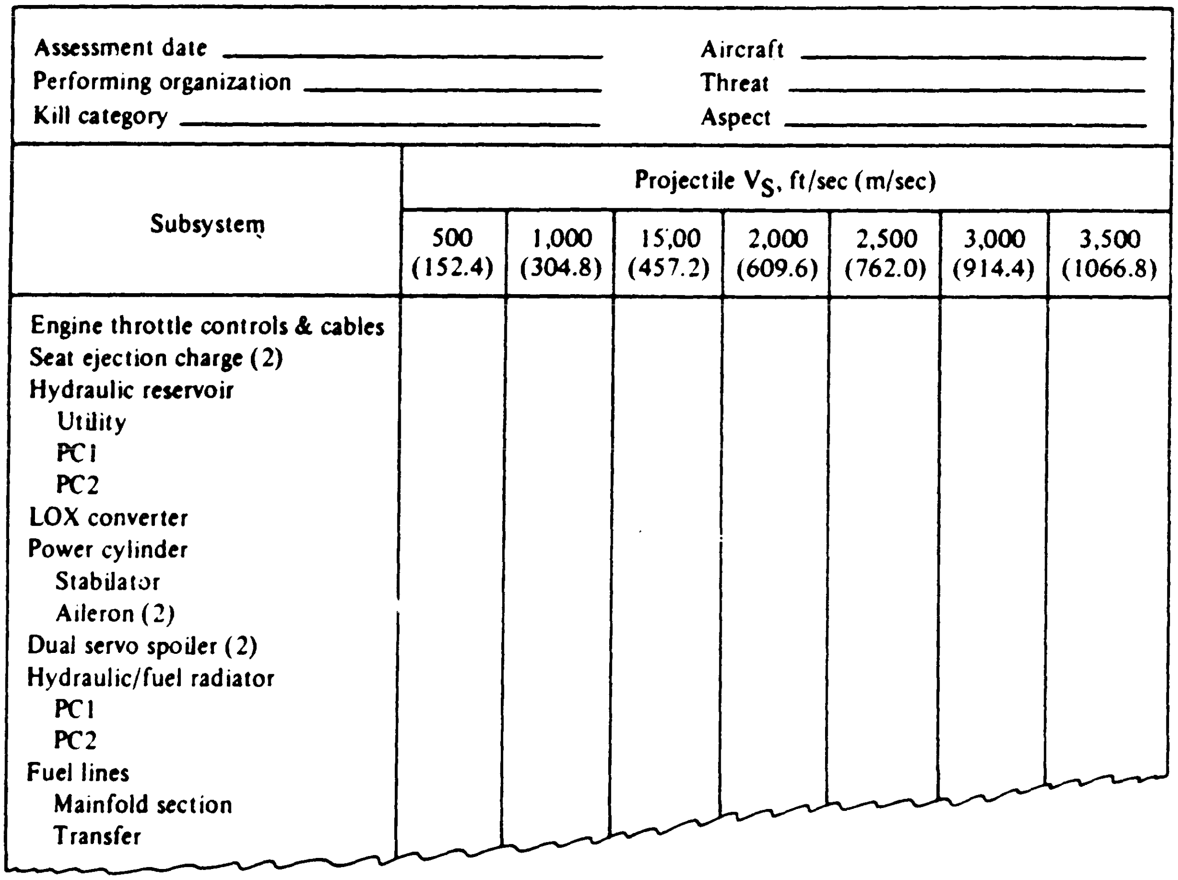
x_2 = Attack direction

x_3 = Striking velocity

x_4 = Aircraft kill level

x_5 = Critical components

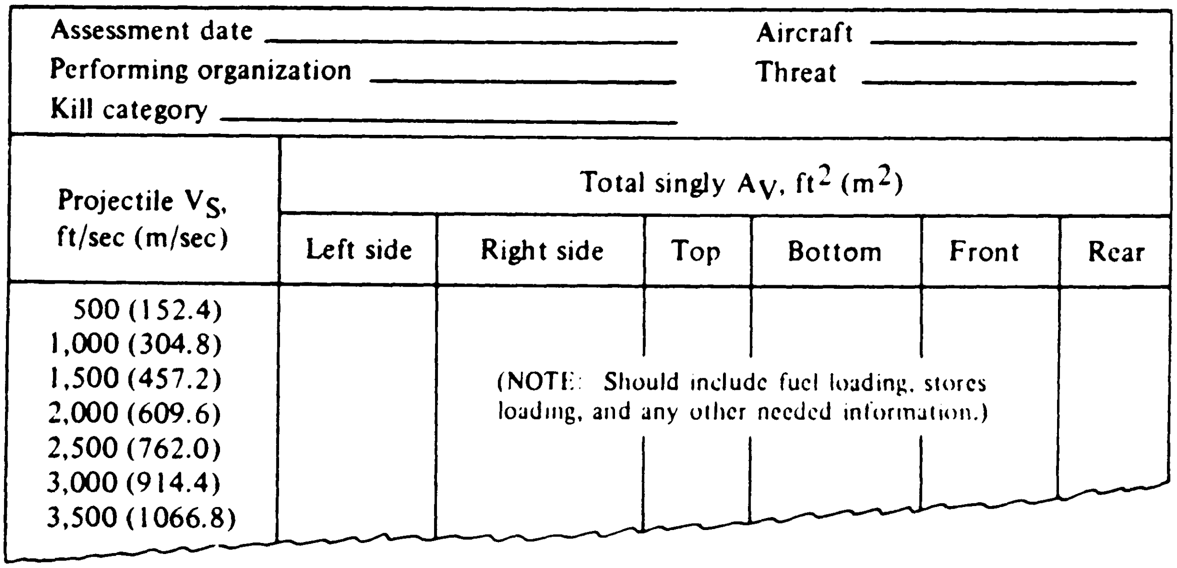
x_6 = Fuel loading



Assessment date ______________________ Aircraft ______________________
Performing organization ______________________ Threat ______________________
Kill category ______________________ Aspect ______________________

Subsystem	Projectile V_S, ft/sec (m/sec)						
	500 (152.4)	1,000 (304.8)	15,00 (457.2)	2,000 (609.6)	2,500 (762.0)	3,000 (914.4)	3,500 (1066.8)
Engine throttle controls & cables							
Seat ejection charge (2)							
Hydraulic reservoir							
Utility							
PC1							
PC2							
LOX converter							
Power cylinder							
Stabilator							
Aileron (2)							
Dual servo spoiler (2)							
Hydraulic/fuel radiator							
PC1							
PC2							
Fuel lines							
Mainfold section							
Transfer							

FIGURE 5-16. Typical singly vulnerable area summary form, ft^2 (m^2).

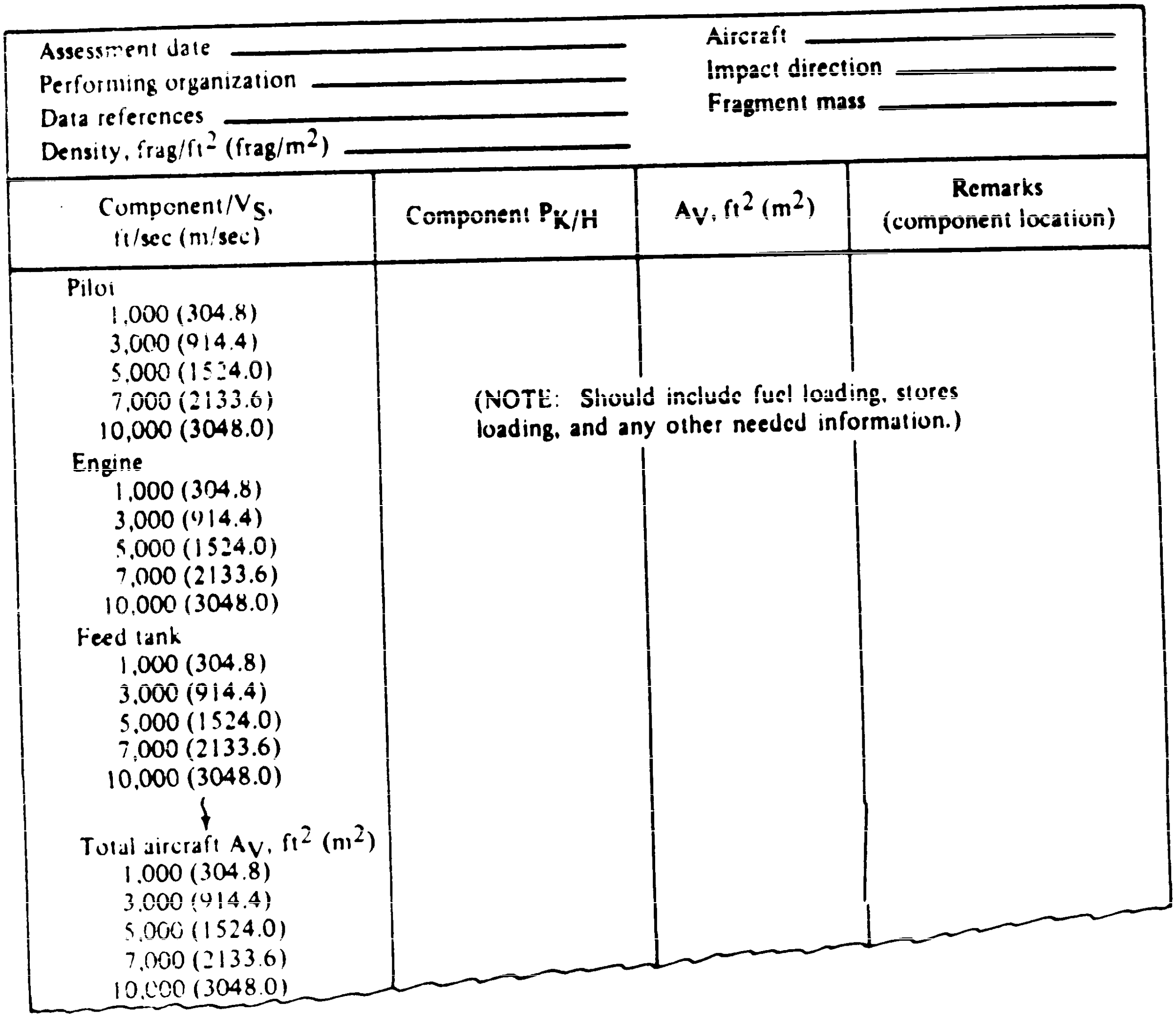


Assessment date ______________________ Aircraft ______________________
Performing organization ______________________ Threat ______________________
Kill category ______________________

Projectile V_S, ft/sec (m/sec)	Total singly A_V, ft^2 (m^2)					
	Left side	Right side	Top	Bottom	Front	Rear
500 (152.4)						
1,000 (304.8)						
1,500 (457.2)						
2,000 (609.6)						
2,500 (762.0)						
3,000 (914.4)						
3,500 (1066.8)						

(NOTE: Should include fuel loading, stores loading, and any other needed information.)

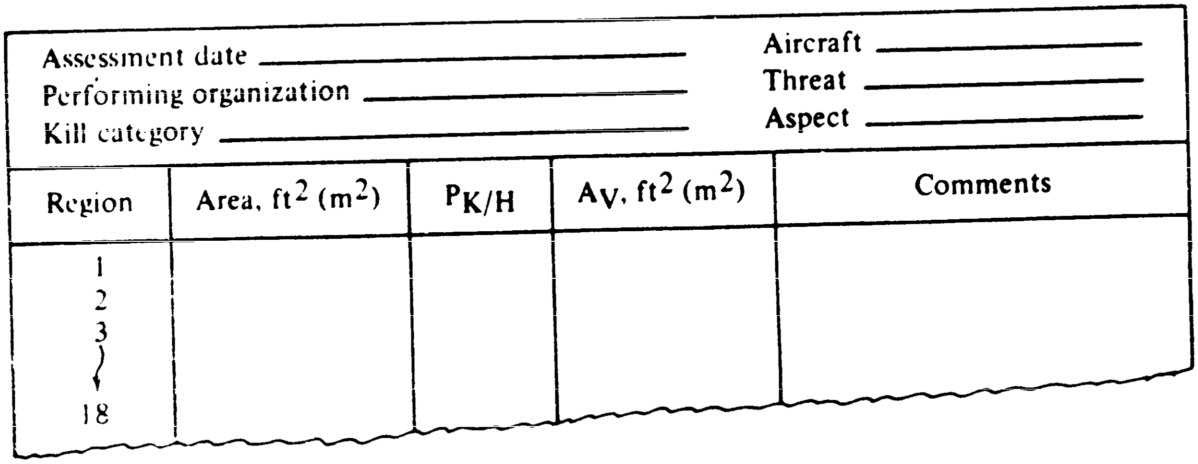
FIGURE 5-17. Typical total aircraft vulnerability summary form.



Assessment date ______
Performing organization ______
Data references ______
Density, frag/ft^2 (frag/m^2) ______
Aircraft ______
Impact direction ______
Fragment mass ______

Component/V_S, ft/sec (m/sec)	Component $P_{K/H}$	A_V, ft^2 (m^2)	Remarks (component location)
Pilot			
1,000 (304.8)			
3,000 (914.4)			
5,000 (1524.0)			
7,000 (2133.6)	(NOTE: Should include fuel loading, stores loading, and any other needed information.)		
10,000 (3048.0)			
Engine			
1,000 (304.8)			
3,000 (914.4)			
5,000 (1524.0)			
7,000 (2133.6)			
10,000 (3048.0)			
Feed tank			
1,000 (304.8)			
3,000 (914.4)			
5,000 (1524.0)			
7,000 (2133.6)			
10,000 (3048.0)			
↓			
Total aircraft A_V, ft^2 (m^2)			
1,000 (304.8)			
3,000 (914.4)			
5,000 (1524.0)			
7,000 (2133.6)			
10,000 (3048.0)			

FIGURE 5-18. Typical aircraft fragment A_V summary form.



Assessment date ______
Performing organization ______
Kill category ______
Aircraft ______
Threat ______
Aspect ______

Region	Area, ft^2 (m^2)	$P_{K/H}$	A_V, ft^2 (m^2)	Comments
1				
2				
3				
↓				
18				

FIGURE 5-19. HE projectile/contact fuzed missile vulnerable region summary form.

The effect of variations in these parameters on A_V can be analyzed by (1) plotting A_V as a function of any one parameter with all other parameters held constant and (2) incrementing one of the constant parameters to obtain a family of curves or points for construction of a histogram on the same set of coordinate axes. The technique is illustrated in Figure 5-20 (Reference 5), which shows in a systematic manner how normalized aircraft vulnerable area is affected by changes in the significant parameters taken one at a time.

5.5.7.6 Additional formats. Numerous tabular formats other than those discussed in the preceding paragraphs are available for documenting the results of vulnerability assessments. Three of the more commonly used tabular formats are shown in Figures 5-21 through 5-23. Use of these formats is the same as discussed in paragraph 5.5.7.4 and is further illustrated in references 181 and 185.

5.5.7.7 The survivability modes of aircraft component kill (SMACK). The SMACK chart is a combination tabular/graphical format used to document vulnerability assessment results. This technique (illustrated by figure 52) is discussed in paragraph 7.4.5 of this volume. Additional information is also available in reference 73.

5.5.8 Vulnerability to externally detonated rounds. The vulnerability of an aircraft to externally detonated rounds (projectiles or warheads) must be assessed in terms of the predominant damage mechanisms employed by these rounds. These include damage by external blast and damage by external fragmentation. The methodology for assessing aircraft vulnerability to external blast is presented in section 5.5.8.3 of this volume, and the methodology for assessing aircraft vulnerability to externally fragmenting rounds is presented in 5.5.8.2 No attempt is made to devise or present a single measure of vulnerability to the combined effects of both external blast and fragmentation. However, the survivability of an aircraft exposed to weapons which employ both damage mechanisms can be assessed using the methodology presented previously in this section.

5.5.8.1 Threat weapons. The threat weapons of concern when considering external blast vulnerability are AAA, air-to-air missiles and surface-to-air missiles, all with exploding warheads. The AAA threat employs a high explosive fragmentation warhead with two po-sible fuzes, contact and variable time. The missiles primarily use a proximity fuze. The primary kill mechanism is high energy fragments propelled outward by the exploding charge. Overpressure caused by the blast can cause serious damage to the aircraft components and/or structure, but if the charge explodes close enough to inflict such damage, the fragments would have probably caused even more damage. Any damage caused by the fragments should be considered first, then any additional damage caused by by blast overpressure should be investigated. Based on the fragmentation size, shape and velocity profiles, a vulnerability (or lethal) envelope can be defined, within which an exploding warhead can cause the specified level of damage.

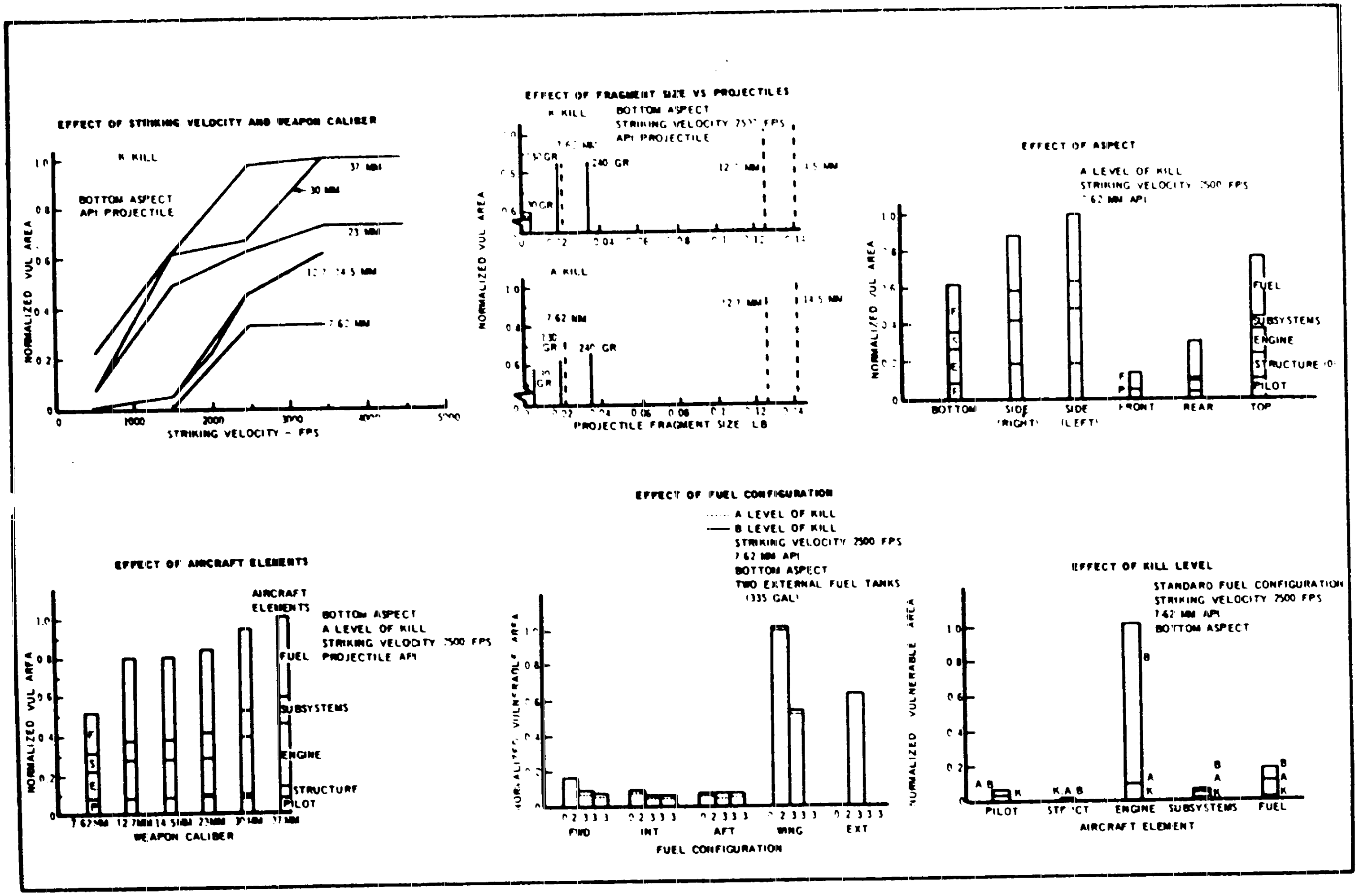


FIGURE 5-20. Typical graphical summaries.

Region	Critical Component	A_p, ft^2	$P_{K/H}$	A_V, ft^2
1	Fuselage fuel structure			
2	Fuel tankage wing structure			
3	Flight control structure			
Total	Bottom aspect			

FIGURE 5-21. Typical single threat summary form.

MR, grains	VR, ft/sec	Head & torso	Arms & legs
110	100 to 500 500 to 1,000 >1000		
20	100 to 500 500 to 1,000 >1000		

FIGURE 5-22. Single fragment $P_{K/H}$ for pilot.

System/component and threat	Area, ft^2					
	Left	Right	Top	Bottom	Front	Rear
Cockpit						
23-mm HEIT						
57-mm HE						
SA-7						
Fuselage Fuel						
23-mm HEIT						
57-mm HE						
SA-7						
Fuel Boundary						
23-mm HEIT						
57-mm HE						
SA-7						
Wing Fuel						
23-mm HEIT						
57-mm HE						
SA-7						
Fuel Line						
23-mm HEIT						
57-mm HE						
SA-7						
Flight Controls						
23-mm HEIT						
57-mm HE						
SA-7						
Structure						
23-mm HEIT						
57-mm HE						
SA-7						
Ammunition						
23-mm HEIT						
57-mm HE						
SA-7						
Total						
23-mm HEIT						
57-mm HE						
SA-7						

FIGURE 5-23. Typical component and total aircraft single shot A-kill A_V form.

5.5.8.2 Vulnerability to fragments. The vulnerability of an aircraft and its critical components to kill (or damage) by a fragmenting round (projectile or warhead) detonated externally to the aircraft is usually expressed in terms of vulnerable areas computed for a range of expected fragment sizes and striking velocities, as discussed previously. The probability of aircraft kill due to the detonation of a specific round can then be determined for a particular set of encounter conditions which define the direction of attack, size, density, and velocity of fragments striking the aircraft. The average probability of aircraft kill given an encounter with a specific round can then be determined from a knowledge of the expected distribution of burst points and the orientation of the resulting spray patterns with respect to the aircraft. The methodology for computing the probability of aircraft kill due to a single exposure to the burst of a specific round and for a single set of encounter conditions is presented in this section. The generalization of this methodology to obtain an average probability of aircraft kill (or survival) per encounter based on an expected range and distribution of burst points is presented below.

5.5.8.2.1 Kill by a single externally detonated round. The probability of aircraft kill due to a single exposure to the burst of a specific round and for a particular set of encounter conditions can be determined in a straightforward manner when (a) the aircraft consists solely of singly vulnerable components, (b) sequential and commutative compound damage is excluded, and (c) the entire presented area lies within a uniform density spray of fragments as indicated by Figure 5-24. In this case, the expected number of hits (E_H) on the aircraft presented area (A_p) at the aspect under consideration is given by:

$$E_H = \rho A_P$$

where:

ρ = the average number of fragments per unit area incident on A_p.

The expected number of killing (or lethal) hits (E_K) is similarly given by:

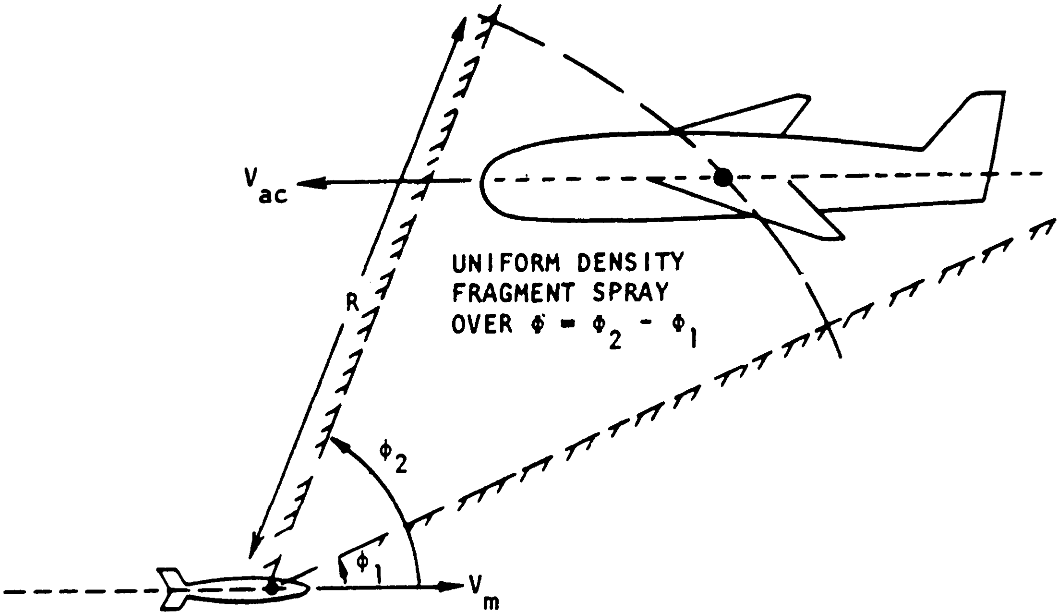
$$E_K = \rho A_V = P_{K/H} G_H$$

where:

$A_V = P_{K/H} A_p$ = aircraft vulnerable area at the aspect under consideration.

The probability of aircraft kill ($P_{K/E}$) given a single exposure to ρ can therefore be expressed as the probability of at least one fragment striking the vulnerable area of the aircraft. That is:

$$P_{K/E} = 1-(1-P_{K/H})^{E_H} \approx 1-\exp\ (-E_K)$$



$E_H = \rho Ap$ = expected number of hits on Ap by fragments from uniform spray density ρ

$E_K = \rho A_V = \rho P_{K/H}\,Ap$ = expected number of hits on $A_V = P_{K/H}Ap$

$P_{K/E} = 1 - (1 - P_{K/H})^{E_H} \approx 1 - \exp(-E_K)$ = probability of kill given exposure to ρ

QUALIFICATIONS

1. Aircraft consists solely of singly vulnerable components
2. Sequential and commutative damage are excluded
3. Applies entirely within uniform density fragment spray

FIGURE 5-24. Basic case for estimating probability of aircraft kill by externally detonated fragmenting round.

a. The restriction concerning single vulnerable components can be removed by considering an equivalent single vulnerable area calculated as in 5.5.5.

b. The restriction concerning sequential compound damage can be removed by considering $P_{K/H}$ to be a function of E_H; i.e., $P_{K/H} = f(E_H)$.

c. The restriction concerning total exposure of A_p to a uniform fragment density can be removed by dividing the presented area A_p into M subareas (A_{p_i}), each exposed to a uniform fragment density (ρi) so that

$$E_H = \sum_{i=1}^{M} \rho_i \, A_{p_i} = \sum_{i=1}^{M} E_{H_i}$$

and

$$E_K = \sum_{i=1}^{M} \rho_i \, A_{V_i} = \sum_{i=1}^{M} E_{K_i}$$

In this case, the probability of aircraft kill given an exposure to a single burst is given by

$$P_{K/E} \approx 1 - \exp\,(-E_K) = 1 - \exp\left(- \sum_{i=1}^{M} E_{K_i}\right)$$

$$P_{K/E} = 1 - \exp\,(-\rho A_V)$$

A procedure for computing the probability of aircraft kill due to a single exposure to the burst of a specific round and for a single set of encounter conditions is outlined in the following paragraphs for the basic case illustrated in Figure 5-24.

5.5.8.2.2 Detailed methodology for estimating $P_{K/E}$. To compute $P_{K/E}$, it is necessary to know the warhead characteristics, encounter conditions, aircraft characteristics, and kill level of interest. Given these parameters, it is possible to compute $P_{K/E}$ by means of the following steps:

a. Determine initial fragment velocity (V_o)

b. Determine fragment striking velocity (V_a)

c. Determine fragmentation dynamic spray angles (ϕ)

d. Determine fragment density incident on aircraft presented area (ρ)

e. Determine aircraft vulnerable area (A_V)

f. Calculate $P_{K/E} \;\; 1 - \exp\,(-E_K) = 1 - \exp\,(-\rho A_V)$.

5.5.8.2.3 Initial fragment velocity. The case under consideration is one in which the missile and aircraft are on parallel paths, with the head-on approach being illustrated. See Figure 5-25, which shows how to compute the initial fragment velocity from a dynamic warhead detonation (V_o) given the initial fragment velocity and direction from a static warhead detonation (V_{os}) together with the encounter velocities of the warhead (or missile) and the target aircraft.

5.5.8.2.4 Fragment striking velocity. Fragment velocity decreases with range in an approximate exponential manner. As such, the striking velocity (V_s) at any range r is given by an equation of the following form:

$$V_s = V_o \exp(-\beta r)$$

where:

V_o = Initial fragment velocity from dynamically detonated warhead

β = Constant which depends on air density, fragment size, mass, and a drag coefficient.

5.5.8.2.5 Fragmentation spray limits. In a static firing of a warhead, the fragments are assumed to travel out radially on the surface of an imaginary expanding sphere. In Figure 5-26, the fragments are assumed to be uniformly distributed in a spray pattern contained between the angles α_1 and α_2. A method is given for determining the angular limits (ϕ_i) of the dynamic fragment spray pattern in terms of the static angles (α_i). These latter parameters must be obtained for the specific warhead under consideration. If the fragment density cannot be assumed uniform over the entire spray pattern, then the angular limits can be determined in a similar manner for smaller subpatterns (or bands) over which the density can be assumed constant.

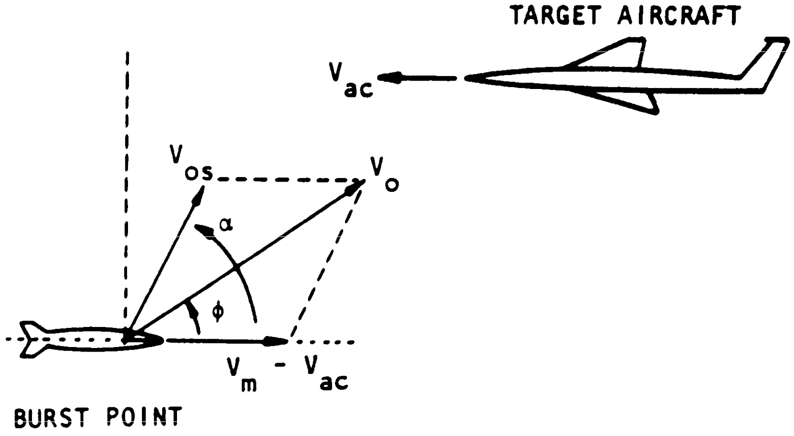
5.5.8.2.6 Fragment spray pattern density. The fragment density incident on the aircraft presented area within the fragment spray pattern can be obtained (Figure 5-27) from a knowledge of the total number of fragments emitted at warhead detonation, assuming the fragments are uniformly distributed, the angular limits of the dynamic spray pattern, and the radius (or range) between the burst point and the aircraft presented area at the time of fragment impact. The number of fragments emitted (n) must be determined for the specific warhead under consideration. The angular limits on the fragment dynamic spray pattern (ϕ_i) can be determined as in 5.5.8.2.5 and the range between the aircraft and the burst point can be determined from the input encounter conditions.

5.5.8.2.7 Conditional probability of kill. The probability of aircraft kill due to detonation of a specific warhead and for a particular set of encounter conditions can thus be obtained by means of the following expression:

$$P_{K/E} \approx 1 - \exp(-E_K) = 1 - \exp(-\rho A_V)$$

where:

A_V = Aircraft vulnerable area at the aspect under consideration determined



$$V_o = \left[(\vec{V}_m + \vec{V}_{ac} + V_{os} \cos \alpha)^2 + (V_{os} \sin \alpha)^2\right]^{1/2}$$

Where: V_o = initial fragment velocity from dynamic warhead detonation

V_{os} = initial fragment velocity from static warhead detonation

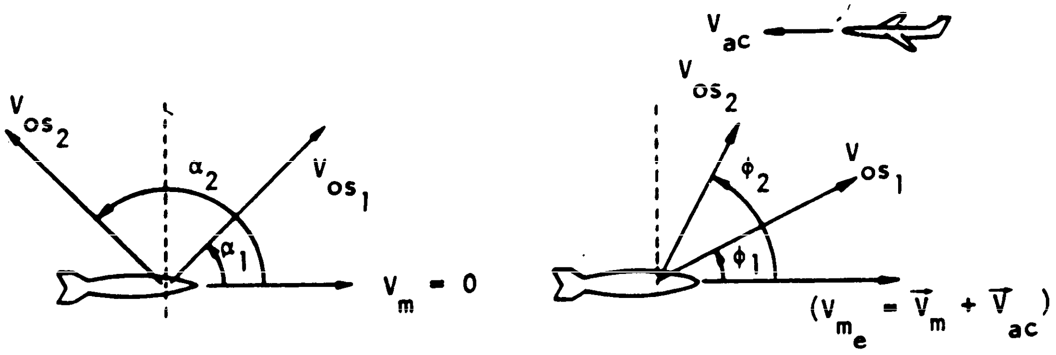
V_m = missile (or warhead) velocity

V_{ac} = target aircraft velocity

α = angle between fragment path and missile path for a static warhead detonation

ϕ = angle between fragment path and missile path for a dynamic warhead detonation

FIGURE 5-25. Initial fragment velocity.



STATIC DETONATION

DYNAMIC DETONATION

α_i = Angular limits of fragment spray from a static warhead detonation $(i = 1,2)$

ϕ_i = Angular limits of fragment spray from a dynamic warhead detonation $(i = 1,2)$

$V_{m_e} = \vec{V}_m + \vec{V}_{ac}$ = Missile velocity relative to target aircraft

$$\phi_i = \text{Arctan}\,\frac{V_{os_i} \sin \alpha_i}{V_{m_e} + V_{os_i} \cos \alpha_i} \qquad (i = 1,2)$$

FIGURE 5-26. Fragmentation spray angles.

n = Total number of fragments emitted from warhead detonation

ϕ_i = Angular limits of dynamic fragmentation spray pattern (i = 1,2)

ψ = Solid angle subtended by spray pattern

$$\psi = A_{s_1} \; 2\pi Rh \quad (R = 1)$$

$$A_{s_1} = 2\pi R(\cos\phi_1 - \cos\phi_2)[R = 1]$$

A_{s_1} = Surface area of spherical zone subtended by ϕ_i on a sphere of unit radius (R = 1)

N = Fragment density per steradian $= \frac{n}{\psi} = \rho R^2$

ρ = Surface area density of fragments at any radius R

$$\rho = \frac{N}{R^2} = \frac{n/\psi}{R^2} = \frac{n}{2\pi\ (\cos\phi_1\ \cos\phi_2)R^2}$$

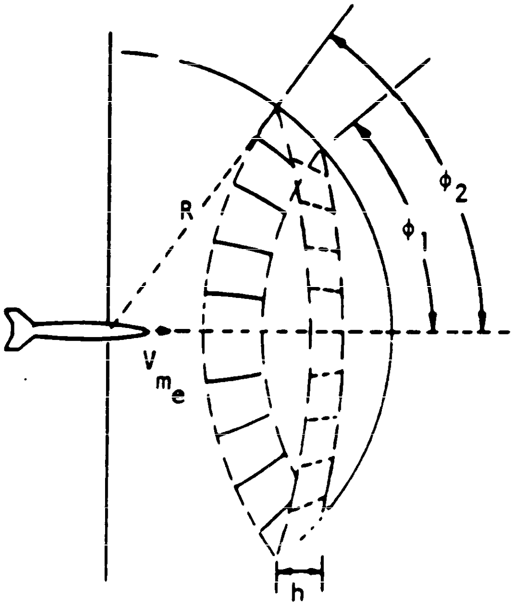


FIGURE 5-27. Fragment spray density.

P = Area density of fragments incident on A_V determined as in 5.5.8.2.6.

An example illustrating the methodology for computing $P_{K/E}$ is shown in Figure 5-28.

5.5.8.3 Vulnerability to blast. To evaluate the vulnerability to blast effects, the following four steps must be examined:

a. Study input requirements

b. Analysis techniques

c. Vulnerability computation

d. Summary

5.5.8.3.1 Study input requirements. The required study inputs concern a) weapon terminal effects, b) the encounter conditions between the weapon effects and the aircraft, c) the resulting damage (or kill) levels of the aircraft, and d) the characteristics of the aircraft under consideration. These requirements are discussed here in the aforementioned order.

GIVEN:

STATIC WARHEAD PARAMETERS	Spray angles, $\alpha_1 = 30°$, $\alpha_2 = 80°$ Number of fragments, $n = 1000$ Fragment velocity, $V_{os} = 7000$ fps
ENCOUNTER PARAMETERS	Missile speed, $V_m = 1500$ fps Head-on encounter with miss distance, $R = 20$ ft
AIRCRAFT PARAMETERS	Aircraft speed, $V_{ac} = 1000$ fps Aspect vulnerable area, $A_v = 5$ ft^2 to fragment sizes and striking velocity under consideration

REQUIRED:

Single-shot probability of kill ($P_{K/E}$)

SOLUTION:

INITIAL FRAGMENT VELOCITY

$$V_{o_1} = \left[(V_m + V_{ac} + V_{os} \cos \alpha_1)^2 + (V_{os} \sin \alpha_1)^2\right]^{1/2}$$

$$= \left[(1000 + 1500 + 7000 \cos 30°)^2 + (7000 \sin 30°)^2\right]^{1/2}$$

$$= \left[(8560)^2 + (3500)^2\right]^{1/2} = 9220 \text{ fps}$$

$$V_{o_2} = \left[(V_m + V_{ac} + V_{as} \cos \alpha_2)^2 + (V_{os} \sin \alpha_2)^2\right]^{1/2}$$

$$= \left[(3725)^2 + (6890)^2\right]^{1/2} = 7840 \text{ fps}$$

$$\overline{V}_o \quad \frac{V_{o_1} + V_{o_2}}{2} = 8530 \text{ fps}$$

FRAGMENTATION DYNAMIC SPRAY ANGLES

$$\phi_1 = \text{ARCTAN} \frac{V_{os} \sin \alpha_1}{V_m + V_{ac} + V_{os} \cos\alpha_1} = \text{ARCTAN} \frac{3500}{8560} = 24.2°$$

$$\phi_2 = \text{ARCTAN} \frac{V_{os} \sin \alpha_2}{V_m + V_{ac} + V_{os} \cos\alpha_2} = \text{ARCTAN} \frac{6890}{3725} = 61.7°$$

FRAGMENT SPRAY DENSITY

$$\psi = 2\pi\ (\cos\phi_1 - \cos\phi_2 0 = 2\pi\ (\cos 24.2° - \cos 61.7°)$$

$$= 2.75 \text{ steradians}$$

$$N = \frac{n}{\psi} = \frac{1000}{2.75} = 364 \text{ fragments/steradian}$$

$$\rho = \frac{N}{R^2} = \frac{364}{(20)^2} = 0.909 \text{ fragments/ft}^2$$

PROBABILITY OF KILL

$$E_K = \frac{N A_v}{R^2} = \rho A_v = (0.909)(5) = 4.54 \text{ hits}$$

$$P_{K/E} \approx 1 - \exp(-E_K) \approx 1 - \exp(-4.54) = \boxed{0.989}$$

FIGURE 5-28. Fragmentation $P_{K/E}$ example.

a. Weapon terminal effects. The weapon terminal effect (or damage mechanism) under consideration is the blast wave resulting from detonation of a threat warhead in the vicinity of (i.e., external and adjacent to) the target aircraft. A spectrum of charge weights is chosen for which aircraft vulnerability measures are to be computed in the vulnerability assessment. The specific charge weights selected should be representative of the expected threat projectiles/warheads of interest. The spectrum of charge weights should be broad enough to account for differences in the type of explosive used, warhead "casing" effects, moving "charge" effects, and moving "target" effects. These data determine the vulnerability envelope as discussed in 5.5.8.3.

(1) The blast wave characteristics must be defined to evaluate the vulnerability envelope. Figure 5-29 shows the changing shape of the blast wave as it propogates outward in an exponentially decaying manner.

(2) Figure 5-30 shows what an observer standing at distance D from the explosion point would experience. After T_1 seconds, the initial overpressure shock would be felt. The pressure would decay exponentially for T seconds, and then drop below ambient. Therefore, there are three variables, the peak overpressure (P), the positive pressure duration (ΔT), and the impulse (I). The impulse is the area under the positive portion of the curve.

b. Encounter conditions. The required encounter conditions include (1) aircraft speed and altitude at the time of charge detonation and (2) a preliminary estimate of the expected distribution of burst points about the aircraft. The latter information is required to reduce the vulnerability assessment workload by indicating the most important aspects of interest about the aircraft as well as those aspects which are not exposed and for which no vulnerability assessment is necessary. Aircraft speed is required in order to select a sufficiently broad spectrum of equivalent charge weights which will account for moving "target" effects. Aircraft altitude is required since the damaging effects of a given charge vary with altitude.

c. Damage levels. Aircraft damage (or kill) levels to be considered in the vulnerability assessment must be specified so that critical components of the aircraft can be identified for each kill level and the corresponding threshold defeat criteria for each critical component can be computed. Blast kill levels of most interest in the past have been "K" and "A" levels, since, most existing experimental data on which to base threshold defeat criteria for critical components are available only for these kill levels.

d. Aircraft characteristics. Required aircraft characteristics include:

(1) the identification of critical components for each aircraft kill level of interest and,

(2) determination of the corresponding threshold defeat criteria for each critical component and kill level at each aspect of interest. Aircraft critical components vulnerable to external blast damage consist principally of portions of the airframe structure (e.g., wings) and control surfaces. Failure mechanisms of these components which can result in aircraft

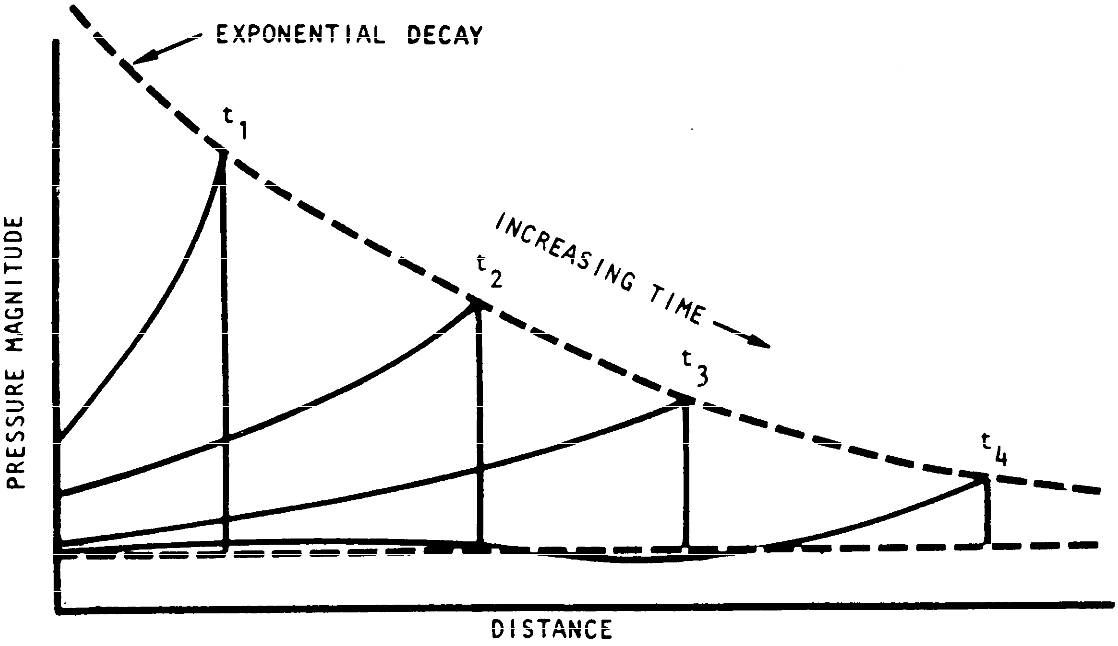


FIGURE 5-29. Blast wave propagation.

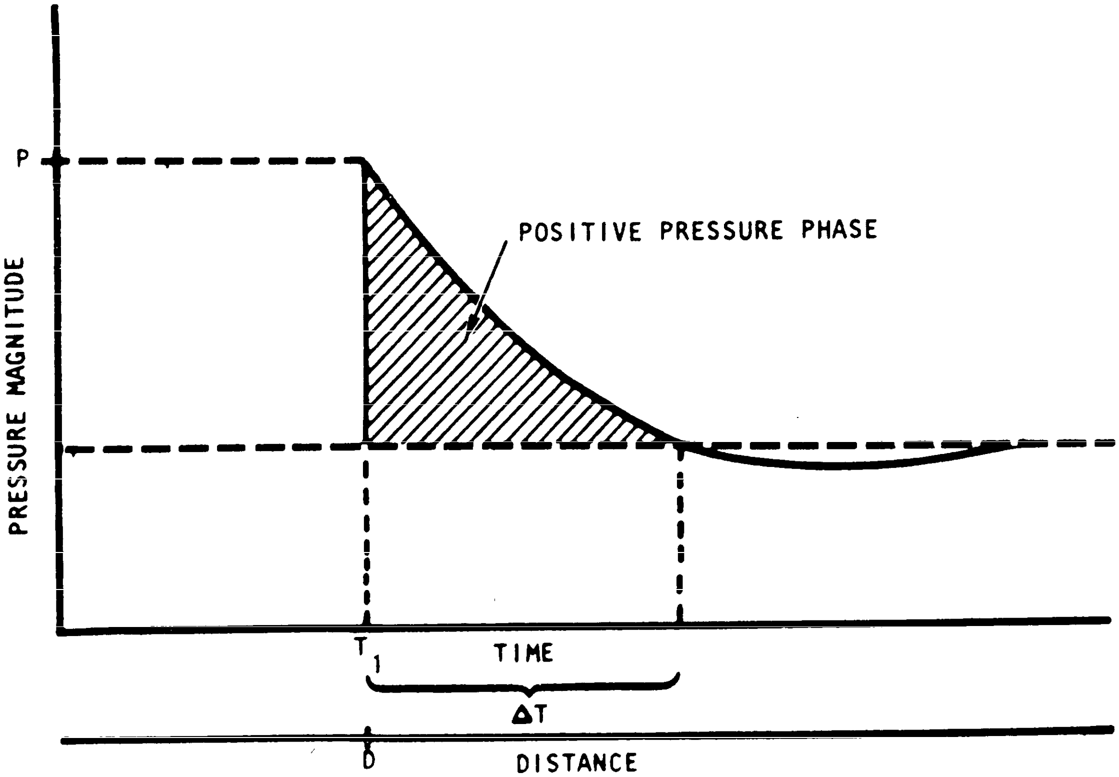


FIGURE 5-30. Pressure felt by observer.

kill include structural deformation or failure and aerodynamic gust effects. Structural deformation can also result in defeat of other components such as the jamming of control surfaces or bomb bay doors. Threshold defeat criteria for critical components are usually expressed in terms of the peak reflected or incident pressure and impulse levels required to effect a specified level of aircraft kill. Incident pressure and impulse levels are employed for components, the presented areas of which are sufficiently small that reflection phenomena can be ignored. Otherwise, threshold defeat criteria are expressed in terms of reflected pressure and impulse levels. Threshold defeat criteria for critical components can be derived by conducting structural and aerodynamic analyses to determine the value of peak pressure and impulse levels on critical component presented areas at aspects of interest which will result in the required level of aircraft kill. Alternately, existing experimental data on threshold defeat criteria for similar critical components and aircraft can be extrapolated to the case of the aircraft under consideration.

5.5.8.3.2 Analysis techniques. Analysis techniques and appropriate vulnerability measures must be selected based on the damage mechanism under consideration, aircraft characteristics, and possible failure modes. The measure of aircraft vulnerability to external blast loading is the vulnerable volume or envelope about the aircraft within which the detonation of a specified warhead weight will result in the required aircraft kill level and outside of which the detonation will result in no damage to the aircraft. In any one plane passing through the aircraft, the vulnerability measure reduces to a contour line about the aircraft cross section in that plane. This vulnerable contour is the trace of the vulnerability envelope in the particular projection plane under consideration. Any one point on such a vulnerable contour can be characterized by its location in a two-dimensional set of coordinates in the plane and, more generally, any point on the vulnerable envelope can be characterized by its location in a three-dimensional coordinate system. The primary problem is to locate sufficient data points on the vulnerable envelope for each charge weight in a sufficiently broad spectrum of charge weights to satisfy the vulnerability assessment objectives.

5.5.8.3.3 Computation of aircraft vulnerability. Having defined the study inputs and selected the analysis techniques and appropriate vulnerability measures, the next step is to compute aircraft vulnerability. This is accomplished by locating sufficient data points on the vulnerable envelope to each charge weight in a sufficiently broad spectrum of charge weights to satisfy the vulnerability assessment objectives. If the objective is to provide vulnerability data for a survival analysis, then only sufficient data points are generally required to define an approximating vulnerable sphere or ellipse. If, however, the objective is to determine the relative contribution of critical components to overall aircraft vulnerability in order to provide a basis for design or modification decisions, then it is necessary to determine the shape and extent of the vulnerable envelope in more detail. Hence, the number of data points which are required depends on the study objectives which must be determined in each specific case.

5.5.8.3.3.1 Location. To locate a point on a vulnerable envelope it is necessary to know the threshold defeat criteria for a critical component. Given the threshold defeat levels of peak pressure and impulse on a presented surface area, it is possible to determine the distance from that surface at which the detonation of an uncased spherical charge of TNT will result in the threshold defeat levels of pressure and impulse on the surface. This is accomplished by employing blast scaling values similar to those shown in Figure 5-31. For the example shown, where a peak incident overpressure (ΔP_Z) of 1.0 psi, at 90,000-foot altitude, would cause structural failure.

To illustrate the use of the graph drawn in Figure 5-31, the following steps were taken based on an example of a 1.0 psi overpressure at 90,000 ft altitude. The warhead charge weight was 8 pounds;

a. Draw a horizontal line from the peak overpressure (1.0 psi)

b. Find the intersection of the aircraft altitude under consideration (90,000 ft)

c. Draw a vertical line to the scaling factor 1 (15 ft/lbs TNT)$^{1/3}$

d. Draw a line through the warhead charge weight (8.0 lbs)

e. The intersection is the separation distance within which damage will occur (55 ft)

5.5.8.3.4 Summarizing results. The principal results of a blast vulnerability assessment are the calculated data points for failure levels in all planes around the aircraft. Each data point represents the distance from the aircraft surface at which the detonation of a specified charge weight of uncased spherical pentolite will result in a required level of aircraft kill at a given encounter altitude. Mathematically, within a given plane of interest, the distance from the aircraft surface (R) represented by each data point can be expressed as a function of three parameters: charge weight (W), encounter altitude (h), and kill level (k). That is,

$$R = f(W, h, k)$$

Hence, it is possible to summarize the data in a number of ways, depending on which parameters are treated as constants and which as variables in any one presentation. Also, the summaries can be presented as graphs, or the data merely tabulated. Two graphical formats which have been used previously are discussed below; however, they do not exhaust all possible formats.

a. The first graphical presentation which has been found useful in the past is that of charge weight (W) versus distance (R) for a constant kill level (k). Several curves can be drawn on the same graph, one for each altitude (h) of interest. For example, let k = K kill level and h = sea level. Then the graphical presentation might appear as shown in Figure 5-32. It should be noted that a similar graph is required at each azimuth and elevation angle of interest about the aircraft.

b. The second graphical method which has been found to be useful is to construct iso-charge weight (W) contours for a given aircraft kill level (k) and altitude (h) in all planes of interest through the aircraft. The envelope of all such contours about the aircraft is thus the blast vulnerability envelope of the aircraft to a specified charge weight at a given encounter altitude and aircraft kill level. Figures 5-33 through 5-35 are three examples of this graphical formal illustrating aircraft kill (such as A kill for these examples) resulting from the detonation of 100 and 200 pound charges of uncased pentolite at sea level. The use of this format is also illustrated in Appendix A of Reference 185.

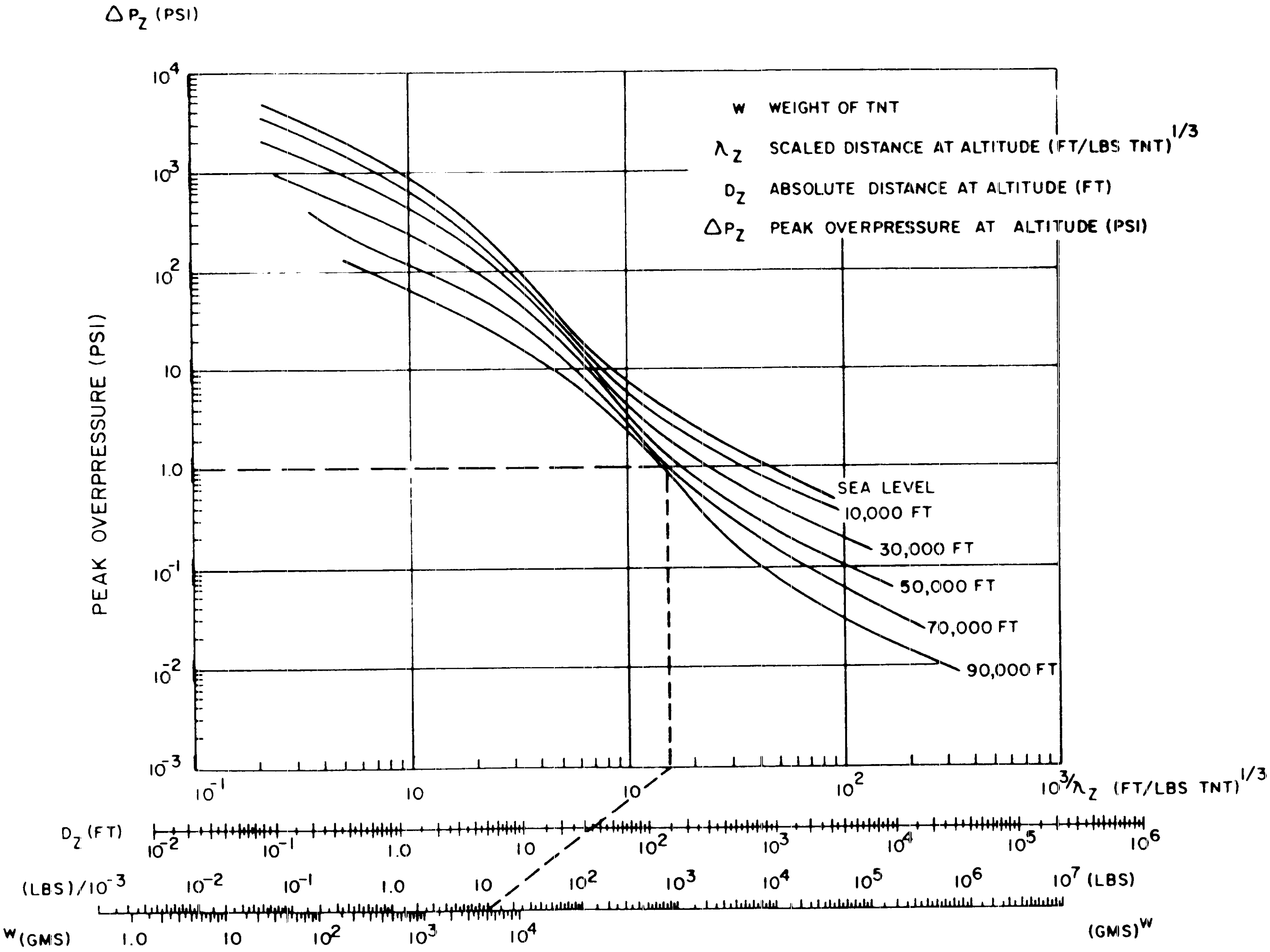


FIGURE 5-31. Blast scaling values.

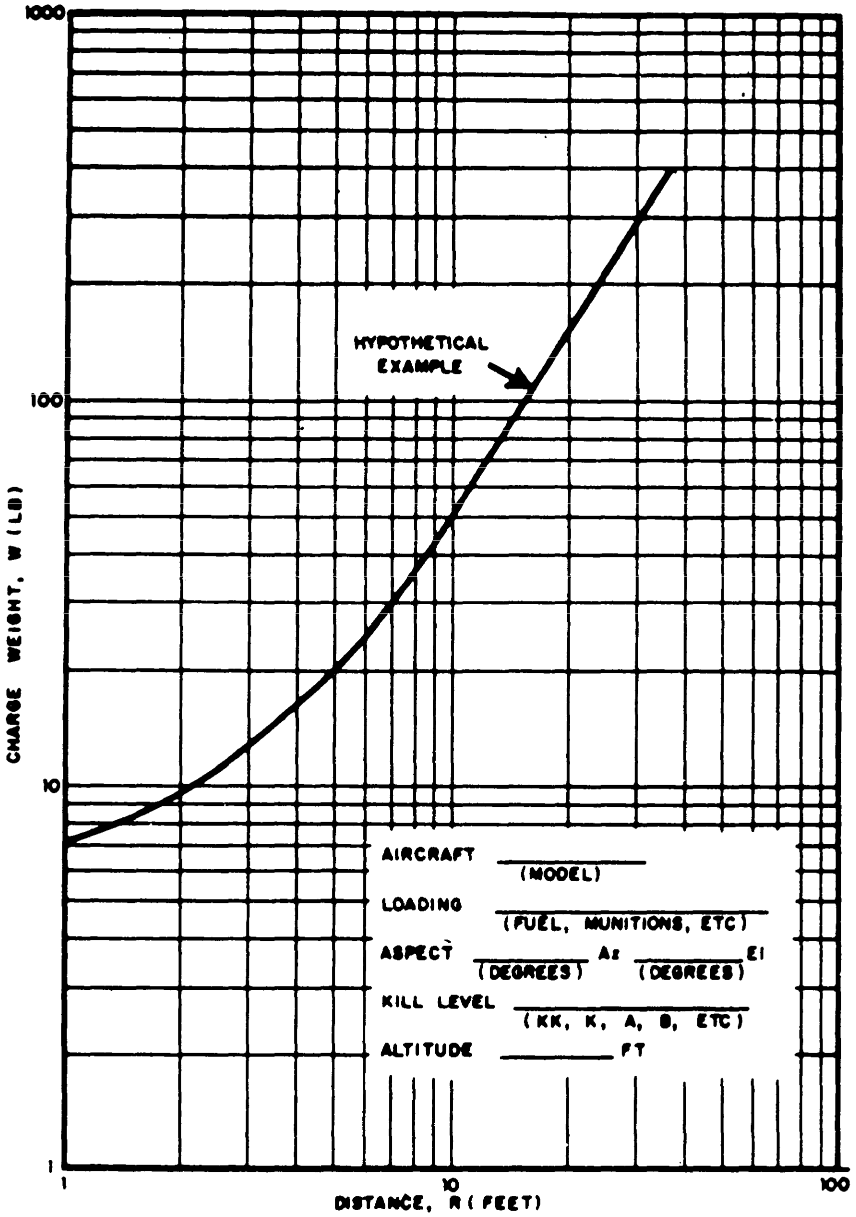


FIGURE 5-32. External blast vulnerability measure (charge weight vs distance).

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5.6 Vulnerability assessment computer models. An extensive number of computer models have been developed by the military and industry for assessing aircraft vulnerability to nonnuclear weapon effects. A listing of those computer programs recognized and endorsed by the JTCG/AS is contained in this section. A brief description of each is provided to acquaint the reader with the basic capabilities of each program. Both ballistic and high-energy laser vulnerability assessment models are contained in the listing along with the applicable target-description programs. A generalized flow diagram describing the relationship of the various inputs and resulting output as they interface with the computer program is shown in Figure 5-36.

5.6.1 GIFT. Geometric Information For Targets

a. Sponsoring Agency: U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.

b. Use: Target geometric description model.

c. Description: The primary input to the GIFT code, is "target description" data which defines the three-dimensional shape and spacial location of the components of a target. A target may be a tank, truck, building or any other physical structure. To prepare target description data, engineering drawings, photographs, technical and reference manuals and/or any other data which describe the three-dimensional shape and space of components of the target are required. With only the prepared target description data as input, the GIFT code can output the following:

(1) An illustration of the components of the target (as modeled by the target description data) from the front, top, side or any view of the target.
(2) Simulated engineering drawings of the components of the target described in the target description data
(3) The projected area of the components of the target from the front, top, side or any view of the target
(4) The centroids of area and perimeter of the target from any view
(5) The volume of the components of the target
(6) The angular and spacial values between the components of the target (geometric data on the target) required as input by the different "target energy effects" simulation codes when, in addition to the target description data, the densities of the components of the target are provided as input, the GIFT code can output the following:
(7) The moments of inertia of the target from any view of the target
(8) The center of gravity of the target
(9) The weight of the components of the target

The GIFT code can compute many of the Physical properties of a target much cheaper and faster than they can be measured via empirical test procedures. For the different target energy effects simulation codes, the GIFT code simulates the paths of different energy sources and computes and outputs thousands of angular and spatial values between the components of the target. The vulnerability analysis and the

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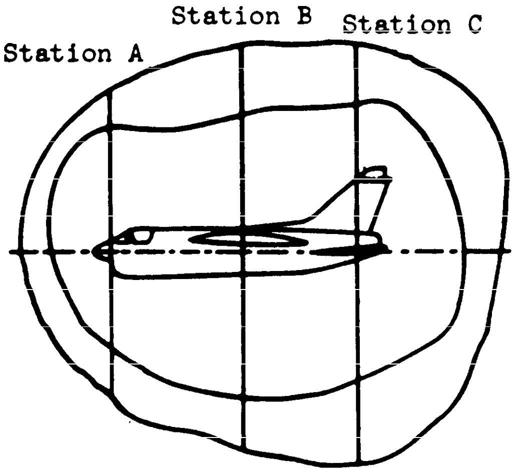

FIGURE 5-33. Typical external blast contours for A/C kill, side view.

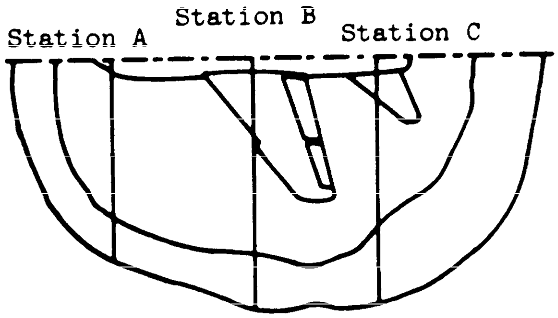

FIGURE 5-34. Typical external blast contours for A/C kill, top view.

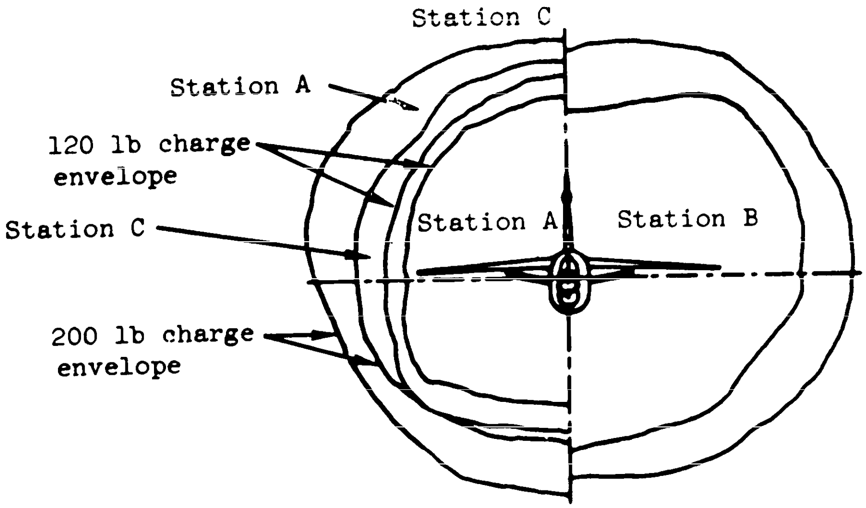

FIGURE 5-35. Typical external blast contours for A/C kill, front view.

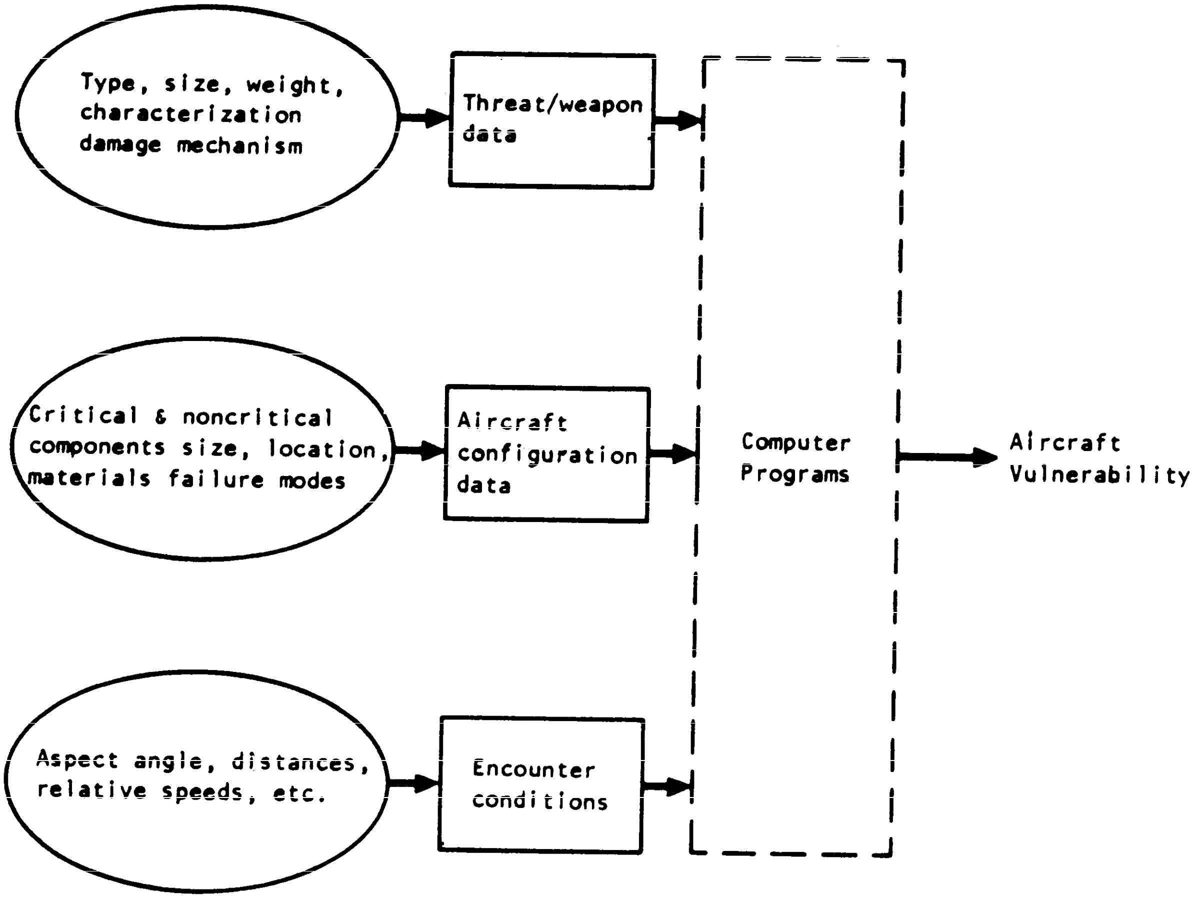

FIGURE 5-36. Generalized flow diagram.

target-signature codes are two examples of target-energy-effect simulation codes. For the AVVAM-1 and other vulnerability analysis codes, the GIFT code simulates the paths of projectiles and fragments (energy sources) through the target, and computes and outputs the following for each simulated projectile and fragment path:

(10) A list of the components of the target as they are encountered by the simulated projectile or fragment

(11) A thickness value for each component that the simulated projectile or fragment must penetrate

(12) The angle of incidence between the simulated projectile and fragment paths and the surfaces of the encountered components for the group of target-energy effects simulation codes referred to as target signatures codes, the GIFT code simulates the path of signature-energy sources and computes and outputs the angular and spatial values of the components of the target that the different target signature codes require as input. An example of a target-signature code is the ETHM code. The signature-energy source for the ETHM code is a beam of laser energy. The GIFT code simulates the paths of laser energy from an external source to the target, and outputs the following data:

(13) The components of the target encountered components by each laser path

(14) The angle of incidence between the encountered components and the laser path

(15) Data to determine the angles of scattering between the laser paths, the target and detectors
Using the GIFT-code data as input, the ETHM code simulates the laser semiactive terminal homing situation and outputs intensity-versus time data for each laser pulse and for each quadrant of a four-quadrant detector. The amount of computer core memory required to run the GIFT code varies with the amount of input data.

The GIFT code consists of approximately 7,000 cards or lines of coding and 3,000 lines containing comments (comment cards) which document the GIFT code. (An analyst manual of the GIFT code is also planned.) Because of the large number of lines (about 10,000) in the GIFT code, a listing or printout of the GIFT code is not contained within this report. BRLESC (a BRL-built computer), CDC, UNIVAC and IBM FORTRAN versions of the GIFT code are available. Each version of the GIFT code is slightly different because of the differences between the computer systems; however, the input requirements of the GIFT code, presented in this report, are the same for every computer system.

d. Documentation: No formal report available

5.6.2 MAGIC. MAGIC Computer Simulation.

a. Sponsoring Agency: Department of the Army, Ballistic Research Laboratories.

b. Use: The MAGIC computer simulation generates target-description data with the detail and completeness required for vulnerability studies. A combinatorial-geometry technique is used in the simulation to represent a complex target structure. A large number of parallel rays, randomly located in grid cells, are traced through the target structure to produce item-by-item listings of the components and air spaces.

c. Description: The combinatorial-geometry technique has been developed to produce a model that is both accurate and suitable for a ray-tracing analysis program. The basic technique for a geometry description requires defining the locations and shapes of the various physical regions (wall, equipment, etc), utilizing the intersections and unions of the volumes of 12 simple bodies. The geometric bodies are as follows:

(1) Rectangular parallelepiped
(2) Box
(3) Sphere
(4) Right circular cylinder
(5) Right elliptical cylinder
(6) Truncated right angle cone
(7) Ellipsoid
(8) Right angle wedge
(9) Arbitrary convex polyhedron of four, five, or six sides
(10) Truncated elliptic cone
(11) Arbitrary surface
(12) Torus

A special operator notation uses the symbols (+), (-), and (OR) to describe the intersections and unions. These symbols are used by the program to construct tables used in the ray-tracing portion of the problem. If a body appears in a region description with a (+) operator, the region being described is wholly contained in the body. If a body appears in a region description with a (-) operator, the region being described is wholly outside the body. A region may be described in terms of several subregions lumped together by (OR) statements.

d. Variants: GIFT - A combination of SHOTGEN and MAGIC methods into a very efficient code that also provides a number of computer-generated graphic-display outputs.

e. Documentation: MAGIC Computer Simulation

(1) Volume I, User Manual 61 JTCG/ME-71-7-1, July 1970 (Reference 7).
(2) Volume II-1, Analyst Manual 61 JTCG/ME-71-7-2-1, May 1971 (Reference 8).
(3) Volume II-2, Analyst Manual 61 JTCG/ME-71-7-2-2, May 1971 (Reference 9).

5.6.3 SHOTGEN. Shot Generator Computer Program.

a. Sponsoring Agency: Warhead Analysis Branch, Naval Weapons Center, China Lake, Calif.

b. Use: Accepts geometrical-model data and produces a series of parallel line penetration descriptions of the target commonly called "shot line" or "line of sight" (LOS) descriptions.

c. Description: The SHOTGEN provides a detailed-target description by developing detailed item-by-item listings of the components and airspaces encountered by a large number of uniformly distributed parallel rays emanating from any attack aspect and passing through any type of target.

The method used to obtain the basic input data for the description of any target is based on the fact that the surfaces, flat or curved, exterior or interior, of the individual components of that target may be approximated by a group of flat surface segments and, therefore, may be described as a series of consecutively adjacent triangles whose points (vertices) may then be located in space.

The computer routine transforms the target triangle points relative to the attack aspect being considered and super-imposes a grid over the surface of the target as viewed from the attack aspect. Any grid size can be specified. Parallel rays are randomly located in each grid cell and the routine checks for ray-encounters with component surfaces as it passes through the target. Each ray-surface encounter is listed sequentially and identifies the ray location, the component identification, the surface thickness, entrance and exit obliquity angles, the airspaces encountered, and the distance between the components. Basic input data consists of:

(1) The coordinate measurements from a given origin in space
(2) The code number, which is composed of the plate mode or influence mode symbol (when applicable), a normal thickness (when applicable), a space identification code number, and a component identification code number
(3) The sequence number. These data are required for each and every target point of the complete target. The geometrical target model utilized is based on several simple truisms. These are:
(4) A target is composed of a group of components.
(5) Each of these real components is a volume of material.
(6) Each of these components has interior and exterior surfaces.
(7) Components can be geometrically described if the components' surfaces can be represented.
(8) A sequential group of triangles which completely covers the outside and inside of a component defines the surface of the component.
(9) A triangle is composed of a group of three distinct points in terms of Cartesian coordinates which are acceptable computer input. This model offers the following:

(10) The triangle approximation method involves a set of simple, quickly learned rules.
(11) The rules are universal from one target type to another without change.
(12) All degrees of approximation are available depending on the shape of the surface and the desired detail.
(13) Simple and rapid computer computations yield the desired output.

The output of this program consists of line-of-sight data for each ray. The data is output in binary format on magnetic tape and printed on paper or 35-MM film. The medium to be used for the printed output is specified by the input parameter IMED.

In addition to line-of-sight data, various lines of data and information are printed during execution of the program.

The program is written in FORTRAN IV language and requires a large-scale digital computer. The running time to compile the program and execute a simple target is 1.33 minutes on a Univac 1108 computer.

d. Variant: FASTGEN - An optimized version of SHOTGEN with several of the MAGIC geometric shapes added.

e. Documentation: Shot Generator Computer Program.
  (1) Volume I, User Manual 61 JTCG/ME-71-5-1, July 1970 (Reference 10).
  (2) Volume II, Analyst Manual 61 JTCG/ME-71-5-2, July 1970 (Reference 11).

5.6.4 VAREA. - VAREA Computer Program.

a. Sponsoring Agency: Weapons Analysis Divisions, Weapons Development Department, Naval Weapons Center, China Lake, Calif.

b. Use: Computes vulnerable area for appropriately described targets. Used in conjunction with SHOTGEN, FASTGEN, MAGIC.

c. Description: The VAREA computer program computes target vulnerability data in terms of vulnerable area for specified penetrators. The modeling and methodology involves positioning all vulnerable components and shielding elements of a target in their correct positions in space and evaluating damage to these components. The program accepts as input a series of shotlines randomly distributed over the target and alined with a specified attack azimuth and elevation angle. The shotline description is generated using the SHOTGEN Program and is input to VAREA by means of a magnetic tape.

The program treats the target attack aspect in terms of views, where a view is defined as the geometric location of a series of shotlines relative to a set of orthogonal axes centered on the target. The target has a grid overlay imposed on it such that the grid is perpendicular to the view shotlines. Each grid cell is small enough so that a single shotline may be considered representative for the cell. The shotline descriptions prepared by the Shot Generator Program are input to VAREA from a binary magnetic tape and include the azimuth, elevation, target number, component code numbers, space code numbers, obliquity angles, and line ofsight and normal thicknesses for each component which is intersected by a given shotline.

The program treats the target/penetrator interaction in a realistic manner by allowing the penetrators weight and velocity to decay as it penetrates successive components along a shotline as defined by the THOR penetration relationships.

The THOR penetration relationships are used to define a penetrator's residual weight and velocity changes as it penetrates successive components along a shotline. These relationships require certain penetrator and component parameters to be adjusted by 10 experimentally developed penetration constants to account for penetrator weight and velocity decays as the penetrator penetrates material. The penetrator parameters that must be adjusted include its striking velocity, weight, and presented area. The component parameter which is adjusted is the thickness.

The kill contribution of each vulnerable component is computed using either a curve or a step-function which relates a penetrator's striking weight and velocity to a conditional kill probability. The kill contribution of each vulnerable component is computed from vulnerability data read from card input records used in conjunction with the striking weight and velocity of the penetrator being considered. The program offers three options in the form of the component-vulnerability data to be used. These are a closed-form solution, a two-step function, or a four-step function. The closed-form solution requires the input from card records of seven constants peculiar to the component. The step functions are comprised of a velocity and $P_{K/H}$ pair for each step of a given fragment weight class.

Once the $P_{K/H}$ for a shotline is developed, the vulnerable area for that shotline is found by taking the product of the $P_{K/H}$ and the grid cell area. Summing all the shotline vulnerable areas in a given region defines the vulnerable area of the target for the view. The program also computes target-vulnerable areas averaged over all views (eight azimuths) at a given elevation as well as an average vulnerable area over all views contained in the three elevations: 0, + 30, and +60 degrees.

Each of the sets of vulnerable areas computed are presented in a tabular format with penetrator weights and velocities utilized as headings for the rows and columns, respectively. Each of the tabular output titles contains a description of the target in terms of the attack aspect as well as the expedient and thorough repair times. Vulnerable area tables for the target and its individual vulnerable components are presented for a selected combination of penetrator weights, velocities, and attack aspects.

Summary tables are also presented which average the results of all selected azimuth angles for each selected elevation angle as well as averaging all azimuth angles for 0-, 30-, and 60-degree elevation angles combined.

d. Variants: COVART - A simulation program for: Computation of Vulnerable Areas and Repair Times.

e. Documentation: VAREA Computer Program
   (1) Varea Computer Program, Volume I - User's Manual, JTCG, February 1971, (U) (Reference 12)
   (2) Varea Computer Program, Volume II - Analyst Manual, JTCG, February 1971, (U) (Reference 13)

5.6.5 COVART. Covart Computer Program.

a. Sponsoring Agency: JTCG/ME/ATV Computer Programs Modification and Standardization Panel, Aberdeen Proving Ground, Md.

b. Use: A simulation program for Computation Of Vulnerable Areas and Repair Times. The program is used to determine the vulnerable areas and estimated repair times for specific levels of damage caused by single penetrators (fragments and projectiles) against various target types.

c. Description: The COVART computer program combines two models, VAREA02 (an optimized version of VAREA), and HART which provides single-round expected repair times. The COVART program has been written to accept information generated by tracing parallel shot lines through a geometric description of the target. Program COVART accepts shot line information which has been generated by Program SHOTGEN, Program MAGIC or the equivalent. This program was designed primarily for aerial targets, including helicopters. However, it can also be applied to ground targets as long as the damage definitions are consistent.

Vulnerable areas and repair efforts are determined for penetrators impacting the target within a pre-selected weight and speed matrix. Each penetrator is evaluated along each shot line, and the contributions made along that trajectory to the target vulnerable area and repair effort are determined. Target vulnerable area is a function of the target presented area, the weight and speed of the impacting penetrator, the target components encountered by the penetrator, and the resistance to penetration encountered by the penetrator. Target repair effort is a function of the target presented area, the probability that the target survives the damage sufficiently to return to a repair area, and the accessibility of a specific component for replacement or repair.

The majority of the program data are entered by card input. The shot line description data are entered by card input or tape; however, when a target description is entered via card input, a tape is produced in Program COVART format which thereafter may be used for the target description - input. Program output can be divided into four types: a record of major input items, input diagnostics, run/error diagnostics, and program results. The output is dependent upon the options specified within the input.

Program COVART allows a number of options, when exercised properly, will allow most targets to be evaluated. The major options available are defeat definition, type of component vulnerable area, repair time selection, and type of line-of-sight data input. Other options available include type of output units, type of weapons, type of slowdown equations, and line-of-sight data trace.

5.6.6 LV. Laser Vulnerability Code

a. Sponsoring Agency: U.S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland

b. Use: Generates a plot of probability of kill given "lock on" versus time for the target vehicle, identifies contributing critical components and the kill criteria.

c. Description: Geometric figures are used to model the target, and the coordinates of those figures are evaluated in order to best describe the actual target. The LV uses either COMGEOM (combinatorial geometry i.e., MAGIC or GIFT) descriptions, which are Boolean combinations of solid figures to describe the target; or TRIANGULATION (SHOTGEN) descriptions, which describe the target as a collection of triangles. Since the use of such target descriptions is becoming quite common within DoD, and since COMGEOM and TRIANGULATION are by far the most often used methods, it is anticipated that off-the-shelf geometric descriptions will be available for LV analysis.

The existence of two major target description techniques, combinatorial geometry (COMGEOM) and TRIANGULATION, has necessitated two versions of the LV code, herein referred to as LV/COMGEOM and LV/TRIANGLE, respectively. These versions differ only in the geometry preprocessing and ray-trace techniques; the laser-effects portions of the two versions are basically the same. The COMGEOM version of LV uses a modification of GIFT suited to the LV requirements. In this modification, the ray trace is exceptionally fast, tracing about 50 rays per second through an average (350 region) target. The LV version of TRIANGULATION was completely rewritten to incorporate particularly efficient sorting and searching routines. The result is a fast-ray trace, tracing up to 90 rays per second through an average (300 component) target. The input control card is read by the master program. Source input is unchanged from the original TRIANGULATION, except that the sequence number is ignored, and the last source card must indicate END-OF-FILE.

To describe the laser Delivered Energy Distribution (DED), we first define the incident plane as a plane normal to the incident beam and fixed to the closest corner of an imaginary box that contains the target. Describing the beam requires information on the temporal and spatial behavior of the flow of energy through this plane. Since the goal of the analysis is to evaluate the probability of a kill from an arbitrary shot under specified conditions, no attempt is made to consider the temporal and spatial history of one particular shot. Rather, the probable distribution of accumulated energy density (the integral of the flux that has passed through each point on the incident plane from start of shot unit time t), is used to describe the laser DED.

As in conventional analyses, it is necessary to specify the desired kill category, i.e., the desired level of incapacitation of the target. Next, one identifies those components of the target, called critical components, whose destruction would satisfy the kill category. The remaining components are defined as shields. The target response is thus divided into describing the penetration of shields, and the failure of critical components.

Care was taken in LV to preserve two of the main advantages of parameterization, viz, ease-of-update and case-of-sensitivity analysis. The modular construction of LV makes it a simple matter to change the parametric forms used in the code. Thus, new developments in tracking, for example, or the response of new countermeasure materials can be described by interchanging subroutines. Ease-of-sensitivity analysis is accomplished by providing an efficient and straightforward method of repeating the calculation many times, making predetermined changes in selected parameters, in order to span the parameter ranges of interest.

At present the LV code is oriented toward UNIVAC 1108 computer under EXEC 8 control. To use the code on another computer will require translation and rearrangement of some of the control statements. Such statements, however, should primarily be confined to file handling and I/O functions which tend to be machine oriented, and would most likely require local programmer attention anyway. Control of the calculational portions of the program are relatively machine-independent. The source language is UNIVAC FORTRAN V, with liberal use of comment statements to aid in the program flow. The Edgewood Arsenal UNIVAC 1108 computer, on which the LV code was originally resident, is a fast-access, mass-storage oriented system. Thus, the current files for LV are FASTRAND-type files; however, because I/O is minimized, tape files would be an efficient substitute.

Finally, it should be noted that the LV code was specifically designed to be flexible, allowing easy change of the parametric forms as required by future data, and creating different outputs as needed. Therefore, updates and future versions of the LV code are anticipated.

d. Documentation: LV Methodology and Code-User's Manual BRL R 1779, April 1975 (Reference 14).

Additional information regarding the application of LV methodology is available in references 183 and 184.

5.6.7 LVAC. Information on this computer model is classified. Refer to volume 4 of this design handbook for the model description under paragraph number 5.1.6.7.

5.6.8 FASTGEN II - FASTGEN II Computer Program

a. Sponsoring Agency: AF Aeronautical Systems Division, Deputy for Development Planning, Mission Analysis Directorate (ASD/XRM, WPAFB, OH)

b. Use: Accepts geometrical model data and produces a series of parallel line penetration descriptions of the target. These descriptions are usually referred to as shot line or line of sight (LOS) data and are used as inputs to fragment or projectile vulnerability assessment programs, such as COVART.

c. Description: FASTGEN II provides a detailed target description by developing detailed item by item listings of the components and air spaces encountered by uniformly distributed parallel rays emanating from any attack aspect and passing through any type of target. The information saved for each component consists of intercept coordinates, entrance and exit obliquity angles, and distance. FASTGEN allows representation of the target components using right truncated cones, spheres, rods, as well as the triangular approximations as used in SHOTGEN. The added bodies allow faster, easier, and more flexible representations of targets than with SHOTGEN. Another program feature is the use of tables of allowable interferences which permit targets to have components interfering with each other without generating errors in shotline processing. This allows quicker target preparation and input by relaxing the accuracies required for modelling closely fitting and irregularly shaped components for which small interferences would not affect the vulnerability usage of the data. Target model envelopes can be specified in the input deck to process only a portion of the target or to eliminate the evaluation of shotlines which cannot intercept target components.

FASTGEN II is coded in ANSI FORTRAN to facilitate operation on a wide variety of computers. The computer program requires approximately 33,000 decimal words of core storage, two random access devices, and nine sequential files of which two normally are magnetic tape devices for permanent data storage. The program can also run SHOTGEN target descriptions as well as those prepared for FASTGEN II. The program outputs are directly compatible with the COVART program and can be easily processed to become compatible with other existing vulnerability programs including VAREA.

d. Documentation: FASTGEN II Target Description Computer Program, January 1980. (Reference 195).

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6. THREAT SYSTEM DESCRIPTION

6.1 Hostile Weapon Systems. All equipment and structures in any airborne weapons system are sensitive to the kill mechanisms resulting from hostile nonnuclear threat interaction with the target system. In manned target systems, the aircrew is also sensitive to the same kill mechanism effects. Assurance that the threats and their contiguous effects are adequately considered in operational systems design where a nonnuclear protection requirement exists, necessitates the definition of those nonnuclear threat characteristics that can have an impact on the system design. The nonnuclear threats addressed in this handbook are conventional ballistic threats and high-energy laser threats. Classified information is presented in volume 4. The potential enemy systems described in this handbook, and the resultant threat effects are those of Communist and Communist-controlled countries.

The deployment and usage of specific weapon systems, which could be a potential target for threat systems, are contingent on operational strategies and tactics. Comparison of operational scenarios with threat deployment strategies show the nonnuclear ballistic threat deployments are variable across the range of operational scenarios. This requires consideration of the system design related to only those threat systems considered to be pertinent to the operational scenario considered. The nonnuclear threat parameters will vary depending on what adversary is involved in the operational encounter.

The gross kill mechanisms with ballistic nonnuclear threats include:

a. Impact and penetration
   (1) Projectiles
   (2) Fragments
   (3) Spallation

b. Incendiary particles (fire initiation)

c. Blast effects
   (1) Overpressure
   (2) Heat

The adversary threat systems are defined in this handbook to be those existing in Communist and Communist-controlled and supplied hostile forces. Their offensive and defensive forces and weapon systems are deployed in predictable combinations for types and levels of hostile actions.

Information concerning the defensive orders of conflict for their threat systems are contained in a number of military documents. Review of that data indicates defensive weapon deployment is contingent upon the specific battle scenario. This data has been reviewed and a set of summary information tabulated for combat scenario versus general types of weapon system encounters. This summary for hostile ballistic weapons is shown in Table 6-I. For design of aircraft systems that are expected to encounter hostile missile systems, refer to ASD-TR-77-16 "Generic Missile Warheads", for preliminary threat characteristics information reference.

TABLE 6-I. Manned target situation, tactical situation.

Threat System	Strategic Strike			Battlefield Strike Staging and Supply		Troop Support		Naval Strike		Recon		
	Alt<500	Alt 500-55K	Alt>55K	Alt<500	Alt 500-55K	Alt<500	Alt 500-55K	Alt<500	Alt 500-55K	Alt<500	Alt 500-55K	Alt 55K-70K
Small Arms												
O 7.62mm	Δ -	- -	- -	Δ -	- -	Δ -	- -	Δ -	- -	Δ -	- -	- -
O 12.7mm	Δ -	- -	- -	Δ -	- -	Δ -	- -	Δ -	- -	Δ -	- -	- -
AAG/AAA												
O 14.5mm ZPU4	Δ -	- -	- -	Δ -		Δ -	- -	Δ -	- -	Δ -	- -	- -
O 23mm GS-H23	- -	- X	- X	- -	- X	- X	X	- -	- X	- -	- X	- -
O 23mm N-23	- -	- X	- X	- -	- X	- X	X	- -	- X	- -	- X	- -
RO 23mm ZSU23	Δ -	Δ -	- -	Δ -	- -	Δ -	- -	Δ -	- -	Δ -	- -	- -
O 30mm	- X	- X	- X	- -	- X	- -	- X	- -	- X	- -	- X	- -
RO 37mm	Δ X	Δ X	- X	Δ -	- X	Δ -	- X	Δ -	Δ -	-	- X	- -
RO 57mm	Δ	Δ -	- -	Δ -	- -	Δ	- -	Δ -	Δ -	Δ -	Δ -	- -
R 85mm	Δ	Δ -	- -	- -	- -	- -	- -	- -	- -	Δ -	Δ -	- -
R 100mm	Δ	Δ -	- -	Δ -	- -	- -	- -	- -	- -	Δ -	Δ -	- -
R 130	Δ	Δ -	- -	Δ -	- -	- -	- -	- -	- -	Δ -	Δ -	- -
AAR Aircraft Carried												
OS-3 122	- -	- X	- X	- X	- X	- X	- X	- -	- X	- -	- X	- -
OS-5 57	- -	- X	- X	- X	- X	- X	- X	- -	- X	- -	- X	- -
OS-21 210	- -	- X	- X	- X	- X	- X	- X	- -	- X	- -	- X	- -
OS-24 240	- -	- X	- X	- X	- X	- X	- X	- -	- X	- -	- X	- -
AAM Aircraft Carried												
Alkali AA-1√	- -	- X	- X	- -	- X	- -	- X	- -	- X	X	- X	-
Atoll AA-2 R	- -	- X	- X	- -	- X	- -	- X	- -	- X	X	- X	-
Arab AA-3 *	- -	- X	- X	- -	- X	- -	- X	- -	- X	X	- X	-
Ash AA-4 *	- -	- X	- X	- -	- X	- -	- X	- -	- X	X	- X	-
AA6 *	- -	- X	- X	- -	- X	- -	- X	- -	- X	X	- X	- X
SAM												
SA-1	- -	Δ -	Δ -	- -	- -	- -	- -	- -	- -	- -	Δ -	Δ -
SA-2	- -	Δ -	Δ -	- -	Δ -	- -	Δ -	- -	- -	- -	Δ -	Δ -
SA-3	- -	Δ -	Δ -	- -	Δ -	- -	Δ -	- -	- -	- -	Δ -	- -
SA-4	- -	Δ -	Δ -	- -	Δ -	- -	Δ -	- -	- -	- -	Δ -	- -
SA-5	- -	Δ -	Δ -	- -	- -	- -	- -	- -	- -	- -	Δ -	Δ -
SA-6	Δ -	Δ -	- -	Δ -	Δ -	Δ -	Δ -			Δ -	Δ -	- -
SA-7	Δ -	Δ -	- -	Δ -	Δ	Δ -	Δ -			Δ -	Δ -	- -
SA-8	Δ -	Δ -	- -	Δ -	Δ	Δ -	Δ -			Δ -	Δ -	- -
SA-9	Δ -	Δ -	- -	Δ -	Δ	Δ -	Δ -			Δ -	Δ -	- -
Beamrider							San1	Δ -		Δ -	Δ -	- -
*=IR							San2	- -	Δ -	- -	Δ -	Δ -
O=Optical							San3	Δ -	Δ -	Δ -	Δ -	Δ -
R=Radar							San4	Δ -	- -	Δ -	Δ -	- -
√= Beam Rider							Na/Al					- -

-=Not Applicable
Δ=Ground Based
X=AirBorne platform

6.1.1 Ballistic weapon systems. The adversary nonnuclear threat systems that use ballistic kill mechanism include small arms, antiaircraft artillery (AAA), ground-to-air missiles (SAM), and Naval surface-to-air missiles (SAN). Weapon systems carried on airborne platforms include air-to-air rockets (AAR), air-to-air missiles (AAM), and airborne cannon. The nonexplosive threat kill mechanisms are impact and penetration forces, which generate heat, structural damage stresses, and tissue damage and shock for crew members. The explosive threat damage mechanism uses a high explosive charge triggered by target proximity, impact, command signal, or set time fuzes. The detonation of the high-explosive charge shatters the carrying projectile (warhead) into multiple high-velocity fragments and generates extremely high-pressure blast waves, shock waves, and high temperature thermal environments.

6.1.1.1 Surface systems. The ballistic threats that originate in surface systems can be either nondetonating (projectiles) or detonating (projectile and missile warheads). Nondetonating threats include small arms threat and threats of small caliber AAA. Threat systems using detonation as a terminal effect include AAA systems larger than 14.5-mm and SAMs, SANs and AAMs. The threat system detects, locates and tracks the target, aims the threat in the direction of the target, and provides the locomotion or the initiation of the propelling forces necessary for the threat to reach the vicinity of the target where it will be effective. The ground platforms from which the threat is launched can be categorized as fixed, mobile or waterborne (Naval). The ground-fixed threat system equipment from which the threat is launched toward the target processes characteristics that significantly impact the efficiency of the threat during its flight and terminal phase (impact or detonation). These characteristics are related to the detection, acquisition, tracking, and aiming of the threat and affect its effective threat range and limits, fusing, and terminal accuracy. Incendiary components may be added to both nondetonating and detonating threats during their manufacturing process. This additive enhances the destructive effect of the threat, where flammable materials are contained in the target. The presence of the incendiary component is identified in the threat designator i.e., AP-I, HE-I are armor piercing - incendiary and high-explosive - incendiary, respectively.

6.1.1.1.1 Parameters.

6.1.1.1.1.1 Specific threat system parameters. The specific threat system parameters that affect the threat range and its accuracy in the terminal phases include the following:

a. Threat system to target slant range.

b. Target detection range.

c. Target tracking rate limits.

d. Platform angular operating limits and arming accuracy.

e. Threat launch velocity, i.e., for guns-muzzle velocity.

f. Brightness, light level, or illumination for day vs night

g. Terminal guidance mode.

6.1.1.1.1.2 Environmental parameters. Environmental parameters that affect the terminal threat efficiency include air density, wind velocities, wind direction, visibility, cloud cover and moisture. Intrinsic projectile and fragment threat parameters that affect its flight accuracy and terminal efficiency include:

a. Initial velocity

b. Ballistic drag - (aerodynamic shape)

c. Stability

d. Projectile weight

e. Ogive design (penetration capability)

f. Projectile material strength properties

6.1.1.1.1.3 Design and construction parameters. Several design and construction parameters that affect the terminal efficiency of the detonating threat include:

a. Method of detonation initiation

b. Detonation delay times

c. Weight size and shape of primary HE charge

d. Type of HE

e. Weight and thickness of warhead casing

f. Case scoring

g. Terminal guidance mode

6.1.1.1.1.4 Ballistic parameters. Pure ballistic factors affecting the efficiency are:

a. Warhead drag characteristics prior to detonation

b. Fragment shape, weight, drag characteristics, and peak velocities after detonation

6.1.1.1.2 Small arms. Small arms are defined as weapons which fire projectiles up to and including 14.5 mm in size. The 14.5 mm weapons have in some publications, been considered to be antiaircraft artillery threats. In this handbook the 14.5 mm threat will be considered to be small arms and appropriately cross-referenced in paragraph 6.1.1.1.3 antiaircraft artillery. A general greakdown can be made as follows:

a. Hand held: pistols

b. Shoulder fired: submachine guns, carbines, rifles, assault rifles

c. Mounted: company machine guns, light machine guns, heavy antiaircraft machine guns, small-caliber antiaircraft machine guns for land-based and Naval use.

6.1.1.1.2.1 Sizes. Standard weapon calibers defined as small arms and available in Communist Bloc countries are, 7.62 mm, 12.7 mm, and 14.5 mm. Weapon sizes in the Communist Bloc countries are limited in the interest of standardization and logistical problems.

6.1.1.1.2.2 Types. The types of small arms weapons available are as shown in Table 6-II, with capabilities for each category shown in Table 6-III.

TABLE 6-II. Small-arms weapons and sizes.

Type	7.62 mm	12.7 mm	14.5 mm
Submachine guns	X		
Carbines	X		
Assault rifles	X		
Company machine guns	X		
Light machine guns	X		
Heavy machine guns	X		
Heavy antiaircraft machine guns		X	X
Naval installations, i.e., ships		X	X

a. Submachine Guns - Submachine guns use the same ammunition as 7.62-mm pistols, although tracer-type ammunition may also be used. These weapons, since they are heavier and shoulder fired, have two to four times the effective range of pistols. Typical 7.62-mm submachine guns include the 1941 Shpagin (PPSh), type 50, and 1943 (PPS). These are the only shoulder-fired weapons that use pistol ammunition. All 7.62-mm weapons, with the exception of pistols, submachine guns, and heavy machine guns, are chambered to accept one of two 7.62-mm cartridge configurations - intermediate (INT) or standard (STD). The intermediate is somewhat smaller than the standard with respect to weight and is used with lighter 7.62-mm guns.

b. Carbines - Carbines in general use are chambered for 7.62-mm intermediate or 7.62-mm standard ammunition. Those chambered for 7.62-mm intermediate include the SKS and type 56 carbines. Those chambered for 7.62-mm standard ammunition include the M1944 and the type 53 carbine. These weapons may be used against slow and low-flying aircraft.

c. Assault Rifles - Assault rifles, being designed for lightness and portability, are chambered only for the 7.62-mm intermediate ammunition. This weapon has a higher practical firing rate, due to larger size magazines. This is considered a threat to slow and low-flying aircraft. Models typical of this weapon are the AKM AK-47.

TABLE 6-III. Summary of small-arms weapon capabilities.

Weapon System	Weight Unloaded (lb)	Max Effective* Range (meters)	Practical Rate of Fire	Operation Mode	Ammo Type	Magazine Capacity (rounds)	Mount for Firing	Sighting	Typical Muzzle Velocity (fps)
Submachine Guns									
7.62 mm type 50	8.0	200	15-200	Selective	B, BT	35	(Shoulder-fired)	Mech	1,908
7.62 mm 1943 (PPS)	7.5	200	120	Automatic	B, BT	35	(Shoulder-fired)	Mech	1,640
7.62 mm 1941 (PPSh)	9.75	300	120	Selective	B, BT	71***	(Shoulder-fired)	Mech	1,650
Carbines (STD)									
7.62 mm M1944	8.6	500		Manual	B, BT API, IT	5	(Shoulder-fired)	Mech	2,690
7.62 mm Type 53	8.6	500		Manual	B, BT	5	(Shoulder-fired)	Mech	2,658
Assault Rifles (Inf)									
7.62 mm AKM	6.93	500		Selective	B, BT API, IT	30	(Shoulder-fired)	Mech	2,329
7.62 mm AK47	9.48	500,		Selective	B, BT API IT	30	(Shoulder-fired)	Mech	2,329
Light Machine Gun (INT)									
7.62 mm RPK	10.8	500	150	Selective	B, BT API IT	75	Bipod	Mech	2,411
Light Machine Gun (STD)									
7.62 mm DPM	20.0	800	80	Automatic	B, BT API IT	47	Bipod	Mech	2,766
Company Machine Gun (STD)									
7.62 mm RP-46	29.75	1,000	230-250	Automatic	B, BT IT API, AP	250	Bipod	Mech	2,736
Heavy Machine Gun									
7.62 mm SGM	29.8	1,000		Automatic	B, BT IT API, AP	250.	Tripod, Wheel Carriage	Mech	2,625
Heavy AA Machine Gun									
12.7 mm 38/46 DSHK	347**	1,000	80	Automatic	API-T API	50	Single ground	Mech	2,822
12.7 mm QUAD	1331**	1,000	80/gun	Automatic	API-T API	50/gun	Quad carriage	Mech	2,766
Heavy AAMG ZPU									
14.5 mm model ZPU-2	838**		150/gun	Automatic	API-T API	150/gun	Dual Wheeled and ground	Mech/Opt	3,281
14.5 mm model ZPU-4	4400**		150/gun	Automatic	API-T API	150/gun	Quad Wheeled and ground	Mech/Opt	3,281

B = ball; AP = armor-piercing; I = incendiary; T = tracer

*Effective ground combat range is used where effective AA slant range is not applicable.

**Includes mount.

***71 Drum, 35 Box

d. Light Machine Guns - The lightest 7.62-mm mounted machine gun is chambered for the intermediate and standard ammunition. These guns are bipod-mounted, have a good practical rate of fire and are always a threat to slow and low-flying aircraft within range. Typical of this weapon are the DPM and RPK light machine guns using standard ammunition.

e. Company Machine Guns - These guns may be heavier than the light machine guns and have a larger capacity as well. They are bipod-mounted guns. These guns are chambered for the 7.62-mm standard ammunition round. Typical weapon is the RP-46.

f. Heavy Machine Gun - This is a battalion-level gun, mounted on a tripod or a wheeled carriage and chambered for 7.62-mm standard ammunition. Typical is the SGM gun.

g. 12.7 MM Antiaircraft Heavy Machine Gun - The antiaircraft function of this gun is becoming obsolete, although it is still used against aircraft by guerrilla and irregular forces. This weapon is effective against slow and low-flying aircraft. Typical are the model 28/46DSHK and the Quad 12.7 antiaircraft heavy machine gun.

h. 14.5-MM Heavy Antiaircraft Machine Gun - This weapon is a standard antiaircraft defense for Communist Bloc countries in single and multiple carriage. This weapon is quite effective against slow and low-flying aircraft and also effective against aircraft flying at moderate subsonic speeds. Typical are the Dual ZPU-2 and the Quad ZPU-4.

6.1.1.1.3 Antiaircraft artillery (AAA). Antiaircraft artillery are found in land-fixed and mobile installation and aboard ships as Naval weapons. Weapon bore sizes range from 14.5 mm up to and including 130 mm. Weapons through 57 mm are found in land mobile systems. Larger weapons are located in fixed installations. Weapons larger than 85 mm are deployed in limited number with frequency of deployment decreasing. A summary of the installation options for the various weapons are shown in table 6-IV.

TABLE 6-IV. AAA installation options.

Bore Sizes (MM)	Land Mobile	Land Fixed	Naval
* 14.5	X		
23	X		
37	X		X
57	X	X	X
85		X	X
100		X	
130		X	

*The 14.5 mm weapon may be categorized as either a small-arm or antiaircraft artillery

The descriptive data for antiaircraft artillery threat systems are classified and are located in Volume 4. Typical threat system data found therein include deployment usage and physical characteristics. Threat information includes flight and terminal ballistics data.

6.1.1.1.4 Surface-To-Air Missile.

6.1.1.1.4.1 Land Based. Land-based SAM's are found in both fixed and mobile installations. Shown in table 6-V are the installation options for land based SAM's. Almost all information on land-based surface-to-air missiles is classified. The descriptive data will be found in Volume 4 of this handbook. Additional information is also contained in Reference 15 and 166.

TABLE 6-V. SAM installation options.

	Land Mobile	Land Fixed
SA1		X
SA2	X	
SA3	X	
SA4	X	
SA5		X
SA6	X	
SA7	X	
SA8	X	
SA9	X	
SA10	X	
SA11	X	

6.1.1.1.4.2 Sea based. Sea-based surface-to-air missiles are found installed on various types of ships and are mobile only in the sense of the mobility of the ship on which installed. Descriptive data for these threat system are classified and are to be found in Volume 4. Included are the following threat systems:

SA-N-1
SA-N-2
SA-N-3
SA-N-4

6.1.1.1.5 Airborne systems. Airborne threat systems are defined as those that use air vehicles as firing or launching platforms. These airborne systems may be classified by their combat roles as follows:

Weapon Platform	Role
Fighter/interceptor Fighter bomber	Strategic defense
Ground support aircraft Tactical fighter Attack bombers Helicopters	Ground troop support
Bomber	Offense

The airborne threat systems carried by these aircraft include cannon, rockets and missiles. The details of threat complements, and description of airborne threat systems are classified and are contained in volume 4, of this handbook.

These threat systems include:

Airborne Rockets	Airborne Missiles	Airborne Cannon
S-3	AA-1	23 mm
S-5	AA-2	30 mm
S-21	AA-3	37 mm
S-24	AA-4	
	AA-6	
	AA-7	
	AA-8	

6.1.2 High-energy laser weapons. In the advanced weaponry field, a new threat system is evolving that is of considerable concern to military system survivability. This is the high-energy laser (HEL) weapon. The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. The basic damage mechanism for these weapons is the concentration of a high level of heat energy, as a beam, on a target for a relatively short duration. The descriptions of postulated hostile high-energy laser systems are highly classified and restricted. Such information is not considered appropriate for inclusion in this design handbook. Any information on the threat system will be supplied by the military on a need-to-know basis for each specific program.

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6.2 Terminal weapon effect characteristics - The damage produced by the threat is the result of kinetic energy transferred into the target during the terminal phase. These kinetic energies are threat inherent and related, for projectiles and fragments, to mass and velocity, i.e., $KE = 1/2\ mv^2$. Designers use both passive and active methods to improve projectile damage capability. Size limitations at present preclude the use of high-explosive fillers and fuzing mechanisms in small arms projectiles. Thus, active small-arms projectiles are limited to incendiary and tracer fillers. The function of incendiary mixtures which develop thermal kinetic energies is to generate high-temperature particles which, in the presence of flammable materials, will initiate fires. Tracer mixtures are sometimes added to aid in aim accuracy improvement by burning with visible light radiation through the flight of the projectile. Larger projectiles may contain a high-explosive filler. In this configuration, the projectile is referred to as a warhead. This high-explosive filler is the source of a large amount of energy in the form of stored potential energy. Upon detonation this potential energy is converted into thermal and high-pressure energies. The function of the high pressure energy is to cause (1) structural breakup of the threat casing and acceleration of the breakup residue (fragments) and (2) generation of overpressure and shock waves that generate abnormal stresses in the target resulting in structural damage. Most projectile and warhead threats have auxiliary identifiers that denote their specific function. The primary ones for aircraft targets are as follows:

a. Ball (B) - a passive projectile with a relatively soft metal interior (core) (used against personnel and lightly armored targets).

b. Armor-piercing (AP) - a passive projectile with a hard, tough core which has a shape designed to maximize its penetrability.

c. Tracer (T) - an active bright-burning subelement of the core, always used with a primary core, which may be either ball or armor-piercing material.

d. Incendiary (I) - a thermally active projectile filler used with a passive core, either ball or armor-piercing material. The active filler is located in front of the passive core. The passive core penetrates the exterior structure, driving and shattering the incendiary filler ahead into the interior of the target. Incendiary fillers are also used as an adjunct to high-explosive fillers with the spread of the thermally active ingredients done by the explosive detonation.

e. High-explosive (HE) - an active filler used in place of a passive core and detonated using various fuzing techniques to:
   (1) Cause fragmentation of the projectile and accelerate the resulting fragments to high velocities
   (2) Generate blast and shock phenomena whose purpose is to overstress and breakup structural elements in the vicinity of the explosion.
   (3) Generate thermal phenomena whose purpose is to initiate fires in flammable materials.

Threat physical characteristics and characteristics related to the projectile and missile threat terminal phases can be translated using vulnerability analysis techniques into target damage potentials and target protection requirements. These assessment and analysis techniques are found in volume 2.

6.2.1 Projectiles

6.2.1.1 Small arms Projectiles. A summary of terminal phase threat characteristics for the various small-arms ammunition used by hostile forces are presented in volume 2. Data with more detail are classified and shown in volume 4. The impact velocity of the small-arms threat at impact with the target determines, along with the weight of projectile, the energy available to produce damage. Range-Velocity curves for characteristic small arms projectiles are shown in Figure 6-1. This can also be determined from knowing the muzzle velocity, the slant range from gun to target and the ballistic drag of the projectile. Penetration characteristics are determined from application of the mathematical methods presented in volume 2.

6.2.2 Missiles and rockets.

6.2.2.1 Surface-to-air missiles. The physical and terminal phase ballistic characteristics of SAM and SAN are classified. This data is contained in volume 4 and includes the following threats:

Land-based	Sea-based
SA1	SA-N-1
SA2	SA-N-2
SA3	SA-N-3
SA4	SA-N-4
SA5	
SA6	
SA7	
SA8	
SA9	
SA10	
SA11	

6.2.2.2 Airborne cannon and antiaircraft artillery projectiles (gun systems). Projectile threats originating from gun systems with caliber sizes larger than small arms, i.e., greater than 14.5 mm, are seen in airborne guns (cannon) and in surface based guns (antiaircraft artillery). Terminal phase damage mechanisms include projectile penetration incendiary action and high-explosive fragmentation and blast. A listing of the various gun system threats are presented in volume 2. The physical and terminal phase ballistic characteristics are, in general, classified and are contained in volume 4.

6.2.2.3 Missile warheads. Warheads included are associated with airborne rockets and missiles and surface-to-air missiles (which may be ground or ship-launched). The identification of these missiles is presented in paragraph 5.2.1.1. The terminal characteristics of these weapons are classified and are contained in volume 4.

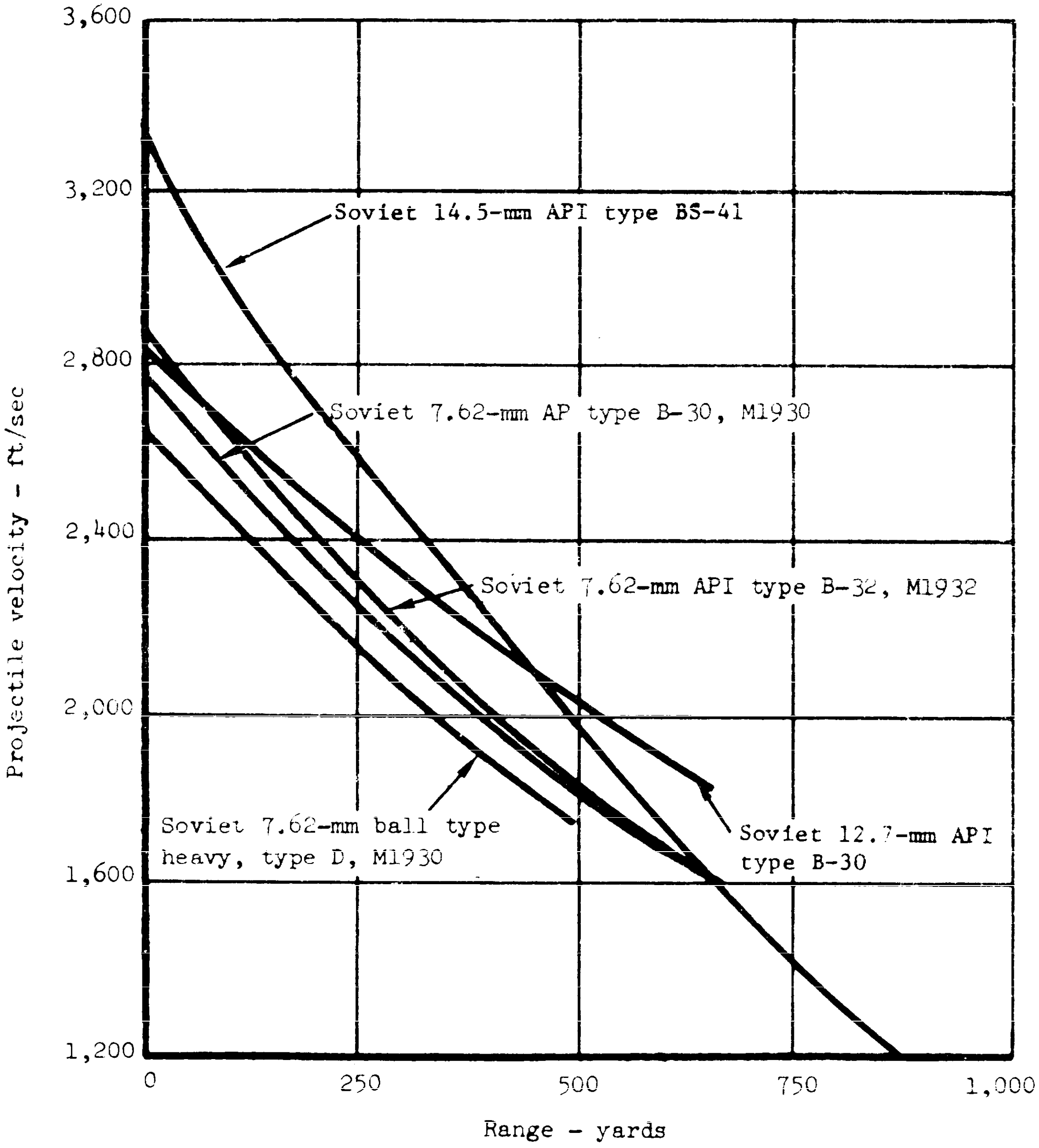

FIGURE 6-1. Range versus velocity curves.

6.2.3 High energy laser weapon effects. HEL weapon effects are highly dependent on the characteristics of the propagation medium between target and weapon which, in the case of the atmosphere, are in turn dependent on a number of linear properties including humidity, aerosol content, and turbulence and the nonlinear effects of thermal blooming and possibly kinetic cooling. Thermal blooming (the degradation due to atmospheric heating) can be mitigated by beam motion or slewing, while kinetic cooling affects only CO_2 HEL propagation and is generally not significant at low altitudes. HEL weapon effects can be defined in terms of beam duration, size, and intensity incident on the target. Beam duration on the target is largely determined by the engagement scenario and firing doctrine, while the target plane beam size and intensity are primarily functions of HEL weapon and propagation medium characteristics. HEL weapon effects are sensitive to many system parameters other than those of the propagation medium. These include HEL weapon characteristics, engagement scenario, firing doctrine and geometry, and target characteristics including countermeasures. In general a detailed engagement simulation model, such as ESP-III (reference 4), is required to perform a sensitivity analysis and to determine HEL weapon system requirements and effectiveness.

6.2.3.1 Propagation medium. The interrelationship between HEL weapon systems and propagation medium characteristics and the resulting target plane beam intensity and size is complex and best illustrated using a computerized model, such as COMBO, which was developed by the Air Force Weapons Laboratory (reference 24). This model incorporates the major phenomena important to the propagation of high-power, continuous wave laser beams and calculates the intensity and size of a focused or collimated laser beam by dividing the propagation path into a large number of increments and examining the atmosphere's effect within each increment. COMBO program inputs are summarized in volume 4.

6.2.4 Low energy laser weapons effects. Low energy lasers may also be a potential threat to an air vehicle system. Sensitive items, (i.e., aircrew eyes, infrared detectors, T.V. scanners, etc.) may be permanently or temporarily "blinded" by the low energy laser beam.

7. SURVIVABILITY ASSESSMENT

7.1 General. As indicated by the definition of survivability, it is the capability of an aircraft system to avoid and to withstand a manmade hostile environment without sustaining an impairment of its ability to accomplish its designated missions. The capability of the aircraft to avoid hostile weapon systems is affected by a large number of variables. Each of these must be considered and evaluated in a survivability assessment. These are defined as combat encounter parameters and are listed in a subparagraph of this section. Also included is a listing and brief description of a number of survivability assessment computer programs endorsed by the JTCG/AS as acceptable for use in evaluation of military aircraft. Survivability assessments are conducted for a variety of combat mission conditions. These range from single-shot kill probabilities to entire mission scenarios. Each are used to provide the military and/or the aircraft system designer with an evaluation of the effectiveness of that particular system in a given combat situation. The majority of survivability assessment methods and procedures descriptions are unclassified. This information is presented in this section. All classified information on the subject is contained in volume 4 of this publication. It is referenced in the text of this section and identified in the same paragraph numbering system as the unclassified section.

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7.2 Combat encounter parameters. Survivability assessments of military aircraft systems require careful consideration of all the variables that can have an effect upon the outcome of an encounter with a hostile weapon complex. The capabilities of the hostile weapon systems must be established in relationship to the encounter conditions. The basic elements of the hostile weapon system capabilities, for both surface based and airborne systems, are:

a. Target Detection/Acquisition/Identification
   (1) Visual
   (2) Electro-optical
   (3) Radar
   (4) Infrared
   (5) Aural
   (6) Electronic Warfare Support Measures (ESM)

b. Target Tracking
   (1) Visual
   (2) Electro-optical
   (3) Radar
   (4) Infrared

c. Threat Launch envelope
   (1) Position
   (2) Range
   (3) Velocity
   (4) Aspect Angle

d. Terminal Guidance
   (1) Radar
   (2) Infrared
   (3) Electro-optical

e. Weapon Fuzing
   (1) Proximity
   (2) Contact
   (3) Command
   (4) Time

f. Weapon Effects
   (1) Penetrators
   (2) Blast
   (3) Incendiaries

7.2.1 Terrain parameters. The terrain characteristics of the combat encounter site can have a significant contribution to the survivability capability of an aircraft system. This is especially significant for attack type aircraft, either fixed or rotary wing, where terrain masking is used for "sneak-and-peak" type of tactics. The basic parameters that should be evaluated are:

a. Surface Contours
   (1) Hills
   (2) Flat lands
   (3) Sea Surface

b. Vegetation
  (1) Brush
  (2) Trees
  (3) Jungles

c. Man-made Features
  (1) Roads
  (2) Wires, towers, dykes
  (3) Cities, built-up areas

7.2.2 Climatic conditions. The climatic conditions can have an effect upon the capability of a hostile threat system to detect and track an aircraft system. Conversely, it also affects the capability of an aircraft system to detect, identify and avoid or destroy a hostile threat system. The major environmental parameters that can be of concern in a survivability assessment are:

a. Light (day/night)

b. Cloudiness

c. Humidity level

d. Precipitation

e. Winds

f. Temperature

g. Visibility

7.2.3 Aircraft system parameters. For an aircraft system, there are many of its characteristics that can significantly affect its probability of survival (P_s) in a combat encounter. Each must be considered in proper relationship to the total encounter condition. These parameters are:

a. Detectables
  (1) Visual
  (2) Radar
  (3) Infrared
  (4) Aural
  (5) Electronic emissions

b. Performance
  (1) Speed, altitude
  (2) Maneuverability (agility)
  (3) Acceleration/deceleration
  (4) Handling qualities

c. Threat Countermeasures
  (1) ECM
  (2) Chaff/Aerosols/Flares
  (3) Decoys

d. Lethal Defense
  (1) Guns
  (2) Missiles
  (3) Rockets

e. Vulnerability
  (1) Flight essential components
  (2) Mission essential components

f. Crew Performance
  (1) Endurance
  (2) Reaction time
  (3) Task loading

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7.3 Survivability assessment methods/procedures. In this section, the basic survivability assessment analytical methods are described. They include the encounter survival assessments for single-shot and multiple-shot conditions. The two basic encounter categories are engagements with surface based (ground or water) hostile systems, and with airborne hostile weapon systems. Each of these may employ gun, missile, or high-energy laser weapons. The major portion of survivability assessment methodology to date has been concerned with gun systems.

7.3.1 Encounter survival. A hostile weapon system's effectiveness is measured by its ability to defeat a target. For any type of antiaircraft system, a number of essential functions must be performed in sequence during an encounter for the system to be effective. The omission of any one step could seriously degrade or completely nullify the effectiveness of the system. The essential steps are summarized in Figure 7-1. First, a radar or visual line-of-sight to the target must exist before any engagement can take place. Next, the target aircraft must be detected, recognized, and identified as an enemy. Projectile or missile launch can then occur given that the target is within the (1) range, (2) angular-rate limitations, and the (3) maneuverability limits of the defense weapon. Successful guidance to the target is a function of the defense system type, the launched projectile or missile associated with the defense system (i.e., free flight projectile, radar or IR guided, etc), and kinetic aspects of the target. The degree of sophistication employed in an analysis of defense system effectiveness depends upon the intended use of the results and the confidence level placed upon the inputs. Realistic "real-world" results require the inclusion of many parameters. This necessarily involves a dynamic simulation of the defense system and target aircraft encounter. Operational constraints such as aircraft maneuvers, weather conditions, mass penetrations, intelligence data, and terrain variances must be simulated. Based on these considerations the probability of target kill per defense weapon encounter, or conversely probability of survival per encounter, can be obtained as a function of the vulnerable areas, or blast and fragmentation envelopes of the target, depending upon the kill mechanisms of the particular weapon and weapon system accuracy (i.e., dispersion, miss distance). The probability of survival per encounter ($P_{S/E}$) can be determined as follows:

$$P_{S/E} = (P_{LOS})(P_D)(P_L)(P_G)(P_{DET}) \left[\overset{n}{\pi} \quad (1-P_{SSK}) \right]$$

where:

P_{LOS} = Probability of line-of-sight to the target

P_D = Probability of detection, given line-of-sight

P_L = Probability of launch or firing, given detection

P_G = Probability to successful guidance, given launch or firing

P_{DET} = Probability of warhead detonation (fuzed warheads), given successful guidance

n = Number of shots fired during a pass

P_{SSK} = Single-shot kill probability

The equation above does not explicitly include terms for degradation due to ECM which can affect both the probability that a launch or firing will occur, as well as miss distance or dispersion, σ , and single-shot kill probability given launch or firing.

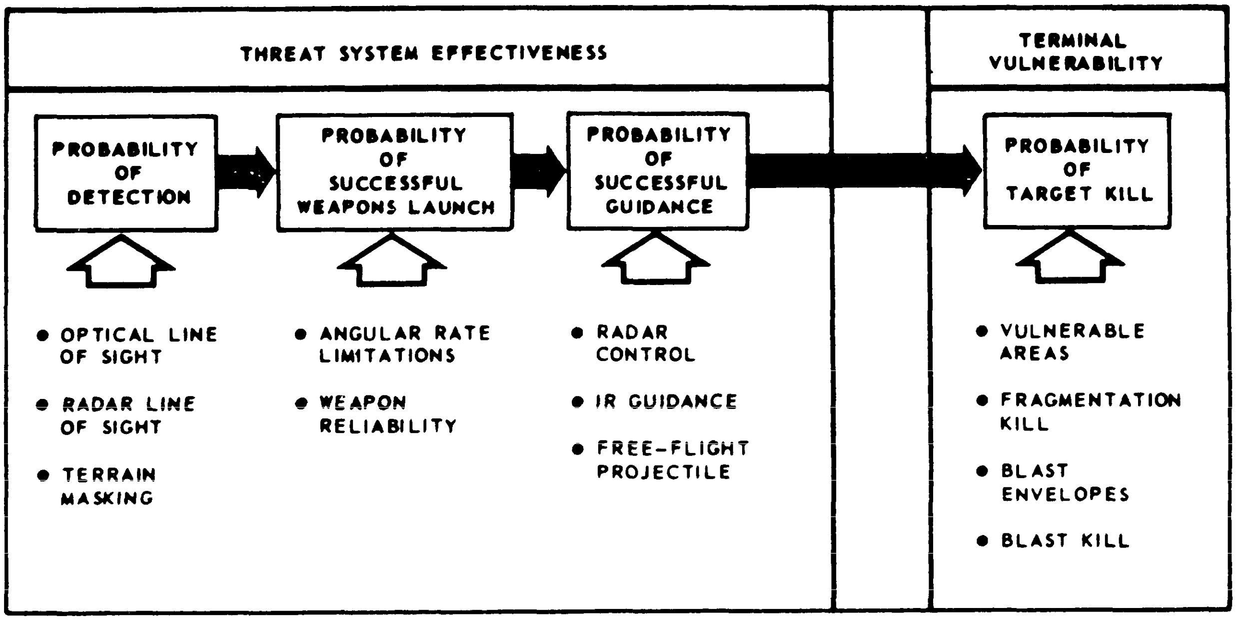


FIGURE 7-1. Encounter sequence.

7.3.1.1 Single-shot kill probability. Analytical methods are used for estimating the single-shot kill probabilities, P_{SSK}, for free-flight contact fuzed rounds and for externally detonated rounds. For externally detonated rounds (projectiles or warheads) which use blast, fragments, or both as target kill mechanisms, the methods are based on the procedures defined in Reference 5. It is suggested that this document be used for a more general treatment of the methodology.

7.3.1.1.1 Single-shot probability by contact fuzed projectiles. The method for calculation of single-shot kill probability for a contact fuzed high-explosive projectile is contained in volume 4.

7.3.1.1.2 Single-shot kill probability by externally detonated warheads. The method used for estimating single-shot kill probabilities for externally detonated rounds assumes that the intercepting missile approaches the target along a trajectory parallel to the target velocity vector. The distribution of warhead burst points is described by a trivariate normal distribution. The value of P_{SSK} thus obtained is a mean target kill probability for a single weapon encounter in which it is assumed that all components of the weapon system have functioned as designed to deliver the warhead to the vicinity of the target. The mean value of P_{SSK} is obtained as the statistical sum of the kill probability due to blast (P_b) and the kill probability due to fragments (P_f) considered as independent events. That is,

$$P_{SSK} = 1-(1-P_b)(1-P_f)$$

A method for calculating P_f is presented next and this is followed by a method for computing P_b.

To facilitate integration, the region, V, can be subdivided into three regions V_1, V_2, and V_3 so that

$$P_f = P_f(V_1) + P_f(V_2) + P_f(V_3)$$

The areas (V_i) are determined by the intersection of the blast vulnerability envelope and the half-cones bounding the fragment vulnerable volume. The integrals over these regions are evaluated by means of the expressions presented in figures 7-2, 7-3, and 7-4.

7.3.1.1.2.1 Warhead burst point distribution. A coordinate system is defined about the target as follows: the target files in the X_1 direction, X_2 is aloft, and X_3 to the pilot's right. The origin of the system is located along the target longitudinal axis; the target center of gravity (CG) will be used in this presentation. The warhead burst points are assumed to be normally distributed along each of the three axes with variances $\sigma X_1{}^2$, $\sigma X_2{}^2$, $\sigma X_3{}^2$, and the mean at the origin or aircraft CG. Errors in the X_1 direction will be referred to as range errors ($\sigma_{X_1}{}^2 = \sigma_f{}^2$) which are principally due to fuzing uncertainties. The distribution of bursts along X_2 and X_3 are denoted as guidance errors and can generally be assumed equal ($\sigma X_2{}^2 = \sigma X_3{}^2 = \sigma_g{}^2$) or else some average value assigned. For example,

$$\text{Guidance Error } \sigma_g^2 = \frac{1}{2}\left(\sigma_{X_2}^2 + \sigma_{X_3}^2\right)$$

or

$$\sigma_g^2 = \sigma_{X_2}^2 + \sigma_{X_3}^2$$

The miss distance $r = \sqrt{X_2{}^2 + X_3{}^2}$ is assumed to be Rayleigh distributed, (Reference 173), where r is defined as the distance of closest approach between warhead and target centers of gravity. The Rayleigh distribution function is given by

$$f(r) = \frac{r}{\sigma_g^2} \exp\left[\frac{-r^2}{2\sigma_g^2}\right] \quad (r \geqslant 0)$$

It represents the distribution of radial error in a plane where the errors in each axis are independent and normally distributed with equal variance and zero mean.

$$P_f(V_1) = \frac{Pg}{\sigma\sqrt{A_1+B}} \exp\left[-\frac{K_1}{2}\right] \int_{-\infty}^{L(A_1U_1K_1)} \frac{1}{\sqrt{2\pi}} \exp\left[-\frac{w^2}{2}\right] dw$$

where:

$$Pg = \frac{\alpha^2}{\alpha^2 + \sigma g^2}$$

$$A_1 = \frac{\tan^2 \phi 1}{\sigma g^2 \; Pg} + \frac{1}{\alpha^2}$$

$$B = \frac{1}{\sigma_f{}^2}$$

$$U_1 = \frac{A_1 h_1}{A_1 + B}$$

$$K_1 = \frac{h_1{}^2 \; A_1 \; B}{A_1 + B}$$

$$L(A_1U_1K_1) = \sqrt{A_1 + B}\,(K_1 - U_1)$$

K_1 = y coordinate of the intersection of the blast vulnerability envelope and V_1

h_1 = y coordinate of the center of vulnerability (CV)

α^2 = 1.25 NA_v

FIGURE 7-2. Expressions for evaluating $P_f(V_1)$.

$$P_f(V_2) = \frac{Pg}{\sigma_f\sqrt{A_2+B}} \exp\left[-\frac{K_2}{2}\right] \int_{L(A_1U_1K_1)}^{L(A_2U_2K_2)} \frac{1}{\sqrt{2\pi}} \exp\left[-\frac{w^2}{2}\right] dw$$

where:

$$Pg = \frac{\alpha^2}{\alpha^2 + \sigma_g^2}$$

$$A_2 = \frac{\tan^2 \phi 2}{\sigma g^2 \ Pg} + \frac{1}{\alpha 2}$$

$$B = \frac{1}{\sigma_f^2}$$

$$U_2 = \frac{A_2 h_1}{A_2 + B}$$

$$K_2 = \frac{h_1^2 A_2 B}{A_2 + B}$$

$$L(A_2U_2K_2) = \sqrt{A_2 + B}\,(K_2 - U_2)$$

K_2 = y coordinate of the intersection of the blast vulnerability envelope and V_3

h_1 = y coordinate of the center of vulnerability (CV)

α^2 = 1.25 NA_v

FIGURE 7-3. Expressions for evaluating $P_f(V_2)$.

$$P_f(V_3) = \frac{Pg}{\sigma_f\sqrt{A_3+B}} \exp\left[-\frac{K_3}{2}\right] \int_{L(A_2U_2K_2)}^{L(A_3U_3K_3)} \exp\left[-\frac{w^2}{2}\right] dw$$

where

$$Pg = \frac{a^2}{a^2+\sigma_g^2}$$

$$A_3 = \frac{\tan^2\phi_3}{\sigma_g^2\ Pg} + \frac{1}{a^2}$$

$$B = \frac{1}{\sigma_f^2}$$

$$U_3 = \frac{h_1 + h_2(a^2A_3 - 1)}{a^2(A_3+B)}$$

$$K_3 = \frac{A_3 a^2\left[(h_1-h_2)^2 + B\ a^2h_2^2\right] + B\ a^2(h_1^2-h_2^2) - (h_1-h_2)^2}{a^4(A_3+B)}$$

$$L(A_3U_3K_1) = \sqrt{A_3+B}\ (K_1 - U_3)$$

$$L(A_3U_3K_2) = \sqrt{A_3+B}\ (K_2 - U_3)$$

K_1 : coordinate of the intersection of the blast vulnerability and V_1

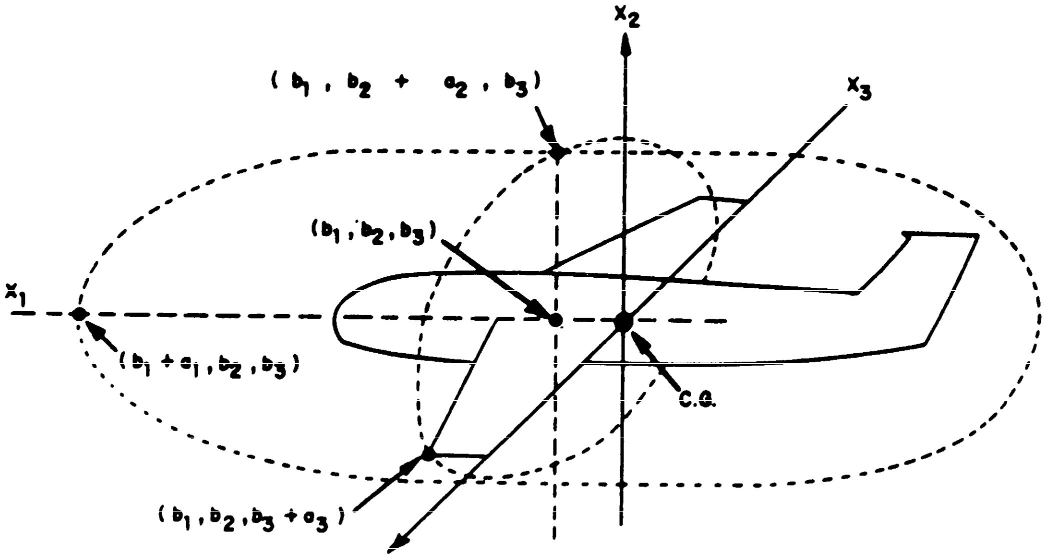
h_1 : y coordinate of the center of vulnerability (CV)

h_2 : y intercept of the line approximating the boundary between the blast vulnerability envelope and V_2

$\tan\phi_3$: slope of the line approximating the boundary between the blast vulnerability envelope and V_2

FIGURE 7-4. Expressions for evaluating $P_f(V_3)$.

7.3.1.1.2.2 Blast vulnerability. Blast vulnerability data express target kill as a function of charge weight, altitude, and distance of burst from various stations on the target. Based on this information, a vulnerable envelope can be defined about the target. The probability of blast kill (P_b) is practically 1.0 for a burst occurring within the envelope and outside the envelope it is 0. For evaluation purposes, the blast envelope can be approximated by one or more ellipsoids. The number of ellipsoids used will depend on the accuracy desired. The shape of the envelope will approximate the actual shape of the target for small warheads and grow to a spherical volume for the larger warheads. The ellipsoids considered will be nonintersecting so that the probabilities of bursting in the individual ellipsoids can be summed to obtain the total chance of blast kill, P_b. Figure 7-5 shows an example of a single approximating blast ellipsoid and its describing equation.



$$\frac{(x_1 - b_1)^2}{a_1^2} + \frac{(x_2 - b_2)^2}{a_2^2} + \frac{(x_3 - b_3)^2}{a_3^2} = 1 = \sum_{i=1}^{3} \frac{(x_i - b_i)^2}{a_i^2}$$

FIGURE 7-5. Blast vulnerability ellipsoid approximation.

7.3.1.1.2.3 Blast kills. The probability of a blast kill (P_b) is equivalent to the probability of a warhead burst within one of the k nonintersecting ellipsoids which define the vulnerable blast envelope of the target. This may be expressed mathematically for the jth ellipsoid as

$$P_{b_j} = P_r \left[\sum_{i=1}^{3} \frac{\left(X_i - b_{i_j}\right)^2}{\left(a_{i_j}\right)^2} \leqslant 1 \right]$$

and P_{b_j} is summed over the k ellipsoids to yield P_b, i.e., $P_b = \sum_{i}^{k} = 1\ P_{b_j}$. A method for evaluating the probability of a warhead bursting within one of the k ellipsoids is summarized below:

For the j^{th} ellipsoid

$$P_{b_j} = P_r \left[\sum_{i=1}^{3} \frac{(X_i - b_i)^2}{a_i^2} < 1 \right] = P_r\ (Q \leqslant 1) = P_r (t \leqslant t_o)$$

where:

t is approximately normally distributed, N(0, 1)

and

$$Q = \sum_{i=1}^{3} V_i\ (U_i + A_i)^2$$

$$U_i = \frac{X_i}{\sigma x_i}$$

$$A_i = \frac{b_i}{\sigma x_i}$$

$$V_i = \frac{\sigma x_i^2}{a_i^2}$$

$$t_o = \frac{\sqrt[3]{1/m} - (1-v/9m^2)}{\sqrt{v/9m^2}}$$

$$m = E(Q) = \sum_{i=1}^{3} V_i(1 + A_i)^2$$

$$V = E(Q-m)^2 = 2 \sum_{i=1}^{3} V_i^2 (1 + 2A_i^2)$$

Required inputs are the parameters which define the blast ellipsoid (b_i and a_i) and the warhead variances in range and guidance errors (σf and σ_g^2). By means of transformation parameters, the value of P_{b_j} may be evaluated as the area under the normal distribution curve from $-\infty$ to t_o. That is,

$$P_{b_j} = P_r\,(t \leq t_o) = \int_{-\infty}^{t_o} \frac{1}{\sqrt{2\pi\sigma}} (-t^2/2\sigma^2)dt$$

where:

$$t_o = \frac{(1/m)^{1/3} - \left(1 - \frac{v}{9m^2}\right)}{\left(\frac{v}{9m^2}\right)^{1/2}}$$

$$m = \sum_{i=1}^{3} V_i(1 + A_i)^2$$

$$v = 2 \sum_{i=1}^{3} V_i^2 \left(1 + 2A_i^2\right)$$

$$A_i = \frac{b_i}{\sigma_{X_i}} \quad (i = 1, 2, 3)$$

$$V_i = \frac{\sigma^2_{X_i}}{a_i^2} \quad (i = 1, 2, 3)$$

An example which illustrates the blast kill methodology is presented in Figure 7-6.

7.3.1.1.2.4 Fragment vulnerability. The target will be defeated by fragments if at least one fragment strikes one of the designated vulnerable areas of the target. For simplicity, these areas are considered grouped into one or more points or centers of vulnerability (CV) centered on the target axis. For any such target grouping, as shown in Figure 7-7. there is an earliest

BLAST ELLIPSOID PARAMETERS:

$b_1 = -6$ ft $\quad a_1 = 29$ ft

$b_2 = 0 \quad a_2 = 3$ ft

$b_3 = 0 \quad a_3 = 2.5$ ft

WARHEAD DISPERSION PARAMETERS:

$\sigma_f = \sigma_{x_1} = 10$ ft

$\sigma_g = \sigma_{x_2} = \sigma_{x_3} = 10$ ft

TRANSFORMATION PARAMETERS:

$$A_i = \left[\frac{b_i}{\sigma_{x_i}}\right] \quad A_1 = \frac{-6}{10} = -0.6 \quad A_2 = 0 \quad A_3 = 0$$

$$V_i = \left[\frac{\sigma_{x_i}{}^2}{a_i{}^2}\right] \quad V_1 = \frac{10^2}{29^2} = 0.119 \quad V_2 = \frac{10^2}{3^2} = 11.1 \quad V_3 = \frac{10^2}{2.5^2} = 16$$

$$m = \sum_{i=1}^{3} V_i(1 + A_i)^2 = 0.119(1 - 0.6)^2 + 11.1(1)^2 + 16(1)^2 = 27.1$$

$$v = 2\sum_{i=1}^{3} V_i{}^2(1 + 2A_i{}^2) = 2(0.119^2(1.72) + 11.1 + 16) = 758$$

$$t_0 = \frac{(1/m)^{1/3} - (1 - v/9m^2)}{(v/9m^2)^{1/2}} = \frac{0.333 - (1 - 00992)}{(0.0992)^{1/2}} = -1.7$$

$$\therefore P_b = P_r\left[t \le t_0\right] = 0.0446$$

Obtained by integration or reference to a table of areas under the standard normal distribution curve.

FIGURE 7-6. Probability of blast kill example.

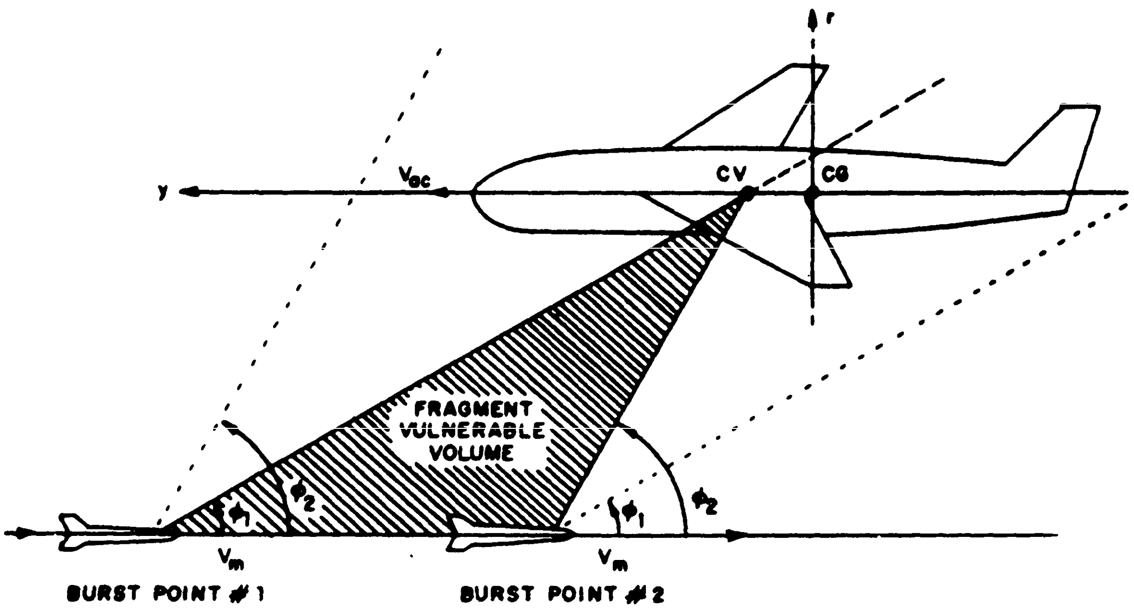


FIGURE 7-7. Fragment vulnerable volume (target invulnerable to blast).

burst point (No. 1) and a latest burst point (No. 2) which will contain the CV within the fragment spray pattern. The enclosed area when rotated about the CV forms what is termed the fragment vulnerable volume. Only bursts occurring within this volume will contain the CV in the fragment spray. If the CV is in the spray, the probability of at least one fragment striking (and thereby killing) the vulnerable area is

$$P_f = 1 - P\ (\text{zero hits}) = 1 - \exp\ (-E_K)$$

where (E_K) is the expected number of lethal hits and is defined in 5.1.5.8.2.1 of this Volume. For computational ease, the Carlton approximation, (Reference 173), to E_K is used:

$$E_K = \frac{d^2}{2a^2} = \frac{d^2}{2.5\ NA_V} = \frac{1}{2.5\ \sigma A_V}$$

where:

$a^2 = 1.25\ NA_V$ for good fit

d = distance of fragment travel to target

N = fragment density (frag/steradian)

ρ = area fragment density = N/d^2.

7.3.1.1.2.5 Fragmentation kills. The fragmentation kill probability, P_b, is obtained by integrating the burst probability at each point, weighted by the kill probability at that point, over the fragment vulnerable volume. This three-dimensional problem can be solved in two dimensions due to symmetry about the target axis. The volume, in X_1, X_2, X_3 space, reduces to the area, V, in the r, y space $(y = X_1)$. If a blast envelope is being considered, the area, V, begins outboard of the intersection of the blast vulnerability envelope with V, as indicated in Figure 7-8. So,

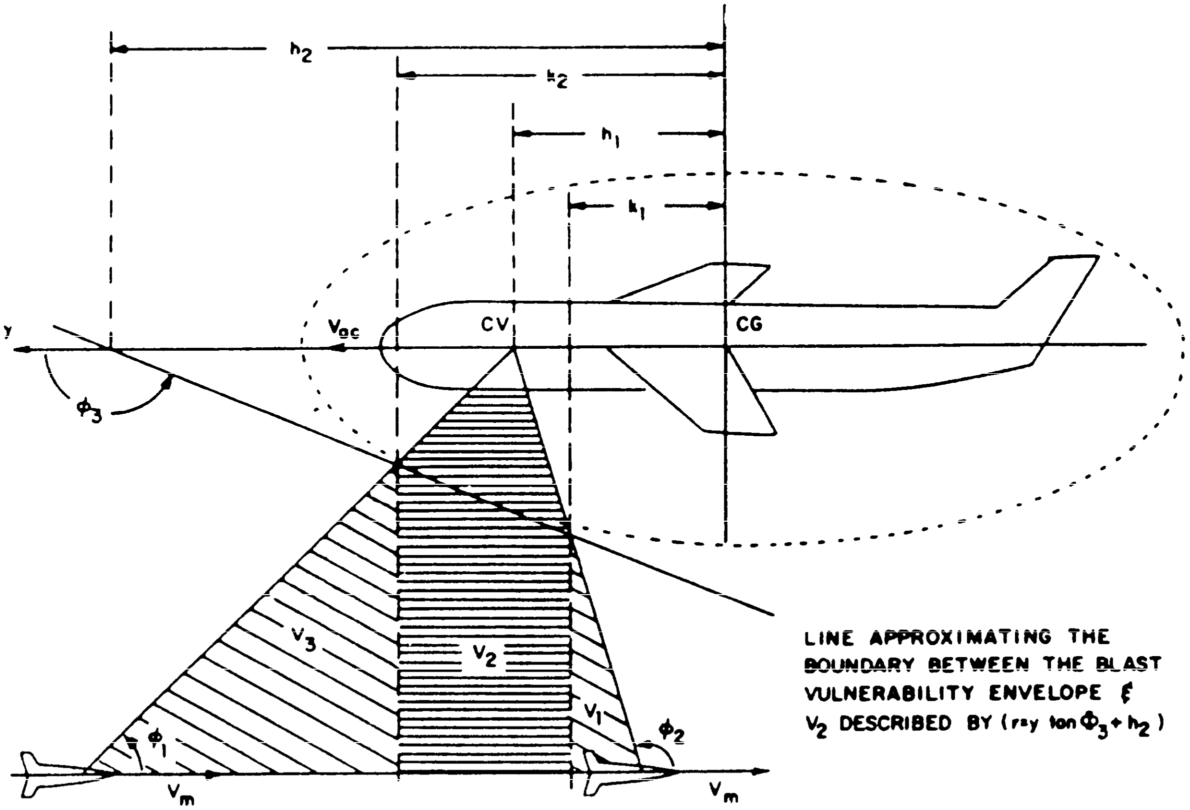
$$P_f = \int\!\!\int_V f(r)\ f(y)\ \exp\ (-E_K)\ dr\ dy$$

where:

$$f(r) = \frac{r}{\sigma_g^2} \exp \left[\frac{-r^2}{2\sigma_f^2} \right]$$

$$f(y) = \frac{1}{\sqrt{2\pi\sigma_f^2}} \exp \left[\frac{-y^2}{2\sigma_f^2} \right]$$

$$\exp\ (-E_K) = \exp \left(\frac{-d^2}{2a^2} \right)$$



LINE APPROXIMATING THE BOUNDARY BETWEEN THE BLAST VULNERABILITY ENVELOPE & V_2 DESCRIBED BY ($r = y \tan \Phi_3 + h_2$)

k = y coordinate of the intersection of the blast vulnerability envelope and V_i

h_1 = y coordinate of the center-of-vulnerability (CV)

h_2 = y intercept of the line approximating the boundary between the blast vulnerability envelope and V_2

ϕ_i = fragmentation dynamic spray angular limits (i = 1, 2)

ϕ_3 = slope of the line approximating the boundary between the blast vulnerability envelope and V_2

CG = orgin of (r, y) coordinate system, taken to be the aircraft center-of-gravity in this presentation

FIGURE 7-8. Fragment vulnerable volume (general case).

[illegible]

(2) spacing between aircraft is large enough that they constitute separate targets under fire by separate weapons. Given these assumptions, the nomogram may be used with the following corrections:

a. Multiply the effective weapon density by a factor 1/F, where F is the number of aircraft in the sortie formation.

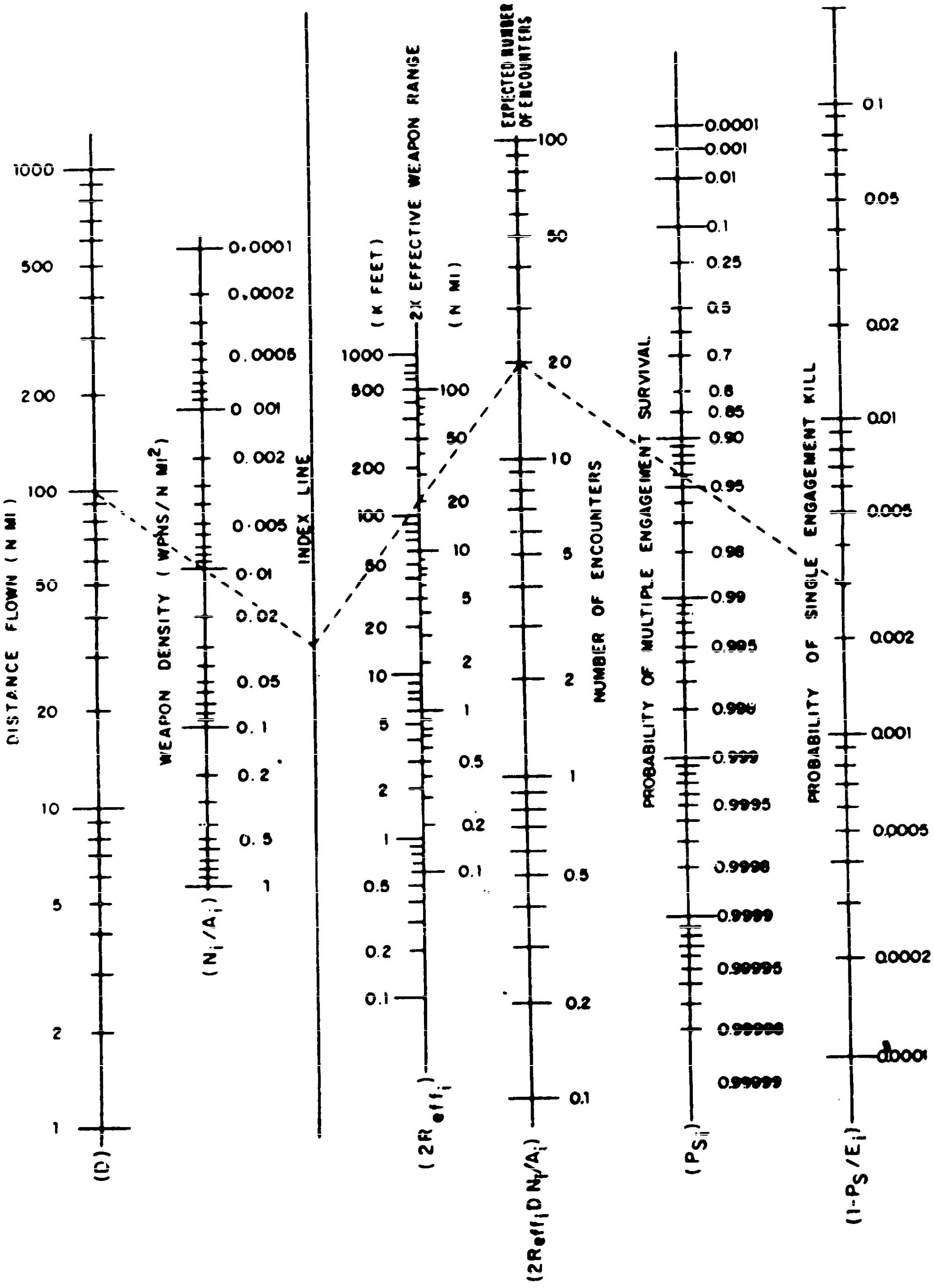


FIGURE 7-9. Probability of survival nomograph.

Given: $D = 100\ N\ Mi$

$$\frac{N_i}{A_i} = \frac{0.01}{(N\ Mi)^2}$$

$2R_{eff_i} = 20\ N\ Mi$

Then: $1 - P_s/E_i = 0.003$

Number of Encounters, $N_{E_i} = 20$

$P_{S_i} = 0.94$

FIGURE 7-10. Multiple engagement survival example.

b. Increase the exposure of the formation by multiplying the distance flown by a factor of $1 + S/2R_{eff}$, where S is the breadth of the formation and R_{eff} is the effective range of the weapon. The following restrictions apply to the factor $1 + S/2R_{eff}$:
   (1) If S is greater than $2R_{eff}$, the formation must be divided into smaller groups such that S is not greater than $2R_{eff}$. Each such group is evaluated separately.
   (2) If all of the smaller groups are of equal size, the probability of survival will be the same for each aircraft in all groups.
   (3) If the groups are of unequal size, the weighted average of the group's survival probabilities can be taken as an approximation.

c. The probability of multiple engagement survival, P_{S_i}, obtained by the procedure is the probability of survival for each aircraft in the formation for the particular weapon considered.

7.3.3 Survivability assessment computer programs. A selected number of survivability assessment computer programs are described in this section. They are applicable to fixed and rotary wing aircraft as defined in their descriptions. Each program is identified by its proper nomenclature and acronym, where appropriate. The source agency is identified and the intended use of the program. An overall description of each program is included to provide the reader with an indication of the capabilities of the assessment programs and the identification of the military activity responsible for its development and maintenance. The responsible activities should be contacted for the latest version of the computer programs and to acquire the program itself for specific applications.

7.3.3.1 TACOS II (Tactical Air defense Computer Operational Simulation). Air Penetration/Ground Based Air Defense Operational Simulation.

a. Source agency: Braddock, Dunn and McDonald, Inc, 5301 Central Ave NE, Albuquerque, New Mexico 87108.

b. Use: Large scale air attack/air defense engagement simulation.

c. Description: The tactical Air Defense Computer Operational Simulation (TACOS II) represents interactions which occur between a large deployment of air defense systems and a large attack of aerial penetrator vehicles in a conventional setting over a field army. The deployment may consist of virtually any mixture of various SAM (Surface-to-Air Missile) systems and AAA (Anti-aircraft Artillery) gun systems. The attack may consist of aircraft and missiles. Each air defense fire unit and each serial generator vehicle is represented separately. TACOS II output is composed of both the history listing and summaries of outcomes of all engagements cross-referenced several ways.

The TACOS II utilizes a detailed, digitized terrain file to provide a realistic environment for the air attack/defense battle. TACOS II not only portrays the interactions between attack aircraft and defensive systems but also the interactions of the military planners with systems in their environment. Terrain masking and terrain following flight paths are represented. The ECM representation includes the effects of stand off barrage and spot noise jamming, self-screening barrage and spot jamming, and various types of self-screening deception jamming. The operations resulting from processes are simulated rather than the processes themselves. A "critical event" technique conserves computer time over a "time step" technique. TACOS Monte Carlos randomizes decisions rather than aggregating probabilities.

Any System/360 possessing at least 512K bytes of core memory and capable of supporting the Operating System may be used for TACOS. A complete run occupies between 1/4 and 6 computer hours on a 360/50. Additional replications of a given situation run 15 percent of the time required for the first replication. The TACOS has been constructed utilizing a highly modular approach allowing detailed submodels to be added with relatively little effort. It is written primarily on FORTRAN IV (H) with some Assembler code to aid in storage utilization and running time efficiency.

The effect of the terrain on the defense abstracted into dominant mask functions. The effect of the terrain on the offense is described in the detailed flight paths. The interaction between the two effects or the effect of the terrain on engagements is described (along with sensors and ECM) in the environment events. Geometric events are those that, if they are to occur, will occur at a completely predictable time. The FRAG3 is the replicative portion of TACOS. It produces a complete battle history and a summary of important statistics concerning the battle.

The TACOS II is the fourteenth distinct evolution of a family of tactical air attack/ground based air defense models whose development dates back to 1962. A version of TACOS II called TACOS-C^2 has been developed which simulates command control of the air defense deployment to the extent of individual messages and their interactions with the battle presently simulated by TACOS II. The TACOS-EW, a version of TACOS II in which the ECM submodel is extended to include support jamming, expendable jammers, and chaff is being planned. For further information about TACOS II, TACOS-C^2, TACOS-EW, other BDM simulations, and related services, please contact any of the people listed in the foreword of this report.

d. Variants:
(1) TACOS VIA IDM. The intelligent Data Module (IDM) was developed to simplify and automate TACOS input data requirements. Analysts, employing TACOS via IDM, supply only a minimum number of input parameters for TACOS execution. The IDM supplies default values for optional variables not supplied by the analysts, and generates values for the remaining TACOS variables via assumptions and deductions.
(2) QR - TACOS. For a quick response analysis of a mix of air defense systems, the degree of realism afforded by such attention to detail may not be desired. To reduce to a minimum the time and amount of input data required to define the scenario for a TACOS run, the Quick Response Scenario Generator (QRSG) was developed. The QRSG entirely replaces FRAG1 and utilizes minimal input data to develop scenario information suitable for input to FRAG2.

e. Documentation:
(1) TACOS II - Air Penetration/Ground Based Air Defense Operational Simulation - BDM/W-193-73-TR, January 1972 (Reference 16).
(2) TACOS II VIA - A Simplified Input Scheme - BDM/H-74-015TR, May 1974 (Reference 17).
(3) QR-TACOS - Quick Response Tactical Air Defense Computer Operational Simulation - BDM/W-73/0025, September 1973 (Reference 18).

7.3.3.2 SIMFIND2. Digital Simulation for Aircraft Survivability.

a. Sponsoring agency: Institute for Defense Analysis.

b. Use: Simulates engagements between aircraft and an antiaircraft weapon site.

c. Description: The SIMFIND2 computer program is a FORTRAN IV language program which simulates an anti-aircraft weapon system firing at an aircraft.

The model is useful for determining: (1) the relative attrition of aircraft which can be achieved by various types of guns, (2) the relative attrition which a given type gun can exact from various types of aircraft or from one type of aircraft flying various maneuvers and (3) the relative attrition attained by guns at various locations relative to an aircraft flight path. This information may find application in a wide range of studies, such as: (1) evaluation of the reduction in aircraft losses to be expected from reducing aircraft vulnerability, (2) comparison of aircraft types, (3) comparison of gun types, (4) development of aircraft maneuvers, (5) selection of aircraft attack headings, and (6) selection of sites for anti-aircraft gun systems.

SIMFIND2 is applicable specifically to weapon sites with either (1) optical-mechanical computing sights or (2) central fire directors. The model simulates an aircraft flight path in three dimensions, computes range and tracking angles relative to a gun location, finds the gun pointing angles with the appropriate lead angle, determines the distance between the true center of impact and aircraft position, and assesses the probability of damaging the aircraft.

(1) The optical-mechanical computing sight simulated by SIMFIND2 uses crew inputs of aircraft range, speed, course angle and climb angle.

(2) The fire director simulated by SIMFIND2 uses continuous inputs of range, azimuth and elevation. Both systems and their simulations use straight line extrapolation of aircraft position to determine the aimpoint.

The SIMFIND2 model is essentially a Monte Carlo simulation, i.e., random variables are sampled repeatedly and the values in the sample are used to simulate numerous engagements. The overall engagement result (engagement P_k) is the average of the results of the engagements.

d. Documentation: No formal report available.

7.3.3.3 TAC AVENGER. Tactical Air Capabilities, Avionics, Energy Maneuverability Evaluation and Research.

a. Sponsoring agency: Assistant Chief of Staff, Studies and Analysis, Headquarters USAF.

b. Use: Simulates two aircraft in a close-in maneuvering air duel.

c. Description: The TAC AVENGER Model is a digital computer simulation of two aircraft in a close-in maneuvering air duel. In this simulation, each aircraft maneuvers in three dimensions; each pilot reacts on a second-by-second basis to the maneuvers of the opponent; and each pilot expends ordnance against the other aircraft as opportunities occur. The aircraft and weapons performance are described in detailed engineering data. The individual aircraft tactics are selected from a range of reasonable choices based upon the tactical situation, the relative performance capability of the aircraft, and pilot preferences. These individual pilot preferences were originally derived from empirical, real-world data and are selected using a random selection method within the model. The model measures the contribution of avionics, energy maneuverability, and weapons-to-fighter effectiveness.

The TAC AVENGER was written for the IBM 7094, IBSYS 13, FORTRAN IV, Map and has since been converted to the G-635, GECOS III, FORTRAN IV, GMAP, and MULTEX. The model uses 32K words of core with 74 routines having 9,000 source statements. The average 7094 run time is 5 minutes for each 5 minutes of simulation.

d. Documentation: No formal report available.

7.3.3.4 P001. Antiaircraft Artillery Simulation Computer Program.

a. Sponsoring agency: Air Force Armament Laboratory, Weapons Systems Analysis Division, Eglin AFB.

b. Use: Generates single-shot probability of kill of a target aircraft encountering an anti-aircraft artillery site.

c. Description: The Antiaircraft Artillery Simulation Computer Program, AFATL Program P001, computes the single-shot probability of kill of a target aircraft flying a predefined flight path. The modeling and methodology involve the processes by which the antiaircraft artillery system computes an aim point for the aircraft, the analyses which lead to quantifications of the various errors to which these processes are subject, the mathematical techniques used to simulate the firing process with inherent errors, and the computation of the probability that a given shot yields an aircraft "kill" based on the vulnerable area presented to the projectile.

d. Aircraft flight path profile history: The flight path profile history of the aircraft is entered by milestones, or major coordinates along the flight path, which are given in terms of a flight path coordinate system. The distance between any two successive milestones forms a straight-line flight path leg. Flight path coordinate data are then computed by linear interpolation for each increment of the flight path based on a given interval rate, and these data are converted and stored in relation to the ground weapon coordinate system.

(1) The ground weapon complex coordinates are entered with respect to the general reference coordinate system and can consist of one or more ground weapons. If there is more than one ground weapon in the ground weapon complex, the ground weapons are equally spaced on a circle of a given radius (depending on cable length) around the coordinates of the ground weapon complex. The program considers each ground weapon in the complex separately. If the coordinates of the ground weapon complex are known, the flight path attrition is computed against that given position. However, if the flight path is over an area within which the position of the ground weapon complex is not known, the program computes the P_k for the assumed location of the weapon complex, applies a density factor, and sums the flight path attrition against all user-specified locations of the ground weapon complex. The term "density factor" is the probability that the weapon complex is at the specified location and firing.

(2) Aircraft vulnerable area data are input to the program in the form of a three-dimensional array as a function of impact latitude and longitude, and the magnitude of the relative striking, or closing, velocity. Aircraft latitude is measured from the bottom of the aircraft (0 degrees) to the top of the aircraft (180 degrees), and aircraft longitude is measured counterclockwise from the rear (0 degrees) when viewing the aircraft from the top. The increment of angle in latitude or longitude can be varied to correspond to the degree of fineness of the available data. However, present program methodology is such that 26 aircraft vulnerable areas must be input, corresponding to a view of the aircraft at every 45 degree increment in both latitude and longitude.

(3) Aircraft attitude with respect to the projectile at the time of mean intercept determines the latitude and longitude of the impact, which are then used, together with the aircraft/projectile closing velocity, in a linear three-dimensional interpolation within the table of vulnerable areas. The method for computing aircraft/projectile latitude and longitude angles is accomplished by first constructing a new coordinate system, called the aircraft coordinate system, such that one axis points out the nose of the aircraft, one out the left wing, and the third axis out the top of the aircraft. The closing velocity vector, which is readily available in the gun-centered coordinate system, can then be expressed in the aircraft coordinate system by use of a linear transformation which describes the relationship between the two coordinate systems. The components of the closing velocity vector, therefore, completely specify the impact latitude, longitude, and speed.

The amount of vulnerable area presented to the projectile at the time of mean intercept is determined by linearly interpolating within a table which presents the given aircraft vulnerable area as a function of both aircraft aspect with respect to the given projectile and striking velocity. Relative aspect is fully determined once the aircraft's course with respect to the ground weapon, its dive angle, and its roll angle are known. The roll angle is part of the input flight path profile history.

e. User options: Due to the nature and flexibility of the AFATL P001 Computer Program, there are a number of options available to the user depending upon his study requirements. Following is a list of possible uses:

(1) Study the effects of a given ground weapon site against various types of aircraft flying identical flight paths.

(2) Study the effects of a ground weapon site against an aircraft at various altitudes and offset distances.

(3) Study the effects of various ground weapon parameters against an aircraft on a single flight path.

(4) Study the effects of an aircraft flying over an area where the location of one or more ground weapon sites is only probabilistically known.

(5) Determine the aircraft sectors most vulnerable to ground fire from a known or only probabilistically known ground weapon site.
(6) Determine the P_k versus time along the flight path.
(7) Study the effects of terrain masking by use of the flight path time intervals (only time interval P_k's and not final cumulative P_k's would have any meaning for this use).

f. Documentation: Antiaircraft Artillery Simulation Computer Program - AFATL Program P001 - Volume I: User Manual, TN - 4565-16-73, September 1973, (Reference 19).

7.3.3.5 MASKPAS. MASKPAS Programs, Digitized Terrain, Flight Path Generator, Intervisibility for Evaluation of Air Defense Effectiveness (EVADE).

a. Sponsoring agency: Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, Maryland.

b. Use: Generation of three-dimensional aircraft flight path profile and masking status between the aircraft along that profile and a ground based weapon site. Primarily used with EVADE II.

c. Description: The MASKPAS portion of the EVADE simulation is used to generate information which reflects the influence of terrain and vegetation on air-ground encounters. The information, thus obtained, serves as input data for the attrition calculations in EVADE. The variation in elevation of terrain is usually obtained from standard 1/50,000 Universal Transverse Mercator (UTM) maps. Elevation data are "read" from these maps at regular intervals and stored on magnetic tape for subsequent use.

MASKPAS consists of a set of three computer programs: (1) Flight Path Track and Weapon Site Heights Program, (2) Terrain Following Program, and (3) Intervisibility Program. These programs, written in FORTRAN IV, are executed sequentially to generate a three-dimensional aircraft flight path profile and the mask status between the aircraft along that profile and up to 50 independent ground weapon sites.

In the EVADE II simulation, extensive use is made of digitized terrain information generally obtained from standard 1/50,000 Universal Transverse Mercator (UTM) maps. This terrain information, stored on magnetic tapes, is currently available through the Defense Mapping Agency Topographic Center. The Topographic Center produces terrain elevation data at very small map grid sizes, approximately 0.01 inch by 0.01 inch on standard 1/50,000 maps. Thus, elevation for grids that are 12.7 meters square on the real ground are available. The "bare earth" terrain data have additional heights, superimposed where appropriate, to represent vegetation and built-up areas (cities and towns). Helicopter map-of-the-earth (NOE) flights may require detail to the level of 12.7 meters.

When less detail is required, time consuming calculations may be reduced by utilizing a coarser grid interval (by skipping to every second, fifth, or tenth data file, etc) when reading the terrain tape. Many segments of digitized terrain are currently available through the Topographic Center.

d. Documentation:
(1) MASKPAS Programs
(2) Volume I: User Manual, September 1975
(3) Volume II: Analyst Manual, September 1975
(4) JTCG/ME - (No report number assigned to date.)

7.3.3.6 FLYGEN. Aircraft Flight Path Generator Computer Program

a. Sponsoring agency: Strike Process Studies Branch, Weapon System Analysis Division, Air Force Armament Laboratory, Eglin AFB.

b. Use: Generates three-dimensional flight path trajectories for fighter escorts or close support aircraft for use in antiaircraft attrition/aircraft survivability simulation models.

c. Description: The FLYGEN was created to generate three-dimensional flight path trajectories as a function of time for fixed wing aircraft operating in the fighter escort or close air support mode. The trajectories generated by the program are used in conducting aircraft attrition/survivability studies in conjunction with other computer programs.

Input data for the program fall into three categories that can be entered from either punched cards or magnetic tape. The first category consists of empirically derived aircraft descriptive parameters. The program is written for detailed aircraft performance data input, but it will work equally well with considerably lesser amounts of performance data. Data pertaining to physical characteristics of the aircraft, external stores configurations, as well as thrust, lift, and drag characteristics are in this category. In addition, aircraft aerodynamic limits and maximum allowable rotation rates and accelerations must be specified. The second category of input data deals with program control information used to specify the type of input medium, a list of tolerances for various maneuver termination conditions, and output time intervals for both hard (printed) copy and magnetic tape output. The third or last category of input data, which is in a condensed format requiring extremely close attention to details, is the flight maneuver coding. The coding is extremely sophisticated and requires extra effort on the part of the user, but it is this complexity that provides FLYGEN with the versatility that is its forte. Maneuver segments, or specifications, are used to compile a basic maneuver string that can consist of as many as 99 segments. A continuation option allows subsequent runs to begin from the state in which the last run ended. No break occurs in the tape output under this option, and hence maneuver strings of arbitrary length can be simulated.

There are four basic maneuvers used in the program, and each maneuver specification can have different meanings depending upon the parametric values entered from punched card or magnetic tape. Each of the maneuver specifications in the maneuver string is executed in sequence. Termination of each segment is dependent upon parametric values entered into the program. Trajectory variable values are saved and printed and/or written on magnetic tape as specified on one of the program control information records. After all maneuvers of the maneuver string have been executed, another data set, if one or more exists, is entered into the program and execution of the program using the new input data occurs. The process is repeated until an end-of-file is encountered, at which time program execution is terminated.

Three different output lists can be generated by FLYGEN depending upon the control cards entered upon program execution. Two of the lists are printed output (hard copy), while the third is written on magnetic tape and is used for aircraft attrition/survivability modeling using other computer programs. The primary printed output contains a summary of the aircraft descriptive parameters, a listing of the maneuver specifications that make up the maneuver string, followed by a time history of flight path trajectory variable values based on an inertial reference system. A second printed output contains a time history of flight path trajectory variable values based on the aircraft body axis system. The magnetic tape output is designed for use in aircraft attrition/survivability studies in conjunction with antiaircraft simulation models. Items recorded on the tape include: time along the flight path, aircraft positions in meters, aircraft velocity and its components in meters/second, acceleration components in meters/second, aircraft normal load factor, and aircraft attitude angles.

Execution of the FLYGEN program requires a large scale digital computer with a standard FORTRAN IV capability. Approximately 15,000 (or 36,000) words of computer memory are required for program execution. Two software packages for date and time of execution are unique to the CDC 6600 installation at Eglin AFB. The use of these packages and the A10 format used for reading and writing some of the program input/output information may require program modifications prior to use at other computer facilities.

d. Documentation: Aircraft Flight Path Generator Computer Program:
   (1) Volume I: User Manual, April 1976
   (2) Volume II: Analyst Manual, April 1976
   (3) JTCG/ME - (No report number assigned to date).

7.3.3.7 DATAM I. Dynamic air-to-air model computer program.

a. Sponsoring agency: AFATL/DLYD. Air Force Armament Laboratory, Eglin AFB.

b. Use: Air-to-air gunnery simulation model for use in the evaluation of gun and ammunition systems.

c. Description: The Dynamic Air-to-air Model (DATAM-I) is a digital computer program developed and utilized by the Gun Effectiveness Analysis Team of the Weapon System Analysis Division in the Air Force Armament Laboratory. The DATAM-I is a digital expected-value simulation of the air-to-air gunnery created to fill a void in aerial gunnery terminal effectiveness analysis.

The target aircraft is modeled as a rectangular parallelepiped whose faces correspond in area to the presented areas for the rear, side, and top views of the aircraft. This area description of the target along with the firing pass geometry permits the computation of the composite target area presented to the incoming projectile. Target vulnerable area values are derived from tabular vulnerable area data which are defined as functions of the azimuth and elevation angles of the projectile with respect to the target at impact. The three-dimensional fire control errors are described by a circular normal distribution about a prediction bias point. The bias point is a function of the type of sight mechanization, target maneuvers, and gun performance. All effects of gravity on the projectile are accounted for in the fire control system.

The distribution of the bullet stream in space is treated as a pilot-controlled fire line, and is examined about each possible aim point within the fire control circular normal distribution. The positions of the individual bullets within the fire line are dependent upon the rate of motion along the line (introduced by the pilot) and the rate of fire for a given burst. Ballistic dispersion of the bullets is introduced about each of the possible impact points along the fire line.

The gun system characteristics that are evaluated by this program include muzzle velocity, rate of fire, number of rounds, caliber of the round, external ballistics, projectile lethality, and gun system weights. These characteristics all affect the performance of the gun system in a given encounter. This program allows the influence of each of these characteristics on the gun system effectiveness to be examined.

A number of firing bursts comprise a firing pass. The hit and kill probabilities for the entire firing pass, commencing at an initial angle-off and open-fire range and continuing for a selected period. are determined. In addition, the number of expected hits is determined, and is compared with predetermined hit levels. The percentage of the points that equal or exceed each level is printed. Finally, range-weighted kill probabilities are computed based on percentage distributions from actual aerial combat data.

Execution of the DATAM-I program requires a large scale digital computer with a standard FORTRAN IV capability. Approximately 20,000 (or 47,000) words of computer memory are required for execution. Optimal plotting routines have been included in the source program. These are written for the CDC 6600 installation at Eglin AFB, and will require modifications for use at other computer facilities.

d. Documentation: Dynamic air-to-air model computer program.
   (1) Volume I: User Manual, 61 JTCG/ME-75-5, March 1975, (Reference 20).
   (2) Volume II: Analyst Manual, 61 JTCG/ME-75-6, March 1975, (Reference 21).

7.3.3.8 EVADE II. Evaluation of Air Defense Effectiveness.

a. Sponsoring agency: Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, Maryland.

b. Use: Simulation of two-sided engagement between aircraft and ground based weapons systems.

c. Description: This program calculates the time history of probability of kill for each participant in multiaircraft versus multiground weapon encounters.

Up to 20 simultaneous independent flight path tracks against as many as 50 individual ground weapon sites can be simulated. More than one aircraft can be played on a given track, and more than one "barrel" can be located at one ground position. Thirteen different combinations of ground gun and fire control system types from 7.62 mm to 57 mm are available. Aircraft can fire 7.62 mm, 12.7 mm or 30 mm gun systems or the TOW missile system, as appropriate. The IR missile systems (surface-to-air) are played in conjunction with, but external to, the model. Seven different weather and five different lighting conditions can be superimposed on the model scenario. These conditions affect visual target detection and acquisition from ground to air.

Extensive use is made of digitized terrain maps, with small grid sizes. A 12.7-meter grid, minimum, is presently being utilized. A 40 x 47 km area of west central Germany including approximately 13 million individual terrain heights is stored on magnetic tape for use with the program's intervisibility subroutine. This "bare earth" data with superimposed vegetation is used in conjunction with detailed three-dimensional map-of-the-earth flight profiles. From this information, a realistic time history of intervisibility between all weapon sites and all aircraft is obtained. This "mask" history is then input to the base engagement model. Each engagement within the scenario follows a time-dependent sequence of events, such as: target detection; either visual, acoustic, infrared, or RF; acquisition; unmasking; weapon system reaction time; target moving into maximum effective range; projectile or missile time of flight; arrival at the first intercept point; and subsequent accumulation of attrition or probability of kill. This process continues until the target becomes masked, goes into a dead zone, is suppressed or killed; runs out of ammunition, or, perhaps, goes out of range. Six different criteria for rules of engagement and target selection can be employed. Weapons can be burst-fired, using any desired firing criterion with both dependent and independent methods of attrition calculation. Up to 13 levels of component damage or kill criteria, including multiply vulnerable components, can be simultaneously evaluated.

The EVADE II is not a dynamic simulation. Flight profiles and weapon locations must be preplanned. This model is an expected values simulation. In the one-aircraft-versus-one-ground-weapon case it reduces to the Markov-type solution. Where there are more than two participants, as in its normal usage, classic caveats associated with all expected value models must be kept in mind. Primarily this means that the expected value resulting might not correspond to the average case which would be predicted by expanded Markov chains or by Monte Carlo solutions, could the former be mechanized or the latter be afforded.

Program output consists of the time history of air and ground systems suppressed or destroyed, ammunition expenditure, and the time history of all major events which transpire. The location of these events, detect, unmask, fire, remask, reload, re-acquire, etc., along each flight path track are also available.

This program is useful as a means of obtaining a first-order estimate of the practicality of flight paths; adequacy of weapon deployments; or as a relative survivability indicator when investigating tactics, techniques, equipments, environmental variations, and other systematic variations of input parameters to the engagement problem.

Other organizations and installations presently using or considering the use of the EVADE II Model are the Air Force Foreign Technology Division at Wright-Patterson Air Force Base, the Army Aviation Systems Command at St. Louis, and the Army Electronic Command at Fort Monmouth.

The EVADE II (Evaluation of Air Defense Effectiveness) computer program was written in FORTRAN IV for the U.S. Army Ballistics Research Laboratory BRLESC computer. It has been rewritten for the CDC 6600. It is being rewritten for the IBM 360 system. Programs written in BRLESC FORTRAN IV are compatible with most computers that have a FORTRAN IV compiler with minor changes. The memory requirement for the EVADE II MAIN program is 73,000 computer words.1) See reference Number 21 for further details concerning BRLESC FORTRAN IV.

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1) Experience has shown that double precision is required for approximately 19,000 of these words on an IBM 360 system.

d. Documentation: The EVADE II is a Simulation Program for the Evaluation of Air Defense Effectiveness:
   (1) Volume I: User Manual, December 1974
   (2) Volume II - 1,2: Analyst Manual, December 1974
   (3) JTCG/ME (No report numbers assigned to date).

7.3.3.9 BLUE MAX. The Variable Airspeed Flight Path Generator.

a. Sponsoring agency: Assistant Chief of Staff, Studies and Analysis (ACS/SA), Headquarters USAF.

b. Use: Generates three-dimensional flight path trajectories primarily for ground attack missions.

c. Description: The BLUE MAX provides variable speed flight path descriptions which were suitable as input to AAA and SAM attrition models. The aircraft modeled were limited to fixed-wing subsonic types operating between sea level and 20,000 feet altitude. A flight path is synthesized from a series of flight path maneuver segments specified by the user. There are five different types of maneuvers modeled:
   (1) Navigation
   (2) Base-leg
   (3) Roll-in-and-attack
   (4) Pull-out
   (5) Recovery

The roll-in-and-attack maneuver may be used only once in the flight path, but the other maneuver types are limited only by array dimensions in the program (currently limited to a total of 30 flight path segments). They can be entered and/or repeated in any combination. Hard copy output results can be used in conjunction with antiaircraft attrition and aircraft survivability simulation models.

The BLUE MAX is an easy-to-use program that was designed to simulate realistically an attack aircraft during the attack phase against ground targets. Other simulations, such as FLYGEN, are more suitable for simulating the quick, hard maneuvers of air combat.

The BLUE MAX program is written in FORTRAN IV language and consists of approximately 260 source statements. Because of its relatively small core requirements (4,832 words decimal), it can be executed on a wide range of computers. Running time to produce the sample problem is 14 seconds on a CDC 6400 computer.

d. Documentation: Variable Airspeed Flight Path Generator Computer Program (BLUE MAX), October 1975 (No report number assigned to date), ACS/Studies and Analysis, Headquarters United States Air Force.

7.3.3.10 AMEGS. Aberdeen Blast-Fragmentation, Fixed-Angle Fuze-Missile, End-Game Simulation.

a. Sponsoring agency: The U.S. Army Materiel Systems Analysis Agency, Aberdeen Proving Ground, Maryland.

b. Use: Primary use is to determine lethality of missiles with blast/fragmentation warheads and conical fuzes. Can be applied to other missiles.

c. Description: The purpose of the Aberdeen Missile End Game Simulation (AMEGS) is to predict the probability that a single round fired from a given surface-to-air missile system will kill a given target (aircraft or missile) under a given set of assumptions. By modifying or adding certain features, AMEGS can be applied to a wide range of missiles. For example, if the intercept arming feature is removed or bypassed, the simulation can be applied to any missile with

(1) A semiactive, continuous guidance system,
(2) A semiactive or active fixed-angle fuze, of n beams with or without range gates.
(3) A warhead that has a fragment spray which is symmetrical or nonsymmetrical to the longitudinal axis of the missile.

The radar reflectivity of the target is represented by a number of fixed points called "glitter points." These points are positioned as light backscatter areas on the target. In the end game, the glitter points represent the target as soon by the receiver dish of the missile. Prior to the end game, the missile sees the reflective areas as one large area, and it guides on the centroid of this area. The individual glitter points become discernible only as the missile approaches close to the target. At such close range, the time remaining until intercept is too short to allow significant change in the guidance point.

When used to compute P_K as a function of a constant miss distance, the program resets the missile homing point at the target's cg. This is done to facilitate the conversion of miss distance into radar miss distance. Miss distance is the distance measured from the warhead cg to the target cg at the point of closest approach. Radar miss distance is the distance measured from the warhead to the nearest radar reflector at the point of closest approach to the reflector. When computing P_{SSK} as a function of a constant miss distance, the guidance errors are chosen from a uniform distribution. In the original program, the errors were weighted to include a greater number of small vertical errors.

The machine simulation of the end game engagement of an interceptor missile and its target may be considered as being composed of the following sections:

(a) Input. This section reads information concerning the interceptor and the target into the computer.

(b) Guidance and Fuzing. Using the input, random or fixed angles can be determined for the azimuth and elevation. An interceptor aim point is chosen on or near the target. Random miss distances and a random fuzing error are drawn. A burst point is found by solving the intercept geometry.

(c) Blast. The probability of killing the target by blast is determined in this section.

(d) Perforation. The probability that the interceptor will perforate is determined in this section.

(e) Fragmentation. The probabilities of kill on the vulnerable components by fragments are computed here.

(f) Combinatorials. The desired combinations of the various probabilities are made here. Running sums of the probability combinations are kept. The sums are printed as output upon completion of a predetermined number of engagements.

d. Documentation: Aberdeen Blast - Fragmentation, Fixed-Angle, Fuze-Missile, End-Game Simulation (AMEGS), Technical Report No. 66, April 1973, U.S. Army Material Systems Analysis Agency.

7.3.3.11 AESOPS. The AMSAA EVADE Sustained Operations Performance Simulation Model.

a. Sponsoring agency: Army Material Systems Analysis Agency, Aberdeen Proving Ground, Maryland.

b. Use: Supplement to the EVADE model to simulate sustained Attach Helicopter Operations.

c. Description: The AMSAA EVADE Sustained Operations Performance Simulation (AESOPS) model simulates the continuous operations of a small helicopter unit over a period of several days of combat and introduces the impact of routine maintenance and the repair of combat damage on helicopter availability during such operations. This model has been developed to supplement the survivability results from the EVADE computer model in order to better evaluate the priority characteristics of the Advanced Attack Helicopter (AAH) candidates. The operations of the small helicopter unit described by the Stanford Research Institute in the development of their SOM model have provided the foundation upon which the AESOPS model was developed. However, where SOM employs Monte Carlo simulation, AESOPS is based on an expected values approach. The principal outputs of each model are helicopters lost, targets defeated (or any quantifiable measure of mission accomplishment), and number of missions accomplished over the time period of interest.

d. Documentation: No formal report available.

7.3.3.12 ENDGAME. The ENDGAME is a computer program for estimating Air Intercept Missile Effectiveness.

a. Sponsoring agency. Air Force Armament Laboratory, Eglin AFB.

b. Use: Evaluates the effectiveness of the fuze-warhead systems against air targets, using a unique three-dimensional target model defined by detailed configuration of planar surfaces representing the target exterior profile and interior vulnerable components.

c. Description. The ENDGAME Simulation Computer Program provides the analytical capability for evaluating warhead-fuze system lethality against air targets using a unique three-dimensional target model defined by detailed configuration of planar surfaces representing the target exterior profile and interior vulnerable components. Based on Monte Carlo sampling techniques, a large number of random warhead-target encounters is generated and terminal intercept events of fuze activation, warhead detonation, and target-damage mechanism interaction are evaluated. Probabilities of kill due to direct hit, blast shock wave interaction, and/or fragmentation effects based on component and structural (energy density criterion) damage are computed, and the results are averaged over the number of random engagements to give expected or single shot probability of kill (PSSK).

The ENDGAME program can be used independently as a separate simulation model requiring input-designated or parameterized encounter conditions, or used in conjunction with the missile FLYOUT program which generates expected interceptor/target terminal encounter kinematics. When used independently, selected encounter/target/warhead variables can be specified discretely or parameterized at designated intervals until the PSSK for all desired combinations of parameter values have been computed. For each encounter generated, the program evaluates a large number of variables defining the terminal engagement events. Major areas of computation are described below with pertinent input variables designated in parentheses where appropriate.

(1) The size, shape, and configuration of the target exterior frame and interior components are described using a maximum of 150 discrete planar surfaces or faces. These surfaces are defined in terms of sequential points whose coordinates are input, or by specification of standard geometrical forms from which the faces are computed.

(2) Any fragmentation/blast warhead can be accurately defined using the input parameters available for the warhead model. Fragmentation characteristics are defined in up to 36 fragment polar zones, each of which many have a maximum of 10 classes of fragments, for warheads having an axis of symmetry along its centerline. Fragmentation characteristics are defined for up to 3 polar zones, each with 12 roll zones about the warhead centerline and 10 classes of fragments, for nonsymmetrical warheads having no axis of reflection. The warhead model has no provisions for explicitly including missile structure shielding of the fragmentation other than user degradation of the above fragment projection parameters.

(3) Blast characteristics for the warhead are defined by a lethal radius (BR) measured normal to each vulnerable target face, and a maximum of 10 blast centers corresponding to primary

target zones for blast damage. If the relative warhead detonation point is within the lethal blast radius of any face at the shortest time of blast wave travel to any blast center, the target is considered killed; if not, there is no target damage due to warhead blast.

(4) Fuzing of the interceptor warhead is simulated by determining those target face edges visible to the approaching missile and which interact with the fuzing surface within a designated sensitivity range. Point of earliest intersection is defined as the point of warhead fuzing.

(5) Target damage is evaluated for direct hit, blast, and fragmentation energy density and/or component kill effects. Resulting probabilities of kill for each damage mechanism are combined to generate the expected kill for one sample. The entire process is repeated numerous times with different, randomly selected conditions for each sample, and an average value for the probability of kill for all samples is computed to establish the single shot kill probability.

(6) Probability of target kill due to direct hit of an undetonated warhead is established by computing the intersections of the warhead trajectory prior to detonation with those faces of the target designated as vulnerable to direct hit damage. If any such face is intersected by this portion of the trajectory, the target is assumed killed.

(7) Blast kill of the target is determined by first computing the minimum time of travel for the blast wave to reach any of the designated blast centers located throughout the target model. If position of the detonation point relative to the target at that time is within a specified lethal blast radius (BR) to any target face vulnerable to blast, kill of the target is assumed.

(8) Fragmentation damage is basically computed by mapping fragments projected from discrete sectors about the warhead from the point of detonation onto the target. First, a projection of the target model is made to determine those surfaces or portions thereof which are exposed to the warhead at detonation. Subsequently, each exposed target face is evaluated for fragment impact. Based on the fragmentation definition of the warhead, fragment sectors are mapped (drag included) from the point of detonation onto the infinite face plane. Fractional coverage of the impacting fragment pattern over the actual face is determined, and the resulting number of hits, impacting density, and strike kinematics are computed. Based on the energy density damage criterion, striking energy density of the fragment pattern is compared to input threshold values (EDFM) for each face to ascertain probability of structural kill. If the impacting energy density exceeds the threshold value and sufficient fragment hits are inflicted, energy density structural kill is assumed.

(9) Probability of achieving component kill of the target is a function of the target characteristics, fragment strike velocity, fragment mass, and strike angle. Representation of component vulnerability to damage is accomplished by input of conditional probability of kill (PKC) data (component kill given a random fragment impact over the component presented area from a given direction).

(10) Unlike the evaluation of energy density kill, component kill computation does not explicitly consider shielding of faces from one component by another component. Rather, each component is evaluated separately, and the appropriate shielding effects by other components or target structure are assumed to be previously incorporated in the PKC data.

(11) Once the number of fragment impacts, NHITS, on the vulnerable component is determined and the appropriate PKC value is established, the probability of component kill for fragment impact (PKF) is given by the relationship:

$$PKF = i - e^{-NHITS\ (PKC)}$$

Resulting probabilities of killing each component and group of components are computed, and the total probability of target kill based on component damage, PKFG, is determined.

d. Documentation: ENDGAME is a computer program for estimating Air Intercept Missile Effectiveness.

(1) Volume I: User Manual, AFATL TR-75-13, May 1975, (Reference 188).

(2) Volume II: Analyst Manual, AFATL TR-75-13, May 1975, (Reference 188)

(3) Volume III: Data Manual AFATL TR-75-13, Classified Report, May 1975, (Reference 188).

7.3.3.13 SCAN. SCAN is a computer program for estimating aircraft survivability.

a. Sponsoring agency: Developed at Pacific Missile Test Center.

b. Use: Predicts the probability that an aircraft will survive an attack by a missile armed with a fragmentation warhead. The program simulates the encounter and computes the expected target damage.

c. Description: SCAN is a digital computer program developed at the Pacific Missile Test Center to predict the probability that an aircraft will survive an attack by a missile armed with a fragmentation warhead. The program simulates the encounter between a missile and its airborne target mathematically and computes the expected target damage. The geometric encounter conditions can be obtained from missile flight simulations, from missile performance data or as user supplied parameterized values. The program can generate a random sample of missile trajectories which satisfy specified distributions of encounter parameters. The program reports hit and survival probability computation results at specified component, subsystems, system and total aircraft levels. Various levels of damage severity, including catastrophic failure and mission kills can be defined by the analyst. This program gives the analyst several options in defining individual aircraft components and in using vulnerability criteria to compute the expected damage level. These options allow the analyst to construct efficient models commensurate with time, effort and cost constraints. In addition, the model is contructed to allow adaptability to other damage mechanisms; fragment velocities, densities, masses, etc., are available to the damage computation submodels. The basic features of the model are:

(1) Aircraft geometric representation - The size, shape, and position of each of the internal and external aircraft components are represented by geometric shapes such as polygons, rectangular polyhedrons, and truncated quadric surfaces.

(2) Missile trajectory generation - The user may provide a missile trajectory or may require the computer to generate a set of trajectories with specified statistical properties (mean and standard deviations).

(3) Missile fuzing computation - The analyst may select from several missile fuze simulations to allow the computer to determine the detonation point along the trajectory. Models are provided for infrared, microwave, and active optical fuzes. If the analyst elects to specify the encounter trajectories, the detonation points may be determined by the fuze simulation or may be specified. The fuze simulation must be used if the trajectories are computer generated.

(4) Damage mechanisms - The program reports target damage which results from (1) Direct hit - damage resulting from a collision between the body of the missile and designated target components. (2) Blast damage - crushing the aircraft due to the effects of over-pressure on the aircraft structure. (3) Fragment damage to the aircraft structure due to impact and penetration of components or by warhead fragments.

The vulnerability of components subjected to fragment damage may be designated as belonging to one of six different vulnerability categories involving one of three kinds of damage evaluation. Components may be described as vulnerable to single fragment effects characterized by a given $P_{K/H}$ function or by multiple fragment damage which can be evaluated using either an energy density or area removal criteria.

(5) Target system configuration - The user may specify aircraft systems for which survival probabilities are to be reported for each simulated encounter. Such system descriptions (e.g., fuel, power, or control systems) represent the functional relationships or components as determined by failure analysis of the aircraft target. Reports of the causes of damage (e.g., fuel, fire, structure kill, or avionics loss) can be obtained. System and subsystem survival probabilities are combined in specified ways to obtain overall target survivability for different levels of aircraft destruction.

d. Documentation: No formal report available.

7.3.3.13.1 Aircraft geometric representation. The aircraft surfaces, including skin and major internal and structural components, are represented in the model as a combination of analytical equations which characterize basic geometric shapes. The shapes which the user may employ are polygons, boxes and quadric surfaces. The number of shapes which represent the target is limited to 100, including a maximum of 50 polygons (each with as many as 6 sides), 50 boxes and 50 quadric surfaces bounded by up to 60 planes. If these limits are too restrictive and additional computer storage is available, they may be increased. In addition to its shape, each component is characterized by a unique material composition and thickness which determines its resistance to fragment damage. This allows the program to assess the damage which the warhead may impart to each component individually. Furthermore, this allows different components of the same system to have different vulnerability criteria. Fuel tanks may be designated as vulnerable to multiple fragment effects characterized by the energy density of the fragment pattern, while pumps and piping may be vulnerable to penetration.

7.3.3.13.2 Missile representation. The missile is represented as a set of points. These points are used to determine whether the missile body strikes the aircraft. Other points specified for the missile include the position of the proximity fuze sensors and locations of the warhead fragments prior to detonation. The program provides sufficient storage for a maximum of 36 fragment polar zones in the warhead description. Each zone may include three different mass and velocity classes. At present, warhead fragmentation characteristics are symmetric with respect to the warhead centerline (i.e., no shaped charge or aimable warheads). The warhead description requires that the following parameters be provided:

a. polar angular region in which fragments are ejected.

b. fragment mass

c. fragment initial velocity at each boundary

d. number of fragments of this mass for each polar zone

e. initial position of fragment in the warhead

f. fragment material

g. fragment shape

This data is typical of that obtained from arena testing of U.S. warheads. When the analyst is tasked to obtain survivability against foreign missiles or for future designs for which little or no warhead data is available, the above information can be estimated from the warhead's weight and dispersion pattern. The sample case provided in the user's manual illustrates this method.

7.3.3.13.3 Terminal engagement geometry. The following four (right handed) coordinate systems are employed:

a. System 1: A system fixed to the target and originating at its center of gravity. This system Y_T axis is along the aircraft center line (positive forward) the X_T axis is out the starboard wing and Z_T is directed upward.

b. System 2: The missile coordinate system with its origin at the warhead center and oriented such that the missile center line is along the positive Y_M axis, and in level flight the Z_M axis is directed upward.

c. System 3: The reference (or inertial) system related to a stationary flat earth with Z_{REF} directed upward.

d. System 4: The relative velocity system in which the positive Y_C axis is directed along the closing velocity vector and the X_C axis is horizontal, i.e., lies in the X_{REF}-Y_{REF} reference plane.

The target system is related to the reference system through roll, pitch and yaw angles ψ, θ and ϕ. The missile system is related to the reference system through elevation and azimuth angles EL and AZ. The introduction of the reference coordinate system for measuring the orientation of the missile and aircraft is useful when the terminal engagement parameters are obtained from a missile performance or engagement simulation of the intercept of a missile with a maneuvering aircraft. In cases where the terminal conditions are input relative to the aircraft, the reference and target system can be combined by setting ψ, θ and ϕ to zero. All rotations in a counter clockwise direction are considered positive. Thus positive elevation angles indicate that the aircraft or missile is climbing and negative angles indicate a dive. Positive azimuth angles (less than 180°) signify an orientation in the $-X_{REF}$ hemisphere. If both the aircraft and the missile have 0° azimuth orientation, the missile will approach the target from the rear, whereas a missile with a 180° azimuth orientation and aircraft at 0° azimuth angle (or vice versa) represents a head-on shot.

The ideal guidance aimpoint is specified with respect to the aircraft and is fixed for all terminal approach conditions. The guidance miss distance vector, δ , is defined as the perpendicular distance between the missile trajectory and the aimpoint. When Monte Carlo trajectory samples are desired and a non-zero circular probable error (CEP) is specified, the program will calculate the miss distance so that the probability of ($|\delta| \leqslant$ CEP = .50).

7.3.3.13.4 Program output. For each simulated missile/aircraft encounter the program prints the following information:

a. A summary of the terminal encounter including missile trajectory and fuze performance.
b. An aircraft component damage summary.
c. Subsystem, system and total aircraft survival probabilities with statistical information.

7.3.3.13.5 Summary of terminal encounter parameters. The following information is printed for each missile trajectory as a summary of the engagement situation:

a. The miss distance of the missile measured from the aircraft center line at the time of warhead detonation.
b. The miss distance from the aimpoint measured perpendicular to the closing velocity at the time of closest approach (the closest point between the missile trajectory and the guidance aimpoint).
c. The elevation angle of the missile with respect to the aircraft based coordinate system.
d. The azimuth angle of the missile measured with respect to the aircraft or target system.
e. The range vector from the target CG to the missile warhead center at detonation.
f. The missile closing velocity vector expressed in the target system.
g. If the missile strikes the aircraft, the name of the affected component.

7.3.3.13.6 Aircraft component damage summary. The following information is printed out for each aircraft component to summarize the amount of damage sustained as a result of each missile encounter.

		Program Variable
a.	Component number	
b.	Component name	COMNAM
c.	Component material type	COMMAT
d.	Component vulnerability type	COMTYP
e.	Number of fragments which struck the component during the encounter	COMHIT
f.	Total area removed from component surface	TOTAL
g.	Probability of component kill	CKILL

The possible component vulnerability types available are: (a) energy density vulnerable, (b) single fragment critical, (c) area removal vulnerable, (d) non-critical, (e) non-vulnerable to direct hits, (f) non-critical IR source.

7.3.3.13.7 Survival probabilities. For each aircraft system, the following statistical information is printed:

	Program Variable
a. System Name	KNAME
b. Probability of system survival during the last encounter simulated	P(I2)
c. Mean system probability of survival over all encounters	APK
d. Standard deviation of system survival probabilities	SSD
e. Standard error of the mean	SEM
f. 90% confidence interval	PLOWER, UPPER
g. No. of kills of this system	NKILL

In addition, the blast and direct hit survival probabilities are printed.

The data is read in the following order (1) target geometry, (2) system definitions, (3) warhead data, (4) fuzing data, (5) blast envelope dimensions, (6) limiting parameters, and (7) engagement parameters. However, only the engagement parameters may be changed during subsequent executions.

The program uses an iterative time-step procedure in two situations. In the first instance, time stepping is used to move the missile along its trajectory to determine the positions at which fuzing and warhead detonation occur. In the second case, the fragments' trajectories are produced by an iterative process to account for effects of aerodynamic drag and target motion. These trajectories are followed until the fragments strike the target or pass beyond it entirely.

7.3.3.14 SESTEM II. SESTEM II is a computer program to evaluate the terminal effectiveness of nonnuclear missiles against aerial targets.

a. Sponsoring agency: USAF/ASD/KROT Wright-Patterson AFB, Ohio.

b. Use: Assists in preliminary warhead design and fuze optimization for short range missiles. Used to formulate tactics and electronic countermeasures. Used in air-to-air duels and missile launches.

c. Description: The target is simulated in the computer as a collection of various shapes representing the various vulnerable, masking, or fuzing components. Each vulnerable component has assigned its appropriate table of fragment vulnerable areas as a function of aspect and striking velocity. The program constructs the external blast kill contour for the target, missile and altitude being evaluated using the appropriate input data. The computer represents the components by means of a grid of variable side length scribed on the surface. A "target point" is generated in the center of each grid square, represented by direction cosines, and x, y, and z coordinates. The target point is then used to represent that grid square in subsequent fragment interaction computations. The missile warhead parameters and fuzing equations are simulated in the program using the static input data listed below.

Dynamic resolution of the static warhead input data for the encounter conditions being considered is done internally in the program. Various types of fuzes; radar, contact, or proximity; may be simulated. The target and the missile are assumed to fly constant speed, straight-line trajectories during the terminal phase. They approach along their relative trajectories until the fuzing equations are satisfied. After the appropriate delay time the warhead detonates and the dynamic interaction with the vulnerable components is computed. The probabilities (P_K) of killing the target by blast, direct hit, and each component by fragments, are computed and combined to predict the probability of target kill. Early or late fuzing effects may be examined by using as many as 11 fuzing points for each trajectory.

Various means for the generation of trajectories are available to compensate for errors and unknowns in the actual trajectory (CEP). Other parallel trajectories may be generated randomly by assuming various types of expected distributions or by discretely specifying trajectories. The encounter P_K is then computed as the average of that obtained from the various trajectories.

d. Documentation: No detailed description has been written. A general description of a somewhat earlier form of this simulation is contained in: ASBES WP 67-13, "SESTEM I and II - Missile Terminal Effects Models" (U), CONFIDENTIAL Report, December 1967.

7.3.3.14.1 Input data. The program requires three general types of input data as follows:

a. Encounter Data
    (1) Terminal geometry
    (2) Missile aimpoint
    (3) Target and missile encounter altitude

b. Missile Warhead and Fuze Data
    (1) Circular Error Probable (CEP)
    (2) Fuzing Equations
    (3) Fuze Delay Time
    (4) Fragment sprayband and fragment distribution
    (5) Fragment average mass and initial velocity
    (6) Fragment cross-sectional area and coefficient of drag

c. Target Data
    (1) Component size and location
    (2) Individual component fragment
    (3) External blast kill contours

7.3.3.14.2 Output and options. The output of the simulation is very flexible and may be readily altered to conform to the usage being made of the program. Normally the output is the probability of kill due to direct hit, blast and fragments averaged over the 90 trajectories characterizing the encounter. For parametric studies the probability of kill due to each mechanism; direct hit, blast, or fragment kill of each fragment vulnerable component; may be generated separately, as well as the averaged P_K due to all of them. These data may be generated for as many as 11 different fuzing points on each trajectory.

7.3.3.14.3 Model limitations.

a. Both the missile and the target are assumed to be flying straight, unaccelerated trajectories during the terminal phase. This has been shown to be a satisfactory assumption as long as the beginning of the endgame is not greater than several hundred feet.

b. Only 36 components may currently be used to represent the target aircraft. This limitation was dictated by core storage requirements in ASD's IBM 7094 computer. Since small components in close proximity to each other may be 'lumped' together, this limitation has never seriously affected the accuracy of target representation or the results. With the larger CDC 6600 computer core storage capabilities, this limitation could be removed if desired. This would of course result in a penalty in increased time to run the computer and to prepare the target for the computer.

c. Perfect reliability for the warhead and fuze are assumed. This assumption is easily removed by degrading the probabilities of kill by the appropriate factor. Perfect reliability is assumed because of the difficulty of obtaining the data on some systems, and also to provide absolute comparisons of the relative effectiveness of threat missiles.

d. The blast kill is assumed to be a "yes-no" thing, with detonation on or inside the contour producing a kill, while detonation immediately outside the contour is assumed to result in no kill. Available test data indicates that this may not be an unreasonable assumption. Additionally, detonations in the region immediately outside of the assumed blast kill contour generally result in a high fragment kill probability, so this assumption does not usually affect the final engagement P_k markedly.

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7.4 Analytical tools. The general procedure for conducting survivability analysis is presented in this section along with brief descriptions of the associated computer software.

7.4.1 Procedure. The general procedure for assessing survivability entails four sequential tasks:

a. Mission/threat definition

b. System and components requirements analysis

c. Vulnerability assessment

d. Attrition modeling

7.4.1.1 Mission/threat definition. The first task consists of defining the aircraft mission and threat environment. The objective of this task is to describe the aircraft mission and threat in sufficient detail for encounter simulation. The aircraft mission is described in terms of flight path, combat tactics, operational modes, and various configuration factors (e.g., weight, center-of-gravity location, remaining fuel, payload, etc, as functions of mission time). Definition of the threat environment includes complete descriptions of all hostile threats anticipated on the mission. The important parameters which describe the threats include gun position relative to the aircraft flight path, sighting and tracking method, slew rate limits, firing doctrine, penetrator mass and composition, and penetrator velocity/range characteristics.

7.4.1.2 System and components requirements analysis. In the second task, system and component requirements are analyzed with respect to the aircraft mission. First, the system functions essential for mission completion are determined. Essential functions are established down to the level that major components required to perform the function are identified. Then, a failure mode and effects analysis (FMEA) (reference 163) is performed to determine the various ways in which the individual components can be damaged and the effects produced by the damage on the rest of the system. Finally, survivability logic is constructed combining the results of the essential functions investigation with the results of the FMEA analysis. This logic relates failure of the entire system to the survival characteristics of the individual components. It can be expressed in many ways, as survivability logic diagrams (reference 73), as Boolean survivability logic statements (volume I or reference 161), or simply as a list of critical and redundant components.

7.4.1.3 Vulnerability assessment. A vulnerability assessment of the individual components in the system is performed in the third task. Vulnerable area tables are obtained for each component damage mode of interest. These tables express the vulnerability of the components as functions of attack direction, threat type, and penetrator impact velocity. Vulnerable area is defined by the equation:

$$A_V = P_{d/h} A_p$$

where:

A_V = Vulnerable area (areal dimensions)

$P_{d/h}$ = Probability of damaging the component, given that it is hit by a penetrator of given mass and velocity (nondimensional)

A_p = Component presented area (areal dimensions)

Given a threat penetrator with specific mass and velocity, component vulnerable area depends on the physical size and composition of the component, the amount and type of shielding material surrounding the component, and the penetration characteristics of the threat. Physical characteristics of the component and shielding material surrounding it are obtained from engineering drawings of the system. Penetration characteristics are obtained from experimental data.

7.4.1.4 Attrition modeling. Finally, in the last task, the results of the three previous tasks are input to an attrition model which simulates the aircraft/threat engagement process and calculates the probability of system survival (or alternatively the probability of system kill). Attrition models compute the probability of hitting various locations of the aircraft with the threat projectiles and the probability of damaging the individual components which comprise the system. The probability of killing the system is then computed by combining the individual component damage probabilities according to the survivability logic established in the second task. In addition, some attrition models also compute various parameters which measure the relative contributions of the individual components to the overall system kill probability. These models are especially useful in performing design trade-off studies with aircraft survivability enhancement as a goal.

7.4.2 Computer software. Table 7-I lists some of the computer programs which can be used to analyze survivability. In general, the programs perform the last two tasks in the analysis procedure - vulnerability assessment and attrition modeling. They are further subdivided in the table according to their specific purpose, as follows:

a. Shot line generators

b. Vulnerable area routines

c. Kill probability routines

The routines in the first two subdivisions are used to construct component vulnerable area tables. The routines in the last subdivision simulate the aircraft/threat engagement process and evaluate aircraft kill probabilities. Brief descriptions of the routines within each subdivision are given in the following paragraphs.

7.4.3 Shot line generators. These programs generate shot line descriptions of aircraft targets for use in the codes which calculate vulnerable area. The technique used in these programs involves modeling the aircraft and its component structures with a set of geometric bodies. Shot line descriptions are obtained by projecting the target model onto a grid network perpendicular to the attack direction and by passing parallel shot lines through the individual grid cells. The programs trace the paths of the shot lines through the aircraft, generating sequential lists of components encountered along each shot line. This information is used in the "detailed" vulnerable area routines to determine component shielding and impact/exit obliquities.

7.4.3.1 Program comparisons. Three shot line generator routines are described in table 7-I, MAGIC, GIFT, and SHOTGEN. Two of these three codes, GIFT and MAGIC, are basically the same program. GIFT is an improved version

TABLE 7-I. Survivability analysis tools.

PROGRAM	OPERATION STATUS	DESCRIPTION	DOCUMENTATION
Shot Line Generators			
MAGIC	In production, validated	Uses basic body shapes such as spheres, boxes, cylinder, etc. to model the target. Output ray history data includes line-of-sight thickness through each region and entrance obliquities.	"MAGIC Computer Simulation." Tech Note 4563-3-71, Naval Weapons Center, May 1971. (Ref. 7, 8, 9)
GIFT	In production, validated	Upgraded version of MAGIC with simpler input and faster (cheaper) computer run time. Same output data as MAGIC.	User's Manual in progress.
SHOTGEN	In production	Uses triangular patchwork method to describe the target. Output information includes components encountered along each shot line, entrance and exit obliquities, and coordinates of entrance point.	User's/Analyst's Manuals: "Shot Generator Computer Program." Tech Note 4565-3-70, Naval Weapons Center, 1970. (Also published as Report 61 JTCG/ME-71-5). (Ref. 10 & 11)
Vulnerable Area Routines			
VAREA	In production, validated	Needs shot line description of target as input. The program computes vulnerable area tables of the target and its vulnerable elements for user specified penetrator masses, velocities, and attack aspects. THOR relations are used to account for penetrator mass and velocity decay as it penetrates successive components. Does not account for spalling effects or ricochet. Best suited for in-depth analysis, too expensive for preliminary design estimation.	"VAREA Computer Program," Tech Note 4565-1-71, Naval Weapons Center, February 1971, (also published as Report 61 JTCG/ME-71-6). (Ref. 12 & 13)
VAREA02	In production, validated	Evolved from VAREA program. Added the air gap fire model, the multiply vulnerable component model, the THOR/DRI penetration option, and the component incremental vulnerable area option. Input and output are similar to VAREA. Best suited for in-depth analysis.	
COVART	In production, validated	Combines the fixed wing vulnerable area routines from VAREA02 and the battle damage repair time and helicopter vulnerable area routines from the HART computer program. Accepts shot line input data from MAGIC and SHOTGEN, or any other source provided it is compatible with input format requirements. COVART is perhaps the most versatile of the modern vulnerable area routines based on the shot line approach.	User's/Analyst's Manual: "COVART, A Simulation Program for Computation of Vulnerable Areas and Repair Times." Report JTCG/ME-75-No Number, August 1975.

TABLE 7-I. Survivability analysis tools (continued).

PROGRAM	OPERATING STATUS	DESCRIPTION	DOCUMENTATION
Vulnerable Area Routines (Continued)			
COMVAT	In development	Simplified vulnerable area routine developed specifically for obtaining preliminary design type estimations of vulnerable area. Does not follow the shot line approach, rather the target aircraft is described in terms of "representative" component types, thicknesses, and shielding. Currently limited to consideration of ball and AP type projectiles. Very easy and inexpensive to use.	Methodology and software are documented in "Backup Flight Control Design Considerations to Increase Survivability of Aircraft," TCG/AS-76-, Naval Air Development Center, April 1976.
Kill Probability Routines			
P001	In production, validated	Simulates the aircraft/ground threat encounter process and computes the single shot and multiple shot kill probabilities for a target aircraft from consideration of its vulnerable areas. This program can also be used to generate encounter history data (bypassing the kill probability evaluation) for use in other kill probability routines which do not include an aircraft/ground thread encounter model.	User's/Analyst's Manuals: "Antiaircraft Artillery Simulation Computer Program, AFATL Program P0001," Tech Note 3565-16-73, Naval Weapons Center, September 1973.
PKILL	In development	Computes aircraft kill probabilities based upon the Boolean algebraic approach to survivability analysis. Specifically designed for preliminary design work. Generates individual component dependence measures which are extremely useful in developing survivable flight control systems. Input requirements (encounter history data, vulnerable area tables, survivability logic statements) and computer runtime are very modest.	Methodology and software are documented in "Backup Flight Control Design Considerations to Increase Survivability of Aircraft," TCG/AS-76-, Naval Air Development Center, April 1976.
SAG/FCS	In production, validated	Similar to PKILL only it uses a graphical method to express survivability logic and a truth table approach to evaluate system kill probabilities.	Methodology and software are documented.

of MAGIC with simpler input requirements and more efficient computation. The third code, SHOTGEN, is similar to the other programs, but uses the triangular patch method, a more general method of describing component geometries. The GIFT and MAGIC codes use basic body shapes such as spheres, boxes, cylinders, ellipsoids, etc, to describe component geometries. These three codes are discussed in detail in paragraph 5-6. All of the shot line generators are relatively expensive to use, as they require detailed input information and perform many computations in generating the shot line data. Thus, these routines are only appropriate for in-depth analysis problems. Of the three, SHOTGEN requires the least computer time for a typical problem. MAGIC requires the most time, and GIFT is in the middle.

Additional shot line generator computer programs are discussed in reference 164.

7.4.4 Vulnerable area routines. These programs generate component vulnerable area tables for use in the codes which calculate kill probabilities. The vulnerable area routines listed in table VII can be divided into two groups: the so-called "detailed" routines, which use the shot line approach to compute vulnerable area, and the "simplified" routines, which use simplified approaches to estimate vulnerable area. The routines in the detailed group are used for problems requiring in-depth analysis. The simplified routines are appropriate for problems in which a cursory analysis is desired.

7.4.4.1 Detailed group. Of the programs listed in table 7-I, COVART, VAREA02, and VAREA belong to the detailed group. Inputs to these programs consist of shot line descriptions of the target model, conditional kill probability functions, empirical penetration relations (THOR and/or DRI equation constants), and weapon characteristics data. Component vulnerable area data are output in tabular form for use in the kill probability routines.

a. VAREA is the oldest and least comprehensive of the three routines in this group. It was developed in 1965 to conduct vulnerability analyses of systems subjected to fragmentating-type threats and uses THOR penetration equations to compute penetrator mass and velocity decay.

b. VAREA02, completed in 1973, evolved from the VAREA program. Its added capabilities include (1) a projectile penetration mode, (2) an air gap fire model, (3) a multiply vulnerable components model, and (4) an option to use DRI penetration equations instead of THOR relations.

c. COVART currently represents the state-of-the-art in vulnerable area routines. It incorporates all features of the VAREA02 program and includes a battle damage repair time model.

The computer program COMVAT is representative of the routines which belong to the other group, the "simplified" codes. These routines were developed to fulfill the need for shortcut methods of estimating vulnerable area. They are intended to be used in situations when use of the more sophisticated routines is not feasible or timely, such as during preliminary design studies. The simplified routines are not as accurate as the detailed routines, but they require considerably less effort and computer run time to use.

COMVAT was developed specifically to compute the vulnerable areas of aircraft components to projectile threats. It is based upon the same principles as the detailed routines, but it does not use shot line descriptions of the aircraft; instead, it computes component vulnerable areas on the basis of input data describing "average" shielding conditions on the components. The THOR penetration equations are used to model projectile velocity decay. Secondary effects such as spalling, projectile yawing motions, and projectile breakup are ignored. Additional information on the COMVAT program is contained in reference 161. References 164 and 165 contain descriptions of similar routines written for desk-top calculators.

7.4.5 Kill probability routines. The program in this category perform two separate functions - they simulate the aircraft/threat engagement process, and they compute the probability of kill for the system. The first program listed in this category in table VII, P001, combines the two functions in one routine. The other routines cited, PKILL and SAG/FCS, perform only the second function, computation of kill probability.

a. P001 computes the probability of kill of a target aircraft flying a predefined flight path, as a result of its being fired on by ground-based antiaircraft artillery. It is usually used in conjunction with one of the detailed vulnerable area routines (COVART, VAREA02, or VAREA); however, vulnerable area tables can be input from any source as long as they are in the correct format. A modified version of P001 is also available which only simulates the aircraft/threat engagement process and does not compute kill probability. This version can be used to generate encounter history data for routines which only compute kill probabilities such as PKILL. Separation of the encounter simulation process from the kill probability computations is especially important in conducting concept trade-off studies. In this application, separation of the two functions substantially reduces analysis costs, as the aircraft/threat engagement process only needs to be simulated once for all concepts. (Differences between the concepts usually will not affect the encounter results; they only affect the kill probability results). Documentation of the changes required in P001 to modify it to only simulate aircraft/threat encounter is contained in Volume II of reference 161.

b. The second computer program in this group, PKILL, is used to compute kill probabilities, given a description of the aircraft/threat encounter results. This routine is based upon a Boolean algebraic approach to survivability analysis. Boolean algebraic statements are used to define the combinations of component losses which result in aircraft loss. Aircraft kill probability is obtained by evaluating the probability associated with the Boolean statements. The evaluation procedure involves substituting the individual component kill probabilities directly into the Boolean statements, using the basic rules of Boolean analysis to compute the results. In addition to computing aircraft kill probability, PKILL also computes component criticality parameters and component sensitivity parameters. Criticality parameters measure the contributions of the individual components to the overall system kill probability. Sensitivity parameters quantitatively measure the effect of changes in component kill probability on system kill probability. These parameters provide insight into the survival characteristics of the system and are particularly useful in investigating potential methods of increasing survivability. In this application, the criticality parameters can be used to single out the individual components which need to be improved, and the sensitivity parameters can be used to obtain estimates of the effects of suggested modifications. Input requirements for PKILL include component vulnerable area tables, encounter history data, and Boolean survivability statements. The vulnerable area data requirements are modest, consisting of only six attack directions for each component. Normally, these data are obtained from COMVAT; however, the tables can be obtained from any source as long as they are in the correct format. Encounter history data can be obtained from P001 or any other program which simulates aircraft/threat encounters on a shot-by-shot basis.

c. Aircraft kill probabilities can also be computed with the remaining program in this group, SAG/FCS. Actually, this program computes survival probability instead of kill probability, but the two are equivalent (one is the complement of the other). SAG/FCS is also based upon the Boolean algebraic approach to survivability analysis; however, it utilizes different methods of inputting and evaluating survivability expressions than PKILL. SAG/FCS uses the survivability modes of aircraft component kill (SMACK) chart technique, Figure 7-11, to input survivability logic. In this technique, survivability logic is expressed in diagrammatical form rather than in algebraic form. Survivability expressions are evaluated in SAG/FCS using a truth table analysis procedure in which all possible combinations of component survivals are formed, and system survival probability is computed from the sum of the probabilities of those combinations resulting in aircraft survival. Input requirements for SAG/FCS are similar to the input requirements for PKILL, consisting of component vulnerable area tables (six attack directions), hit density information, and survivability logic. Hit density data are a simplification of encounter history data. The difference is that encounter history data are a shot-by-shot record of the engagement process, whereas hit density data are one set of numbers summarizing the outcome of all shots.

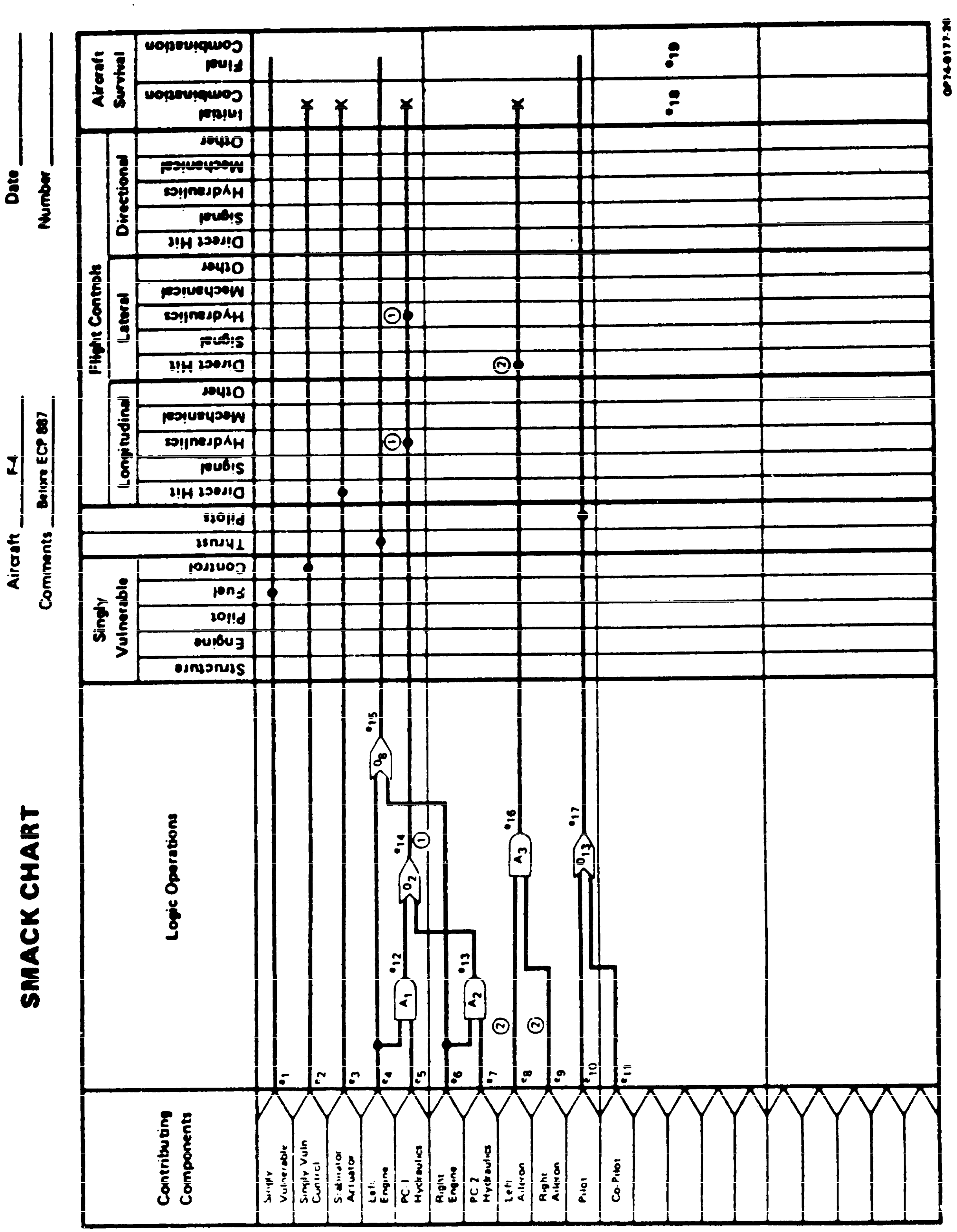

FIGURE 7-11. Typical SMACK chart.

8. SYSTEM EFFECTIVENESS

8.1 General. The justification for selection and incorporation of a survivability feature into an aircraft system must be proven by an evaluation of its contribution to the effectiveness of the total system. This effectiveness must also be evaluated in terms of its impact upon the total life-cycle cost of the system. Currently, there is no single life-cycle cost assessment method established or endorsed for triservice use by the JTCG/AS or other service agencies. The specific method to be used on any given aircraft system is established through negotiation between the contracting agency and the contractor. This section contains a compilation of methods and approaches that are presented as examples for potential use by the reader. The major objective of this section is to present the most significant trade-off factors that must be considered for aircraft survivability enhancement and emphasis on the importance of their impact upon the systems lift-cycle cost. This is considered to be one of the most important factors in the ability of the government and industry S/V Engineering Community to ensure that adequate and effective survivability of each aircraft weapon system is achieved. This process is essential to provide the aircraft systems design management (both government and industry) with the information necessary to enable the proper decisions on incorporation os specific design features to be made. This is illustrated in Figure 8-1 (Reference 23) that shows the dependence of design direction upon the results of S/V trade studies and system cost effectiveness analyses. As shown, it is an iterative process that is continued throughout the design and development program. In this section, general trade off and life-cycle cost evaluation methods are presented. Specific classified examples of the methods are contained in Volume 4 of this publication.

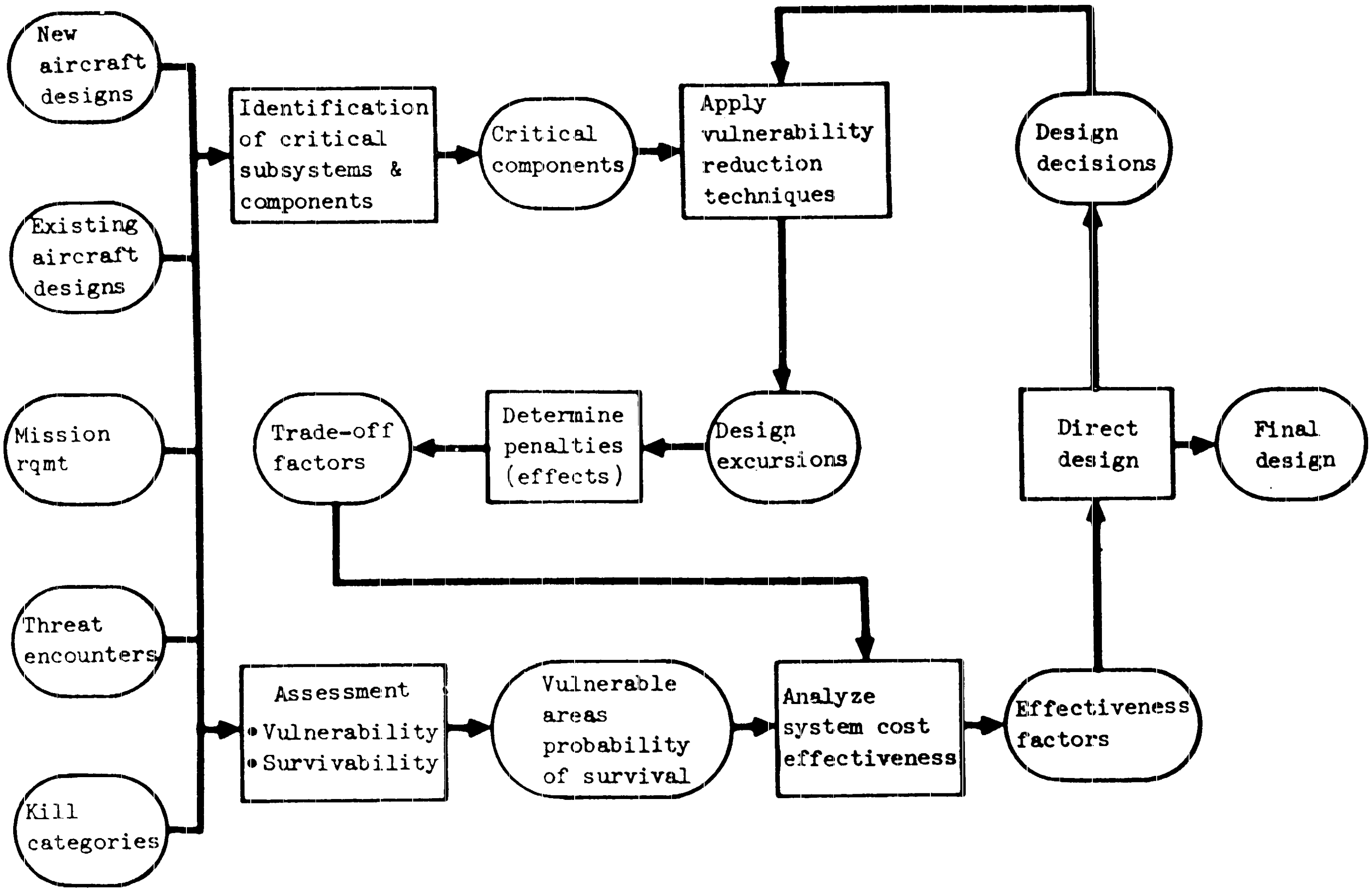

FIGURE 8-1. Survivability tradeoff studies program.

8.2 Tradeoff factors. The basic tradeoff factors for survivability enhancement features are related to the effect each has on the overall system effectiveness and lifetime cycle costs, including combat and noncombat operations. They include the following areas:

a. Probability of survival (P_s)

b. Vulnerability

c. Safety

d. Maintenance

e. Reliability

f. Logistics

g. Performance

h. Cost

i. Weight

j. Operational effectiveness

Each of the above factors must be carefully evaluated to determine the impact of their influence upon the total system costs for each candidate survivability enhancement feature. To evaluate the overall impact, a summary of the tradeoff factor values can be developed, as shown in Figure 8-2. General definitions of the trade factors are contained in subsequent subparagraphs.

8.2.1 System safety. Probable changes in system safety rates must be evaluated for candidate survivability enhancement techniques. In most cases, they would be expected to be improvements for safety. For example, a lubrication bypass system that permits continued flight after weapon effects damage to an oil cooler provides a greater probability of safe recovery of the aircraft and aircrew because of a material failure or maintenance error that also results in lubrication oil leakage from the oil cooler and its associate lines, hoses, and components.

Aircraft crashworthiness is defined as the ability of the aircraft structure to maintain living space for occupants throughout a crash, as well as the ability of the particular personnel seating and restraining system to adequately support the individual against the accelerations produced during a potentially

Survivability Enhancement Techniques	Trade off factors															
	Installed weight	Flyaway cost	RDT&E cost	Installed volume	Total system survivability	Total system vulnerability	Maintenance	Human factors	Safety	Reliability	Logistics	Secondary power	Electrical power	Total system cost impact	Total system weight impact	Life-cycle cost impact
Minimized detection																
RCS																
Infrared (IR)																
Visual																
Aural																
Active mission countermeasures																
Performance																
ECM/threat detection																
Decoys/chaff/aerosols																
Tactics																
Protection methods																
Redundancy/separation																
Damage tolerance																
Delayed failure																
Leakage suppression/control																
Fail safe response																
Masking/armor/geometry																

FIGURE 8-2. Survivability enhancement techniques and tradeoff factors summary matrix.

survivable aircraft crash. This parameter also includes the requirement for insuring that the integrity of the aircrew station area is not violated through the failure of bracketry or attachments which are used in installing passive defense provisions. An obvious degradation to crashworthiness will involve the effects of armor weight added to the seat or system, and also the backup structure which ultimately carries the loads transferred from the seat-man combination during a crash situation. In addition, weapon systems should have fail safe operation so that if they fail (or are failed by enemy threat impacts), they remain in an unarmed condition. The above factors should be evaluated to determine their contribution to changes in:

a. Accidents per flying time

b. Aircrew survival per accident

8.2.2 Maintenance. Addition of survivability design features as a modification to an existing aircraft generally results in an increase of maintenance man-hours, (scheduled and unscheduled) for the total system. For new designs, the penalties can be minimized and, in some cases, may result in benefits. Each design feature must be judged on its own merits, such as the man-hours malfunctioning or time-inspection-limited piece of equipment. Concentration and integration of a number of components in a subsystem, to minimize its vulnerability to weapon effects, may also require less maintenance effort and time to troubleshoot and repair. The above factors are evaluated for changes in:

a. Maintenance man-hours per flight hour (MMH/FH)

b. Downtime per flight hour

c. Mean task times (accessibility)

8.2.3 Reliability. System reliability values can be affected by survivability enhancement features. The addition of redundant subsystem circuits may impose higher reliability requirements upon individual components within each of the redundant systems in order to attain the overall system reliability allocations. The above factors are evaluated for changes in:

a. Component reliability

b. Component redundancies

c. Mission success reliability

8.2.4 Logistics. The operation of military aircraft requires logistic support in order to perform their designated missions. The major items that can be affected by survivability enhancement features include fuel consumed, spares required, and payload (munitions) expended to achieve a given level of combat effectiveness. The addition of weight to a design, for survivability improvements, requires more fuel to be used to achieve a given level of performance. Increase in system complexity will affect the number of aircraft for specific missions over a given time period. These factors are evaluated to determine the changes affected in terms of dollar costs.

8.2.5 Performance. Aircraft performance penalties are generally expressed in terms of mission range (or radius) loss or reduction in payload. For major subsystem additions in the case of advanced aircraft designs, the penalties may be expressed in terms of aircraft growth, with performance factors remaining constant. Modifications to the fuel subsystem (foam in tanks, self-sealing tanks, etc.), for example, will result in a dry weight penalty and a corresponding reduction in fuel weight due to displacement. The combined effect of an increase in dry weight and a decrease in internal fuel weight can result in either decreased mission range capability or a reduced payload. Major changes may also affect limitations on aircraft speed and maneuverability. Smaller changes and weight additions will generally have a negligible effect on aircraft performance. Techniques which require displacement of external store stations can also significantly affect aircraft performance, depending on the particular aircraft and store configuration. Figure 8-3 shows a representative plot of performance trade-off results for a basic mission flight profile and payload.

8.2.5.1 Performance factors. Aircrew performance factors refer to the effects which the principal protection concepts have on the ability of the aircraft aircrew to perform their assigned tasks such as flying the aircraft, navigating, accurately delivering weapon/payloads, observing the terrain flown over, etc. The parameter also includes the effect on personnel mobility during emergency egress. Performance factors are measured for changes to those accountability items that influence cost or effectiveness:

a. Mission range

b. Payload capability

c. Turnaround time

d. Radar cross-section signature

e. Infrared (IR) signature

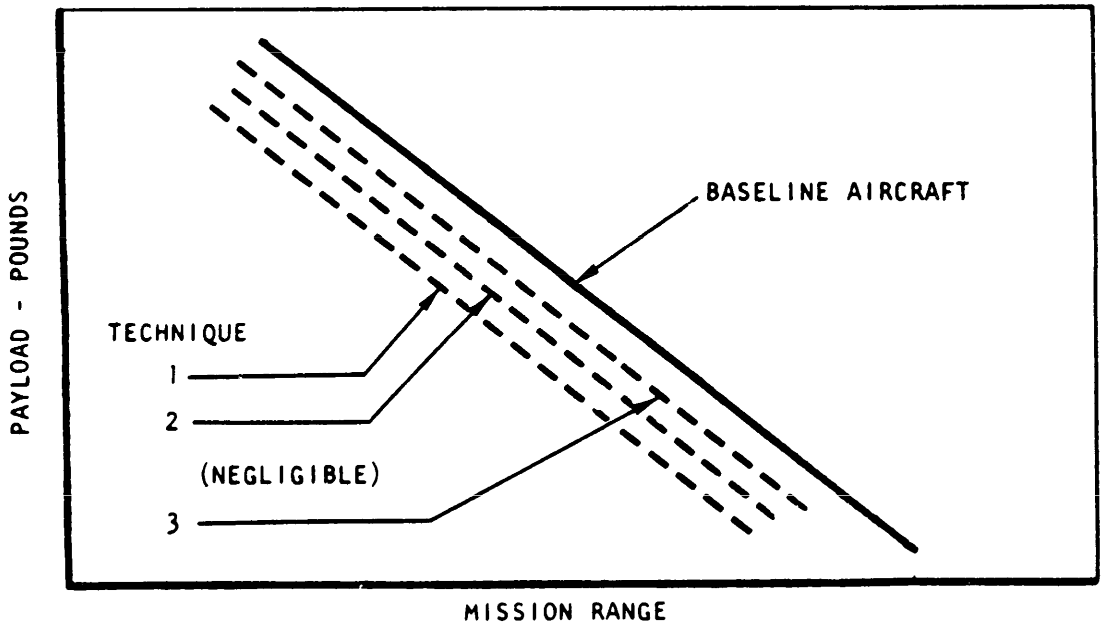

FIGURE 8-3. Effect of survivability enhancement techniques on aircraft performance.

8.2.6 Operational effectiveness. The capability of an aircraft to perform its designated missions is a measure of its operational effectiveness. The parameters involved in this area are:

a. Combat missions accomplished.

b. Number of targets killed.

c. Number of aircraft available for flight.

d. Number of training missions accomplished.

e. Utilization rate (number of hours flown per month).

8.2.7 Costs. The costs of an aircraft system is the one factor to which all trade-off study values must be ultimately related. It provides a basis upon which design management can decide what combinations of survivability enhancement features will be the most effective for a specific design configuration and hostile threat spectrum. Cost factors that may be influenced by survivability features are:

a. Development costs (RDT&E).
   (1) Aircraft design
   (2) Tests
   (3) Research

b. Acquisition costs
   (1) Production aircraft
   (2) Spares
   (3) RDT&E
   (4) PEMA (Planning Engineering Maintenance Ability)

c. Life cycle costs.
   (1) Peacetime operations/logistics
   (2) Wartime operations/logistics
   (3) Peacetime attrition
   (4) Wartime attrition
   (5) Acquisition costs

8.2.8 Probability of survival. Survivability assessment models consider the aircraft mission flight profiles, speed, altitudes, penetration distances, attack tactics, the numbers and types of defense elements encountered, exposure times, number of rounds fired, firing errors, and kill probabilities in computing mission or sortie probabilities of survival. In the broadest sense, the models use measures that reflect the probability that an aircraft will survive or, conversely, fail to accomplish its mission due to the action of enemy defenses. These measures involve both active and passive defense capabilities of the aircraft as well as the abilities of the enemy defense systems to find, hit, and destroy the aircraft. At present, no standard general evaluation model exists that will make such an evaluation possible for the wide class of situations that are encountered. Vulnerability assessment models, for example, are generally restricted to the situation where it is assumed that the aircraft has suffered a single hit, or multiple hits to specific subsystems, with exposure to a specific type or hostile defense weapon. The results (vulnerable areas) are then integrated into more general survivability models according to the particular situations involved. The general models evaluate survivability enhancement techniques in terms of increased survival payoffs by countermeasures, decoys, lethal defense, and other specific standoff and evasive tactics, as well as aircraft hardening. In a sense, the general survivability models can evaluate the outcome of the proposed offense and defense employment tactics, or these same type data can be developed parametrically.

8.2.8.1 Modifications. When an addition or modification is made to an existing baseline aircraft to enhance survivability, some penalties may be incurred due to additional costs, maintainability, reliability, logistics, or other pertinent operational factors associated with the modification. If the modification is large in terms of installation size and weight, it may also have a significant impact on the performance of existing operational aircraft. In the case of new aircraft designs, additional costs can result due to an increase in aircraft overall size and gross weight necessary to accommodate the modification assuming the basic mission performance requirements remain constant. It is in the initial design phases where there is opportunity to obtain the survivability benefits at the least and, in some areas, no penalty. A classical example is the arrangement of the airframe and subsystems ro provide natural shielding of the crew or essential subsystems. Air vehicle configuration analysis methods are used by the aircraft designer to evaluate the significance of design changes and modifications on aircraft characteristics and performance for new aircraft designs and existing designs, as required, throughout the aircraft's life cycle. Aircraft performance characteristics calculations include mission radius, range, speed and time, take-off and landing distances, maneuver load factor, specific excess power, etc. Variable design parameters include external shapes and areas (wing loading), thrust/weight ratios, gross weight, fuel weight, weight and volume of equipment (subsystems), operating items and/or payload, etc. The sensitivity of design changes on aircraft performance can vary considerably depending on the type of aircraft involved, mission requirements, and the nature of the change. Figure 8-4 shows the sensitivity of subsystem weight increases on take-off gross weight for new aircraft designs, which in indicative of the growth factors for various classes of military aircraft. For existing operational aircraft, modification penalties will generally show up in terms of decreased performance, range, payload capability, and increased maintenance and support.

8.2.9 Survival/attrition relationships. For large numbers of repeated sorties per aircraft, such as is common in tactical nonnuclear strike operations, successful continuation of operations is sensitive to the level of combat attrition experienced per sortie. Even what appear to be relatively low attrition rates can result in significant aircraft losses and very large combat attrition costs during extended periods of operations. The data presented in Figure 8-5 show, for example, that for a total of 300 strike sorties per aircraft per year (an average of 25 sorties per month per aircraft) approximately 26% of the force is depleted if the average attrition rate per sortie is 0.1%. If the attrition losses are caused almost entirely by projectile impacts from small arms and automatic weapon threats, then a reduction in vulnerable area by 50% against these threats will reduce the attrition rate by approximately one-half (0.05%) or 14% force depletion for an equal number of

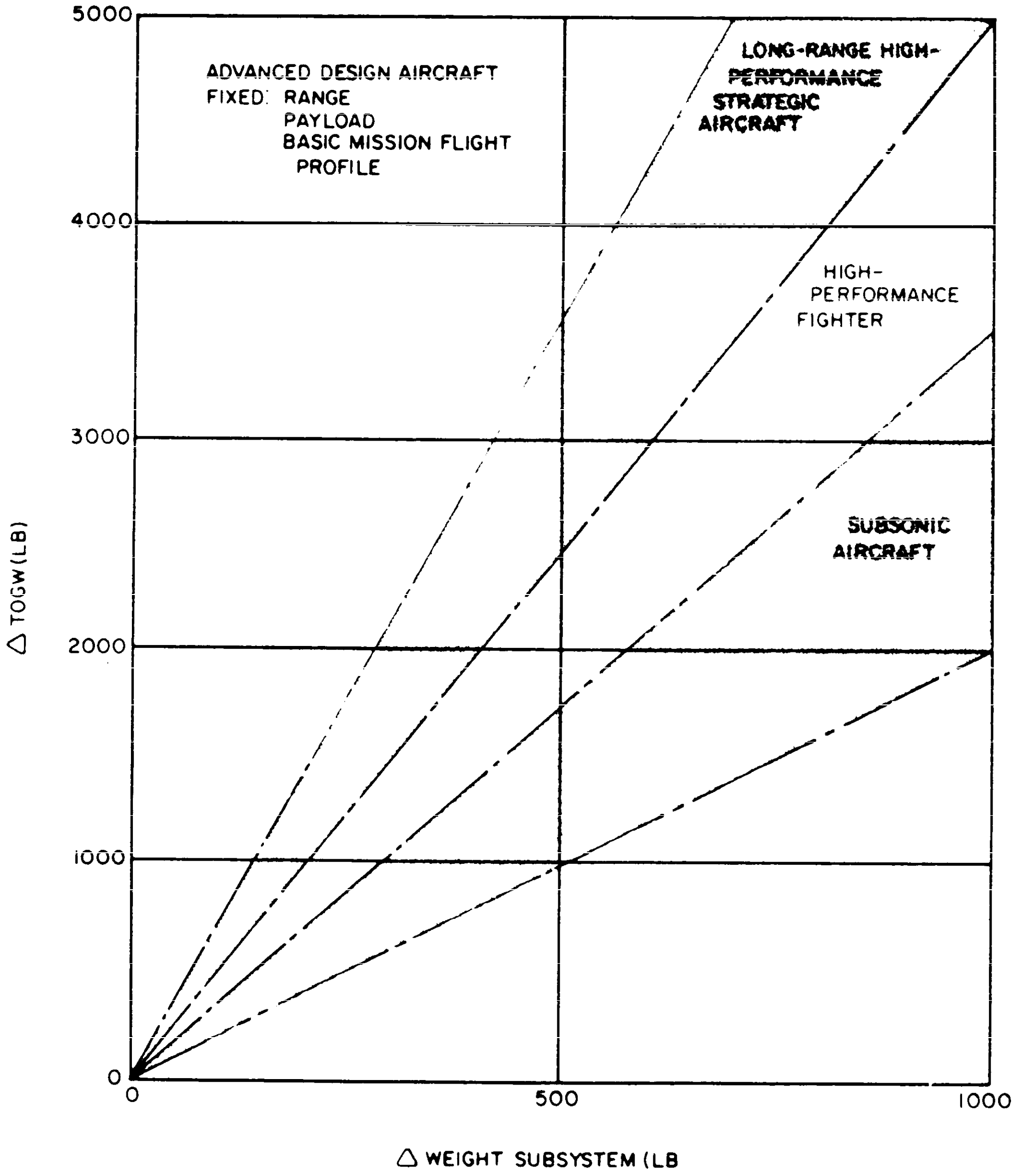

FIGURE 8-4. Takeoff gross weight sensitivity to increases in subsystem weight.

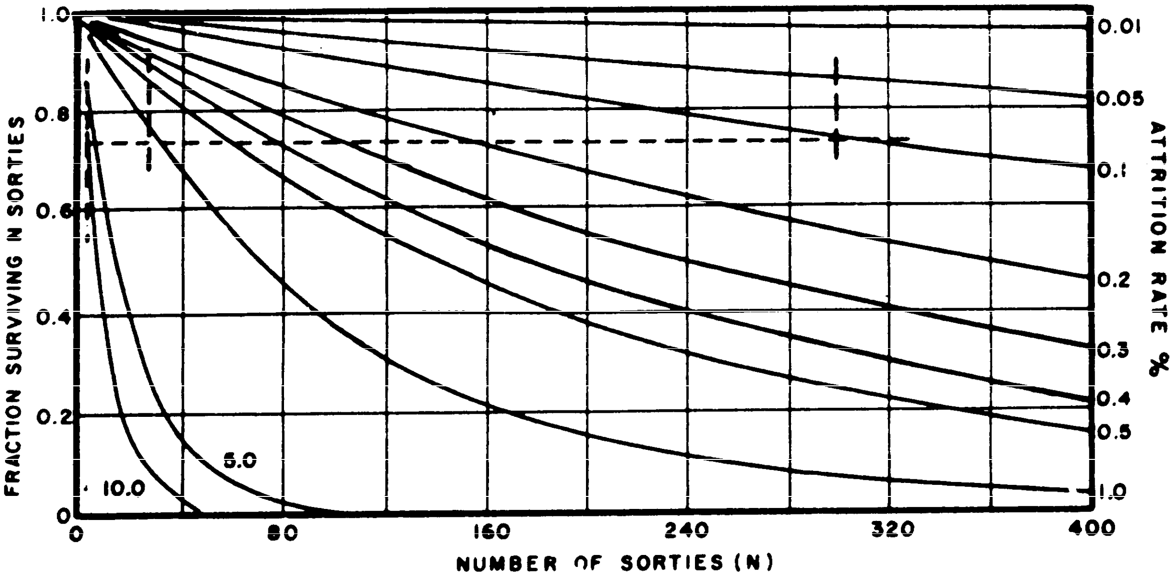

FIGURE 8-5. Survival as a function of attrition.

sorties, assuming other factors, such as tactics and payload, are constant. Since it is generally true that a large number of total combat losses often occur during a small percentage of the total number of sorties, the data show that for 30 or 3 sorties (10% or 1% of 300 sorties) and an attrition rate of 1% or 10%, respectively, the fraction surviving is also 0.74 or 26% annual depletion of the strike force. Survivability enhancement by vulnerability reduction methods can also reduce attrition rate and losses significantly for these higher threat environments. However, if the losses are incurred primarily from larger AAA rounds (57mm and above) and high-density fragments from large rockets and missiles with proximity fuzed warheads, more effective survivability enhancement payoffs are obtained by (1) improvement in penetration and attack tactics or (2) the use of countermeasures.

9. VERIFICATION PROCEDURES

9.1 General. For each design requirement in an aircraft system specification, a corresponding requirement in the quality assurance section of the specification is provided. The intent of this section is to establish the means by which the required level of survivability enhancement can be demonstrated and verified. Two basic methods are generally used, either individually or together. These are by analysis and/or test. The analysis method is used where sufficient test data is available on similar survivability enhancement design concepts or where the cost of testing will not significantly increase the confidence level provided by the analysis. For example, the total aircraft system survivability and vulnerability values are determined by analysis methods since it would be impractical to subject the total aircraft system to a series of tests representative of the total threat spectrum. Certain subsystems and components are subjected to tests to verify that the required protection level has been achieved. An example of a component-level verification test requirement, for a fuel cell, from ADS-11A (Reference 2) is provided.

a. The following is the test procedure to be followed to verify that the fuel cell is ballistically protected against 14.5 mm API projectiles when this capability is specified:
   (1) For fuel cells which are 100% protected against 14.5 mm API projectiles, one round shall be fired for each 15 gallons of fuel capacity. A minimum of four rounds and a maximum of ten rounds apply to this test.
   (2) For fuel cells which are only partially protected against 14.5 mm API projectiles, four rounds shall be fired.
   (3) When the requirements require four rounds, two rounds shall be 3/4 to fully tumbled and two rounds shall be fired 90 degrees to cell surface. For additional required rounds, 40% of the rounds shall be 3/4 to fully tumbled.
   (4) At least two of the rounds shall be fired into the corner area and all rounds shall be fired into the ballistically protected area or for fully protected fuel cells, the rounds shall be fired into the lower 1/4 portion of the cell.
   (5) The fuel cell shall be filled 2/3 full with Type I fluid and the fuel cell shall be mounted in an actual section of the aircraft structure. There shall be no cause for rejection of a test round (i.e., the causes for rejection of test rounds as stated in MIL-T-27422B are not applicable). All shots shall be at service velocity. A damp seal is required in two minutes.
   (6) This requirement shall be satisfied in addition to the qualification requirements specified in MIL-T-27422B (Reference 196) in regard to 0.50 caliber ballistic testing and the number of shots.

b. All fuel cell qualifications shall include at least two rounds fired so as to demonstrate, on a worst case basis, that the fuel cell is protected from airframe structure flowering into the cell material and holding the wound open.

9.2 Verification tests. Verification tests are also included in the specifications for specific components and materials where given protective or performance levels are required. For example, in MIL-STD-1288 Aircrew Protection Requirements, Nonnuclear Weapons Threat, (Reference 197) test requirements and procedures are provided in Section 6 of the document. For self-sealing fuel tank bladders, the verification test requirements are set forth in the specification MIL-T-5578C (Reference 198).

For individual subsystem and component nonnuclear S/V verification requirements, the reader is directed to Reference 22.

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