Process-Based Manufacturing and Assembly Cost (PBMAC) Models

(ASCAC Methods Development Peer Review)

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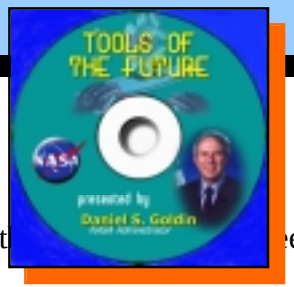
ISE Program (2000-2001)
(Intelligent Synthesis Environment)

Vision

To effect a cultural change that integrates into practice widely-distributed science, technology and engineering teams to rapidly create innovative, affordable products

Long-Term Goal

To develop the capability for personnel at dispersed geographic locations to work together in a virtual environment, using computer simulations to model the complete life-cycle of a product/mission with near real-time response time before commitments are made to produce physical products



Motivation: Accurate Cost Estimation for Advanced Concepts

Excerpts from1996 MDOB Peer Review report

- *"The ability to correctly account for cost in MDO studies is imperative."*
- *"Traditional weight-based parametric methods using historical data are inadequate."*
- *"Process and function based cost estimating would be clearly be superior."*

Verbatim quote from the 1994 MDORRC Industry Tour

- *"High-Payoff MDO Problems: Cost models which give realistic estimates of the effects of design and process changes."*

Issues

- Cost models are company proprietary data
- Reliable cost data are difficult to acquire
- Cost models are unique to individual companies
- Cost model for advanced aerospace concepts cannot be based on the traditional cost models for conventional aerospace vehicles

Aerospace Vehicle Cost Concepts

- Lumped cost models (e.g., weight-based)
- Detailed cost models (e.g., PBMAC)
- Extrapolation of PBMAC to new advanced vehicle design

Traditional Weight-Based Approach

- Airplane Design by Jan Roskam (1990)

$$Cost = (aW_{ampr}^{b})(cV_{\max}^{c})\mathrm{L}$$

- Space Transportation: A Systems Approach to Analysis and Design by W. Hammond (1999)

$$Cost = (k_{complexity} aW^{b})\mathrm{L}$$

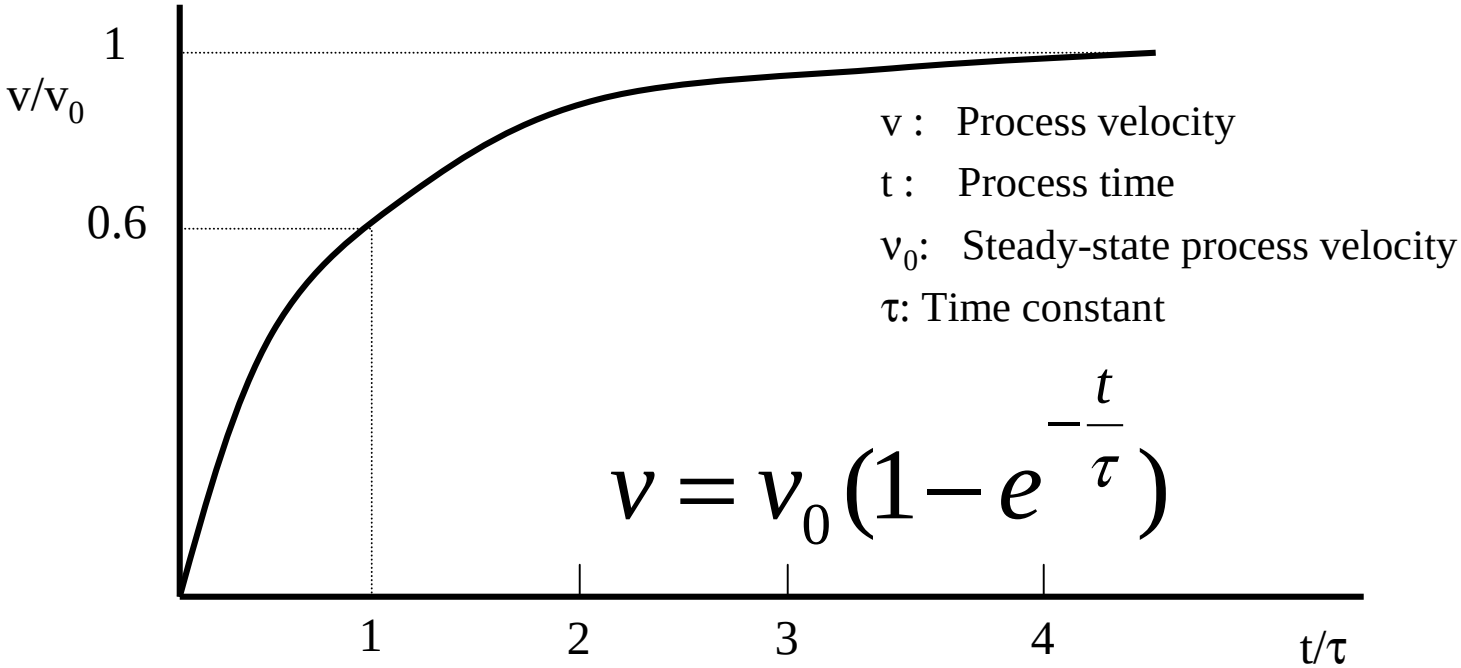
Detailed Cost Models

- Are based on critical design information such as ribs, spars, skin, …
- Account for
  - Manufacturing
    - Process
    - Materials
  - Assembly

First Order Velocity Model

- **Background**:
  - NASA/Boeing Advanced Technology Composite Aircraft Structures (ATCAS) Initiative (Contract NAS1-18889)
  - MIT's Center of Excellence in Manufacturing and Design of Composite Structures (Professor Timothy G. Gutowski)
  - Ph.D. Thesis :"Adaptive Framework for Estimating Fabrication Time", E.T. Neoh, MIT 1995
- **Basic Premises**:
  - Vital Few and Trivial Many
  - Manufacturing operations can be represented as dynamic systems with first order velocity response to a step input.

First Order Velocity Response



v : Process velocity

t : Process time

ν_0: Steady-state process velocity

τ: Time constant

$$v = v_0 (1 - e^{-\frac{t}{\tau}})$$

- Advantages of above formulation of process velocity:
  - Amenable to physical modeling
  - ν_0 and τ have meaningful physical interpretation

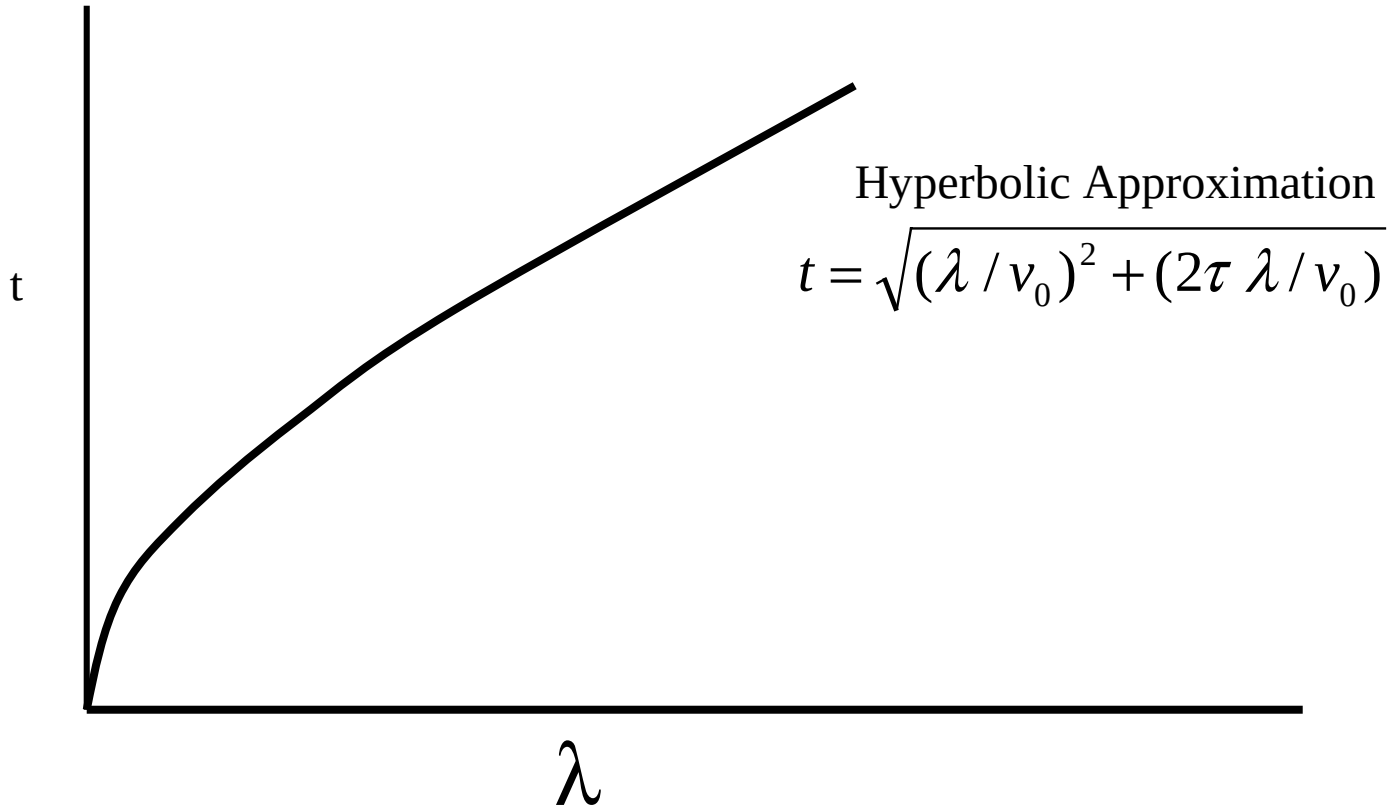
First Order Model

- Estimation of process time for commercial airframe structures:

Material	Item	V_0	τ, min	Design feature
Aluminum	Skin Fabrication	3.024	3.1123E+04	Wetted area, in^2
	Rib Fabrication	2.059	4.1423E+04	Wetted area, in^2
	Spar Fabrication	2.462	3.6934E+04	Wetted area, in^2
	Wing Assembly	0.0395	2.1341E+04	Perimeter, in
Composite	Skin Fabrication	2.1447	4.3883E+04	Wetted area, in^2
	Rib Fabrication	0.8236	1.0356E+05	Wetted area, in^2
	Spar Fabrication	1.4485	6.2788E+04	Wetted area, in^2
	Wing Assembly	0.02826	2.9877E+04	Perimeter, in

First Order Model (Cont.)

$$\lambda = \int_{t'=0}^{t} v dt' = \int_{t'=0}^{t} v_0[t' - \tau \quad (1 - e^{-t'/\tau})]dt'$$



Major Findings Concerning First-Order Velocity Models

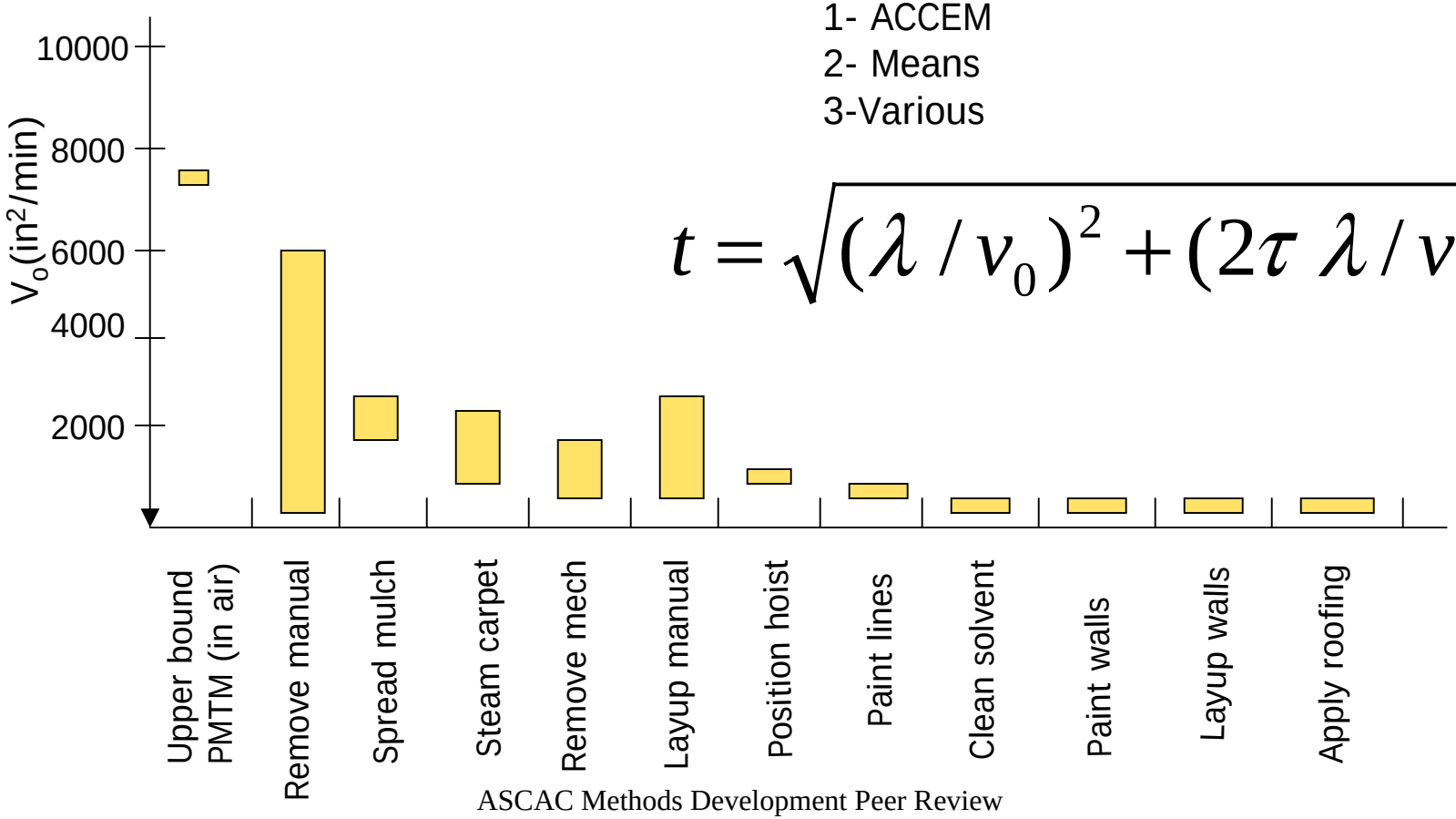
$$t = \sqrt{(\lambda / v_0)^2 + (2\tau \lambda / v_0)}$$

- Boeing Project (Reference: ATCAS Reports) clearly indicated that process time can be accurately related to a few critical parameters, e.g., wetted area for machining and perimeter for assembly, through ν_0.
- τ is indicative of current shop environment, i.e. setup time for productive work.
- "Vital few and trivial many" law applies, i.e. 20% of process steps governs 80% of total process time.

Master Chart for V_0 across Different Fields (Neoh 95)

- Area Velocities V_o

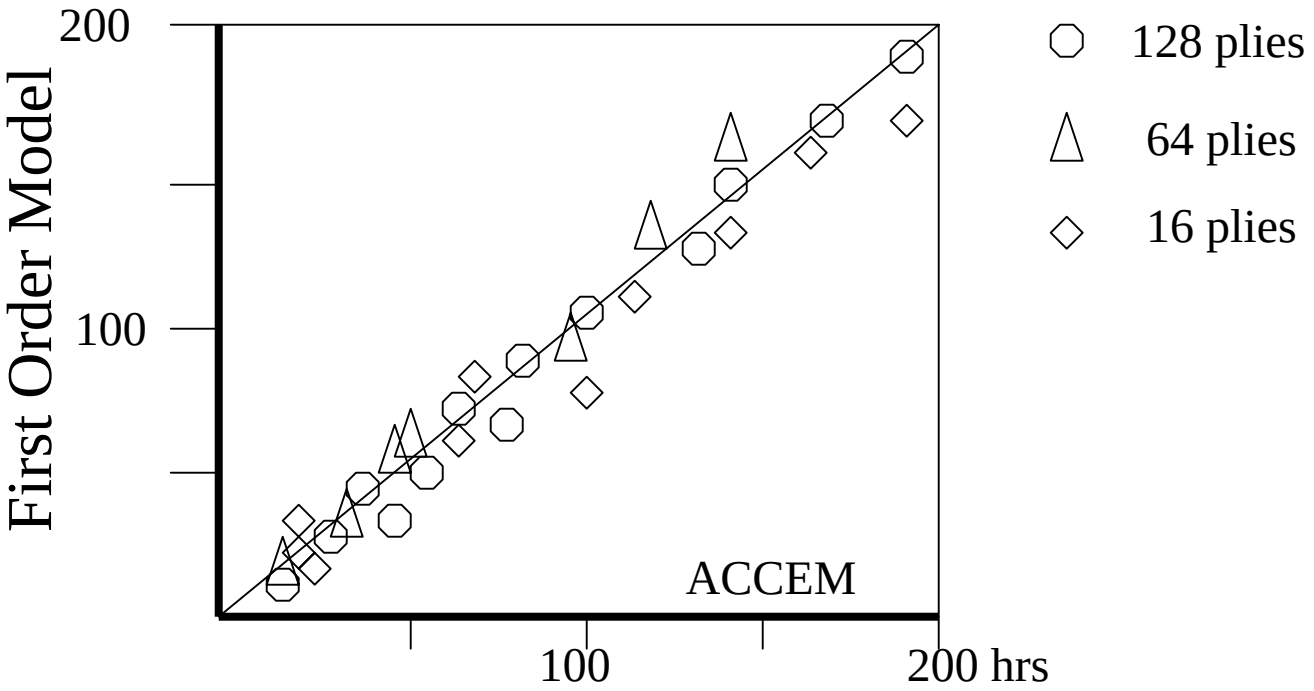
Sources:
1- ACCEM
2- Means
3-Various



$$t = \sqrt{(\lambda / v_0)^2 + (2\tau\, \lambda / v_0)}$$

First Order Model Validation

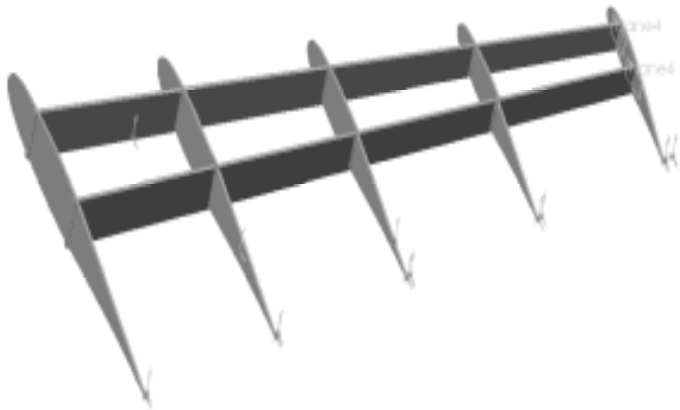
- Validation of Model (Neoh 95):



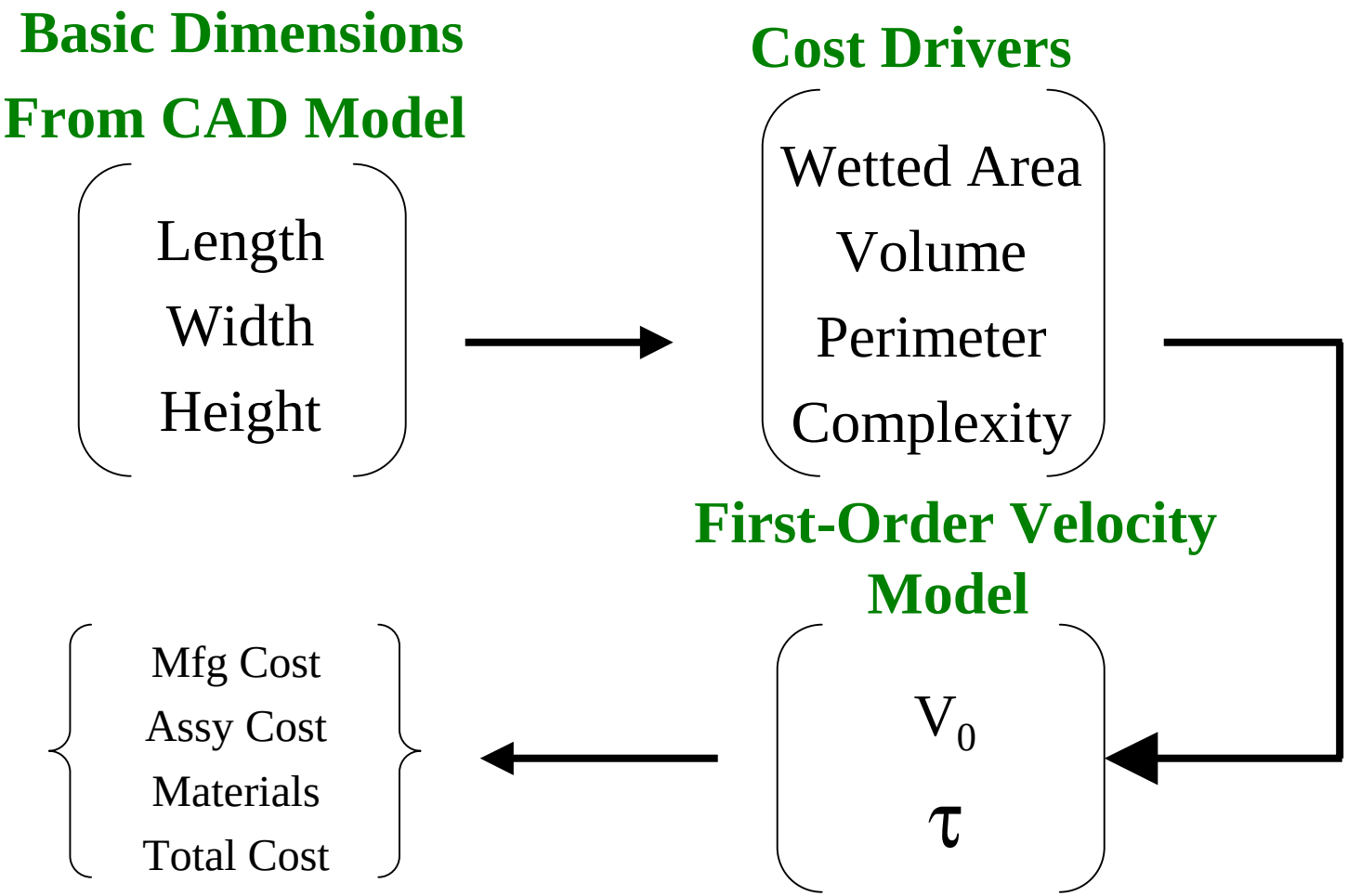
Comparison between First Order and ACCEM for Hand Layup

First Order Model for Generic Wing

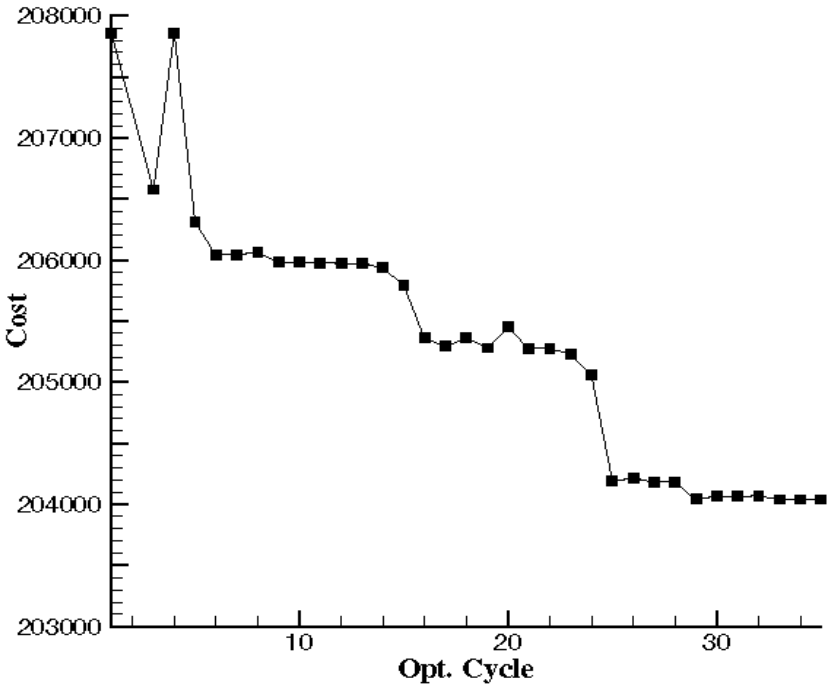
- Cost Estimation of Generic wing
  - Physical elements:
    - Front and Rear spars
    - Five ribs
    - Skins
  - Process Costs Include:
    - Fabrication of Spars
    - Fabrication of Ribs
    - Fabrication of Skins
    - Assembly of Spars, Ribs, and Skins into Wing

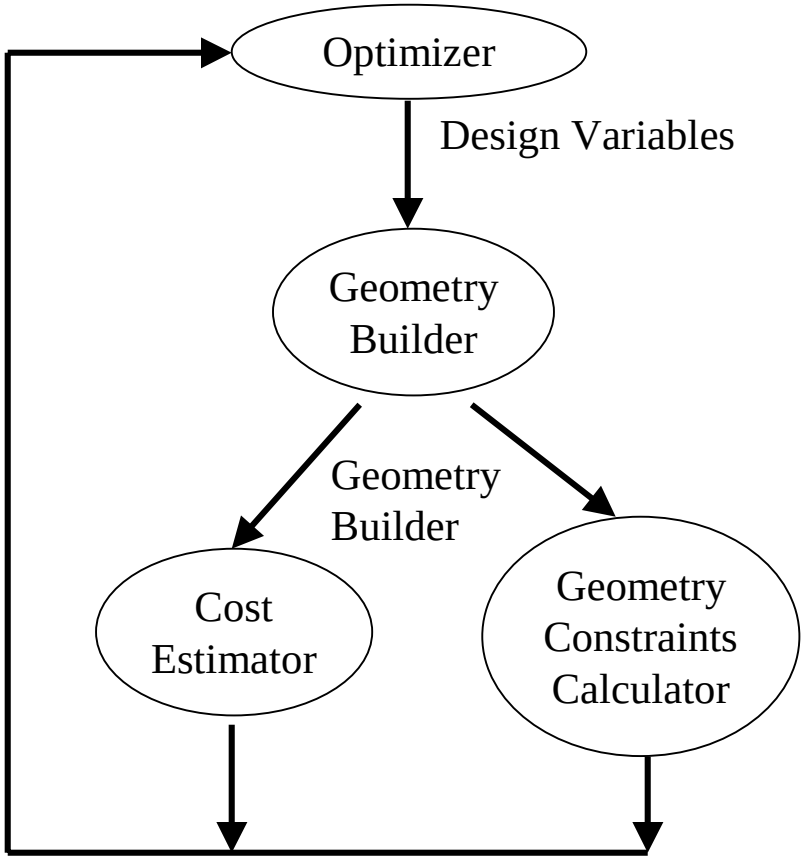


Overview of Process-Based Cost Modeling



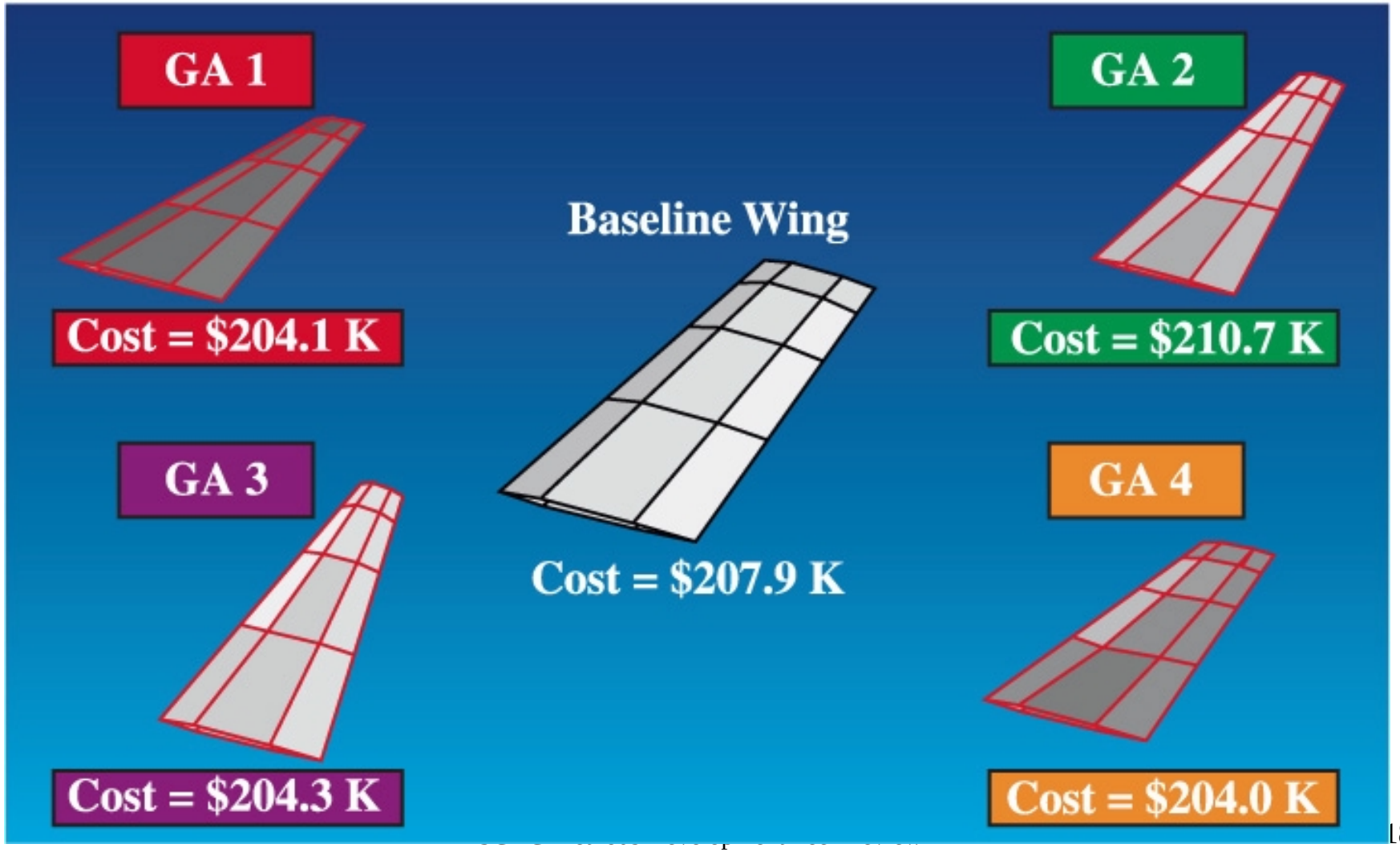
Cost Optimization Process





Cost Optimization of an Aircraft Wing

Genetic Algorithms Identify Numerous Local Minima



Extrapolation of PBMAC

- Concept of Cost Modulus (C_m)

$$Cost\ of\ Design = C_m \bullet Cost\ of\ Reference\ Design$$

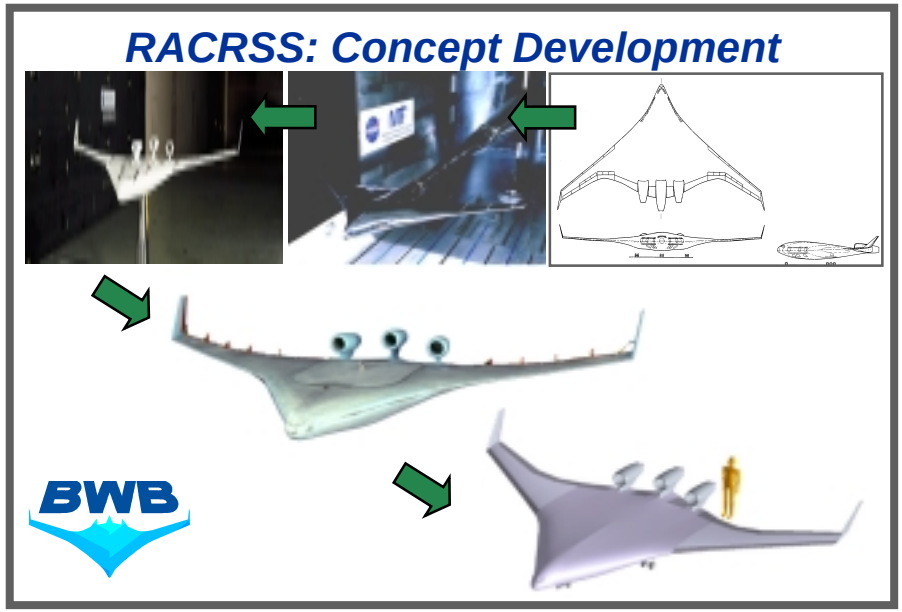
- Cost of Reference Design is assumed known, e.g. from PBMAC
- C_m is derived from physical characteristics of new design; specifically its size, shape, material, dimensional tolerance and surface finish requirements, and equipment requirements

RACRSS Project (2000-2001)
(Revolutionary Airframe Concept Research & System Studies)

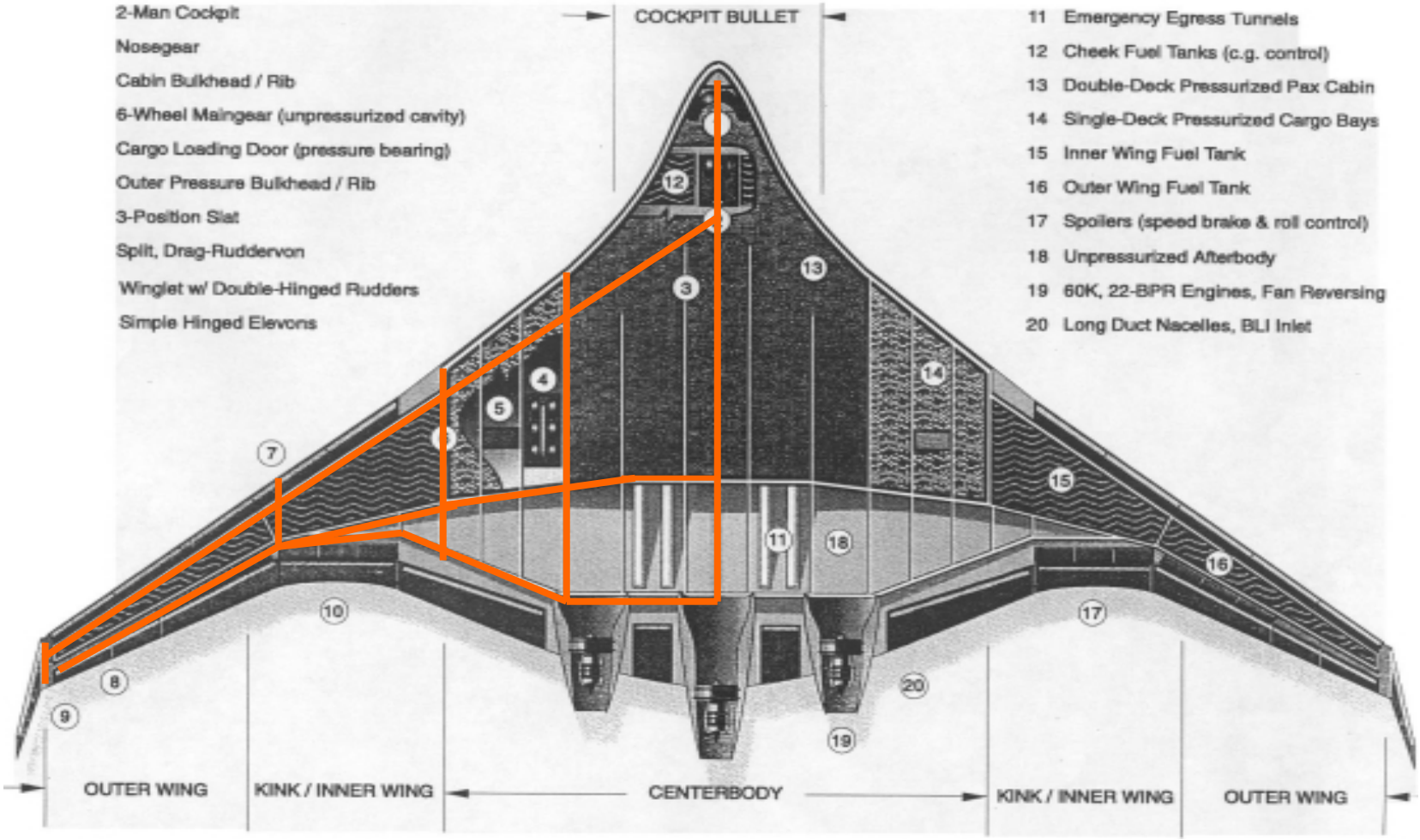
Project Goal
- Accelerate the maturation of innovative aircraft concepts that have large potential impact on the Aeronautics Enterprise Three Pillars for Success Goals

Objectives
- Enhance interdisciplinary problem solving across base programs and with industry/academia
- Create, mature, and develop technology and configurations for application to experimental flight vehicles (X-Planes)

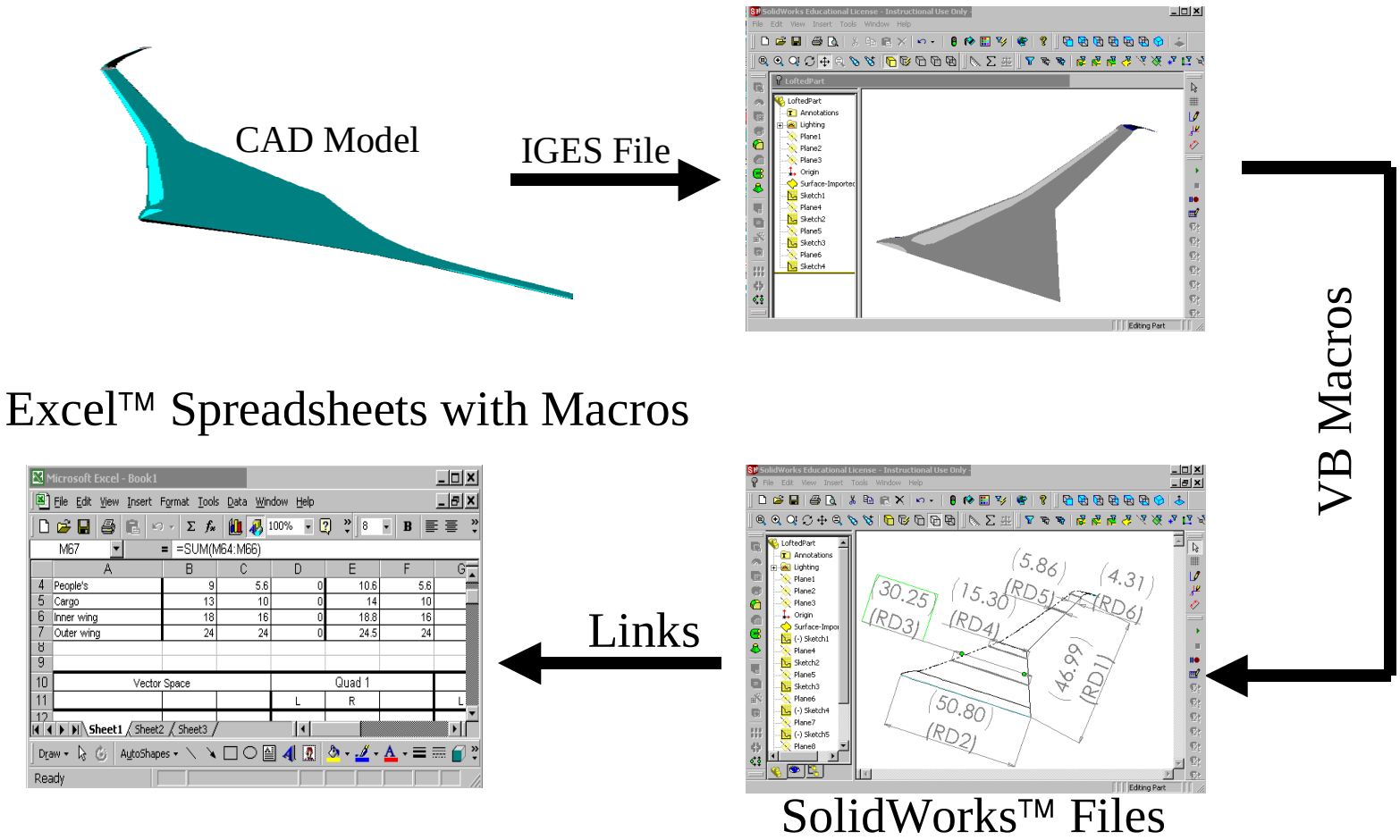
Benefit
- Significant acceleration in the development of viable advanced technologies and configurations
- Provide vehicle focus for integrated research within the Aeronautics Enterprise
- Identify potential experimental aircraft (X-Plane) concepts



Functional Arrangement of BWB (MASCOT Project)



CAD-Based Cost Estimation for a BWB



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Summary

- Lumped cost models (e.g., weight-based) do not reflect actual manufacturing and assembly costs
- Detailed cost models (e.g. PBMAC) account more correctly for cost in MDO studies
- For advanced vehicle design, PBMAC requires adjustments for size, shape, material, tolerance and surface finish, and equipment needs. Close-loop cost equations, e.g. cost modulus, offer a viable approach to quantify these adjustments

References

- Bao, H. P. and Samareh, J. A., "Affordable Design: A Methodology to Implement Process-Based Manufacturing Cost Models into the Traditional Performance-Focused Multidisciplinary Design Optimization", AIAA Paper No. 2000-4839, 8th AIAA/NASA/USAF/ISSMO Symposium onMultidisciplinary Analysis and Optimization, Long beach, CA, September 6-8, 2000.
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- Proctor, M.R., Metschan, S. L., and Klein, H. S., "Cost Optimization Software for Transport Aircraft Design Evaluation", NASA Contractor Report 4739, August 1996.