Comparison of Invar and Composite Tooling Materials for Precision Composite Part Manufacture

Presented at:

SAMPE Brazil

October 2015

Paul Walsh

My Background

- **M.S. Materials Engineering – Univ of Utah**

- **Have held various technical and management roles at Goodrich Aerospace, Hercules Aerospace (now ATK), and Zoltek Carbon Fibers**

- **Today President and COO of Ascent Tooling Group, the largest aerospace tooling business in the world**
  - Coast Composites, LLC
  - Odyssey Industries, LLC
  - Global Tooling Systems, LLC

What constitutes a good mold?

1. **Dimensionally accurate**
   – At room temperature <u>and</u> at cure temperature

2. **Vacuum tight bagging surface**

3. **Thermally stable over time & repeated cycles**
   – Dimensions don’t change
   – Vacuum integrity doesn’t degrade
   – Surface finish doesn’t degrade

4. **Durable through required production quantity + buffer**

Aircraft Part Tolerances

Stringers located on sub-assembly fixture

Skin positioned to stringers via DA

DA Locating Feature

- **Trend towards determinant assembly (DA) is driving part tolerances**
  - Typical profile tolerances ~1.5 mm
  - Positional tolerances for DA holes **~ 0.5 mm**
- **Tool tolerances are typically 25% to 50% of part tolerances**

Thermal expansion differences between tool and part must be considered to achieve desired tolerances

Coefficient of Thermal Expansion

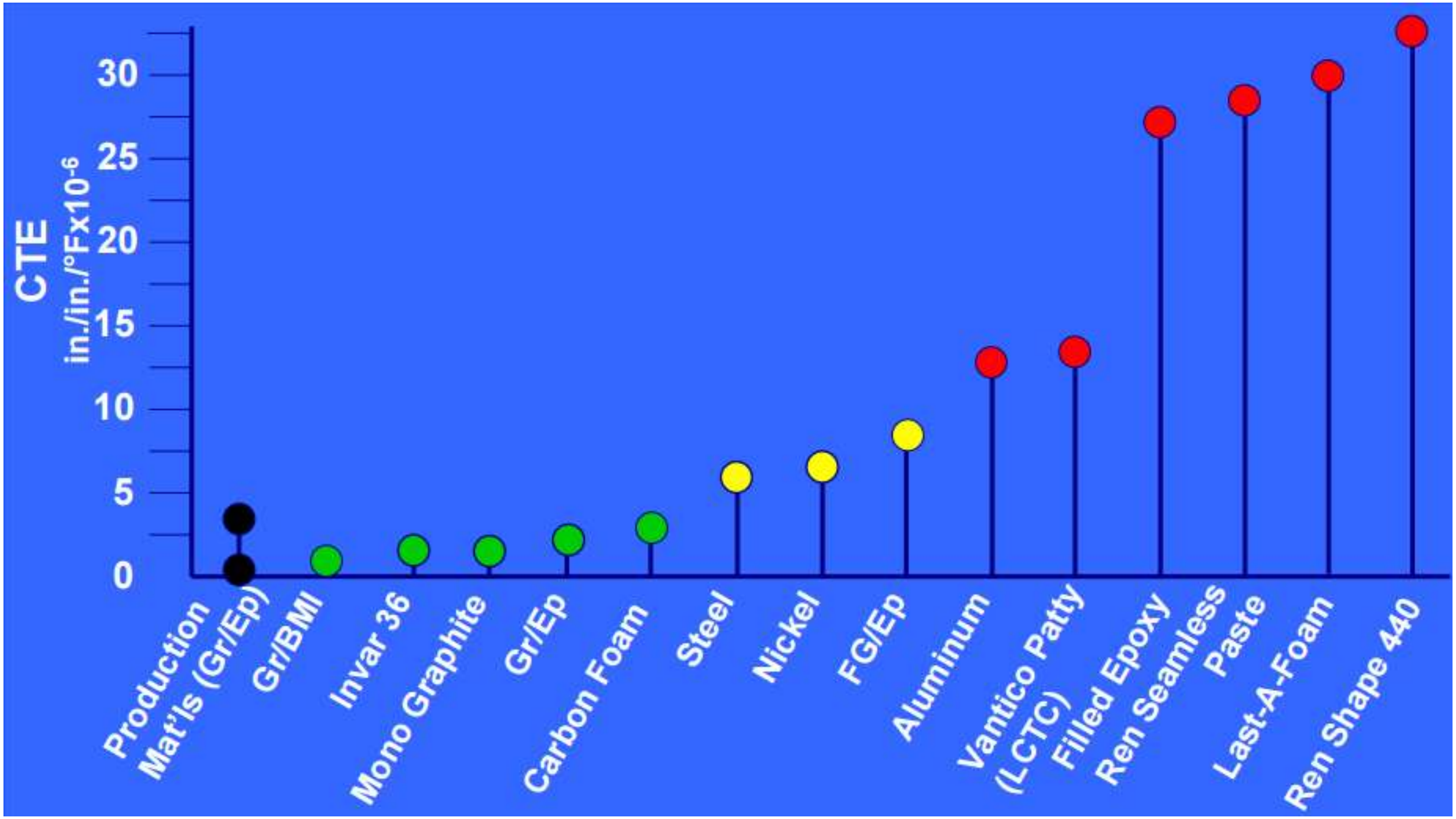
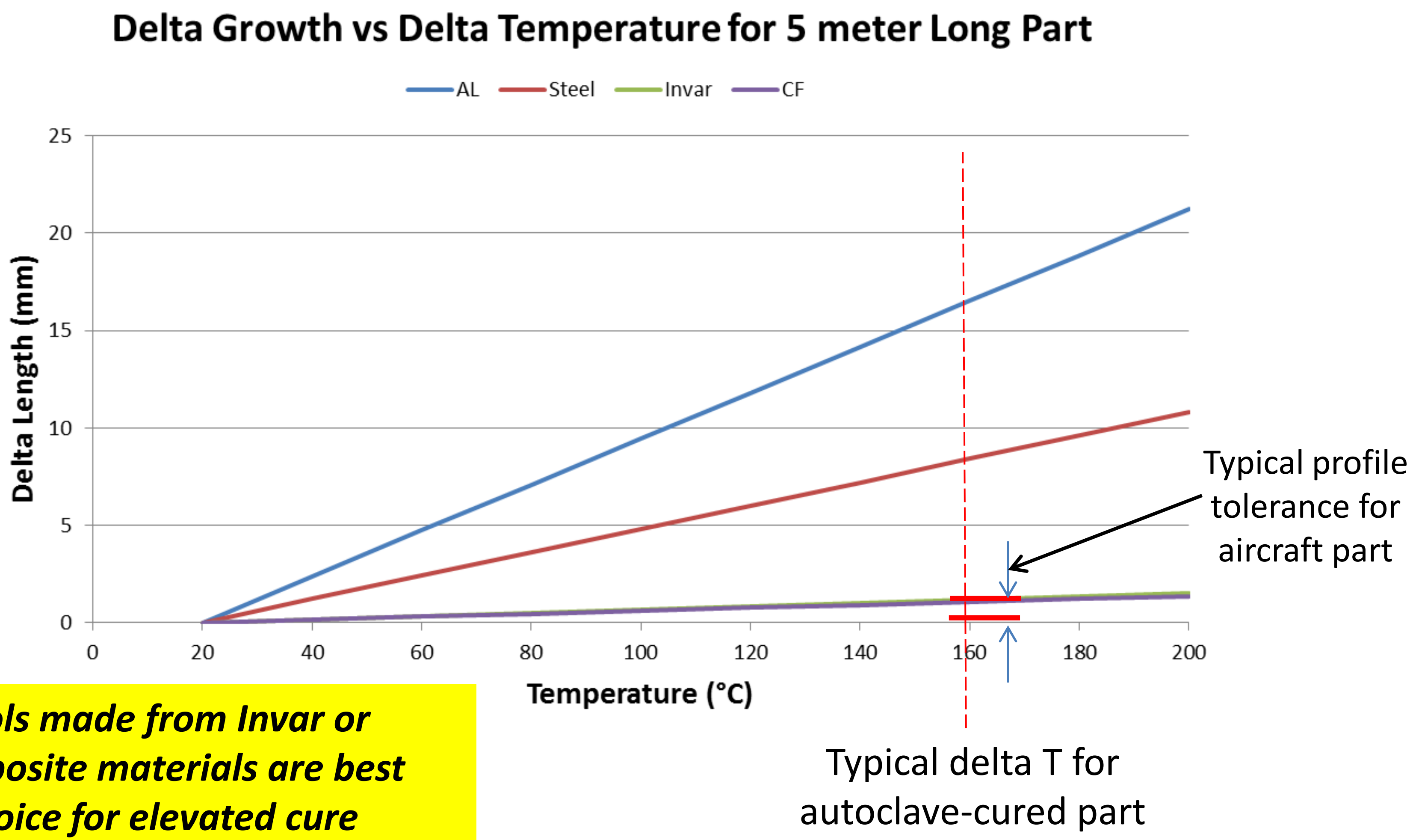


Chart: sme.org, credit Dave Dickson

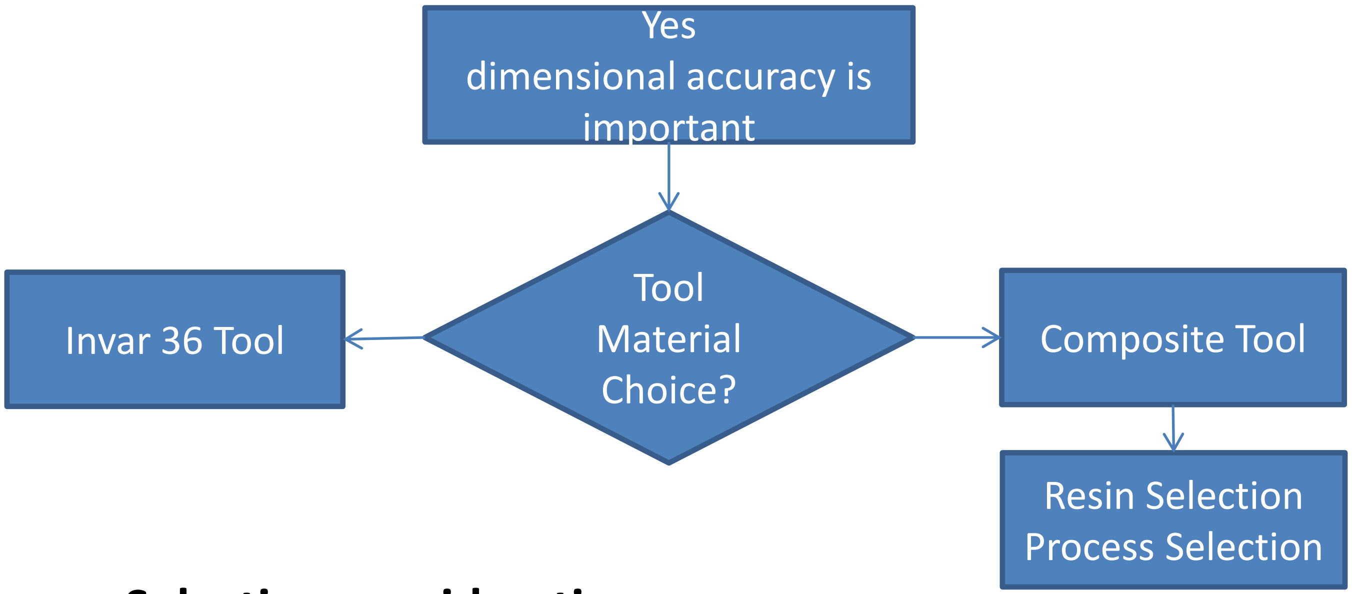
ASCENT TOOLING GROUP
AN AIP AEROSPACE COMPANY

Problem Statement



Tools made from Invar or Composite materials are best choice for elevated cure temperature composite parts

Production Tool Choices - Invar or Composite – which one should I select?



Selection considerations

- Number of parts to make
- Manufacturing process
- Program risk
- Schedule limitations
- Cost limitations
- Infrastructure and equipment constraints

Tool Life Considerations

- **How many parts do you need to make?**
  - Prototype/R&D tool
  - Limited run
  - Long-term production run
- **How long will program run?**
- **Anticipated design changes?**
  - Minor, reconfigure existing tool
  - Major, make new tool

CFRP tools can be locally reconfigured by adding material to existing laminate

Qualifiers – Composite Tool Life Dependencies

- **Resin**
  - BMI is more thermally stable, less microcracking & dimensional change
- **Manufacturing process**
  - Ply consolidation during layup
  - Ply consolidation during cure
  - Machining techniques
- **Shop practice**
  - Trimming plys on tool surface
  - Demolding practices
  - Exposure to temperatures above Tg
  - Cleaning solvents & practices
  - Proper storage – avoid UV and moisture

Shop practices that shorten tool life:

Cutting on tool surface:

Demolding with metal wedges:

Composite tool exposed to moisture:

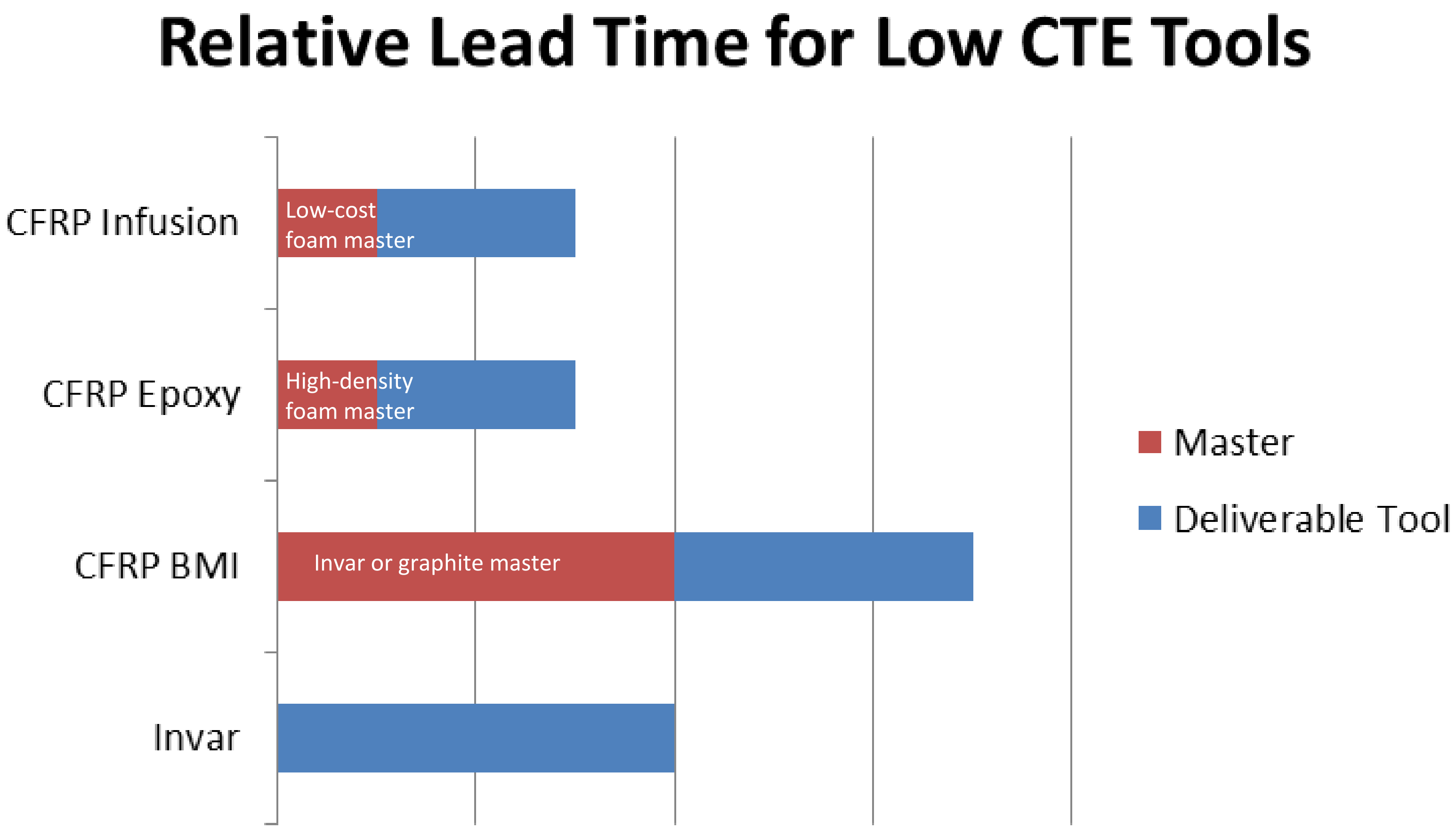
Durability and Ease of Repair

- **Typical types of tool damage**
  - Knife cuts, scratches, nicks
  - Dents from impact damage
  - Delaminations due to damage, over-temp, UV exposure, or moisture exposure

Scratches from knife cuts

Invar	CFRP
Very Durable	**Medium durability**
Straightforward to repair with conventional metalworking practices	**Major defects difficult to repair**
Vacuum leaks can be fixed with weld	**Vacuum leaks need material removal and replacement**

Manufacturing Times



Tool Weight Considerations

Photo: aerospaceengineeringblog.com

CFRP BMI was used for this tool due to weight and rotational force considerations on AFP machine.

- **Movement and handling**
  - ? Rotational mass on AFP machine
  - ? Push cart / forklift / crane / AGV

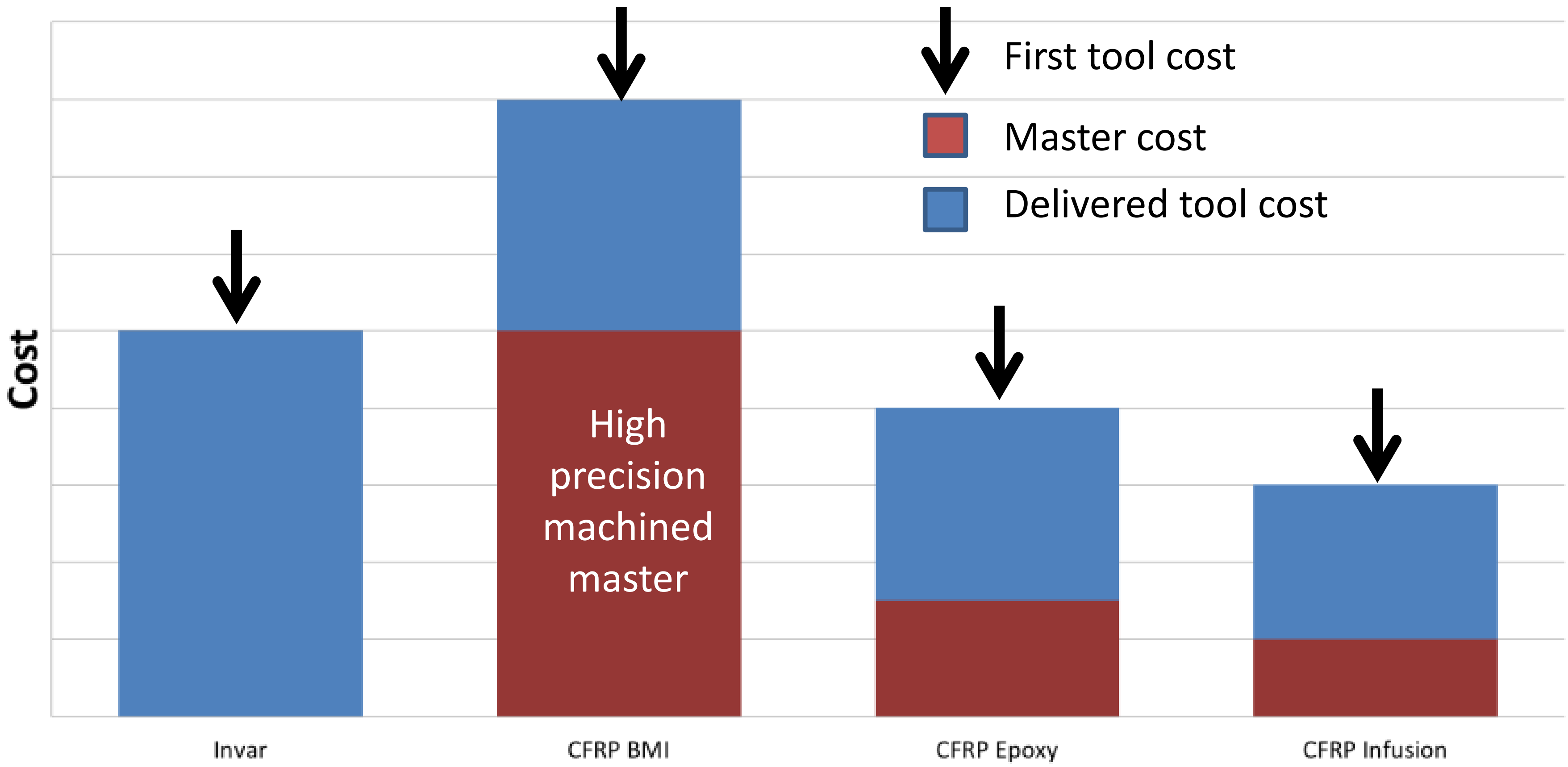
- **Thermal mass**

CFRP	Invar
Lightest tool	Moderate weight
Least thermal mass	Moderate thermal mass
Shortest cycle*	Longer thermal cycle*

*Thermal cycle time often limited by cure profile and not tool

ASCENT TOOLING GROUP
AN AIP AEROSPACE COMPANY

Cost – Initial and Rate Tooling



Life of program cost can be higher for composite tools because of limited life

Choosing Between Low CTE Tooling Materials

Low CTE Layup Tool Materials		Tool Life (thermal cycles)	Weight	Durability	Initial Cost	Rate Tool Cost	Ease to Reconfigure	Ease to Repair	Tool Technology Legacy
		@ 350F	***Lighter *Heavier	***More Durable *Less Durable	***Lower Cost *Higher Cost	***Lower Cost *Higher Cost	***Easy *Difficult	***Easy *Difficult	Years in Service
Invar		Unlimited	*	***	**	*	*	***	25
CFRP BMI		Up to 500	***	**	*	**	**	*	10
CFRP Epoxy (autoclave cure)		Up to 100	***	*	**	***	**	*	20
CFRP Epoxy (infused)		Up to 20	***	*	***	***	**	*	10

Summary

- **Low CTE layup tooling is critical to the manufacture of precision composite aircraft parts**
  - **Invar is still the gold standard for production aerospace molds based upon 25 years of manufacturing and use experience**
    - First choice for production layup tooling if no weight constraints
    - Least long-term risk (durable, easily repaired)
  - **Composite materials and processes are improving and have a growing place for layup molds**
    - BMI and benzoxazine tooling offer improved long term durability and higher temperature capability than traditional epoxy resins
    - Solves weight and infrastructure constraint challenges

Acknowledgements

- **Mike Fox – Composite Tool Manager, Coast Composites, LLC**
- **Dan Brennan – Mfg Engineer, Coast Composites, LLC**
- **Don Sowers – Design Manager, Coast Composites, LLC**
- **Ken Page – Design Manager, Odyssey Industries, LLC**
- **Mark Media – VP Engineering, Global Tooling Systems, LLC**
- **Bob Mitchell – Technical Director, Ascent Tooling Group**
- **Colin Birtles – Technical Director, Ascent Tooling Group**

APPENDIX

Abstract

Composite aerostructures depend on precision cure tooling to satisfy dimensional requirements, repeatability in manufacture, and part fit-up. Low CTE (coefficient of thermal expansion) materials that are closely matched to that of the composite material used for the part are the key to achieving these goals. Today, invar and composite materials are commonly used for tooling applications because their CTE is closely matched to the composite part.

This paper will contrast tooling made from invar and composite materials and discuss reasons for selection of one versus the other.