240N HYDRAZINE THRUSTER DE-RISK ACTIVITY

KP2: DM1a Manufacturing and Test Results (CHT240N-ASLLAM-TN-0002)

ESA Contract No. 4000138574/21/NL/GLC/rk

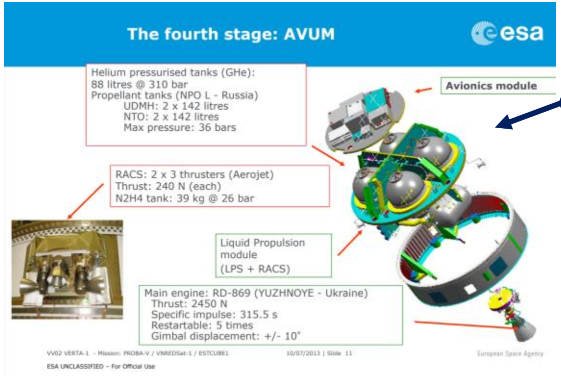
3-12-2024

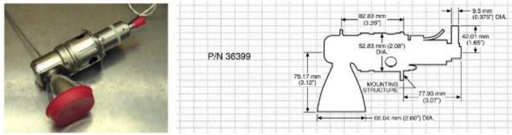
CHT240N – MOTIVATION GSTP PROGRAM

CURRENT DELIVERY OF 240N THRUSTER FOR THE VEGA LAUNCHER IS AT RISK

Roll and Attitude Control System (RACS) of the European VEGA launcher

- Is a Hydrazine-based propulsion system produced by ArianeGroup GmbH and directly delivered to AVIO Customer
- Hydrazine Thrusters are procured from a US supplier (Aerojet) – under responsibility of ArianeGroup
- Aerojet announced a non-availability of their thruster as an integrated assembly with the qualified flow control valve (FCV).
- For recent batch procurement, AGG had to procure the valve from a US supplier and ship it to the Thruster supplier for final integration and test.
- For future batches, the Aerojet proposed to use a different FCV; qualification is still ongoing
- ArianeGroup considers this dependency and a potential obsolescence (e.g. due to delta-qualification failure or change of US supplier's delivery conditions) a significant risk for its own RACS business but also for the European VEGA launcher as a whole.
- In order to pro-actively counter this risk, ArianeGroup was contacted to start a de-risking activity. The aim is to maturate a pre-developed thruster design at ArianeGroup and to confirm its suitability prior to a potential qualification for the VEGA RACS system.




MR-107T 110N (25-lbf) ROCKET ENGINE ASSEMBLY

Design Characteristics

- Propellant .... Hydrazine
- Catalyst .... S-405 / LCH-202
- Thrust/Steady State .... 125 – 54 N (28 – 12 lbf)
- Feed Pressure .... 37 – 7 bar (500 – 100 psia)
- Chamber Pressure .... 4.7 – 1.8 bar (69 – 26 psia)
- Expansion Ratio 21.5:1
- Flow Rate .... 55.8 – 22.7 g/sec (0.123 – 0.05 lbm/sec)
- Valve .... Single Seat
- Valve Power .... <34.8 Watts @ 28 Vdc & 20°C
- Mass .... 1.01 kg (2.23 lbm)
  Engine .... 0.67 kg (1.48 lbm)
  Valve .... 0.34 kg (0.75 lbm)

Performance – ***Reference MR-107S/T Testing in 2007***

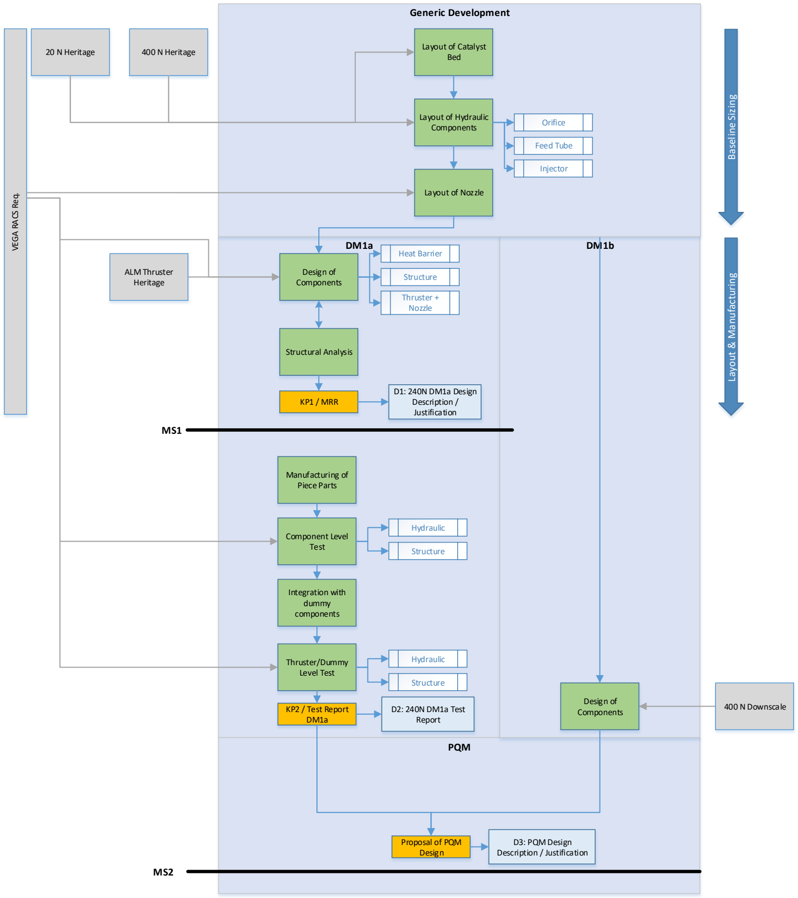
- Specific Impulse .... 222 – 228 sec (lbf-sec/lbm)
- Total Impulse .... 92,967 N-sec (20,900 lbf-sec)
- Total Pulses 14,300
- Steady State Firing .... 100 sec @ 125N (28-lbf)
  .... 100 sec @ 54N (12-lbf)

Status

- Qualified

SCOPE OF THE DE-RISK ACTIVITY

240 N VEGA RACS
Design and Development Approach



Design Process DM1a – ALM Design

- Layout of catalyst bed → Dimensions and mass
- Hydraulic layout → Pressure drop / chamber pressure
- Nozzle layout → Performance tuning
- Design of components based on 20N / 400N / H2O2 heritage
- Structural analysis

→ **KP1 / MRR**

- Manufacturing of test dummy
- Structural test

→ **KP2 / Test Report**

Design Process DM1b – Classic Design

- Design based on 400N heritage (downscale)

→ **KP2 / DM1b Design Justification**

STARTING POINT: CHT240N HERITAGE

THE PROPOSED 240N THRUSTERS USES THE HERITAGE OF QUALIFIED PRODUCTS

The fully ALM printed 240N H2O2 Thruster demonstrated a significant cost and development time reduction but also that one thruster design can be used for multiple propellants by just exchanging the catalyst

	20N	240N	400N
Hydrazine N_2H_4	TRL9 	TRL3 → TRL4 Actual Development	TRL9 
Hydrogen Peroxide H_2O_2		TRL5 	

arianeGROUP

CHT240N DM1a/b – DESIGN

BASELINE THRUSTER SIZING

Baseline Parameters

F=240N
ISP = 230s
Pc = 13 bar

→

Baseline Parameters

$$ISP_{vac} = \frac{F_{vac}}{\dot{m}_{ges}}$$

→

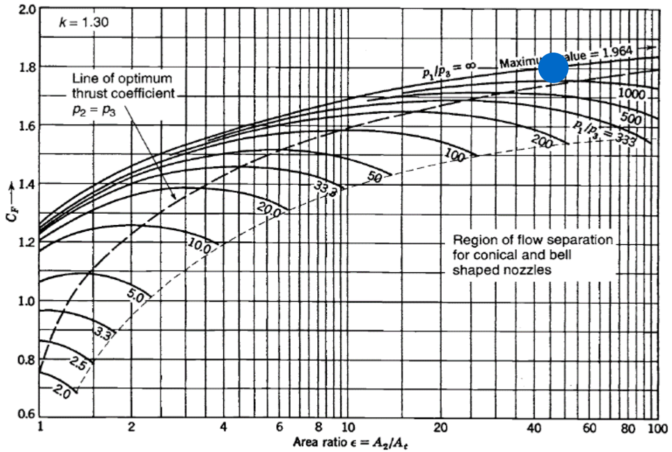
$$ISP_{vac} = c^* \cdot c_f$$

$$c^* = \frac{P_C \cdot A_t}{\dot{m}_{ges}}$$

→

Results

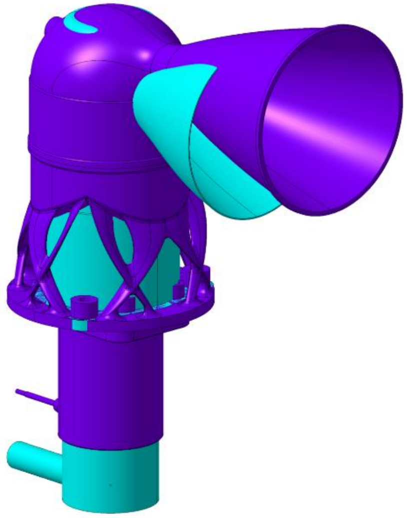
m=106,4 g/s
Dt=11,43 mm



Parameter	Unit	Nom	Remarks
Feed Pressure	[bar]	26	
F-nom	[N]	240	
ISP	[s]	230	
m	[g/s]	106,4	
Pc-nom	[bar]	13,00	first assumption
Nozzle coefficient	[-]	1,80	k = 1,33, ε=50
c*	[m/s]	1253,50	
Throat diameter	[mm]	11,43	
Nozzle expansion ratio	[-]	50,0	
Exit diameter	[mm]	80,80	

CHT240N DM1a/b – DESIGN

OVERVIEW



Main Performance Data

	DM1a/b	VEGA RACS Heritage*
Thrust	240 N at 26 bar	240 N at 26 bar
Isp	≥ 229 s	229 s
Chamber Pressure	10 bar	approx. 8.5 bar
Length Chamber + Nozzle	approx. 120 mm	approx. 105 mm
Total Length incl. FCV	approx. 190 mm	approx. 173 mm
Outer Chamber Diameter	58 mm	
Nozzle Exit Diameter	67 mm	66 mm
Expansion Ratio	26	21
Thruster mass	1.2 kg	1.01 kg
FCV Power	<19 W per coil	34.8 W

*all information derived from public data available on www.rocket.com

DM1 Layout

Item	DM1a Configuration / Concept	DM1b Configuration / Concept
Flow Control Valve	ArianeGroup 400 N Bi-Propellant FCV	ArianeGroup 400 N Bi-Propellant FCV
Trimming	Orifice	Orifice
Thermal Standoff	3D printed Hastelloy X	Brazed / welded solution
Injector	Three injector elements	Injector Ring
Catalyst Bed	Two beds	Two beds
Nozzle	90° canted nozzle, RAO optimized	90° canted nozzle, RAO optimized
Sealing Concept	O-Ring / C-Ring	O-Ring / C-Ring
Interface	To be adapted to the requirements	To be adapted to the requirements

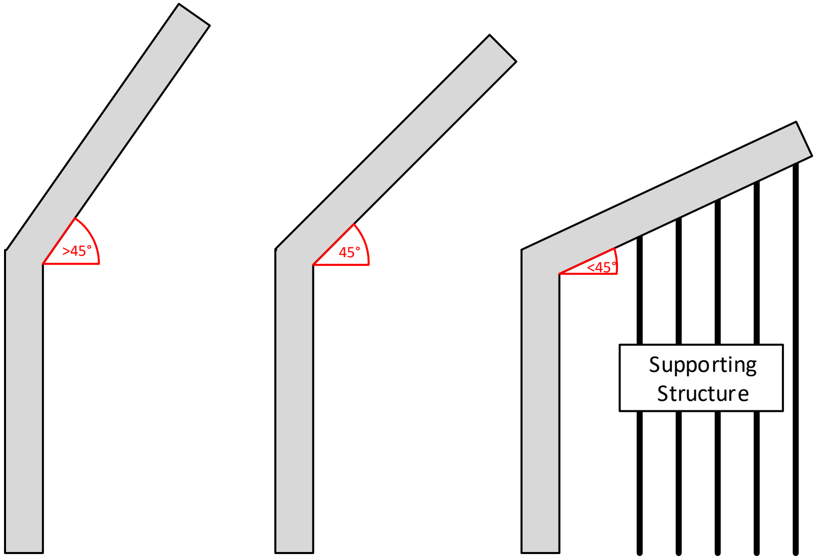
CHT240N DM1a/b – DESIGN

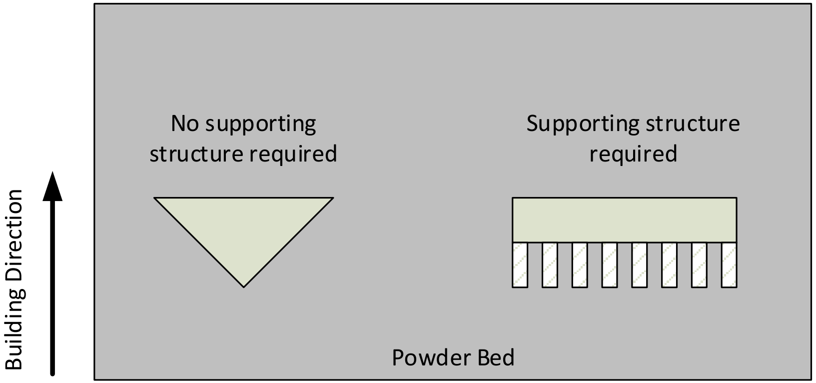
FLOW CONTROL VALVE

	AGG 400N Mono	AGG 400N Bi	MOOG 53-203	ValveTech 15027
				
Manufacturer (Country)	**AGG (D)**	**AGG (D)**	**MOOG (US)**	**ValveTech (US)**
Seats / Coils	1 seat / 1 coils	1 seat / 2 coils	1 seat / 2 coils	1
Voltage	28 ±4 VDC	24 ±3 VDC	24 ±3 VDC	
Power per coil	< 18 W	< 19 W	< 22 W	
Response	< 20 ms	< 20 ms	< 20 ms	
Cycle life	4.000	5.000	5.000	100.000
Weight	0,68 kg	0,43 kg	0,41 kg	
Inlet Filter	additional	40 µm absolute	25 µm absolute	
Seat Material	EPDM	PTFE	PTFE	AFE411
Reference Pressure Drop @ 100 g/s H_2O	0,7 bar	1,5 bar	2,14 bar	1,655 bar
Pressure Drop @ nom operation point	0,93 bar Opt 1 0,27 bar Opt 2	1,99 bar Opt 1 0,59 bar Opt 2	2,84 bar Opt 1 0,84 bar Opt 2	
Cost Index	100%	50%	60%	unknown

CHT240N DM1a – DESIGN

3D PRINTING DESIGN BOUNDARIES



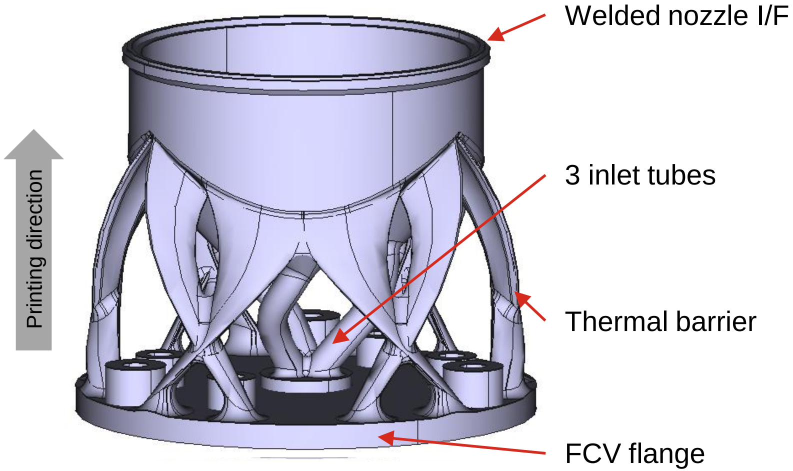


CHT240N DM1a – DESIGN

HEAT BARRIER

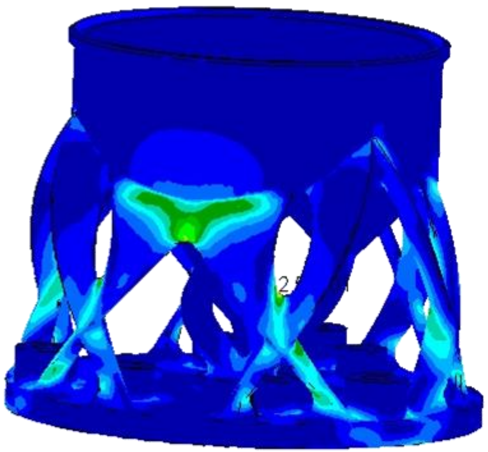
DM1a – ALM Design

- Thermal decoupling of decomposition chamber and FCV
- 3D printed in Hastelloy X (qualified for Ariane 6 APU)
- Comprises trimming orifice, injectors and upstream catalyst bed



DM1a – Analysis

- Sine Vibration MoS > 10
- Random Vibration MoS 0.77



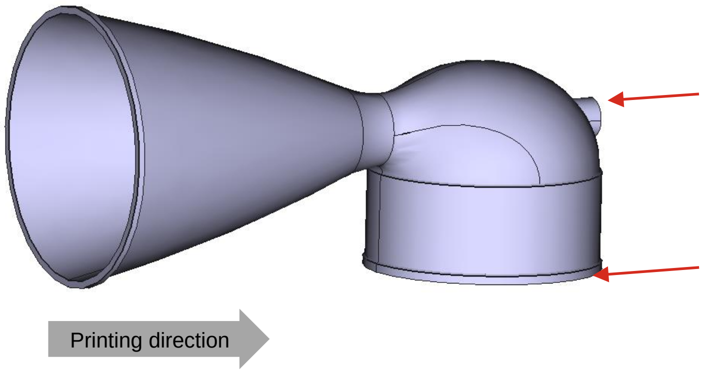
Sine Vibration von Mises Stress x-axis

CHT240N DM1a – DESIGN

NOZZLE

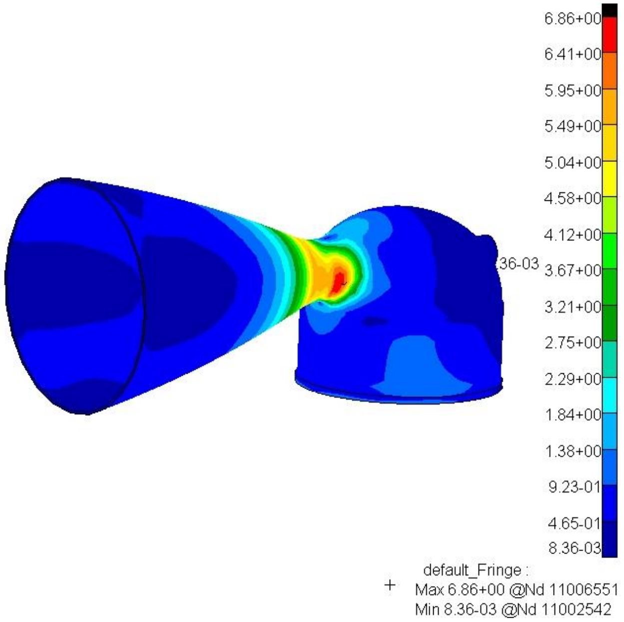
DM1a – ALM Design

- 3D printed in Hastelloy X
- Comprises downstream catalyst bed and nozzle
- Expansion ratio of 26 / exit diameter 66 mm



DM1a – Analysis

- Sine Vibration MoS > 40
- Random Vibration MoS > 3

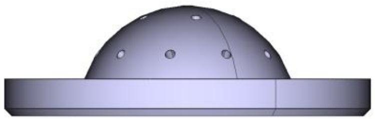


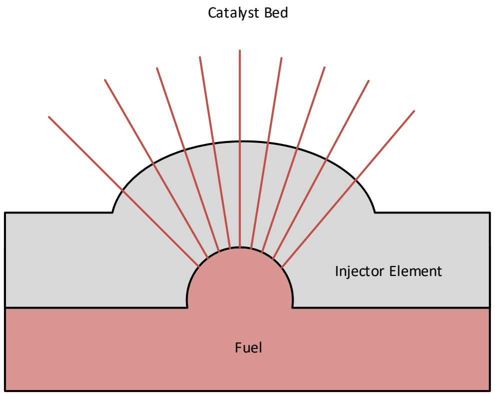
CHT240N DM1a – DESIGN

ADDITIONAL COMPONENTS

Injector Element

- 3 hemispherical elements for optimized propellant distribution
- Conventionally manufactured
- Protected via hemispherical filter





Catalyst Bed Separators

- Separation via filters + support structure

Catalyst

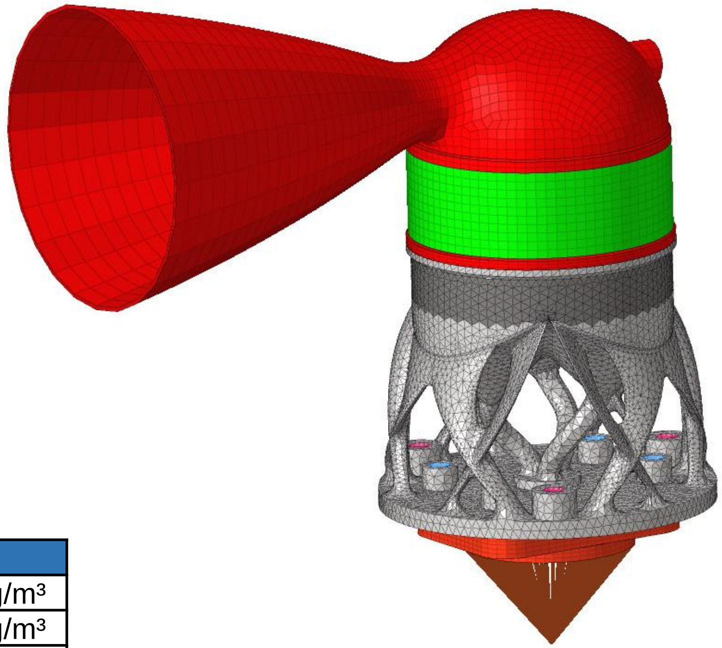
- 2 catalyst beds with variation in activity and porosity
- Total mass approx. 79 g

CHT240N DM1a – ANALYSIS

STRUCTURE

DM1a – Model Description

- FE model of full thruster + FCV mass dummy
- Nozzle section modelled using HEX elements with shell elements as surf. for stress extraction. Max. element size ~2mm
- Heat barrier modelled using non-linear tetra elements (10 nodes). Maximum element size 1.5mm.
- The FCV is modelled with HEX elements includes body flange and seat subassembly. The rest of the FCV is modelled with a concentrated mass element
- Weld between nozzle and heat barrier performed using MSC Nastran glued contact.
- Analysis performed: Modal analysis, frequency response (sine) and random analysis.



Section	Material	E-Modulus	ν	ρ
Nozzle + Heat barrier	Hastelloy X LBM	190.2 GPa	0.32	8220 kg/m³
Filters	Haynes 25	225 GPa	0.298	9130 kg/m³
FCV Flange	WL1.4546.9	199.9 GPa	0.32	7900 kg/m³

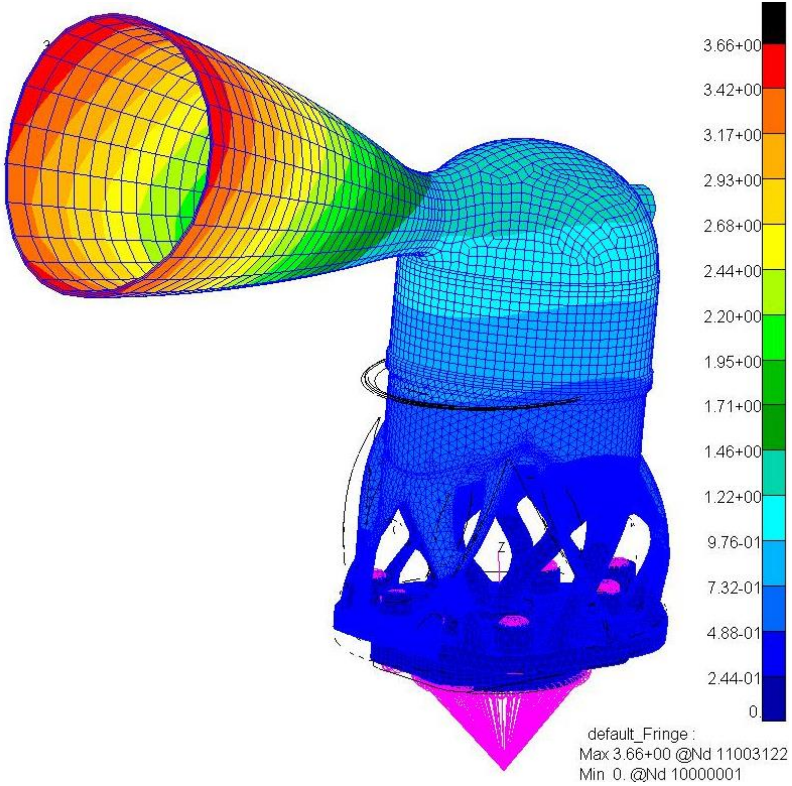
CHT240N DM1a – ANALYSIS

STRUCTURE

DM1a – Results

- Lowest eigenfrequency at 699 Hz (thruster x-axis)
- Sine vibration MoS > 10
- Random vibration MoS 0.77
- Structural tests for validation of FE modelling techniques

→ Current design can be manufactured and tested



CHT240N DM1a – MANUFACTURING

DM1a ALM PRINTING

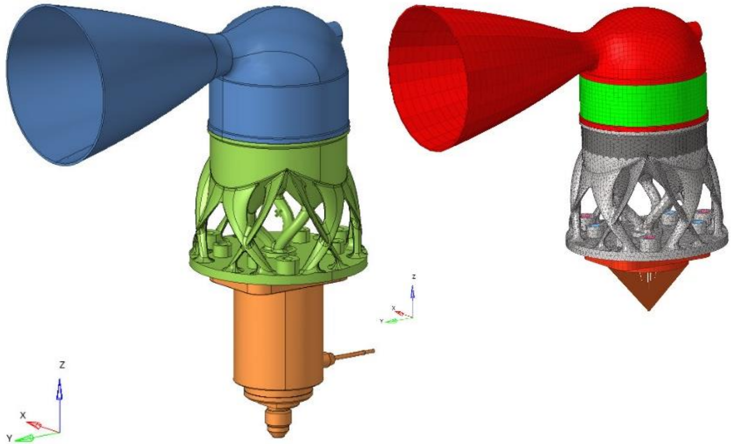
Heat Barrier with flange and decomposition chamber

Stagnation chamber and nozzle

CHT240N DM1a – MANUFACTURING

DM1a FINAL INTEGRATION AND PHYSICAL PROPERTIES EVALUATION

DM1a thruster fully assembled



	CAD	FEM	Diff. [%]
Mass [gr]	1260.35	1247.67	-1.01
CoG X [mm]	-0.00035	0.000851	-
CoG Y [mm]	5.578	5.582423	0.08
CoG Z [mm]	24.85	24.57316	-1.11

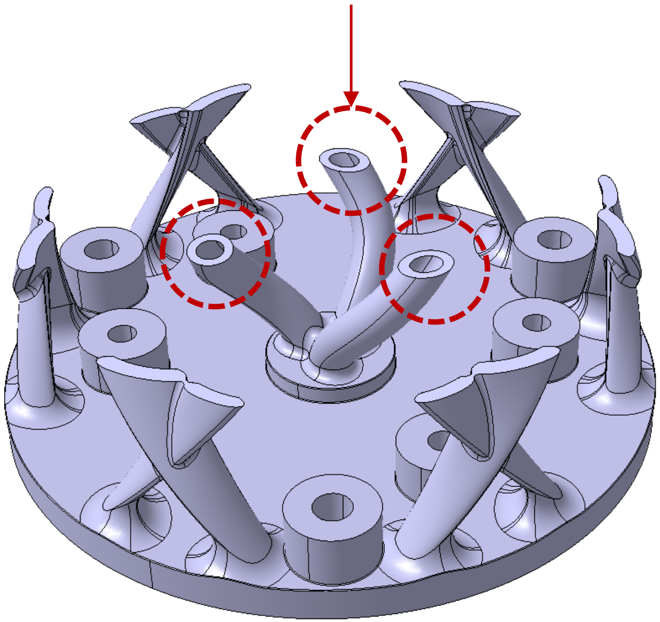
Differences of CAD model (left) and FEM model (right)

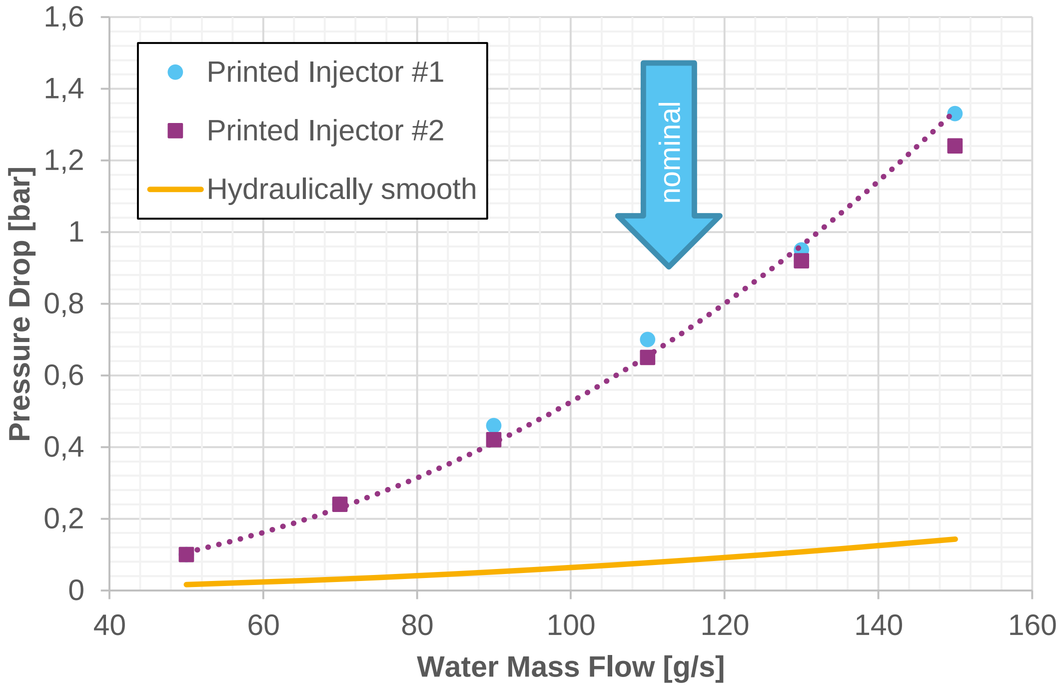
CHT240N DM1a – TEST PLAN & STATUS

Test Step	Title	Status / Results
1.1	Incoming Inspection	Parts printed, heat treated and sample probes evaluated – no anomalies
	Mechanical Post Processing and Integration	Tools adapted and post processing performed
1.2	Visual Inspection	nominal
1.3	Physical Properties Examination	Performed, no anomalies detected
1.4	Hydraulic tests	Pressure drop tests with water against atmosphere performed
n.a.	Integration of nozzle dummy	**Additional work done:** Complete integration of thruster with injector, 2 cat beds and flight nozzle performed
2.1	Visual inspection	Performed, no anomalies detected
2.2	Physical Properties Examination	Performed, no anomalies detected
2.3	Vibration	Performed, no anomalies detected
2.4	Final Inspection	Performed, no anomalies detected

CHT240N DM1a – TEST RESULTS

HYDRAULIC VERIFICATION OF ALM PRINTED HEAT BARRIER

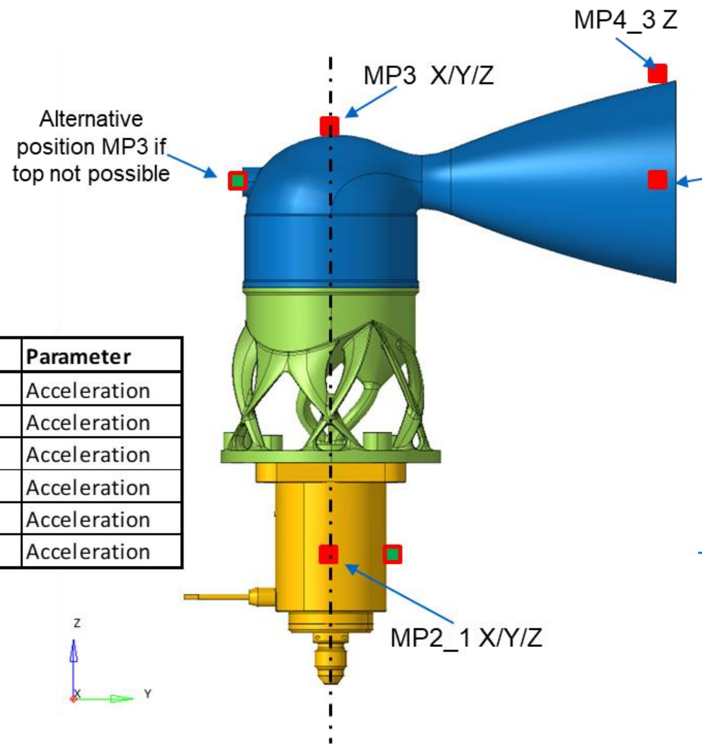


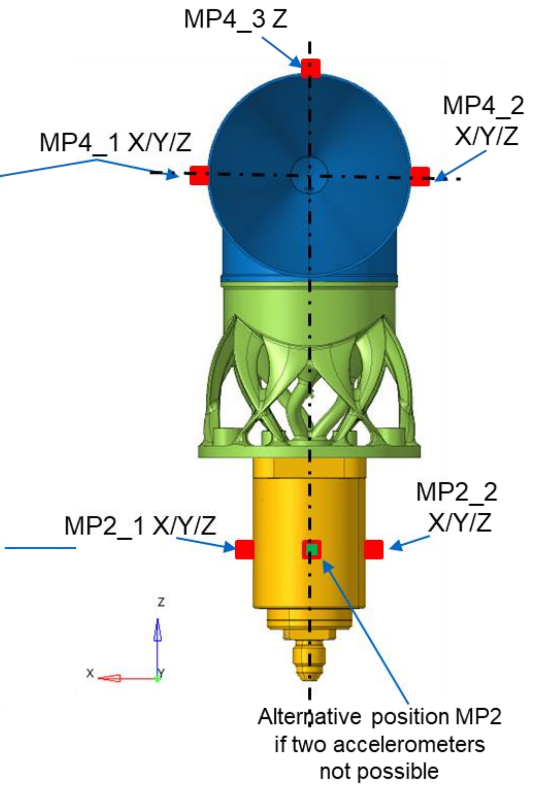


CHT240N DM1a – TEST RESULTS

VIBRATION TESTS – DEFINITION OF SENSORS

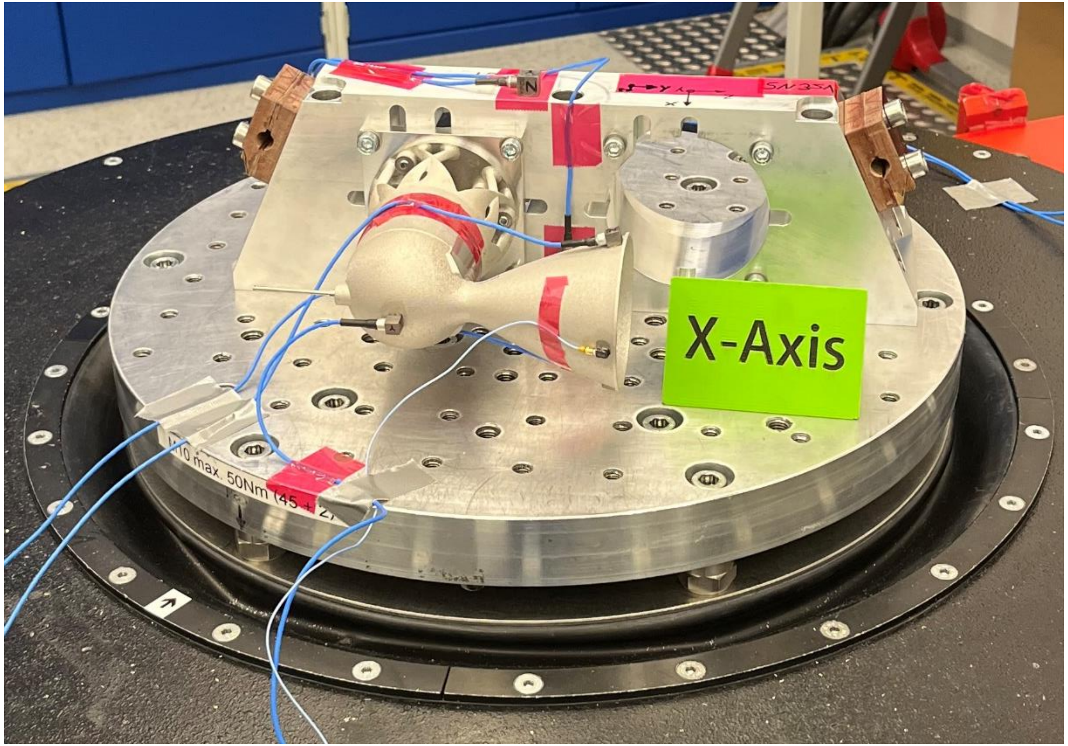
Location	Sensor ID	Parameter
Valve Body	MP2_1 (X/Y/Z)	Acceleration
	MP2_2 (X/Y/Z)	Acceleration
TCA Top	MP3 (X/Y/Z)	Acceleration
Nozzle	MP4_1 (X/Y/Z)	Acceleration
	MP4_2 (X/Y/Z)	Acceleration
	MP4_3 (Z)	Acceleration





CHT240N DM1a – TEST RESULTS

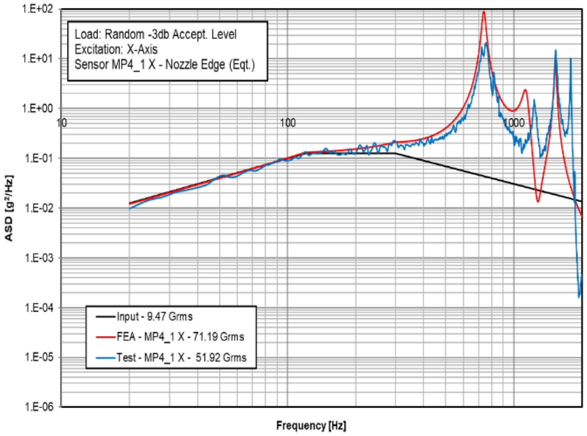
VIBRATION TESTS – TEST SETUP AND RESULTS

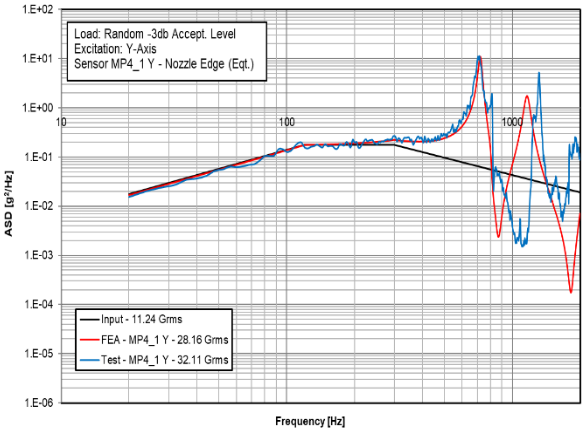


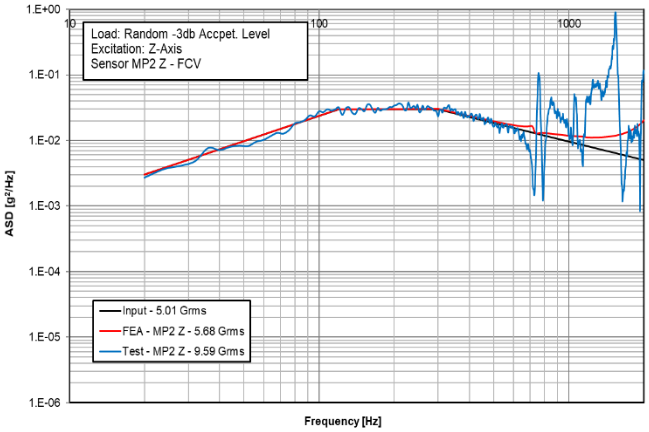
Random Vibration Qualification Level					
Thruster X Axis		Thruster Y Axis		Thruster Z Axis	
Freq. [Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]
20	0.05	20	0.07	20	0.012
120	0.5	120	0.7	120	0.12
300	0.5	300	0.7	300	0.12
2000	0.054	2000	0.076	2000	0.02
gRMS	18.9	gRMS	22.42	gRMS	9.99
Random Vibration Acceptance Level					
Thruster X Axis		Thruster Y Axis		Thruster Z Axis	
Freq. [Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]
20	0.0251	20	0.0351	20	0.0060
120	0.2506	120	0.3508	120	0.0601
300	0.2506	300	0.3508	300	0.0601
2000	0.0271	2000	0.0381	2000	0.0100
gRMS	13.4	gRMS	15.87	gRMS	6.51
Random Vibration Test -3db from Acceptance					
Thruster X Axis		Thruster Y Axis		Thruster Z Axis	
Freq. [Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]	Freq. Hz]	ASD [g²/Hz]
20	0.0126	20	0.0176	20	0.0030
120	0.1256	120	0.1758	120	0.0301
300	0.1256	300	0.1758	300	0.0301
2000	0.0136	2000	0.0191	2000	0.0050
gRMS	9.47	gRMS	11.24	gRMS	5.01

CHT240N DM1a – TEST RESULTS

VIBRATION TESTS –COMPARISON BETWEEN FEM AND TESTS AT NOZZLE (MP4_1)







Main Results

- FE model is reliable enough to predict the thruster dynamic behavior or at least small modifications can be performed to have a better correlation.
- The highest difference in general is when loading in the Z direction. This can be associated in part that the test jig has been improvised and can induced some extra modes and accelerations not capture by the FE analysis
- The general design of the thruster shows that it will be able at least to sustain the dynamic loads.
- Further verification needs to be performed for its behavior for hot vibration as well as general thermo-mechanical fatigue behavior during operation.

CHT240N DM1b – CLASSICAL MANUFACTURING

MAIN DIFFERENCES CLASSICAL VS. ADDITIVE MANUFACTURING

Heat Barrier: Printed (DM1a) vs. Classical (DM1b)

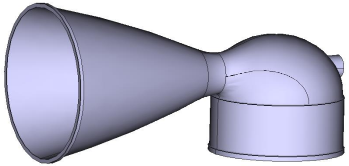
- Classical manufacturing includes manufacturing of 14 pieceparts (flanges, distance tubes, injector tubes) and subsequent assembly via brazing
- Significant reduction of manufacturing cost and lead time
- Hydraulic differences at feed tubes to be considered, post-processing to be considered

DM1a printed Heat Barrier (cat chamber at the top)

DM1b Classical Manufacturing (400N Hydrazine design, cat chamber at the top)

Canted Nozzle: Printed (DM1a) vs. Classical (DM1b)

- Classical manufacturing includes manufacturing of 2 pieceparts (nozzle and canted interface) and subsequent assembly via brazing
- Reduction of manufacturing cost and lead time
- With current printing accuracy nozzle throat (and TBC nozzle inner contour) has to be reworked



DM1a printed Nozzle Cant

DM1b Classical Manufacturing (400N Hydrazine design)

CONCLUSIONS

240N HYDRAZINE THRUSTER DE-RISK - ESA CONTRACT NO. 4000138574/21/NL/GLC/RK

- In order to pro-actively counter the risk of a non-availability of a 240N thruster for the VEGA RACS system, ArianeGroup was contacted to maturate and pre-develop a 240N thruster design and to confirm its suitability prior to a potential qualification.
- A basic thruster design according to the launcher needs was performed and 2 different design solutions were investigated:
  - *The primary design that was investigated was an advance design (DM1a) that takes into account modern manufacturing techniques and lessons learned form recent monopropellant thruster developments*
  - *A classical design (DM1b) based on the 400N class heritage thruster of the Ariane 5 RACS thruster*
- For the DM1a thruster design a first complete thruster design was performed and this design was stepwise optimized based on structural calculations
- The stress calculations show a minimum freq. at 699Hz. Sine vibration is not critical for the thruster strength; random vibration at VEGA-RACS qualification levels is the most critical load.
- A complete functional thruster was manufactured via ALM printing and finally fully integrated. This additional work could be performed due to synergies with another program (240N Hydrogen Peroxide thruster) where the only difference compared to the Hydrazine version is the catalytic bed
- Hydraulic tests of the printed parts were performed that showed a higher pressure drop of printed tubes compared to classical tubes – this difference has to be taken into account and change of print parameters or a post-processing to be implemented
- Vibration tests were performed and the results confirmed the assumptions of the structural analysis
- The Contact was fulfilled and exceeded as a fully functional flight like thruster is now ready for hot firing tests

CHT240N GSTP PROGRAM DELIVERIES

TIMELINE OF GSTP PHASE 1 AND FOLLOW-ON ACTIVITIES (FOR INFORMATION)

Doc ID	Title	Milestone	Description of documents
D1	240N DM1 Design Description / Justification	KP1	Description of DM1 thruster layout for decision to release the manufacturing of Test Items for Hydraulic / Structural Tests
D2	DM1a Test Report	KP2	DM1a Hydraulic / Structural Test Report
D3	240N PQM Design Description / Justification	KP2	Proposed 240N PQM thruster design and development roadmap taking into account DM1a and DM1b results
TDP	Technical Data Package	Final Review	Data package containing all documents that are to be delivered in the frame of this contract
ESR	Executive Summary Report	Final Review	Executive summary of final report as self-standing document
FR	Final Report	Final Review	Summary of PQM design description, injector hydraulic test results and proposed detailed work content of Phase 2 including separate proposals for side aspect 1 (European FCV) and side aspect 2 (ceramic chamber)
CCD	Contract Closure Documentation	Contract Closure	As requested by ESA
FP	Final Presentation	Final Review	
TAT	Technology Achievement Template	Final Review	Will be provided by ESA Technical Officer