Integrated Survivability Assessment (ISA): Bridging DT&E, LFT&E, and OT&E

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**Integrated Survivability Assessment**

- **Motivation:** comprehensive system survivability evaluations in OT&E
  - Integrated LFT&E and survivability OT&E
    - Rather than separate assessments
    - Linking in DT&E results
  - Developed for the Joint Aircraft Survivability Program (JASP) at the request of DOT&E
    - Initially for air weapons systems
    - Extensible to ground and sea systems

- **ISA** is a process for evaluating all aspects of system survivability in a coordinated fashion
  - Using both M&S and T&E resources where appropriate

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The Key to bridging DT&E, LFT&E, OT&E:
Common, Testable Metrics throughout the acquisition process
What does the Integrated Survivability Assessment Process Do?

• Measures system survivability in the context of missions and scenarios
  – “Cover the Waterfront” to avoid a point design

• Consistent treatment of survivability throughout the system acquisition lifecycle
  – Requirements development, AOA, spec compliance, DT&E, LFT&E, OT&E, retrofits, SLEP, system mods, training applications…

• Trading Survivability, Effectiveness, and Mission Metrics
  – Within a Consistent and Documented Process
Elements of Survivability

1. Damage Tolerance
2. Crew Protection
3. Damage Resistance
4. Signature Reduction
5. Defensive Countermeasures
6. Situational Awareness
7. Performance
8. Precision & Standoff Weapons
9. SEAD & DEAD
10. Jamming
11. Mission Planning
12. Policy & ROE
13. Tactics & Doctrine

Off-board Elements

Vulnerability
Susceptibility
Other
Developing an Integrated Survivability Assessment Process

• **Checklist**
  – Of important survivability factors

• **Metrics**
  – Applied to DT&E, LFT&E, OT&E

• **Assessment**
  – A modeling path to quantify metrics
  – Test range assets and processes to quantify metrics

• **M&S Validation**
  – A path to validating M&S with available test range data
  – Model - test – model approach
The Threat Kill Chain: A Checklist of Survivability Factors

Susceptibility:
On-board EA, signatures, countermeasures, speed and altitude, maneuverability, agility (last ditch maneuver), target acquisition (standoff), ...

Vulnerability:
Fire/explosion protection, self-repairing flight controls, redundant and separated hydraulics, multiple engines, no fuel adjacent to air inlets, hydrodynamic ram protection, nonflammable hydraulic fluid, rugged structure, armor, ...

Off Platform Factors
Tactics, standoff weapons, anti-radiation missiles, self defense weapons, off-board EA, night/all weather capability, threat warning, situational awareness, C4ISR
Survivability Metrics

- **Threat Shot Opportunities**
  - Situational Awareness: Number of threat systems correctly detected, identified and located, with what location range and accuracy

- **Mission Level Survivability**
  - Missions Accomplished: percentage of vignettes that can be accomplished considering survivability constraints
    - Force Survivability
    - Targets at risk
    - Targets not engaged (leakers) (air to air)
      - Robustness

- **Recoverability**

- **Effectiveness**

- **Personnel Survivability**
  - Expected # casualties given a hit
  - Probability of personnel survival given loss of aircraft control due to hit

- **Engagement Level Survivability**
  - Threat System Pk Envelopes
    - Hit locations on Aircraft
    - Robustness

- **Robustness**

- **Engagement Level Susceptibility**

- **Vulnerability**
  - Aircraft Pk/h (or damage given a hit or an intercept)
    - Component Pk/h (or damage given a hit)
    - Vulnerable area
  - List of components vulnerable to various damage mechanisms

Primary Metric (MOE) – Red
Sub-Metric (MOP) - Black

Mission Level
Survivability

• Missions Accomplished: percentage of vignettes that can be accomplished considering survivability constraints
  • Force Survivability
  • Targets at risk
  • Targets not engaged (leakers) (air to air)
    • Robustness

Engagement Level Susceptibility

Threat Envelopes (with and w/o CM)
• F-Pole, A-Pole, E-Pole
  • Detection Range
  • Acquisition Range
  • Tracking Range
• ECM/IRCM Effectiveness
• First Shot Opportunity (Air to Air)
The Survivability Assessment Process

Susceptibility Assessment (Phit)
- Environmental Effects
- Countermeasures
- Signatures
- Threat Sensors

Vulnerability Assessment (Pk/hit)
- Vehicle Geometry
- DMEA
- Component $P_{K/H}$
- Flight & Mission Essential Components
- Vulnerability Indices

Mission-Threat Analysis

System Survivability Assessment

Engagement Assessment
- EW/EC
- SAM
- Guns
- AAM
- Lasers

Mission and System Metrics

Mission Assessment
- Air-to-Air Combat
- Air-to-Ground Missions

System Trade Evaluations
M&S in DT&E, OT&E, LFT&E

- M&S cannot replace testing, only provide support
- M&S objectives in DT&E, OT&E, LFT&E
  - Support Test Planning
    - “What tests should we conduct?”
    - “What data should we collect, with what fidelity and frequency?”
    - “What do we think will happen?”
  - Support Test Analysis
    - “Why’d that happen instead?”
    - “What should we do about it?”
  - Support COI resolution
    - “So the test result is that – so what?”
- Use of M&S in combined survivability DT&E, OT&E and LFT&E should be from these perspectives
- Integration of M&S and testing enhances credibility of both
Data Sources for a Typical Survivability Assessment

\[ P_{K/E} = P_{A/E} \times P_{T/A} \times P_{L/T} \times P_{I/L} \times P_{F/I} \times P_{H/F} \times P_{K/H} \]

DT/OT&E

M&S

LFT&E

E = Engagement
A = Acquisition
T = Track
L = Launch
I = Intercept
F = Fuzing
H = Hit
K = Kill
Integrated Survivability Assessment: Model-Test-Model Concept

1. Develop Detailed Test Plans
2. Program Documents (TEMP, ORD, etc.)
3. Library of M&S (incl. Credibility Info.)
4. Existing Fixed Data (Terrain, Threat, etc.)
5. Existing Data (System Specific)
6. Characteristics of System Under Test
7. Create Vignettes Applicable to System Under Test
8. Assess M&S Needs
9. Select M&S Suite Best-Suited to System Under Test
10. Execute M&S (Pre-Test Analyses)
11. Develop Detailed Test Plans
12. Conduct T&E
13. Collect LFT&E data
14. Collect OT&E data
15. Conduct Analysis To Yield Survivability Metrics
16. Execute M&S (Post-Test, i.e., Using LFT&E and OT&E Data)
17. Assess T&E Needs
18. Select T&E Site(s) Best-Suited to System Under Test
19. Test results dictate major program change?
20. LFT&E, OT&E Report
21. M&S Support Test Plan Development

Flowchart:
- Start with Program Documents, Library of M&S, Existing Data, Existing Fixed Data.
- Develop Vignettes Applicable to System Under Test.
- Select M&S Suite and T&E Site(s) Best-Suited to System Under Test.
- Execute M&S for Pre-Test Analyses and Post-Test.
- Conduct T&E and collect data.
- Conduct Analysis to yield survivability metrics.
- Determine if test results dictate major program change.
“Case Study” Example

• **Unmanned Combat Aircraft System (UCAS):**
  
  **Role:** CAS, battlefield interdiction, SEAD/DEAD, etc.

  **Dimensions:**
  
  **Weight:**
  
  **Speed:**
  
  **Range:**

• **To be determined:**
  
  **RCS:**
  
  **IR signature:**
  
  **DECM/IRCM:**
  
  **Vulnerability:**
  
  **etc.**
## EXAMPLE: UCAS VIGNETTES

<table>
<thead>
<tr>
<th>Driving Factors</th>
<th>3rd World Urban</th>
<th>Advanced Threat, Forested</th>
<th>Conventional Threat, Desert</th>
<th>3rd World Mountains</th>
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</thead>
<tbody>
<tr>
<td>ISR</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Force Protection</td>
<td>X</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SEAD DEAD</td>
<td>X</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>C2</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All Weather, Night Strike</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CSAR</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Ж</td>
</tr>
</tbody>
</table>

**Ж = Most stressing Scenario**

- Target Acquisition: Difficult Conventional Threat
- IADS, Wx, Target Acquisition: Advanced Threat
- Flat Terrain, Clear Wx High Threat
- High Altitude, Rough Terrain Conventional Threat
Example: SEAD/DEAD
Mission Vignette

Timeline
- TOT -12 Checkpoint α
- TOT -5 Decoys on @ β
- TOT -4 2 x HARMs
- TOT -3 2 x HARMs
- TOT -2 2 x HARMs
- TOT -1 Weapons away
- TOT -0 Weapons impact
- TOT +1 2 x HARMs
Threat Engagement Assessment

Output Metrics:
- Detection, Acquisition Range Tracking
- Range Contours
- Threat Envelopes
- ECM/IRCM Effectiveness
Example Susceptibility Results: Impact of RCS and Terrain on Detection

Detection range vs. RCS

Effects of Terrain Masking on Detection Contour

A/C Flight Paths
Planning Susceptibility Tests: Impact of ECM on Miss Distance

A/C Flight Paths

<table>
<thead>
<tr>
<th>Test points</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ECM</td>
</tr>
<tr>
<td>With ECM</td>
</tr>
</tbody>
</table>

Miss Distances in Meters

Locations in KM

Threat System
Assessing M&S results for all vignettes, the following susceptibility-related test data are required:

- Surface-to-air threat acquisition & tracking data applicable to system under test (for IR and RF threats)
- Surface-to-air threat engagement envelopes applicable to system under test (for IR and RF threats)
- IR and RF threat functional element characteristics
- etc.
Vulnerability Assessment

Critical Functions Analysis

- FMECA (FMEA/DMEA)
  - Fault Trees
  - COVART, AJEM

- Geometric Model

- Pd/h Functions

LFT&E Data

OUTPUT METRICS:
- Pk/h (Aircraft and Component)
- Vulnerable Area

OUTPUT METRIC:
- List of vulnerable components by damage mechanism
Vulnerability Metric: Vulnerable Area

Vulnerability Reduction Technology

- Flight Controls & Dry Bay
- Fuel Leakage Mitigation
- Dry Bay Protection
- Flight Controls
- Ullage Protection
- Baseline

NOTE: EXAMPLE ONLY
Planning Vulnerability Tests: Warhead Fragment Mass Distribution

![Graph showing the distribution of warhead fragment mass with a test point indicated at a specific mass value.](image-url)
Planning Vulnerability Tests: Warhead Fragment Velocity
Based on an analysis of results from all UAV vignettes (and a survey of existing data), the following live-fire shots are required:

<table>
<thead>
<tr>
<th>Threat Weapon</th>
<th>Focus of Frags off Warhead Nose</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Miss Distance, ft</td>
</tr>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0</td>
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<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
</tr>
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</table>
Threat Missile Endgame (Pk) Assessment

- Test Range Measurement Data
- PROX FUZE MODEL GTD (RF)
- TARGET NEAR-FIELD SIGNATURE MODEL
- INTERCEPT PARAMETERS/DISTRIBUTIONS (from threat performance assessment M&S)
- WARHEAD MODEL
- TARGET VULNERABILITY MODEL (COVART)
- SHAZAM, AJEM Blast, Direct Hit, Fragmentation
- LFT&E Data
- Pk
Engagement Survivability Results: Effect of ECM on PK

No ECM
A/C Flight Paths

With ECM
A/C Flight Paths

High PK Region

Threat System
Mission Survivability Assessment

**Engagement Level Results**
- Detection, Tracking Range Contours
- Threat Pk Envelopes
- ECM/IRCM Effectiveness

**Flight Paths (Multiple Aircraft)**

**ECM/IRCM Effects (Test Data)**

**ESAMS (RF SAMS)**
- ADAM (ADA)
- MOSAIC (IR SAMS)
- LELAWS (LEL)
- DREAM (HPM)

**MISSION LEVEL MODELS**
- JIMM
- SUPPRESSOR
- EADSIM

**OUTPUT METRICS**:
- Mission Accomplishment: percent of vignettes that can be accomplished considering survivability constraints
- Force Survivability
- Targets at risk
- Robustness
- Threat Shot Opportunities
- Situational Awareness: Number of threat systems correctly detected, identified and located, with what location range and accuracy

**Blue C4ISR**

**Threat C3**

**Limited Open-Air Range Testing**
- Multiple Threat Systems
- Multiple Air Vehicles

**Blue Weapons Effects (JMEM)**

**Man-in-the-loop simulators**
- DIADS
Integrated Survivability Results: Impact of IRCM Improvements

- **NONE**: Fewest losses, highest unit cost.
- **ALQ-144 DIRECTED ENERGY**: Lowest Life Cycle Cost.

**NOTE**: EXAMPLE ONLY.
Integrated Survivability Results: Impact of IR Signature Reduction

NOTE: EXAMPLE ONLY
# Overall Vignette Results

<table>
<thead>
<tr>
<th>Driving Factors</th>
<th>Urban</th>
<th>Forest</th>
<th>Desert</th>
<th>Mountains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Acquisition</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Difficult Convention Threat</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>IADS, Wx, Target Acquisition Advanced Threat</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
</tr>
<tr>
<td>Flat Terrain, Clear Wx High Threat</td>
<td>Ж</td>
<td>Ж</td>
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</tr>
</thead>
<tbody>
<tr>
<td>CAS</td>
<td>Ж</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Battlefield Interdiction</td>
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<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
</tr>
<tr>
<td>SEAD/DEAD</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
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<tr>
<td>Strategic</td>
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<td>Ж</td>
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<tr>
<td>Tactical</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
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<tr>
<td>Targeting</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
<td>Ж</td>
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<tr>
<td>&amp; Landing</td>
<td>Ж</td>
<td>Ж</td>
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</table>

**Ж = Most stressing Scenario**
Vignette Results for OT&E

- **Red vignette means system cannot be effectively used for that scenario/mission**
  - Underlying M&S, DT&E, LFT&E and OT&E results show why the SUT fails that vignette

- **OTA and DOT&E will need to decide the implication of that failure:**
  - SUT will require additional resources to accomplish the mission in that type of situation
  - SUT will require modification to perform the mission
  - SUT tactics manual will restrict where the system can be used
  - If the vignette is very important, loss of SUT may be deemed acceptable if mission can be accomplished (may be unique to UAV systems)

*OR,*
  - SUT fails OT&E
Some Known Deficiencies in ISA Process

- **General Issues**
  - Model linkages; data availability, including validation data; links to TEMP; analyst experience

- **Modeling and Simulation Issues**
  - Aggregation of M&S results from lower level models to higher level
  - Engagement level: DECM, threat fuzing, human operator, signatures, body-on-body effects, external blast, DEW, fire & explosion
  - Mission Level: networked systems, operator tactics, data/sensor fusion, C4ISR

- **Test Range Issues**
  - Number of platforms, threats in test, test range size – can’t fully test integrated system
    - Signal Density – may not be representative on ranges
  - Limitations in current T&E capabilities
    - Missile Miss Distance Measurement
    - Threat System Variability – system to system variations
  - Insufficient pre-planning:
    - Completeness & fidelity of OT&E data
    - System calibration issues
Summary

• ISA process integrates LFT&E data (vulnerability) with DT&E and OT&E survivability data (susceptibility)
  – In a “model-test-model” approach, with consistent metrics across system acquisition and test
  – M&S results are used to support test plan development and to put test results into context of mission/scenario vignettes
  – Test results are used to support improvements to M&S

• Vignette approach:
  – Provides consistency in evaluation criteria across program development stages (requirements, specification, LFT&E, DT&E, OT&E)
  – Highlights any problem areas and potential solutions
  – Ensures the SUT is not a point design from the standpoint of survivability

• Current deficiencies in M&S and T&E resources need to be addressed
  – Gradually being improved via JASP, CTEIP, etc.
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