SAFE-SEPARATION ANALYSIS
SYSTEM SAFETY ENGINEERING STUDY

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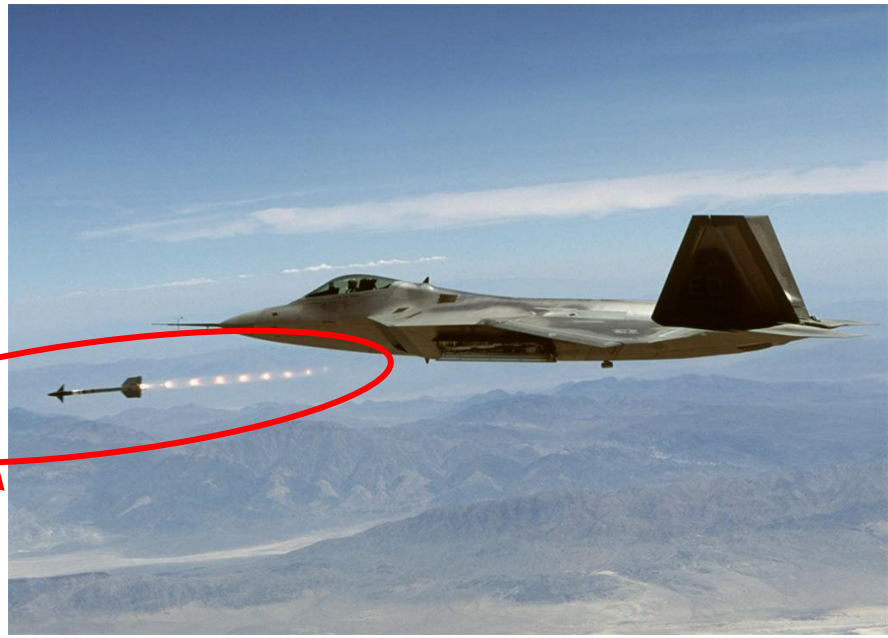
Safe Separation/ Safe Escape Analysis



How far away before it's safe to arm?

Must the aircraft maneuver to be safe?

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Study Tasking

- **Review Safe Separation/Safe Escape Analysis Approaches**
  - **Different Approaches across the Services**
  - **Differences between Agencies within a Service**
- **Compare and contrast Service approaches**
- **Consider additional sources of information**
  - **Survivability analyses (aircraft vulnerability models)**
  - **Other known risks to aircraft (enemy weapons, etc.)**
- **Provide independent recommendations for improvement and standardization**

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Study Technical Approach

- **Develop Consistent Evaluation Questionnaire**
  - **Assumptions (post-launch aircraft maneuvers, weapon variations, environmental variations, launch modes, S/A device variations)**
  - **Requirements (risk probability, hit and/or kill, analysis objectives, post-launch maneuver requirement)**
  - **Definitions (safe separation, safe escape, safe arming, definition source)**
  - **Aircraft Modeling (flight path, physical description, vulnerability, maneuvers, air target maneuvers)**
  - **Weapon Modeling (trajectory, debris model fidelity, variations, S/A device modeling)**
  - **M&S and Credibility (what M&S, capability, accuracy, usability)**
- **Interview Service Safe-Separation/Safe-Arming Analysts**
- **Analyze Interview Results (and any additional data collected)**
- **Formulate Recommendations**
- **Document Results**

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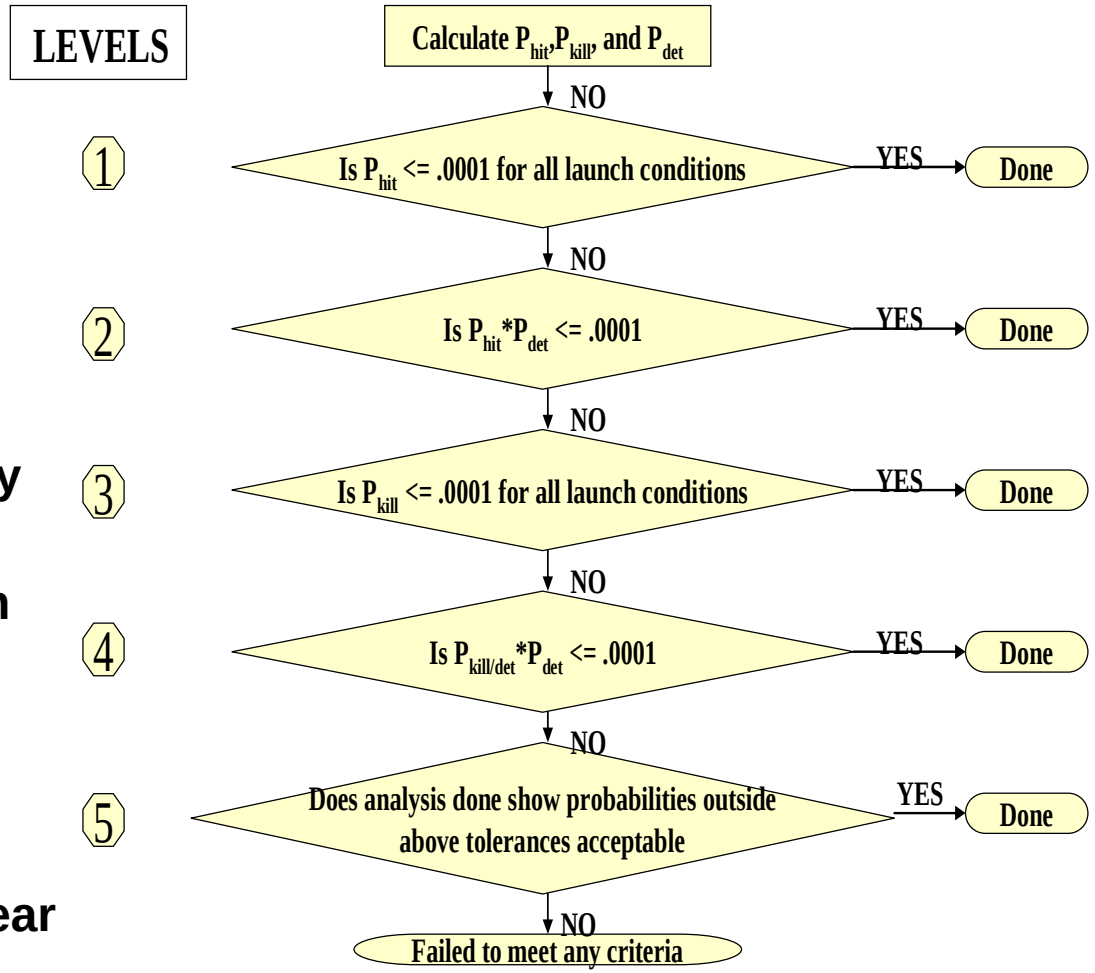
Data Collection Results

- **Interviewed NAWCWD and AMRDEC analysts**
  - **NAWCWD Warfare Analysis Division at China Lake**
  - **Aviation Engineering Directorate at Redstone Arsenal**
- **Seek Eagle and NAWCAD analysts referred us to JSF JSEAS effort**
  - **Joint Safe Escape Analysis Solution**
  - **JSF provided document "JSF Common Safe Escape Criteria"**
    - Agreement on 23 joint requirements for safe escape analysis
- **We filled in some information from other sources**
  - **NAWCWD and Seek Eagle have close working relationship**
  - **Air Force, Army briefings from Seek Eagle conferences**

Safe Escape Analysis Requirements

Notes:

- **Basic safety criterion is Phit or Pkill less than 1/10,000**
- **Air Force, NAWCAD only use Phit**
- **Army, NAWCWD, British also use Pkill (or similar metric)**
- **Pdet (for levels 2 & 4) cannot be less than 0.01**
- **NAWCAD does not appear to use level 5 analysis**



Fuze Management Board Joint Agreement on Safe Separation Analysis for Air-Launched Munitions (Signed by the Army, Navy and Air Force on 23 February 1978)

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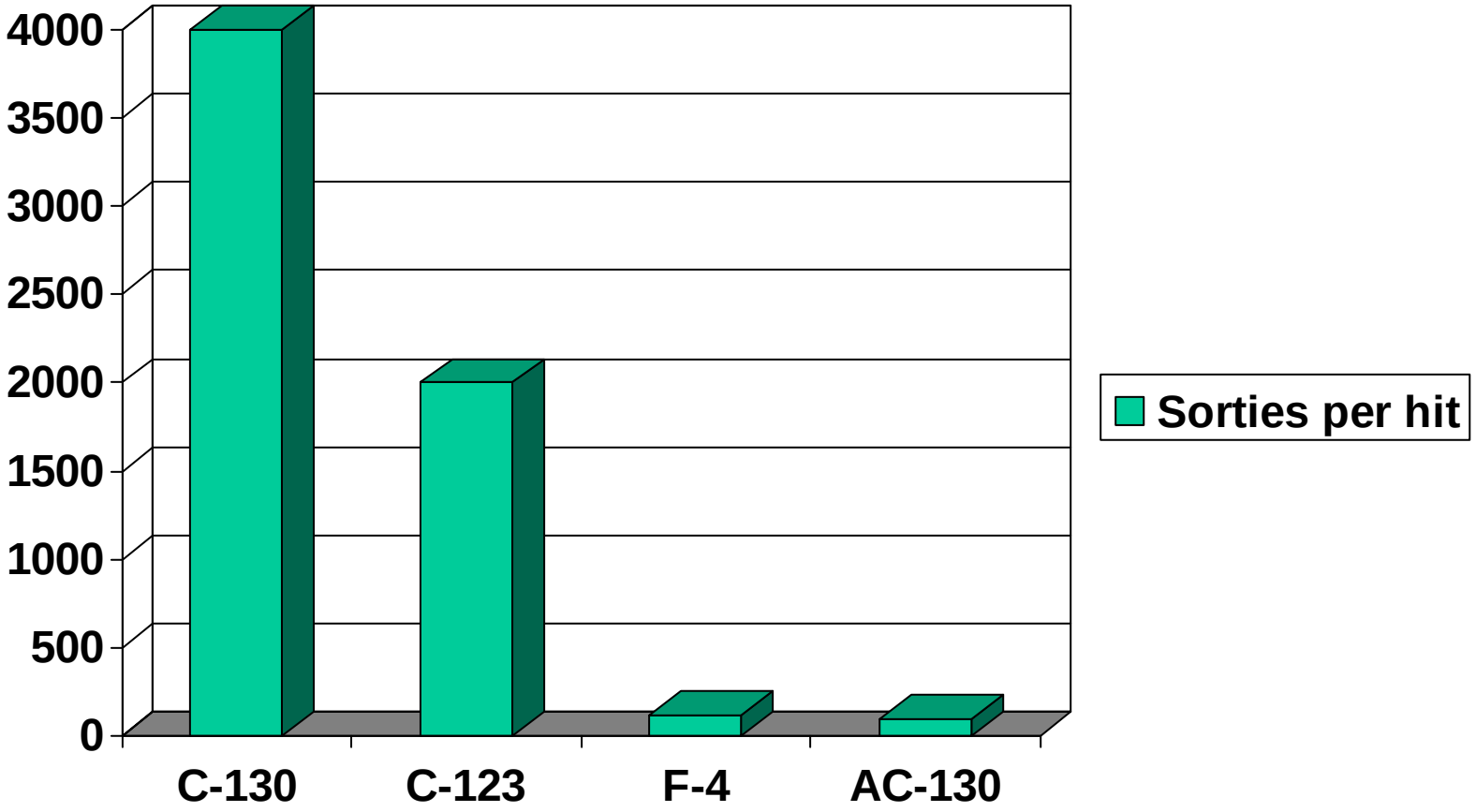
Where did the P_{hit} <.0001 Requirement Come From?

- **10^{-4} requirement purported to be based on historical data**
  - **Long-lost 1973 letter describing Vietnam data**
  - **No documentation available from original decision (1978 Joint Fuze Management Board Agreement)**

- **Our Approach:**
  - **Analyzed available hit rate data from SEA and Desert Storm**
  - **Obtained mishap rate data for F-16 and UAV systems**
  - **Compared to Phit requirement**

SEA Hit Rate Experience
Air Force Aircraft



P_{hit} per sortie ~ 10^{-3} for transports, 10^{-2} for attack a/c

Source: ASD/XRM Analysis
SURVIAC Data

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SEA Hit & Kill Rates
USN & USMC Fixed Wing Aircraft, (Apr 1965 – Mar 1973)

Service	Hit Rate (per 1000 sorties)	Kill Rate (per 1000 sorties)
USN	5.23	1.05
USMC	6.32	0.54

P_{hit} per sortie ~ 10^{-2}

P_{kill} per sortie ~ 10^{-3}

Source: ***U.S. Navy, Marine Corps and Air Force Fixed Wing Aircraft Losses and Damage in Southeast Asia (1962-1973),*** **Center for Naval Analyses, Aug 1976**

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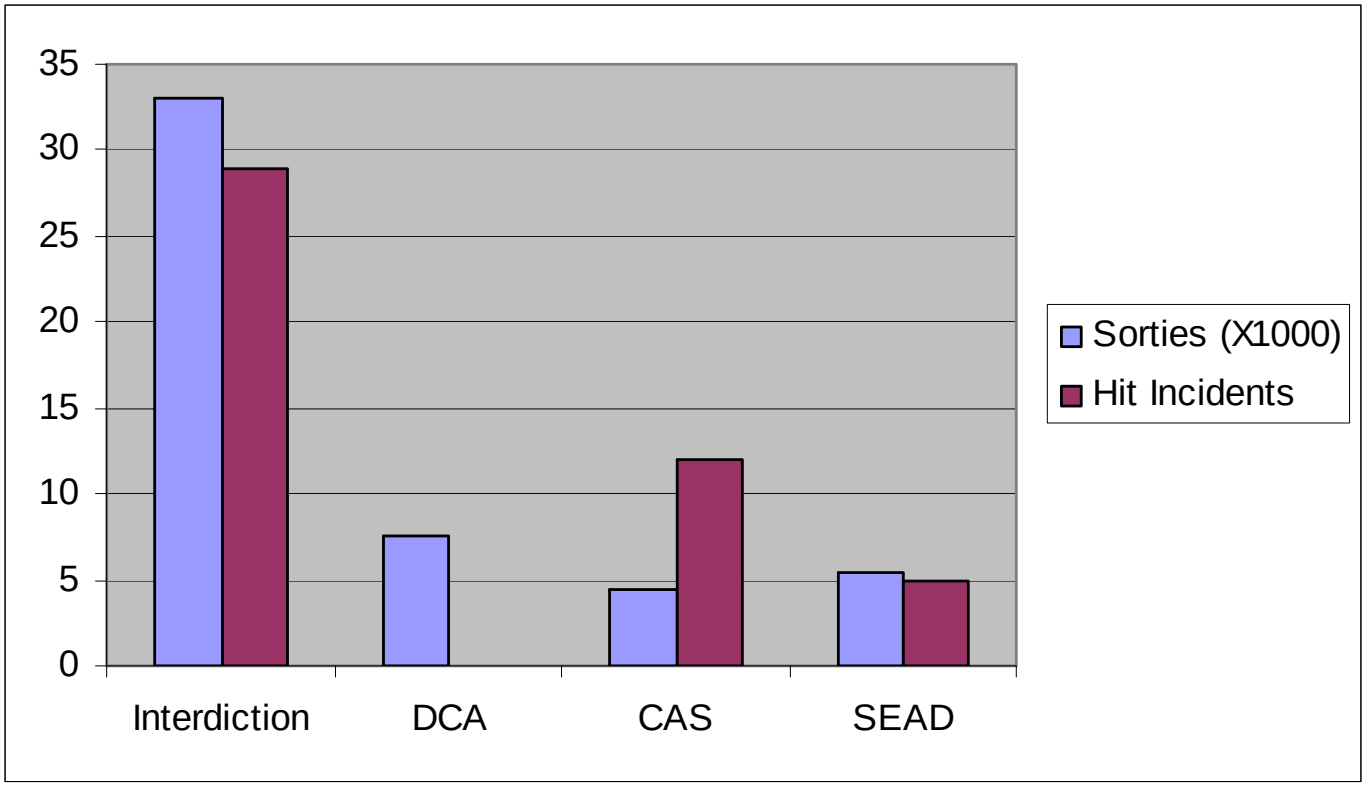
Desert Storm
Hits by Mission Type



P_{hit} per sortie ~ 10^{-3}

(or zero, for DCA – no threat a/c)

Source: SURVIAC

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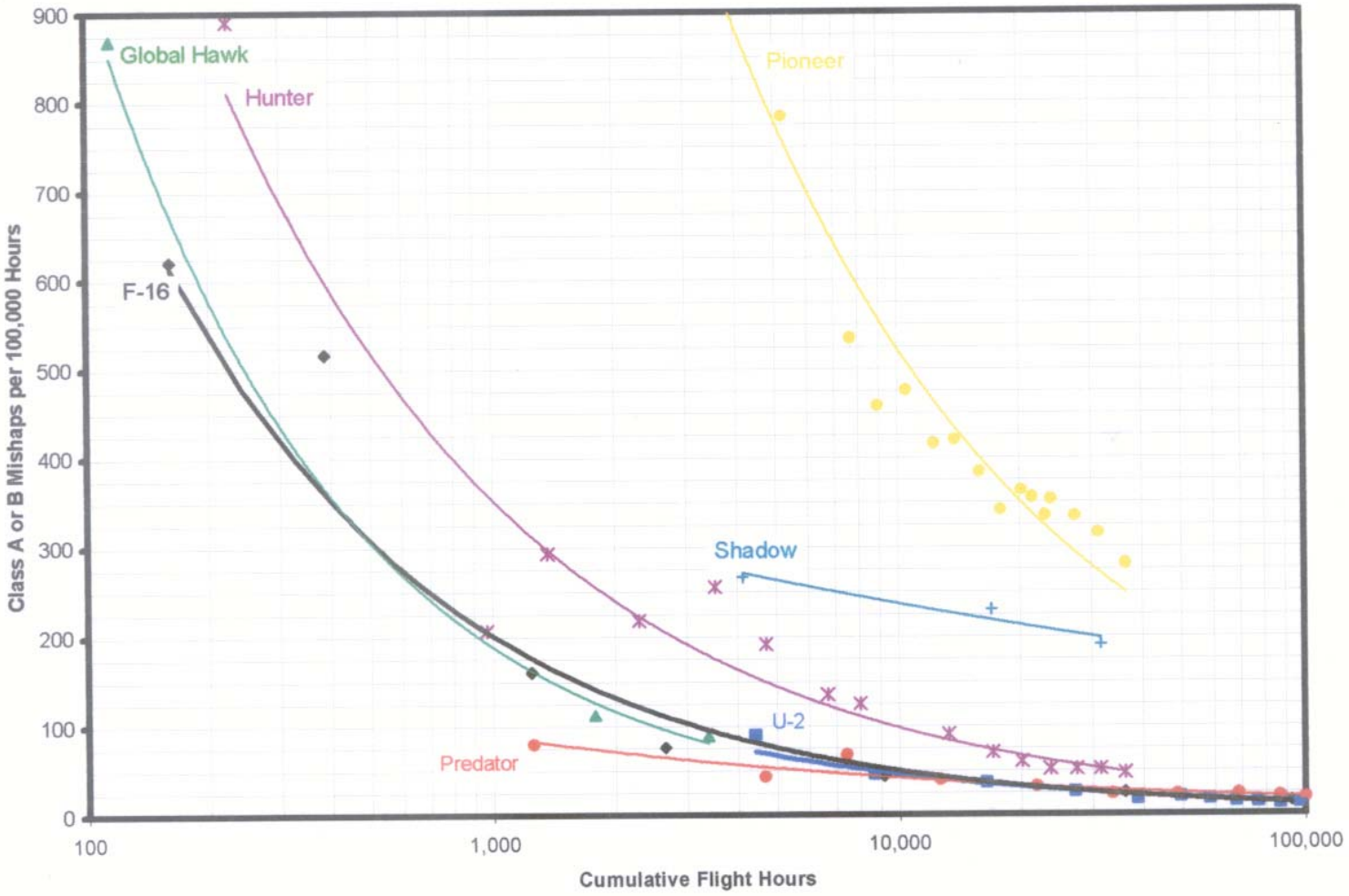
Mishap Rate Comparison



Mishap Rate Approaches 10^{-4} as cumulative flight hours approach 100,000

Source: UAS Roadmap 2005

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P_{hit} Requirement and Historical Data

- **Historical Data Summary**
  - **SEA and Desert Storm Combat hit rates per sortie vary from 10^{-2} to 10^{-3}, depending on aircraft type and mission**
  - **Aircraft combined Class A and B mishap rates per flight hour converge to around 10^{-4}**
- **Apples and Oranges:**
  - **Mishap rate per flight hour**
  - **Combat hit rate per sortie**
  - **Weapon fragment hit probability per weapon release**
- **However, a 10^{-4} requirement is not inconsistent with overall historical rates**
  - **Not exactly supported by history, but not completely out of line**
  - **Combat hit rates support "additional analysis of other risks" to justify not meeting probability requirement (level 5)**

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MIL-HDBK-1763 Definitions

3.1.27 Safe escape/safe arming

Safe escape is the minimum release altitude which will provide the delivery aircraft acceptable protection from weapon fragmentation for detonation at the preplanned point. Safe arming separation is the selection of a minimum safe fuze arm time setting which will provide the delivery aircraft acceptable protection from weapon fragmentation if early detonation should occur.

3.1.28 Separation

The terminating of all physical contact between a store, or portions thereof, and an aircraft; or between a store, or portions thereof; and suspensions equipment.

3.1.28.1 Safe separation

The parting of a store(s) from an aircraft without exceeding the design limits of the store or the aircraft or anything carried thereon, and without damage to, contact with, or unacceptable adverse effects on the aircraft, suspension equipment, or other store(s) both released and unreleased.

3.1.28.2 Acceptable separation

Acceptable store separations are those which meet not only the "safe" separation criteria, but also meet pertinent operational criteria. For instance, guided weapons as a minimum must remain within control limitations consistent with mission effectiveness. Conventional weapons, bombs, should not experience excessive angular excursion which induce ballistic dispersions that adversely affect weapons effectiveness, or bomb-to-bomb collisions.

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Other Documents' Definitions

MIL-STD-1316E:

Safe Separation Distance: The minimum distance between the delivery system (or launcher) and the launched munition beyond which the hazards to the delivery system and its personnel resulting from the functioning of the munition are acceptable.

1978 Joint Fuze Management Board Agreement:

Safe-Separation Distance: the minimum distance between the launching system (AIRCRAFT & PILOT) and its launched munitions at which hazards associated with munitions functioning are acceptable. This distance may be achieved by providing arming delays(s) (time or distance).

Analysis Definitions

- **All analysts in all Services call what they do "safe escape analysis" vice "safe separation analysis"**
  - **Consequently, should consider changing the MIL-STD and Joint Agreement definitions to make "safe separation" mean safe release of the weapon from the launch mechanism**
  - **Change "safe separation distance" to "safe arming distance" or "safe escape distance"**
- **However, not all safe escape analyses involve determining minimum release altitude (MRA) or minimum safe release altitude for fragment avoidance (MinAlt) per the MIL-HDBK definition**
  - **Air to air analyses do not in general determine safe release altitudes**
- **So there is still some difference in definition of safe escape analysis that needs to be resolved**

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Conclusions Summary

- **Assumptions:**
  - Little information available on assumptions other than NAWCWD and implications from JSEAS report
- **Requirements:**
  - Probability requirement of 1/10,000 not inconsistent with historical data
  - Use of Pkill and additional hazard analyses not consistent across agencies
  - JSEAS covers detailed requirements, but not for Army or for air-to-air missiles
- **Definitions:**
  - “Safe Separation” definitions can cause confusion
  - All practitioners call these analyses “safe-escape” analyses
- **Aircraft Modeling:**
  - Physical models similar across Service agencies
  - Aircraft flight path models similar in detail, but use different methodologies
- **Weapon Modeling:**
  - Program Office detailed flight simulations used to generate weapon trajectories
  - Weapon fragmentation and debris obtained from arena testing, similar fidelity
- **M&S and Credibility:**
  - Different M&S used, but except for Army all originally based on NSWCDD Path-2 model
  - No available VV&A documentation on any M&S used

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Recommendations Summary

- **Assumptions: Should be Joint guidance for assumptions used in safe-escape analyses**
- **Requirements: JSF Joint Safe Escape Analysis System (JSEAS) requirements should serve as the starting point**
  - **Expand to include Army requirements, air-to-air weapon system requirements and the process outlined in the original Joint Agreement between all the Services**
- **Definitions: change MIL-HDBK-1763 and MIL-STD-1316E/F Definitions to spell out safe escape and safe arming as distinct from safe separation**
  - **Would require fairly extensive changes to MIL-HDBK-504 processes and definitions**
- **Aircraft Modeling: Should be guidance for launch aircraft post-launch maneuvers to consider for safety reasons.**
- **Weapon Modeling: Should be guidance for fidelity of weapons debris modeling**
- **M&S and Credibility:**
  - **Services should consider standardizing on latest version**
  - **Conduct V&V and adequately document methodologies**

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UAS Safe Escape

ISSUE: Safe escape requirements have not been established for unmanned systems, even though UAS are being armed at a steadily increasing pace

- **Safe Escape hazards to UAS are to the vehicle only, not to the operator (if there is one)**
  - **Consequently, safe-escape issues are not direct hazards to personnel**
- **Though not a direct safety issue, increasing costs of UAS indicate it would be prudent to establish safe-escape requirements for higher cost UAS systems**
  - **Particularly for UAV carrying complex weapons systems**
- **However, any safe-escape requirements for UAV should not unduly impact their operational capability**

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Some UAS Safe Escape Options

- **Option 1: Establish a requirement for armed UAS programs to perform a risk assessment of damage to the launching UAV**
  - **Using the same safe-escape methods as for manned aircraft**
    - **Including assessment of risks other than from the weapon being launched**
  - **Do not require specific P_{hit} or P_{kill} thresholds be met, but do require that the risk assessment be performed**
    - **Provides informed decisions about weapon release conditions**
    - **Use manned aircraft P_{hit} and P_{kill} thresholds (.0001) as *guidelines* for UAV**
  - **This option is consistent with current requirements for assessment of other risk factors to UAS**
    - **For instance, draft 13034.1D requires a hazard risk index (HRI) for unusual risk conditions**

- **Option 2: Establish required P_{hit}, P_{kill} probability thresholds based on UAV value**
  - **Not just dollar value, but value to battlefield commander**
  - **Requires development of a methodology to determine value of UAS to the battlefield**

Recommendation: Select Option 1, but pursue development of methodology to implement Option 2

Status

- **Draft Revisions to Handbooks, Standards:**
  - **1978 Joint Fuze Management Board Agreement on safe-escape analyses**
  - **Definitions and methodology descriptions in:**
    - **MIL HDBK 1763, *Aircraft/Stores Compatibility: Systems Engineering Data Requirements And Test Procedures***
    - **MIL STD 1316E & F, *Department of Defense Safety Criteria For Design Criteria Standard, Fuze Design***
    - **MIL HDBK 504, *Guidance On Safety Criteria For Initiation Systems***
    - **STANAG 4187E4, *Fuzing Systems Safety Design Requirements***
    - **MIL STD 1911A, *Department Of Defense Design Criteria Standard, Safety Criteria For Hand-emplaced Ordnance Design***
- **UAS Safe Escape**
  - **Draft white paper**

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Briefing Status

- **Presented results to the DoD Fuze Engineering Standardization Working Group (FESWG), November 2006**
  - **Study recommends changes to Joint definitions, establishing Joint guidance for analysis assumptions and methodologies**
  - **FESWG recommended we brief the DOD Fuze IPT**
- **Presented results to DOD Fuze IPT, 28 February 2007**
  - **IPT supported recommendations for changes to standards and process documents**
  - **Recommended FESWG as the technical standards group**
- **Briefed results at PMA 201 Fuze Safety Summit, March 2008**
- **Briefed results to weapons safe escape group (AIR 5.1.6.9) at Pax River, 28 Aug 2007**
- **Scheduled for briefing to FESWG July 2008**
  - **For recommended action from DOD Fuze IPT**

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BACKUPS

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From: Fuze Management Board Joint Agreement (1978)

- **Pkill:** **"If the minimum safe-separation distance *(resulting from the Phit<.0001 requirement)* restricts tactical delivery conditions, the probability of a fragment hit may be further qualified by considering only the presented area of critical systems or components rather than the area of the complete launching system."**
  - **Interpreted by NAWCWD (and AMRDEC) as Pkill**
  - **UK uses "self damage" metric**
- **Risk Analysis:** **"If the above procedures *(Phit or Pkill <.0001)* still result in restricting tactical delivery conditions, then selected fuze arming conditions which are such that a safe-separation distance is not achieved must be justified by a thorough analysis."**
  - **"This analysis should consider probability of a specific type of damage, decreased risk from enemy ordnance, and tactical advantage gained by use of the recommended fuze arming characteristics"**
- **Fragment Hit:** **"A fragment which contains sufficient kinetic energy to penetrate the launch aircraft skin which is exposed to the hazard."**
  - **Army uses KE>5 ft-lbs, or V_{50} analysis**
  - **Not clear what, if anything, anyone else uses as hit criteria**

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Results: Assumptions

Assumption	NAWCWD	NAWCAD	SEEK EAGLE	AMRDEC
Launch aircraft maneuvers	Assume straight and level is worst case; fixed “g” maneuvers; altitudes & speeds from tactics guides		Assume straight and level is worst case; fixed “g” maneuvers; altitudes & speeds from tactics guides	Hover, Bank,Dive, attack run, break turn toward masking terrain after launch, or vertical or lateral unmask & egress
Weapon Variations	Hot/cold motor when data available; no roll variations; variable launch modes		Hot/cold motor when data available; no roll variations; variable launch modes	Hot/cold motor when data available and IFS of sufficient fidelity
S/A Device Variations	Spec value plus and minus tolerance	Spec value minus tolerance	Spec value minus tolerance + delay	UNK

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Results: Requirements

Requirement	NAWCWD	NAWCAD	SEEK EAGLE	AMRDEC
Launcher vulnerability metric	Hit & Kill	Hit Only	Hit Only	Hit (frag KE>5 ft-lbs or $V>V_{50}$) & Kill
Probability requirement	.0001 or .01* or outside hazards analysis	.0001	.0001 or .01* or outside hazards analysis	Zero, or 10^{-6} In some cases may use .0001**
Maneuver after launch required if probability not met?	Yes (in one or two cases)			No
Analysis Objectives	Safety of flight clearance; safe escape maneuver determination		Safety of flight clearance; safe escape maneuver determination	Minimum low-altitude safe release range; risk assessment

* Modified by Pdet

** AMRDEC System Simulation and Development Directorate

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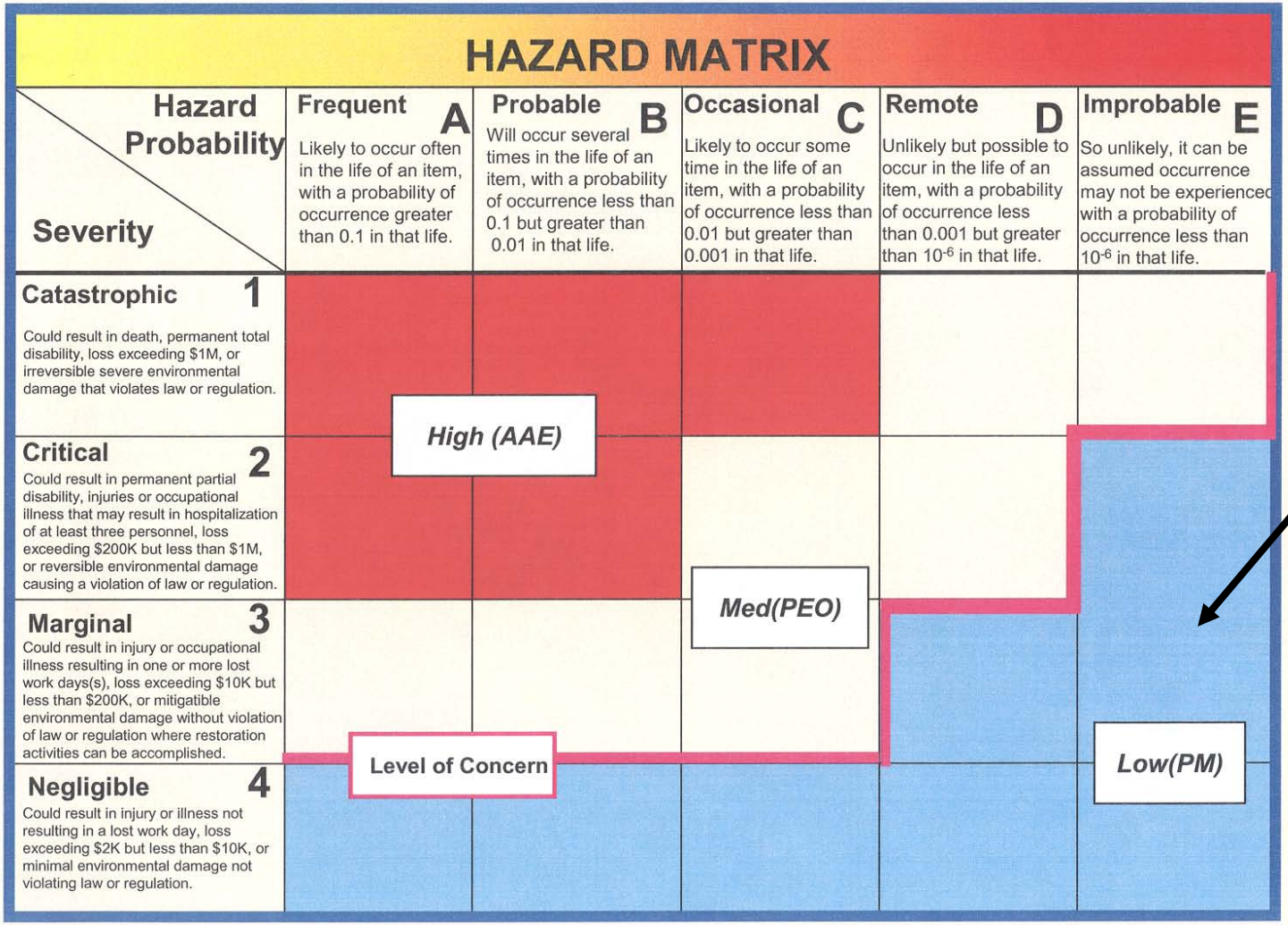
Army Hazard Matrix



Drive S/A Results to Blue Area

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Results: Aircraft Modeling

Aircraft Modeling Issue	NAWCWD	NAWCAD	SEEK EAGLE	AMRDEC
Physical Description	6-view presented area		6-view presented area	6-sided box enclosing aircraft + CAD model
Vulnerability Description	6-view vulnerable area (from survivability analysis)	NA	NA	AJEM model
Target Maneuvers (air-to-air)	Straight and level (assumed worst case); occasionally consider target maneuvers		UNK	NA
Aircraft Flight Path Model	JAAM		JAAM, AWDS	RCAS or FlightLab
Target Debris Model	Not modeled		Not Modeled	Not Modeled

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Results: Weapon Modeling

Weapon Modeling Issue	NAWCWD	NAWCAD	SEEK EAGLE	AMRDEC
Weapon trajectory	Program office 6-dof		Program office 6-dof	Program Office 6-dof
Motor Temperature	Hot/Cold variations if data available		Hot/Cold variations if data available	Hot/Cold variations if data available
Debris source	Arena Test Data		Arena Test Data	Arena Test Data
Debris frag zones	5-10 deg polar zones; uniform distribution		10 deg polar zones; 24 roll zones	5 deg polar zones; unif. dist.
Debris Frags	Large frags & warhead frags modeled separately; no min frag size or velocity; no data available for statistical variations		Large frags & warhead frags modeled separately; no data for statistical variations; unk min frag size or velocity	UNK treatment of large & warhead frags; small frags KE<5 ft-lbs removed; Monte Carlo frag flyout simulation
S/A Device	Arm time plus & minus spec tolerance	Spec value minus tolerance	Spec value minus tolerance + delay	UNK

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Results: M&S & Credibility

M&S Issue	NAWCWD	NAWCAD	SEEK EAGLE	AMRDEC
M&S Used	ASEP	Path 4	CASES	ASEAT
Capability	Adds asymmetric roll zones to Path 3D	3D dynamic frag zones	Pre-generated warhead data files; adds GUI to ASEP	Monte-Carlo, two passes (hit box, then CAD model)
Accuracy	No formal V&V; comparison runs between ASEP & CASES; no data V&V documented; no formal validation; accreditation package done by SEEK EAGLE		No formal V&V; comparison runs between ASEP & CASES; no data V&V documented; no formal validation; accreditation package done by SEEK EAGLE	AJEM V&V; no V&V or documentation available on ASEAT and associated M&S
Usability	User Manual & Analyst Manual; SEEK EAGLE provides limited user support		UNK Documentation; SEEK EAGLE provides user support	

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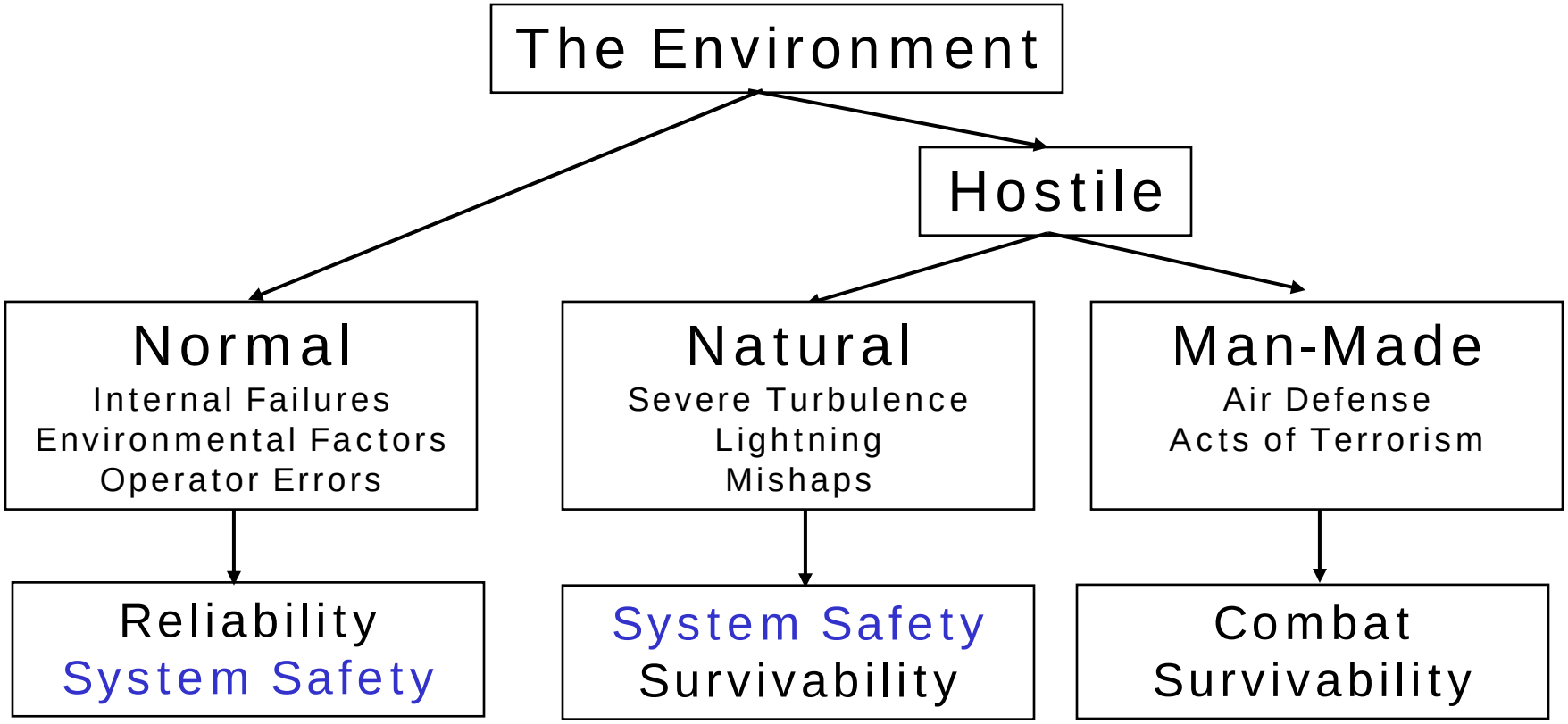
Combat Survivability, Reliability and System Safety



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Recommendations

- **Assumptions: Should be Joint guidance for assumptions used in safe-escape analyses**
  - **Launch aircraft maneuvers, weapon variations (angle of attack, motor temperature, roll orientation, etc.), environmental factors, safe-arm device variations, and other factors that potentially drive the analysis results**
- **Requirements: JSF Joint Safe Escape Analysis System (JSEAS) requirements should serve as the starting point for expansion to include Army requirements and air-to-air weapon system requirements**
  - **Include provision for application of the process outlined in the original Joint Agreement between all the Services**

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Recommendations (Continued)

- **Recommend changing MIL-HDBK-1763 Definitions to:**
  - **Safe escape: Safe escape is the required release conditions and post-launch maneuvers that will provide the delivery aircraft acceptable protection from weapon fragmentation for detonation at the preplanned point or at or after arming; this may result in a minimum safe release altitude.**
  - **Safe arming: Safe arming is the selection of a minimum safe fuze arm setting that will provide the delivery aircraft acceptable protection from weapon fragmentation if detonation should occur at or after the fuze arm time/distance.**
- **Also change MIL-STD-1316E and Fuze Management Board Joint Agreement definitions of "safe separation distance" to be "safe arming distance" (or "safe escape distance")**
- **Would require fairly extensive changes to MIL-HDBK-504 processes and definitions**

Recommendations (Continued)

- **Aircraft Modeling: Should be guidance for launch aircraft post-launch maneuvers to consider for safety reasons.**
  - **Conduct Sensitivity Analyses to determine whether there is a need for more detailed aircraft representations than 6-view presented areas (as in AMRDEC approach)**
- **Weapon Modeling: Should be guidance for:**
  - **Fidelity of weapon debris modeling (polar zones, etc.).**
  - **When to segregate "unusual" fragments for separate analysis**
    - **Such as bomb lugs, warhead fragments that are likely to have much higher velocities than debris fragments, etc.**
  - **What fragments to include in the weapon debris model**
    - **Capable of penetrating the skin of the aircraft**
      - **Per the Joint Agreement definition of "fragment hit"**
    - **Consistent with the Army's KE>5 ft-lbs requirement for fragment inclusion in the debris model (or V_{50} analysis)**
  - **Conduct sensitivity analyses to determine requirement for variations in weapon orientation (roll, pitch,yaw) and effect on results**

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Recommendations (Continued)

- **M&S and Credibility:**
  - **USN representatives should consider migrating to the latest version of the Seek Eagle methodology (CASES)**
  - **When available, the JSEAS methodology should be assessed for adoption as the standard Joint Service methodology**
  - **Documented verification and validation evidence should be developed for all M&S tools used in safe escape/safe arming analyses**
  - **Documentation of all methodologies used by the Services should be developed, maintained and distributed to users**
  - **An Accreditation Support Package (ASP) should be developed for the M&S tools that are continuing in use**