
An Exploration of Vulnerability Analysis and how it Integrates into the Aircraft Design and Requirements Setting Process

Matthew C. Largent

Aerospace Systems Design Laboratory

Georgia Institute of Technology

November 16, 2000

Intro/Background

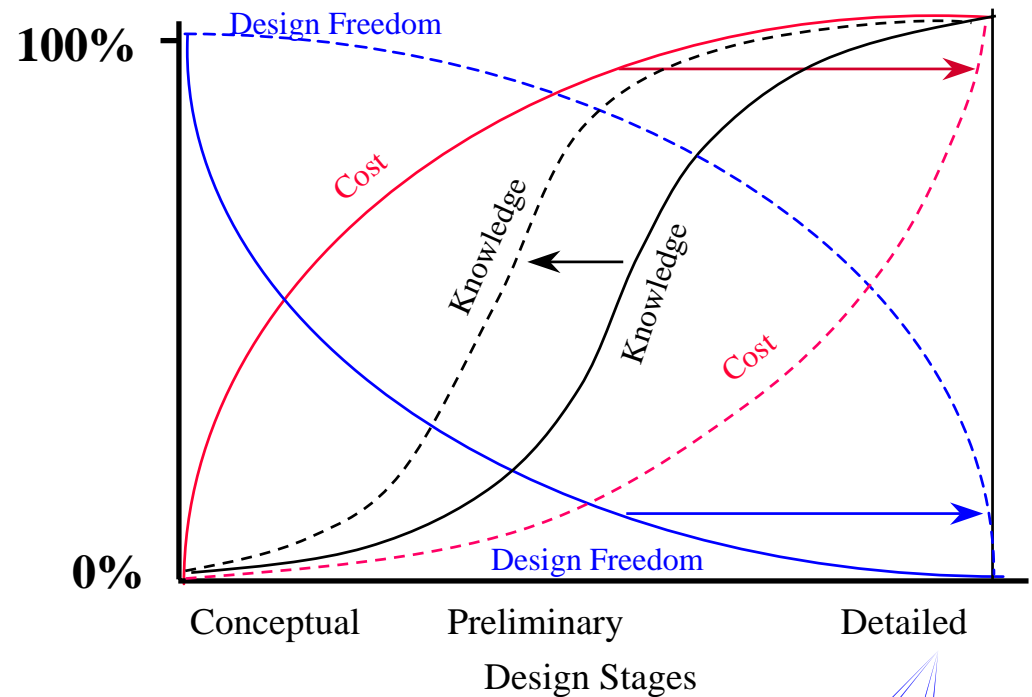
- There is a growing concern that aircraft vulnerability analysis is not being given due consideration
- Stealth has had a rising importance, with susceptibility overshadowing vulnerability
- Warfighters, planners, and requirements setters would rather have an aircraft that cannot be hit, but still need to look at what will happen when it is hit.

NDIA Vulnerability Report

- Points raised:
 - Need for Robust Analysis
 - Need for new or alternative Measures of Merit
 - Need a process to advance information from detailed level to mission and theater level of operation.
- “Early incorporation of Low Vulnerability (LV) design features are less costly than later retrofit”

Vulnerability and Design

- Conceptual design for vulnerability is usually accomplished through guidelines
- Usually vulnerability modeling and simulation isn't addressed until more detailed level of design
- Like any discipline, more information earlier on in the process is better



Design at ASDL

(Aerospace Systems Design Laboratory)

- Focused on enabling the designer or decision maker to create the best system
- Use a number of methods to assist in this task
 - Response Surface Methodology (RSM)
 - Robust Methods
 - Technology Identification, Evaluation, and Selection (TIES)

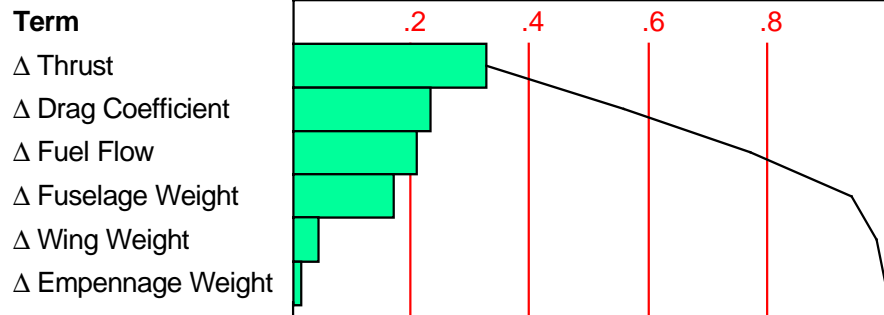
Response Surface Equation (RSE)

- Used to model complex analysis in a simple manner

$$R = b_o + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k b_{ij} x_i x_j$$

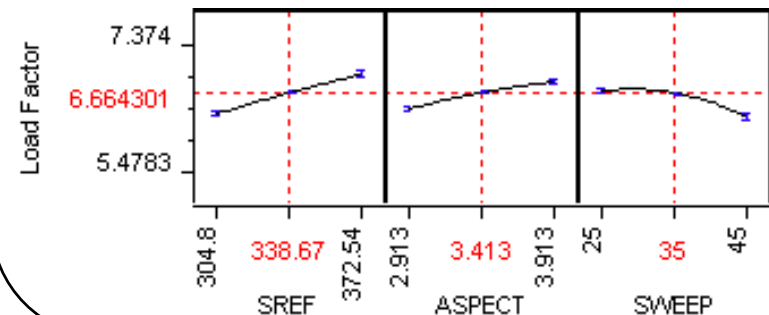
Screening Test

- Used to determine which variables most affect the *change* in response values



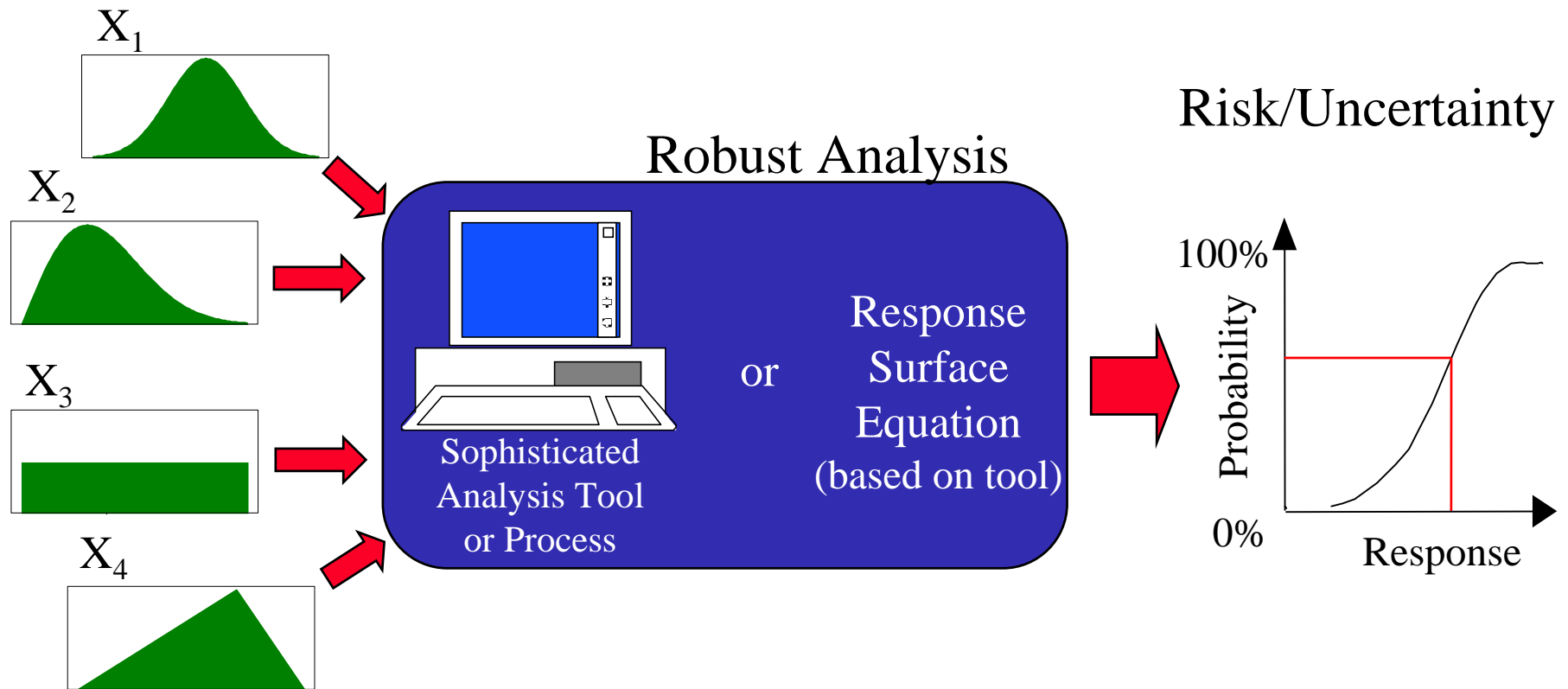
Prediction Profile

- Used to visualize the relationships between design variables and response values



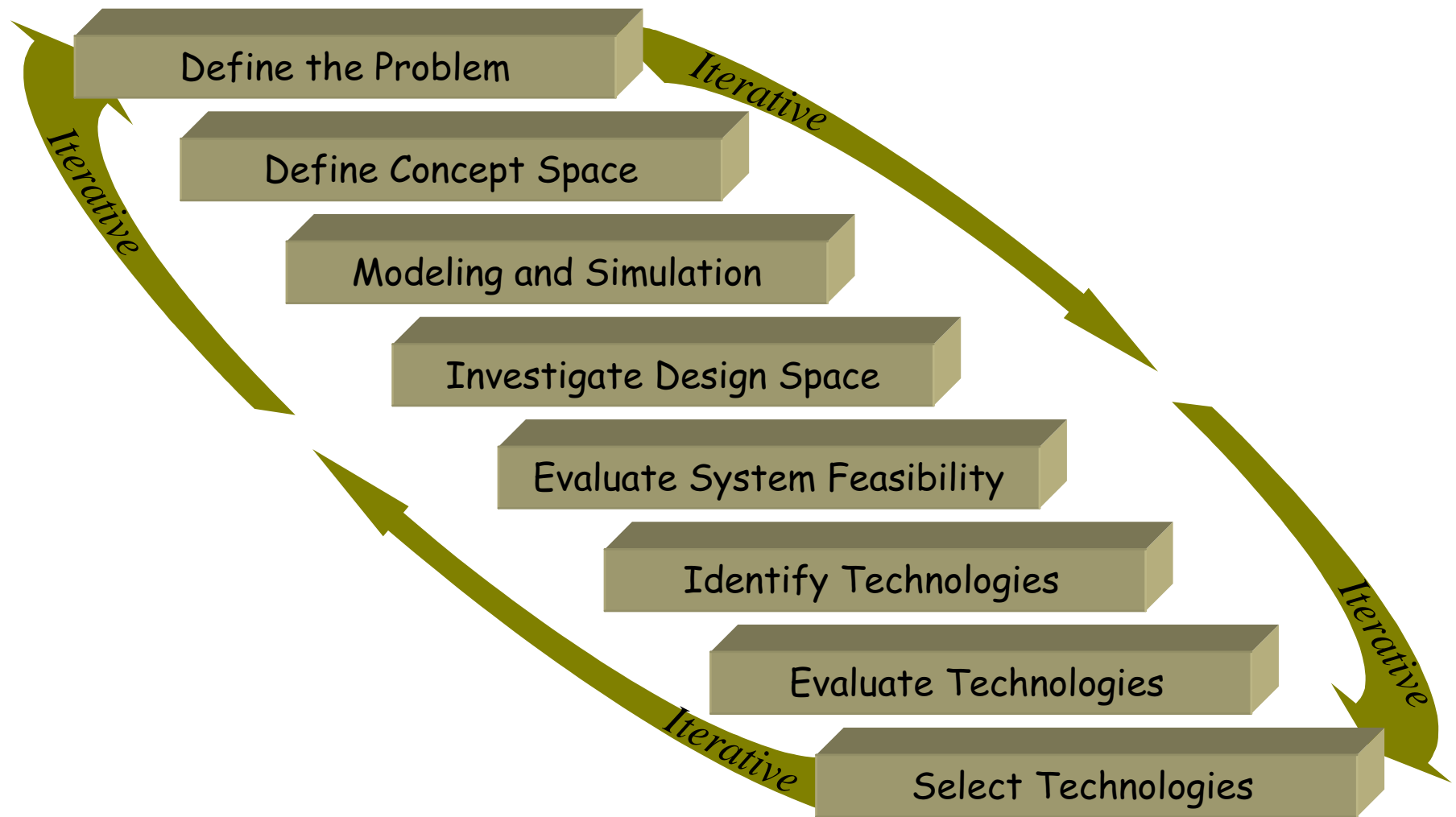
Robust Methods

Probabilistic Inputs



TIES:

Technology Identification, Evaluation, and Selection



What is Missing?

- These methods can handle robust scenarios, and allow for modeling of technology
- Fall prey to following problems when applied to vulnerability
 - Lack of Analysis Methodology
 - There must be a way to accurately perform vulnerability analysis and transform the detailed information into the appropriate level metrics
 - Lack of Appropriate Measures of Effectiveness (MOE)
 - If MOEs are not descriptive enough to show effects of technologies or design decisions, then ASDL methods will not help

Vulnerability/Lethality Taxonomy

- Method developed at Army Research Lab by Deitz and others
- Provides a way to pass information from initial conditions of threat/target interaction up to theater level analysis
- Divides vulnerability information up into a series of *Levels* that are linked by *Operators*

Level Descriptions

Level 1

Level 1: Threat and target system initial conditions: this includes geometry, locations, velocities, etc.

Level 2

Level 2: Damage description: usually a list of components with a damage status of each one

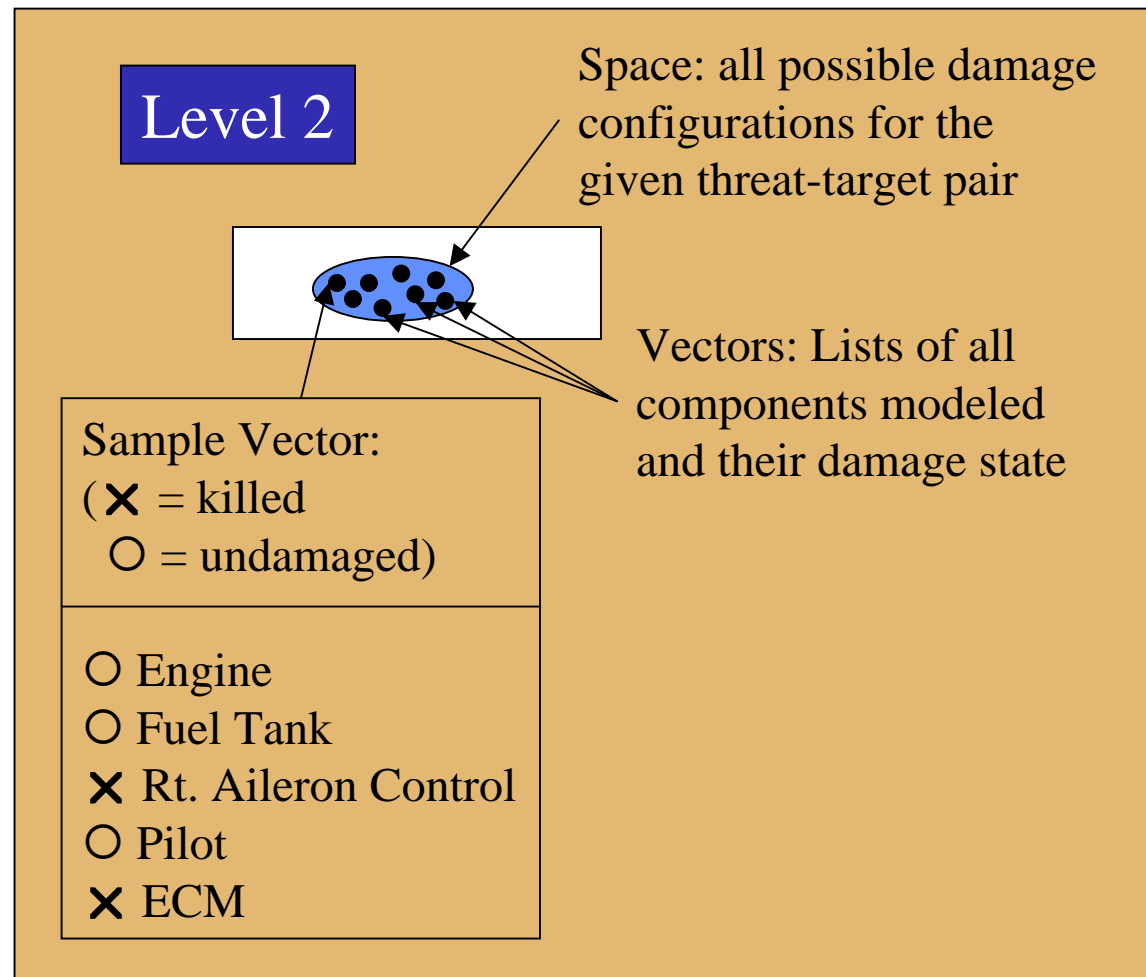
Level 3

Level 3: System capability: a list of system capability metrics, and the level at which the damaged system stands

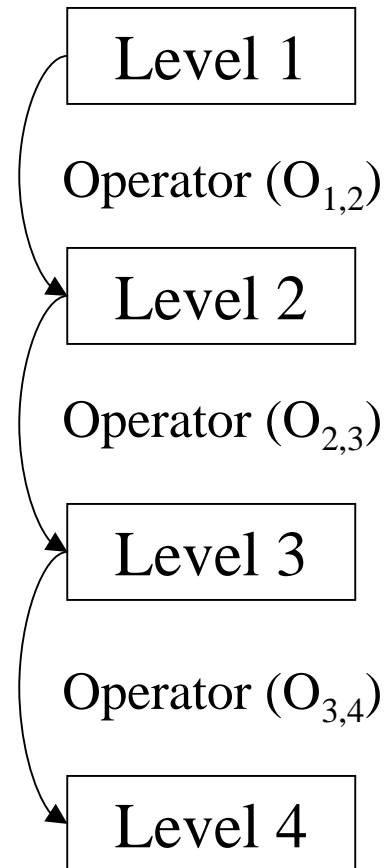
Level 4

Level 4: Battlefield utility: usually a list of mission or theatre level MOEs relating to the performance of the system

Level Details



Operator Descriptions

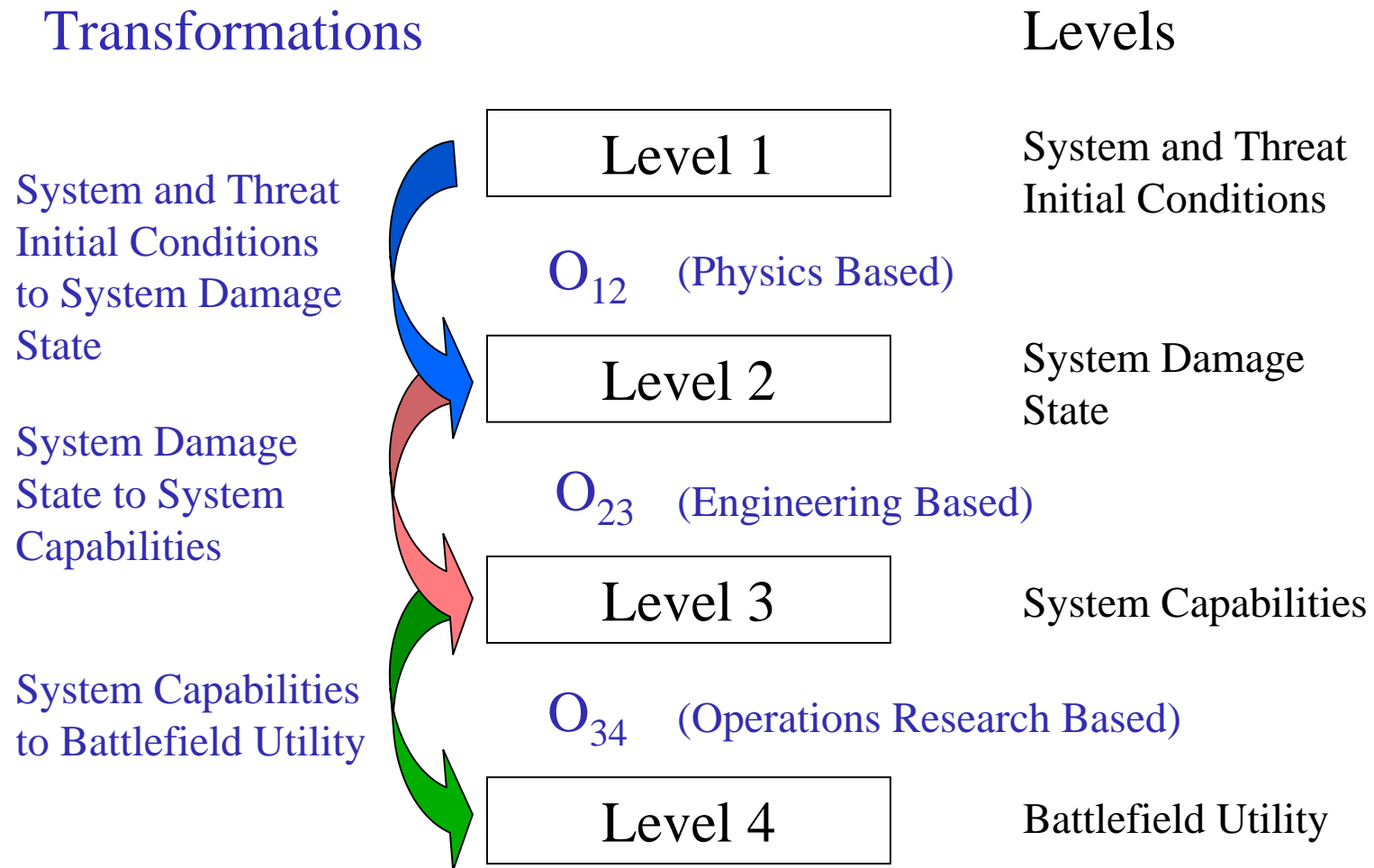


$O_{1,2}$: Transforms initial conditions into list of damaged components, typically physics-based. Can use codes like COVART or AJEM

$O_{2,3}$: Transforms list of damaged components into system capabilities, typically engineering-based. One method developed by ARL is the Degraded States Vulnerability Method (DSVM)

$O_{3,4}$: Transforms system capabilities into battlefield utility. Must be a collaboration between vulnerability analyst and campaign analyst.

Vulnerability/Lethality Taxonomy



Benefits from Taxonomy

- Structured Method
 - Lays work out in series of defined steps
 - Develops terminology to describe these steps that aids in describing the problem
- Design Oriented
 - Allows different operators to be used given the fidelity of analysis necessary.
 - Could be automated to allow ease of analysis

Benefits from Taxonomy

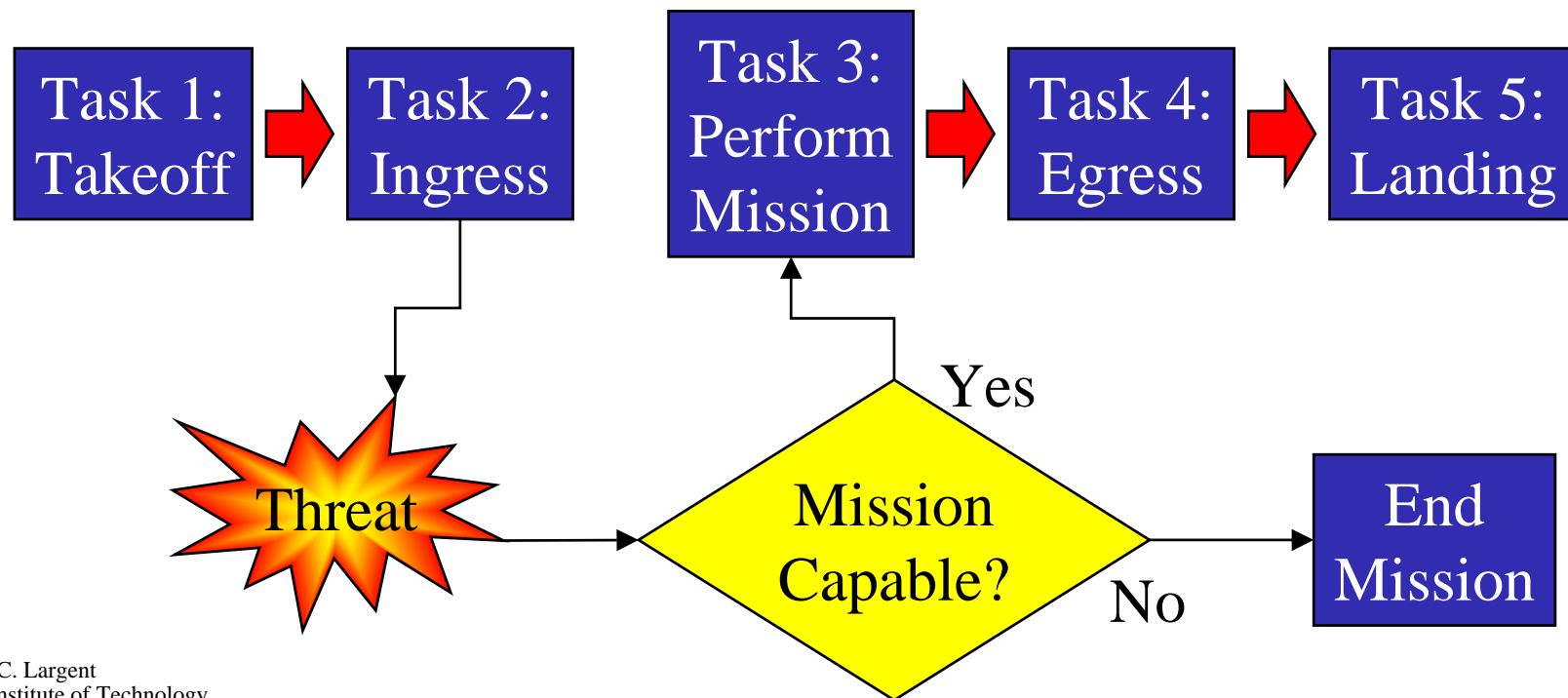
- System Capability Level
 - Allows more information to be collected about the effect of damage on the aircraft.
 - For Tanks, might have Mobility, Firepower, Communications, Acquisition, Crew, and Ammunition.
 - For Aircraft have to look at things differently, Mobility or Control kill causes kill of entire Aircraft!
 - Use Kill criteria and levels as possible measures of capability
 - Keep track of crew lives
 - Communications, Weaponry, Targeting important in modern systems.

Weaknesses of Taxonomy

- Still detail intensive
 - Need to know components, not a Conceptual design problem
- Limited to tool accuracy
 - Uses existing analysis capability
- Work in progress
 - $O_{3,4}$ and Level 4 have not been defined fully, until this is finished, the method is not complete

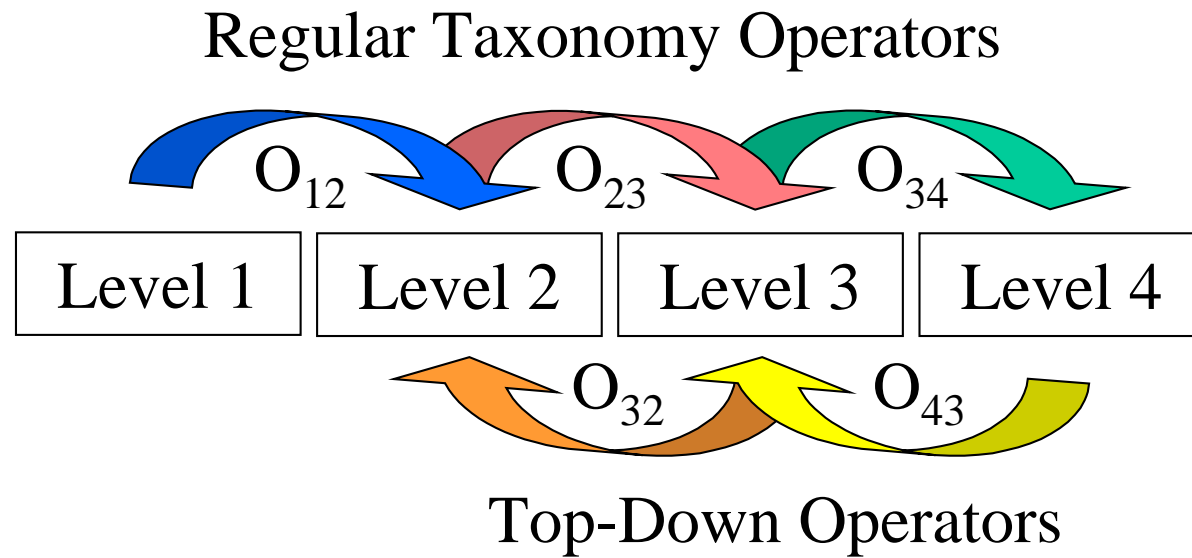
Current Taxonomy Work

- Defining Level 4 and $O_{3,4}$
 - Task-oriented mission definition
 - Threats degrade capability
 - Mission tasks require certain capability



Current Taxonomy Work

- Top-down analysis
 - Looking at using mission definition at theater level to define capabilities and components necessary to complete mission
 - NOT the reverse of the regular operators, need new Top-Down operators



Current Taxonomy Work

- System of systems representation
 - Model each system as a series of components
 - Communication between systems is a capability
 - Destruction of communication components would then degrade the capability of the systems to act together
 - With Top-Down analysis, allows possibility of mission resolution to be found with a number of systems.

Conclusions

- Vulnerability/Lethality Taxonomy provides a method of classifying and propagating vulnerability information that can be beneficial to the aircraft community
- Focusing on capability will provide information on effects of damage or LV technology beyond P_K
- Keeping track of information, such as which components are killed, will benefit designers
 - Also track crew lives
- Combined with advanced design methods, tradeoffs can be performed to find “Best” solution

Future Work Possibilities

- As a system is examined earlier in the design process, how will operators and levels change to allow vulnerability analysis to be performed?
- What specifics need to be addressed to assist in applying the V/L Taxonomy to aircraft?
 - How should capabilities be defined for aircraft, and how should they be calculated?
- What could be done to existing analysis programs and the V/L Taxonomy to make them more design oriented?

Matthew C. Largent

Aerospace Systems Design Lab
Georgia Institute of Technology

www.asdl.gatech.edu

mlargent@asdl.gatech.edu

(404) 894-3343