Joint Special Operations Response Department

Naval Surface Warfare Center
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Human Reliability Analysis and the Advanced Man Portable Air Defense System: A Case Study

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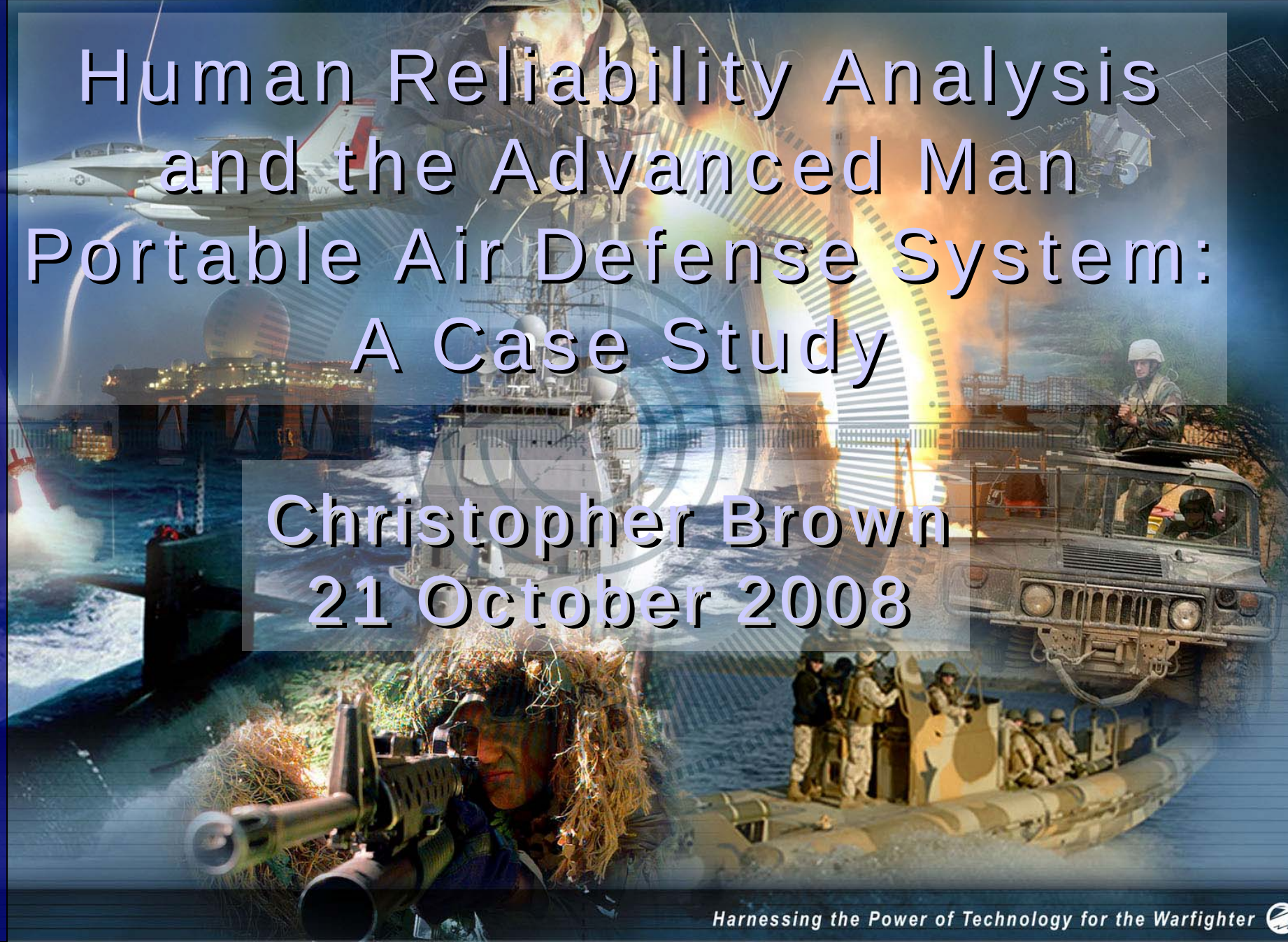
21 October 2008



Harnessing the Power of Technology for the Warfighter

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A-MANPADS

- The Advance Man Portable Air Defense System (A-MANPADS) allows the Marines of Low Altitude Air Defense (LAAD) battalions to successfully meet their primary mission.
  - Marine Corps LAAD units deploy in one of two primary missions; convoy support or local area defense. In both roles, LAAD units provide primary air defense.
- The A-MANPADS provides a means to safely and expeditiously transport 4 Stinger missiles in WRCs and ancillary equipment.
- The installation of the weapons station allows the Marines the option of mounting a crew served weapon such as the 7.62 machine gun, M240B, or the .50-caliber machine gun, M2 Heavy Barrel (HB). The crew served weapon could be utilized for self-protection against both air and ground threats within the inner launch boundary of the missile.

A-MANPADS with 240B Machine Gun

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Mk 93 Pintle

- **In the case of the A-MANPADS, the crew served weapon is flexible therefore the pintle needs to be flexible.**
  - **The Mk 93 Universal Pintle provides the ability to switch between all crew served weapons in the Marine Corps' arsenal with a minimum of effort.**
  - **The Mk93 includes an adjustable safety stop for restricting the depression angle. This allows the pintle to not only adjust depending upon the weapon system, but also the vehicle load out.**

Mk 93 Pintle Installed on an A-MANPADS

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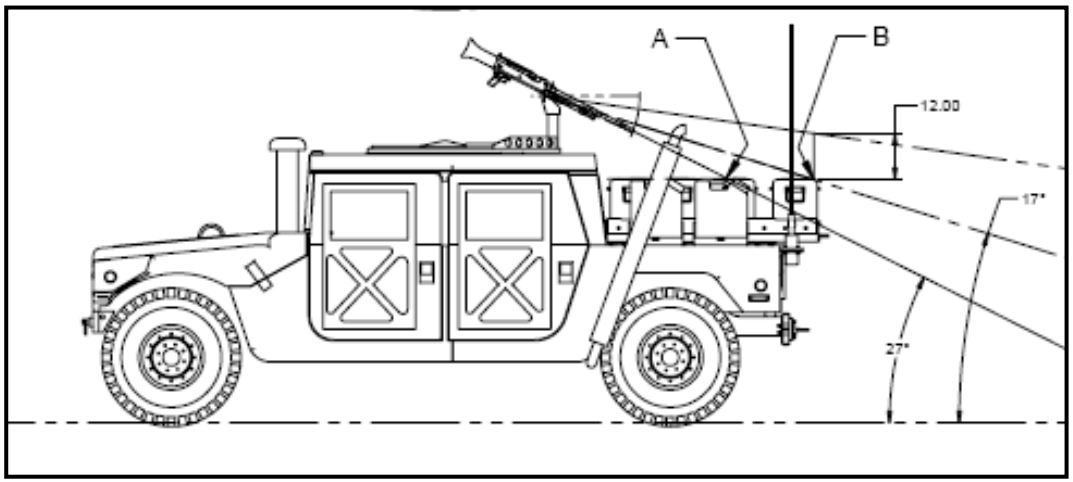
Safety Hazard

- **The Mk 93 pintle utilized with the HMMWV weapons station and a crew served weapon allows for a maximum declination angle of 27º. In the standard configuration with the M1025/M1043 slant-back HMMWV, this angle does not present an issue. The trajectory of the round would pass through the HMMWV outer shell in an area where no gear is stowed. However, the addition of the WRCs adds height to the rear dimension. If allowed to fire at maximum depression the round would impact the WRC as demonstrated by the figure.**



Trajectory of Crew Served Weapon Round

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Safety Assessment

- **The methodology used to classify and rank mishap risks is based upon criteria and guidelines specified in MIL-STD-882**
  - **A combat loaded A-MANPADS is valued at less than $300k. With this in mind the dollar values were removed and system damage was evaluated with the MIL-STD-882C criteria.**
- **A group of independent system safety engineers determined that an impingement incident was both catastrophic and likely to occur several times during the life of the A-MANPADS.**
  - **The Hazard was assessed a Risk Level of High, IC. Thus requiring the Assistant Secretary of the Navy to accept the risk.**
- **The Program Manager requested an in-depth review of the Hazard.**

HAZARD RISK INDEX	RISK LEVEL	ACCEPTANCE AUTHORITY
I A/B/C, II A/B, IIIA	High	Component Acquisition Executive (Assistant Secretary of the Navy for Research, Development and Acquisition)
I D, II C, III B	Serious	Program Executive Officer (Commanding General, Marine Corps Systems Command)
I E, II D/E, III C/D/E, IV A/B	Medium	Program Manager (Program Manager, Air Defense Weapon Systems)
IV C/D/E	Low	Program Manager (Program Manager, Air Defense Weapon Systems)

Risk Acceptance Levels as stated in MIL-STD-882C

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Severity Assessment

- **An accurate assessment of the severity of a round striking a Stinger missile can be garnered from a simple evaluation of the end results.**
  - **The Stinger Missile costs less than $100k**
  - **The missile is a mission critical component.**
    - **If the missile is rendered inoperable, the A-MANPADS becomes non-mission capable, temporarily resulting in a de facto combat loss.**
- **The Hazard is assessed a Severity of Category I, Catastrophic.**

SEVERITY	CATEGORY	RESULT CRITERIA
Catastrophic	I	Could result in death, permanent total disability, system loss, or irreversible severe environmental damage that violates law or regulation.
Critical	II	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, major system damage, or reversible environmental damage causing a violation of law or regulation.
Marginal	III	Could result in injury or occupational illness resulting in one or more lost workdays, minor system damage, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.
Negligible	IV	Could result in injury or illness not resulting in a lost workday, less than minor system damage, or minimal environmental damage not violating law or regulation.

Mishap Severity Categories as stated in MIL-STD-882C

Probability Assessment

- **The original Safety Analysis assessed a Probability level of C, Occasional, based on the following criteria:**
  - **Properly setting the adjustable depression stop is a training issue.**
  - **Training issues are a result of human error.**
  - **Human error has a probability of 1 x 10^{-3}**

DESCRIPTIVE WORD	LEVEL	INDIVIDUAL ITEM	FLEET OR INVENTORY
Frequent ($X > 10^{-1}$)	A	Likely to occur frequently	Continuously experienced
Probable ($10^{-1} > X > 10^{-2}$)	B	Will occur several times in life of an item	Will occur frequently
Occasional ($10^{-2} > X > 10^{-3}$)	C	Likely to occur sometime in life of an item	Will occur several times across fleet
Remote ($10^{-3} > X > 10^{-6}$)	D	Unlikely, but possible to occur in the life of an item	Unlikely, but can reasonably be expected to occur
Improbable ($10^{-6} > X$)	E	So unlikely, it can be assumed occurrence may not be experienced	Unlikely to occur, but possible

Mishap Probability Levels as stated in MIL-STD-882C

Probability Quantification

- ***Weapon System Explosives Safety Review Board* (*WSESRB*) has stated**

"programs need to be utilizing one of the various methods (of human error prediction) and not use a blanket number (1×10^{-3})"

Human Error Quantification, WSESRB Executive Session, November 2005

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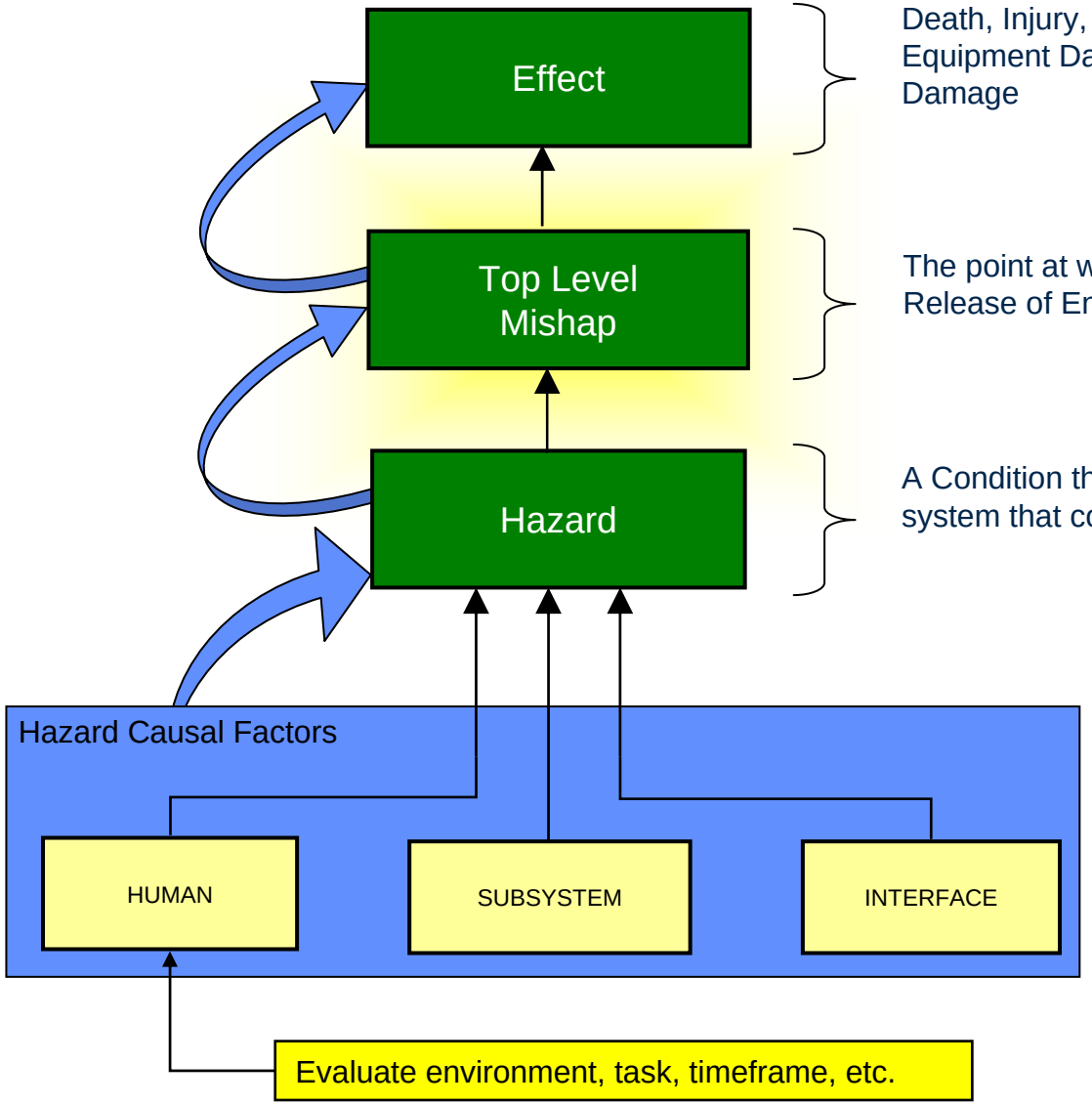
Human Error



Death, Injury, Illness, Equipment Loss, Equipment Damage, Environmental Damage

(e.g. **person cutting their arm** after coming in contact with the sharp edge)

The point at which the Inadvertent Release of Energy Occurred

(e.g. **person coming in contact** with the sharp edge)

A Condition that exists within the system that could lead to a TLSH

(e.g. a **sharp edge**)

Element within the system design, implementation, or operation that leads to a hazard

Fault Tree Analysis

- **The original assessment had only considered the final action that would lead to the mishap.**
- **Assessing a probability of failure for a situation starts by determining the series of actions that the operator undertakes for the particular situation. The methodology to determine the actions is known as a fault tree analysis (FTA).**
- **An FTA begins with the selection of an undesirable outcome, the root. Then, each situation that could cause that outcome is added to the tree. Further branches are added by assessing possible causes for each successive layer of contributing factors.**

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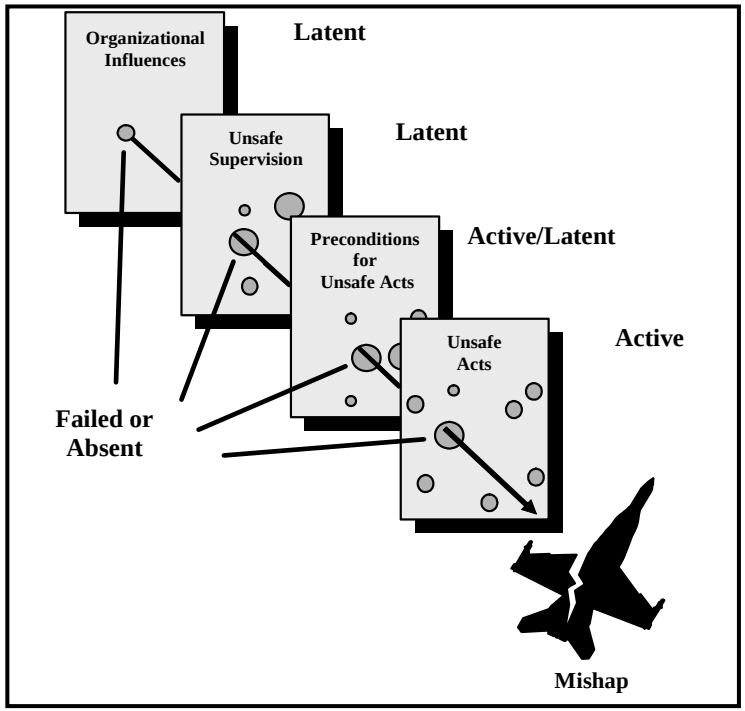
HFACS

- The Human Factors Analysis and Classification System (HFACS) was selected for the A-MANPADS due to the inclusion of environmental, psychological, emotional, and physical influences on the operator, in addition to the active faults of the operator.
- HFACS was originally developed by the Federal Aviation Administration (FAA) and has been adopted by the US Navy for investigating the underlying reasons for human error in aviation accidents.
- HFACS was developed based on the "Swiss Cheese" model of human error described by James Reason (Reason, 1990). Most investigations only focus on the operator's final error(s) that lead to the mishap. However, the "Swiss Cheese" model states that it is the alignment of many factors at many levels of the organization that align perfectly to allow or lead to the final error, much like the holes of many layers of Swiss cheese aligning to allow light through.



Reason "Swiss Cheese" Model

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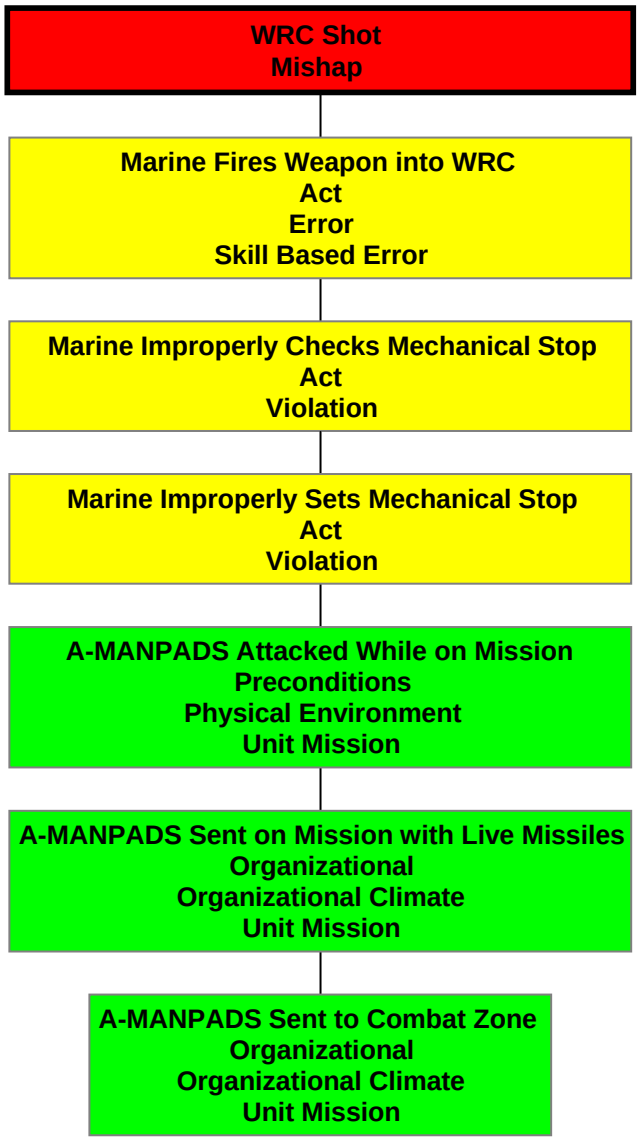
HFACS Analysis

- **Not only were the actions of the Marine firing the weapon evaluated, but also the preexisting environmental conditions and the organizational doctrine required to initiate the chain of events.**



Human Error Probability Techniques

- **Human Error Assessment and Reduction Technique (HEART) Method**
  - The HEART Method provides two tables to find the human error rate. A factor from the first table is multiplied by chosen factors from the second table.
  - Based on expert opinion – cannot be validated
  - There is the difficulty in dealing with the many variables which contribute to the probability of error occurrence at any point in time.
- **SPAR-H Method**
  - Provides a simple worksheet with multipliers for stress, complexity, experience, etc.
  - Computationally intensive
- **Operator HEP Estimate**
  - The Reactor Safety Study lists Operator Human Error Probability (HEP) Estimates for each scenario description
  - Has a limited number of scenarios. Expert judgment must be used in selecting a scenario that can be used as a substitute.
- **Human Reliability Table**
  - Lists Operator HEP Estimates for each general scenario description.
  - Generalized scenarios limit fidelity. Expert judgment must be used in selecting a scenario that can be used as a substitute.
- **WSESRB Guidebook Worksheets**
  - Supply complex tables of factors that take into account fatigue, stress, training, complexity, etc. These factors are used in a series of binomial equations which derive a final error rate.
  - Computationally intensive

SPAR-H

- The Standardized Plant Analysis Risk Human Reliability Analysis (SPAR-H) developed by the US Nuclear Regulatory Commission (NRC) takes into account performance shaping factors (PSFs). SPAR-H makes allowance for the following factors:
  - Available Time
  - Stress and Stressors
  - Experience and Training
  - Complexity
  - Ergonomics
  - Procedures
  - Fitness for Duty
  - Work Processes
- Not only does SPAR-H account for a greater number of influences, but it also takes into account positive benefits derived from some PSFs.
- SPAR-H makes a distinction between diagnosis (i.e., the processing of information) and action (i.e., the response).
- It assigns a base value to the HEP for basic processes. A multiplier for each of the eight PSFs is then factored into determining the overall HEP.
- SPAR-H allows for the occasion where the diagnosis, and the action are so interrelated that they can not be separated. Likewise, SPAR-H includes a correction factor for cases where the influence of PSFs is so great that an inaccurate HEP is produced.

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SPAR-H Multipliers

- ***Available Time:*** **Available time refers to the time the operator has to make a diagnosis and act upon the diagnosis. When time is short an operator tends to analyze fewer possible alternatives.**
- ***Stress/Stressors:*** **Stress is broadly defined as motivating forces that have both positive and negative effects on human performance. Small amounts of stress can lead to increased work performance, however, as the level of stress increases the ability to successfully complete tasks decreases.**
  - **The previous work that SPAR-H derived from allowed a multiplier of 25 when the operator believed himself to be in a life-threatening situation. When in combat the operator knows that he is in a life-threatening situation. Therefore a multiplier of 25 will be utilized for combat situations.**
- ***Complexity:*** **Complexity incorporates both the difficulty and the ambiguity of a task. If the task is mentally or physically difficult to perform the likelihood of failure increases noticeably.**
- ***Experience/ Training:*** **Formal schooling, on the job training, years of experience with the system, and previous exposure to similar events are all factors taken into consideration when determining the value of this PSF.**

Category	SPAR-H Value		Combat Adjustment
Available Time	Inadequate	Failure	N/A
	Time Available = Time Required	10	
	Nominal Time	1	
	Time Available > 5x Time Required	0.1	
	Time Available > 50x Time Required	0.01	
Stress/ Stressors	Extreme	5	25
	High	2	
	Nominal	1	
Complexity	Highly Complex	5	N/A
	Moderately Complex	2	
	Nominal	1	
Experience/ Training	Low	3	N/A
	Nominal	1	
	High	0.5	

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SPAR-H Multipliers

- ***Procedures:*** **This PSF accounts for the existence and usage of formalized procedures.**
- ***Ergonomics:*** **Ergonomics considers the ease of interaction between the human and the machine. Such factors include, availability of instrumentation, positioning of instrumentation, ease of understanding the information presented, and the layout of the controls.**
- ***Fitness for Duty:*** **This PSF considers the physical and mental capacity of the operator to properly perform the task. Considerations include drug usage, illness, fatigue, distractions, and personal problems.**
  - **While combatants are generally physically fit, the conditions surrounding combat not only equalize this advantage but often degrade the fitness of the operator beyond that of a fever or some cough syrup. To account for this a multiplier of 10 is utilized for combat situations.**
- ***Work Process:*** **Work Process captures the company culture and "way of doing business". It considers how the work is planned and communicated, how management supports or enforces policies, and how the company as a whole values safety, quality, and the individual worker.**

Category	SPAR-H Value		Combat Adjustment
Procedures	Not Available	50	N/A
	Incomplete	20	
	Available but Poor	5	
	Nominal	1	
Ergonomics	Missing/ Misleading	50	N/A
	Poor	10	
	Nominal	1	
	Good	0.5	
Fitness for Duty	Unfit	Failure	10
	Degraded Fitness	5	
	Nominal	1	
Work Process	Poor	2	N/A
	Nominal	1	
	Good	0.8 – 0.5	

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SPAR-H Calculations

$$HEP_{Nominal} = HEP_{Base} \bullet PSF_{Time} \bullet PSF_{Stress} \bullet PSF_{Comp} \bullet PSF_{Train} \bullet PSF_{Proc} \bullet PSF_{HMI} \bullet PSF_{Fit} \bullet PSF_{Work}$$

- **The multipliers are utilized by multiplying the base HEP for action or diagnosis by the 8 PSF multipliers.**
- **The Base Multipliers are:**
  - **0.01 for diagnosis**
    - **The user is required to decide what the correct action should be based on external stimuli.**
  - **0.001 for action**
    - **The user implements the action as stated in a procedure or that they have chosen based on their diagnosis.**
- **If the PSFs are significantly negative, the HEP can become inordinately large. To help adjust the HEP in the event of overwhelming negative influences a simple mathematical formula is provided below:**

$$HEP_{Adjusted} = \frac{HEP_{Nominal} \bullet PSF_{Composite}}{HEP_{Nominal} \bullet \left(PSF_{Composite} - 1\right)} + 1$$

Probability of Attack While Carrying Missiles

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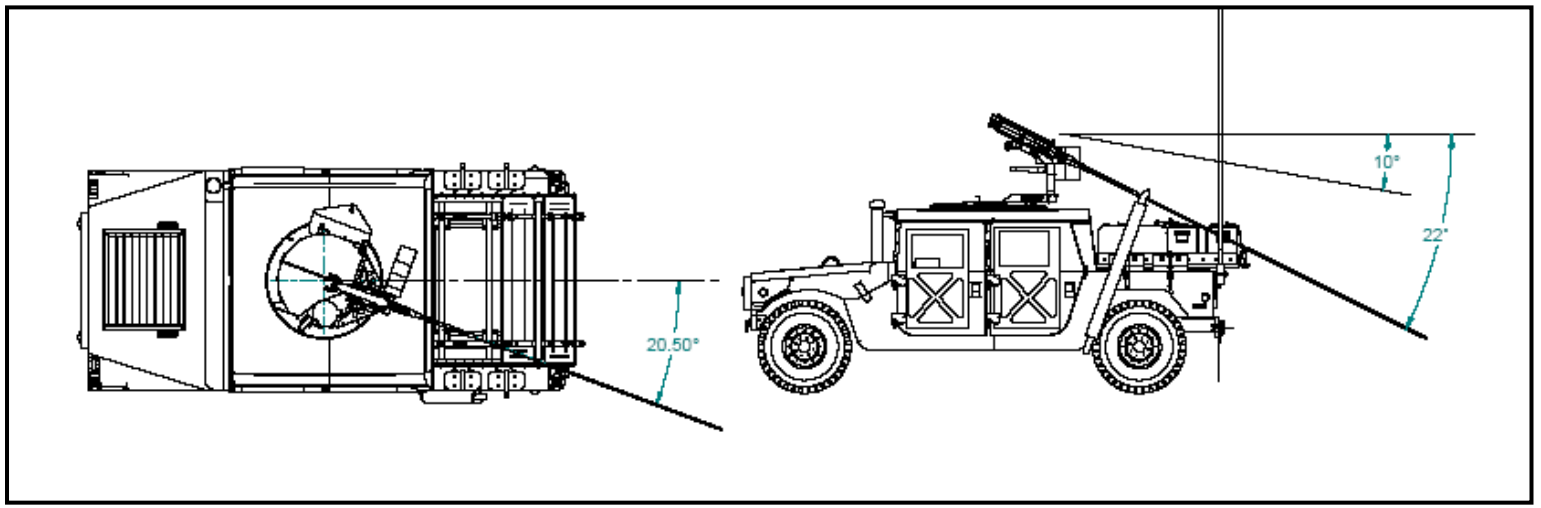
- **Conservative assumptions made.**
  - **All armored A-MANPADS and only armored A-MANPADS**
  - **Used a quarter of their life cycle in combat**
  - **Loaded with live missiles half of the time.**
  - **Under attack every time they went to combat**

$$P_{Combat} = \frac{AMANPADS_{Armored}}{AMANPADS_{Total}} \bullet P_{Life} \bullet P_{Missiles} \bullet P_{Attack}$$

$$0.0266 = \frac{40}{188} \bullet 0.25 \bullet 0.5 \bullet 1$$

2.66% chance of an A-MANPADS transporting missiles while being attacked

Probability of Shooting into the Danger Zone



- **Just because the Marine returns fire does not guarantee the rounds are traveling towards the missiles.**
- **In lieu of data representing the number of attacks to the rear of vehicles, the percentage of the area on the vehicle considered to be the danger zone will be calculated.**
  - **The assumption is made that the operator never fires the machine gun elevated.**

$$P_{DZ} = \frac{DZ_{AZ}}{360^\circ} \bullet \frac{DZ_{EL}}{22^\circ}$$

$$0.0621 = \frac{41^\circ}{360^\circ} \bullet \frac{12^\circ}{22^\circ}$$

6.21% chance of being attacked from the rear

Probability of Armorer Failing to Set Depression Stop

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- When the armorer receives a new pintle, a new mission role with a load out that requires a depression angle change, or a misaligned pintle is returned, the armorer sets the depression angle.
- A **0.005%** chance that the armorer will fail to complete the adjustment is reasonable.
  - It is a required step of a procedure, ample time is supplied to complete the process, a follow on procedure performed by an independent person checks for the completion of this task, and the steps are well documented and simple.

Category	Level	Value	Reason
Base HEP	Action	0.001	Action only
Available Time	5x Req	0.1	Armorer completes the task offline with more than ample time.
Stress/ Stressors	Nominal	1	With ample time to complete and no dependency on outcome, armorer is not stressed.
Complexity	Nominal	1	Steps are straight forward and easy to follow
Experience/ Training	Nominal	1	The job is simple but the armorer only does it.
Procedures	Nominal	1	The procedure is well documented and clearly written.
Ergonomics	Nominal	1	Ergonomics neither impede nor help
Fitness for Duty	Nominal	1	The armorer is more than fit enough.
Work Process	Good	0.5	The expectations are well defined and communicated clearly.
Nominal HEP		0.00005	

Probability of Marine Failing to Check Depression Stop

- As the Marine is installing the pintle and the machine gun, the procedures instruct the Marine to check the depression angle using available components and tools.
  - The Marine is instructed to alert the armorer if the pintle is misaligned.
  - Before leaving on the mission, the senior Marine in the vehicle ensures that preoperational checks were preformed.
- A **0.05%** chance that the operator will fail at the check is reasonable.
  - It is a required step of a procedure completed often, a person in a supervisory role checks for completion, and the steps are well documented and simple.

Category	Level	Value	Reason
Base HEP	Action	0.001	Action only
Available Time	Nominal	1	Part of the installation of the weapon and sufficient time is provided
Stress/ Stressors	High	2	Operator is preparing for combat, anticipation and fear begin to increase stress
Complexity	Nominal	1	Steps are straight forward and easy to follow
Experience/ Training	High	0.5	The same procedure is followed every time the weapon is installed
Procedures	Nominal	1	The procedure is well documented and clearly written.
Ergonomics	Nominal	1	Ergonomics neither impede nor help
Fitness for Duty	Nominal	1	The operator may be uncomfortable but their fitness is not degraded.
Work Process	Good	0.5	The expectations are well defined. Additionally the supervisor ensures that the process is completed.
Nominal HEP		0.0005	

Probability of Marine Shooting WRC

- When the Marine identifies a threat and begins firing, there is a probability that he will continue to fire even if the rounds are going to impact the WRC.
- An adjusted value of **47.39%** is a reasonable percentage to expect.
  - When in combat and under attack, operators are likely to experience tunnel vision and fixate on the threat until it is eliminated.
  - The adjustment equation was utilized to correct for the overwhelming multipliers.

Category	Level	Value	Reason
Base HEP	Action	0.001	Action only
Available Time	Avail = Req	10	In combat Oper. Always has just enough time
Stress/ Stressors	Combat	25	Life threatening situation
Complexity	Nominal	1	Firing the weapon is relatively easy
Experience/ Training	Above Avg	0.6	Even the newest member of the squad trains on the system rigorously. However, rear attacks and shooting around the WRC are not well rehearsed.
Procedures	Nominal	1	Procedures are well established and followed explicitly.
Ergonomics	Nominal	1	Ergonomics neither impede or help
Fitness for Duty	Combat	10	Even the most physically fit personnel suffers from degradation of fitness in combat
Work Process	Above Avg	0.6	While fog of war impedes the process; expectations are clear, concise, well communicated, and strictly enforced.
Nominal HEP		0.9	
Adjusted HEP		0.47393365	Due to the large number of negative multipliers the adjustment was used.

Probability of Most Likely Scenarios

- **WRC Shot When No Depression Stop is Present:**
  - **The A-MANPADS is in combat**
  - **The weapon enters the "danger zone"**
  - **The Marine fires the weapon while in or around the "danger zone".**

$$P_{NoStop} = P_{Combat} \bullet P_{DZ} \bullet HEP_{Shoot}$$

$$7.8301 \times 10^{-4} = 2.6596 \times 10^{-2} \bullet 6.2121 \times 10^{-2} \bullet 4.7393 \times 10^{-1}$$

With no stop present and conservative representations of the likelihood of the A-MANPADS being in combat with a live missile and attacked from behind, the probability of shooting the WRC is 7.8301×10^{-4} or 7.83 chances in one thousand.

Probability of Most Likely Scenarios

- **The Depression Stop is Misaligned by the Marine:**
  - **The A-MANPADS is in combat**
  - **The weapon enters the "danger zone"**
  - **The Marine fires the weapon while in or around the "danger zone".**
  - **The operator misaligns the pintle**

$$P_{Check} = P_{NoStop} \bullet HEP_{Check}$$

$$3.9151 \times 10^{-7} = 7.8301 \times 10^{-4} \bullet 5 \times 10^{-4}$$

With the addition of a depression stop the probability of shooting the WRC is 3.9151×10^{-7} or approximately one in 250,000.

Probability of Most Likely Scenarios

- **The Depression Stop is Misaligned by the Armorer:**
  - **The A-MANPADS is in combat**
  - **The weapon enters the "danger zone"**
  - **The Marine fires the weapon while in or around the "danger zone".**
  - **The armorer misaligns the pintle or fails to align the pintle at all**
  - **The operator does not find the misalignment.**

$$P_{Misalign} = P_{Check} \bullet HEP_{Misalign}$$

$$1.9575 \times 10^{-11} = 3.9151 \times 10^{-7} \bullet 5 \times 10^{-5}$$

By making the armorer responsible for the adjustment of the safety stop, the probability of shooting the WRC becomes 1.9575×10^{-11} or approximately one in 50 Billion.

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Final Assessment

Scenario	Severity	Probability	Acceptability	Authority
No Depression Stop	I	D	ID	Program Executive Officer
Adjustable Depression Stop	I	E	IE	Program Manager
Armorer Adjusts Pintle	I	E	IE	Program Manager

- **The risk associated with the A-MANPADS operating with the adjustable stop provided with the Mk 93 pintle is of a level acceptable by the Program Manager.**
  - **Based upon**
    - **The condition that all controls and procedures are complied with**
    - **The A-MANPADS will be operated within stated parameters**

Conclusion

- After the study was conducted, the Program Manager was able to accept the risk associated with the hazard, the Program received a full rate production decision, and all systems were fielded on schedule.
- The use of a fault treat analysis such as HFACS for Safety Assessment Probability Levels is crucial to capturing a true picture of all the factors leading to a hazard.
- While the use of SPAR-H requires computational effort, I have demonstrated that the math is uncomplicated and relatively concise.
- SPAR-H includes the flexibility to be utilized for any Program. It does not depend upon predetermined scenarios, but rather considers 8 performance shaping factors that are crucial to success in any action or diagnosis.
- With the comparative ease of applying SPAR-H, there is no need for a program to arbitrarily apply a blanket number (1×10^{-3}) to their Safety Assessment Probability Levels.

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Questions?