



AERO BOOSTERS

EASA – CAAS ADDITIVE MANUFACTURING WORKSHOP SINGAPORE, 15-16 OCTOBER 2018

LBM LUBE UNIT HOUSING CERTIFICATION APPROACH

L. Schuster

15th october 2018

Route de Liers, 121
B-4041 HERSTAL (Milmort)
Belgique
NATO CODE : B1316
Tel+32 (4) 278 81 11
TVA: BE 0432.618.812 RPM Liège

	Intern	
Class	C	
Category	4	
Redaction	Function	
	Name	Schuster L.
	Signature	
Verification	Function	
	Name	
	Signature	
Approbation	Function	
	Name	
	Signature	
<u>Referenced documents</u>		
<u>For application</u>		
<u>For information</u>		
<u>Addresses</u>		



56PRE225896.A000

1

LUBE UNIT DESCRIPTION

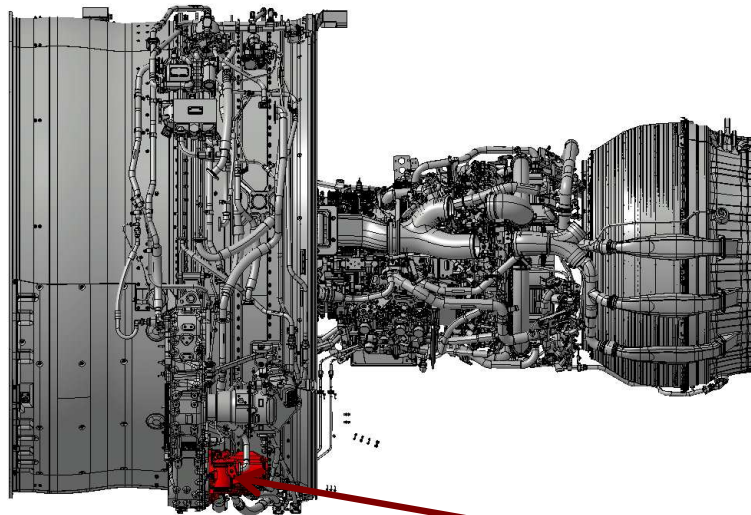


56PRE225896.A000

Lubrication Unit – Description #1/2

Lubrication Unit functions :

- ◆ Supply functions : supply oil from oil tank to bearing chambers and gears (AGB / TGB)
- ◆ Scavenge functions : scavenge oil from bearing chambers and gears to oil tank
- ◆ Driven by Accessory Gearbox (AGB)
- ◆ Protect oil circuit (valves)
- ◆ Filter the oil



56PRE225896.A000

Lubrication
Unit

Lubrication Unit – Description #2/2

Lubrication unit is composed by :

◆ Stack-up :

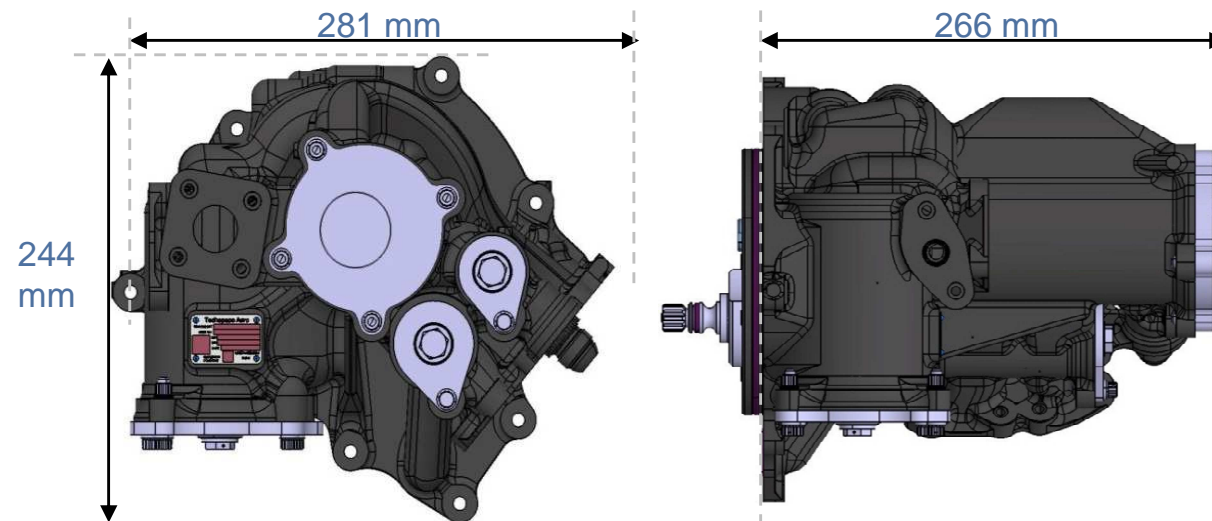
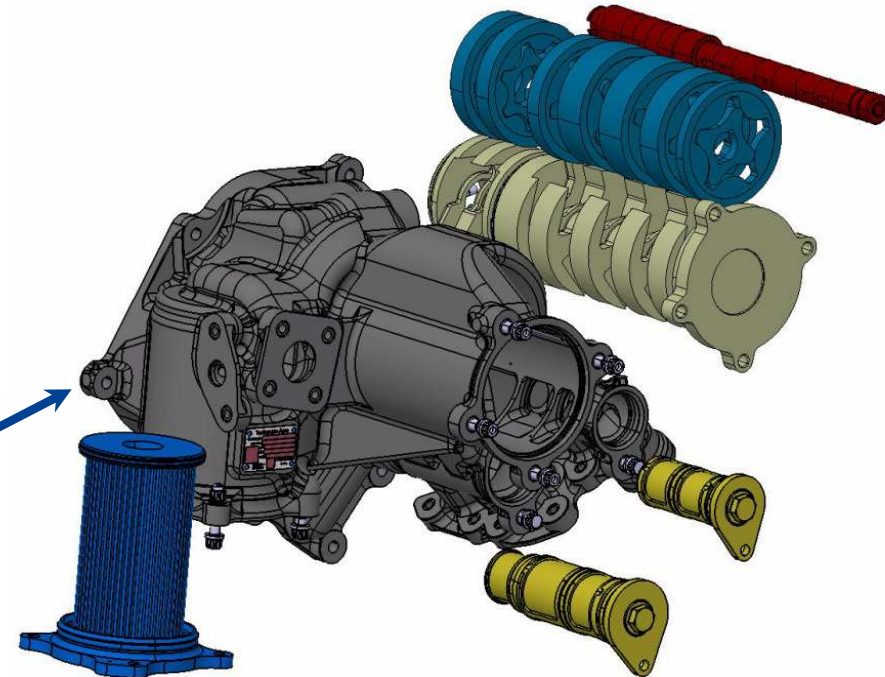
- > **Pumping elements** (supply and scavenge)
- > **Spacers** (between each pumping element)
- > **Shaft(s)**

◆ Housing proposed SLM part

>

◆ Accessories :

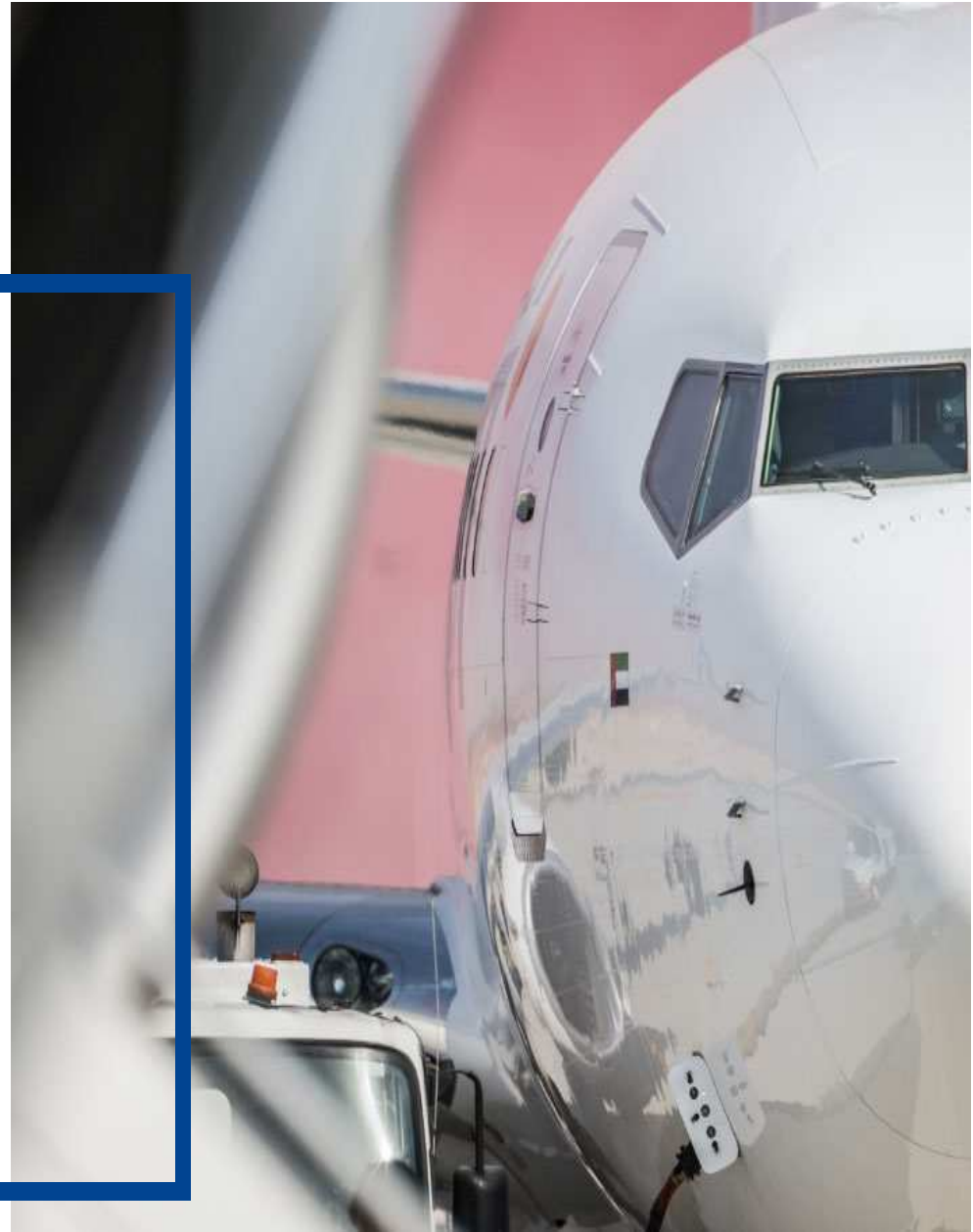
- > **Filter cartridge**
- > **Strainers**
- > Valves



56PRE225896.A000

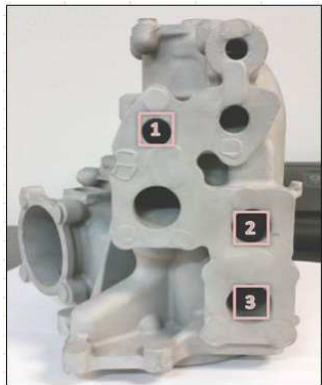
2

LUBE UNIT DESIGN

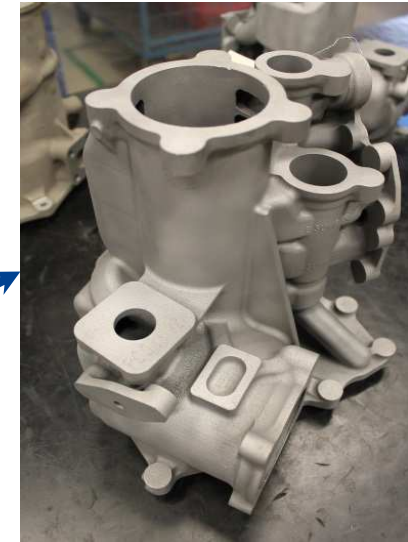
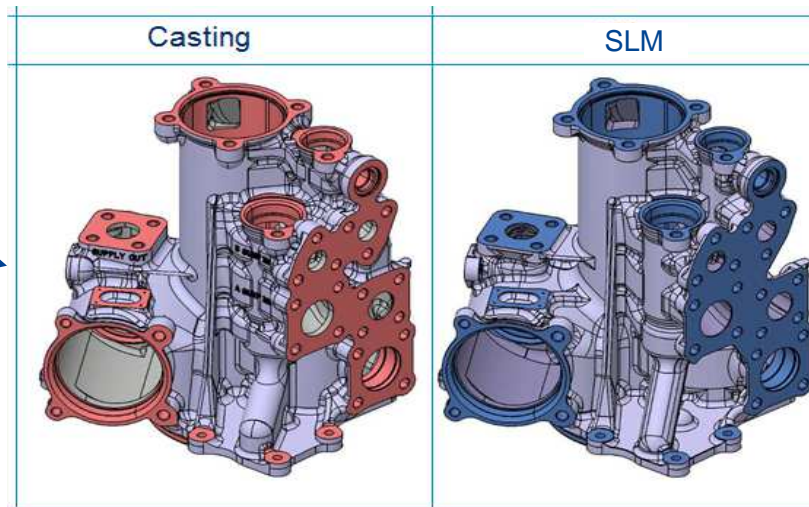


56PRE225896.A000

Lubrication Unit – Description #1/1

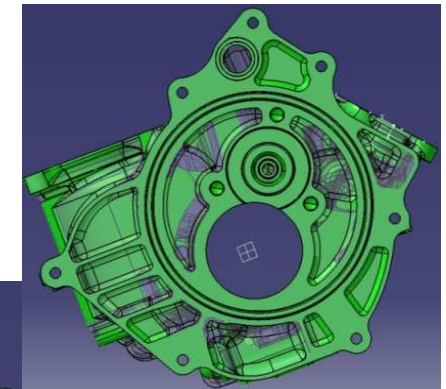
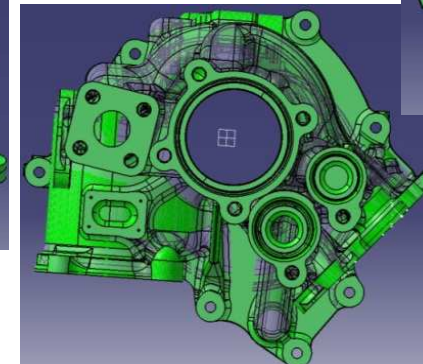
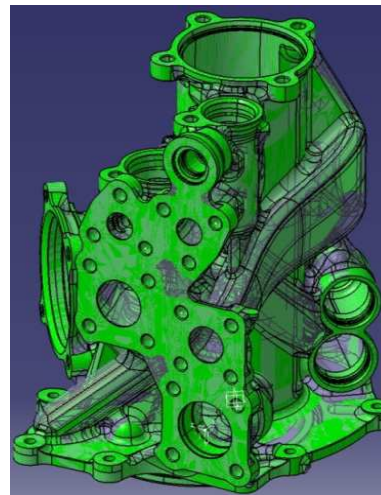
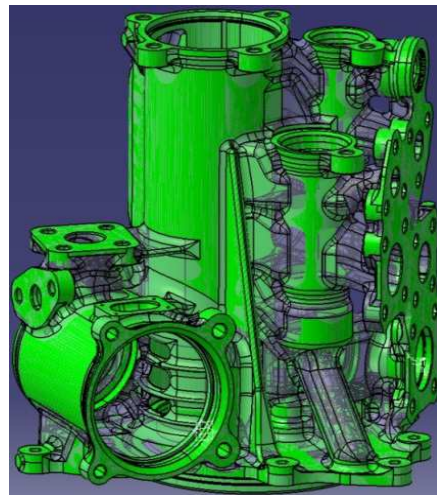
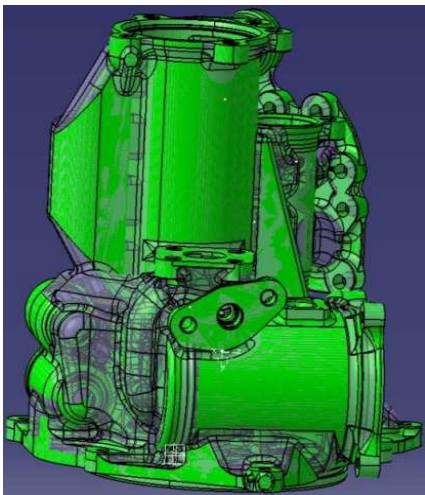


Mat'l : A357



Mat'l : A357

In green, areas shared between casting and SLM ; in grey, those that concern only SLM housing :



56PRE225896.A000

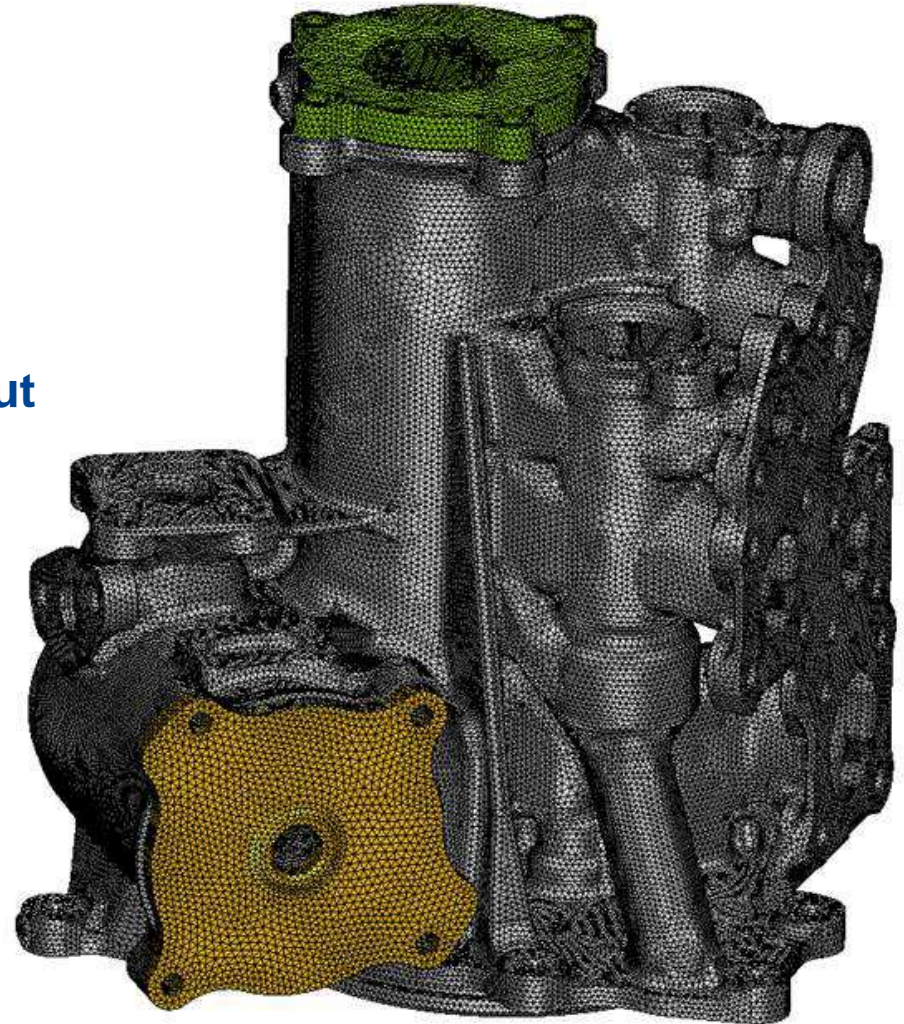
Finite Element Analysis #1/2

Meshing and methodology

Second degree tetrahedral meshing :

- ◆ Number of volume elements : 959228
- ◆ Number of skin elements : 362618
- ◆ Number of nodes: 1643095

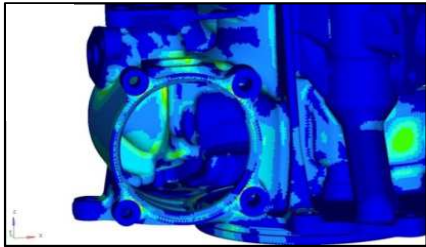
Three loads : Pressure, Vibration, Fan Blade Out



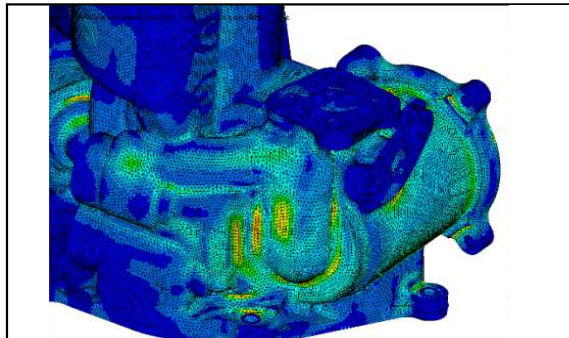
56PRE225896.A00

Finite Element Analysis #2/2

Pressure

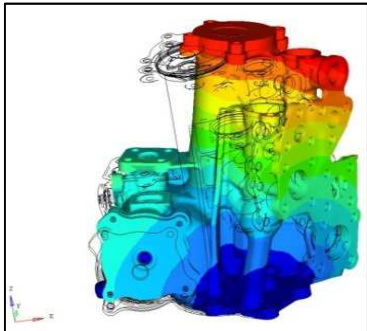


Outside

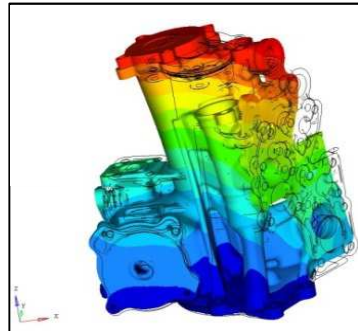


Vibration – Modal Analysis

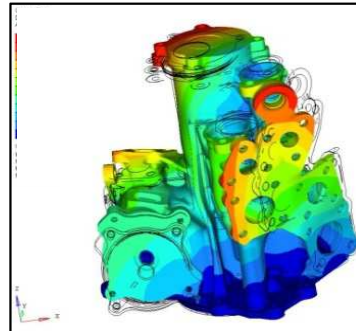
Mode 1



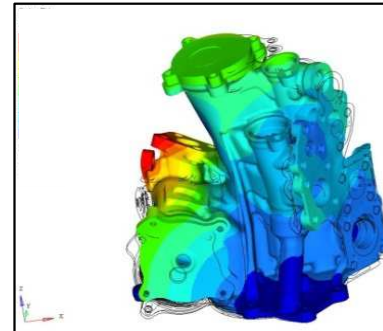
Mode 2



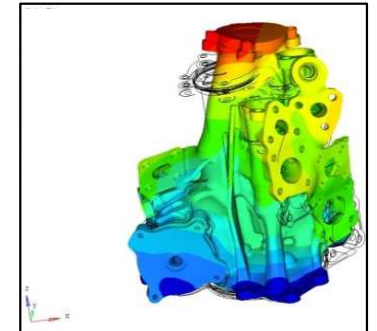
Mode 3



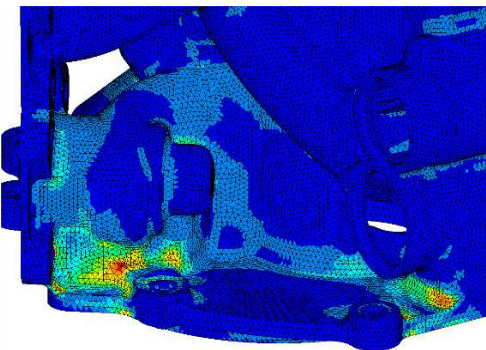
Mode 4



Mode 5



FBO Load



56PRE225896.A000



3

CERTIFICATION

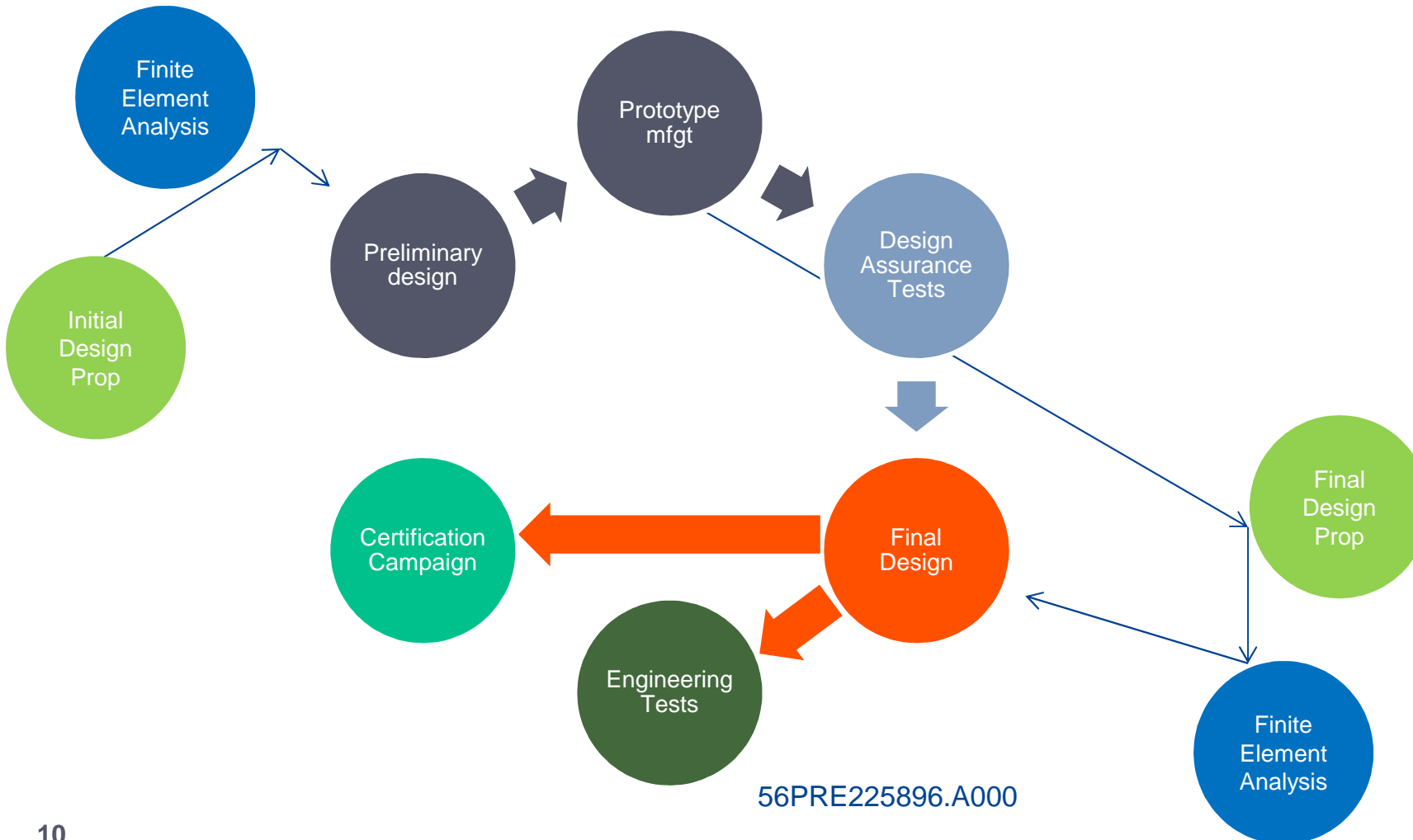
56PRE225896.A000

Part Validation #1/1

The project development is planned according to:

Safran processes and legacy

EASA Memorandum dedicated to Additive Manufacturing CM-S-008 Issue 1



Design Assurance Testing #1/1

Design Assurance Tests

ALM#01



Cyclic Pressure :
Equivalent to Certification rqt :

- 60.000 cycles NWP
- 500 cycles MET
- 500 cycles MWP



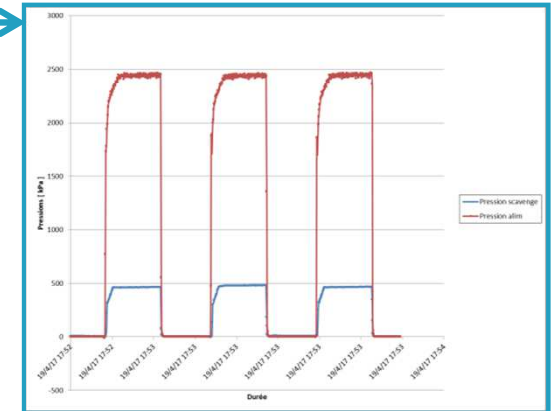
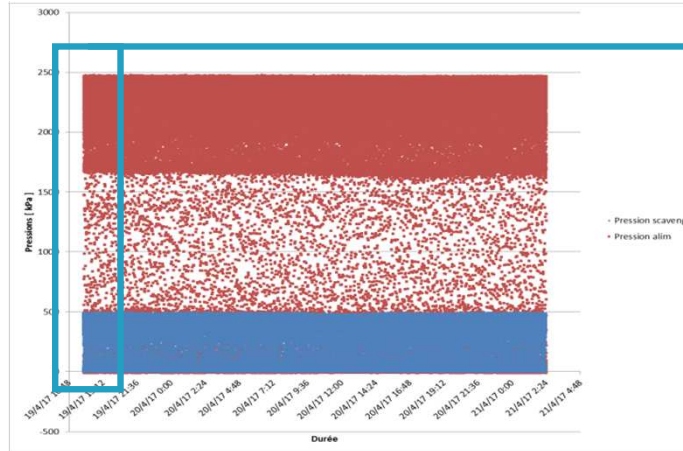
HALT* :

- 60.000 cycles NWP

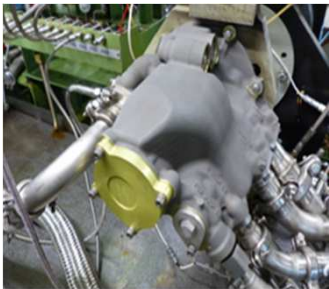


Success Criteria:

- FPI post-test
- DER post-test



ALM#02



HT Endurance :

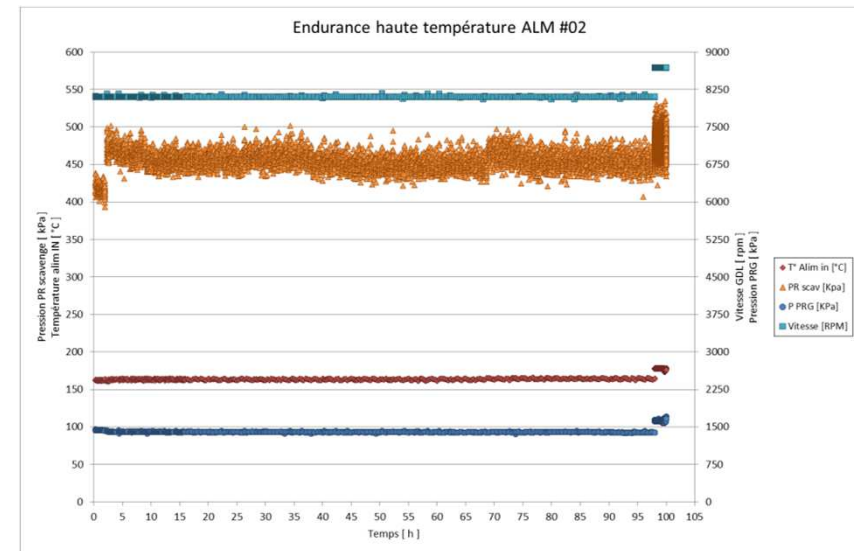
Equivalent to Certification rqt : 97h

- Duty-Cycles à 162°C (324F)
- 3h Duty-Cycles à 177°C (351F)



Success Criteria :

- FPI post-test
- DER post-test



56PRE225896.A000

Design Values construction #1/4

The Design Office requires the following data

- ◆ Yield strength ($T = -55^{\circ}\text{C} (-67^{\circ}\text{F})$ to $230^{\circ}\text{C} (446^{\circ}\text{F})$)
- ◆ Ultimate tensile strength ($T = -55^{\circ}\text{C} (-67^{\circ}\text{F})$ to $230^{\circ}\text{C} (446^{\circ}\text{F})$)
- ◆ LCF $R=0$ ($A=1$)
- ◆ HCF $R=-1$ ($A=\infty$)



Final
Design
Prop

Design Values are built from specimens and parts fabricated, with same frozen parameters as lube unit housings. The part is classified as CF2/AFA (N2). The Design Values requirements for such a classified part is

Design Value	Category	Minimum rqt	Comments
Physical (density, CTE,...)	IV	1 lot, 2 levels, 2 tests	2 powder suppliers, Up to 9 recycling, over 12 batches
Statical (YS, UTS, ...)	II	4 lots, ~25 tests (min 4 temp, 4 tests/Temp)	2 powder suppliers, Up to 9 recycling, over 12 batches
Fatigue (LCF, HCF)	III	2 lots, ~15 tests (min 4 level, 4 tests/Level)	2 powder suppliers, Up to 9 recycling, over 12 batches

56PRE225896.A000

Design Values construction #2/4

Final
Design
Prop

Characteristic	Condition	Test Specification	Specimens geometry
On specimens	SLM 280 HL, layer thickness 50 µm (2 mil), frozen parameters and software, AS7G06, HIP, T7		
Density	RT	ISO 1183	Half-Cylinder : Ø : 15 mm & L:20 mm
Thermal expansion	Min LT to Max HT	Internal process (COFRAC accreditation)	Cylinder : Ø : 6 mm & L : 25 mm Parallelepiped : C : 5 mm & L:25 mm
Young Modulus	Min LT to Max HT	ASTM-E8	485-920-111-0
Yield Strength	Min LT to Max HT		
Ultimate Tensile Strength	Min LT to Max HT		
HCF	RT; HT stress ratio R=-1 (A=∞)	ASTM E466	485-920-525-0 Cylinder
LCF	RT; HT stress ratios R=0 (A=1)		
On components	SLM 280 HL, layer thickness 50 µm (2 mil), frozen parameters and software, AS7G06, HIP, T7		
Real Parts	DAT (Design Assurance Test) Engineering Tests		

56PRE225896.A000

Design Values construction #3/4

Final
Design
Prop

Each production includes	3 Axis
Cylinder specimens	X
	Y
	Z



Specimens (tensile & fatigue)



Material Structure
Chemical composition

Specimens (tensile & fatigue axis Z)



Specimens (tensile & fatigue)

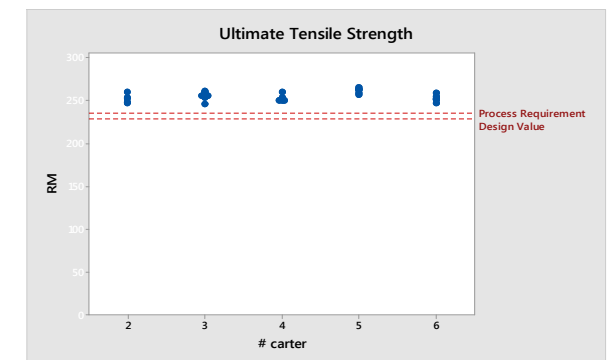
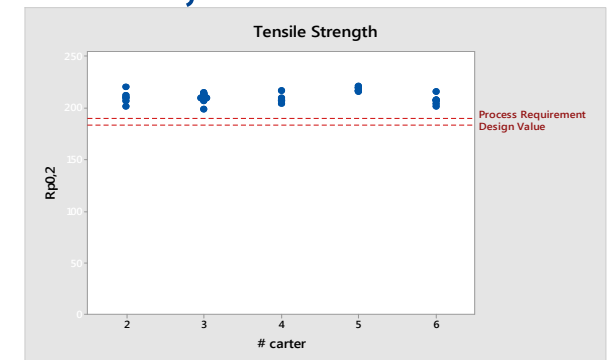
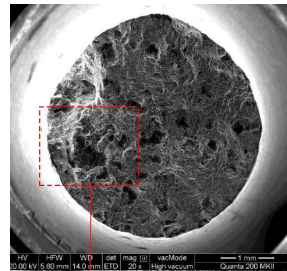
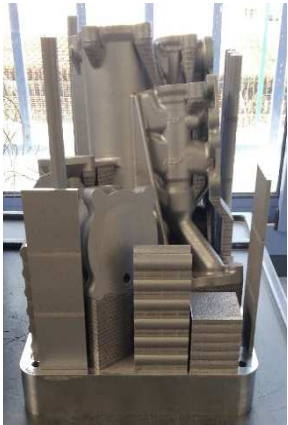
Total	Tensile	Fatigue
Qty of tested specimens	>100	>80

56PRE225896.A000

Design Values construction #4/4

Final
Design
Prop

- 14 Lube Units printed for Engineering Test and Certification Campaign
- Over 350 coupons printed in three orthogonal directions X, Y and Z



Requirements on tensile test results > design values

56PRE225896.A000

Engineering tests

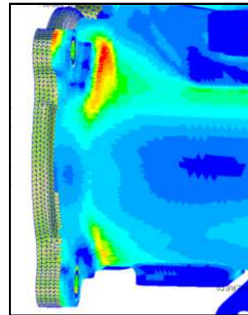
Objective: risk mitigation prior to certification tests

High temperature tests : ✓

- ◆ 3 x certification duration

Pressure cycle tests : ✓

- ◆ 2 x number of certification cycles without rupture
- ◆ Addition of 2000 cycles at burst pressure until oil leak in the filter housing flange area
- ◆ Location of the leak consistent with the FEA



56PRE225896.A000

Engineering test (on LEAP 1A engine) #2/2 (598010/3@ test rig PHENIX AFI - Paris)

LU#2 _ 2017 (housing PE033490)			
Endurance Engine Leap 1A 598010/3 @ test rig PHENIX AFI (Paris)		Oil System event	Date
Installation of SLM LU + 2h20		No event	12/01/2018
Rotating Time (hh:mm)	512:22	No event	01/06/2018
Starts:	3004		
Engine Cycles B	2416		
Engine Cycles C1	2487		



✓ Engineering Endurance Engine end on June 1st, 2018

56PRE225896.A000

Certification Plan #1/2

Certification
Campaign

Certified part

Part Name: Unit, Lubrication CCL Item No.: CCL 1653	Certification Method	T = Test -- = Not Applicable CA = Comparative Analysis	EA = Analysis
Electrical: No Rotating Parts: Yes / No Aircraft Power: Yes / No Category: 2	Test Type	E = Engine SR = System Rig C = Component SC = Sub Component -- = Not Applicable	
		G = Compliant per CPC CPC Compliance + = per CPC with additional information D = Deviates from CPC	
Requirements:			Notes:
1. High Temperature	T/EA	C	D
2. Low Temperature	T	C	D
3. Room Temperature	T	C	G
4. Contaminated Fluids	T	C	D
5. Vibration	T	C	G
6.1 Impact: Operational Shocks	T	C	G
6.2 Impact: Crash Safety	T	C	G
7. Sustained acceleration	EA	--	G
8. Sand and Dust	EA	--	G
9. Fluid Susceptibility	EA	--	G
10. Salt Spray	EA	--	G
11. Fuel System Icing	--	--	G
12. Induction Icing	--	--	G
13. Fungus	EA	--	G
14. Temperature and Altitude	EA	--	G
15. Thermal Cycle	--	--	G
16. Explosion Proofness	--	--	G
17. Humidity	--	--	G
18. Water	--	--	G
19. Pin injection	--	--	G
20. Power Input	--	--	G
21. Proof Pressure	T/EA	C	D
22. Burst Pressure	T/EA	C	D
23. Pressure Cycling	T	C	G
24. Fire	T	C	G
25. Rotor Containment	EA	--	G
26. Spec Test	--	--	G

AM part

Part Name: Unit, Lubrication CCL Item No.: CCL#1653	Certification Method	T = Test EA = Engineering Analysis -- = Not Applicable CA = Comparative Analysis	E = Engine ST = System Test -- = Not Applicable C = Component SC = Sub Component
Electrical: NO Rotating Parts: YES Aircraft Power: NO Category: 2	Test Type		G = Compliant per CPC + = per CPC with additional information D = Deviates from CPC
Requirements:			Notes:
1. High Temp. Demonstration	T	C	Test will be done with same parameters as previous lube unit
2. Low Temp. Demonstration	T	C	Test will be done with same parameters as previous lube unit
3. Room Temp. Demonstration	CA	--	based on certification test conducted on current version 362-074-103-0 (B1316-06163) and also based on High and Low temperature tests
4. Contaminated Fluids	CA	--	based on certification test conducted on current version 362-074-103-0 (B1316-06163) and casing geometry analysis
5. Vibration	T	C	Test will be done with same parameters as previous lube unit
6.1. Impact: Operational Shocks	T	C	Test will be done with same parameters as previous lube unit
6.2. Impact: Crash Safety	T	C	Test will be done with same parameters as previous lube unit
7. Sustained acceleration	EA	--	Based on - The structural integrity of the component will be based on the vibration test and also based on - The proper functional behavior of the component will be substantiated by analysis identical to the one presented for the current version 362-074-103-0 (B1316-06163)
8. Sand and Dust	EA	--	Based on material characteristics
9. Fluid Susceptibility	EA	--	Will be complete at the reduction of CTL Based on - The analysis of the resistance to Skydrol of the materials used for the design of the alternative Unit, Lubrication and also based on item 10 - Salt Spray
10. Salt Spray	EA	--	based on material characteristics
11. Fuel System Icing	--	--	--
12. Induction Icing	--	--	--
13. Fungus	EA	--	based on the bill of material of the Unit, Lubrication, stating their resistance to fungus
14. Temperature and Altitude	EA	--	Based on the temperature requirement that will be covered by the demonstration of High and Low Temperature (items 1 and 2) and also altitude requirement will be covered by the demonstration of Proof Pressure (item 21).
15. Thermal Cycle	--	--	--
16. Explosion Proofness	--	--	--
17. Humidity	--	--	--
18. Waterproofness	--	--	--
19. Pin injection	--	--	--
20. Power Input	--	--	--
21. Proof Pressure	T	C	Test will be done with same parameters as previous lube unit
22. Burst Pressure	T	C	Test will be done with same parameters as previous lube unit
23. Pressure Cycling	T	C	Test will be done with same parameters as previous lube unit
24. Fire	T	C	Test will be done with same parameters as previous lube unit
25. Rotor Containment	EA	--	based on casing geometry and material analysis
26. Spec Test	--	--	--

56PRE225896.A000

Certification test

	Certification tests	Completion
✓	Proof & Burst	100%
✓	High temp.	100%
✓	Pressure cycling	100%
✓	Vibration	100%
✓	Low temp.	100%
✓	Fire	100%

56PRE225896.A000

4

PROCESS CONTROL



56PRE225896.A000

Process control #1/5

- A first list of significant parameters have been defined based on an existing FMECA used by other Safran group company :

Process	LBM sur AS7G06
Dates de réunion	15/02/2017
Objectifs	Planifier les actions préventives pour les risques majeurs
Participants	Nicolas TABUS, Didier HABERT
Hypothèses	L'AMDEC traitera du procédé de fusion laser et de la gamme associé appliqués à l'AS7G06 Cette AMDEC est basée sur l'AMDEC réalisée par Safran Aircraft Engines sur CoCr28Mo6 et sur notre retour d'expérience sur la plateforme collaborative SUPCHAD
Grille de cotation	Les critères Gravité, Fréquence et Déteabilité seront cotés selon 5 notes : 1 - 3 - 5 - 7 - 10 selon la grille de Cotation jointe

PHASE / OPERATION		criticité initiale										N°	ACTIONS Préventives/Correctives	Pilote	Délai mise en œuvre
		MODE DE DEFAILLANCE / RISQUES	EFFET	Grav.	CAUSES	Fréq.	DETECTION	Détectabilité	I P R						
Désignation	Fonction	Défauts possibles ou connus en regard du critère qualité	Conséquences pour l'utilisateur aval ou final	G	Connues ou possibles	F	contrôles possibles ou existants	D	GxFxD	action	Si IPR>=100 ou si G=10	Nominatif			
Contrôle réception poudre	Vérifier la composition de la poudre	Granulométrie poudre non conforme	Casse pièce	10	Erreur fournisseur	1	Pas de contrôle	10	100						
	Vérifier la qualité de la poudre	Composition poudre non conforme	Casse pièce	10	Erreur fournisseur	1	Contrôle visuel	7	70						
		Pas de contrôle	Casse pièce	10	Oubli de la réception	6	Pas de contrôle	6	360	1	Préciser le contrôle dans la fiche d'instruction				
		Mauvais contrôle	Casse pièce	10	Contrôleur non habilité	1	Surveillance habilitation opérateur en course	3	30						
Stockage de la poudre	Stocker la poudre avant utilisation			10	Défaut machine	1	Contrôle périodique	6	60						
		Agrégation de poudre	Casse pièce	10	Taux d'humidité trop élevé	3	Pas de contrôle	10	300	2	Intégrer une zone de stockage dédiée avec appareil de mesure (selon Pr)				
			Casse pièce	10	Température de stockage non adéquate	6	Pas de contrôle	10	600	2	Intégrer une zone de stockage dédiée avec appareil de mesure (selon Pr)				
				10	Départ feu (poudre réactive)	1	Pas de contrôle	10	100						
	Danger pour l'opérateur	Blessure de l'opérateur	10	Inhalation ou ingestion de poudre par l'opérateur	3	Pas de contrôle	10	300	3	Mettre en place des protections individuelles complètes et une filtration de l'air ambiante plus poussée					
				10	Inhalation de gaz dangereux	1	Alarme machine	3	30						
		Oxydation de la poudre	Casse pièce	10	Pas de protection gazeuse	1	Pas de contrôle	10	100						
Préparation de la poudre avant introduction dans la machine	Contenir une poudre tamisée	Particules de dimensions trop importantes	Casse pièce	10	Taux d'humidité trop élevé	1	Pas de contrôle	10	100						
				10	Taux d'oxygène trop élevé	1	Pas de contrôle	10	100						
	Enlever un maximum de particules de dimensions excédant la taille des mailles	Pollution par des particules étrangères	Casse pièce	10	Mailles du tamis endommagées	1	Pas de contrôle	10	100						
				10	Poudre sans protection lors de la préparation machine	1	Pas de contrôle	10	100						
				10	Tamis pollué par des particules étrangères	1	Pas de contrôle	10	100						
				10	Départ feu (poudre réactive)	1	Pas de contrôle	10	100						
	Danger pour l'opérateur	Blessure de l'opérateur	10	Inhalation ou ingestion de poudre par l'opérateur	3	Pas de contrôle	10	300	3	Mettre en place des protections individuelles complètes, appareil de mesure du taux de particules et suivi médicale					
			10	Inhalation de gaz dangereux	1	Alarme machine	3	30							

56PRE225896.A000

Process control #2/5

The FMECA has been updated to our process thanks to Safran and Supplier experiences

The significant parameters are

> Melting parameters

- ◆ Layer thickness
- ◆ Laser power
- ◆ Laser speed
- ◆ Laser spot diameter
- ◆ Lasing strategy (hatching distance, fill pattern,...)

> Machine and build chamber parameters :

- ◆ AM machine (qualification on SLM280 only)
- ◆ Argon pressure
- ◆ Bed temperature
- ◆ Argon flow speed
- ◆ Powder spreading device :
 - Speed
 - Wiper replacement frequency
 - Powder volume per layer

> Software parameters :

- ◆ Magics and Build Processor software versions
- ◆ .step file (part geometry), .stl file, .magics file, .slm file

> Powder :

- ◆ Granulometry distribution
- ◆ Apparent and tap density
- ◆ Chemical composition
- ◆ Recycling level

All these parameters are frozen

56PRE225896.A000

Process Control #3/5

Master Part

- Part – Hardness, Chemical Composition, Tensile test, Microstructure
- Coupons – Hardness, Chemical Composition, Tensile test, Microstructure

Periodical Cut up (25th part, 50th part, 100th part, min 1 per year)

- Part – Hardness, Chemical Composition, Tensile test, Microstructure
- Coupons – Hardness, Chemical Composition, Tensile test, Microstructure

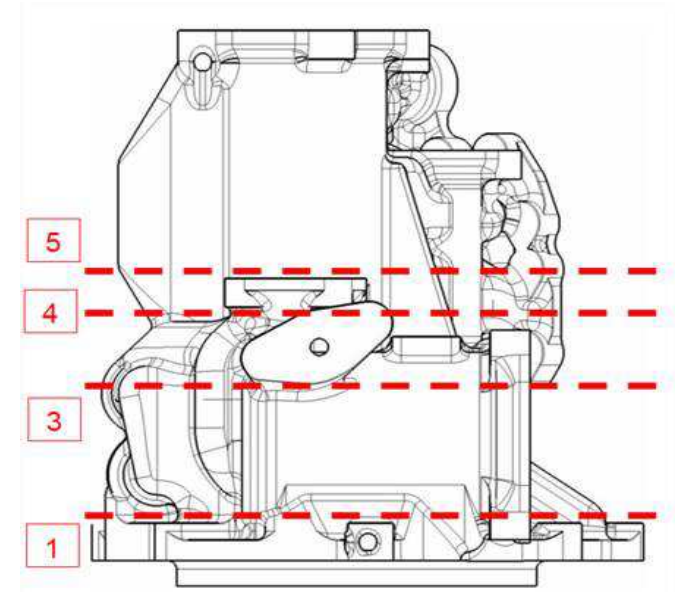
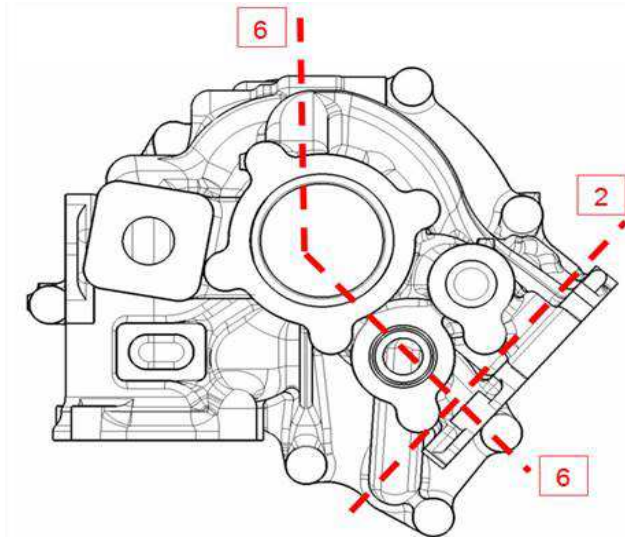
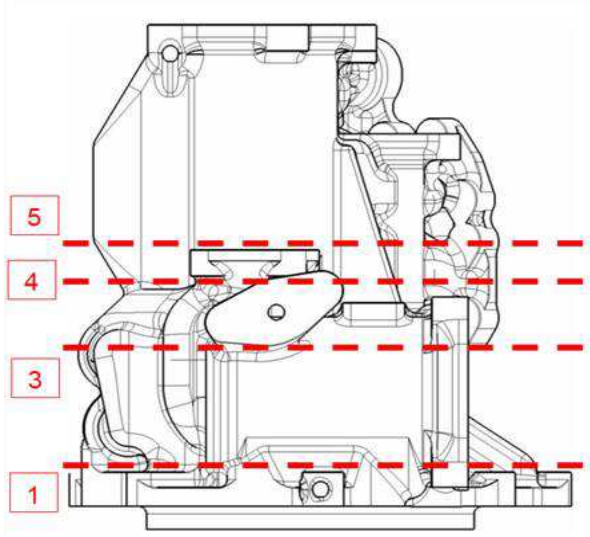
Production Part

- Part – Hardness
- Coupons – Hardness(*), Chemical Composition, Tensile test, Microstructure

(*) Per heat treatment lot

56PRE225896.A000

Process Control #4/5



Specific attention on

- High stressed zones
- Downskin and upskin zones
- Unsupported zones

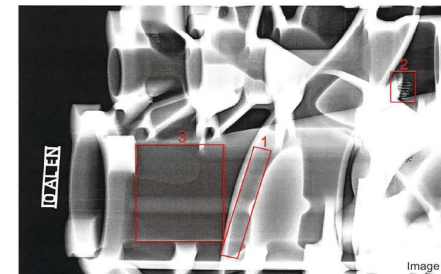
56PRE225896.A000

Non destructive testing is exactly the same as the equivalent casting part

Visual Inspection

X-Ray iaw Pr-5200 (film) or Pr-5250 (digital) or other process approved by Quality department of Safran Aero Boosters

- ◆ Procedure : X-ray inspection procedure must be established by manufacturing source and approved by Safran Aero Boosters X-Ray Level III. Approval shall be based on design margins and manufacturing capabilities.
- ◆ Frequency : on every part, before or after machining
- ◆ Criteria : same as casting



FPI iaw Pr-5000 or other procedure approved by Quality department of Safran Aero Boosters

- ◆ Sensitivity : Liquid penetrant type 1A, sensitivity 2, developer “type A” – dry
- ◆ Frequency : on every part, before and after machining
- ◆ Criteria : same as casting



56PRE225896.A000

“DVI”: Safran management of Special Processes to support a Type Design #1/1

EN9100, EN9102 & EN9103 standard

DVI process from development to serial production (GRP 165: industrial validation)

Certification specification requirements compliance

Type design (Part21J):

Dimensional + manufacturing req.+ (eg **04MTF217657**)
Material requirement (eg **Ma2500**) + manufacturing Process req (**eg Pr7210**) + airworthiness limitations +...

Characteristics: Dimensional and other measurable characteristics

Key Charac included in material spec :
Cut up, Sample, raw material, ...

Key Charac for Special Process to be controlled, incl raw material

DVI structure (Part21G) DVI stored in Safran Quality base

Part Number

FAI (First Article Inspection)

Conformance to raw material spec

Key Process parameters list (PFMEA including AM files)

Key Charac tolerances & measures

Inspection plan

Key process parameters robustness (serial production capability)

DVI change control

56PRE225896.A000

5

RISKS MITIGATION PLANS



56PRE225896.A000

Risks Mitigation Plan #1/1

Criticality

Probability

	1	2	3	4
16	16	32	48	64
4	4	8	12	16
2	2	4	6	8
1	1	2	3	4

On the Lube Unit Functions

	Risks	Initial Quote 03/17		Risks mitigation plan	Current Status	
		C	P		C	P
0	Risk of easily released particles	4	4	Several cleaning and a Final Acceptance Test are performed after final assembly removes the easily removed particles	1	1
1	Risk of not easily released particles (in the field released)	4	4	A filter is located after the lub unit to catch the not easily removed particles	2	1
2	Risk of sealing failure	16	2	All the sealing zones are machined, final roughness after machining is similar to casting	1	1
3	Risk of hydrodynamic performance lost	4	4	Final Acceptance Test are performed after final assembly on each part	1	1
4	Risk of dimensional conformity and variation (part to part)	4	4	Dimensional inspection on the maturation part shows a very good reproducibility	1	1

On the Design Properties

	Risks	Initial Quote 03/17		Risks mitigation plan	Current Status	
		C	P		C	P
0	Risk of mechanical properties variations due to AM construction	4	3	The maturation parts are surrounded by 36 tests coupons and the design properties are built from these coupons. Production parts are surrounded by tests coupons	1	1
1	Risk of metallurgical soundness variation due to unsupported zone	2	4	Metallurgical soundness on unsupported zone is conform and a validated cut-up drawing is required	2	1
2	Risk of metallurgical soundness variation due to laser overlap zone	2	4	Metallurgical soundness on laser overlap zone is conform and a validated cut-up drawing is required	2	1
3	Risk of anisotropy due to building orientation	4	3	HIP and Solution heat treatment nearly delete the anisotropy	1	1
4	Risk of thermal ageing unexpected behavior	2	4	Thermal aged coupons (static and fatigue) shall be evaluated	1	1
5	Risk of lower corrosion resistance	4	2	Salt Spray tests of anodized AM coupons confirm the corrosion resistance	1	1
6	Risk of lower mechanical properties area due to very fine microstructure	2	3	Design properties are built from coupons with the same parameters and same metallurgical soundness as the maturation plan	1	1

56PRE225896.A000

6

CONCLUSIONS

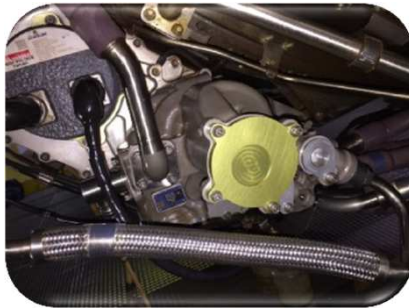


56PRE225896.A000

LEAP-1A engine test

3315 engine start-up

596 h of engine running time



Engineering test

High temperature endurance with 3x certification duration

Pressure cycling: 2x certification cycles + 2000 burst pressure cycles without failure



Certification tests performed

Proof & burst

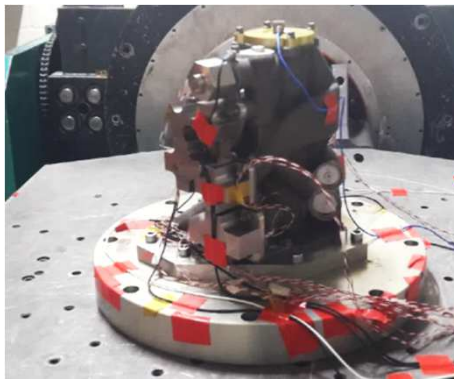
High temp.

Pressure cycling

Vibration

Low temp

Fire



Certification status

Certification test : Done

Fam Meeting with EASA/FAA : Done

TRL level : 6 (achieved in 18 months)

Certification report to be validated by 10/15

CAD Authorities validation by 11/30

Introduction rank : Unit 170 on LEAP-1A

56PRE225896.A000



POWERED BY TRUST
