Composite Manufacturing in Space by Supporting the Needs of the Airframe Industry Supply Chain

Composites Consortium

Dr. Robert G. Bryant
NASA Langley Research Center
Hampton VA, 23681

Email: robert.g.bryant@nasa.gov

History : Enabling Space through Aeronautics

NACA TO NASA

Aircraft to Space Vehicles

Applications of Composites on Flight Vehicles

<u>Structural Components</u>
Fuselage
Wings
Elevators
Vertical Stabilizers
Rudders
Ailerons
Doors
Rotors
Tank Structure

ARES V

B787

A380

Composite Crew module

ARES I

B2

B777

F22

Honda Jet Composite Fuselage

Shuttle Cargo Bay Doors

Beech Starship

A 310

B727 Elevator

DC 10 Rudder and vertical Stabilizer

F-18

F-14

V22

L1011 Aileron

B737 Horz. Stab.

<u>Material Systems</u>
Gr/Epoxy
Gr/Bismalimide
Gr/Epoxy
GrPolyarylene-Ether
Gr/Polyimide

Terrestrial Impacts of Advanced Manufacturing Technologies

Technology	Advantages	Disadvantages
Metallic Powder Bed SLM	• Produces near-geometrically accurate metallic parts. • Low scrap generation/regeneration. • Internalized structure.	• Size limiting powder bed. • Uniform size powder required. • Surface finish may require post machining. • Porosity may be an issue.
Wire Feed Deposition EBF	• Repair of metallic structures. • in-situ builds of alloys and gradients. • Stock material is metal wire.	• Difficultly producing highly planar structures. • Requires a starting platform.
3D Printing Thermoplastic wire with discontinuous reinforcement	• Used to make complex parts and structures. • Stock material is extruded thermoplastic.	• Builds are not highly precise. • Parts do not have the physical integrity as cast or molded plastics. • Requires a starting platform. • Issues due to thermally inducted stress.
Thermoset Composites	• Set using moderate infrared-based heat. • Demonstrated use as a inflatable-rigidizeable space structures. • Low CTE.	• Thermoset shelf life. • Engineering properties not obtained until cure cycle complete. • VOC issues.
Thermoplastic Composites Tool-less process	• Mechanical fasteners not required. • Repair and patching, minimizing scrap. • Compatible with other processes and materials. • Low CTE.	• Currently at TRL 4. • Difficult to make small intricate parts. • Need for continued manufacturing research into production of aerospace quality parts.

SLM= Selective Laser Melting: EBF= Electron beam Fabrication CTE= Coefficient of Thermal Expansion: VOC: Volatile Organic Content

Hype versus Business Case

These technologies save time when:

- Parts can be consolidated
- Final vehicle requires a low count of a specialized component
- Reduces touch labor
- Rework is faster than new parts
- Complements older technology such as stamping, injection molding, etc.

These technologies become cost effective when:

- Part count and inventory is reduced
- Leveraging advanced manufacturing to produce a critical component at reduced cost
- Mitigates costs associated with shelf-life (storage, aging, environmental controls)
- Readily integrated into current processes leveraging capital assets
- Parts versus processes become certified
- New regulations require their implementation

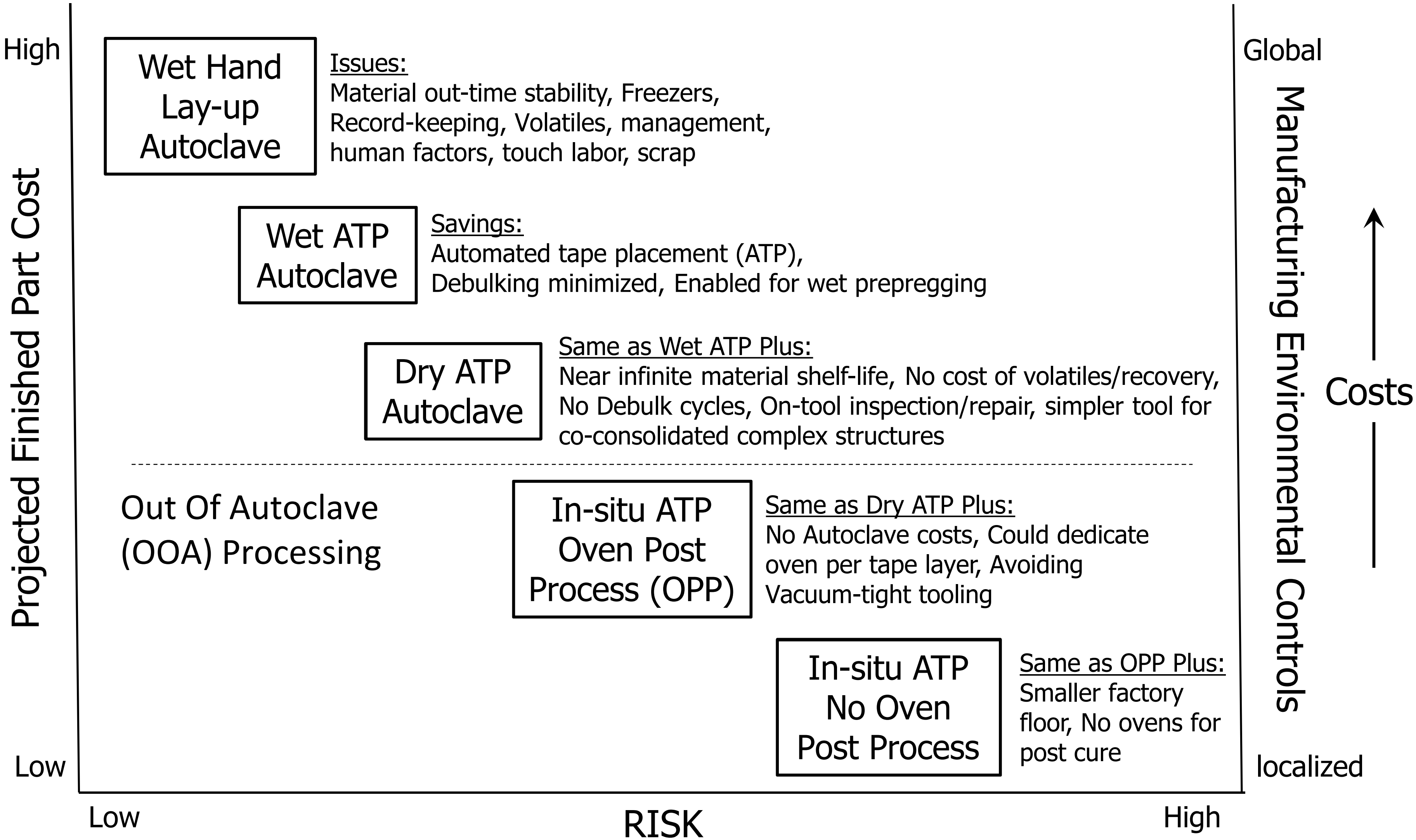
The Rise of Composites for Primary Structures for Large Transports

Structural Material Composition in Commercial Aircraft by Weight

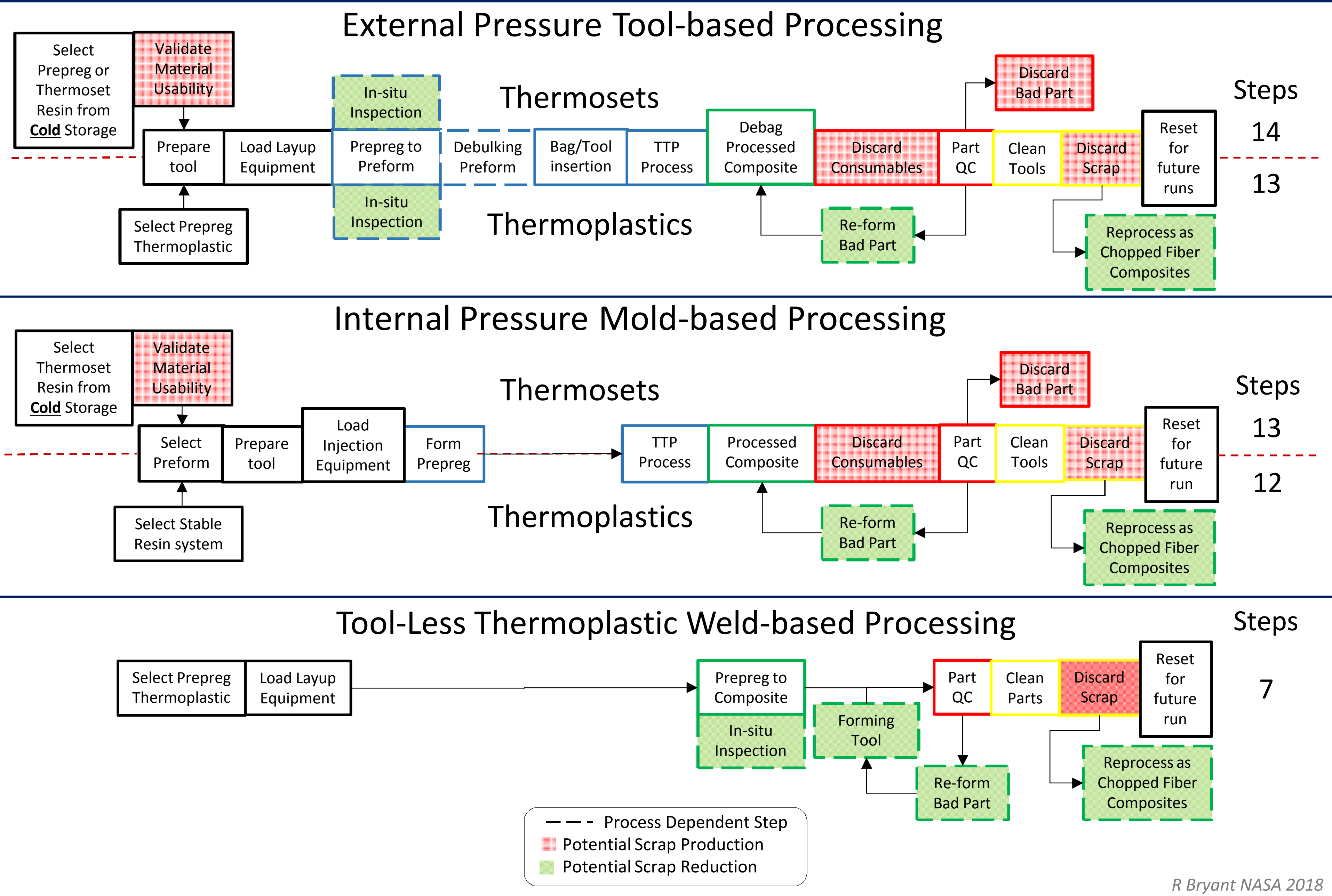
Aircraft	Production	Aluminum	Steel	Titanium	*PMCs	Other
Boeing 747	1970 -	81%	13%	4%	1%	1%
Boeing 757	1981 -	78%	12%	6%	3%	1%
Boeing 767	1981 -	80%	14%	2%	3%	1%
Boeing 777	1995 -	70%	11%	7%	11%	1%
Boeing 787	2009 -	20%	10%	15%	50%	5%
DC-10	1968 - 1980	78%	14%	5%	1%	2%
MD-11	1988 - 2000	76%	9%	5%	8%	2%
MD-12	(1995)	70%	8%	4%	16%	2%
Airbus A320	1986 -	72%	9%	6%	10%	3%
Airbus A380	2003	61%	5%	5%	22%	7%
Airbus A350 XWB	2014	19%	6%	14%	53%	8%

*PMC: Polymer Matrix Composite, the lowest density material presented on Table. [shaded box] = latest aircraft.

Generalized Manufacturing Processes: Risks and Payoffs



Automated Process Steps to Create a Simple-Geometry Continuous Fiber Composite Part



Tool-Less Demonstration

Video with Permission from General Atomics-Aeronautic Systems Inc.

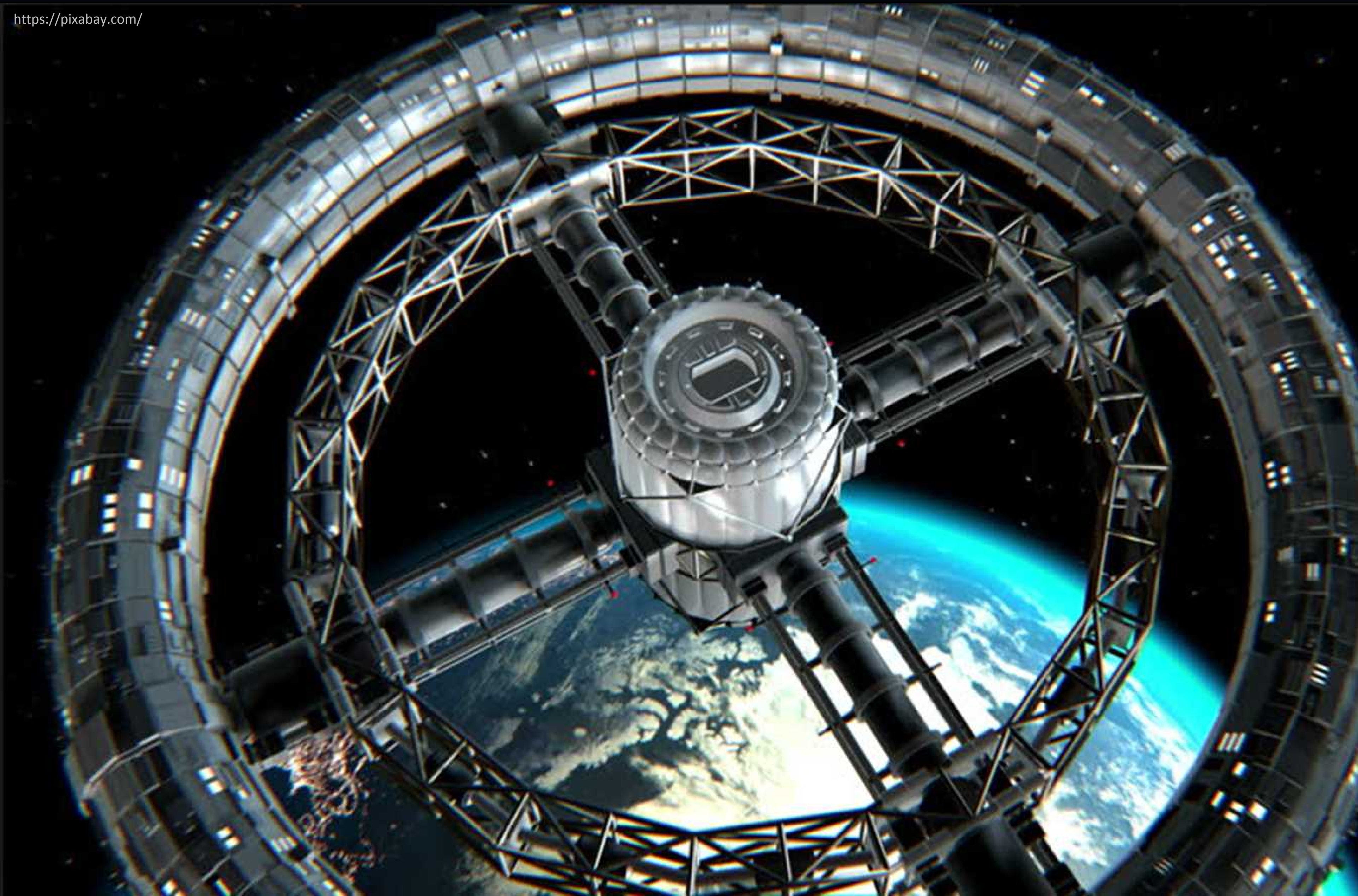
Advantages of the Tool-Less Process

The Manufacturing Economics of Tool-Less Method of TPC Processing are:

- Lower the cost of aerospace manufacturing by:
  - Minimizing tooling cost
  - Using OOA processing
  - **No autoclave/oven limiting part size**
  - Reduced material consumption by 50%
  - **No release paper, bagging paper, tacky tape, or mold release agent**
- Near infinite storage/shelf life of thermoplastics affords:
  - No "out-time" reduction in material properties
  - **No refrigerated storage**
  - The ability to integrate different materials during lay-up
  - No complex cure/staging cycles
  - Material reusability reducing cradle-to-grave costs
  - **In-situ repair during build**
- The development of tool-less fabrication technology enables:
  - Potential 100 lb/hr lay-up
  - **Start-stop processing without affecting as-built properties**
  - Improve strength (improved and consistent material properties)
  - Improve weight (design optimization similar to 3D printing)
  - Unibody to panel-on-frame assembly
  - **Custom and production parts built at the same layup rate**
  - Direct incorporation of components into a build during thermoplastic layup
- Fully compatible with non-aerospace composite sectors.

Personal Communications with Industry

From Art to Reality



https://pixabay.com/

Long-term Human Presence In Space

Requires shelter and platforms as the first step!

Current methods are:

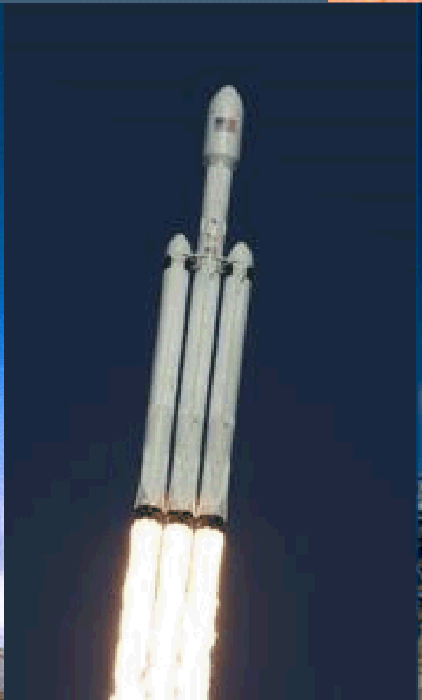
- Launching preassembled hardware
- Deployable structures
- Inflatable habitats

Unfortunately, multiple rocket launches or building larger rockets is not a universally sustainable economical model.

Solution requires near or on-site manufacturing.

- Decrease launching of preassembled structures
- Minimal investment of tooling
- Remote automation/operation
- Must benefit terrestrial-based economies affording a competitive advantage leading to economic sustainability

The Current Dilemma – Human Exploration of Space



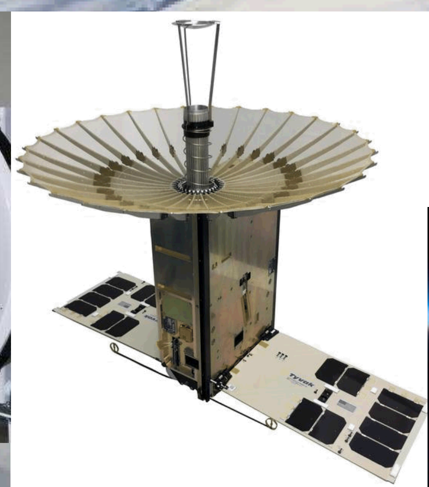
The Changing Launch Profile

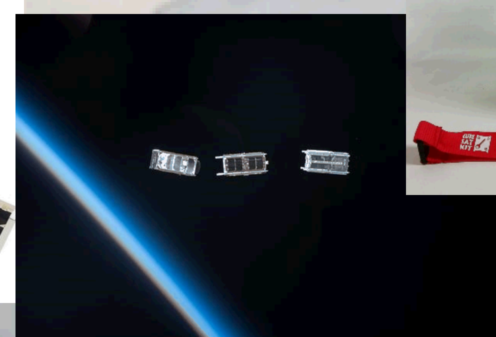
Miniaturization of Critical Hardware

Cray 2	iPhone XS	Micro SD 64Gb
1.9 Gfps	325 Gfps	100 Mb/s
244 MHz	2.4 GHz	none
150-200 kW/h	3-4 W/h	0.2 mW/h (on)
$32M	$900	$10
2500 Kg	150 g	~10 g

https://medium.com/@diego./cray-2-v-iphone-xs-fight-6f05b494efe1

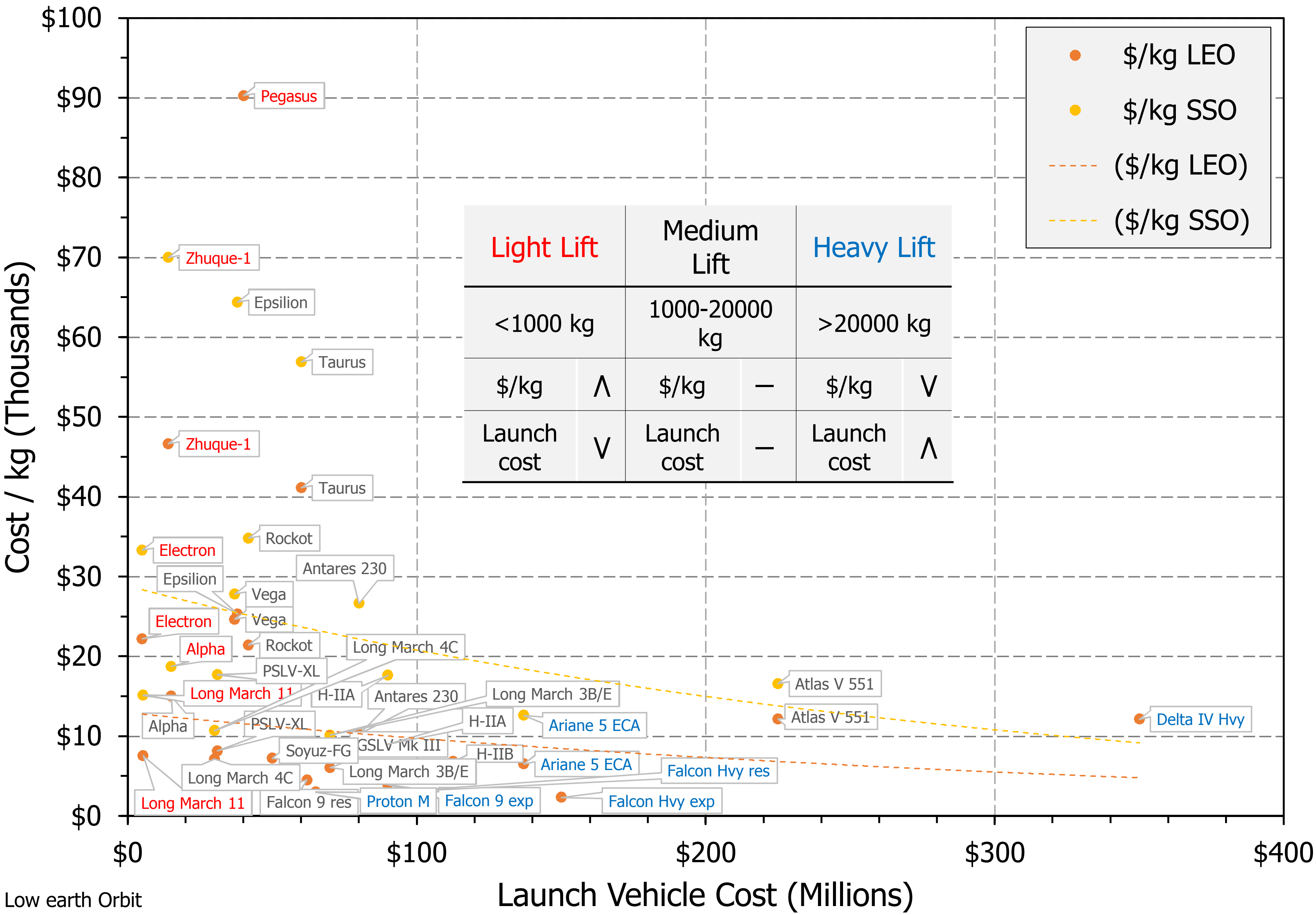
The New Face of Affordable Spaceflight Hardware





https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2018_AST_Compendium.pdf

Impact of Lift Capability on Launch Costs



Light Lift		Medium Lift		Heavy Lift	
<1000 kg		1000-20000 kg		>20000 kg	
$/kg	Λ	$/kg	–	$/kg	V
Launch cost	V	Launch cost	–	Launch cost	Λ

LEO Low earth Orbit
SSO Sun Synchronous orbit

Extraterrestrial Impacts of Advanced Manufacturing Technologies

Technology	Advantages	Disadvantages
Metallic Powder Bed SLM	• Same as terrestrial.	• Same as terrestrial. • Elemental sublimation in UHV. • Low or zero gravity issues. • CTE issues.
Wire Feed Deposition EBF	• Same as terrestrial.	• Elemental sublimation in UHV. • CTE issues.
3D Printing Thermoplastic wire with discontinuous reinforcement	• Same as terrestrial.	• Same as terrestrial.
Thermoset Composites	• Same as terrestrial.	• Same as terrestrial. • Difficult to deploy. • Extremely difficult to process and consolidate.
Thermoplastic Composites Tool-less process	• Same as terrestrial. • Build in-Space. • Semi-complex structures possible. • No post processing.	• Same as terrestrial. • Difficult to make small intricate parts. • Need for manufacturing research into production of aerospace quality parts.

UHV= Ultrahigh Vacuum

<u>Consider</u>: wide spectral ionizing and non-ionizing radiation, ultrahigh vacuum, terrestrial contaminants, heat and cold, and combined effects.

What is Needed to Build in Space

<u>Concept</u>: Use an on-site tool-less process to create or repair complex space durable composite structures needed to support long-term human presence in space.

<u>Enablement</u>: At least two opposed CAD-controlled ATP robotics, with in-situ process control/inspection, to create an infinitely-variable virtual tool surface to weld-bond thermoplastic prepreg to build complex composite structures.

<u>Benefit</u>: Alleviates the current requirement of costly multiple rocket launches, the development of ever-larger rockets to place increasingly complex structures off-planet, and the continued use of highly-complex risky deployables.

I. <u>Ground System</u>:

- At least two connected self articulating robots for test run/simulation
- CAD programming
- Standardized prepreg tape cassette inserts
- Visual link to monitor progress (ground and Space)
- Communication link
- Launch Access
  - Heavy lift Rocket for Robots
  - Light lift Rockets for Resupply

II. <u>Off-Planet</u>:

- At least two connected space-rated self articulating robots
- Communication link
- Capture System (supply capture)
- Closed loop In-situ press control and inspection
- Deorbit capability (Earth or other planets)
- Kick Propulsion System (deploy part)
- Terrestrial placement system

Build in Space

Video with Permission from General Atomics-Aeronautic Systems Inc.

Summary : Currently, the Positive Balance of Trade for the US is Aerospace Products, *BUT*:

The State-of-the-Art (SOA) in Aerospace Thermoplastic Composites is Outside the US!

The Future Choice:

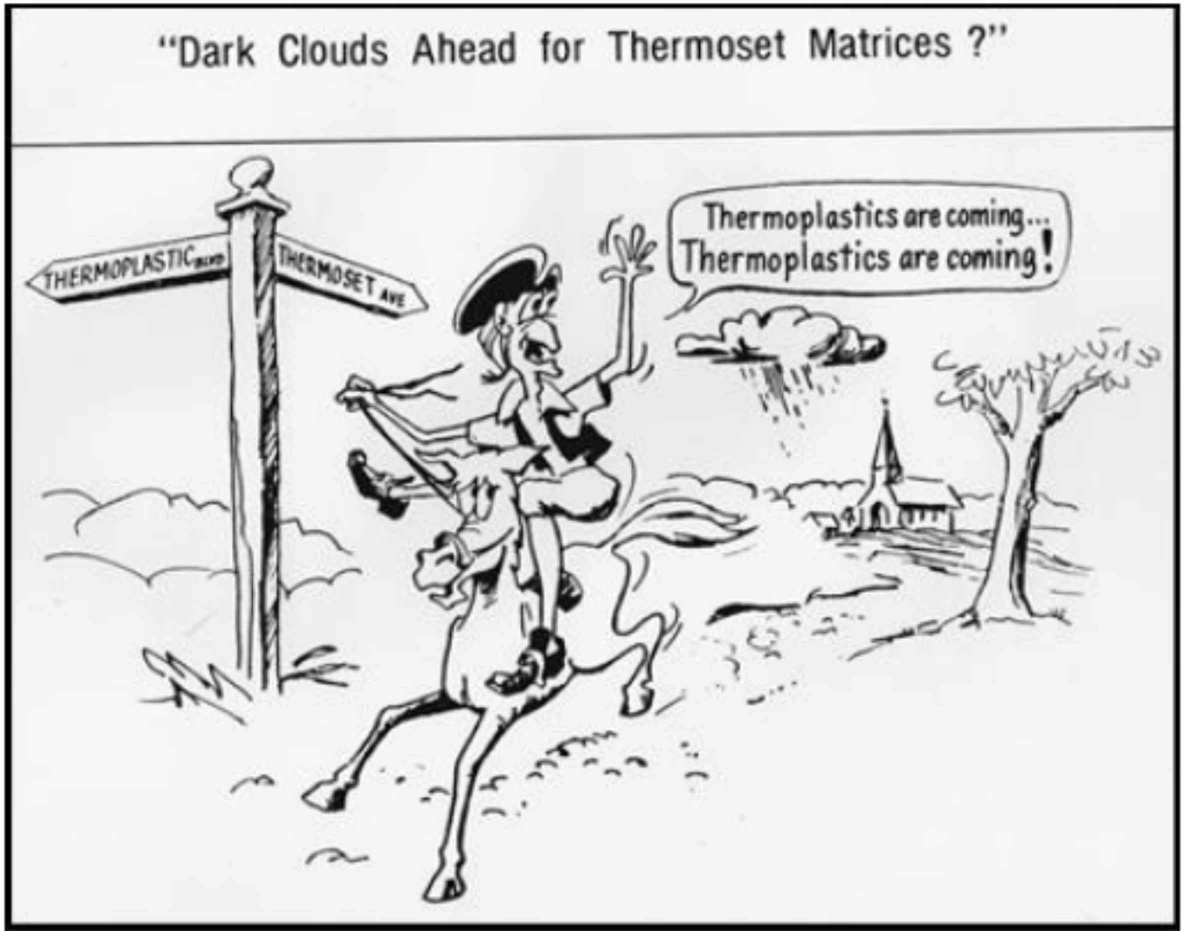
1. Purchase the current SOA manufacturing technology, or
2. Increase the Importation of SOA products, or
3. Develop the technology that supplants the current SOA process

The Requirements for Successful Collaboration:

- Government support in terms of public/private partnership
- Inclusive to all participants in the supply chain
- Governing body
- Development of a tiered participation system
- Ability to handle international relationships
- Institution of failure criteria

To compete: aerospace vehicle developers need an adaptive pathway for implementing innovations in structural manufacturing.

Thermoplastics are not a Panacea, but a Tool



The winner is whoever can profitably produce that part within Spec at the lowest overall cost to the customer.