Survivability & Resilience

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Resilient Systems Working Group Webinar

9 October 2024

Definitions - Resilience

- ***Resilience***
  - *the ability of an architecture to support the functions necessary for mission success in spite of hostile action or adverse conditions. An architecture is "more resilient" if it can provide these functions with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats. Resilience may leverage cross-domain or alternative government, commercial, or international capabilities.*
- ***Resilience encompasses avoidance, robustness, reconstitution, and recovery***
  - ***Avoidance:*** countermeasures against potential adversaries, proactive and reactive defensive measures taken to diminish the likelihood and consequence of hostile acts or adverse conditions **[measure- non-dimensional]**
  - ***Robustness:*** architectural properties and system of systems design features to enhance **survivability** and resist functional degradation **[measure- non-dimensional]**
  - ***Reconstitution:*** plans and operations to replenish lost or diminished functions to an acceptable level for a particular mission, operation, or contingency **[measure- time]**
  - ***Recovery:*** program execution and space support operations to re-establish full operational capability and capacity for the full range of missions, operations, or contingencies **[measure- time]**

Source: "DoD FACT SHEET: Resilience of Space Capabilities"

Definitions - Survivability

- ***Survivability***
  - is the capability of a system to avoid or withstand hostile event(s). (P_s)
  - Extended definitions beyond aircraft combat to include satellite, commercial aircraft, ships, ground vehicles, structures
  - Survivability of DoD Systems is a Title X requirement
- ***Survivability encompasses susceptibility and vulnerability***
  - **Susceptibility (Avoidance)** is the inability of ~~an aircraft~~ a system to **avoid** threats that make up the ~~man-made~~ hostile mission environment. (P_H)
    [system design features, measures, countermeasures, proactive and reactive defensive measures]
  - **Vulnerability** (***Robustness)*** is the inability of ~~an aircraft~~ a system to **withstand** the ~~man-made~~ hostile ~~environment~~ event. ($P_{K/H}$)
  - Kill-ability (P_k) is the complement of Survivability

$$P_k = (P_H)(P_{K/H})$$

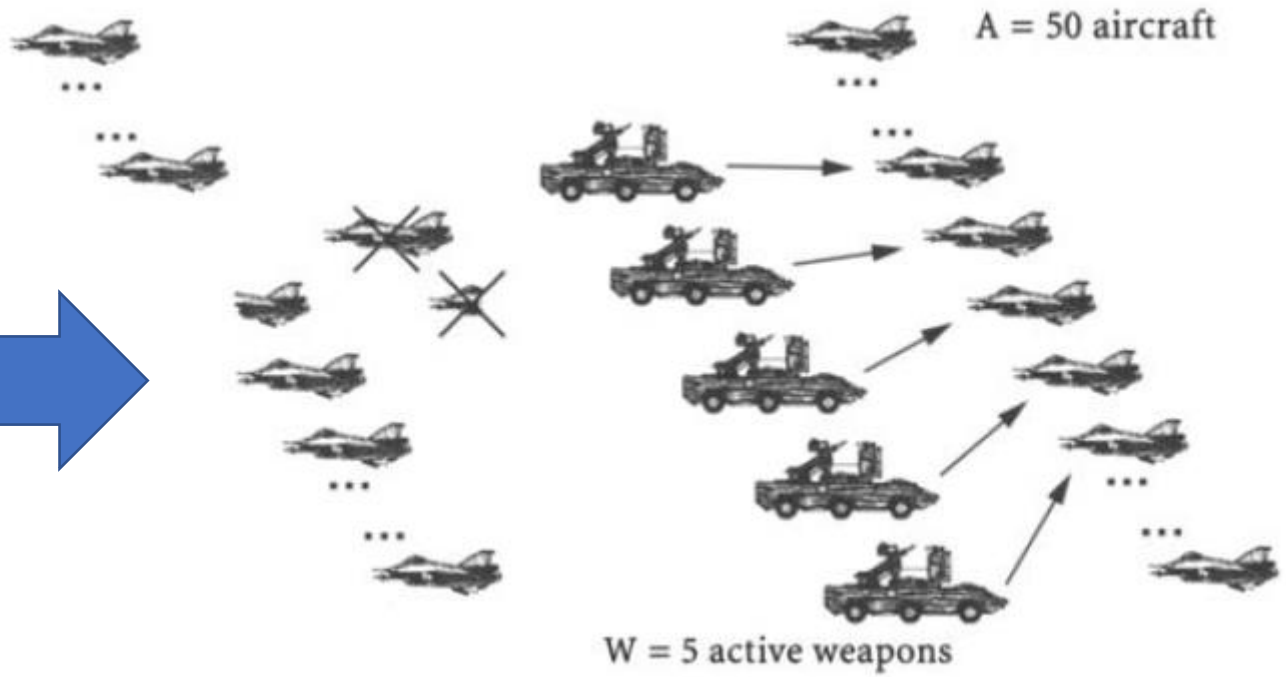
$$P_s = 1 - P_k$$

  - Measuring probability something occurs for a given severity

Robert E. Ball PhD, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," 2nd ed., AIAA, 2003

Levels of Survivability Analysis

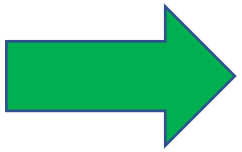
- Performance (System) Level
  - Single-shot $P_s=1-P_k$
  - Multi-shot $P_s= (1-P_k)^n$
  - Many-on-Many $P_s= \pi^n (1-P_k)_n$
  - **Survival focus: Avoidance, Robustnes**
- Effectiveness (Mission) Level
  - Scenario Based
  - System - Force
  - SoS
  - **Survival focus: Avoidance, Robustnes**
- Campaign Level
  - Scenario Based
  - System - Force
  - SoS
  - **Resilience focus: Regroup, Repair, Replace**



Robert E. Ball PhD, "The Fundamentals of Aircraft Combat Survivability Analysis and Design," 2nd ed., AIAA, 2003

Threat Vectors

- Kinetic Weapons
  - Missiles and Guns
- RF Jamming
- Electro Magnetic Pulse
- Lasers
- Bird Strike
- Orbital Debris

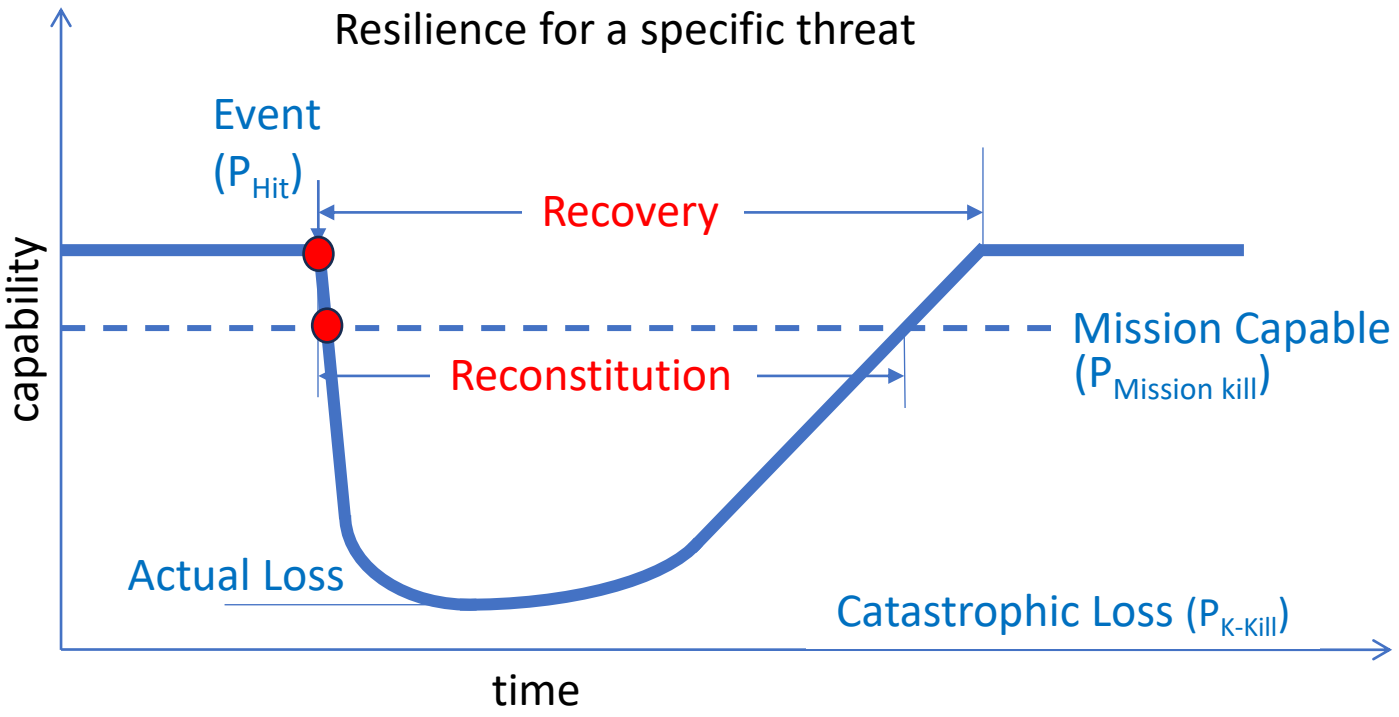


Two Kinds of Kill:

- *K-Kill (Destruction)*
- *Mission Kill*

A Survivable System is a Resilient System

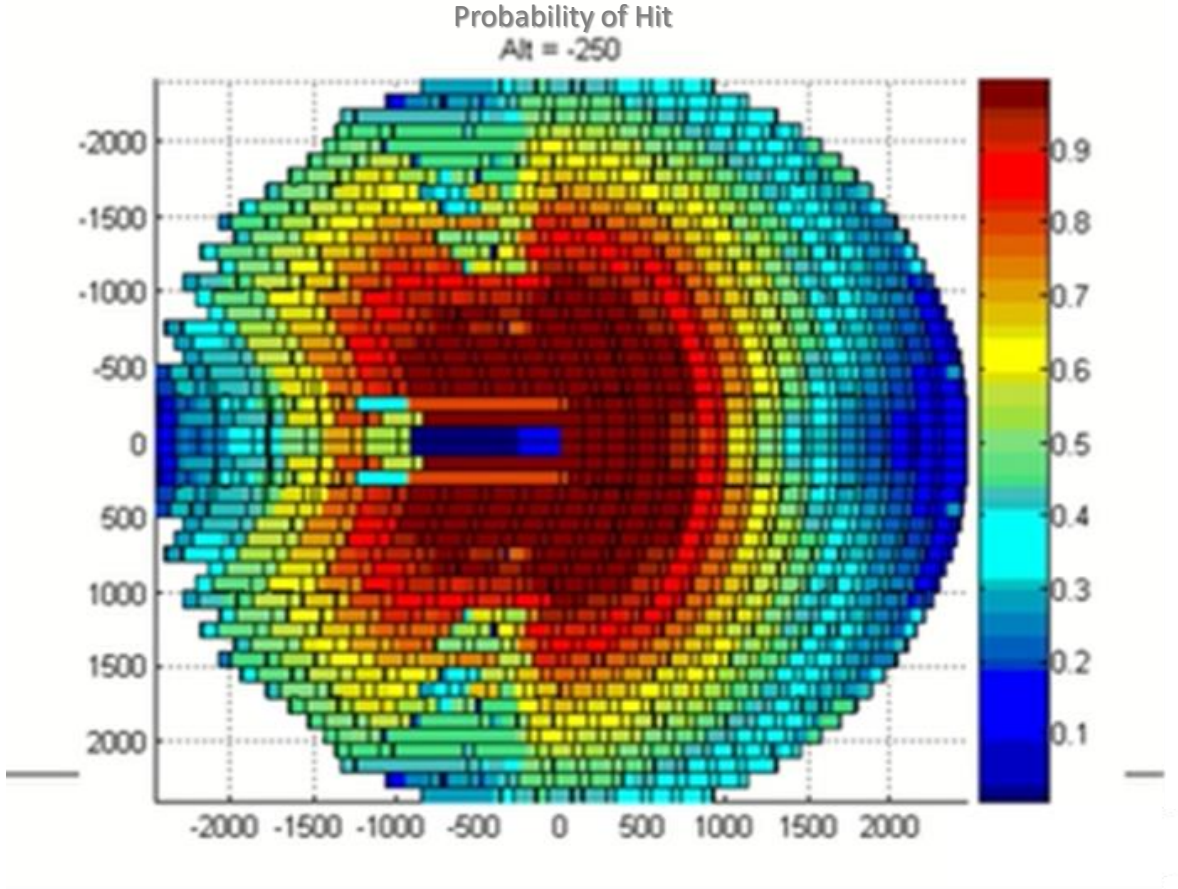
Capability Time Histories



- Calculate P occurrence and P for a given severity
- Recovery/Reconstitution depends on threat and solution
- Multiple Recovery/ Reconstitution times possible each event type (e.g. fast/slow reposition, hot spare, etc.)
- Key Measurement is TIME

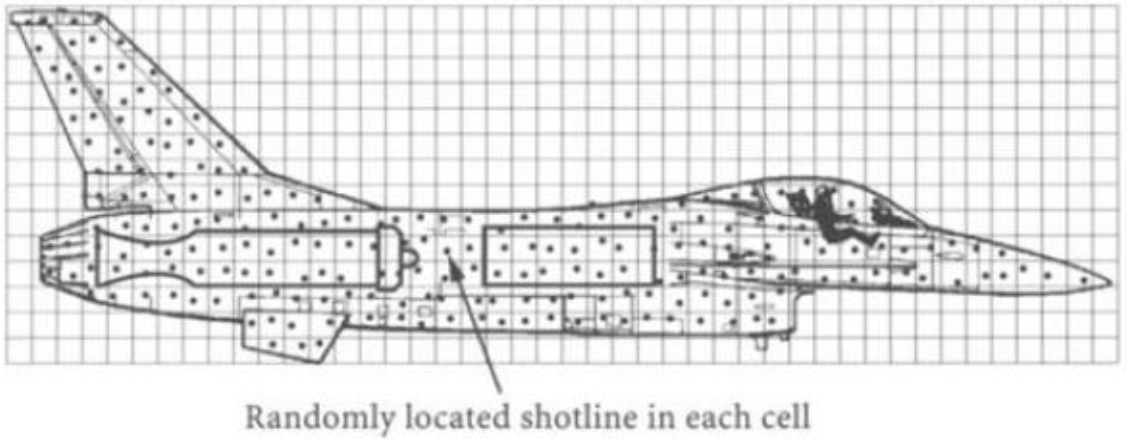
Susceptibility Reduction

- Signature Reduction
  - RF, Optical, IR
- Tactics / Mission Planning
  - Fly High, Terrain Following
  - Stand-off Weapons
- Threat Warning
- Agility
  - Getting out of the way
- Electronic Countermeasures
- Chaff, Flares, Smoke
- Weapon Interception
- Numerical Superiority



Vulnerability Assessments

- Vulnerable Area
  - Threat specific
  - Shot-Line Analysis



- Damage Mode, Effects, and Criticality Analysis (MIL-STD-1629A)
  - Multiple Simultaneous Failures
  - Cascading Failures

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Damage Mode and Effects Analysis Example Kill Modes

Component/system	Kill mode
Fuel	Fuel supply depletion
	Fire/explosion
	In-tank/ullage
	Void space
	Hydrodynamic ram
Structural	Fracture/removal
	Pressure overload
	Thermal weakening
	Delamination/fiber buckling
	Connection failure
Avionics	Mechanical damage
	Fire/overheat
Armament	Fire/explosion
Propulsion	Air inlet flow distortion
	Engine failure
	Fuel ingestion
	Foreign object damage
	Fan/compressor damage
	Combustor damage
	Turbine damage
	Exhaust duct or after-burner damage
	Engine fire
	Engine subsystem or control failure
	Loss of lubrication
	Engine controls and accessories failure

Component/system	Kill mode
Power train and rotor blade/propeller	Mechanical/structural damage
	Loss of lubrication
Flight control	Disruption of the control signal path
	Loss of pilot
	Loss of control lines
	Computer failure
	Sensor damage
	Loss of control power
	Hydraulic failure
	Electrical failure
	Actuator damage
	Damage to control surfaces/hinges
	Hydraulic fluid fire
Electrical power	Severing/grounding
	Mechanical damage
Crew	Overheating
	Injury/death
	Life support failure

Survivability Improvement

- Vulnerability
  - Shielding
  - Redundancy
  - EMP Hardening
  - Plenums
  - Filters
- Susceptibility
  - RCS Reduction
  - RF Countermeasures
  - Agility

Summary

- Survivability direct component of Resilience
  - Differing taxonomy
- Survivability leverages Reliability Studies (DMEA)
- Resilience leverages Survivability Studies
- At system level focus is on avoidance and robustness
- At force level focus is on regrouping, repair, replace
- Maintain effectiveness throughout the conflict
- A Survivable System is a Resilient System

References

- SMC-S-014, “SURVIVABILITY PROGRAM MANAGEMENT FOR SPACE”, Air Force Space Command, SPACE AND MISSILE SYSTEMS CENTER STANDARD, 19 July 2010
- “DoD FACT SHEET: Resilience of Space Capabilities”
- Robert E. Ball PhD, “The Fundamentals of Aircraft Combat Survivability Analysis and Design,” 2nd ed., AIAA, 2003