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A Summary of Industry MDO Applications and Needs

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OUTLINE

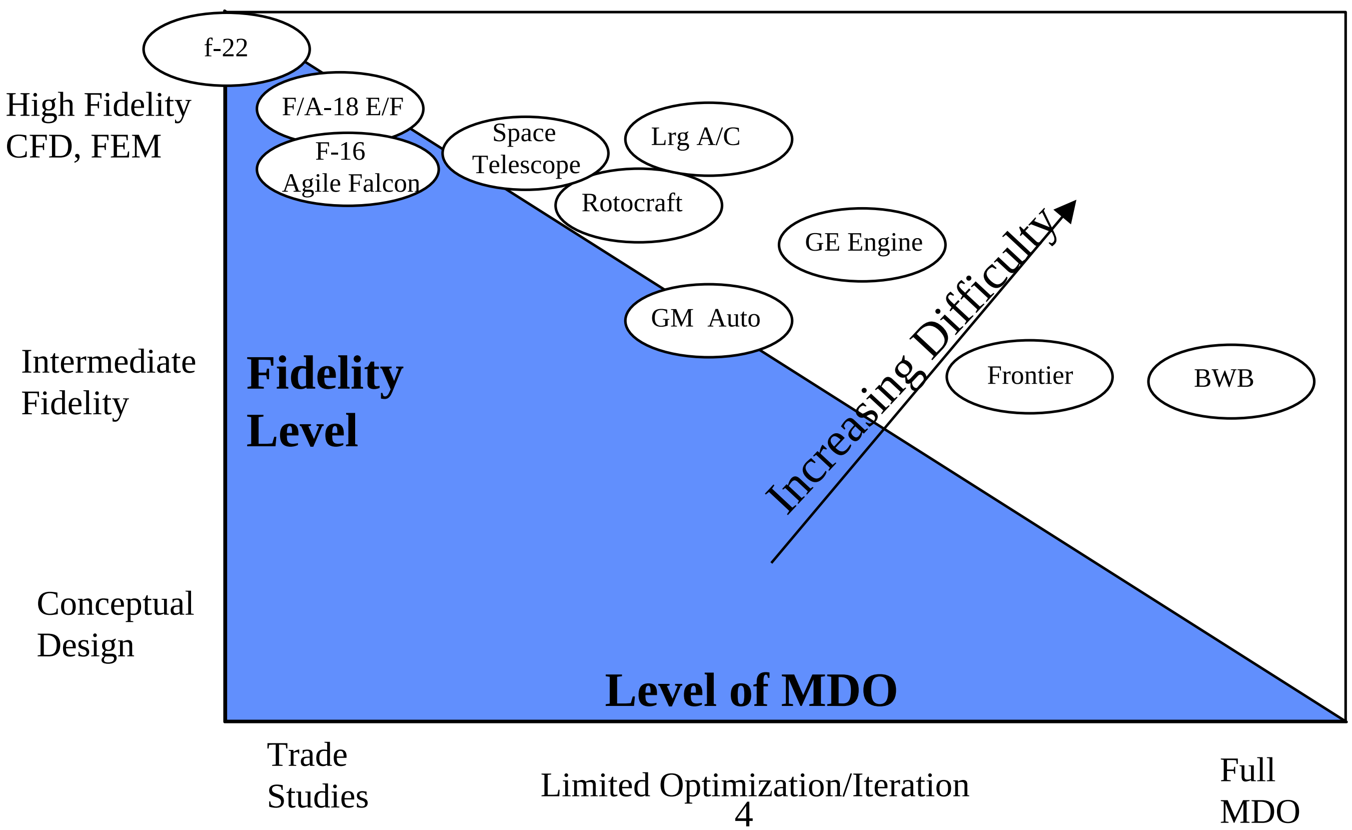
- **Introduction**
- **10 Invited Papers Synopsis Process**
- **Development of MDO Categories (Taxonomy)**
  - **-Process of Extracting Salient Points from Invited Papers**
- **Discussion of Categories**
  - **- Challenges and Issues**
  - **- Needs (in Industry)**
- **Conclusions**
  - **- Satisfying MDO Development Needs**
  - **- Concluding Remarks**

INTRODUCTION

- **Last AIAA MDO Technical Committee White Paper 1991**
  - Technology Push, Providing Benefits of MDO
- **Current White Paper Meant to be a Technology Pull from Industry**
  - Industry Needs in the Area of MDO
  - Provide MDO Developers Help in Planning and Direction
- **White Paper Process**
  - 10 Invited Papers From Industry
  - Plus a Summary Paper
  - Summary Paper to be Reviewed by MDO TC and Invited Authors
  - 10 Papers Plus Summary Will be Put on MDO TC Web Site

SYNOPSIS OF 10 INVITED PAPERS

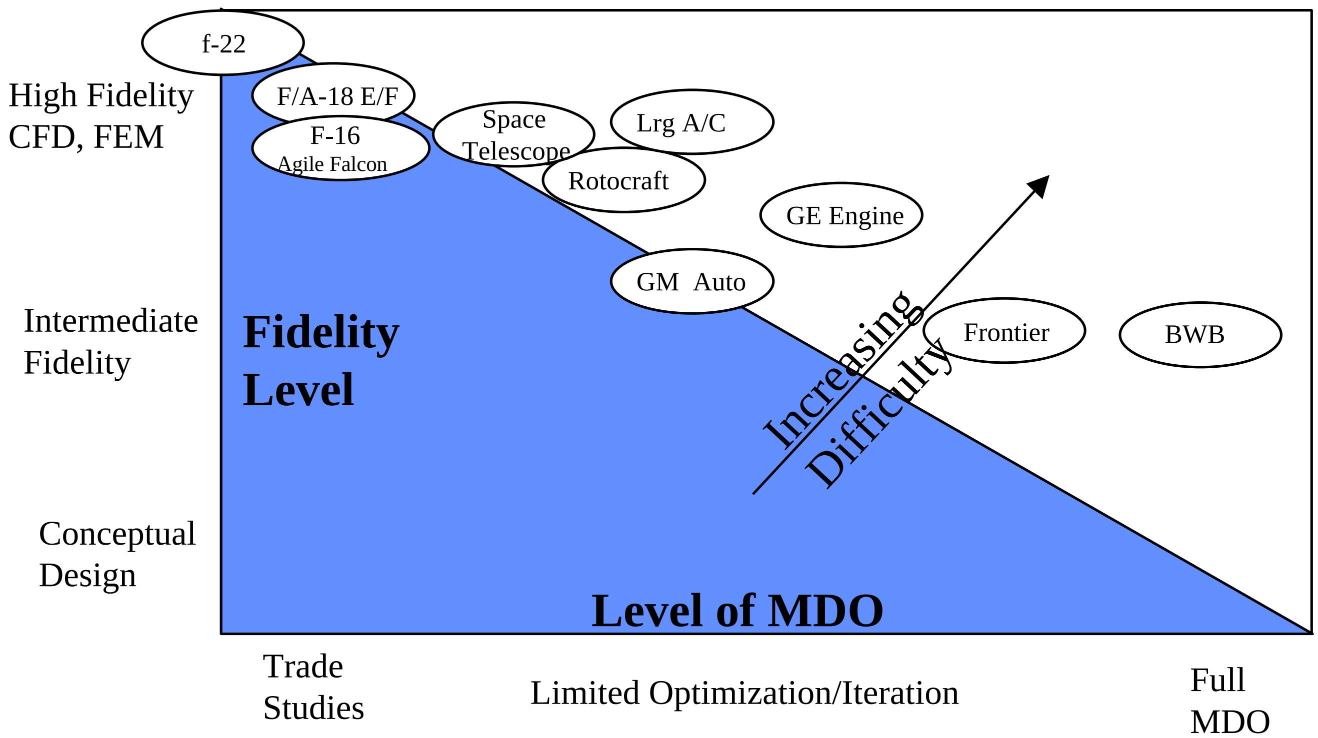
- **Summary Paper Presents Short Synopsis of Each Invited Paper**
  - Basic Design Problem Summarized
  - Several Highlights of the Main Points



High Fidelity
CFD, FEM

Intermediate
Fidelity

Conceptual
Design



DEVELOPMENT OF CATEGORIES

Questions Asked by an Industrial Designer

1) What are my design objectives and critical constraints
2) What are my disciplinary analysis capabilities/limitations/Automation level
3) How do I get critical high fidelity elements into my design in an efficient manner?
4) What design process steps are needed to meet my design objective most efficiently and to know that I have reached my objectives and satisfied my constraints?
5) What MDO or design formulation do I need or what formulations are available to me?
6) What kind of approximation analyses are required?
7) How do I overcome Optimization problems (scaling, smoothness, robustness, effic.)?
8) How do I feed data among disciplinary analyses and the MDO process?
9) How do I overcome computing and data handling issues
10) What is the easiest way to visualize my design space?
11) How robust is my design and how do I check it?
12) Are there commercial systems that can effectively help me?
13) How do I make it all happen at my plant?

FINAL CATEGORIES (MDO TAXONOMY)

MDO Elements

Design Formulations &Solutions

- Design Problem Objectives
- Design Problem Decomposition,Organization
- Optimization Procedures and Issues

Information Management & Processing

- MDO Framework and Architecture
- Data Bases and Data Flow & Standards
- Computing Requirements
- Design Space Visualization

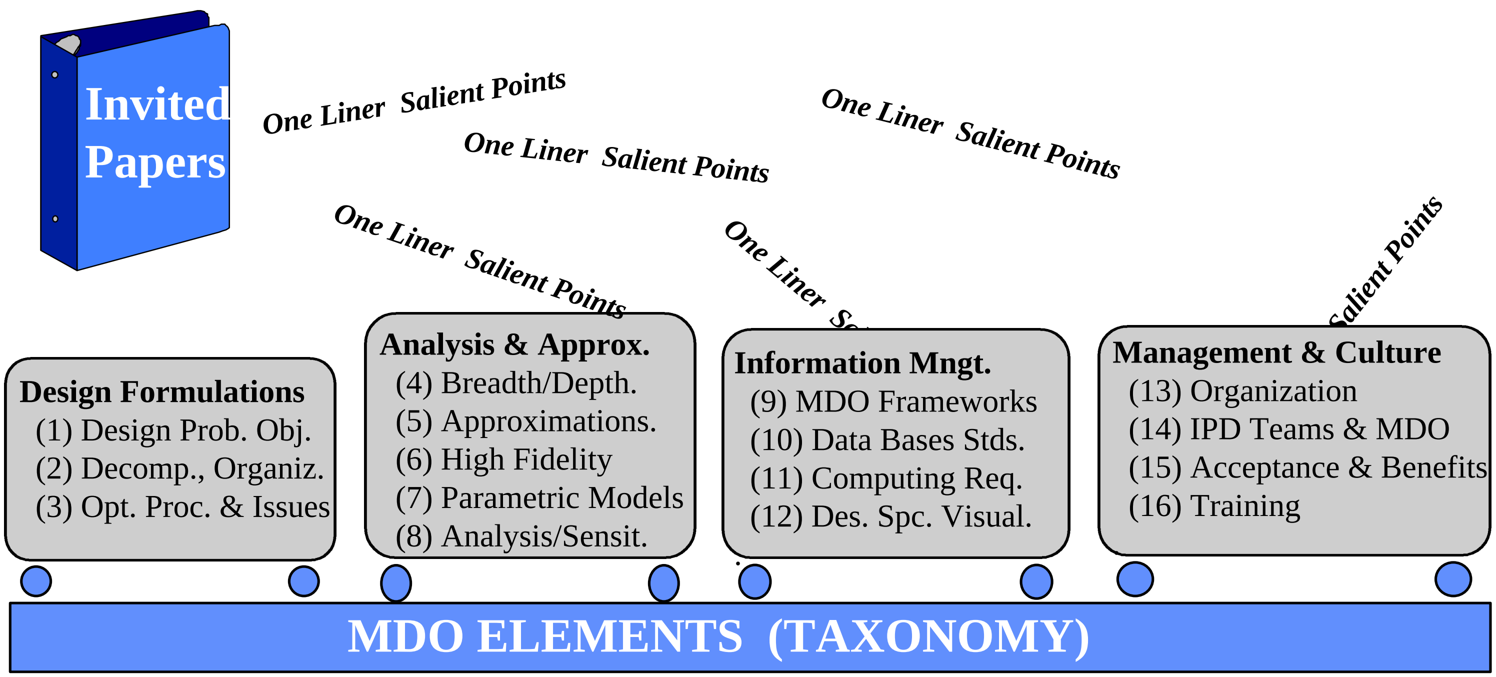
Analysis Capabilities & Approximations

- Breadth vs.. Depth Requirements
- Effective Incl. of High Fidelity Analyses/Test
- Approximation & Correction Processes
- Parametric Geometric Modeling
- Analysis and Sensitivity Capability

Management & Cultural Implementation

- Organizational Structure
- MDO Operation in IPD Teams
- Acceptance, Validation,Cost &, Benefits
- Training

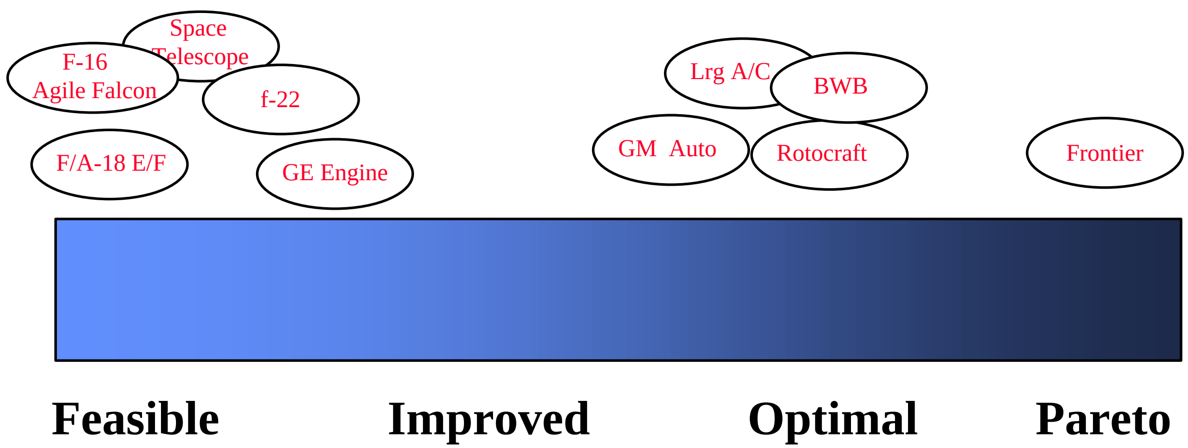
PROCESS OF EXTRACTING SALIENT POINTS FROM INVITED PAPERS AND PLACING THEM INTO THE MDO ELEMENT CATEGORIES



DISCUSSION OF CATEGORIES

(1) Design Problem Statement

Distribution of Design Problems for 10 Papers



- **Industry Design Objective Priority Order**
  - Feasible and Viable Design
  - Robust Design
  - Improved Design
  - Optimal Design

(1) Design Problem Statement

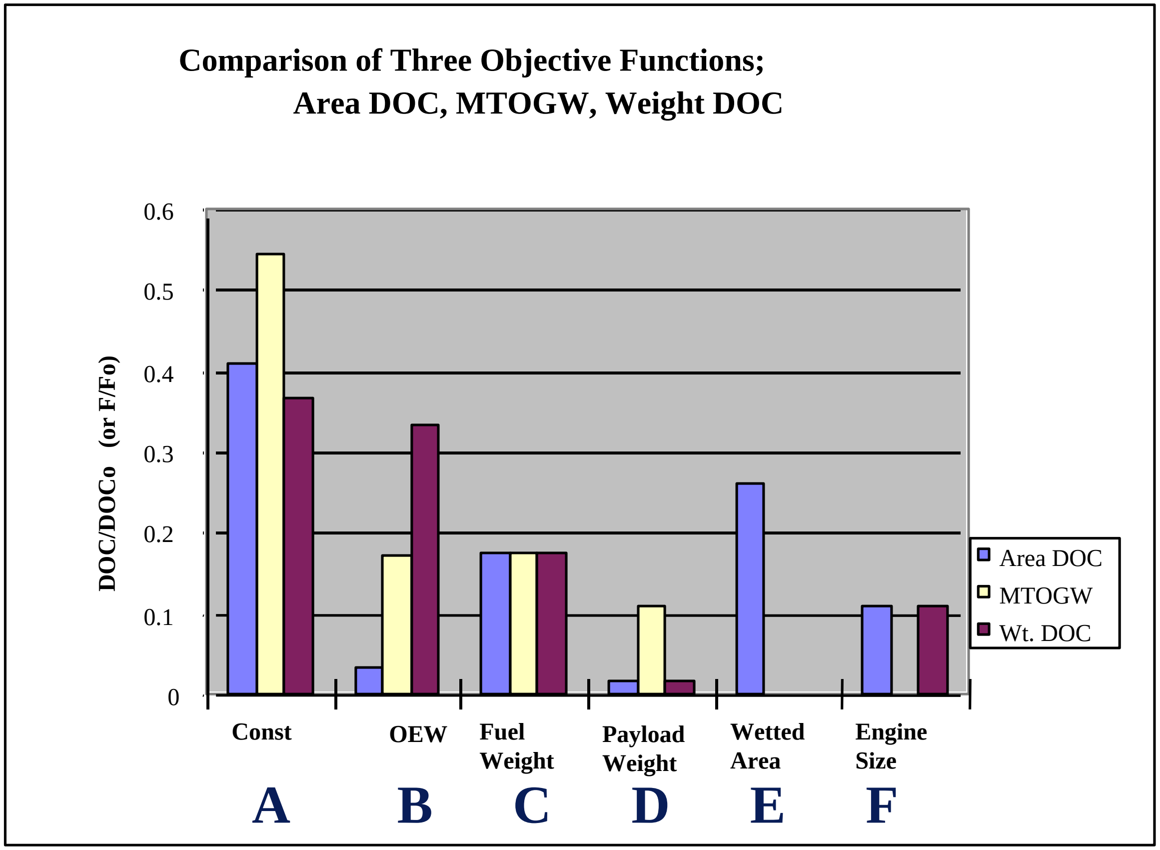
Challenges and Issues

- Each Design Problem Unique
- Design Problem May Not be Known A-Priori

Needs

- Flexible Framework
  - Reconfigurable to Multiple User Needs
- Continued Development of Objective Functions for Industrial Applications

SIMPLIFIED COST RELATED OBJECTIVE FUNCTION FOR MDO



DOC/DOCo **=A** +**B** **OEWA**/OEWAo + **C** **FWT**/FWTo + **D** **PLWT**/PLWTo+ **E** **Swt**/Swto +**F** **T/**To

(2) Design Problem Decomposition and Organization

Challenges and Issues

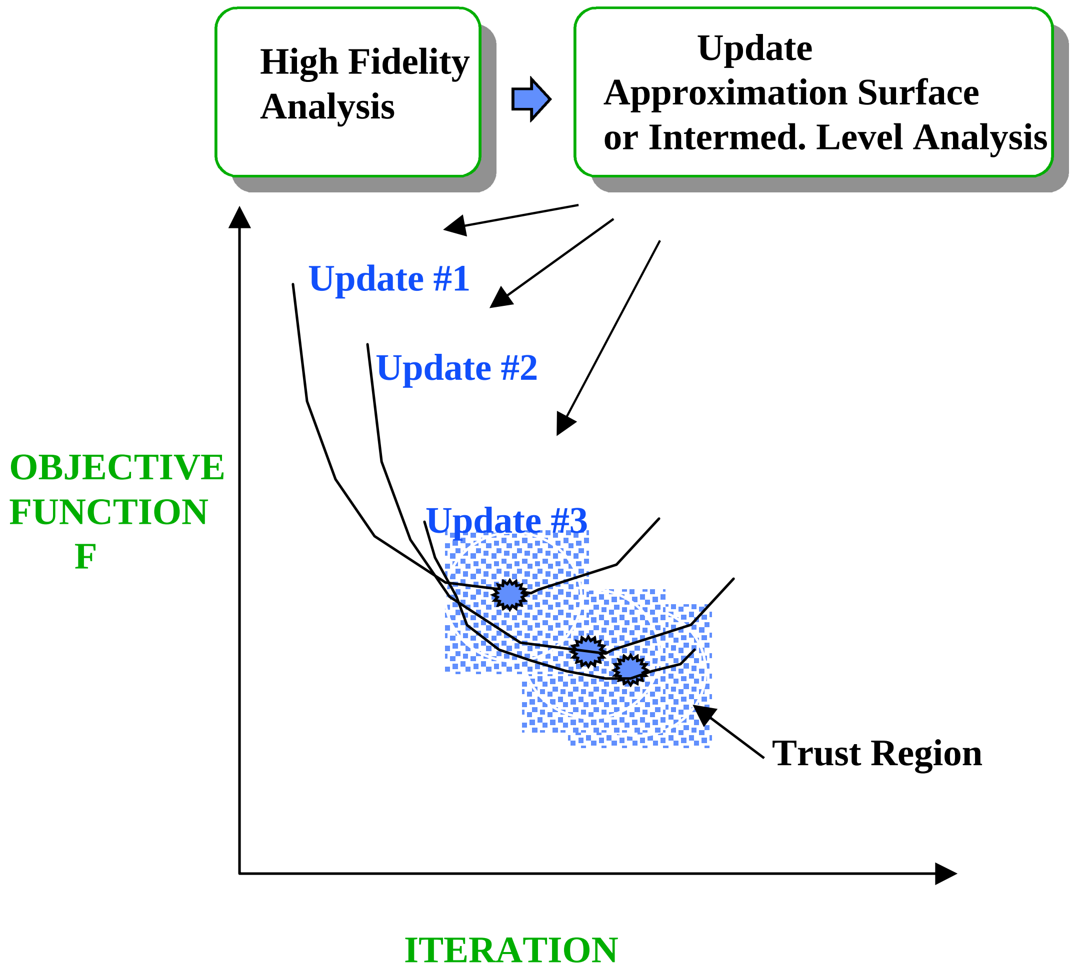
- Sophisticated Decomposition Processes (e.g.. CO , CSSO)
  - Not Fully Mature
  - Not Fully Understood by Industry
- High Fidelity Analysis Processes Difficult or Impossible to Include in MDO
  - Non Automated & Very Long Computing Time

Needs

- Loosely Coupled Systems
  - Include Legacy Codes
  - Global-Local (Multi-Level) Decomposition
  - Easy to Understand Processes
- Decomposition Processes that Converge to High Fidelity Results Without High Fidelity Analyses being Called Directly by Optimizer
  - Update Processes
  - Approximation Processes
  - Other
- Decomposition Processes Tailored & Adapted to Needs and Deficiencies of Analysis Processes

(2) Design Problem Decomposition and Organization

Notional Update Process



(3) Optimization Procedures and Issues

Challenges and Issues

- Lack of Experience in Optimization in Industry
- Optimization Robustness
  - Smoothness Requirements
  - Scaling, Convergence Issues
- Efficiency
- Continuous, Discrete & Hybrid Optimization
- Local Minima

Needs

- Self-Smoothing or Noise Insensitive Opt. Processes
- Self-Scaling Opt. Processes
- Robust Processes for Finding Global Minimum
- Rapid/Efficient Optimization Processes

(4) Breadth and Depth Requirements

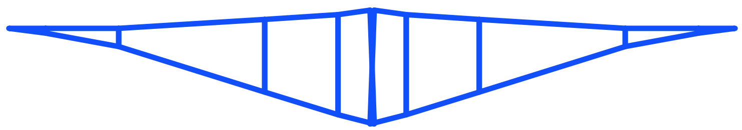
Challenges and Issues

- Identify and Include All Critical Constraints to Avoid Academic Design
- Identify and Include All Critical Physical Mechanisms
  to take Advantage of Available Design Opportunities
- Fidelity Requirements for Each Discipline not Known/Quantified

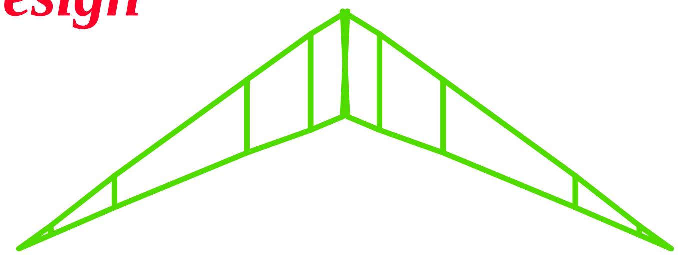
Needs

- Process for IPD Team to Identify All Critical Aspects
  of Design as it Progresses
- Process for Identifying the Fidelity Requirements of Various Disciplines
  - Possible Use of MDO Process Itself (Sensitivities) to Est. Req.
- Process for Identifying Critical Physical Mechanisms

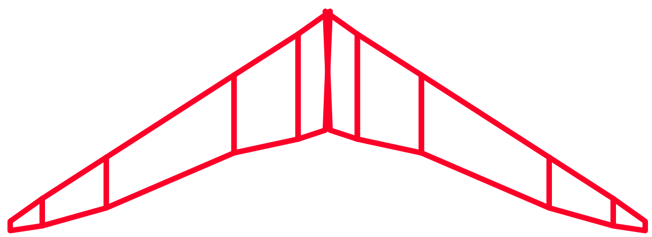
Effect of Objectives and Constraints on Optimal Design



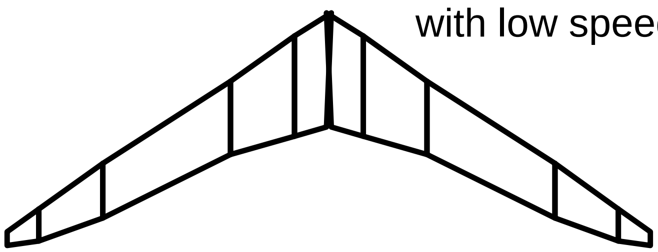
A Minimum induced drag at fixed weight.



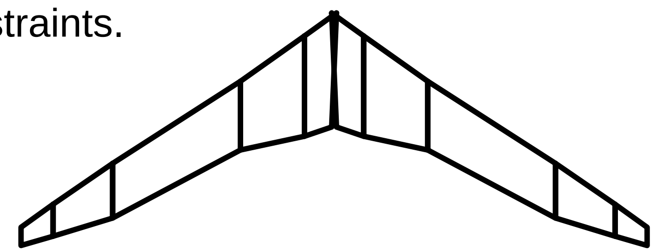
B Minimum total drag at fixed weight.



C Minimum total drag at fixed weight with low speed lift constraints.



D Minimum total drag, fixed weight, low speed lift constraints, and fuel inertia relief.



E Minimum total drag, fixed weight, low speed lift constraints, fuel inertia relief, and static aeroelasticity.

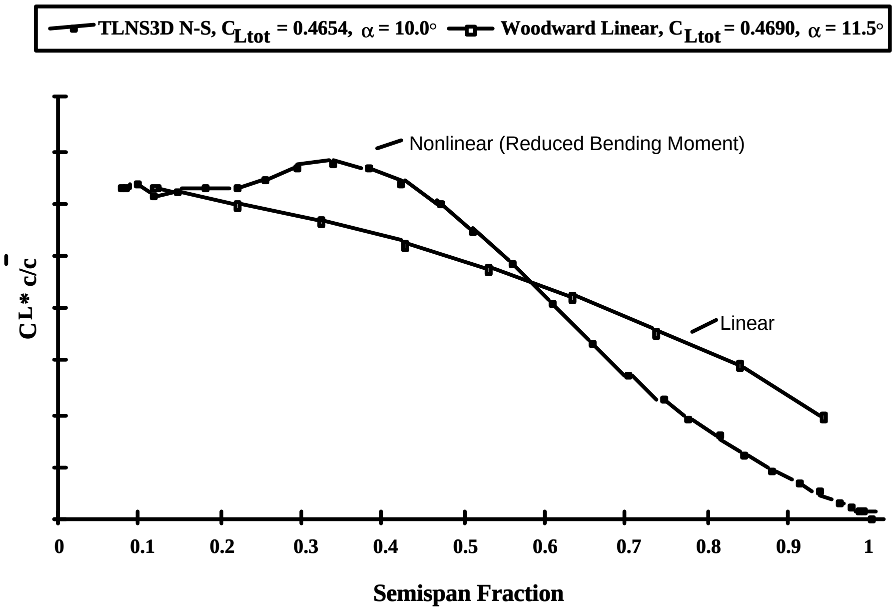
(5) Effective Inclusion of High Fidelity Analyses/Test

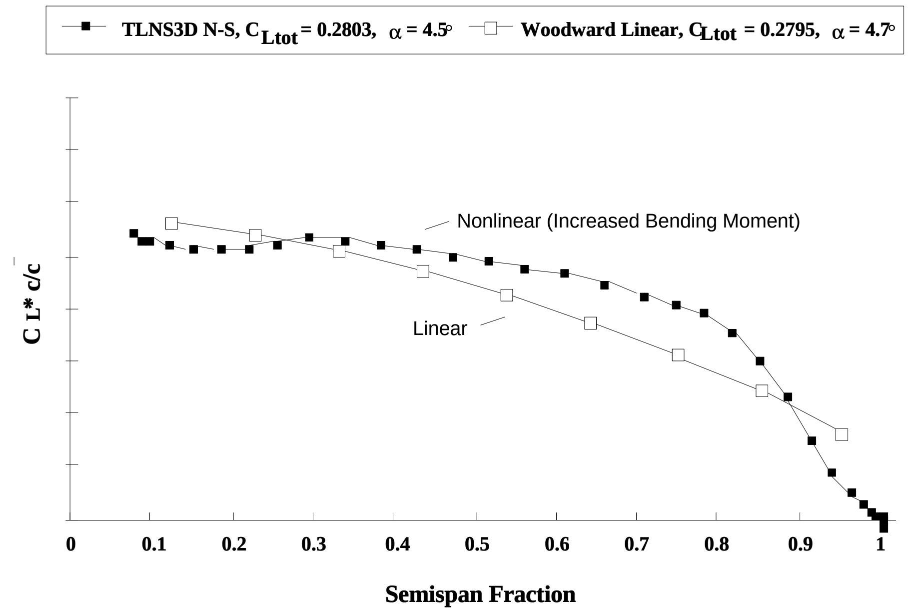
Challenges and Issues

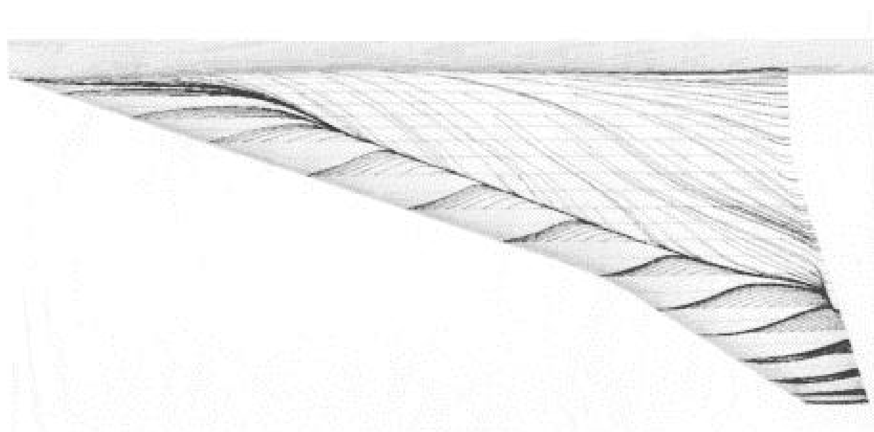
- High Fidelity Process Deficient in
  - Automation (Many Manual Steps)
  - Robustness (Model has to be Iterated and Re-worked)
  - Efficiency (Requires Many Hours on the Computer)

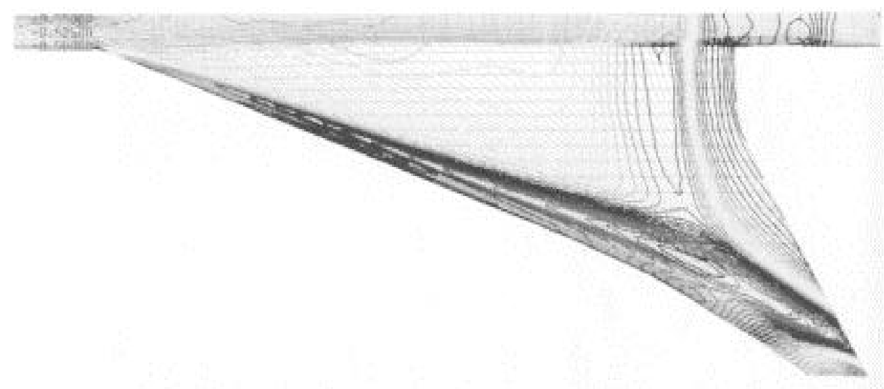
Needs

- Advances in Disciplinary State-of-Art
  - Robustness
  - Efficiency
- Advances in Disciplinary Automation and Parametric Modeling
- Advances in Decomposition or Approximations to Make Up for Deficiencies in High Fidelity Analyses


TLNS3D N-S, C_{Ltot} = 0.4654, α = 10.0°
Woodward Linear, C_{Ltot} = 0.4690, α = 11.5°
Nonlinear (Reduced Bending Moment)
Linear
$C_L * c/\bar{c}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Semispan Fraction


TLNS3D N-S, C_{Ltot} = 0.2803, α = 4.5°
Woodward Linear, C_{Ltot} = 0.2795, α = 4.7°
Nonlinear (Increased Bending Moment)
Linear
$C_L * c/\bar{c}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Semispan Fraction





(6) Approximation and Correction Processes

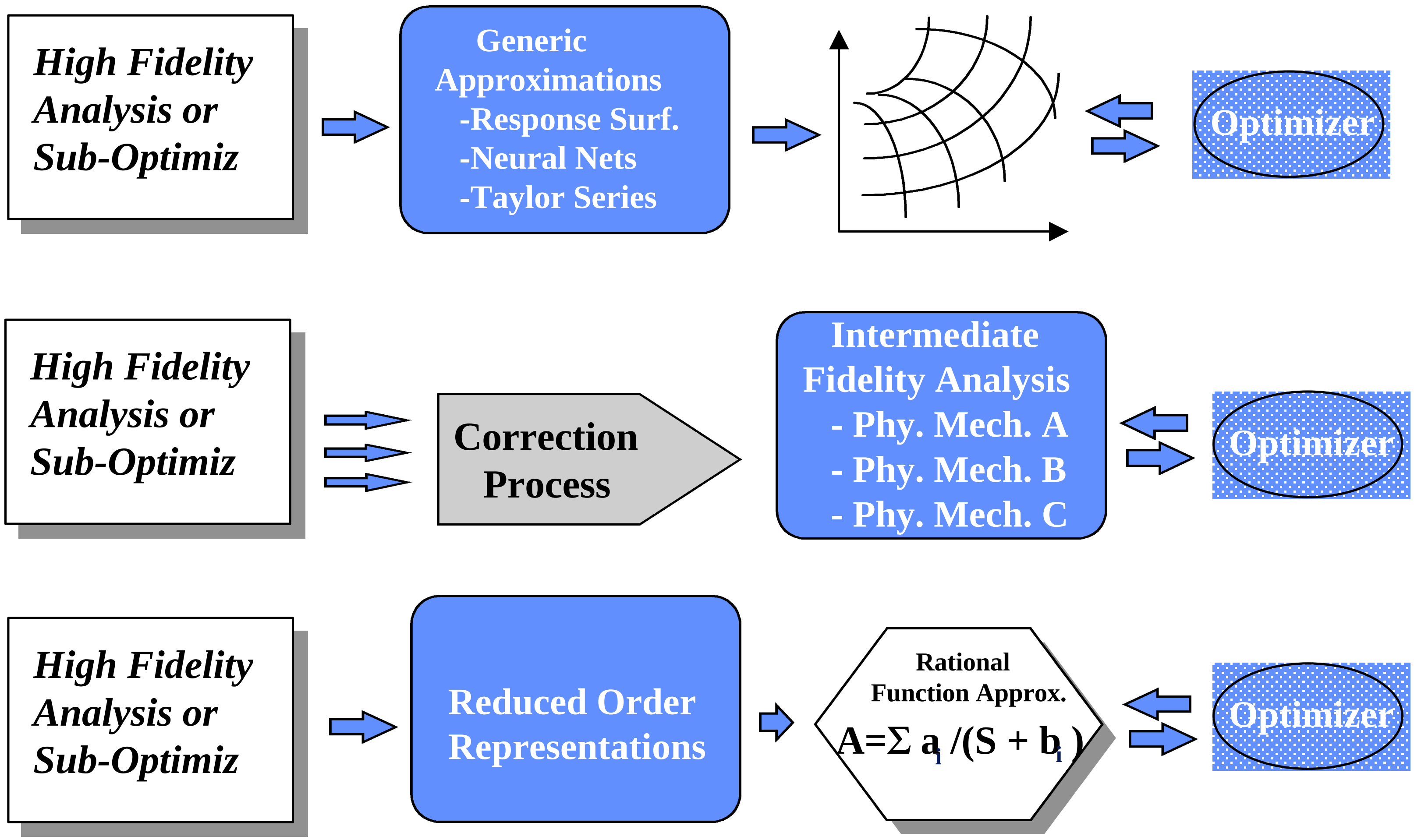
Challenges and Issues

- Generating Data for Response Surfaces (Curse of Dimensionality)
- Isolating Physical Mechanisms
- Intermediate Level Analyses Not Simulating All Critical Physical Mechanisms

Needs

- Response Surface and Other Generic Approximation Software
- Addition of Missing Critical Mechanisms in Intermediate Level Analyses
- Advanced Correction Procedures for Intermediate Level Analyses
    - Separate Correction of Each Physical Mechanism
    - Using Intermediate Analyses as Interpolation/Extrapolation Process
- Reduced Order Approximations for Use in Optimization
    - Parameter Identification

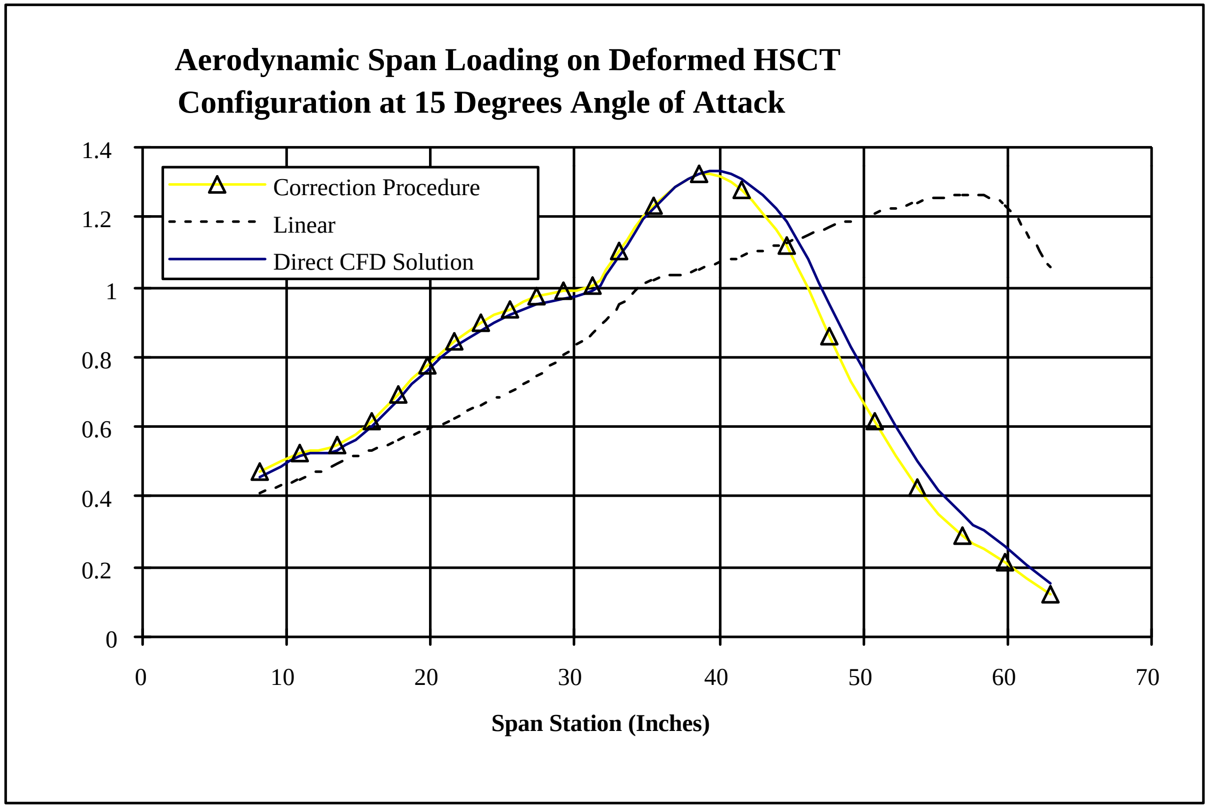
(6) Approximation and Correction Processes



(6) Approximation and Correction Processes

Correction Process

Subsonic, High α Case (M=0.5, AOA=15^o)
Sectional Lift Distribution



(7) Parametric Geometric Modeling

Challenges and Issues

- Large Common Models Expensive
- Existing CAD Software Not Robust Enough for Topology Optimization
- Morphing (Rubberizing) Does Not Always Produce Adequate Layout

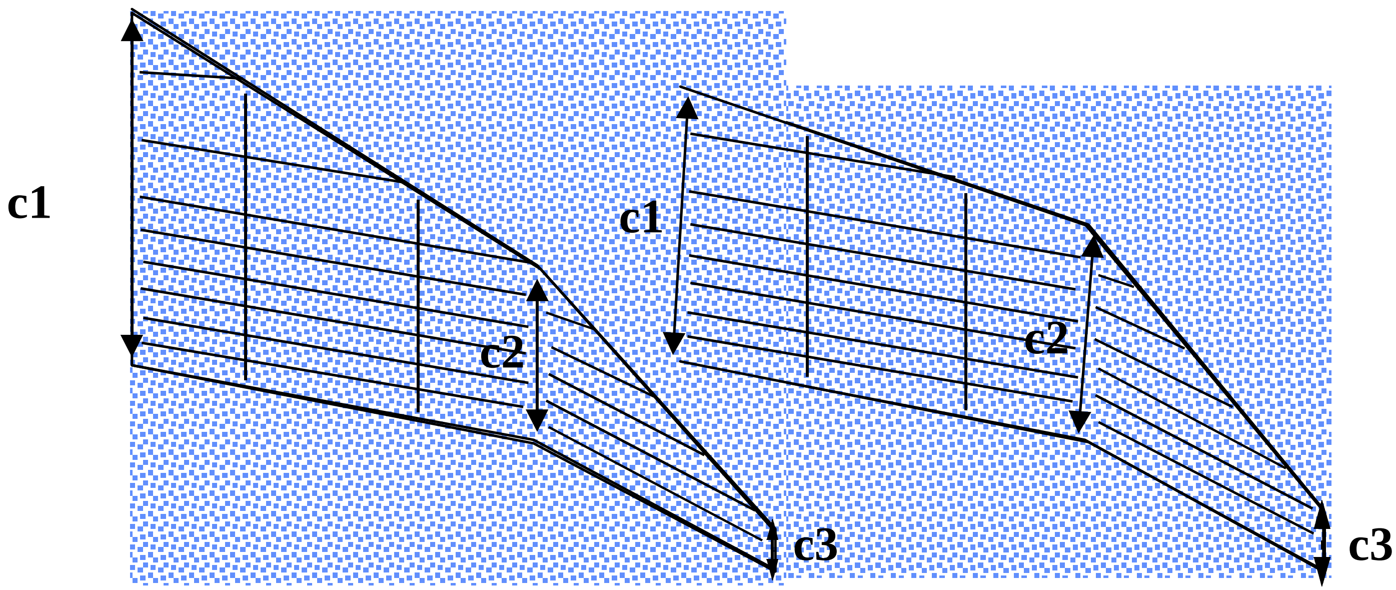
Needs

- Automatic Modeling Tool Kit (e.g.. CFD Meshes, Finite Element Models)
- Parametric Layout Techniques for Changing Topology
- Grid-Mesh Mapping (e.g.. aerodynamic forces on structural nodes and surface deflection of FEM on CFD mesh)
- Software for Robust Processes (Commercial or Otherwise)

(7) Parametric Geometric Modeling

Parametric Model with Topological Changes

Can Not be Rubberized



(8) Analysis and Sensitivity Capability

Challenges and Issues

- Lack of Automation of High Fidelity Codes and Sub-Optimization Processes
- Lack of Cost Models for Use in MDO
- Checking of Analysis Model and Data At Each Step
- Large Computer Run Times for High Fidelity Codes

Needs

- Robust Automated Disciplinary Analyses Modules (Preferably Commercial)
  - CFD, FEM, Nonlinear Loads, Aeroservoelastic
  - Global/Local Structural Sizing
  - Efficient Aerodynamic Optimization
  - Other
- Interactive Analysis Data Monitoring and Checking Tools
- Simplified and Detailed Manufacturing and Maintenance Cost and Constraint Models

(9) MDO Frameworks and Architecture

Challenges and Issues

- Commercial OTS MDO Frameworks are Not Yet Industrial Strength
  - Problem and Model Size Limited
  - Distributed Computing Not Robust

Needs

- Commercial MDO Framework that is:
  - Mature, Robust, Efficient, and Industrial Strength
  - Flexible and User Friendly
  - Able to Include Legacy Codes

(10) Data Bases, Data Flow and Standards

Challenges and Issues

- No Universal Standard for Data
- Hugh Amounts of Data are Used in Industrial Design
- Multiple Platforms and Locations Need to Interact with Design Data

Needs

- Standardized, Industrial Strength Data Base
  - Handle Large Amounts of Data (terabites)
  - Multisite and Heterogeneous Accessible (Internet?)
  - Efficient and User Friendly

(11) Computing Requirements

Challenges and Issues

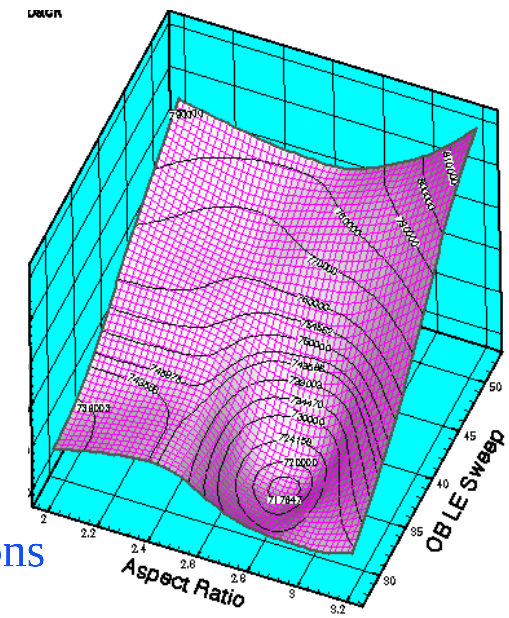
- High Fidelity Analyses Require Massive Computing Power
  - CFD Single Analysis 10 hrs on C-90 Type Super Computer
  - CFD Design (20 design variables) 300 hrs C-90
  - Solution 200 (structural sizing optimization) 50 hours for 9 Iterations on a High End Work Station
  - F-22 Used 10 Terabites of Storage for Structural Design

Needs

- Improved Networking Systems for Work Stations and Other Computers
- New Methods that Work Efficiently on Massively Parallized Computers (e.g. CFD, Structural Sizing Optimization)
- Generic Algorithms Designed Especially for Massively Parallized Computers (e.g. Matrix Manipulation, Eiganvalue Analysis)

(12) Design Space Visualization

Challenges and Issues



- Can Not Physically Visualize More than 3-Dimensions
- Designers May Be More Interested in Seeing the Design Space Than Finding the Optimum Design Point
  - e.g. How Flat is Design Space?
- IPD Team Needs to Understand the Design Space to Make Design Decisions

Needs

- Creative Design Space "Depiction" Techniques Needed
  - Visualize Multi-Dimensional Design Space Directly
  - Generate a New Breed of Data that Will Impart the Needed Design Space Information Without Direct Multi-Dimensional Representations
    - *Reduced Dimensions (Modal or Related Approach)

(13) Organizational Structure

Challenges and Issues

- Who is In Charge of MDO?
- Currently Advanced Design Group Responsible for Own Technology
  - Small Interaction with Discipline Groups
- Each Discipline Responsible for Methods and Data Integrity/Quality
  - How Do These Groups Interact with MDO?
  - How Do Disciplines "Buy In" to the MDO Process & Results?
- MDO Solutions Tend to Compromise Performance of Each Discipline for the Benefit of the Whole System

Needs

- Industry Needs an MDO Team
  - One Part of Team Provides Coordination (Advanced Design?)
  - Each Discipline Maintains Technical Autonomy
  - Each Discipline Is Part of and "Buy's In" to the Process
  - Each Discipline Maintains Responsibility for Integrity and Quality of Data and Technology
  - All Disciplines and MDO Coordination Agree on Interfaces

(14) MDO Operation in IPD Teams

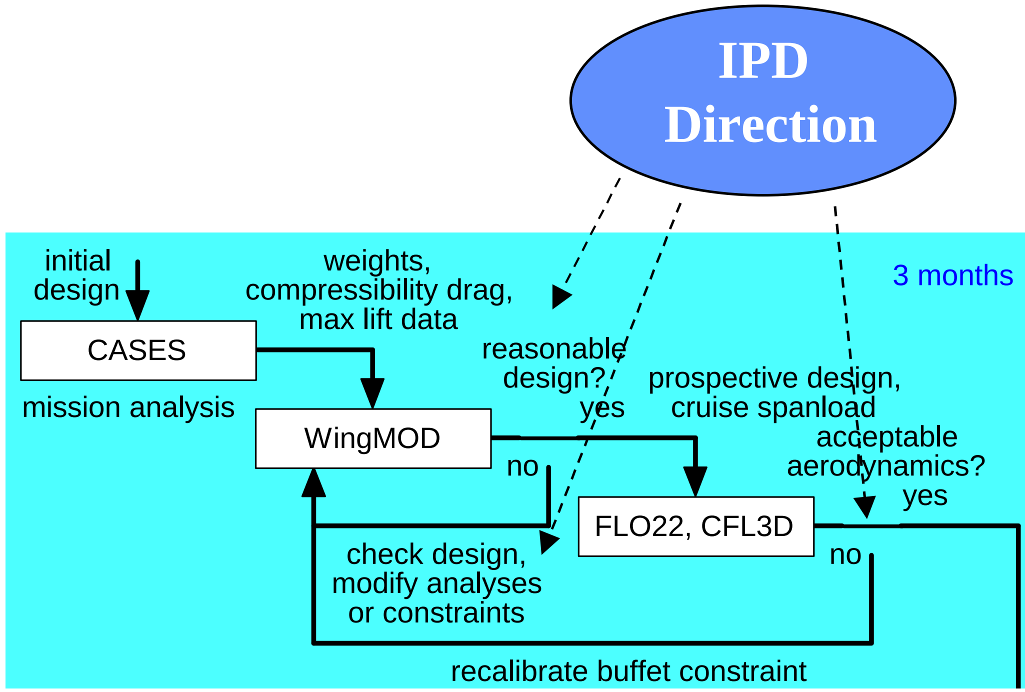
Challenges and Issues

- Not All Design Issues are Incorporated into MDO
- IPD Team Unfamiliar with MDO Tool and How to Interact with It
- Defining MDO Problem is Evolutionary as Design Progresses

Needs

- Understanding the MDO Process and Accepting It As a Tool
- Experience and Training of IPD Teams
  - Interaction and Direction of MDO Process
  - Setting and Changing Constraints and Groundrules for MDO Process
  - Interpreting Results

(14) MDO Operation in IPD Teams



IPD Team Members
- Structures
- Aerodynamics
- Manufacturing
- Stability and Control

(15) Acceptance, Cost and Benefits and (16)Training

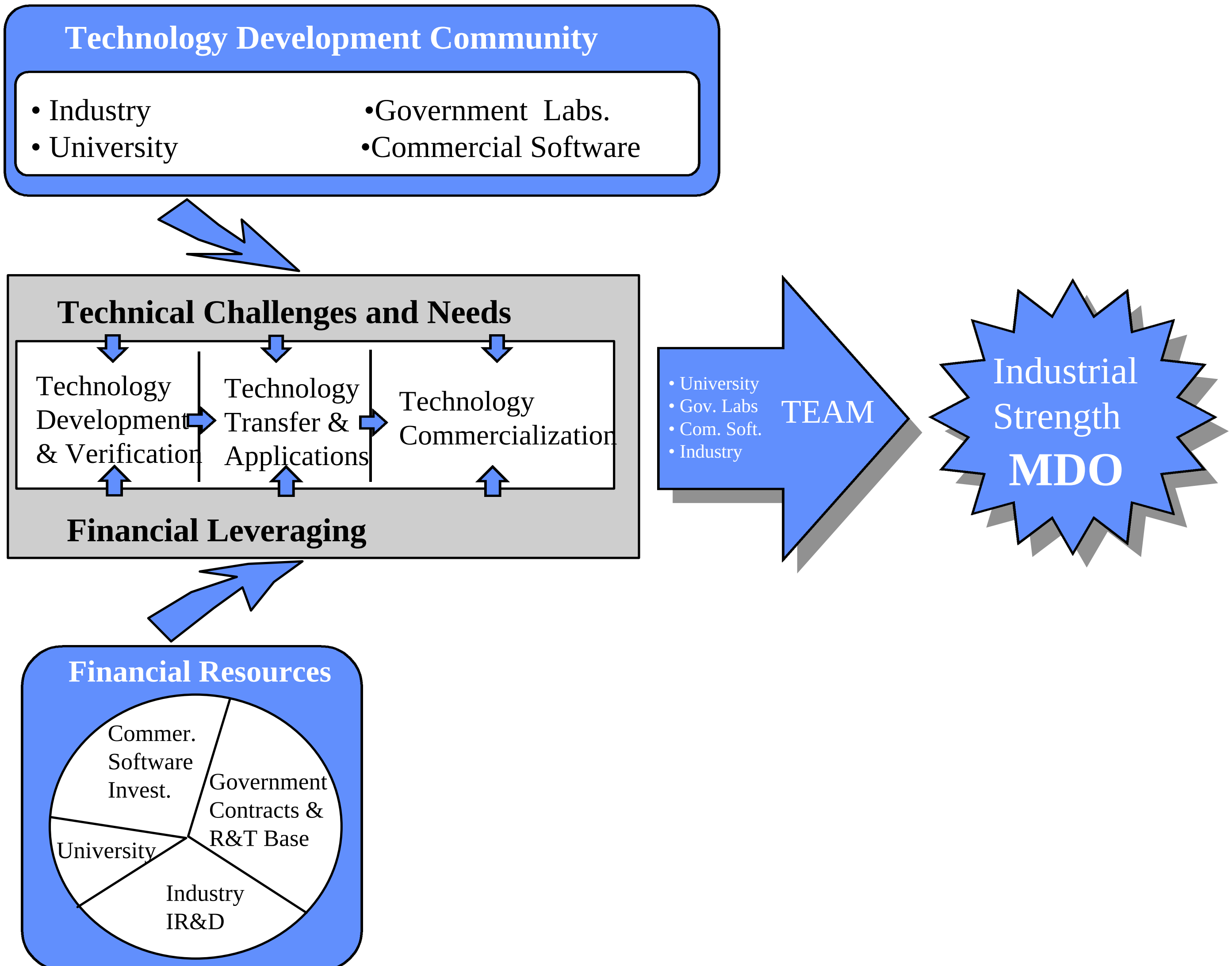
Challenges and Issues

- Lack of Understanding of MDO and Its Place in Industry Environment
- Lack of Training and Education in MDO Techniques
- Cost of Developing a New MDO System
- Lack of Documented Practical Benefits
- Fear of Loosing Tried and True Processes

Needs

- Series of Full Industrial Validation Test Cases
  - Benefit Over Current Practices
  - Industrial Strength Validation Cases, Preferably on Actual Vehicle
- MDO Process Plan and Cost

SATISFYING MDO DEVELOPMENT NEEDS



CONCLUSIONS

- **Broad Cross-Section of MDO Applications and Experience in Industry Represented**
- **Wide Range of Design Objectives Encountered**
- **Modified Taxonomy of MDO Elements Suggested**
- **Practical MDO Challenges and Issues Delineated**
- **Industry MDO Development Needs Presented**
- **Teaming of University, Government Labs, Commercial Software Developers, and Industry Suggested**
    - Produce Industrial Strength MDO Processes for the Future