

# Assessment of the State-of-the-Art in the Design and Manufacturing of Large Composite Structure



presented by  
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at the  
**4th conference on Aerospace Materials, Processes, and Environmental Technology**  
**Von Braun Center, Huntsville, AL**  
**September 20, 2000**

# Outline of Presentation

- **Applications in Commercial and Military Aircraft**
- **Applications in Space Launch Vehicles**
- **Assessment of the State-of-the-Art**
- **Concluding Remarks**

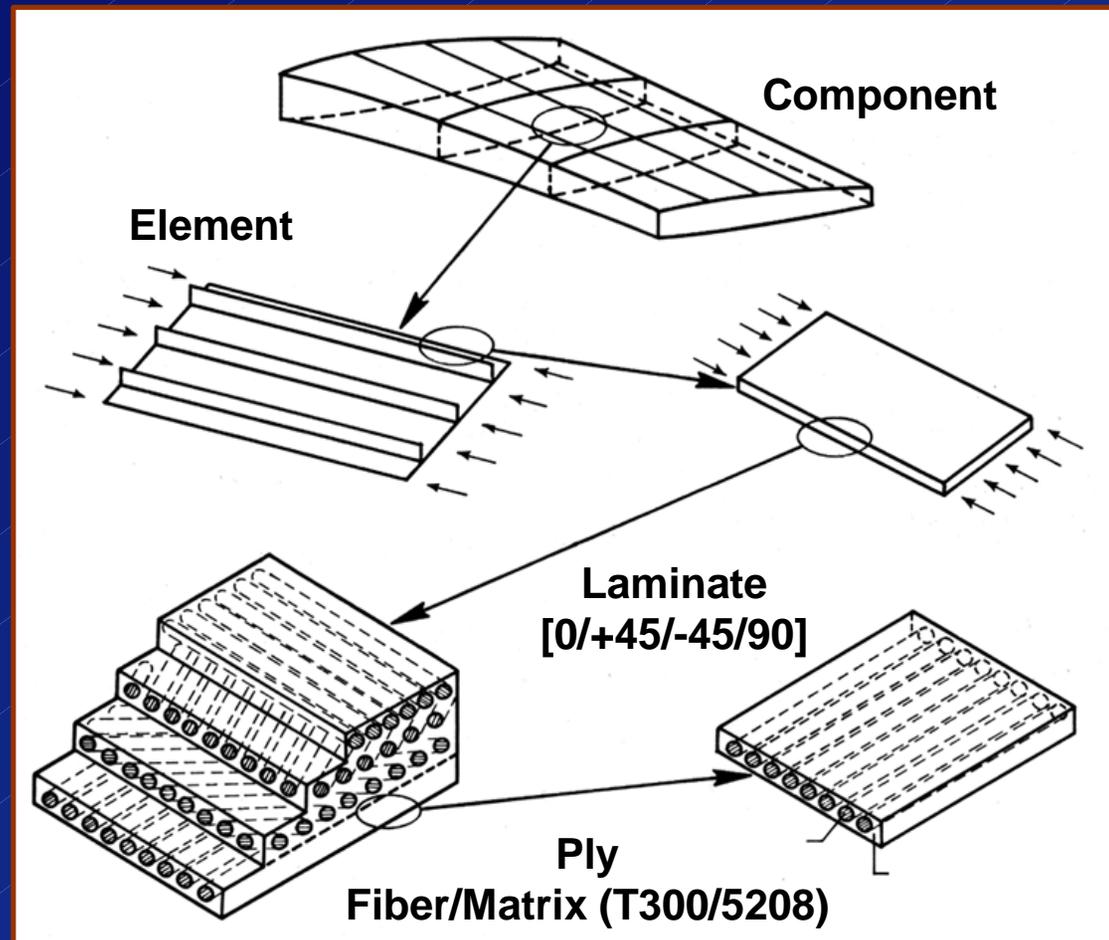


# Scope of the Assessment

Continuous Fiber Reinforced, Polymer matrix composites (CFRP)  
in vehicle structure

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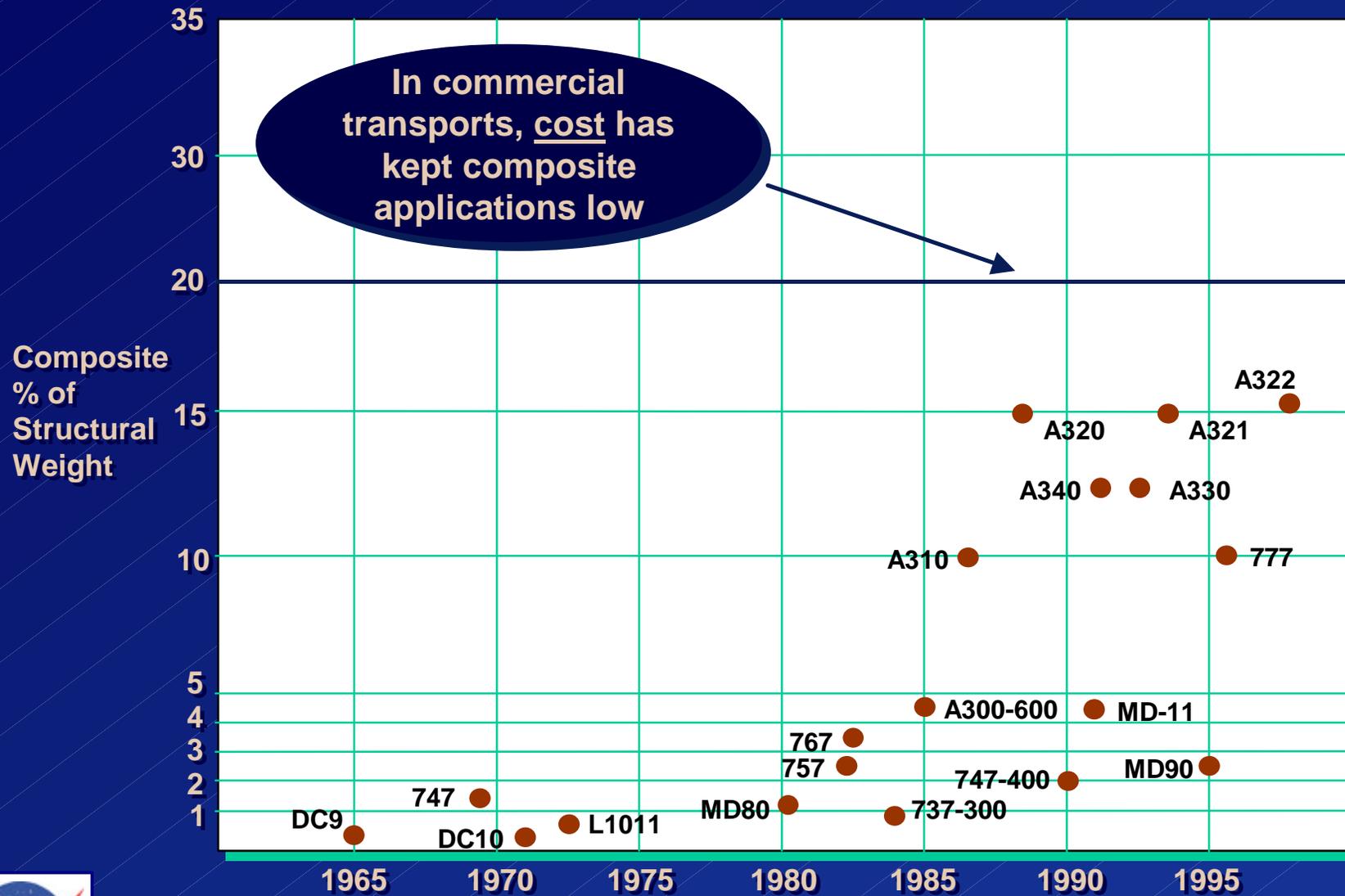


# Historical Development of Structural Composites

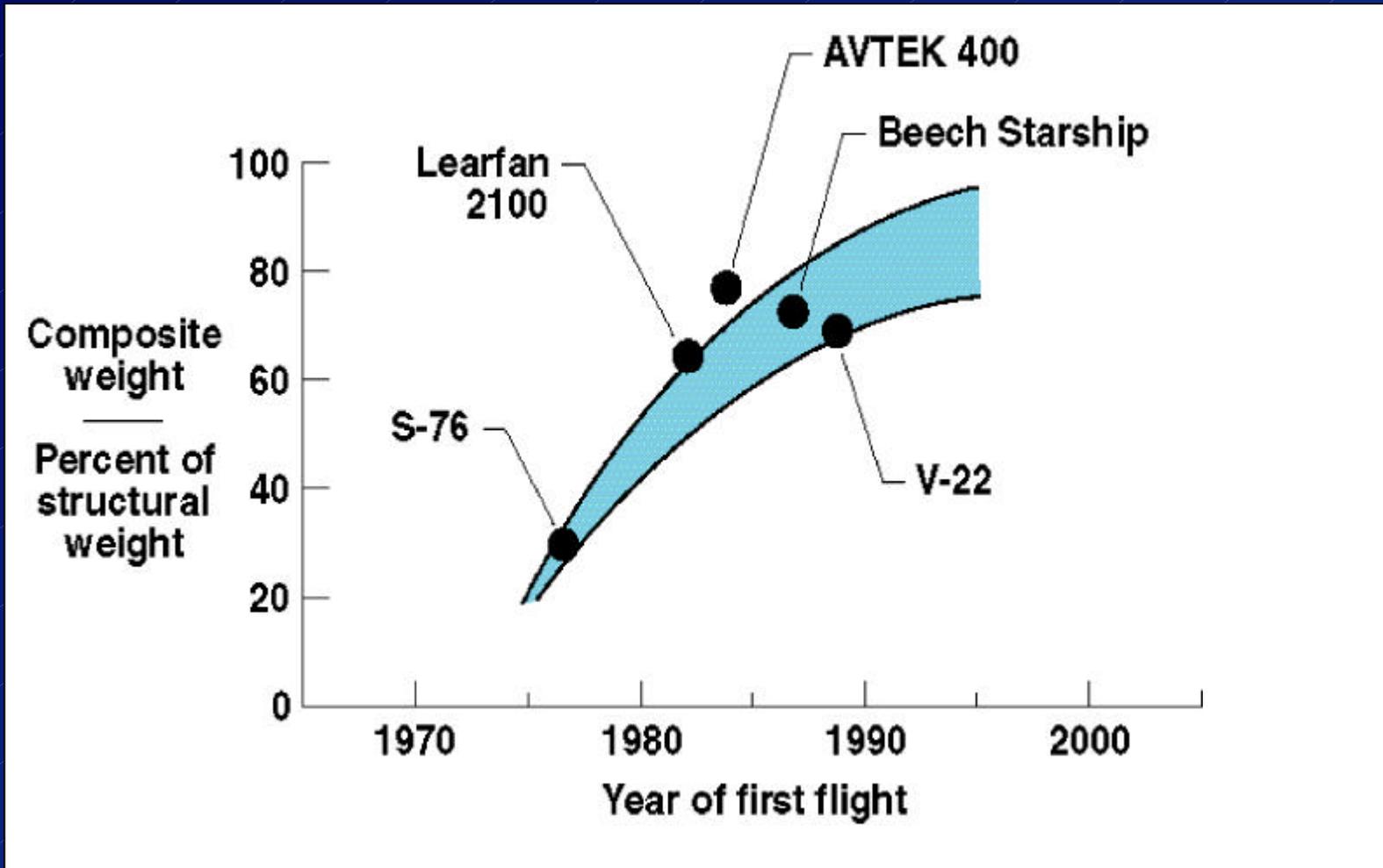
- Applications in Commercial Aircraft
- Applications in Military Aircraft



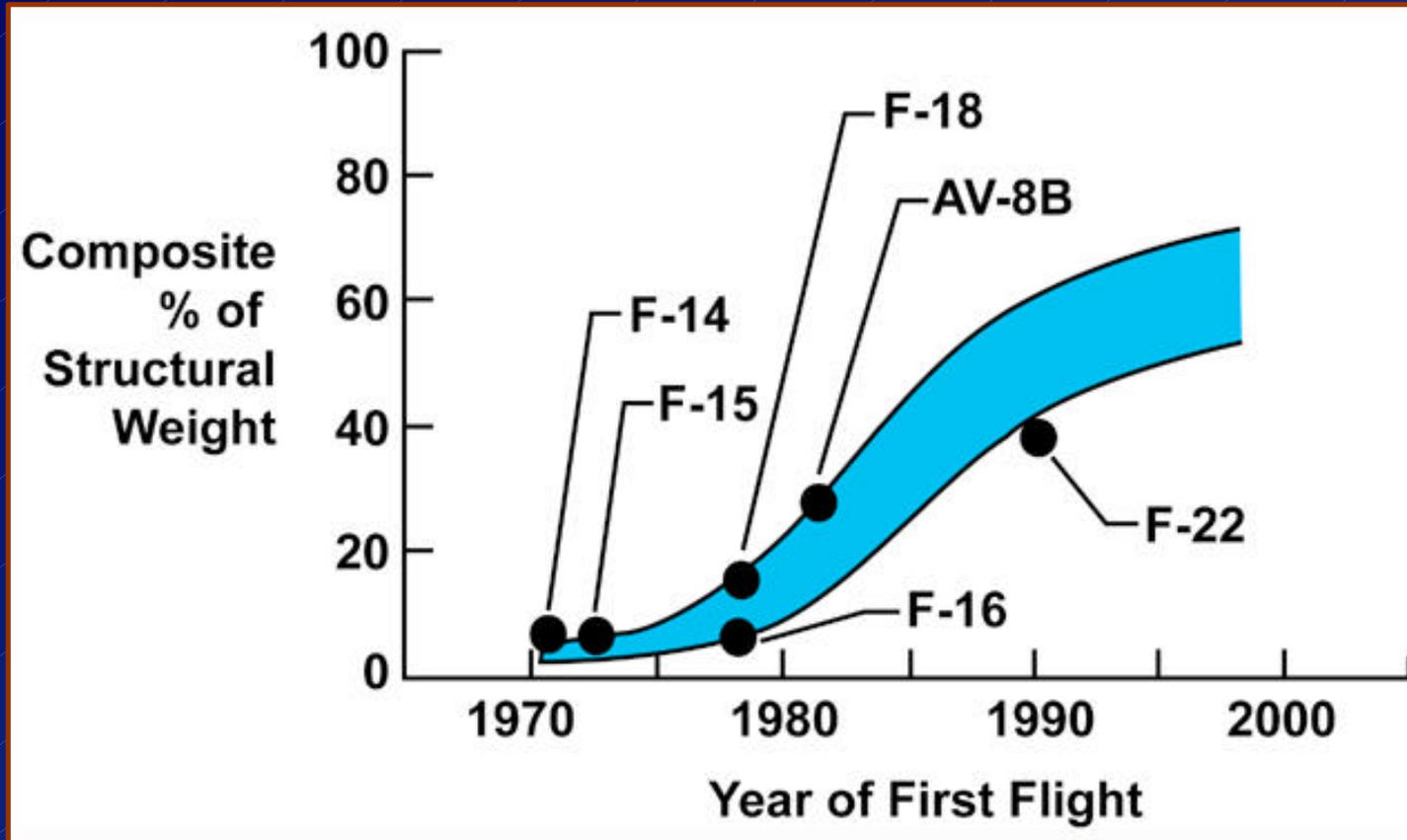
# Composites in Commercial Transport Aircraft



# General Aviation Aircraft and Rotorcraft



# Composite Applications in Military Fighter Aircraft



Performance and weight drivers have led to significant levels of composite application

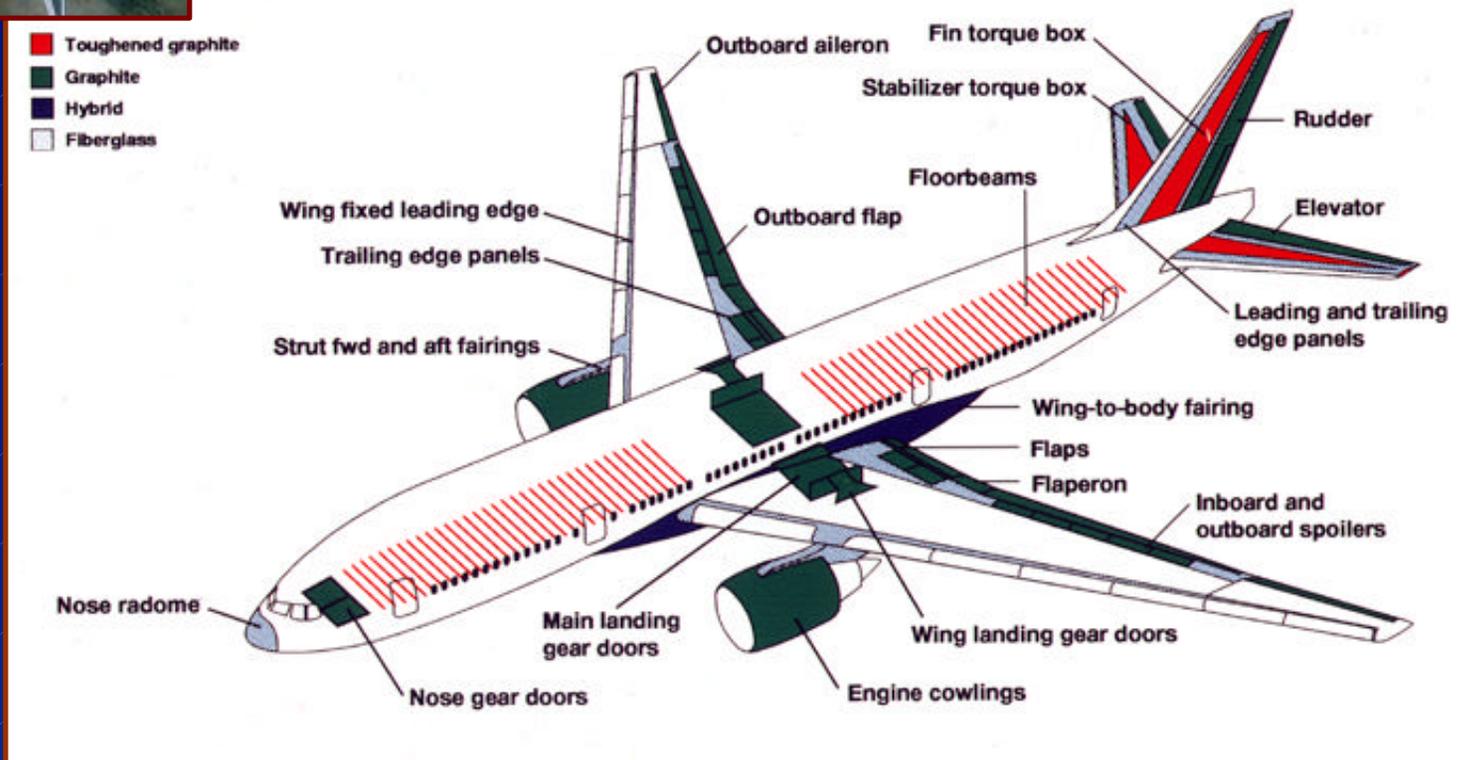


# Structural Composites on the B-777



## 777 composite structure:

- Toughened materials for improved damage resistance and damage tolerance
- Designed for simple, low-temperature bolted repairs
- Corrosion and fatigue resistant
- Weighs less (composite empennage saves over 1,500 lb compared with prior aluminum structure)



# Applications of Composites on the V-22 Tiltrotor Aircraft



- Approximately 41% of the airframe is composites
- Wing is IM6 / epoxy and the fuselage and tail is AS4 / epoxy



## F-22 Structural Materials is about 25% CFRP Composites



- Wing skins are monolithic graphite / bismaleimide
- Horizontal and vertical stabilizers are graphite / bismaleimide



## B-2 Primary Structure Is Almost All Composites



- **First flight test was July 17, 1989**
- **Wing is almost as large as B-747 (span of 172 ft and 5,140 ft<sup>2</sup>)**
- **Wing Box: composite covers and substructure**
- **Fuselage: composite forward, mid, rear, and internal members**

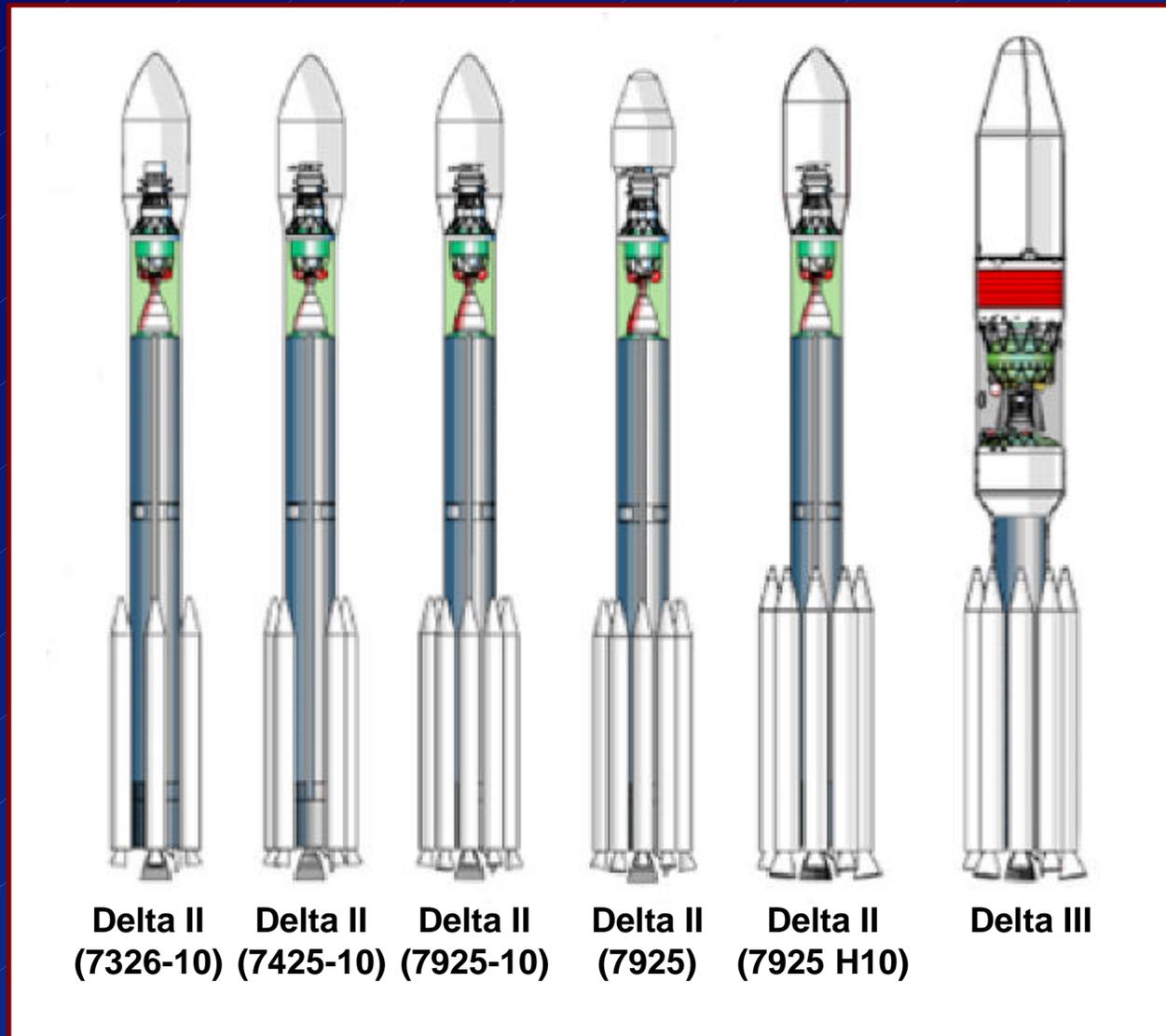


# Applications in Space Transportation Vehicles

- **Structural Composites on Delta Launch Vehicles**
- **DC-XA Technology Components**
- **X-33 Liquid Hydrogen Tank**



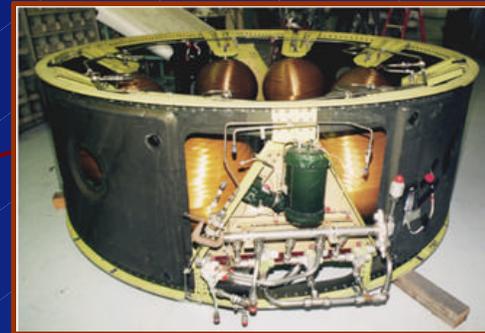
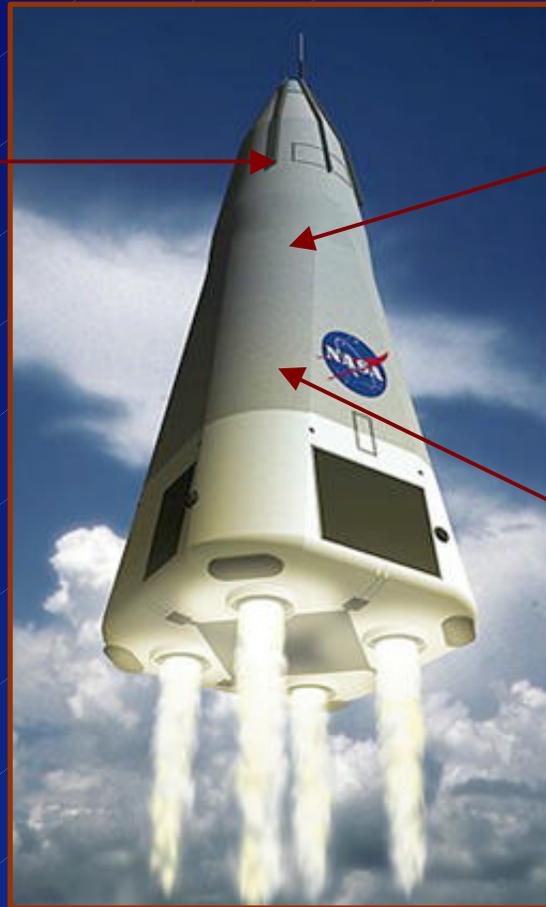
# Structural Composites on Delta Launch Vehicles



# DC-XA Technology Components



Aluminum-Lithium  
LO<sub>2</sub> Tank



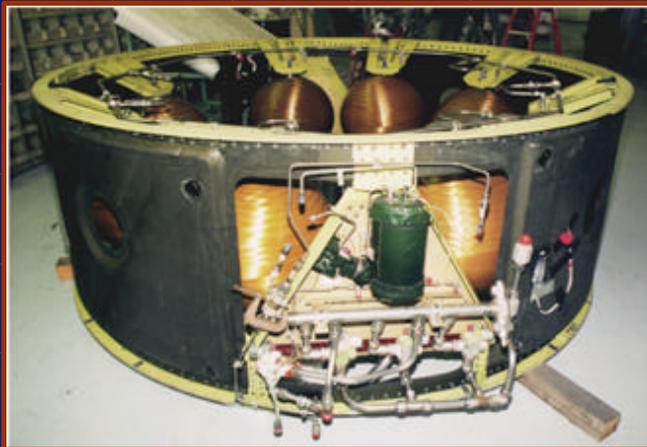
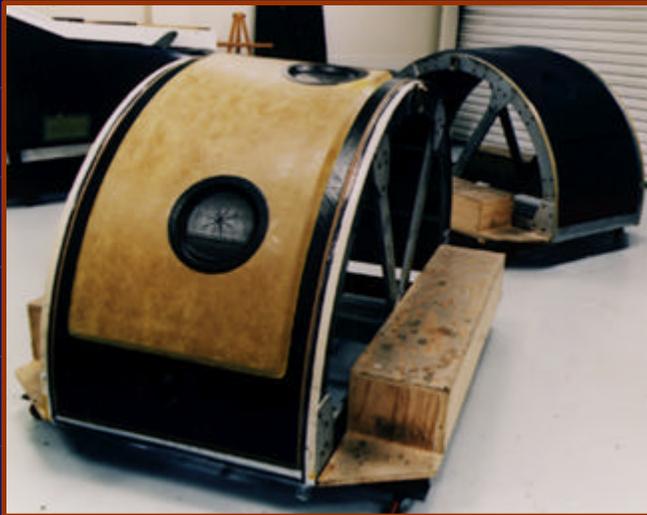
Composite Intertank



Composite LH<sub>2</sub> Tank



# DC-XA Composite Intertank



## Design and Fabrication

- 2 semi-circular pieces bolted together
- IM7/5250-4 graphite / bismaleimide
- Aluminum honeycomb core
- 44% weight savings over DC-X

## Development History

- First semi-circular part failed during fabrication due to rupture of the core
- Process changed by lowering post-cure temperature that avoided outgassing
- Successful ground tested at MSFC

## Flight Test History

- 3 DC-XA flight tests



# DC-XA Composite Liquid Hydrogen Cryotank



## Design and Fabrication

- 2 cylindrical pieces, bonded splice joint
- 24-ply IM7/8552 graphite / epoxy
- Internal 3-D reinforcement urethane foam insulation
- 34% weight savings over DC-X tank

## Development History

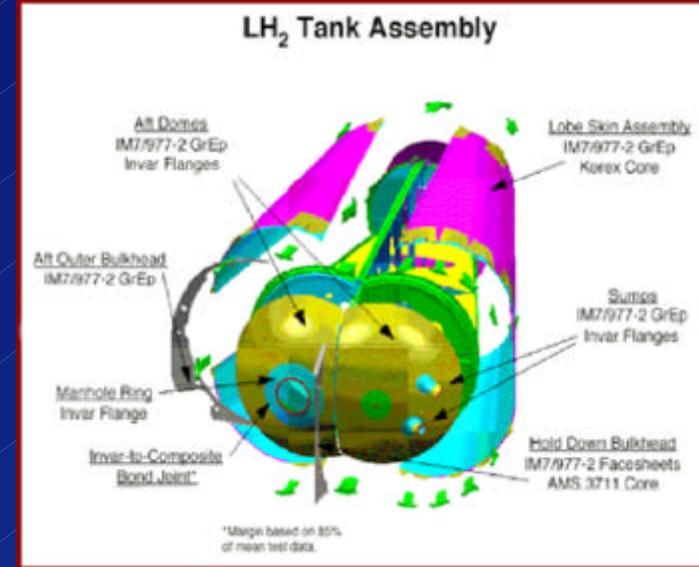
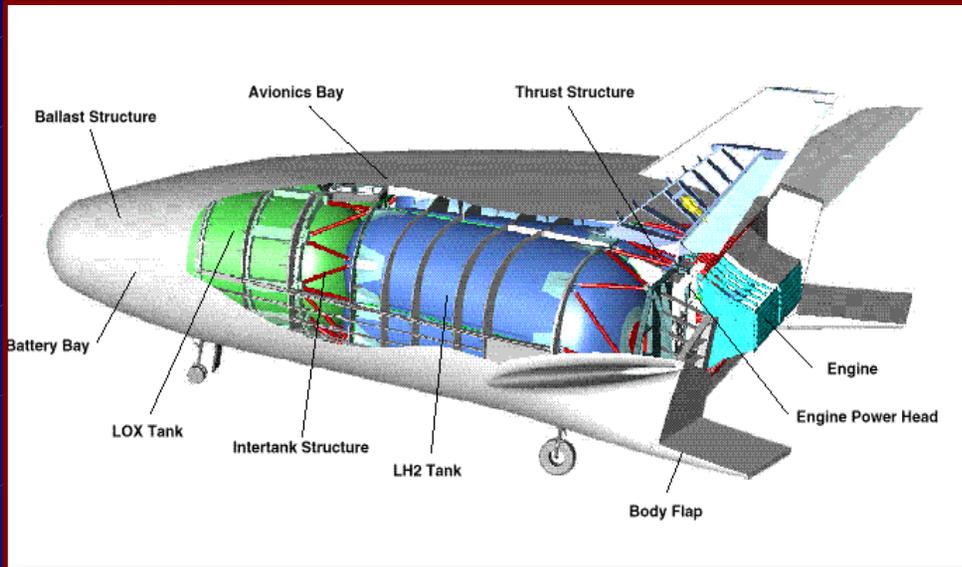
- Repaired damage from shop accident
- Insulation separated from tank wall
- Successfully ground tested at MSFC

## Flight Test History

- 3 DC-XA flight tests



# X-33 Composite Liquid Hydrogen Tank



- Composite structural design was the highest risk concept
- Project recovery plan addressed as-fabricated tank weaknesses
- Tank failed in the ground test as a result of several causal factors



# Assessment of the State-of-the-Art

- Lessons learned
- Assessment of the technology readiness
- The current state-of-the-art

## Technology Readiness Levels (TRL)

1 - 3 Research

4 - 6 Technology Development

7 - 9 Advanced Vehicle Development



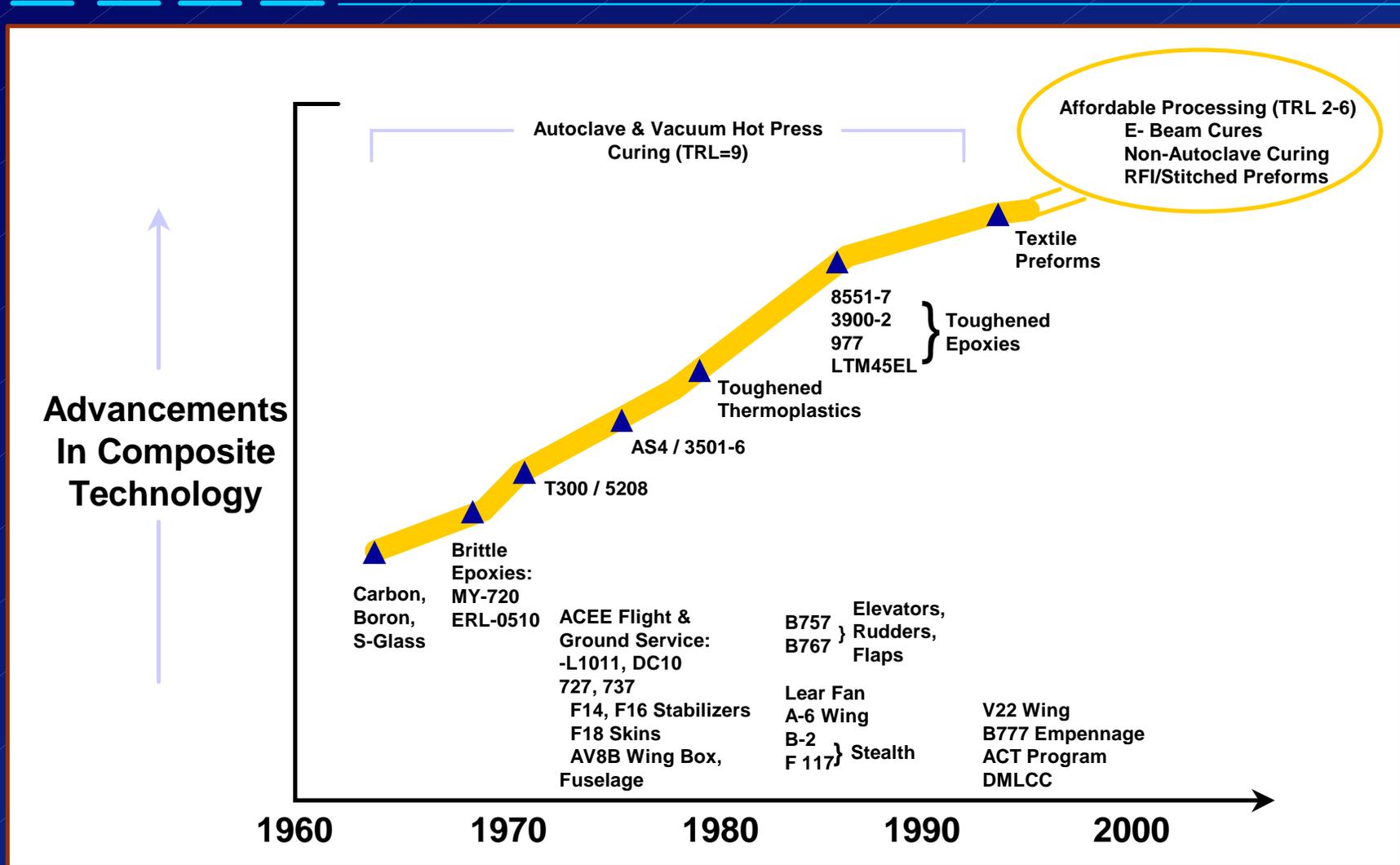
# Materials, Processes, and Manufacturing

## Lessons Learned

1. Materials development in conjunction with product development creates undue risks.
2. Experienced materials and processing engineers should be included in the design phase and must be readily available to correct problems in production processes.
- 3. Manufacturing process scale-up development tests should be conducted to optimize the production processes.**
4. Co-curing and co-bonding are preferred over secondary bonding which requires near perfect interface fit-up.
5. Mechanically fastened joints require close tolerance fit-up and shimming to assure a good fit and to avoid damage to the composite parts during assembly.
6. Dimensional tolerances are more critical in composites than in metals to avoid damage to parts during assembly. Quality tools are essential to the production of quality parts.
7. Selection of the tool material depends on part size, configuration, production rate, quantity, and company experience.
8. Tool designers should anticipate the need to modify tools to adjust for part springback, ease of removal, or maintain dimensional control of critical interfaces.



# Evolution of Composite Materials (Matrix) Development



# Structural Design, Analysis, and Testing

## Lessons Learned

1. Design and certification requirements for composite structure are generally more complex and conservative than for metal structure.

**2. Successful programs have used the building-block approach with a realistic schedule that allows for a systematic development effort.**

3. The use of basic laminates containing 0/90/+45/-45 plies with a minimum of 10% of the plies in each direction is well suited to most applications.

4. Mechanical joints should be restricted to attachment of metal fittings and situations where assembly or access is impractical using alternative approaches.

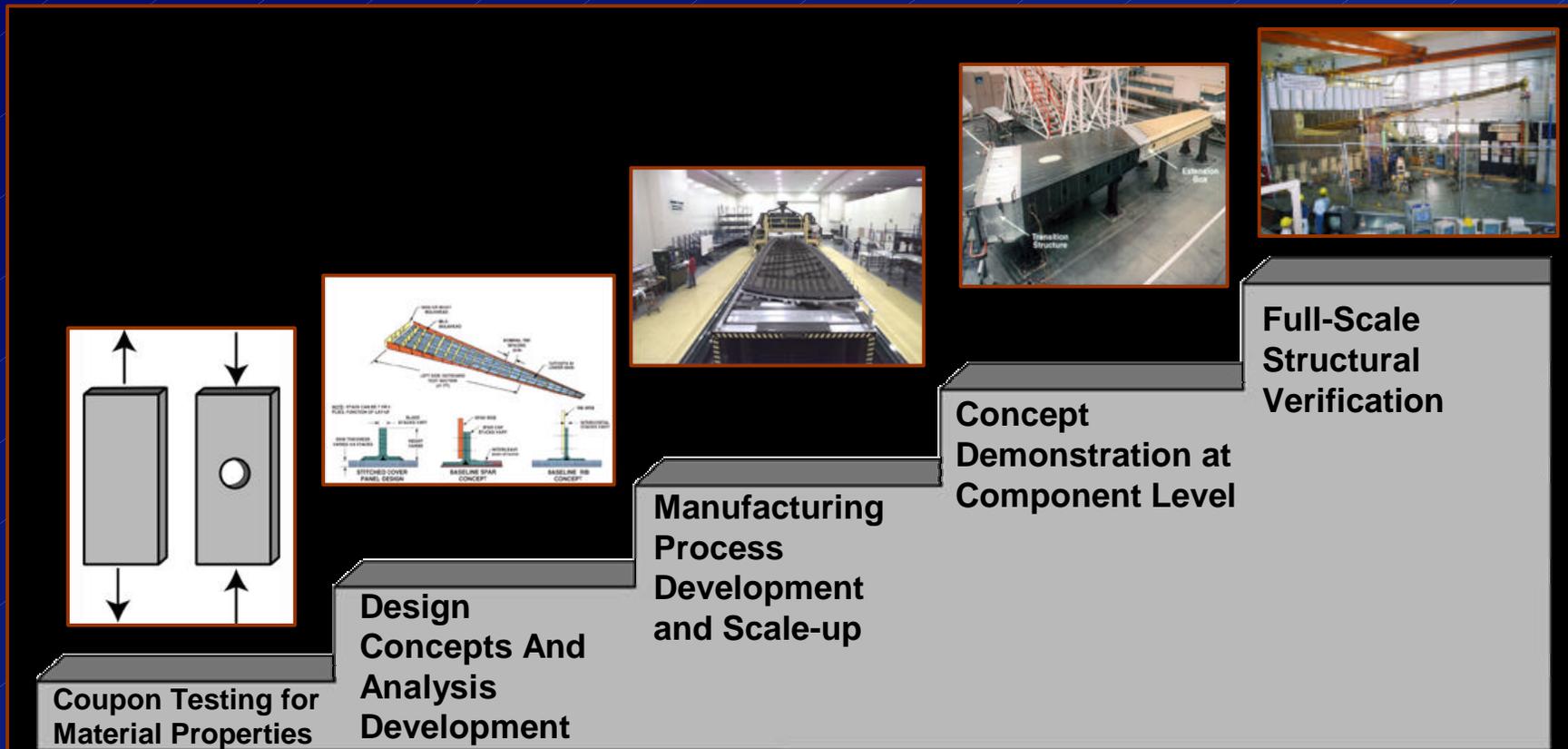
5. Large, co-cured assemblies reduce part count and assembly costs but may require complex tooling.

6. Structural designs and the associated tooling should be able to accommodate design changes associated with the inevitable increases in design loads.

7. Understanding and properly characterizing impact damage would eliminate confusion in the design process and permit direct comparison of test data.



# Current Practice: Test-Based Building-Block Approach



**R&D Goals:** Physics-based computational methods (TRL = 4-6) and reliability-based design methods (TRL = 3)



# Quality Control, Inspection, and Supportability

## Lessons Learned

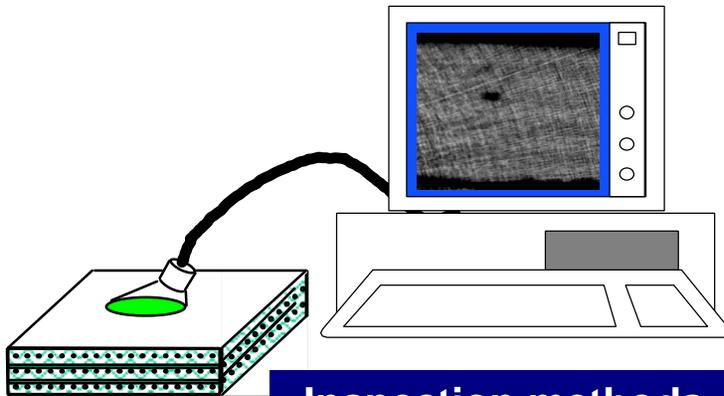
1. Automated processes can help to reduce QC costs.
2. Inspection and quality control should focus on aspects of the process and part that have a direct bearing on part performance.
3. Determine and understand the effects of defects on part performance.
- 4. Supportability should be addressed during design so that composite structures are inspectable, maintainable and repairable.**
5. Most damage to composite structure occurs during assembly or routine maintenance of the aircraft.
6. Repair costs are much higher than for metal structures.
7. Improved Standard Repair Manuals are needed for in-service maintenance and repair.
8. Special long-life and low-temperature curing repair materials are required.
9. Moisture ingestion and aluminum core corrosion are recurring supportability problems for honeycomb structures.



# Development of Nondestructive Inspection (NDI) Methods

## Detection of damage using nondestructive inspection

- Porosity, Fiber Orientation
- Disbonds, Delaminations, Cracks
- Processing Quality Control

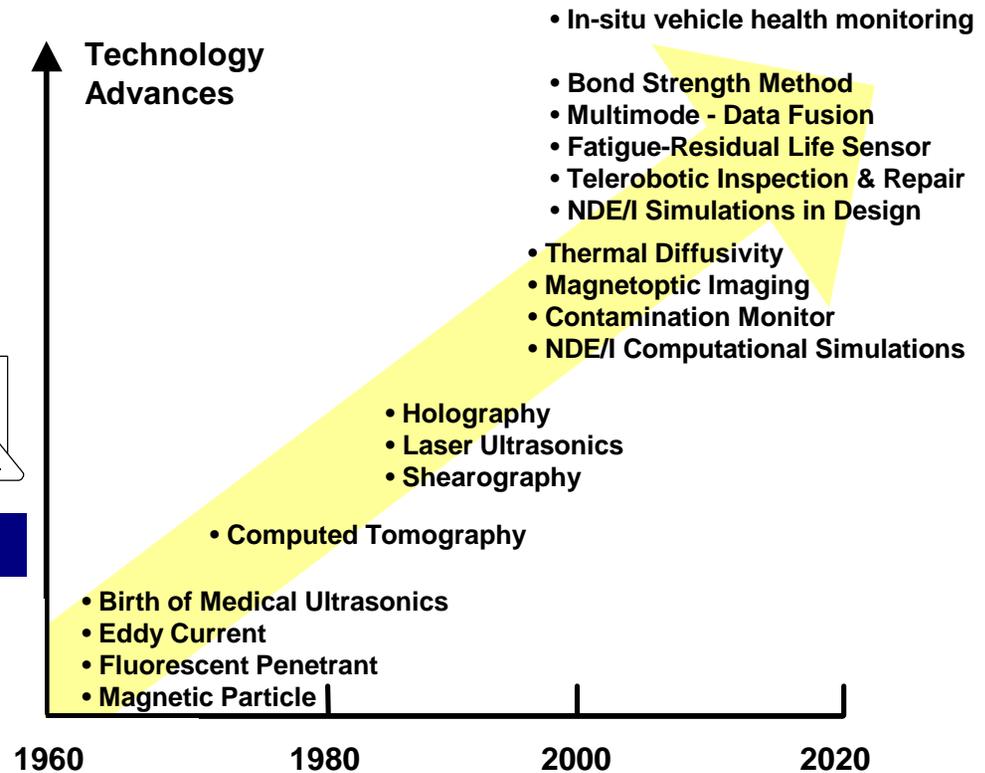


## Inspection methods

- X-Ray
- Ultrasonic
- Thermal
- Electromagnetic
- Optical

## Evolution of NDI Technology

Technology Advances



TRL's vary from 3 to 9, depending on detection objective

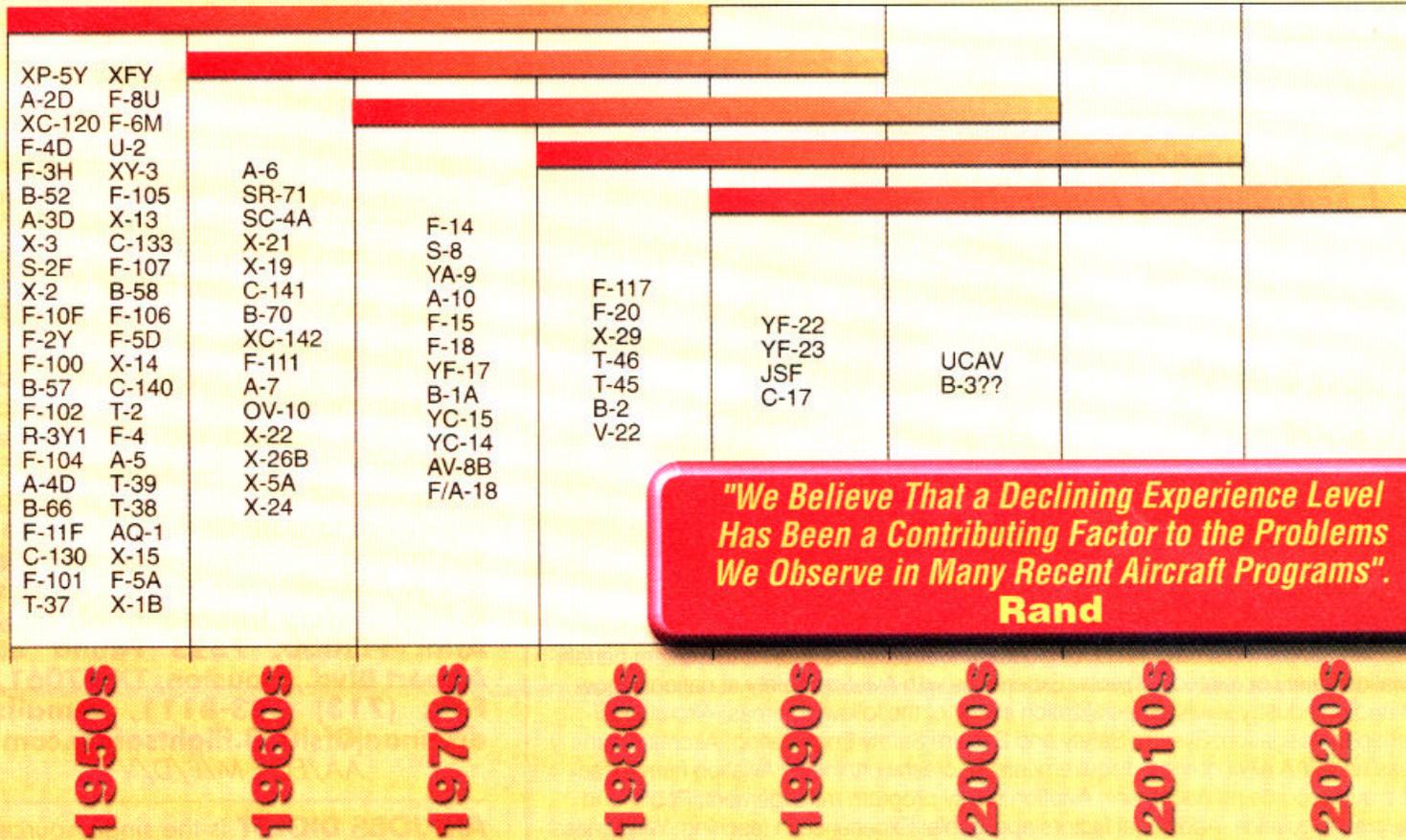
# Summary of The Current State-Of-The-Art

- Designing a composite structure is not the same as designing a metallic structure
- A composite material must be “designed” for each specific structural application
- Composite materials exhibit brittle failure mechanisms that are not well understood
- Fabrication processes are still evolving and fabrication costs are not accurately predictable
- The industrial infrastructure for engineering design and manufacturing of composites is not fully developed



# Engineering Infrastructure is Created Through Design Development Experiences

## Engineer Career Length Vs. New Designs By Decade



*"We Believe That a Declining Experience Level Has Been a Contributing Factor to the Problems We Observe in Many Recent Aircraft Programs".*  
**Rand**

Note: Rand study assumes 40-year career length



# Concluding Remarks

- Project **risk mitigation plans** must include a building-block test approach to structural design development, manufacturing process scale-up development tests, and pre-flight ground test to verify structural integrity.
- **Stay the course!** The potential benefits of composite structures justifies the Agency investment in developing the technology. Advanced composite structures technology is enabling to virtually every Aero-Space Technology Enterprise Goal.

