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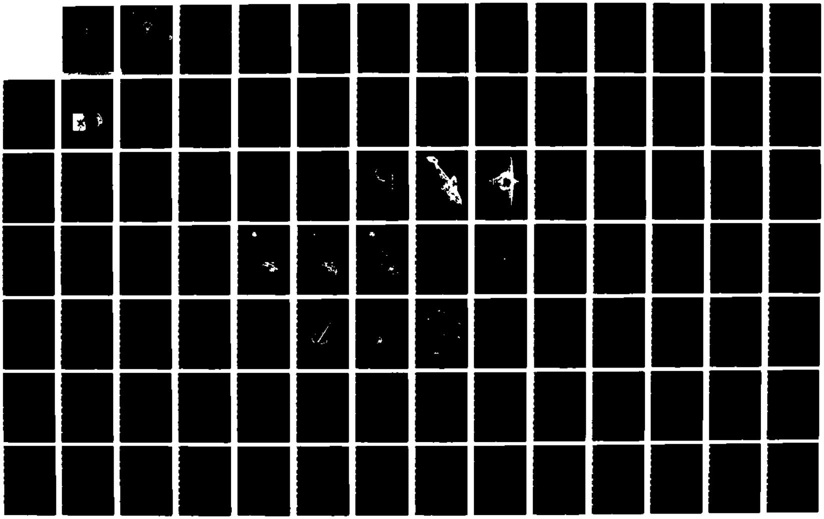

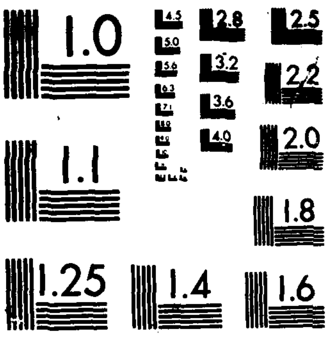

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Monterey, California

THESIS

A CASE STUDY OF A COMBAT HELICOPTER'S SINGLE HIT VULNERABILITY

by

James William Trueblood

March 1987

Thesis Advisor: Dr. Robert E. Ball

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A Case Study of a Combat Helicopter's Single Hit Vulnerability

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

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ABSTRACT

This thesis presents the methodology for a detailed vulnerability assessment of a generic helicopter in the conceptual/preliminary design stage. The intent of this thesis is to provide a workable and understandable example of a vulnerability assessment. Towards that end, the single hit vulnerability of a helicopter to a 100 grain fragment is determined using the methodology presented in the textbook, The Fundamentals of Aircraft Combat Survivability Analysis and Design.

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Most of all I would like to thank my wife, Debbie, and my sons, Danny and Jason, without whose support, love and understanding, nothing is possible.

I. INTRODUCTION

This case study is based on the concepts and methodology presented in The Fundamentals of Aircraft Combat Survivability Analysis and Design [Ref.1], by Dr Robert E. Ball, Professor of Aeronautics at the Naval Postgraduate School (NPS) in Monterey, California. As stated in Dr Ball's book, "The cost of modern aircraft weapon systems, coupled with the requirement that the system be effective, makes imperative the consideration of the aircraft's survivability throughout the life cycle of the system." The requirement for consideration of survivability throughout the life cycle, expressly implies the requirement for a comprehensive survivability program from day one of the conceptual/preliminary design phase. In order for this to happen, aircraft designers and others involved with the design and development of an aircraft must be made aware of the ways to enhance survivability and the methodology for assessing it. This case study was developed to give these people an example of the first step of a survivability program, namely a vulnerability study.

The study is performed on a generic aircraft of the author's own design in order to eliminate any problem of classification. This aircraft was designed to fulfill the requirements of AE4306 "Helicopter Design", taught by Prof. Donald Layton. This course is based on a helicopter design manual written by Prof. Layton [Ref. 2] which provides the historical data and corporate knowledge by which most helicopters are designed today. Helicopter conceptual design is far less definitive than the fixed wing design procedure, therefore performance specifications are generally all that are supplied, with just about everything else left to the imagination of the designer.

This study attempts a single hit vulnerability assessment of a combat helicopter. It is intended as a learning experience for the reader. Therefore, in the interest of accuracy, most if not all of the background information which is required in order to fully understand the case study was paraphrased and in some cases copied directly from one of three references. This is especially true in Chapter II where most of the groundwork is laid. The first reference is listed above as Dr Ball's book. The second is an excellent case study of a fixed wing attack aircraft by Lt Robert Novak [Ref. 3] and the third reference is the DOD MIL STD 2069 [Ref. 4] which provides the requirements and guidelines for establishing and conducting aircraft survivability programs. It is not this author's intention to take credit in any way for information derived from these three references, only to use the information as a basis on which to build the bulk of this case study.

II. GENERAL SURVIVABILITY PROGRAM OVERVIEW

Aircraft combat survivability is defined as "the capability of an aircraft to avoid and/or withstand a man made hostile environment." In an effort to understand and quantify survivability it is divided into two categories, vulnerability, defined as an aircraft's inability to remain under controlled flight given that it is hit by some damage mechanism and susceptibility, defined as the inability of an aircraft to avoid being damaged in the pursuit of its mission. By definition vulnerability is something that is designed into the aircraft and remains with the aircraft regardless of location whereas susceptibility is dependent on a variety of outside factors such as the physical environment and the threat environment. These major concepts are depicted in Figure 2.1.[Ref.1:p2]

A complete survivability program must include all the factors that affect the aircraft's susceptibility and its vulnerability. The tasks of a complete survivability program are defined in MIL-STD-2069. These include:

1. mission threat analysis
2. aircraft description
3. vulnerability assessment
4. susceptibility assessment
5. survivability assessment
6. trade-off studies
7. testing/final aircraft design

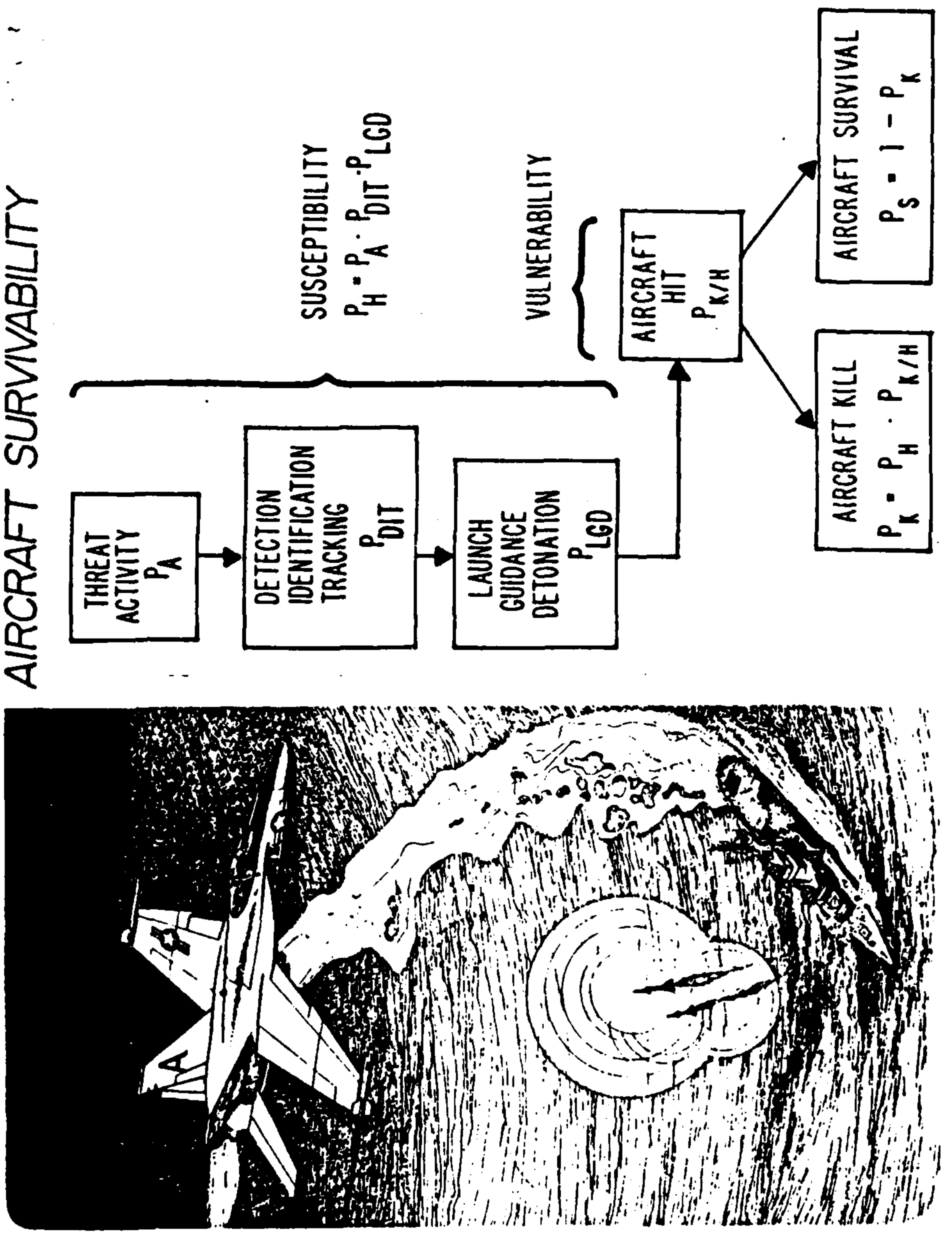


Figure 2.1 Major Concepts of Aircraft Survivability

The general flow of these tasks is depicted in Figure 2.2. [Ref.1:p9] Each of the above tasks will be explained in more complete detail in the following paragraphs.

A. MISSION THREAT ANALYSIS

The ground work for deciding what is required for an aircraft on the drawing board is deciding first what will be required of that aircraft in combat. Specifically this includes defining each operational mode of the aircraft required by the specific mission. Aircraft configuration, operating conditions/environmental factors, ordnance loading, tactics, aircraft performance characteristics all define the operational mode. Secondly, the expected threats to be encountered must be listed, as well as the characteristics of the individual threat systems. Future threat systems must also be considered. Finally, the first two steps are combined to arrive at the encounter conditions. These encounter conditions are then used as a basis for the vulnerability and susceptibility assessments and the trade-off studies.[Ref.1:p115]

A mission threat analysis can be broken down into three distinct areas. The first of these would be the aircraft theaters of operation and types of missions, and the flight and operating conditions, including airspeeds, altitudes, configurations, and types of electromagnetic radiation, for each mission type.

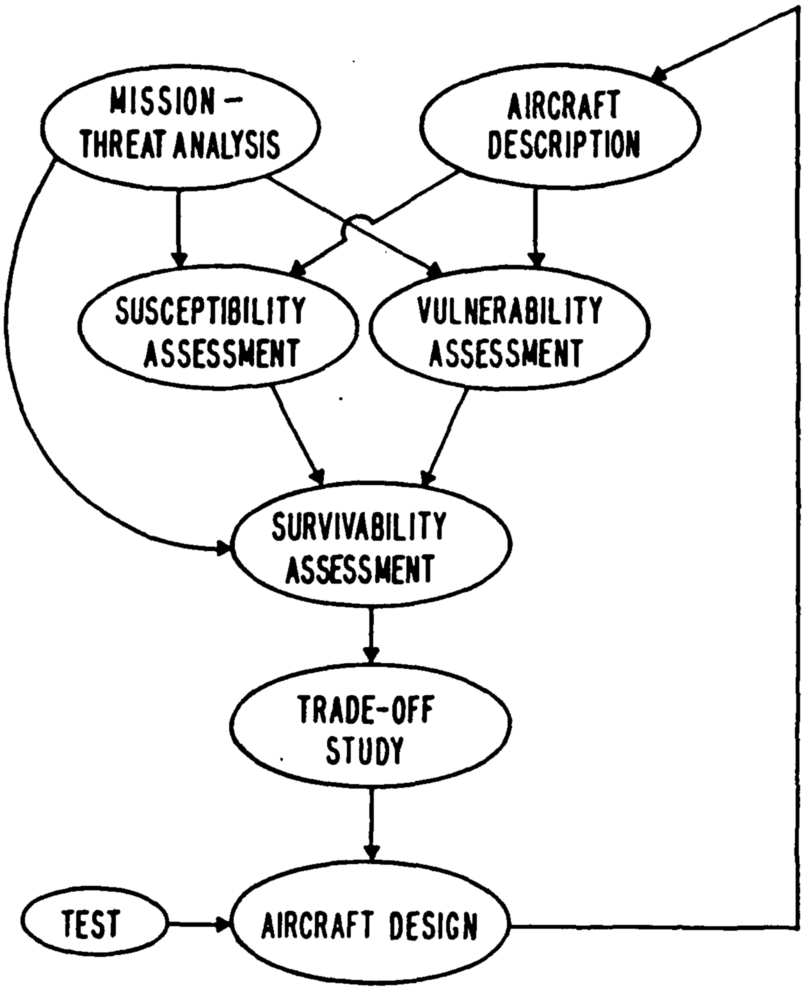


Figure 2.2 Survivability Element Flow

Second is the definition of the threat environment. Included in this definition are the operating conditions and threat envelopes for all weapon systems that one can expect to encounter for each mission and theater. The last of these areas involves evaluating the information gleaned from the other two areas in order to determine the likelihood and conditions of any encounter with hostile fire.

B. AIRCRAFT DESCRIPTION

Vulnerability and susceptibility assessments require that an aircraft description be available. As much technical and functional data as possible must be assembled if these assessments are to be accurate. This description must include general characteristics, such as whether the aircraft is fixed or rotary wing, and more specific information, such as a geometric description and performance parameters, and complete system descriptions of the important systems, such as structural, propulsion, power train and rotor blade, flight control, fuel, crew and armament.

C. VULNERABILITY PROGRAM

As stated earlier, the vulnerability of an aircraft is a measure of that aircraft's inability to maintain controlled flight given that it is hit be some damage mechanism. Failing this, the designers' objective should be a graceful degradation in system performance to allow for a successful egress, first from the hostile environment and then from the aircraft. In other words, the more vulnerable the aircraft is, the easier it is to kill when hit. A complete vulnerability analysis is made up of several components. The first of these is the identification of the aircraft's critical components followed by a vulnerability assessment, and finally recommendations on how to reduce the vulnerability of the aircraft.

A critical component is defined as any component whose loss or damage would lead to an aircraft kill. Therefore, it is essential that all critical components in an aircraft be identified. This identification is performed in a process referred to as the critical component analysis. A general procedure for determining these critical components as is (1) a selection of the aircraft kill levels or categories to be considered, (2) an assembly of the technical and functional description of the aircraft and (3) the determination of the critical components of the aircraft and their damage caused failure modes for the selected kill levels.

Kill_categories measure the seriousness of aircraft damage, as well as how graceful the degradation of system operation is. They are divided into an attrition kill, a mission abort kill, and a forced landing kill. An attrition kill can be further divided into levels; (1) KK kill in which the aircraft is destroyed immediately after being hit, (2) K kill in which the aircraft falls out of manned control within 30 seconds after being hit, (3) A kill in which the aircraft departs from manned control within 5 minutes after being hit, and finally (4) B kill in which the aircraft falls out of manned control within 30 minutes after being hit. The forced landing kill is especially applicable to this case study as it pertains to helicopter aviation. This category includes any forced landing after being hit but prior to the time fuel is exhausted.

Determination of the critical components of the aircraft and their damage-caused failure modes for the selected kill levels is done by first identifying the flight and mission essential functions an aircraft must perform. An example of this can be seen in Figure 2.3.[Ref.1:p139] From this list, the systems and subsystems which perform the essential functions are identified and used to conduct a Failure Mode and Effects Analysis (FMEA). This analysis is a "bottom up" approach which first identifies and documents all possible failure modes of critical systems, subsystems and their components and then determines the effect of these failures upon the flight and mission essential functions. This particular approach is often used by safety analysts and safety engineers. An example FMEA matrix is shown in Figure 2.4.

ITEM	ESSENTIAL FUNCTIONS	MISSION PHASES							
		Alert	Takeoff	Cruise to laager area	Cruise to holding position	Cruise to assault position	Engage targets	Return cruise	Land
	FLIGHT:								
1	Provide lift and thrust								
2	Provide controlled flight								
	MISSION:								
3	Communications • secured voice • unsecured voice • ICS								
4	Start systems								
5	Monitor systems								
6	Provide air data intelligence								
7	Maintain terrain clearance								
8	Employ IFF/ECM								
9	Navigate								
10	Locate/identify targets								
11	Employ weapons								

Figure 2.3 Flight and Mission Essential Functions

SUBSYSTEM					
COMPONENT	LOCATION	FAILURE MODE	EFFECT ON SUBSYSTEM	EFFECT OF DEGRADED SUBSYSTEM ON AIRCRAFT	AIRCRAFT KILL CATEGORY
ROD 3127	LEFT WING	SEVER	AILERON GOES TO HARDOVER (UP) POSITION	HARDIVER EFFECT CAN BE BALANCED WITH OTHER CONTROL SURFACES	AIRCRAFT CAN FLY AND LAND USING OTHER CONTROL SURFACES
		JAM	PILOT'S CONTROL STICK IS LOCKED	NO CONTROL OF FLIGHT	ATTRITION

Figure 2.4 Example FMEA Format

[Ref.1:p142] Following the FMEA, a Damage Mode and Effects Analysis (DMEA) is performed to relate system or subsystem component failures to combat inflicted damage. Figure 2.5 [Ref.1:p143] shows an example DMEA matrix and Table 2.1 [Ref.1:p145] lists the major damage-caused kill modes for the primary aircraft systems. A combination of an FMEA and a DMEA is often called a Failure Mode, Effects and Criticality Analysis, or FMECA.

Although not required by MIL STD 2069, critical components can be identified using a Fault Tree Analysis (FTA). This "top down approach", in contrast to the FMEA, uses logic symbology to determine what sequence of events or singular events will lead to an undesired event. This technique is illustrated in Figure 2.6.[Ref.1:p149]

Once the critical components are identified, they can be represented in a clear, concise manner referred to as a kill tree. This "tree", shown in Figure 2.7, [Ref.1:p153] identifies redundant and nonredundant critical components by their location on the tree. A complete cut through the trunk of the tree is required to kill the aircraft. Similarly this relationship can be represented in a logical kill expression.

The second step in a complete vulnerability analysis is referred to as a vulnerability assessment. This assessment is a process by which numerical values of the aircraft's vulnerability are computed. This procedure can be carried

AIRCRAFT ____________

SYSTEM FLIGHT CONTROLS (MECHANICAL)

FMEA REF ____________

COMPONENT NAME	COMPONENT NUMBER	DISABLEMENT DIAG. NO.	DAMAGE MODE	"KILL" CATEGORY						REMARKS	$P_{k/h}$ FUNC. NO.
				NON REDUNDANT			REDUNDANT				
				ATTRITION	MISSION ABORT	VERTICAL	ATTRITION	MISSION ABORT	VERTICAL		
STICK			BREAK OR DISABLE								
ASSEMBLY										DEGRADED	
(GRIP)	3001				X					FLIGHT CONTROL	32
		1									
			LOSS OF ELECTRICAL							LOSS OF CAS PITCH AND	
CAS SENSOR	3002		CONNECTIONS		X		X			ROLL CONTROL	32
		2	(LOSS OF CAS)							CONTROL THROUGH DEL.	
			LOSS OF ELECTRICAL							REVERSION TO MECH. (IF DEL	
			AND MECHANICAL	X	X					IS LOST). (DEL-DIRECT	
			LINKAGES							ELECTRICAL LINK)	
RUDDER PEDALS	3006		BREAK OR DISABLE								
ARMS	3007		ONE ARM								32
SUPPORT	3008	3									32
FEEL SPRING SUPPORT	3301		BREAK OR DISABLE								32
SPRING	3302		SUPPORT, FEEL							NO ELECTRICAL	32
TRANSDUCER	3303		SPRING ASSY, OR	X	X					INPUTS TO	24
			TRANSDUCER							RUDDERS	

Figure 2.5 Example DMEA Matrix

TABLE 2.1 SYSTEM DAMAGE-CAUSED KILL MODES

Fuel

- Fuel supply depletion
- In-tank fire/explosion
- Void space fire/explosion
- Sustained exterior fire
- Hydraulic ram

Power Train and Rotor Blade/Propellor

- Loss of lubrication
- Mechanical/structural damage

Electrical Power

- Severing or grounding
- Mechanical failure
- Overheating

Propulsion

- Fuel ingestion
- Foreign object ingestion
- Inlet flow distortion
- Lubrication starvation
- Compressor case perforation or distortion
- Combustor case perforation
- Turbine section failure
- Exhaust duct failure
- Engine control and accessories failure

Crew

- Injury, incapacitation, or death

Armament

- Fire/explosion

Flight Control

- Disruption of control signal path
- Loss of control power
- Loss of aircraft motion data
- Damage to control surfaces and hinges
- Hydraulic fluid fire

Structural

- Structure removal
- Pressure overload
- Thermal weakening
- Penetration

Avionics

- Penetrator/fragment damage
- Fire/explosion/overheat
- Radiation damage

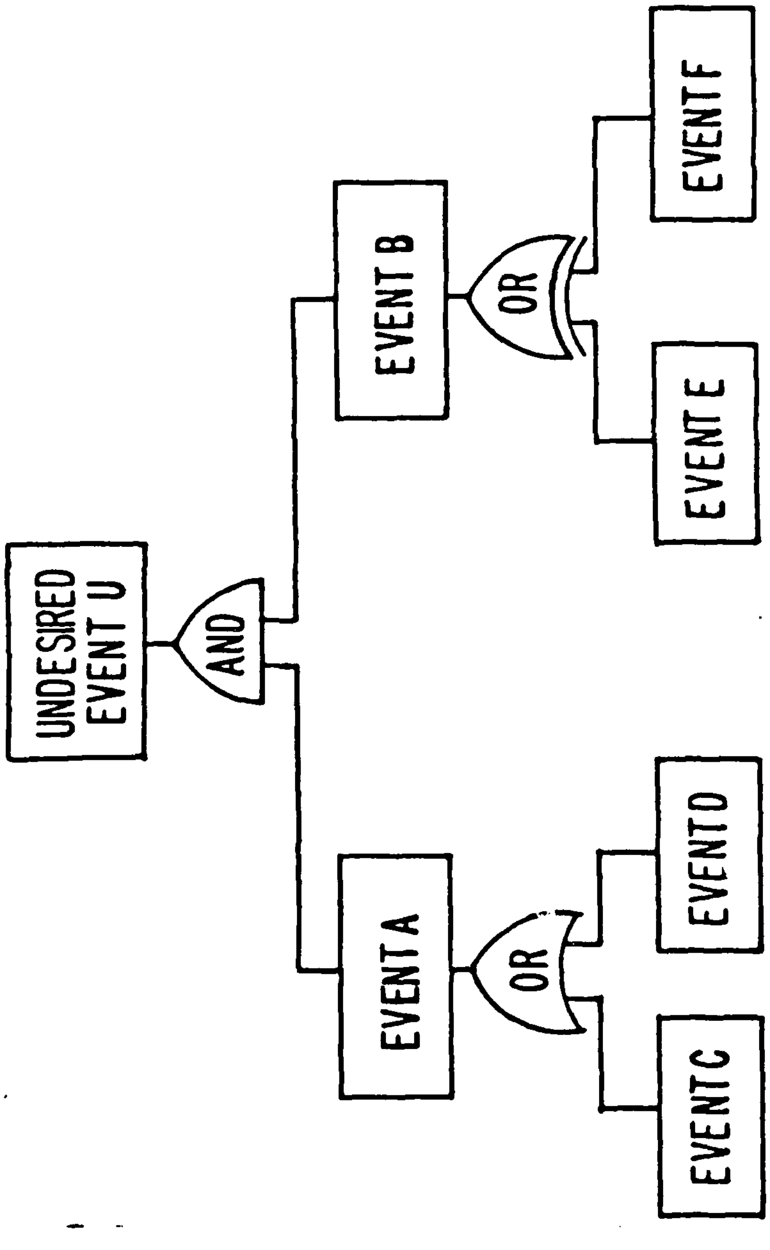


Figure 2.6 Generic Fault Tree Diagram

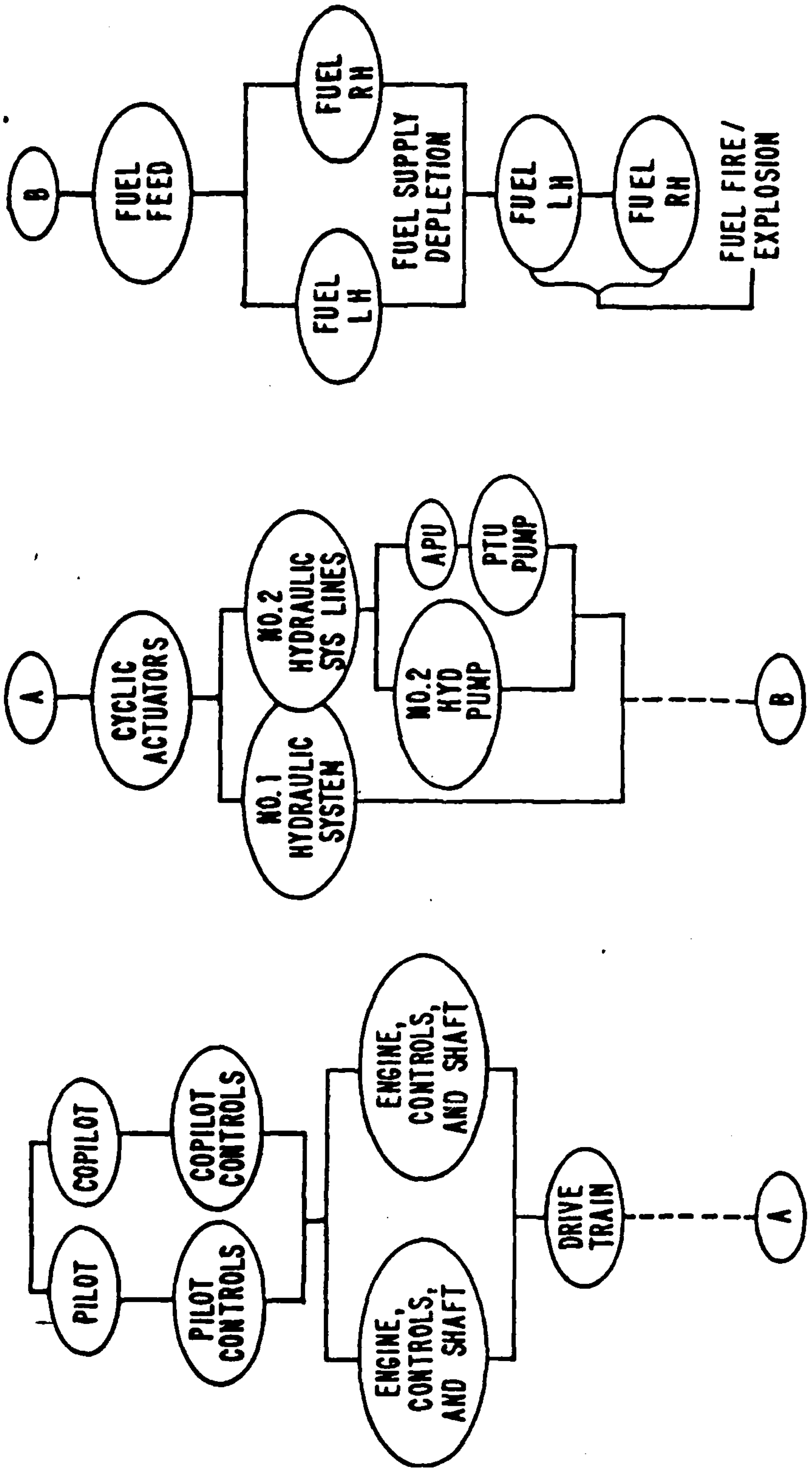


Figure 2.7 Example Kill Diagram

out at various levels of detail. Specifically these levels are estimates, evaluations and analyses in increasing order of complexity and detail. Four specific measures of vulnerability are available for use. These are $P_{K/H}$, A_V, $P_{K/D}$, $P_{L/O}$. $P_{K/H}$is the conditional probability that an aircraft will be killed given a random hit by a damage mechanism. A_V is defined as the aircraft's vulnerable area, a theoretical, nonunique area presented to the threat that, if hit be a damage mechanism, would result in an aircraft kill. $P_{K/D}$is the conditional probability of an aircraft kill given the nearby detonation of an HE warhead. $P_{L/O}$ is the probability of kill given a lock on by laser weaponry.

The threats and damage mechanisms that are usually considered in the assessment are: (1) a nonexplosive penetrating projectile or fragment, (2) the fragments and blast from a internally detonating warhead, (3) external blast, (4) the fragments, penetrators, and missile debris from externally detonating warheads, and (5) the laser. The damage or kill criteria for each of the failure modes of each critical components must be determined for these threats. The four criteria in use today are (1) the $P_{K/H}$ function, (2) the area removal criterion, (3) the energy density criterion and (4) the blast damage mechanism. These four criteria are explained in detail in Reference 1.

Thirdly, and perhaps most importantly in a vulnerability program, is the concept of vulnerability reduction. This reduction is a conscious effort to reduce whatever measure of vulnerability is used in the assessment of the aircraft. This reduction is achieved through the combination or selective use of six specific vulnerability reduction concepts. These concepts are (1) component redundancy, (2) component location, (3) passive damage suppression, (4) active damage suppression, (5) component shielding and (6) component elimination.

D. SUSCEPTIBILITY PROGRAM

Once again, susceptibility refers to the inability of an aircraft to avoid being hit while operating within a man made hostile environment. Susceptibility is, therefore,dependent on the environment, the threat and the aircraft itself. In a manner very similar to that of the vulnerability program, a susceptibility program is subdivided into three major tasks. First is an essential elements analysis (EEA), followed by a susceptibility assessment, and finally recommendations for reducing the susceptibility of the aircraft.

The essential elements analysis parallels the identification of the critical components in the vulnerability program when an FTA is utilized. It is a timewise sequence or chain of events which leads to the final undesired event in much the same manner as a FTA. An example EEA is provided in Figure 2.8. [Ref.1:p226]

The susceptibility assessment is an effort to quantify the susceptibility of an aircraft. In this assessment, each important event and element, such as radar signature of the helicopter, the radar detection of the helicopter, the effectiveness of the chaff in decoying the radar tracker, and the effects of the helicopter maneuvers are modelled, and numerical values are determined for the model parameters.

The final section of the susceptibility program outlines the six susceptibility reduction concepts. The concepts are: (1) threat warning, (2) noise jammers and deceivers, (3) signature reduction, (4) expendables, (5) threat suppression and (6) tactics. These concepts must be evaluated and trade-off studies conducted to determine the consequences, both pro and con, of their incorporation. For example, what effect would the added weight and cost of a jammer have on the overall aircraft weight, and therefore aircraft performance and overall cost.

E. SURVIVABILITY ASSESSMENT

The survivability assessment is the culmination of the combined vulnerability and susceptibility assessments. It combines good engineering judgement with a sound understanding of the proposed tactics and methods of

Events and Elements	EE?	Questions
1. Blast and fragments strike the A/C.	Yes	How many fragments hit the A/C and where do they hit?
2. Missile warhead detonates within lethal range.	Yes	Can the onboard ECM suite inhibit the functioning of the proximity fuze?
3. Radar proximity fuze detects A/C.	Yes	Will chaff decoy the fuze?
4. Missile propelled and guided to vicinity of A/C.	Yes	Can the target A/C outmaneuver the missile? Are i.r. flares effective decoys?
5. Missile guidance system functions in flight.	Yes	Are i.r. flares effective decoys?
6. Missile motor ignites.	Yes	
7. Missile guidance system locked on to target's engine i.r. radiation.	Yes	Are i.r. flares effective decoys? Is the engine's i.r. suppressor effective in preventing lock-on?
8. Target's engines within missile's field of view.	Yes	Are the engine hot parts shielded?
9. Enemy fighter maneuvers to put target into field of view and within maximum range.	Yes	Does the enemy fighter have a performance edge? Does the target A/C have an offensive capability against the enemy fighter?
10. Target acquired by enemy fighter's onboard sensors.	Yes	Does the onboard ECM suite inhibit acquisition by the fighter's radar? Do the tactics place the target outside sensor limits? Is the camouflage paint scheme effective against visual acquisition?
11. Enemy fighter given steering by ground control intercept (GCI) net to acquire target.	Yes	Does the onboard or stand-off ECM suite have a communications jamming capability? Is a fighter escort available?
12. Target A/C designated to enemy fighter and fighter launched.	Yes	Does the onboard or stand-off ECM suite have a communications jamming capability?
13. Fighter available to launch against target.	Yes	Are there any supporting forces to destroy the enemy fighter on the ground?
14. Enemy C^3 net functions properly.	Yes	Does the stand-off ECM suite have a communications jamming capability?
15. GCI picks up track on target A/C.	Yes	Is the target A/C easily detected and tracked by radar? Is the stand-off ECM suite effective against search radars?
16. Target designated hostile by enemy commander.	Yes	Does the stand-off ECM suite have IFFN countermeasures?
17. Early warning net detects and establishes track (course and speed) of target A/C.	Yes	Is the target A/C easily detected and tracked by radar? Is the stand-off ECM suite effective against search radars?

Figure 2.8 Example EEA Summary

aircraft employment. Numerous trade-off studies are required in order to obtain the highest survival rate while still performing the mission for which it was designed. Obviously, the most survivable aircraft in the world is the one sitting in the hangar far from combat. This is not the goal of any survivability program. In fact, as stated by Dr. Ball, "the goal of the aircraft combat survivability (ACS) discipline is the early identification and successful incorporation of those specific survivability enhancement features that increase the effectiveness of the weapon system."

In summary this chapter has attempted a very basic summary of a growing discipline. It by no means even scratches the surface of very complex topic. The following chapters begin the actual case study and are an attempt to scratch the surface in meaningful way.

III. THE AIRCRAFT

The aircraft used for this case study was designed to be a generic lightweight combat helicopter. The requirements for the design were as follows:

A. SUMMARY OF DESIGN REQUIREMENTS

-TYPE	Light/Medium attack helicopter, land based
-PRIMARY MISSION	Air-to-Ground fire support while operating within four miles of the forward line of own troops (FLOT)
-SECONDARY MISSION	Scout/Reconnaissance
-CREW	Single seat
-MAXIMUM GROSS WEIGHT	8000±500 pounds
-USEFUL LOAD (excluding fuel)	1500 pounds
-MAXIMUM RANGE	250 nmi/457.2 km
-MAXIMUM RATE OF CLIMB	2500 fpm
-MAXIMUM FUSELAGE LENGTH	50 ft
-MAXIMUM ROTOR RADIUS	27 ft
-SERVICE CEILING	14500 ft
-HOVER IGE	8000 ft

These requirements formed the skeletal basis from which a generic design, the AH-80 VIPER (Figures 3.1 through 3.3) was conceived. As can be seen from the above requirements, essential systems and subsystems such as the propulsion system, the armament system, the flight control system and

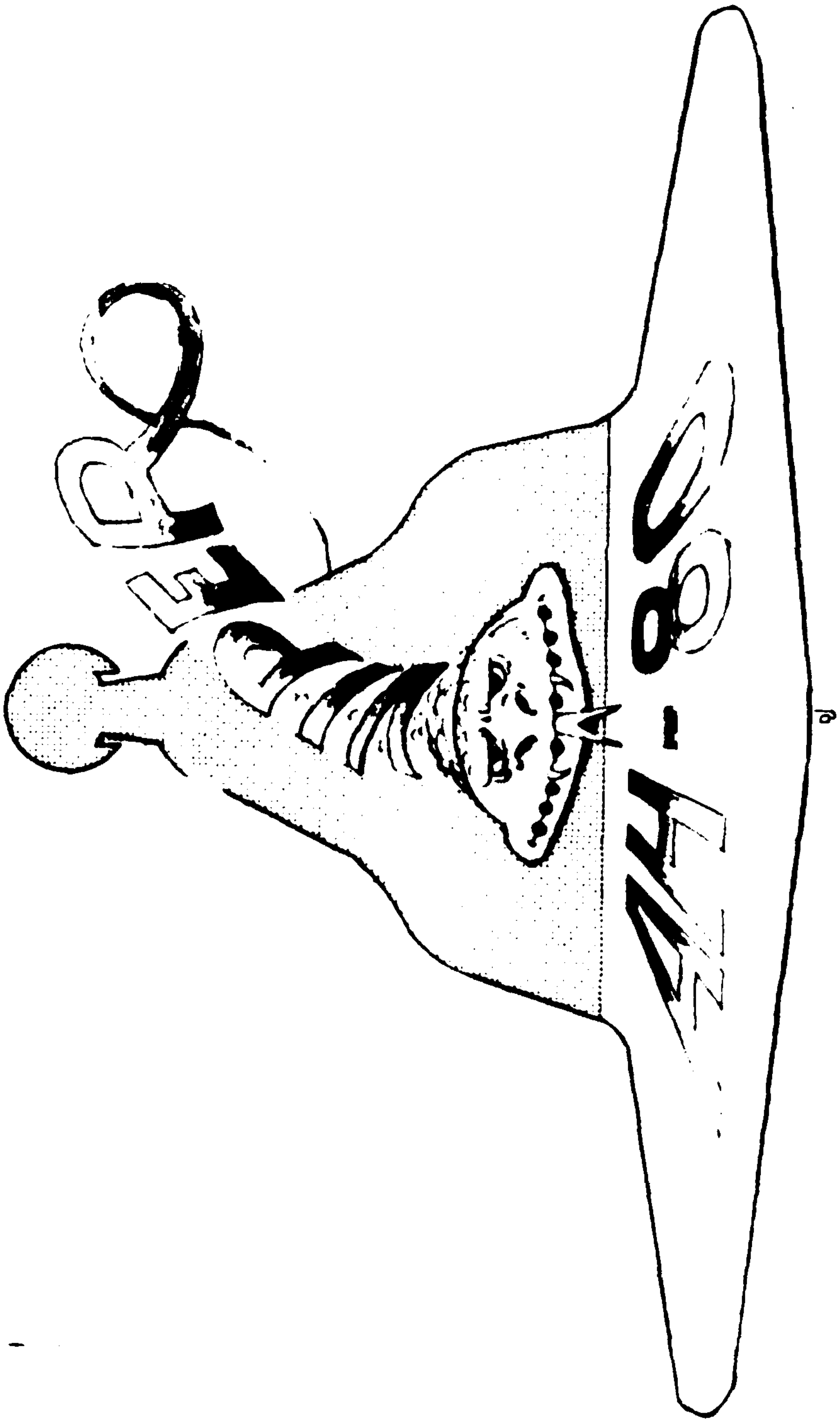


Figure 3.1 VIPER Insignia

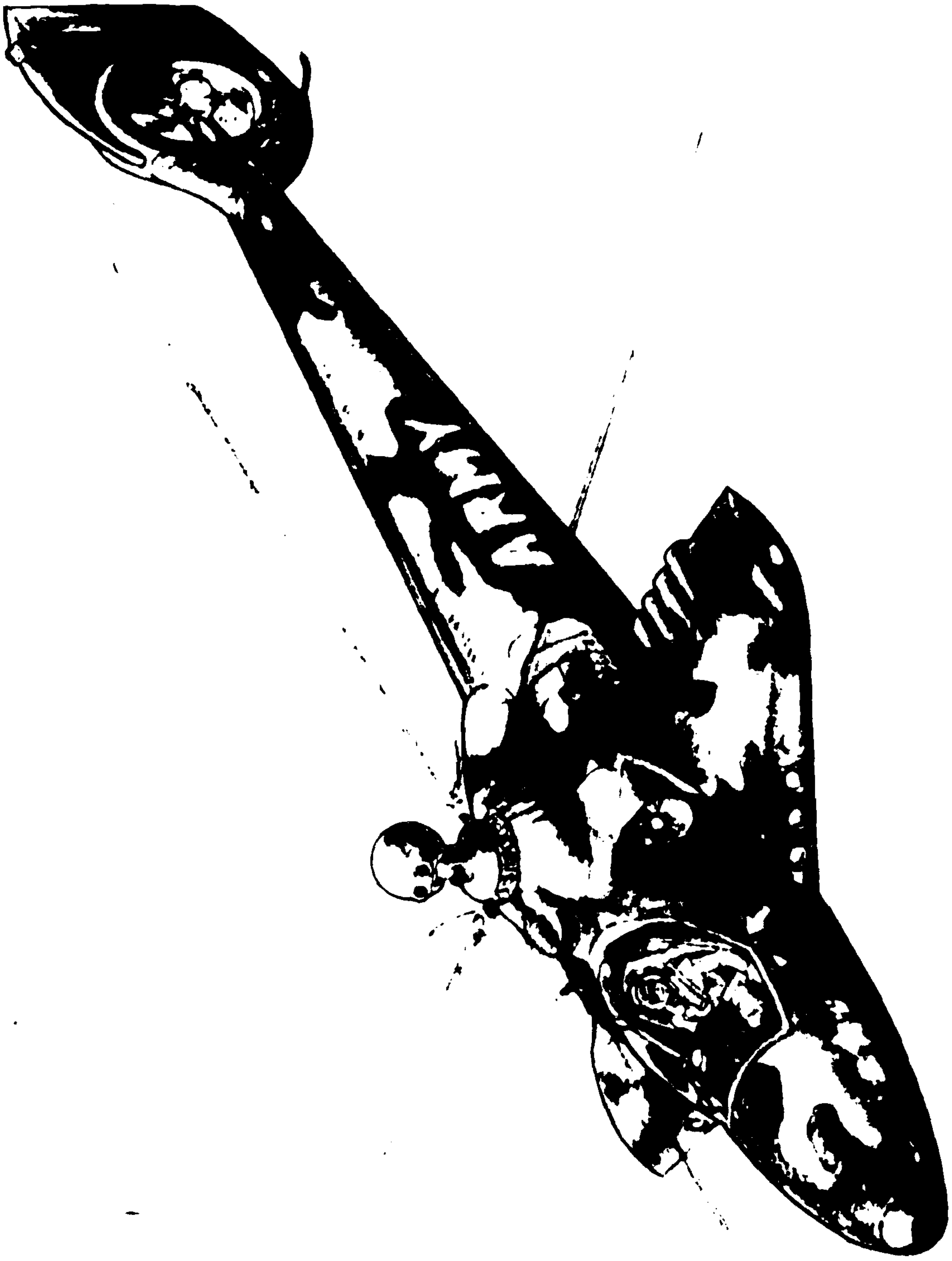


Figure 3.2 VIPER Side View

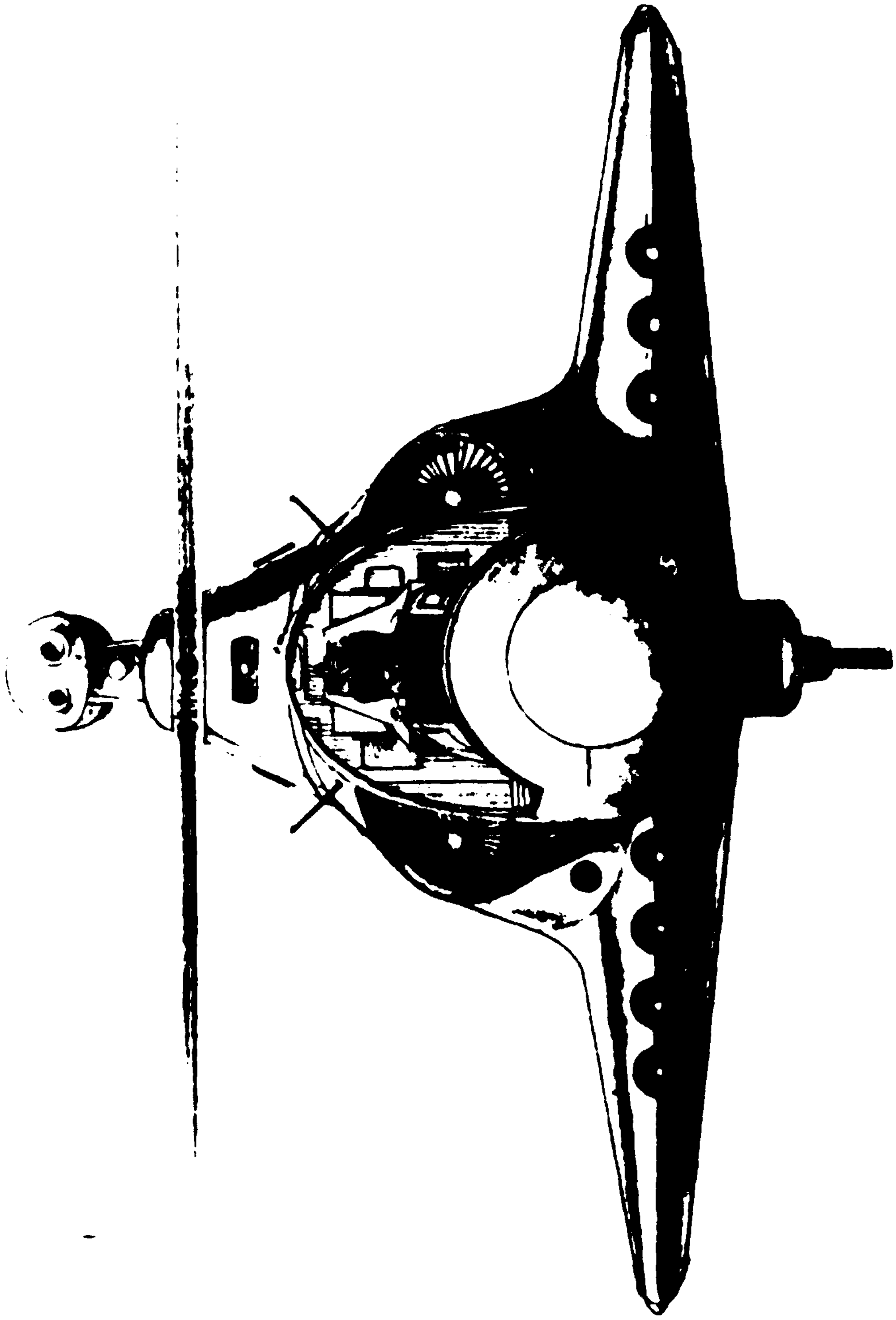


Figure 3.3 VIPER Front View

the tail rotor configuration were not specified and therefore were left entirely at the discretion of the author.

B. FINAL DESIGN/PERFORMANCE SUMMARY

Overall Aircraft

weight w/fuel	8442.3 lbs
weight empty	5780.0 lbs
length	37.5 ft
flat plate area (forward)	13.1 sqft
flat plate area (vertical)	41.8 sqft

Main Rotor System

# main rotor blades	4
rotor radius	23.28 ft
tip velocity	725.98 fps
rotational velocity	31.19 radps
thrust coefficient	0.00396
blade solidity	0.08205
blade aspect ratio	15.518
average lift coefficient	0.26057
blade airfoil lift curve slope	6.25
blade drag coefficient	0.005
disk loading	4.7933

Main Rotor System Performance

maximum advance ratio	0.23417
maximum blade loading	0.07
maximum forward velocity	170 knots
tiploss	0.97775
induced power in hover OGE	481.57 SHP
profile power in hover OGE	144.35 SHP
total power in hover OGE	625.90 SHP
figure of merit	0.75257
percent induced power	76.940
induced power in hover IGE	416.47 SHP
total power in hover IGE	560.80 SHP
main rotor power (function of A/S)	see tabl 3.1

Tail Rotor System

# tail rotor blades	13
radius	2 ft
rotational velocity	362.99 radps
rpm	3456.74
thrust coefficient	0.00396
blade solidity	0.68967
blade chord	0.61283 ft
aspect ratio	6
drag coefficient	0.005

TABLE 3.1

MAIN ROTOR POWER

STANDARD SEA LEVEL
ALTITUDE= 0 FT TEMPERATURE = 59 DEG. F

		POWER			
AIRSPEED (knots)	TIP MACH	INDUCED (SHP)	PROFILE (SHP)	PARASITE (SHP)	TOTAL (SHP)
0.0	0.650	73.05	195.91	259.91	528.88
20.0	0.680	155.36	155.62	26.60	337.58
40.0	0.710	158.03	155.23	25.25	338.51
60.0	0.741	160.78	154.86	23.94	339.58
80.0	0.771	163.63	154.48	22.68	340.79
100.0	0.801	166.58	154.12	21.47	342.16
120.0	0.831	169.63	153.76	20.30	343.68
140.0	0.862	172.78	153.41	19.17	345.36
160.0	0.892	176.06	153.06	18.08	347.20
170.0	0.907	179.45	152.72	17.04	349.21

MAIN ROTOR POWER

SPECIFICATION ALTITUDE
ALTITUDE = 4000 FT TEMPERATURE = 95 DEG. F

		POWER			
AIRSPEED (knots)	TIP MACH	INDUCED (SHP)	PROFILE (SHP)	PARASITE (SHP)	TOTAL (SHP)
0.0	0.629	537.22	116.57	0.00	653.79
20.0	0.658	430.74	117.65	0.88	549.27
40.0	0.688	271.80	120.90	7.05	399.75
60.0	0.717	186.09	126.32	23.78	336.19
80.0	0.746	140.26	133.90	56.37	330.53
100.0	0.775	112.36	143.66	110.09	366.11
120.0	0.805	93.68	155.58	190.24	439.50
140.0	0.834	80.31	169.67	302.10	552.08
160.0	0.863	70.28	185.92	450.95	707.15
170.0	0.878	66.15	194.86	540.90	801.91

Tail Rotor System Performance

tiploss	0.98449
induced power in hover OGE	39.427 SHP
profile power in hover OGE	10.874 SHP
total power in hover OGE	50.302 SHP
induced power in hover IGE	44.124 SHP
total power in hover IGE	52.906 SHP
tail length	25 ft
tail rotor power (function of A/S)	see tabl 3.2

Vertical Stabilizer

planform area	20 sqft
span	9 ft
sweep at mid-chord	45 deg
aspect ratio	4.05
angle of attack	-0.1644 deg
coefficient of lift	0.39086
lift curve slope	3.1839 /rad
lever arm	22 ft
tail rotor power w/vert stabilizer (function of A/S)	see tabl 3.3

Propulsion System

# engines	2
type engines	turboshaft
SFC: lbs/hr/lb thrust	
military	0.57
normal	0.573
cruise	0.599
SHP:	
military	735
normal	685
cruise	550
fuel flow:	
military	837.9 lbs/hr
normal	735.0 lbs/hr
cruise	658.9 lbs/hr
zero horsepower intercept @SSL	126.7378
zero horsepower intercept @spec alt	113.1933
phantom horsepower @SSL	261.972
phantom horsepower @spec alt	233.9749
maximum range velocity	123 knots
maximum range referred horsepower	805.2546
maximum range fuel flow	389.6 lbs/hr
maximum endurance velocity	65 knots
maximum endurance referred horsepower	613.55
maximum endurance fuel flow	296.8 lbs/hr
cruise fuel flow @ SSL	380.3 lbs/hr
cruise fuel flow @ spec alt	334.2 lbs.hr
total fuel required	912.3 lbs

TABLE 3.2

TAIL ROTOR POWER

STANDARD SEA LEVEL
ALTITUDE = 0 FT   TEMPERATURE = 59 DEG. F

		----------- POWER	----------	
AIRSPEED (knots)	TIP MACH	INDUCED (SHP)	PROFILE (SHP)	TOTAL (SHP)
0.0	0.462	39.43	10.87	50.30
20.0	0.492	5.44	11.72	17.16
40.0	0.522	5.56	11.70	17.26
60.0	0.553	5.69	11.67	17.36
80.0	0.583	5.83	11.64	17.47
100.0	0.613	5.98	11.61	17.60
120.0	0.643	6.15	11.58	17.73
140.0	0.674	6.32	11.56	17.88
160.0	0.704	6.51	11.53	18.04
170.0	0.719	6.71	11.51	18.21

TAIL ROTOR POWER

SPECIFICATION ALTITUDE
ALTITUDE = 4000 FT   TEMPERATURE = 95 DEG. F

		----------- POWER	----------	
AIRSPEED (knots)	TIP MACH	INDUCED (SHP)	PROFILE (SHP)	TOTAL (SHP)
0.0	0.447	44.12	8.78	52.91
20.0	0.476	30.94	8.94	39.89
40.0	0.506	12.52	9.43	21.95
60.0	0.535	6.20	10.24	16.44
80.0	0.564	4.53	11.37	15.89
100.0	0.593	4.45	12.82	17.27
120.0	0.623	5.35	14.60	19.95
140.0	0.652	7.26	16.70	23.95
160.0	0.681	10.44	19.12	29.56
170.0	0.696	12.64	20.46	33.10

TABLE 3.3

TAIL ROTOR POWER WITH VERTICAL STABILIZER

STANDARD SEA LEVEL
ALTITUDE = 0 FT   TEMPERATURE = 59 DEG. F

	----THRUST----		POWER				
AIRSPEED (knots)	TAIL ROTOR (lbf)	VERT/ STAB (lbf)	MAIN ROTOR (SHP)	VERT/ STAB (*SHP*)	INDUCED (SHP)	PROFILE (SHP)	TOTAL with v/s (SHP)
0.0	441.5	0.0	528.9	0.0	39.4	10.9	50.3
20.0	363.0	10.6	337.6	13.2	22.9	11.7	34.0
40.0	267.9	42.3	338.5	52.8	6.9	11.7	18.6
60.0	237.1	95.3	339.6	118.9	2.1	11.7	14.8
80.0	246.0	169.4	340.8	211.3	0.6	11.6	14.7
100.0	285.5	264.6	342.2	330.2	0.1	11.6	16.0
120.0	355.3	381.1	343.7	475.4	0.0	11.6	18.1
140.0	457.7	518.7	345.4	647.1	0.0	11.6	20.7
160.0	596.2	677.5	347.2	845.2	0.0	11.5	23.7
170.0	680.2	764.8	349.2	954.2	0.0	11.5	25.3

TAIL ROTOR POWER WITH VERTICAL STABILIZER

SPECIFICATION ALTITUDE
ALTITUDE = 4000 FT   TEMPERATURE = 95 DEG. F

	----THRUST----		POWER				
AIRSPEED (knots)	TAIL ROTOR (lbf)	VERT/ STAB (lbf)	MAIN ROTOR (SHP)	VERT/ STAB (*SHP*)	INDUCED (SHP)	PROFILE (SHP)	TOTAL with v/s (SHP)
0.0	461.2	0.0	653.8	0.0	44.1	8.8	52.9
20.0	387.4	8.9	549.3	11.0	29.5	8.9	38.4
40.0	282.0	35.4	399.8	44.2	9.9	9.4	19.3
60.0	237.1	79.7	336.2	99.4	3.1	10.2	13.3
80.0	233.1	141.7	330.5	176.8	1.0	11.4	12.3
100.0	258.2	221.4	366.1	276.2	0.3	12.8	13.1
120.0	310.0	318.8	439.5	397.8	0.0	14.6	14.6
140.0	389.4	434.0	552.1	541.4	0.0	16.7	16.7
160.0	498.8	566.8	707.2	707.2	0.0	19.1	19.1
170.0	565.6	639.9	801.9	798.3	0.0	20.5	20.5

Overall Performance

total power req (with high spd eff)	see tabl 3.4
compressibility and stall effects	see tabl 3.5

C. SYSTEM DESCRIPTION

As stated in Chapter II, the first step in any vulnerability program is a compilation of as much functional and technical information on the aircraft as possible. The preceeding aircraft description is the very minimum required in order to perform and adequate vulnerability program. In point of fact, this description should also include as many drawings, both exterior and interior cross sections as possible. Additionally, all components and systems should be described as to how they function, what they are made of, and how they relate to the overall operation of the aircraft. A brief description of the six major aircraft systems (the flight control, fuel, propulsion, rotor and drive, armament and structural systems) follows. The flight control system will be described is some detail with the aid of figures and diagrams, whereas the other systems will be treated with only a brief discussion.

1. The Flight Control System

The flight control system for the AH-80 is a standard type helicopter flight control configuration consisting of a collective assembly for collective pitch control, a cyclic assembly for cyclic (i.e., lateral and

TABLE 3.4

COMPRESSIBILITY AND STALL EFFECTS ON POWER REQUIRED

STANDARD SEA LEVEL
ALTITUDE = 0 FT TEMPERATURE = 59 DEG. F

AIRSPEED (kts)	ALPHA (90)	ALPHA (270)	M90	Mcrit	Ps (shp)	Pm (shp)
0.0	-2.702	3.413	0.8374	0.9085	0.0	0.0
20.0	-1.843	0.678	0.7376	0.8740	0.0	0.0
40.0	-1.822	0.660	0.7361	0.8731	0.0	0.0
60.0	-1.801	0.643	0.7346	0.8723	0.0	0.0
80.0	-1.780	0.626	0.7331	0.8714	0.0	0.0
100.0	-1.758	0.611	0.7316	0.8706	0.0	0.0
120.0	-1.736	0.595	0.7301	0.8697	0.0	0.0
140.0	-1.713	0.581	0.7286	0.8688	0.0	0.0
160.0	-1.690	0.567	0.7271	0.8678	0.0	0.0
170.0	-1.666	0.553	0.7256	0.8669	0.0	0.0
190.0	-1.642	0.540	0.7240	0.8659	0.0	0.0

COMPRESSIBILITY AND STALL EFFECTS ON POWER REQUIRED

SPECIFICATION ALTITUDE
ALTITUDE = 4000 FT TEMPERATURE = 95 DEG. F

AIRSPEED (kts)	ALPHA (90)	ALPHA (270)	M90	Mcrit	Ps (shp)	Pm (shp)
0.0	-2.103	-2.103	0.6291	0.8844	0.0	0.0
20.0	-2.391	-2.068	0.6584	0.8960	0.0	0.0
40.0	-2.668	-2.036	0.6876	0.9071	0.0	0.0
60.0	-1.399	1.829	0.7169	0.8562	0.0	0.0
80.0	-1.842	2.376	0.7461	0.8739	0.0	0.0
100.0	-2.189	3.171	0.7754	0.8879	0.0	0.0
120.0	-2.473	4.279	0.8046	0.8993	0.0	0.0
140.0	-2.710	5.808	0.8339	0.9088	0.0	0.0
160.0	-2.920	7.895	0.8631	0.9172	0.0	0.0
170.0	-3.019	9.201	0.8777	0.9212	0.0	0.0
190.0	-3.219	12.454	0.9070	0.9292	0.0	0.0

TABLE 3.5

TOTAL POWER REQUIRED
(With High Speed Effects)
STANDARD SEA LEVEL
ALTITUDE = 0 FT   TEMPERATURE = 59 DEG. F

AIRSPEED (kts)	Pi (shp)	Po (shp)	Pp (shp)	Ps (shp)	Pm (shp)	Ptr (shp)	PT (shp)
0.0	73.0	195.9	259.9	0.0	0.0	50.3	674.8
20.0	155.4	155.6	26.6	0.0	0.0	17.2	550.0
40.0	158.0	155.2	25.2	0.0	0.0	17.3	400.8
60.0	160.8	154.9	23.9	0.0	0.0	17.4	353.8
80.0	163.6	154.5	22.7	0.0	0.0	17.5	366.8
100.0	166.6	154.1	21.5	0.0	0.0	17.6	425.0
120.0	169.6	153.8	20.3	0.0	0.0	17.7	527.4
140.0	172.8	153.4	19.2	0.0	0.0	17.9	677.6
160.0	176.1	153.1	18.1	0.0	0.0	18.0	880.9
170.0	179.4	152.7	17.0	0.0	0.0	18.2	1004.4
190.0	183.0	152.4	16.0	0.0	0.0	18.4	1299.3

TOTAL POWER REQUIRED
(With High Speed Effects)
SPECIFICATION ALTITUDE
ALTITUDE = 4000 FT   TEMPERATURE = 95 DEG. F

AIRSPEED (kts)	Pi (shp)	Po (shp)	Pp (shp)	Ps (shp)	Pm (shp)	Ptr (shp)	PT (shp)
0.0	537.2	116.6	0.0	0.0	0.0	52.9	705.0
20.0	430.7	117.7	0.9	0.0	0.0	39.9	589.2
40.0	271.8	120.9	7.0	0.0	0.0	21.9	421.7
60.0	186.1	126.3	23.8	0.0	0.0	16.4	352.6
80.0	140.3	133.9	56.4	0.0	0.0	15.9	346.4
100.0	112.4	143.7	110.1	0.0	0.0	17.3	383.4
120.0	93.7	155.6	190.2	0.0	0.0	20.0	459.5
140.0	80.3	169.7	302.1	0.0	0.0	24.0	576.0
160.0	70.3	185.9	450.9	0.0	0.0	29.6	736.7
170.0	66.2	194.9	540.9	0.0	0.0	33.1	835.0
190.0	59.2	214.4	755.1	0.0	0.0	42.0	1070.7

longitudinal) control, and a pedal assembly for directional control of the aircraft. Additionally, a control surface has been incorporated on the vertical stabilizer to assist in aircraft directional control during periods of degraded tail rotor operation. The collective, cyclic and directional control systems are depicted in Figures 3.4, 3.5 and 3.6

During periods of normal operation the aircraft is controlled in all axes by these flight controls. Pilot inputs to the collective, cyclic, and pedals result in electrical signals being sent via electrical wires eventually to hydraulic servoactuators located below the mixer assembly for the collective, lateral and longitudinal channels and in the tail boom for the directional channel. Should a signal be interupted for any reason there is automatic and complete mechanical backup available. The flight control surfaces are both electrically and mechanically actuated and hydraulically powered in all axes by a dual hydraulic system. In addition, the mechanical system is capable of controlling the aircraft in all flight regimes with a complete loss of hydraulic power. The afore mentioned "rudder" assembly is a mechanically operated flight control surface designed to maximize high speed performance yet still provide the capability for a nonvertical landing of the aircraft with degraded or no tail rotor thrust performance. This surface can be manually

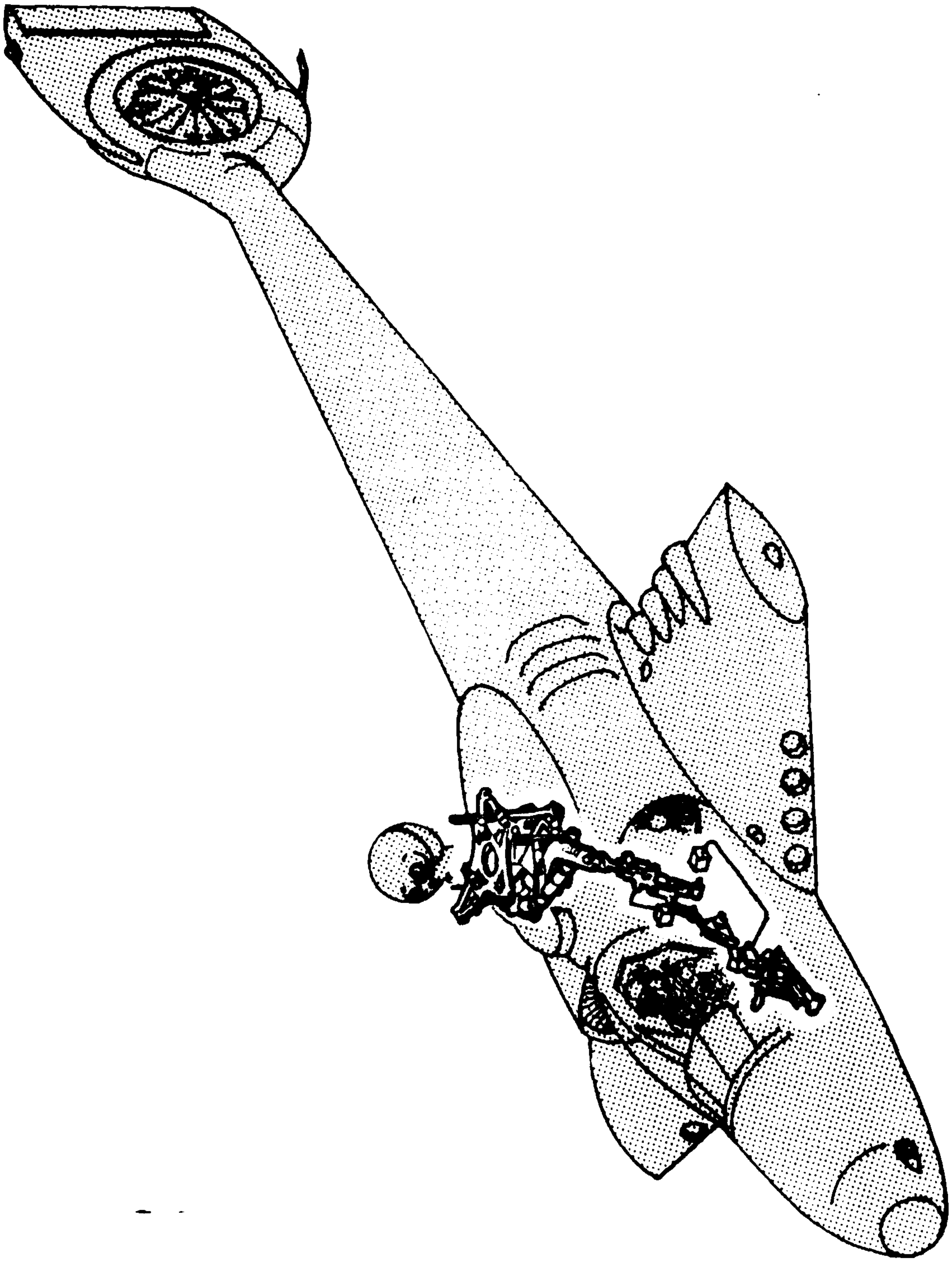


Figure 3.4 Collective Control System

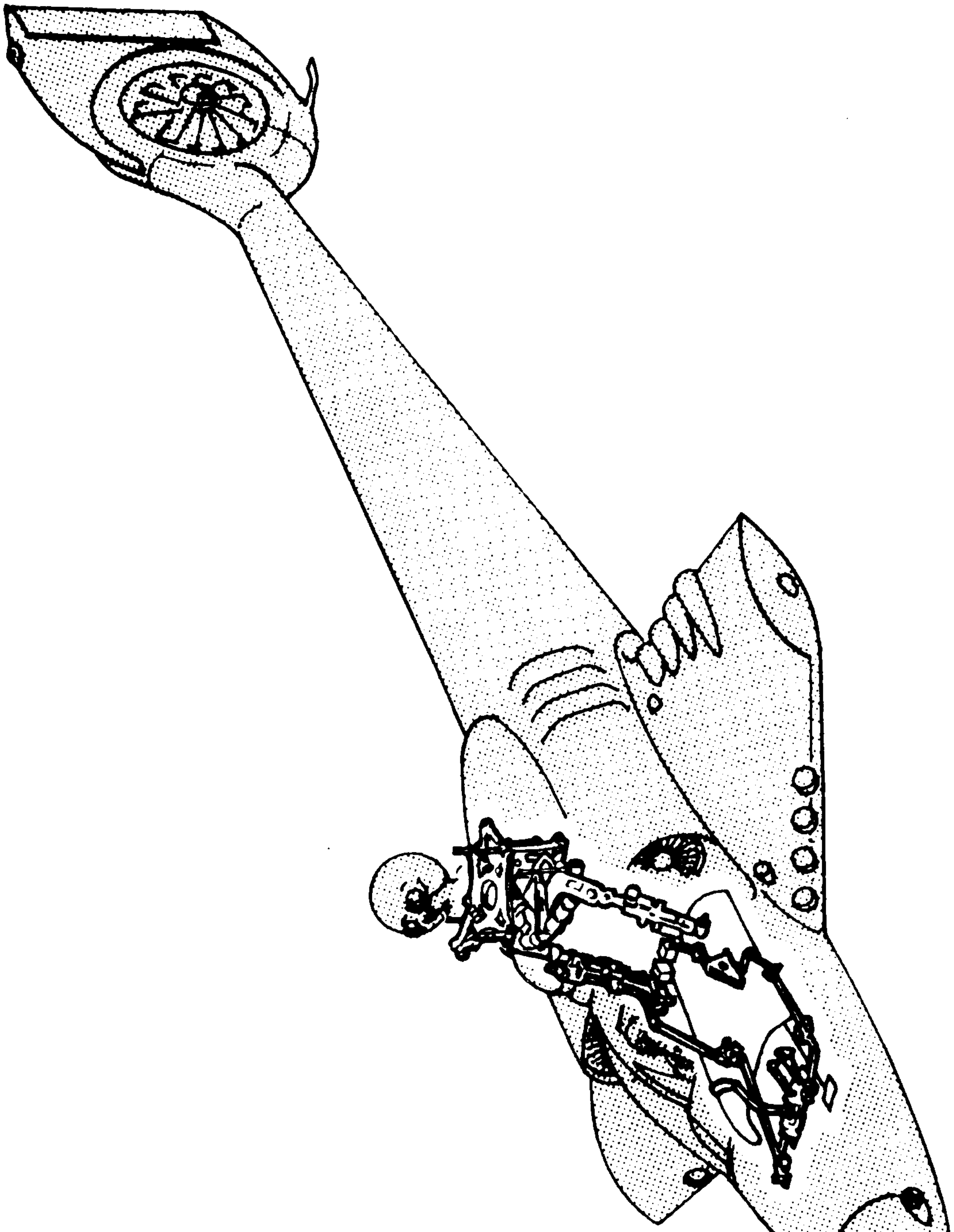


Figure 3.5 Cyclic Control System

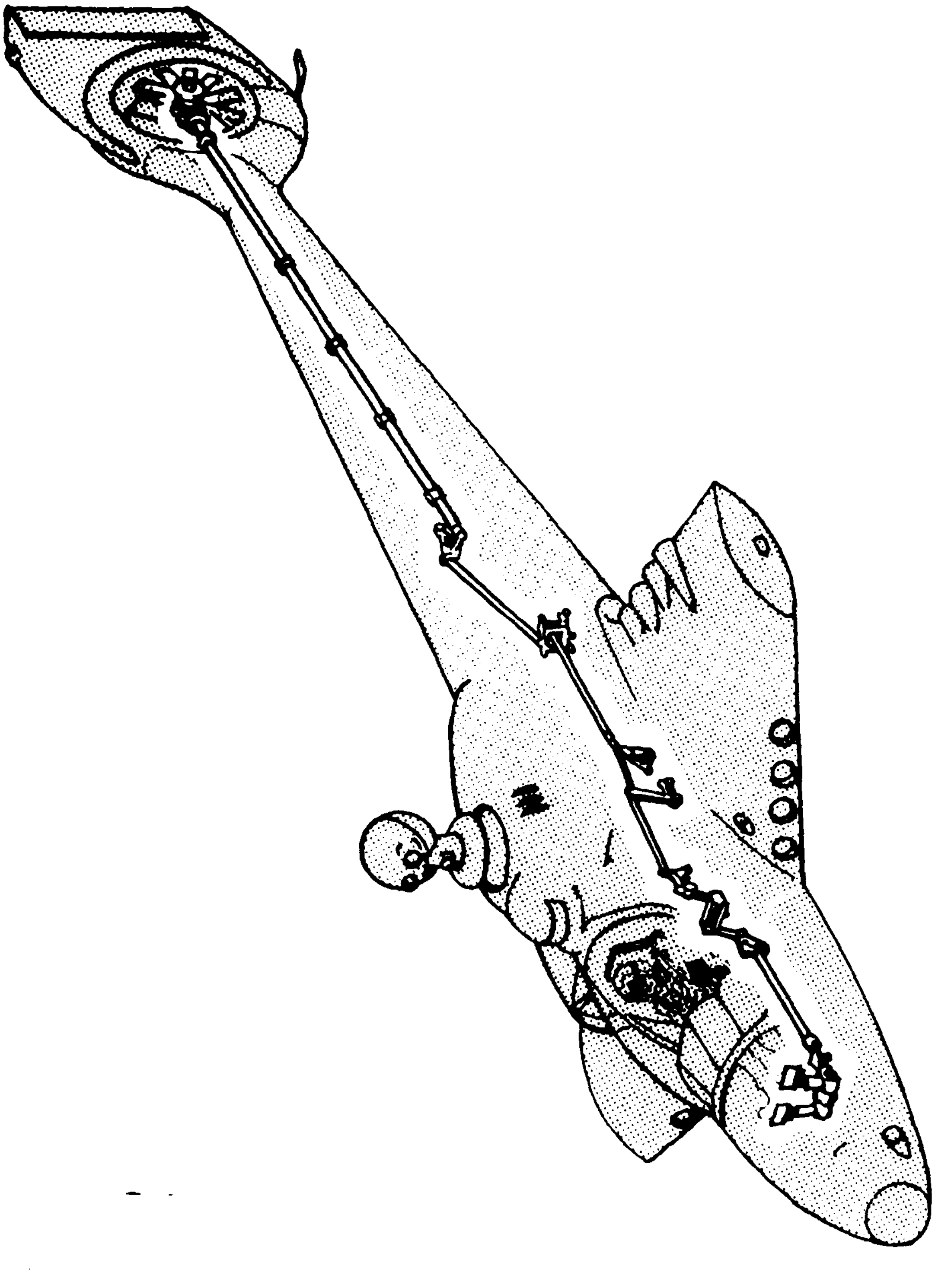


Figure 3.6 Directional Control System

set and adjusted to enable the aircraft to be landed at any airspeed in excess of 70 knots.

The automatic stabilization system incorporates automatic stabilization equipment (ASE), which assists the crew in obtaining and holding a stable weapons platform under any battlefield conditions in any weather. The flight computer for the ASE system is located in the forward avionics mission equipment bay just forward of the crew station.

2. The Propulsion System

The propulsion system for the AH-80 features the installation of twin turboshaft engines. Each engine is capable of 735 shaft horsepower (SHP) for a total of 1470 SHP available. With this engine installed, the aircraft is able to sustain forward flight even under single engine conditions. However, should a single engine condition result while in a hover at maximum gross weight an attrition kill would result.

Each engine is installed relative to the fuselage as shown in Figure 3.7. This installation provides for maximum protection from expected projectile penetration due to the location of the stub wings/weapons bays. This screening effect, when combined with the size and shape of the inlets, also serves to reduce the radar signature of the aircraft when viewed from below. The engines are widely seperated and well shielded in an effort to make them truly

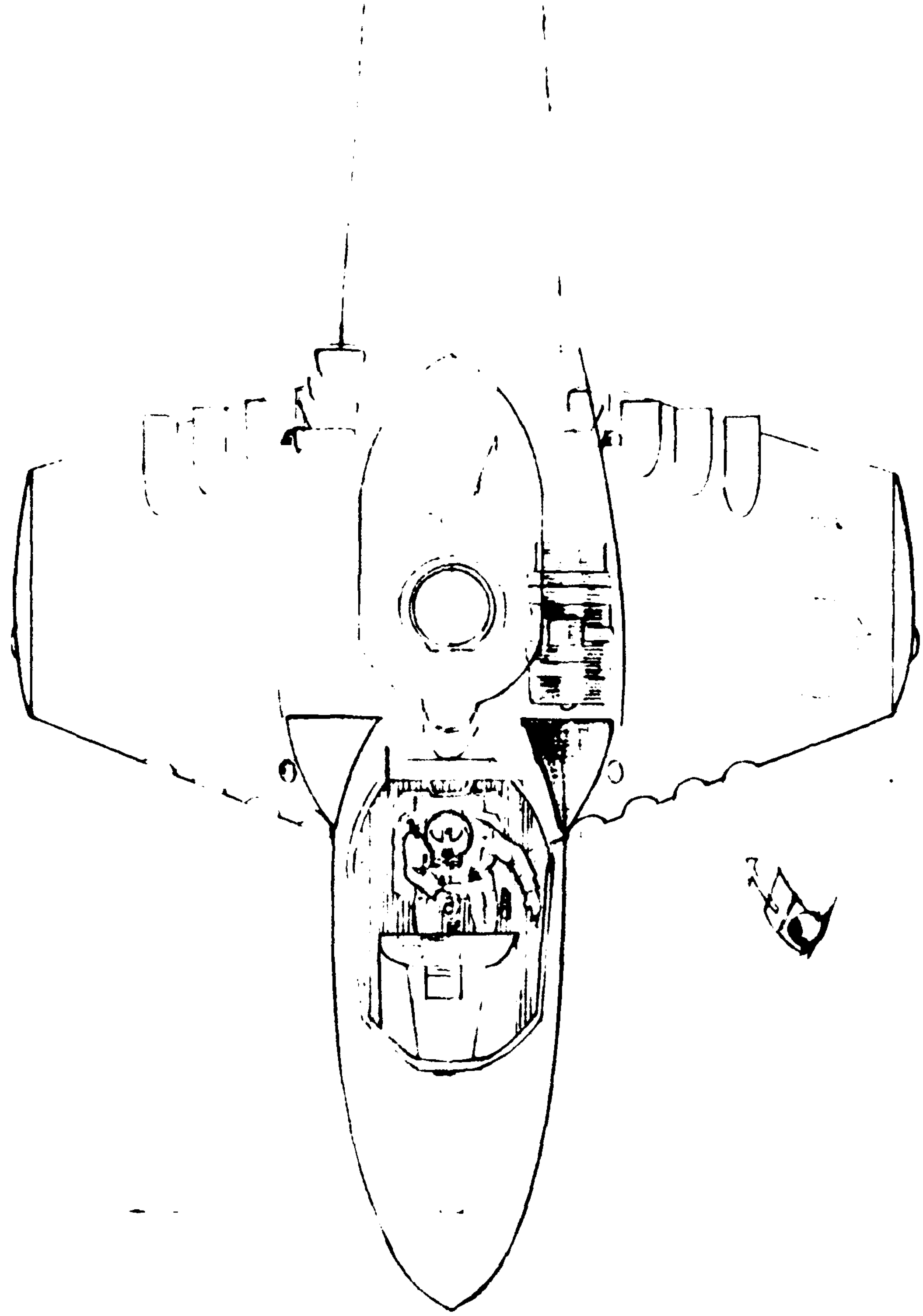


Figure 3.7 Propulsion System Installation

redundant critical components. The inlets are of S-type curved design incorporating air particle seperators. The exhaust is sufficiently cooled by the use of IR suppressors that engine exhaust does not present a signature problem.

3. The Rotor and Drive System

The rotor subsystem consists of four main rotor blades, thirteen tail rotor blades, the main and tail rotor hubs and the main rotor support structure. Both main and tail rotor blades are of advanced composite construction and 1990's design. The blades themselves are designed to be invulnerable to a 23 HEI round. The main rotor hub incorporates standard lead lag hinges, dampers and tension torsion straps for flapping and feathering motions.

The tail rotor is of FENESTRON design to improve its strength characteristics, reduce the power required to obtain the desired performance and also improve the signature of the overall aircraft. The assembly is mounted on plastic bearing which requires no lubrication. Blade pitch change is accomplished by means of a hydraulic servo unit.

The main rotor support structure consists of a mast support structure and a static mast. This arrangement increases the toughness of the mast head and overall rotor system. Additionally, the main rotor mast supports a mast mounted IR sight and electronic warfare components.

The drive subsystem consists of gearboxes on each engine nose, the gearbox to transmission shaft, the main transmission, the main and nose gearbox dual lubrication system, the auxiliary power unit (APU), the rotor brake assembly, the tail rotor drive shaft and associated couplings and the tail rotor gearbox. Each nose gearbox enables the applicable engine to be decoupled from the main transmission in the event of a loss of power. The main transmission itself is capable of performing up to its design loads for up to 30 minutes after a complete loss of lubrication. The tail rotor drive shaft is ballistically tolerant and considered invulnerable to a 23mm HEI round.

4. The Armament System

The VIPER is an extremely potent light attack helicopter. All weaponry is located internal to the aircraft in an effort to reduce the radar signature and and improve its high speed performance by reducing the profile drag. This effort has been very successful with the incorporation of a stub wing/weapons bay. Each wing houses four antiarmor missiles and one air-to-air missile. Further signature reduction is achieved by the use of electrically operated doors which cover the weapons ports when not in use. These doors are fail safe open, enabling all weapons to be operational in the event of an electrical failure. Located forward and below the pilot and to the left of the centerline of the aircraft is an internally mounted 20mm gatling gun and linkless feed system. The gun is powered by the aircraft hydraulic and electrical system.

5. The Fuel System

The AH-80 fuel system consists of two tanks situated fore and aft along the aircraft centerline, and all associated plumbing, filters and pressurization equipment. One electrical fuel transfer pump is located within each fuel cell. There is no provision for either conventional helicopter in flight refueling (HIFR) or in flight refueling via a probe due to the single crew concept and the problems and weight associated with installation of a fuel probe. As much of the plumbing as practical is internal to the tank to reduce the overall vulnerable area of the fuel system. The two tanks together have a capacity of 912.27 pounds of JP-5 which provides the VIPER with a range in excess of 250 nautical miles. This allows the VIPER ample reserve to accomplish its mission. Fire/explosion suppression foam is installed in the ullage of both tanks, and both tanks are self sealing.

6. The Structural System

The major structural sections of the AH-80 are the forward fuselage section, the center fuselage/stub wing section, the upper fairing, the tail boom and the empennage. The forward fuselage section houses the 20mm gun, the forward avionics bay, the forward fuel tank, the cockpit and the forward main landing gear.

The center fuselage section serves as the major structural load bearing member containing the main transmission support assembly, the main transmission, the aft fuel tank, the aft main landing gear, the stub wings and the engine mounts and propulsion system.

The upper fairing serves as a mount for the main rotor support assembly including the static mast and the mast mounted infared sight.

IV. AH-80 MISSION/THREAT ANALYSIS

A. MISSION ANALYSIS

The AH-80 VIPER is designed and armed as a multi-mission all weather light attack helicopter. Additional duties could include scout/reconnaissance, antipersonnel, flank security and utility. The ordnance load for all missions is 8 antiarmor missiles, 2 air to air missiles and a 20mm gatling gun. The antiarmor missle is a semiactive homing weapon while the air to air missle is an IR homing missile. This ordnance can be delivered from any flight regime on target and in any weather. Three particular mission profiles are examined. The first of these is a generic antiarmor mission as depicted in Figure 4.1. The second, depicted in Figure 4.2, is a reconnaissance mission, and the third is the flank security mission profile depicted in Figure 4.3. Airspeeds and flight tactics are also listed for each profile.

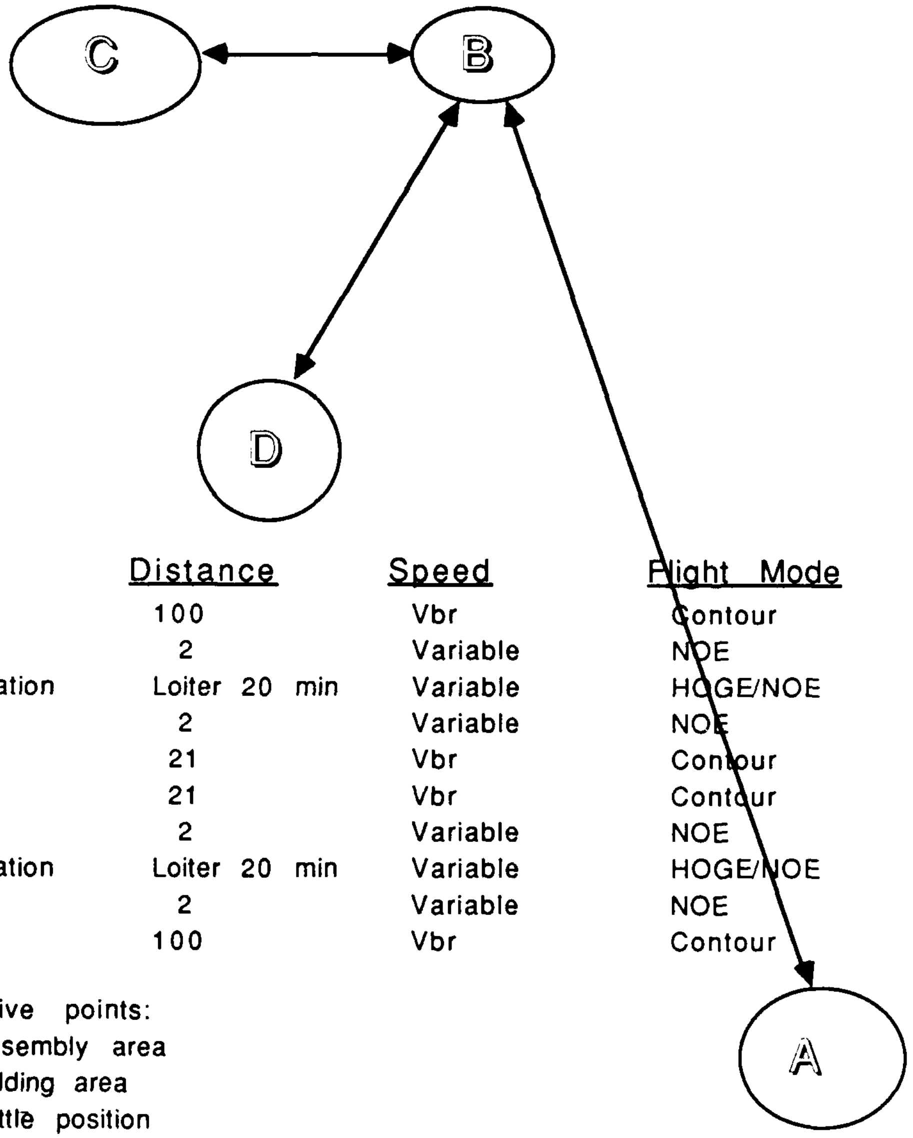
For this case study, the generic antiarmor mission has been chosen. This is an offensive mission with a combat radius of action of up to 300km. This is well within the capabilities of the VIPER. The targets to be engaged can be estimated as approximately 50% tanks, 40% armored vehicles and 10% personnel and other aircraft. The tactics employed during these engagements are similar to those currently employed by aircraft already in the inventory.

Several scenarios are possible. The first involves the VIPER fighting as a section of two aircraft. Each VIPER is equipped with a mast mounted laser designator which enables it to mask itself and still designate the target for a second Viper which engages the target with its antiarmor weaponry. This section could also consist of one VIPER and some other helicopter currently in the inventory. In the second scenario, the AH-80's speed, power, maneuverability and superior targeting capabilities enable it to act completely autonomously, engaging enemy targets without masking and while performing evasive maneuvers to decrease its overall susceptibility. The 20mm gun and the air to air missiles can be used in an air to air role, whereas the 20mm can also be used against ground targets. Specific tactics as conceived by the author are depicted in Figures 4.4, 4.5 and 4.6.

B. THREAT ANALYSIS

The VIPER is strickly an army helicopter operating from a land base. Therfore, the expected threats include only those systems employed by enemy block land forces. No naval weaponry is expected to be encountered. These threats include air defense artillery such as 23mm and 57mm guns, lazer weaponry, air defense missile systems, standard artillery, tank main guns, small caliber gun fire, ground launched anti-armor weaponry and hostile high performance aircraft/helicopters.

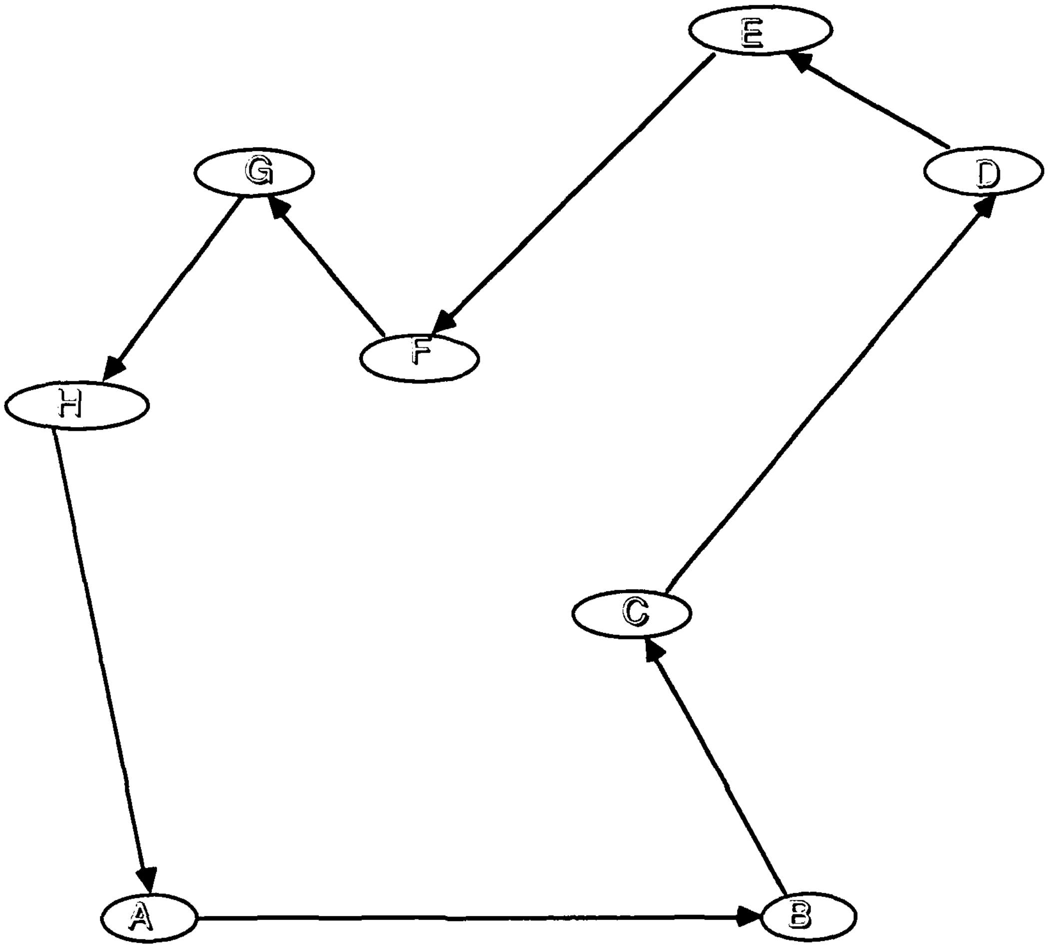
The threat chosen for this study is a generic surface to air IR homing missile with a fragment size of 100 grains.



	Distance	Speed	Flight Mode
a- b	100	Vbr	Contour
b- c	2	Variable	NOE
on station	Loiter 20 min	Variable	HOGE/NOE
c- b	2	Variable	NOE
b- d	21	Vbr	Contour
d- b	21	Vbr	Contour
b- c	2	Variable	NOE
on station	Loiter 20 min	Variable	HOGE/NOE
c- b	2	Variable	NOE
b- a	100	Vbr	Contour

Definitive points:
a. Assembly area
b. Holding area
c. Battle position
d. FARRP

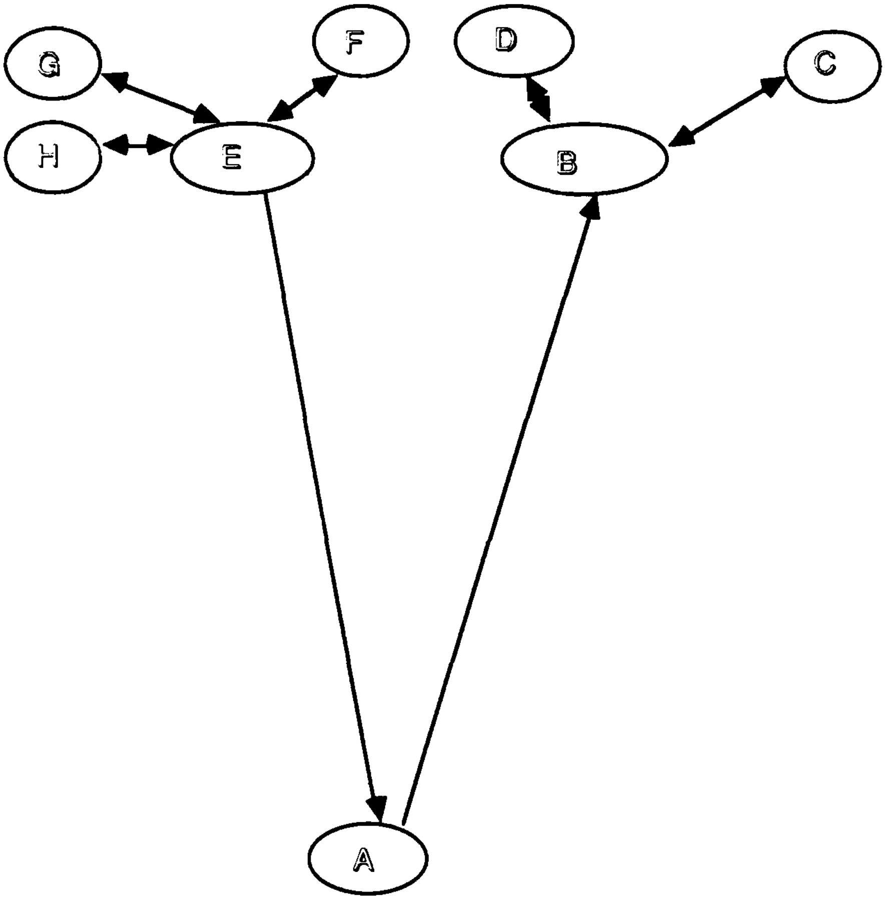
Figure 4. 1 Generic Antiarmor Mission Profile



	Distance (km)	Speed	Flight Mode
a-b	120	Vbr	Contour
b-c	20	Vbe	NOE/Contour
c-d	25	Vbe	NOE/Contour
d-e	15	Vbe	NOE/Contour
e-f	20	Vbe	NOE/Contour
f-g	15	Vbe	NOE/Contour
g-h	25	Vbe	NOE/Contour
h-a	120	Vbr	Contour

Definitive points:
a. Base
b. Air Contact Point (ACP)
c-h. ACP

Figure 4.2 Generic Reconnaissance Mission Profile



	Distance (km)	Speed	Flight Mode
a-b	50	Vbr	Contour
On station OPs	Loiter 30 min	Variable	NOE/HOGE
b-e	50	Variable	NOE
On station OPs	Loiter 30 min	Variable	NOE/HOGE
e-a	50	Vbr	Contour

Definitive points:
a. Base
b. Holding area
c-d. OP
e. Holding area
f-g. OP

Figure 4.3 Generic Flank Security Mission Profile

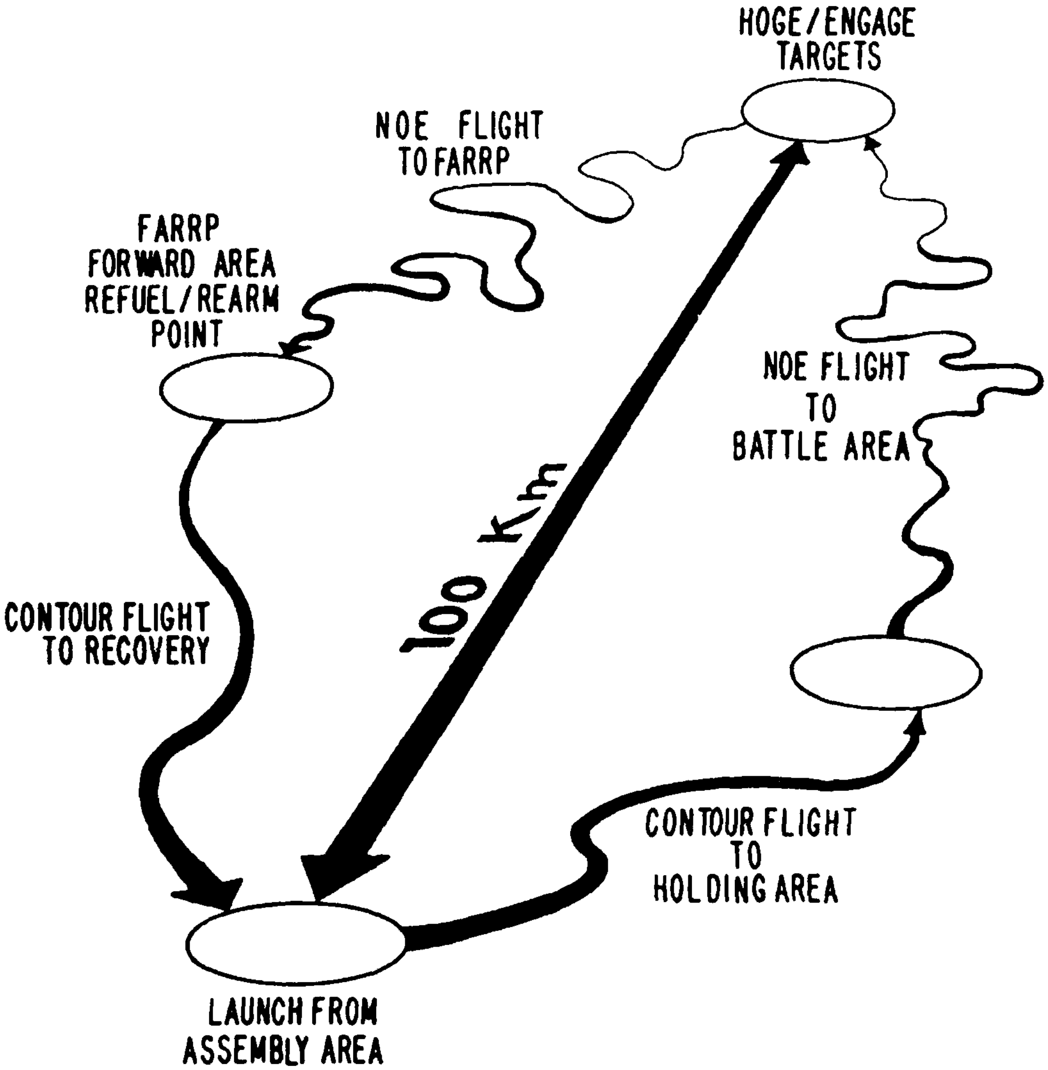


Figure 4.4 Specific Antiarmor Mission Profile

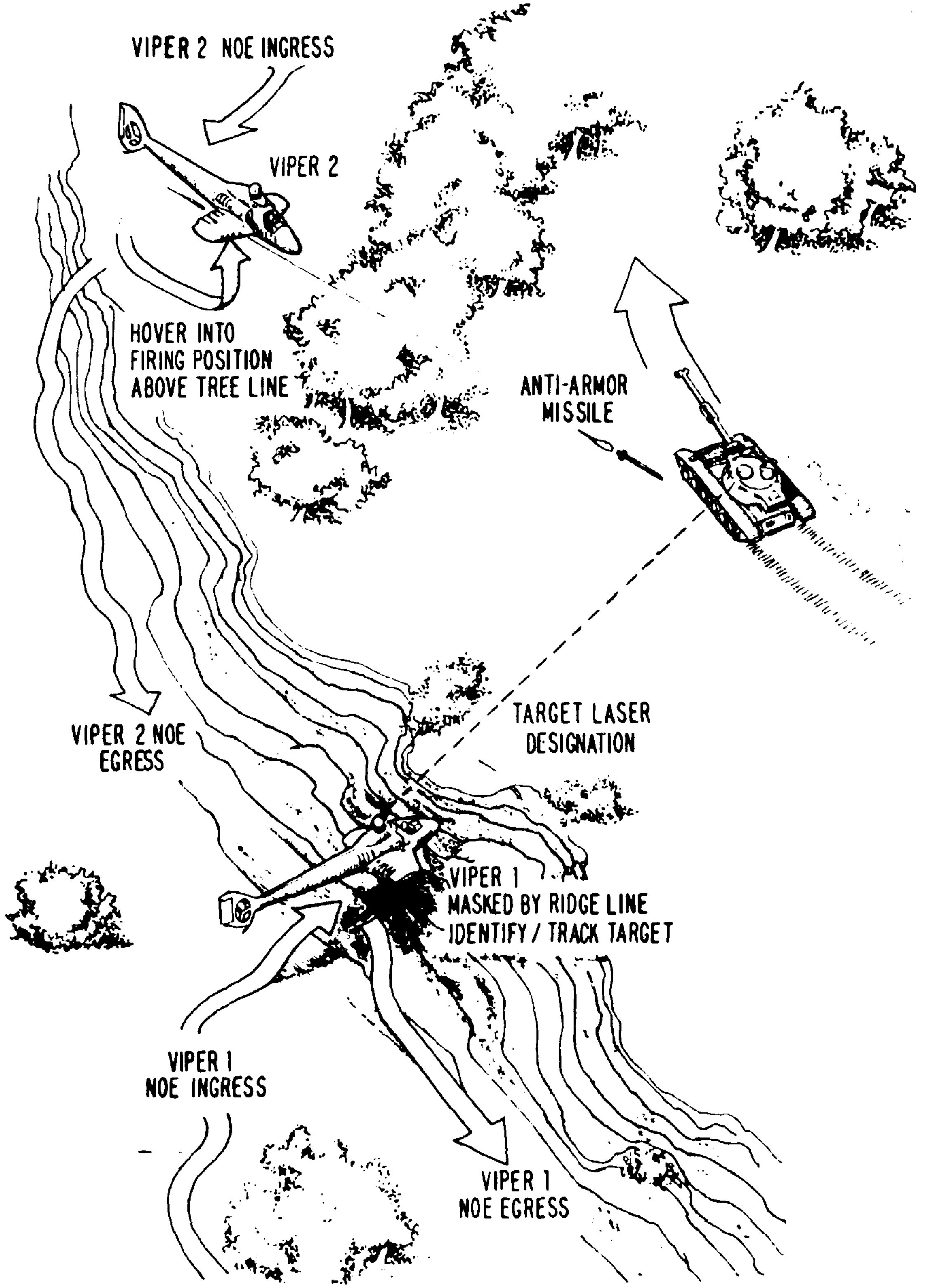


Figure 4.5 Conceptual Tactics

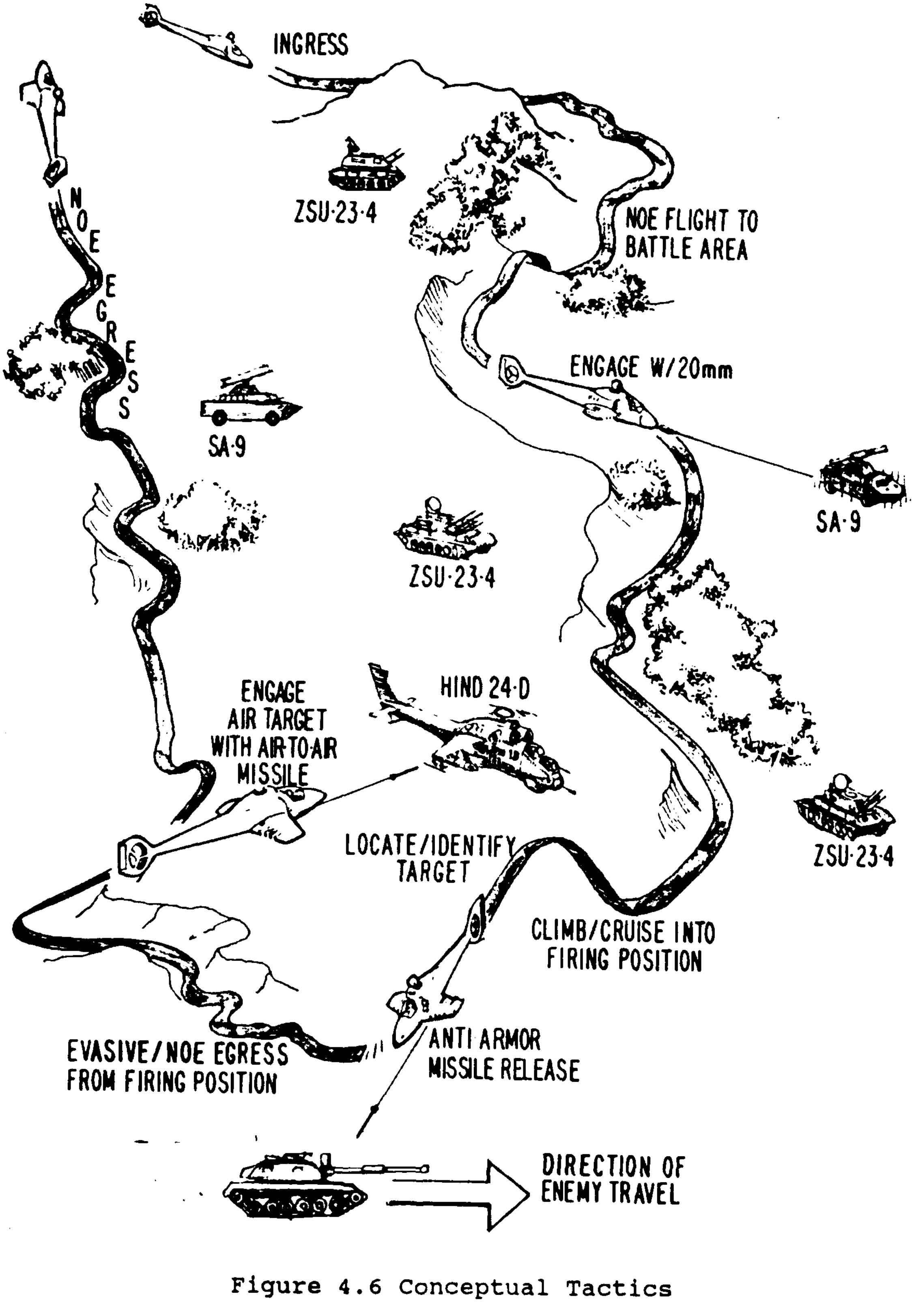


Figure 4.6 Conceptual Tactics

V. AH-80 FLIGHT AND MISSION ESSENTIAL FUNCTIONS

Flight essential functions are those system and subsystem functions required to enable an aircraft to sustain controlled flight. Mission essential functions are those system and subsystem functions required to enable an aircraft to perform its designated mission. Flight essential functions are very clearly those functions which are performed by critical components, defined as any component whose loss or damage would lead to a loss of lift, thrust or control. In the AH-80, the most obvious of these critical components is the main rotor system which provides for all three of these flight essential functions. Mission essential functions are those which are performed during various phases of flight but not during others. Functions such as navigation, communication, weapons delivery and target tracking are not functions which are necessary to keep the aircraft under controlled flight. Rather they are only required while performing a designated mission. The missions required are outlined in the Mission/Threat analysis.

Table 5.1 is a list of the systems and subsystems incorporated in the AH-80 VIPER and their functions. Using this list, each individual system/subsystem can be examined for each particular phase of flight. The phases of flight which are recognized for the antiarmor mission chosen are:

1. Alert
2. Takeoff
3. Cruise to Laager Area
4. Cruise to Holding Position
5. Cruise to Assault Position
6. Engage Targets
7. Return Cruise
8. Land

Table 5.2 correlates these mission phases with the flight and mission essential functions required for each.

By combining Table 5.1 and 5.2, a matrix can be developed which shows which systems or subsystems are required for each phase of flight. It would be entirely too complex and counterproductive to investigate each phase in this type of case study. Therefore, as it is the most interesting, the phase during which the target is engaged will be examined in detail. It can subdivided into the following subphases:

1. Locate and identify target
2. Verify target range
3. Hover/Cruise into firing position
4. Launch antiarmor missiles
5. Launch air to air missiles
6. Fire 20mm gatling gun
7. Depart firing position
8. Land at FARRP and reload

Concentrating on these subphases results in a matrix which shows which systems are required during each subphase of the targeting phase of flight.(Table 5.3) From such a table it_can be seen exactly which functions are considered flight essential and which ones are considered mission essential. Each system contributes to the success or failure of the subphase in some way. Some are obviously required for flight, such as the rotor system while others are strickly mission such as the antiarmor missile system.

Chapter VI will use all of the information developed up to this point to produce the AH-80's FMEA and DMEA or as presented together here, the FMECA.

TABLE 5.1 SYSTEMS/SUBSYSTEMS AND FUNCTIONS

System/Subsystem	Function
Pilot	Maintain aircraft control
Engines	Provide and/or maintain required shaft horsepower necessary for desired rotor rpm
Inlet	
Compressor	
Combustor	
Gas generator	
Power turbine	
Accessory gearbox	
Engine oil/fuel	
Tailpipe	
Hydraulics	Provide hydraulic power for aircraft control, weapons deployment, landing gear, etc.
Primary/secondary mainifold	
Primary/secondary reservoir	
Primary/secondary pump	
Primary/secondary accumulator	
Collective actuator	
Pitch actuator	
Roll actuator	
Yaw actuator	
Pressure and return lines	
Filters and coolers	
Flight Controls	Provide for control of aerodynamic surfaces such as main rotor and tail rotor pitch
Rotary/stationary interface	
Collective installation	
Cyclic installation	
Tail rotor installation	
Structures	Provide for structural integrity of the aircraft
Empennage	
Fuselage	
Rotor support/mast	
Drive	Provide for translation of engine shaft horsepower into main and tail rotor rotational velocity
Main transmission	
Main rotor static mast	
Main oil cooler	
Drive-shaft couplings	
Engine nose gearbox	
Tail rotor drive shaft	
Tail rotor gearbox	
Tail rotor driveshaft vibration dampers	
Hangar bearings	

TABLE 5.1 (cont.) SYSTEMS/SUBSYSTEMS AND FUNCTION

System/Subsystem	Function
Rotor	
Main rotor blades Tail rotor blades Main rotor head Tail rotor head	Provide for required lift thrust and control
Fuel	
Forward fuel cell Aft fuel cell Forward cell sump Aft cell sump Boost pump Fuel lines Shutoff valves APU feed lines	Provide for fuel flow to engines and APU
Electrical	
Battery Generators Wiring Transformers/Rectifier	Provide necessary electrical power to flight/mission systems
Avionics	
UHF/VHF communications Secure communications Navigation Flight/mission computers Instrumentation Electronic warfare components Automatic stabilization	Provide required capabilities during applicable phases of flight
Armament	
Ammunition drum Ammunition feed 20mm barrel antiarmor missiles air to air missiles	Provide required offensive capabilities
Environmental	
Blower assembly Air conditioner/heater Ducting	Provide required environment for selected components and pilot

TABLE 5.2
ATTACK HELICOPTER ESSENTIAL FUNCTION/MISSION PHASE RELATIONSHIPS

Essential Functions	Mission Phases							
	Alert	Takeoff	Cruise to Laager Area	Cruise to Holding Position	Cruise to Assault Position	Engage Targets	Return Cruise	Land
Flight:								
provide lift and thrust		X	X	X	X	X	X	X
provide controlled flight		X	X	X	X	X	X	X
Mission:								
communications								
*secured voice	X					X		
*unsecured voice	X							
start systems	X							
monitor systems		X	X	X	X	X	X	
provide air data intelligence		X	X	X	X	X	X	
maintain terrain clearance			X	X	X		X	

TABLE 5.2 (cont.)
ATTACK HELICOPTER ESSENTIAL FUNCTION/MISSION PHASE RELATIONSHIPS

Essential Functions	Mission Phases							
	Alert	Takeoff	Cruise to Laager Area	Cruise to Holding Position	Cruise to Assault Position	Engage Targets	Return Cruise	Land
Mission (cont.): Employ IFF/ECM					X	X		
navigate			X	X	X		X	
locate/identify targets						X		
employ weapons						X		

TABLE 5.3
TARGET ENGAGEMENT PHASE—FLIGHT AND MISSION ESSENTIAL FUNCTION SUMMARY

m = mission flt = flight b/u = backup

	Targeting Subphases					
System/Subsystem	Locate and Identify Targets	Verify Target Range	Cruise/Hover into Firing Position	Weapon Release	Evasive Flight to Depart Firing Position	Land at FARRP and Reload
Pilot	m/flt	m/flt	m/flt	m/flt	m/flt	m/flt
Rotor	—	—	m/flt	—	m/flt	flt
Fuel	—	—	m/flt	—	m/flt	flt
Mechanical Flight Controls	—	—	flt(b/u)	—	flt(b/u)	flt(b/u)
Electronic Flight Controls	—	—	m/flt	m\flt	m/flt	flt
Electical Power System	m	m	m/flt	m\flt	m\flt	flt
Engines	—	—	m/flt	—	—	m\flt
Hydraulic Systems	—	—	flt	m\flt	m\flt	flt
Structures	—	—	flt	—	—	flt
Environmental Control	m	m	—	m	m	—

TABLE 5.3 (cont.)
TARGET ENGAGEMENT PHASE — FLIGHT AND MISSION ESSENTIAL FUNCTION SUMMARY

m = mission flt = flight b/u = backup	Targeting Subphases					
System/Subsystem	Locate and Identify Targets	Verify Target Range	Cruise/Hover into Firing Position	Weapon Release	Evasive Flight to Depart Firing Position	Land at FARRP and Reload
Drive	—	—	m/flt	m/flt	m/flt	flt
Weapons Control Components	—	m	—	m	—	—
Communication/Identification Components	m	—	—	—	—	—
Electronic Warfare Components	—	—	m	—	m	—
Mission Computers	—	m	—	m	m	—
Instrument Panels	flt	flt	m/flt	m\flt	m	flt
Displays	flt	m\flt	m	m	m	flt
Autostab	flt	—	m/flt	m	m/flt	flt

VI. AH-80 FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS

In the previous chapter, the essential functions required for the VIPER to continue its mission, and the major systems and subsystems required to perform those essential functions, were identified. The next step in a critical component analysis is to conduct a Failure Mode, Effects, and Criticality Analysis (FMECA). The FMECA is broken down into two distinct phases for ease of analysis, the Failure Mode and Effects Analysis (FMEA), and the Damage Mode and Effects Analysis (DMEA). This chapter will apply the FMECA methodology described in a general sense in Chapter II, and presented in Reference 1:pp140-153, specifically to the AH-80. Additionally, though not required by MIL-STD-2069 [Ref.4], a Fault Tree Analysis (FTA) is also included as an aid in the identification of the critical components.

A. AH-80 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

"The failure mode and effects analysis is a procedure that: (1) identifies and documents all possible failure modes of a component or subsystem and (2) determines the effects of each failure mode upon the capability of the system or subsystem to perform its essential functions." As can be seen from this definition, the FMEA is in no way concerned with the cause of the failure, only the effect that that component failure had on the individual subsystem or system it was a member of. "The FMEA is normally provided by engineers who are concerned with system safety, reliability and maintainability. It is based on design requirements, historical data (if the system is still in the concept stage), predicted performance measurements and sound engineering judgement."[Ref.3:p70] As described earlier, the AH-80 flight control system will be the only system analyzed in detail using the FMEA methodology. Each component is examined to determine the role that it plays in the flight control system, what effect its damage would have on its immediate subsystem, and the effect of the failure on the overall mission capability of the VIPER. The results of this analysis are presented in the FMEA matrix, Table 6.1.

B. DAMAGE-CAUSED FAILURE ANALYSIS

As in reference 3, the material presented in this phase of the case study will consist of five sections: (1) The DMEA Matrix, (2) The Disablement Diagram, (3) The Fault Tree Analysis, (4) The Kill Tree, and (5) The P(k/h) Functions. The DMEA Matrix, Disablement Diagram, and the FTA will be presented for the flight control system alone, whereas the Kill Tree, and P(k/h) functions will be presented for the entire aircraft. MIL-STD-2069 [Ref.4] states that following the DMEA matrix, the list of critical

TABLE 6.1 FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Swashplate Assembly (Rotating)	FF/HF	provides for rotating/ nonrotating control interface	loss of mech integrity	loss of main rotor cyclic and collective pitch control	aircraft uncontrollable	Nonredundant critical component; damage tolerant design including shiel ing, oversizing, and highly resiliant material. Loss in flight results in a immediate attrition kill.
Swashplate Assembly (Stationary)	FF/HF	provides for rotating/ control interface	loss of mech integrity	loss of main rotor cyclic and collective pitch control	aircraft uncontrollable	
Swashplate Assembly (Rotating)	FF/HF	"	jamming or limited movement of swashplate		degraded flight control capability	Loss of control authority may lead to a mission abort or attrition kill.
Swashplate Assembly (Stationary)	FF/HF	"				
Bellcrank Assy (Lat)	FF/HF	provides for cont control path	loss of mech integrity	loss of lateral cont	uncontrollable in lat axis	Location/construction provides shieldi and protection from penetrator. Damage will result in an attrition kill.
Bellcrank Assy (Long) Fwd/Aft	FF/HF	"	"	loss of longitudinal control	uncontrollable in long axis	"

TABLE 6.1 (cont.) FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Link Assembly Longitudinal	FF/HF	connect long actuator to nonrotating swashplate	jam/sever	loss of long control path	uncontrollable in longitudinal axis	Nonredundant critical component. Control rods of ballistically tolerant design. Location aids in protection and shielding from penetrators.
Link Assembly Lateral	FF/HF	connect lat actuator to nonrotating swashplate	jam/sever	loss of lat control path	uncontrollable in lateral axis	
Torque Link Assembly	FF/HF	provide anti torque force for nonrotating swash plate	loss of mech integrity	failure of nonrotating system due to induced rotation	uncontrollable	Loss of antitorque force results in nonrotating control linkage destruction and immediate attrition kill.
Pitch Links	FF/HF	provide for main rotor pitch change capability	loss of mech integrity/ jam	loss of main rotor pitch control	uncontrollable in both lat and long axis of flight	Main rotor system will stay at pitch at time of failure. No complete control path to main rotor system. Will eventually lead to an attrition kill.
Scissors Assembly	FF/HF	provide for vertical movement of rotating/ nonrotating interface	loss of mech integrity/ jam	loss of main rotor collective pitch control	uncontrollable in collective channel	Main rotor will have fixed collective pitch. Lateral and longitudinal channels not affected. Aircraft vertical movement controllable through engine power adjustments. Mission abort.

TABLE 6.1 (cont.) FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Collective Servo-actuators	FF/HF	provide for mechanical/ electrical interface	penetration/ loss of electrical signal	no effect	no effect	Duel electrical flight control system widely seperated for true redundancy. Complete loss of electrical power will require mechanical backup utilization
Collective Hydraulic Actuator	FF/HF	provide for hydraulic assist to the collective channel	leakage	mech system required	no effect	Aircraft uncontrollable via fly-by-wire without hydraulic assist. Mechanical system has full authority. Jam-proof actuators utilized to prevent disruption of control path by jamming.
			jamming	loss of coll control	uncontrol- in vertical plane	
			fluid ignition			Forced landing or attrition kill.
Decoupler (Collective)	FF/HF	provide auto decoupling of fly-by-wire system	loss of mech integrity	unable to de-couple dual flight control sys in case of hardover/jam	loss of collective pitch control	Collective decoupler designed using shielding and highly resiliant material. Will automatically decouple one system should a jam or hardover condition develop.
Bellcrank/ Spring Assy	FF/HF	provide for collective installation and operation	loss of mech integrity	collective unusable	loss of collective pitch control	Collective will jam leaving main rotor pitch fixed. Mission abort.

TABLE 6.1 (cont.) FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Cyclic Stick	FF/HF	provides for lat and long control of aircraft	loss of mech integrity	unable to control cyclic pitch of main rotor	uncontrollable in lat and long axis	Nonredundant critical component. Loss in flight will lead to an attrition kill.
Cyclic Push-Rod/arm Lateral	FF/HF	provide for lateral chan continuous mech path	sever/jam	no effect	mechanical lateral channel inop	Mechanical flight control system inop. If jam condition exists decoupler provides automatic decoupling. Fly-by-wire system retains full authority.
Cyclic Push-Rod/arm Longitudinal	FF/HF	provides for long channel continuous mech path	sever/jam	no effect	mech long channel inop	
Deccupler (Lat/Long)	FF/HF	provide auto decoupling of fly-by-wire system	loss of mech integrity	unable to decouple system in case of hardover/jam	no effect	No effect provided flight control system integrity remains intact. Designed using shielding and highly resilient materials to provide auto decoupling of elec and mech systems should a hardover/jam exist
Pitch/Roll Hydraulic Actuators	FF/HF	provide for hydraulic assist to lat/long channels	leakage jamming	mech system required loss of cyclic cont.	no effect	Aircraft uncontrollable via fly-by-wire without hydraulic assist. Mechanical system has full authority. Jam-proof actuators utilized to prevent disruption of control path by jamming.

TABLE 6.1 (cont.) FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Cyclic servo-Actuators	FF/HF	provide for elec/mech interface	penetration/ loss of elec signal	no effect	no effect	Complete loss of electrical power or damage to duel electrical system will require mech backup utilization.
Pedal Assy	HF	provides for directional control of aircraft	sever/jam	loss of tail rotor pitch control	attrition	Loss of tail rotor pitch control in a hover could result in an attrition kill.
	FF				no effect	Tail rotor will maintain pitch fixed prior to disruption of signal path.
Decoupler (Directional)	FF/HF	provide auto decouple for dir control system	loss of mech integrity	unable to decouple flight control sys in case of hardover/jam	loss of T/R pitch control	Decoupler designed using shielding and highly resiliant material. Will automatically decouple system should a hardover or jam condition exist. FF dir control available using rudder.
Servo-Actuator (Directional)	FF/HF	provide mech electrical interface	penetration/ loss of elec signal	no effect	no effect	Complete loss of electrical power will require mechanical backup utilization.
Feel Trim	FF/HF	provides for directional trim capability	loss of electrical signal	unable to trim out control force	no effect	Pilot workload significantly increased.

TABLE 6.1 (cont.) FAILURE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

FF = forward flight HF = hovering flight

COMPONENT	STAGE OF OPERATION	COMPONENT/ SUBSYSTEM FUNCTIONS	FAILURE MODE	FAILURE EFFECT ON		REMARKS
				SUBSYSTEM	AIRCRAFT	
Yaw Hydraulic Actuator	FF/HF	provides for hydraulic assist to directional channel	leakage	mech system required	no effect	Aircraft uncontrollable via fly-by-wire without hydraulic assist. Mech system has full authority.
			jamming	loss of dir control	loss of T/R pitch control	
			fluid ignition			Attrition kill.
Aft Fuselage Linkage	FF/HF	provide cont mech control path	loss of mech integrity	loss of mech directional control sys	no effect	Required for mechanical system only. Mission abort only if prior damage to fly-by-wire system.
Tail Boom Linkage	FF/HF	•	•	•	•	•
Tail Rotor Stationary/ Rotary Interface	FF/HF	provide for rotating/ nonrotating control interface	loss of mech integrity	loss of T/R pitch control	mission abort	Loss of pitch control in a hover may result in an attrition kill. Loss in FF mission abort.
Drive Link Assy T/R	FF	provide for tail rotor drive	loss of mech integrity	loss of T/R antitorque force	mission abort	Loss of T/R thrust in FF will result in mission abort. Rudder has sufficient authority for nonvertical landing.
	HF				uncontrollable	Loss of T/R thrust in hover will result in immediate loss of control and kill.
T/R Pitch Link Assy	FF/HF	provide for T/R pitch change	sever/jam	loss of T/R pitch control	mission abort	Tail rotor will maintain fixed pitch. Sufficient directional control available using rudder.

components is complete; however, here the list will be presented following the FTA in order to show that this list is the natural result of the progression of the analysis from the FMEA, through the DMEA Matrix, the Disablement Diagram, and the FTA. The P(k/h) functions and the list of critical components are required in the next chapter for the vulnerability assessment. Therefore, they must contain components from the entire aircraft, just as if the analysis had been carried out on the entire aircraft all along.

1. The DMEA Matrix

Unlike the FMEA, the DMEA is concerned with the cause of the component failure. Specifically, damage caused by a man made hostile environment, i.e. combat, such as fire, explosion, or fragment penetration is identified and examined. "In the DMEA, the potential component or subsystem failures identified in the FMEA, as well as other possible damage-caused failures, are evaluated to determine their relationship to the selected kill level."[Ref.1:p142]

The DMEA Matrix is presented in Table 6.2. The components and their damage-caused failure modes are related to applicable kill criteria and component redundancy relationships. Reference is also made to Table 6.4 where the P(k/h) values are presented for the critical components.

TABLE 6.2 DAMAGE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

COMPONENT	DAMAGE MODE	KILL CATEGORY		REMARKS	P(k/h)
		NONREDUNDANT A-LEVEL ATTRITION	REDUNDANT A-LEVEL ATTRITION		
Main Rotor Azimuth Assy–					
rotating swashplate	loss of mechanical integrity/jam	X		Loss of rot/nonrotating swashplate will result in loss of control.	See Table 6.4 for P(k/h) values
nonrotating swashplate		X			
lateral link	sever/jam	X		Loss of long or lateral link will result in attrition. Loss or jam of scissors could result in attrition.	
longitudinal link		X			
torque link		X			
scissors		X			
Collective Control Sys Mehanical Linkage–					
collective stick	sever/jam		X	Limited power control avail through engine manipulation.	
bellcrank/spring assy	sever/jam		X		
decoupler	loss of mech integrity		X		
control push/pull tube	sever/jam		X		
collective actuator	puncture/leakage/jam		X	Hydraulic assist required for electrical system only. Jam condition results in the loss of collective pitch control.	
Cyclic Control System Mechanical Linkage–					
cyclic stick	sever/jam	X		Loss will result in loss of main rotor cyclic pitch cont and attrition.	
bellcrank/spring assy	sever/jam	X			
decoupler	loss of mech integrity	X			
lateral push rod/arm	sever/jam		X	Part of mechanical backup flight control system.	
long push rod/arm	sever/jam		X		
pitch actuator	puncture/leakage/jam		X	Hydraulic assist required for electrical system only. Jam will result in attrition.	
roll actuator	puncture/leakage/jam		X		

TABLE 6.2 (cont.) DAMAGE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

COMPONENT	DAMAGE MODE	KILL CATEGORY		REMARKS	P(k/h)
		NONREDUNDANT A-LEVEL ATTRITION	REDUNDANT A-LEVEL ATTRITION		
Directional Control System Mechanical Linkage–					See table 6.4 for P(k/h) values
pedal assembly	loss of mech integrity	X		Loss of T/R pitch control in FF results in mission abort, loss in hover results in kill.	
control/push/pull tube	sever/jam		X	Part of backup system.	
spring assy	sever/jam		X		
directional decoupler	loss of mech integrity		X	Loss in hover will result in attrition.	
yaw actuator			X		
aft fuselage linkage	penetration/ loss of control path		X		
tail boom linkage			X		
Tail Rotor System–					
stationary/mechanical interface	loss of mech integrity		X	Loss of any T/R component in hover will result in attrition "Rudder" has sufficient authority in forward flight for return flight and non-vertical landing.	
drive link assembly	sever		X		
pitch link assembly	sever/jam		X		
Tail "Rudder" Control	structural removal/ penetration		X	Single hit will not cause an attrition kill; backup system only.	
cockpit contols					
aft fuselage linkage					
tail boom linkage					
aft control surface					

TABLE 6.2 (cont.) DAMAGE MODES AND EFFECTS ANALYSIS
AH-80 FLIGHT CONTROL SYSTEM

COMPONENT	DAMAGE MODE	KILL CATEGORY		REMARKS	P(k/h)
		NONREDUNDANT A-LEVEL ATTRITION	REDUNDANT A-LEVEL ATTRITION		
Fly-By-Wire Flight Control System- flight computer servoactuators collective cyclic directional cyclic actuator cyclic wiring collective actuator collective wiring T/R actuator T/R wiring	penetration/ fire/ radiation damage/ loss of aircraft motion data/loss of electrical power/ severing		X	Entire system backed up by mechanical flight controls, hydraulic actuators required for wire system. Jamming of collective or cyclic hydraulic actuators will result in a loss of main rotor pitch control and attrition. Wiring bundles in tail boom seperated from mech linkages to provide true redundancy.	See Table 6.4 for P(k/h) values

2. The Disablement Diagram

The flight control system Disablement Diagram is presented in Figure 6.1. The diagram is a depiction of the locations of individual components within the overall system and shows the failure mode of the individual component, the effect of the failure, and the resultant aircraft kill criterion. For the purposes of this case study, only a few failures are shown on this diagram.

3. The Fault Tree Analysis (FTA)

The FTA is presented here for the loss of control situation only. Reference 3 contains an example of the power of an FTA when performed on an entire aircraft. The methodology for this analysis is discussed in Reference 1, pages 149-151. The FTA begins with an undesired event, and then determines what event or series of events will lead to the undesired result. Logic symbology is used in the fault tree or as it is sometimes called, the Failure Analysis Logic Tree (FALT). The FTA is one of the principal methods of system safety analysis, and can include both hardware failures and human effects.

The undesired event for the VIPER is an A-level attrition kill. While the attrition kill category can be broken down into either the aircraft can not fly, or the aircraft can not land, only the former situation will be explored through the loss of aircraft control.

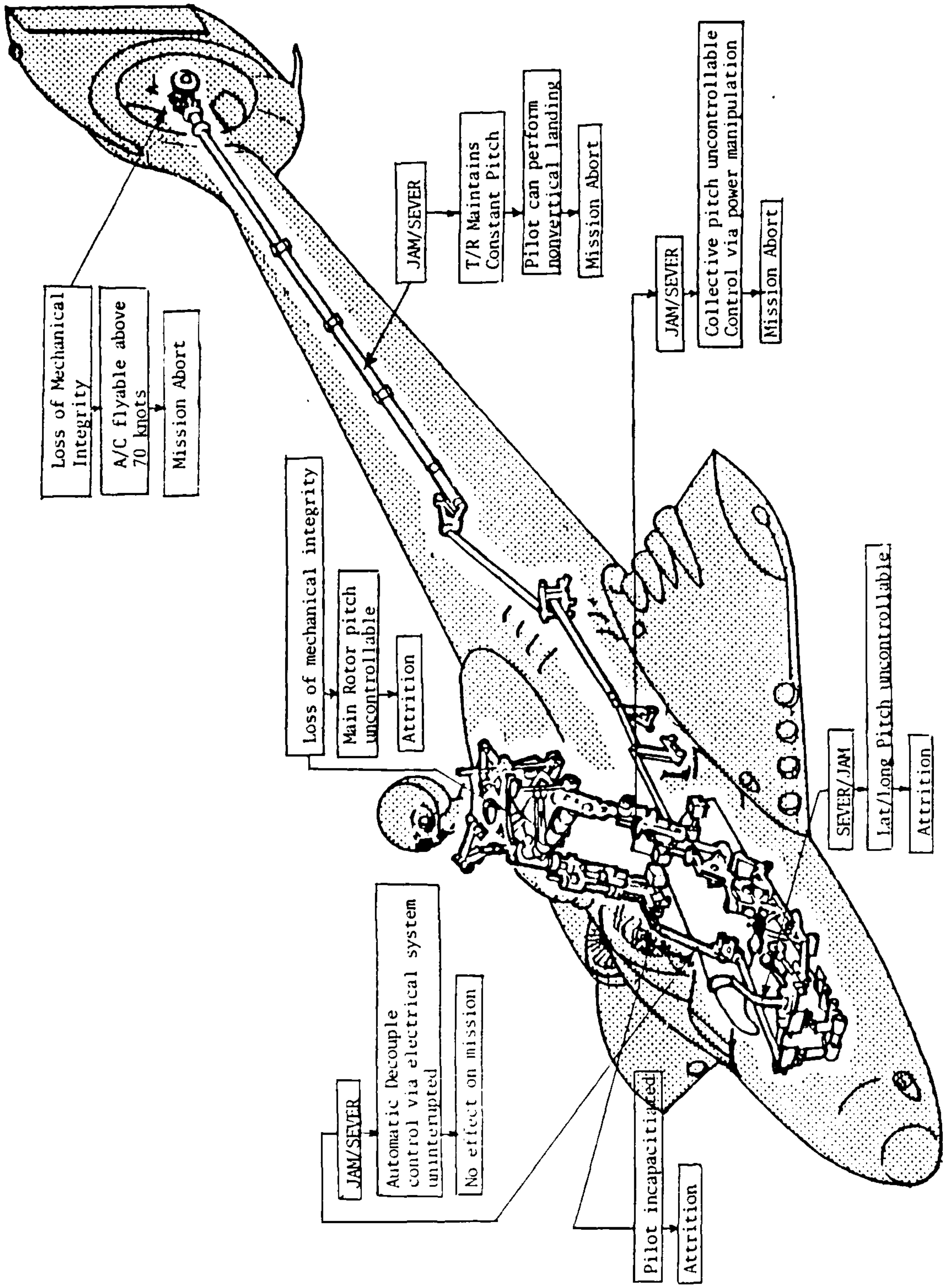


Figure 6.1 AH-80 Flight Control System Disablement Diagram

Figure 6.2 and Table 6.3 show the results of this analysis. Together they break down the aircraft, just as the FMEA did, to determine what event, or series of events, will cause an attrition kill.

4. The Kill Tree

The Kill Tree for the AH-80 is presented in Figure 6.3 for the forward flight mode. This "tree" is a pictorial representation of the critical components and their redundancy relationships. It is invaluable when trying to determine, at a glance, the redundancy relationships for individual systems and subsystems. Components presented in series are nonredundant as their kill alone will sever the trunk of the tree and therefore kill the aircraft. Components presented in parallel are redundant components, as two or more components must be killed in order to sever the trunk.

5. The P(k/h) Functions

The final step in the DMEA process is a listing of the P(k/h) functions for the critical components. The P(k/h) function defines the probability of killing a component, given that it is hit by a fragment or penetrator. This listing is the first step in quantitatively assessing the aircraft's vulnerability. Normally, this list would contain every critical component for each aircraft system and subsystem. However, in order to simplify the list and clarify the methodology involved

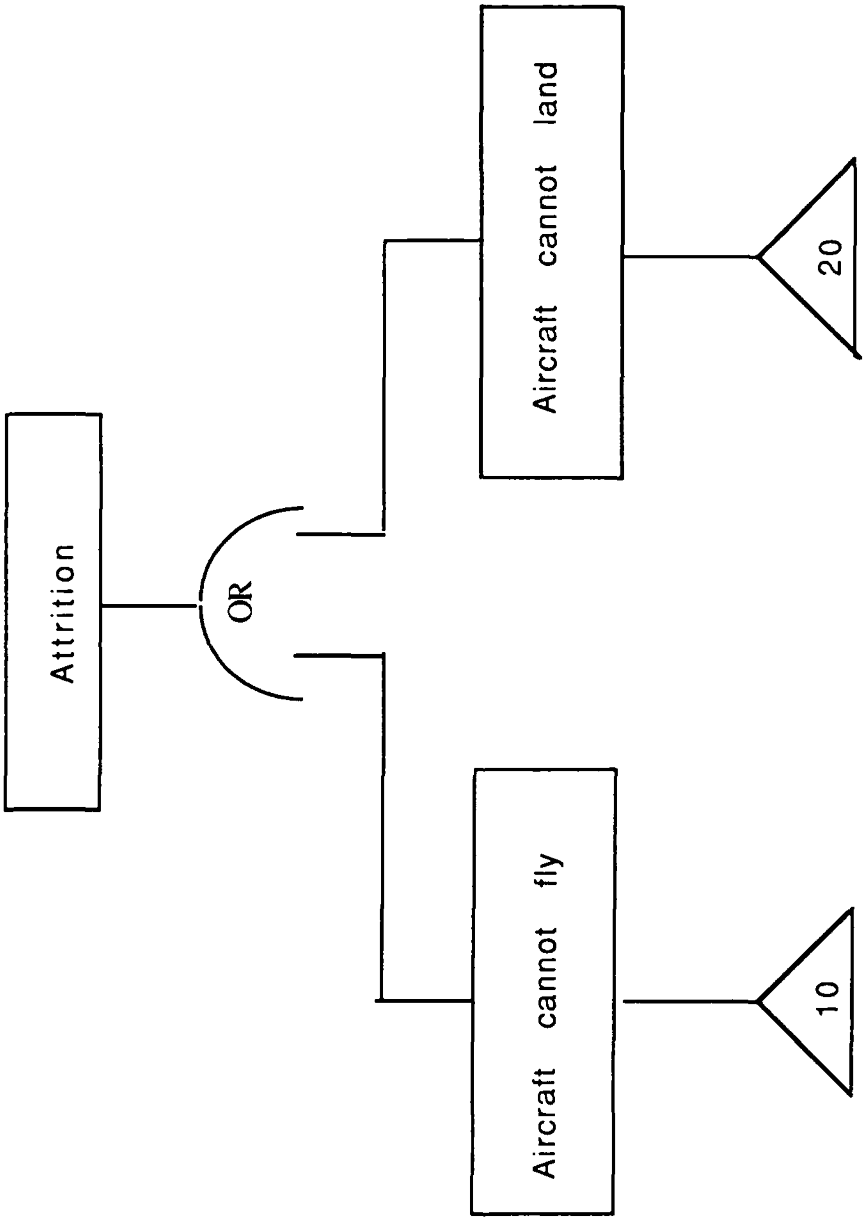


Figure 6. 2 AH- 80 FALT

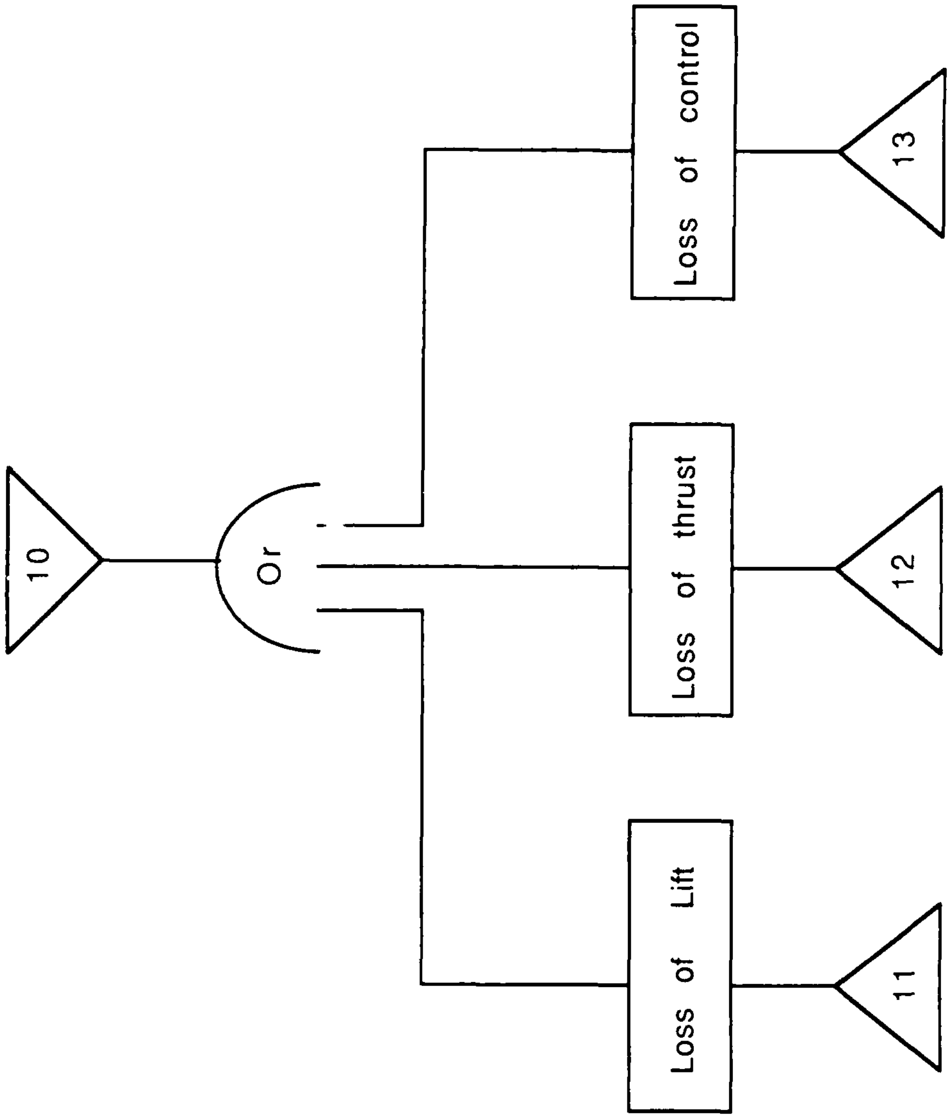
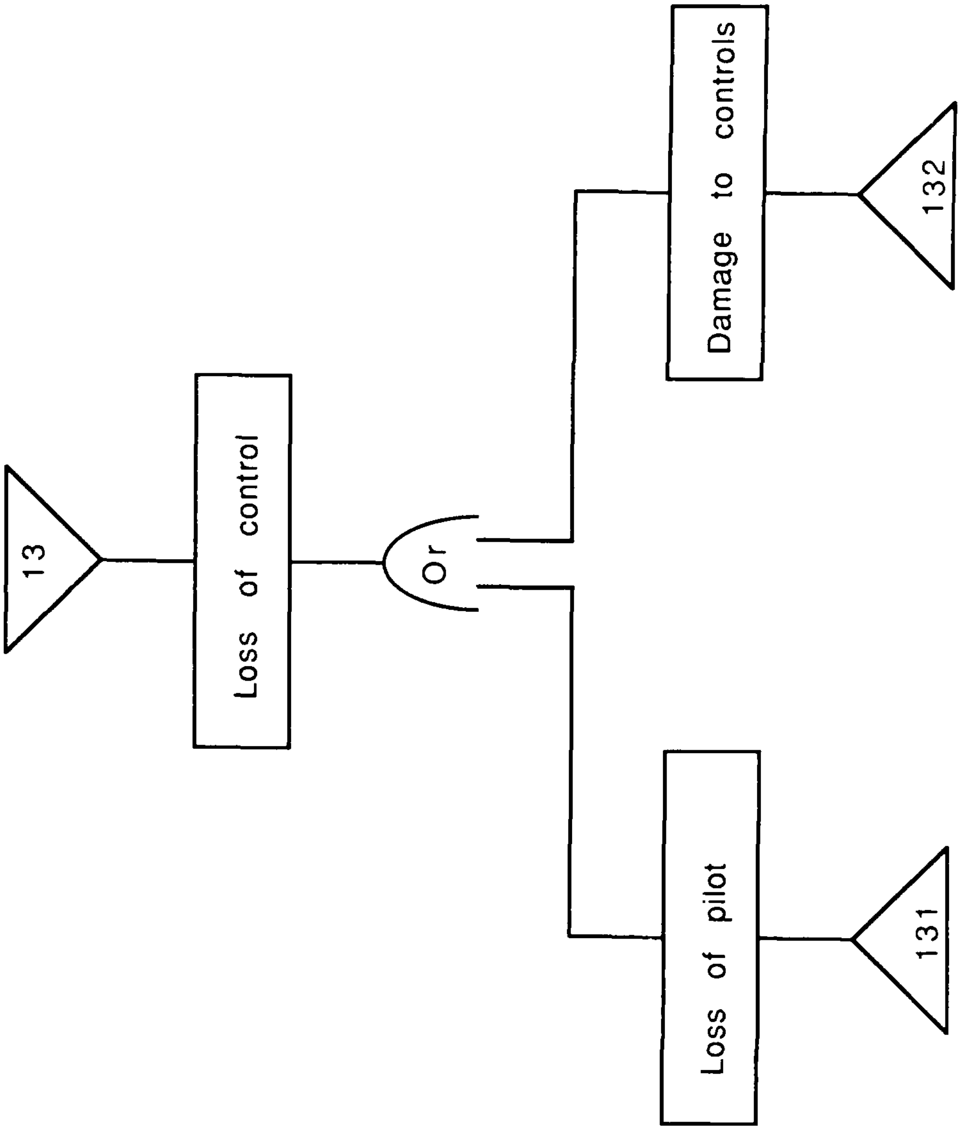


Figure 6. 2 (cont.) AH- 80 FALT



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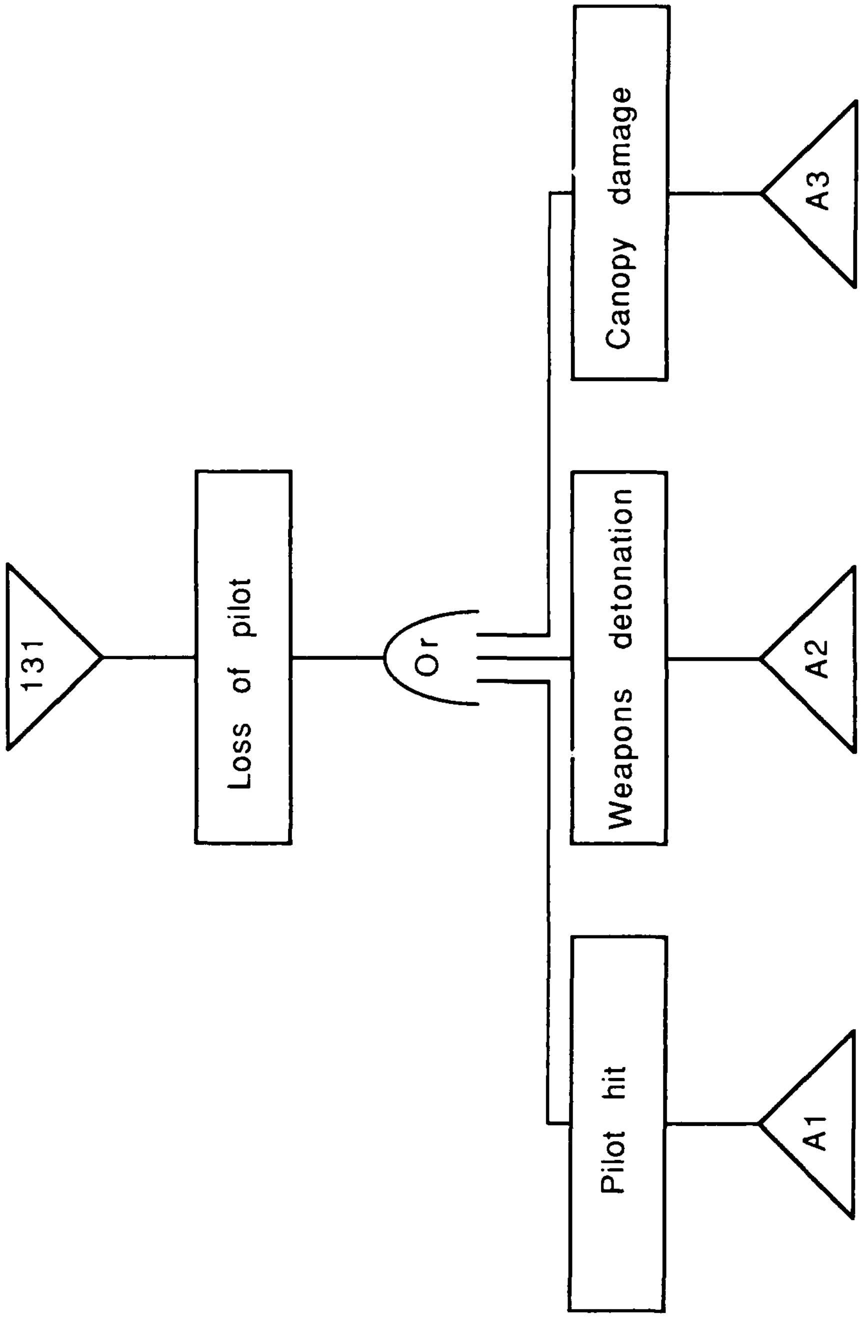

See A1, A2, A3 on the following page

Figure 6. 2 (cont.) AH- 80 FALT

TABLE 6.3 A1 PILOT HIT COMPONENT LIST

COMPONENT	DAMAGE
head	penetration
thorax	penetration
abdomen	penetration
pelvis	penetration
left arm	penetration
left leg	penetration
right arm	penetration
right leg	penetration

A2 WEAPONS DETONATION COMPONENT LIST

COMPONENT	DAMAGE
20mm ammo drum	penetration
antiarmor missile warheads (8)	penetration
air to air missile warheads (2)	of any one of the ten can cause attrition

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A3 CANOPY DAMAGE COMPONENT LIST

COMPONENT	DAMAGE
forward canopy support	sever if more than one severed pilot considered incapacitated
mid canopy support	
aft canopy support	
canopy slide	

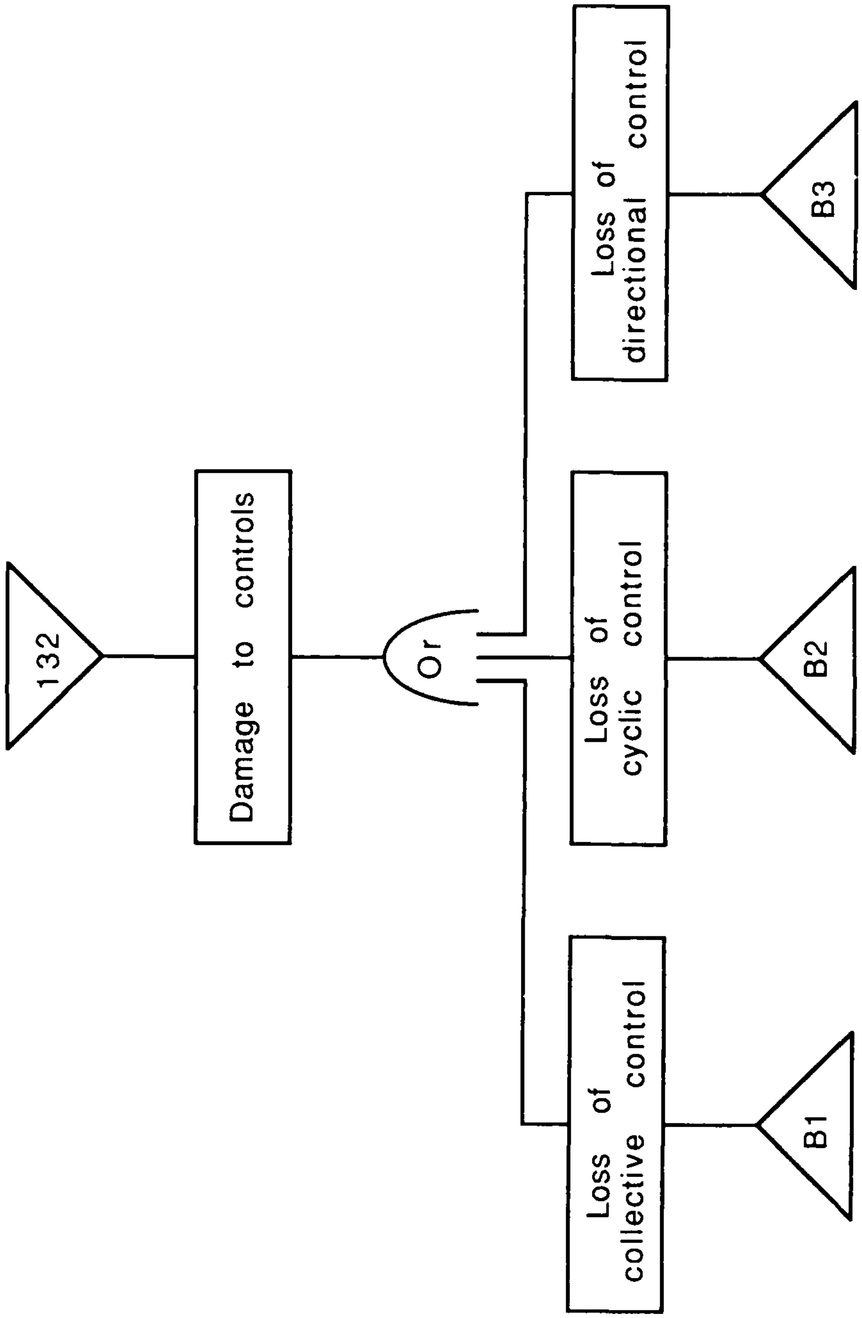


Figure 6. 2 (cont.) AH- 80 FALT

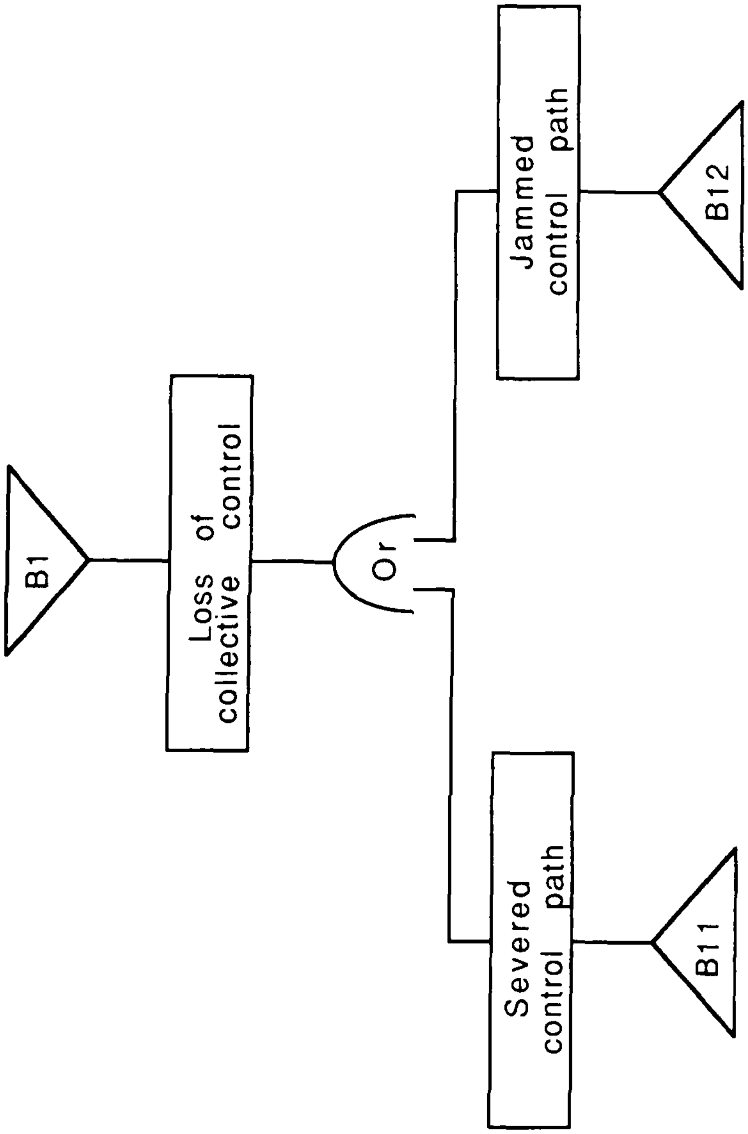
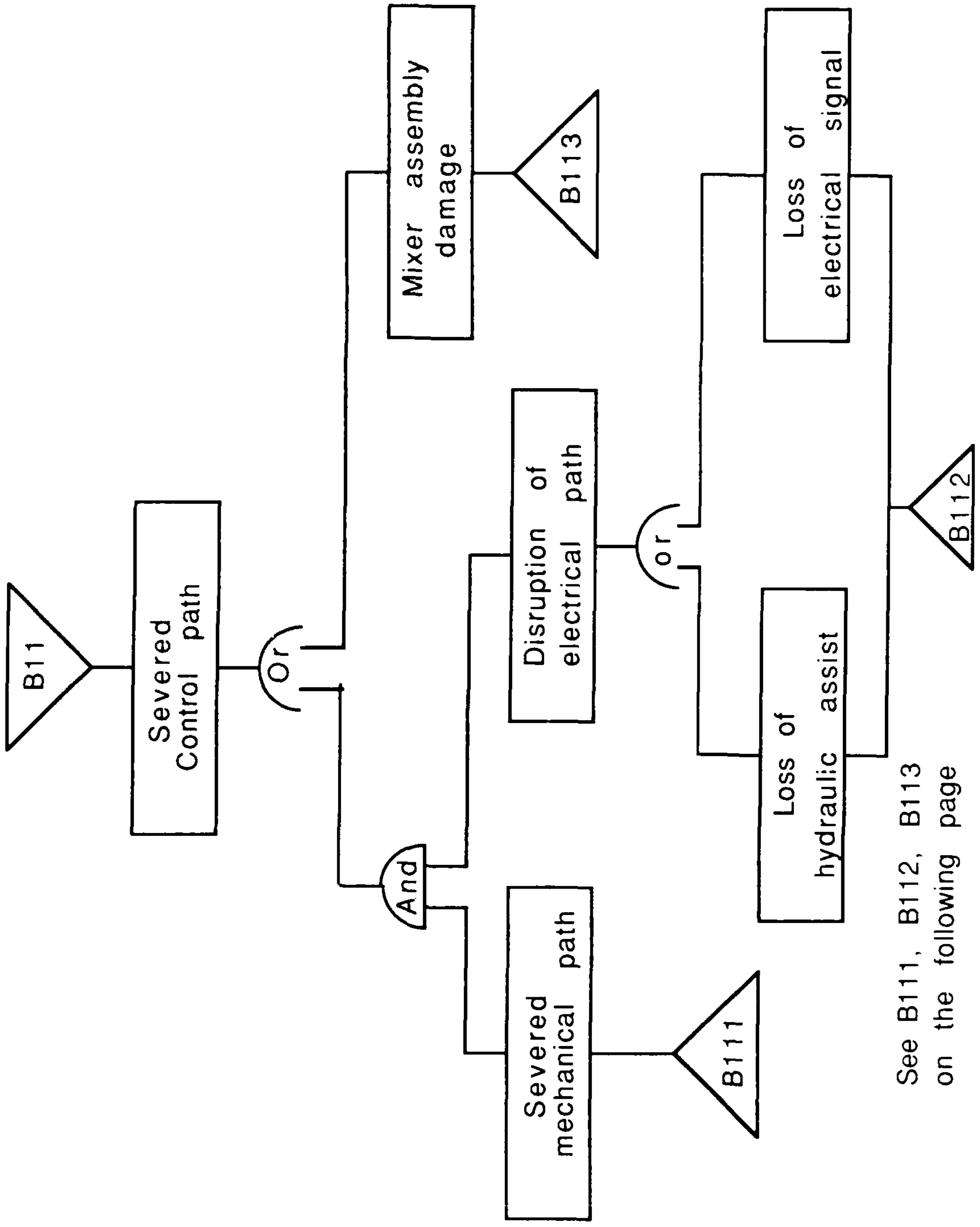


Figure 6. 2 (cont.) AH- 80 FALT



See B111, B112, B113 on the following page

Figure 6. 2 (cont.) AH- 80 FALT

TABLE 6.3 (cont.)
B111 SEVERED MECHANICAL PATH
COMPONENT LIST

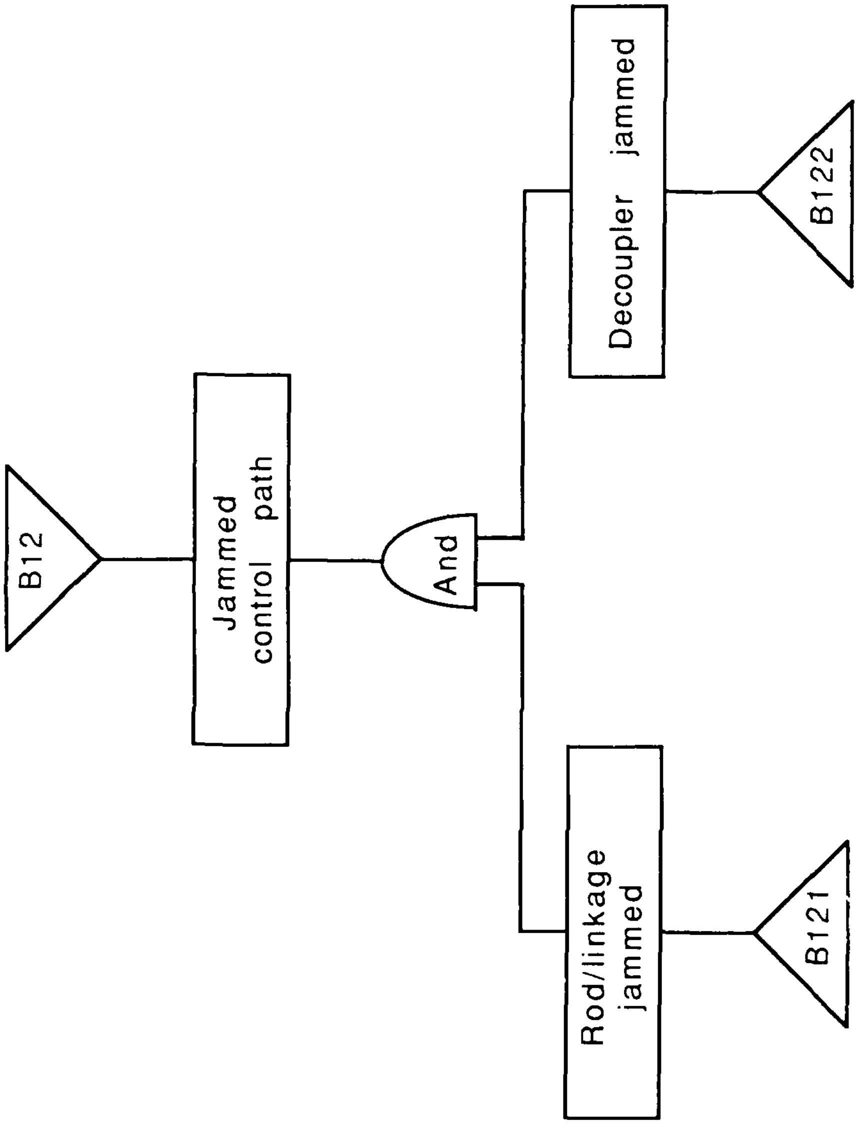
COMPONENT	DAMAGE
hydraulic actuator	penetration/ leakage
bellcrank/spring assy	sever
control rods	jam/sever
rod ends	jam/sever
rodend bearings	jam/sever

B112 DISRUPTION OF ELECTRICAL PATH
COMPONENT LIST

COMPONENT	DAMAGE
hydraulic actuator	penetration/ leakage/jam
servo actuator	penetration
wiring	sever
flight computer	penetration

B113 MIXER ASSEMBLY DAMAGE
COMPONENT LIST

COMPONENT	DAMAGE
swashplate rotating/nonrotating	sever
bellcrank assembly	sever
torque link	sever
pitch link	sever
scissors assembly	sever



See B121, B122 on the following page

Figure 6. 2 (cont.) AH-80 FALT