

Thermoplastic Composite Aircraft Manufacturing Model

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Introduction: Joseph Heil

- PhD- University of Nottingham: Carbon Fiber Recycling
- R&T/ Product Development Engineer, Spirit AeroSystems
 - PI HiCAM Thermoplastics
 - Trade Study, VBO, Materials Characterization focal
- Eagle Scout, Troop 214 Occoneechee Council NC
- Scoutmaster Troop 515 Quivira Council, KS
- Lighting Designer, IATSE stagehand, Technical Director:
Wichita Community Theatre

Birds Eye View

- HiCAM Reference Aircraft
- Key Performance Parameters (KPPs)
- Manufacturing Simulation (ALM, DES)
- Thermoplastic Manufacturing Process Flow
- Using the ALM in trade studies

Hi-Rate Composites Aircraft Manufacturing (HiCAM)

Goal: Demonstrate manufacturing approaches for composite primary airframe structures that enable high-rate production with reduced cost and no weight penalty versus 2020 technology for early 2030s single-aisle aircraft production



Objectives:

- Mature affordable, high-rate composite manufacturing technologies, with reduced labor, equipment, and tooling costs
- Develop model-based engineering tools for high-rate concepts

Approach:

- Baseline: scaled B787/777x composite aircraft production system
- Compete thermosets, thermoplastics, resin transfer molding
- System assessment of production cost and component weight
- Demonstrate capability for full-scale airframe component(s)

Addresses industry needs for rate, cost, and weight

Public-Private Partnership with 50:50 cost share



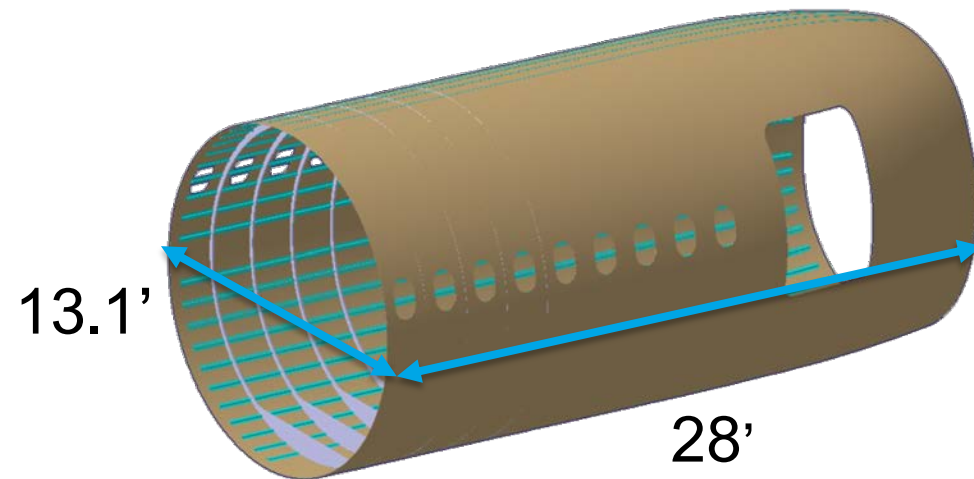
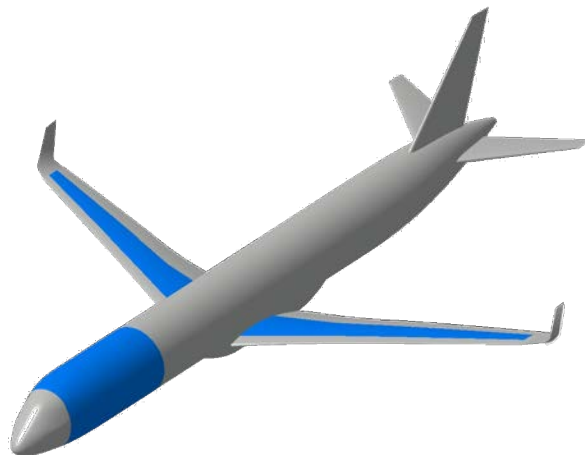
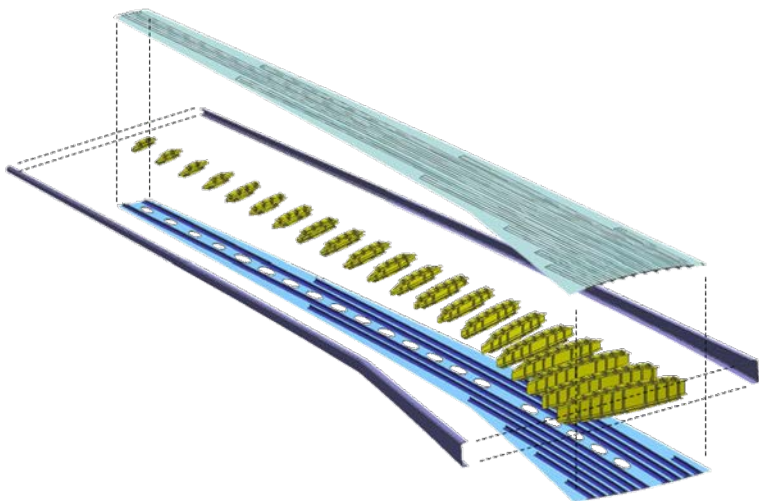
Advanced Composites Consortium

sampe
North America

HiCAM Aircraft

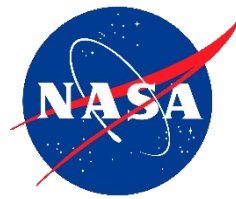
Reference Aircraft

- Fuselage: frames, stringers, skin, door surround, window frames



Baseline Aircraft

- Autoclave cure thermoset prepeg, full barrel
- SOA twin aisle manufacturing, resized for single aisle



HiCAM Success Criteria

- New technologies to build composite aircraft faster (80/ month), lighter and less expensive
 - Next Generation Thermosets
 - Resin Infusion
 - **Thermoplastics**

	Reduction offered by TPC wrt Baseline	Partial Success	Full Success	Savings Driver
KPP: Nonrecurring Cost	31%			OoA, panels vs barrel
KPP: Recurring Cost	45%			No filler plies, stamped body frames
KPP: Factory Area (m²)	34%			
Weight (kg)	12%	<2 % heavier	> 2% lighter	Fewer fasteners, IM fibers
Unit Cost	39%	> 30%	> 50%	

KPP: Key Performance Parameter

Unit Cost: recurring + (nonrecurring / 3600)

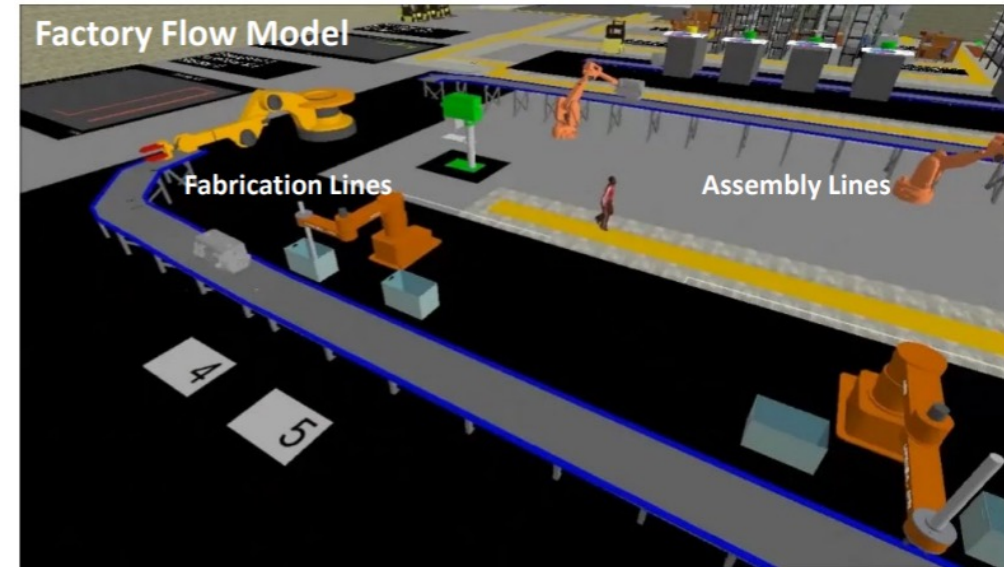
Recurring: material + labor

Nonrecurring: equipment + tooling + factory area



Manufacturing Model Tools

- Activity Level Model (ALM)
 - Static, excel spreadsheets
 - Provides inputs to DES
- Discrete Event Simulation (DES)
 - Adds variability
 - Handles queuing & blocking behavior
 - Calculates KPPs
 - Simio



Activity Level Model

Part	Module	Station	Station_Duration	Max_Head	Station_Labor	Capital_Equipment_Cost	Station_Area	Cumulative Labor Hour	Cumulative Flow Hour	Station %	Cumulative %	Occurance / Shipset	Occurrences / Month	Number of Copies	Capital Required
ety_Panel	AFP Prep	srvAFPPrep	1.30	2.0	2.60	\$ 80,000	2,620	668.5	561.4	0.6%	65.1%	4	320	1.0	\$ 80,000
ety_Panel	Panel Fab	srvPanelAFP	17.29	1.0	17.29	\$ 15,468,000	6,733	737.7	630.6	8.0%	73.1%	4	320	13.0	\$ 201,084,000
ety_Panel	Panel Fab	srvRoughTrim	2.28	1.0	2.28	\$ 6,985,734	3,144	742.3	635.2	0.5%	73.7%	2	160	1.0	\$ 6,985,734
ety_Panel	Panel Fab	srvRoughTrim	2.23	1.0	2.23	\$ 6,985,734	3,144	746.7	639.6	0.5%	74.2%	2	160	1.0	\$ 6,985,734
ety_Panel	Panel Fab	srvSkinStamp	0.55	2.0	1.10	\$ 15,109,333	10,000	751.1	641.8	0.3%	74.4%	4	320	1.0	\$ 15,109,333
ety_Panel	Panel Fab	srvPanelTrim	3.09	1.0	3.09	\$ 8,085,734	3,144	757.3	648.0	0.7%	75.2%	2	160	2.0	\$ 16,171,468
ety_Panel	Panel Fab	srvPanelTrim	3.08	1.0	3.08	\$ 8,085,734	3,144	763.5	654.2	0.7%	75.9%	2	160	2.0	\$ 16,171,468
ety_Panel	Panel Fab	srvDeburr	3.50	3.0	10.50	\$ 50,000	2,620	805.5	668.2	1.6%	77.5%	4	320	3.0	\$ 150,000

Stations
 -from process flow
 -collects & sums costs from other worksheets

Activities
 -detailed task breakdown
 -duration often designed to scale with size

Stationary Equipment
 -equipment/tooling fixed at each station
 - ex hand tools, AFP machines, locating jigs

Material
 -composite material consumed
 -includes waste/ excess

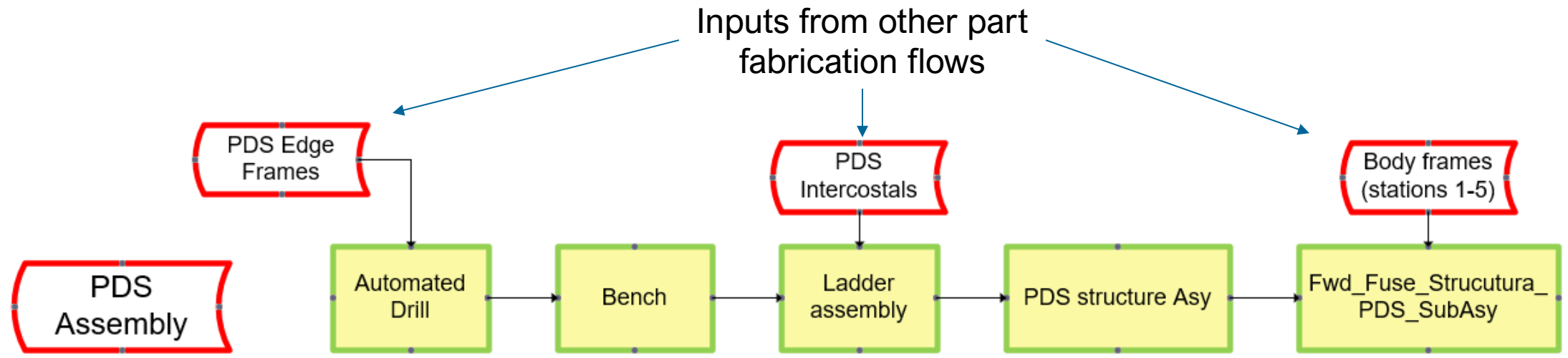
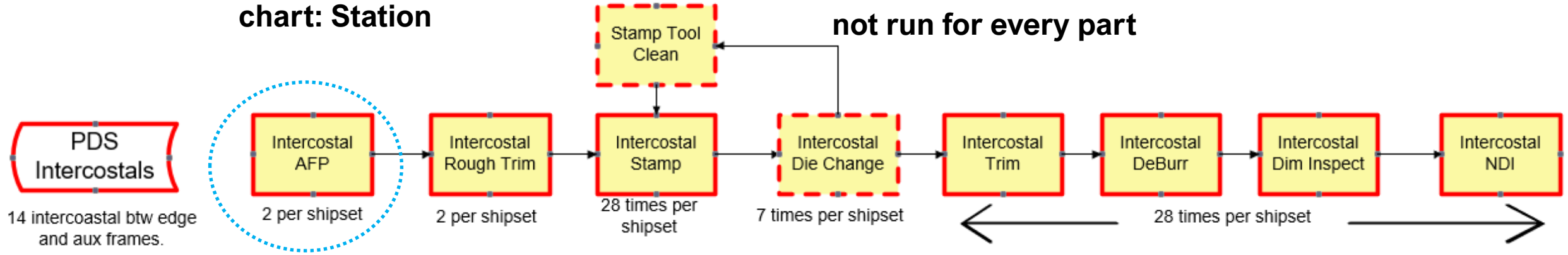
Transient Equipment
 -equipment/tooling that travels with part or is shared across stations
 - ex FPM, transportation vehicle, overhead cranes

Area
 -how much floor space is used
 -supported by 2D layout

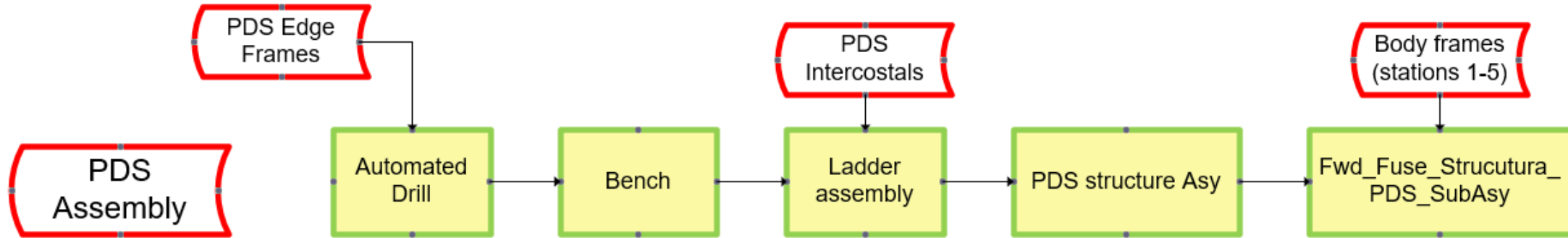
Process Flow

Box on flow chart: Station

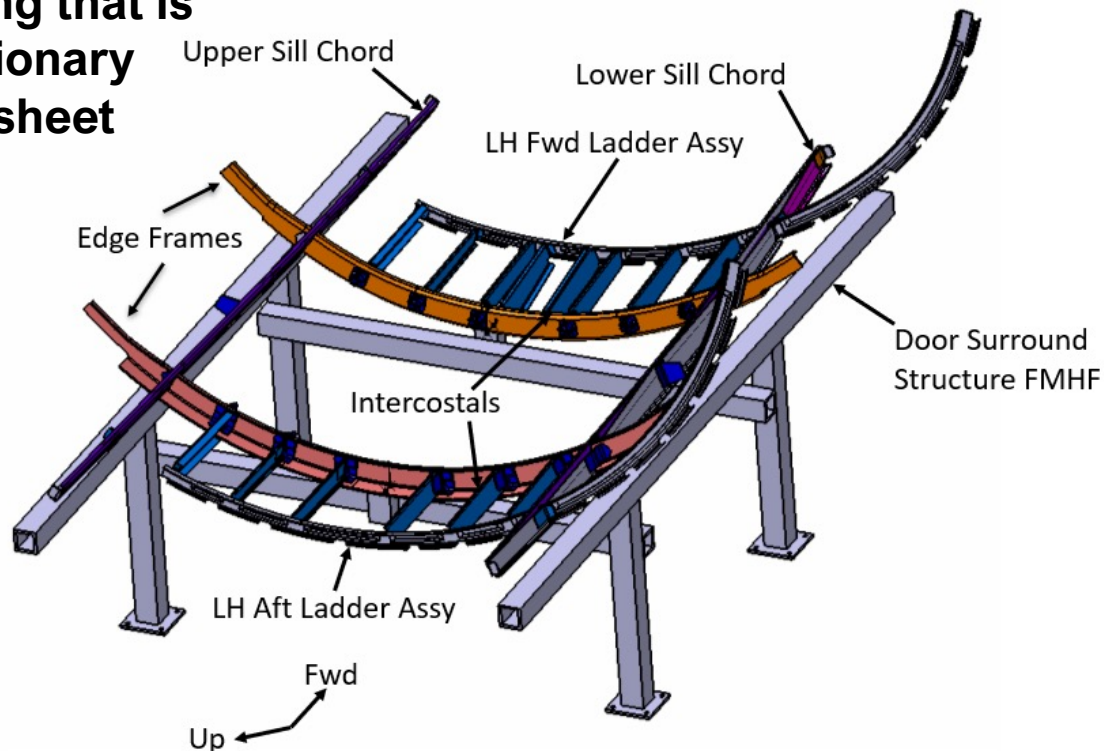
Dashed lines: does not run for every part



Process Flow



Example of tooling that is captured on stationary equipment worksheet

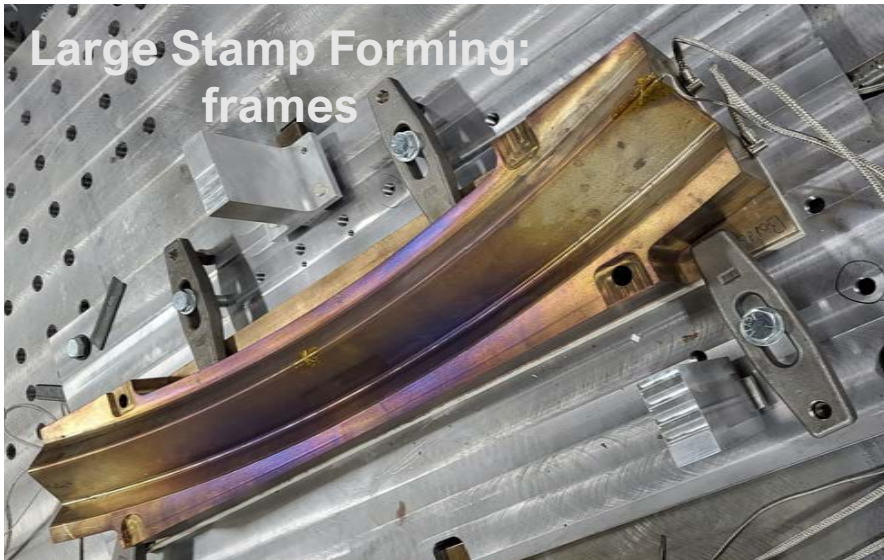


Why do you need a DES?

- Is this tool available?
 - Do I have all my parts yet?
 - Does the task *always* take *exactly* this long?
 - How many transient tools do I need?
 - Where or what is my bottleneck?
- Variability, Queuing, and Blocking*


Leveraging Thermoplastic Traits in Manufacturing Planning

- Rapid detail part fabrication
- Stamp Forming- 5 min cycle time
 - High consolidation pressure
 - Repeatable, high dimensional accuracy



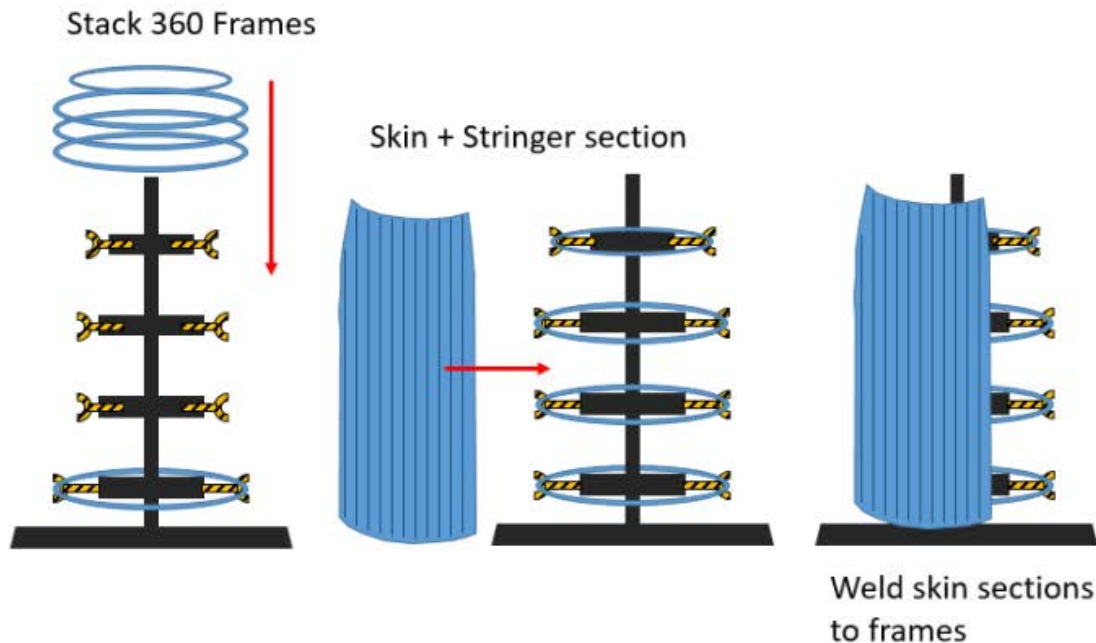
In HiCAM, Skins are made with AFP, all other parts made by stamp forming



Small/ medium Stamping:
Intercostals, Clips & brackets 

Leveraging Thermoplastic Traits in Manufacturing Planning

- Welding to make integrated sub assemblies
 - Holes and fasteners require high degree of inspection and rework
 - No chemical reaction needed
 - Co-Fusion: join and consolidate in same step



ALM Trade Study Co-Fusion vs. Stamp Form Skins

- AFP → Co-Fusion or
- AFP → Stamp → weld stringers
- Stamping
 - Very fast
 - Untested size of equipment and tooling
 - lower risk → more skin panels
 - (size of part/tooling/equipment smaller)



Trade Study: Results

KPP	Savings Compared to Baseline		
	Co-Fusion	Stamp Skins (6 panel)	Stamp Skin (3 panel)
Recurring Cost	48%	49%	52%
NRC	26%	21%	27%
Unit Cost	39%	37%	41%

Less expensive

Stamping: faster than Co-Fusion
Reduced labor
Fewer station replicates

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Significant increase in tooling/equipment costs

more expensive

Model	Station	# of Copies	Labor Hours (per month)	Non-recurring Cost	
Co-Fusion	Co-Fusion Consolidation	3	2366	\$12.8M	0.7%
	Pick & Place Stringers	2	2477	\$10.6M	0.6%
	Skin Support Assembly	10	8336	\$415M	22.7%
	Skin Splice Welding	2	578	\$95.4M	5.2%
Stamped Skins (6 skin panels)	Stamp Skin	1	240	\$7.61M	0.4%
	Pick & Place and Weld Stringers	3	3269	\$17.7M	1.0%
	Skin Support Assembly	11	9672	\$456M	25%
	Skin Splice Welding	3	934	\$143M	7.8%

Why do costs go up?
 -more setup time
 -more time drives more tooling & equipment
 -more tools

- These stations contain disproportional amounts of NRC
- Skin support assembly has highest labor cost

In Summary

- HiCAM: 80 composite airplanes a month
- Need new ways & new materials to build them
- Manufacturing flow simulation can help quantify the costs
- Activity Level Model: back of the envelope
- Discrete Event Simulation: build in variability and additional complexity
- Thermoplastics: labor savings outweighs investment in capital equipment

Questions

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