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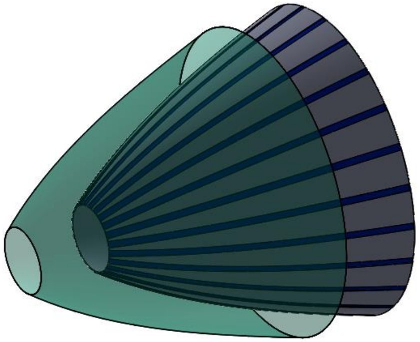
Vulcain Cryogenic Engine Nozzle Project Phase 2

Ref: 4000124286/18/NL/LvH/zk

"ESA PHASE 2"

COMPLETION DATE: NOVEMBER 2022

- Spincraft: All teams involved in the project
- ESA : Andreas Gernorth, Marco De Rosa and their team
- GKN : Fredrik Niklasson and his team



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Setting the context

ILLUSTRATION OF THE TWO ARIANE 6 VARIANTS PLANNED,
A62 (LEFT) AND A64 (RIGHT)

THE VULCAIN®2.1 ON THE PF50 TEST BENCH
AT ARIANE GROUP IN VERNON ©
ARIANEGROUP/DOMINIQUE ESKENAZI

ESA Phase 2 Objectives

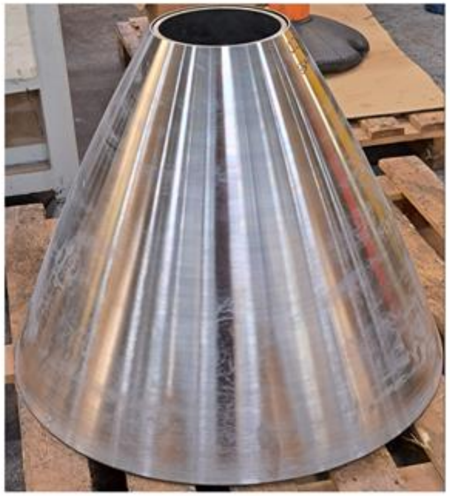
Demonstrate whether:

Metal spinning can be used as a technology for sandwich nozzle launcher manufacturing

Inconel could be used in Nozzle forming technology

Shear forming can be an alternative manufacturing method for Vulcain 2 extension nozzles

SPUN SANDWICH NOZZLE AT SPINCRAFT ETG



Sandwich Cones : 087620 – 006C Paired with 002MA

VULCAIN-2 NOZZLE EXTENSION

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Consisting of SIX Sub-Projects:

P1 : Full Size Carpenter inner nozzle from welded sheet

P2 : Subscale Carpenter inner nozzle from pre-machined circle

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms

P4 : Subscale Inconel inner nozzle from rolled and welded preform

P5 : Subscale Carpenter inner nozzle

P6 : Subscale inner and outer nozzle by optimised process

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ESA PHASE 2

6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet

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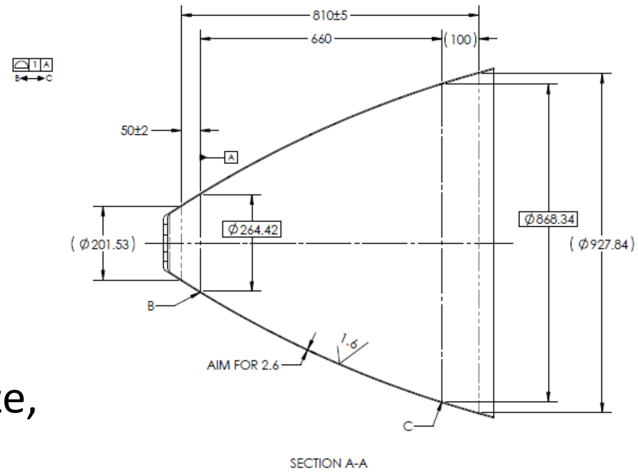
P1 - Full size Carpenter inner nozzle from welded sheet

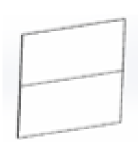
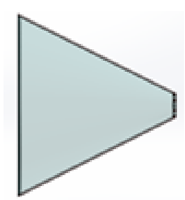
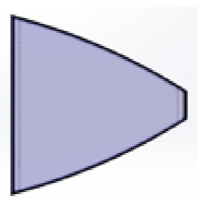
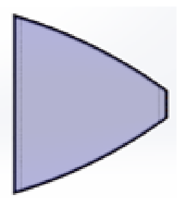
MATERIAL Carpenter 21-6-9

AIM Complete a full-scale inner nozzle using tooling from phase 1

OBJECTIVE Understand influence of HT on grain size, hardness and mechanical properties



Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
 2 segments	 Full scale blank						

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P1 - Full Size Carpenter inner nozzle from welded sheet

Elongated Cone On the Mandrel

Extended flange was cut off at the end

Flange showing 'curled lip'

Finished Elongated Cone still showing larger flange than normal even after being trimmed off.

Similar welded cone before being spun

P1 - Full Size Carpenter inner nozzle from welded sheet

MATERIAL Carpenter 21-6-9

Outcome:

2 parts

Thickness between 6% and 18% above target

Although the parts were spun down to the mandrel, cone profile not achieved.

The material stretched during shear forming causing cone elongation by 100mm.

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6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet

P2 : Subscale Carpenter inner nozzle from pre-machined circle

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms

P4 : Subscale Inconel inner nozzle from rolled and welded preform

P5 : Subscale Carpenter inner nozzle

P6 : Subscale inner and outer nozzle by optimised process

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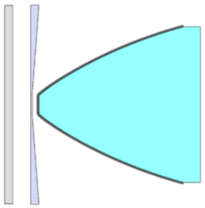
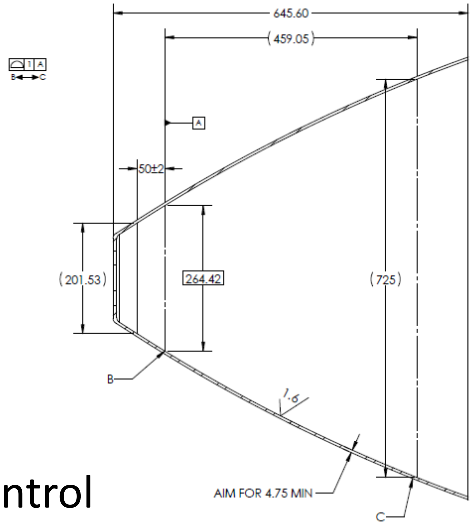
P2 - Subscale Carpenter inner nozzle from pre-machined circle





MATERIAL

Carpenter 21-6-9

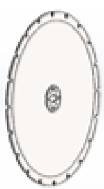
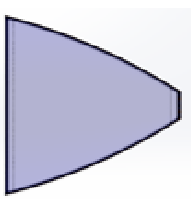
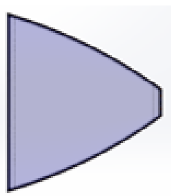
AIM

Form a subscale inner nozzle
Blank was machined prior to forming

OBJECTIVE

Understand influence of HT on grain size, hardness, mechanical properties and profile control

Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
✗	 Machine blank	✗	✗	✗			

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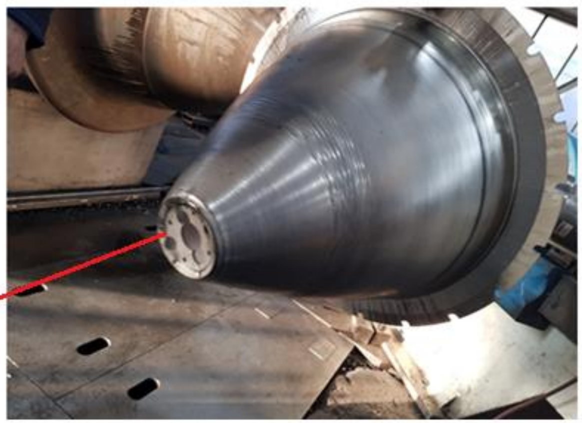
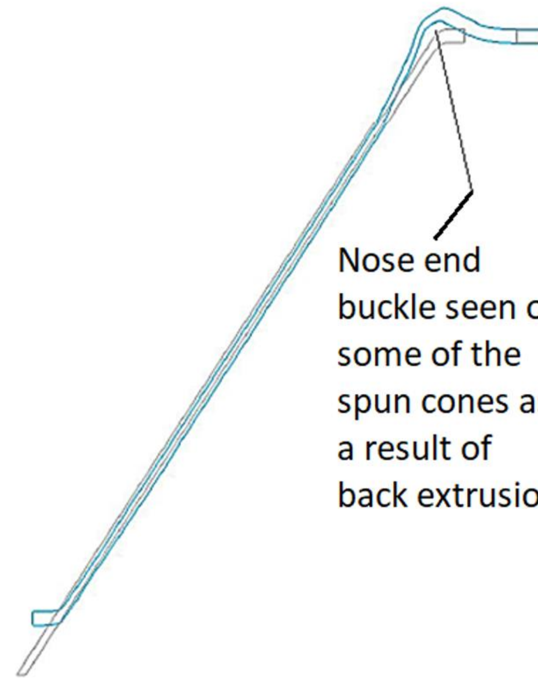
P2 - Subscale Carpenter inner nozzle from pre-machined sheet

MATERIAL Carpenter 21-6-9



Nose End

Failure Modes:
1. Buckled end face
2. Galling- Scratch marks



Nose end buckle seen on some of the spun cones as a result of back extrusion

ESA Project Polyworks profile : cross section of spun cone with end buckle

Part experienced runback of material

Note that front buckle was experienced on all 6 projects.

P2 - Subscale Carpenter inner nozzle from pre-machined sheet

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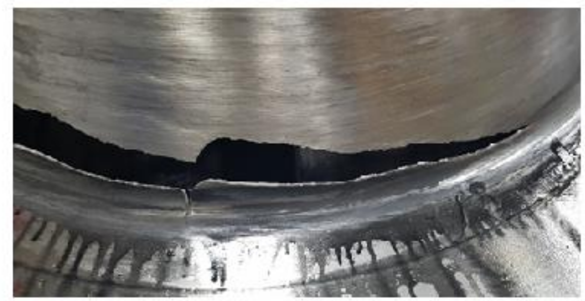
MATERIAL Carpenter 21-6-9

Circumferential ductile fracture failure

Close up of the left end of the crack propagation



Close up of the right end crack propagation

Fractures caused by work hardening ahead of the roller deformation path.

P2 - Subscale Carpenter inner nozzle from pre-machined sheet

MATERIAL Carpenter 21-6-9

Outcome:

3 parts

Thickness between 54% and 69% below target

All 3 parts failed – Run out and conicity issues reported

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6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet

P2 : Subscale Carpenter inner nozzle from pre-machined circle

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms

P4 : Subscale Inconel inner nozzle from rolled and welded preform

P5 : Subscale Carpenter inner nozzle

P6 : Subscale inner and outer nozzle by optimised process

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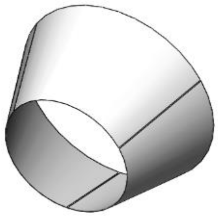
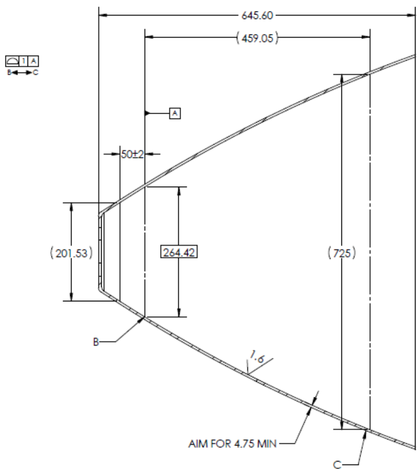
P3 - Subscale Carpenter inner nozzle from rolled and welded preforms

MATERIAL Carpenter 21-6-9

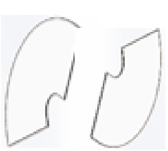
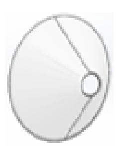
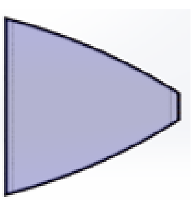
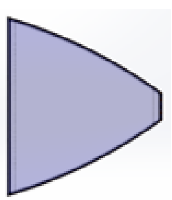
AIM 1 step forming of a subscale

OBJECTIVE Understand cost and future capability





Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
 2 segments	 Rolled and Welded segments and top plate						

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P3 - Subscale Carpenter inner nozzle from rolled and welded preforms

MATERIAL Carpenter 21-6-9

Outcome:

4 parts

Thickness between 12% and 27% above target

All 4 parts failed before turning stage due to weld the fracturing during the spinning process

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Splits of the welds on the conical section. End cap weld started to fail.

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6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet.

P2 : Subscale Carpenter inner nozzle from pre-machined circle.

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms.

P4 : Subscale Inconel inner nozzle from rolled and welded preform.

P5 : Subscale Carpenter inner nozzle.

P6 : Subscale inner and outer nozzle by optimised process.

P4 - Subscale Inconel inner nozzle from rolled and welded preform.

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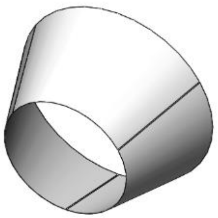
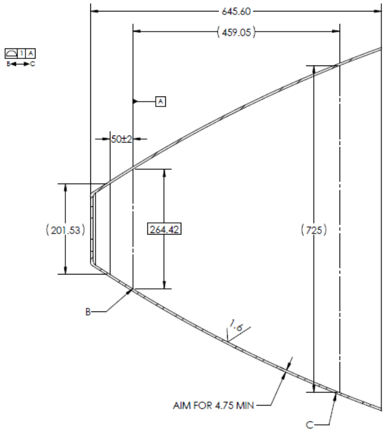
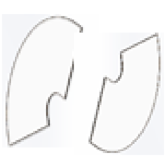
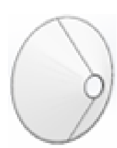
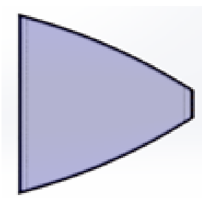
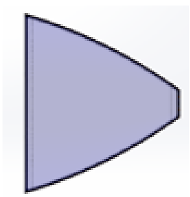
MATERIAL	Inconel 718
AIM	1 step forming of a subscale inner nozzle using segments
OBJECTIVE	Understand cost and future capability





Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
 2 segments	 Rolled and Welded segments and top plate						

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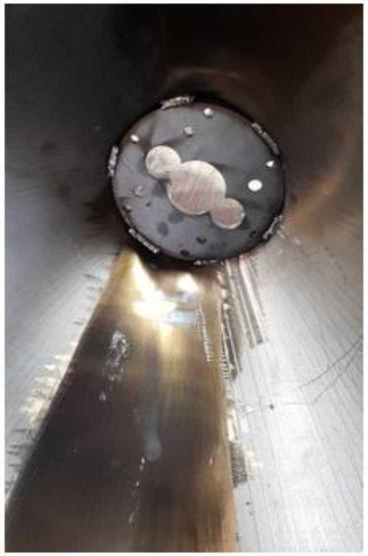
P4 - Subscale Inconel inner nozzle from rolled and welded preform.

MATERIAL Inconel 718

Part welded on side seams, Full penetration weld on outer endcap



Tack welded on inside of endcap

This resulted in endcap popping off 300mm into spinning process

Initial development for P4

P4 - Subscale Inconel inner nozzle from rolled and welded preform.

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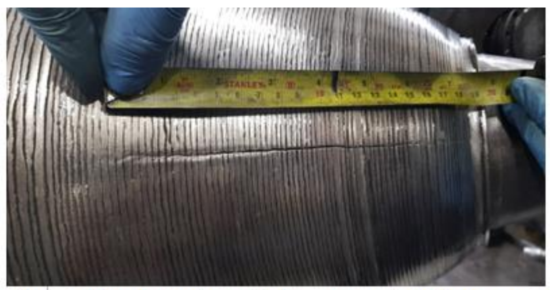
MATERIAL Inconel 718

Full Penetration weld as corrective action for endcap popping off on Inconel Cones Project 4



Despite having full penetration weld, the inconel cones failed again by suffering fractures at the side weld seams

Visual Inspection for Project 4- Inconel Cones

P4 weld seam crack failure 2

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P4 - Subscale Inconel inner nozzle from rolled and welded preform.

MATERIAL Inconel 718

Outcome:

3 parts

Thickness not measured due to early stage failure

All 3 parts failed due to fracturing at the endcap and welded seams

Visual inspection carried out

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6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet.

P2 : Subscale Carpenter inner nozzle from pre-machined circle.

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms.

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P5 : Subscale Carpenter inner nozzle.

P6 : Subscale inner and outer nozzle by optimised process.

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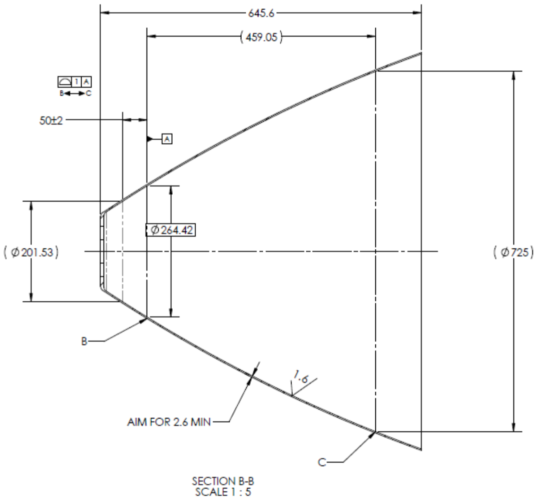
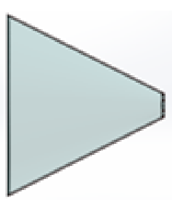
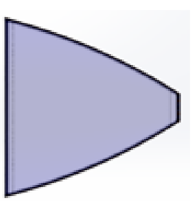
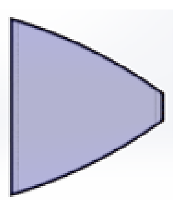
P5 - Subscale Carpenter inner nozzle.

MATERIAL	Carpenter 21-6-9
AIM	Form a subscale inner nozzle
OBJECTIVE	Geometry control on subscale part from single plate



Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
✗	 Subscale blank	✗		🔥		🔥	

P5 - Subscale Carpenter inner nozzle.

MATERIAL Carpenter 21-6-9

Outcome:

3 parts, failed

Target thickness was achieved

Although the parts were spun down to the mandrel, cone profile not achieved.

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ESA PHASE 2

6 Sub-projects

P1 : Full Size Carpenter inner nozzle from welded sheet.

P2 : Subscale Carpenter inner nozzle from pre-machined circle.

P3 : Subscale Carpenter inner nozzle from rolled and welded preforms.

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P5 : Subscale Carpenter inner nozzle.

P6 : Subscale inner and outer nozzle by optimised process.

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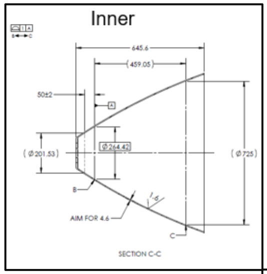
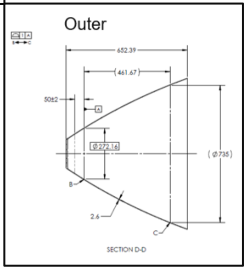
P6 - Subscale inner and outer nozzle by optimised process



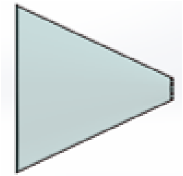
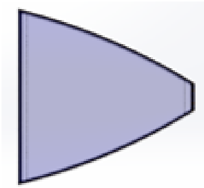
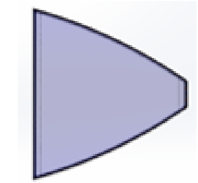


MATERIAL Carpenter 21-6-9 and 253 MA

AIM Form a subscale inner nozzle and spin a subscale outer nozzle over the inner cone

OBJECTIVES Understand the effects of spin forming the outer cone over the inner cone
Understand the geometry control achievable for both cones

Process Stages

Material Segments	Blank	Heat Treatment	Shearformed Part	Heat Treatment	Spin Form Part	Heat Treatment	Turning
	 Subscale blank						

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P6 - Subscale inner and outer nozzle by optimised process

MATERIAL Carpenter 21-6-9 and 253 MA

Outcome:

6 parts, 3 inners and 3 outers

INNER

Target thickness was achieved
Surface profile not achieved

OUTER

Target thickness achieved for 2 parts and failed for 1 part
Surface profile not achieved

Sandwich cones were presented with ovality, concentricity and runout issues after the turning.

D9.2 GKN Heat Treatment Report

GKN concluded the following:

Microstructure

- The microstructure was not completely restored after 20 minutes for the high strained part, but these experiments were done in a pre-heated furnace.
- In production, the part will be loaded in the furnace at room temperature, and therefore be subjected to a longer time at temperature, which will be sufficient to restore the microstructure.

Hardness

- All heat treatments restored the hardness for the low strain part.

Key takeaways

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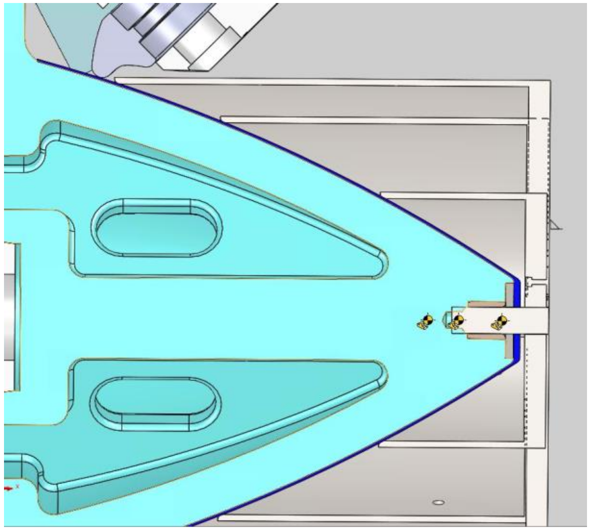
1. Despite not achieving profile tolerance of the drawing, the parts achieved the representative ogive shape.

2. Cone elongation noted in project 1 could be mitigated by holding the part at different stages. Reduced circle size would be beneficial for future development.

3. Pre-machining of the blank caused over-reduction of thickness in project 2. Thicker profile would be required for future development.

4. Multiple stage backplates would improve the runback of material.



Key takeaways

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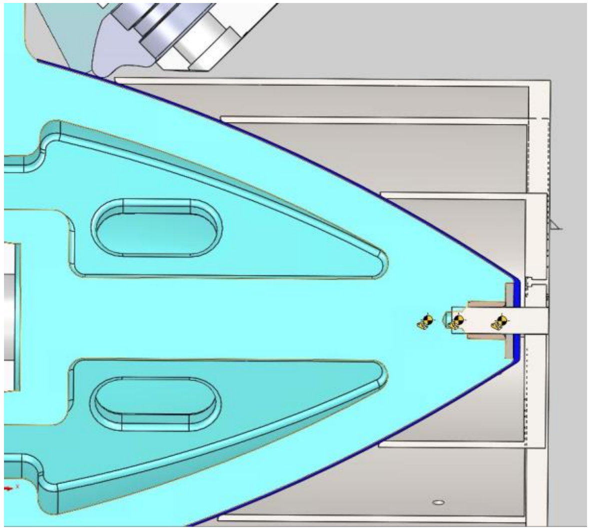
5. Spinning to net shape still has some challenges and that although the 'as-formed' shape can be improved, it is expected that machining will be required to get an acceptable level of conformity

6. To mitigate the material failures, we would propose the use of either heat during forming or additional stress relief operations.



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Engineering - Maria Delgado - mdelgado@spincraft.net

Production – Fred Patrickson – fpatrickson@spincraft.net

THANK YOU