MERiT

MEthane in Rocket nozzle cooling channels - conjugate heat Transfer measurements

Jens Fridh (KTH) / Jan Östlund (GKN), NRFP3 seminar - 15 Nov 2018

Background (1/3)

- Propulsion system using hydrocarbons (Methane)
  - grand challenge for today's rocket and space propulsion systems
  - Possibility for re-fulling @ extraterrestrial territories with local assets of Methane (Mars… H20 CO2)
  - Good performance indicators
    - Reasonably good specific thrust (~380 s @ sea level)
    - Good storage stability, cooling capabilities and availability
    - Low toxicity and production cost

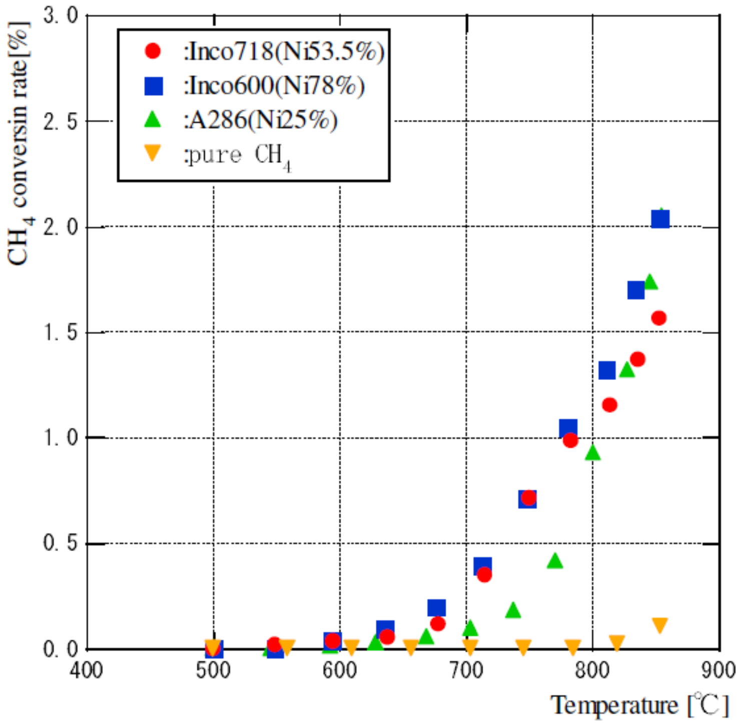
SpaceX
Raptor Engine
Engine tests Sep-16

Background (2/3)

- Rocket nozzle challenges
  - Coking in cooling channels due to fuel impurities and/or from thermal decomposition of methane @ high temperatures
  - Degradation of the heat transfer capabilities
  - Increased cooling channel pressure losses

- It is of utter importance for future nozzle designs to quantify the heat transfer characteristics of typical Nickel-based alloy steels used, e.g. 21-6-9
- Very few places in the world having the infrastructure for heat transfer studies of this type

Background (3/3)



(d) The sweep of temperature experiment increase

Fig.2. Experimental results of CH4 thermal cracking(Ni contents of each material mass level is shown)

Before

After

Reference:
Kazuyuki Higashino et al., AIAA 2008-4753

Project Objectives

- For a relevant alloy (21-6-9) and typical cooling channel geometries, fuel grade and operating conditions determine:
  - heat transfer coefficient
  - degree of coking and corrosion
  - pressure loss

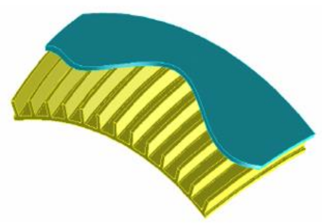
as a function of

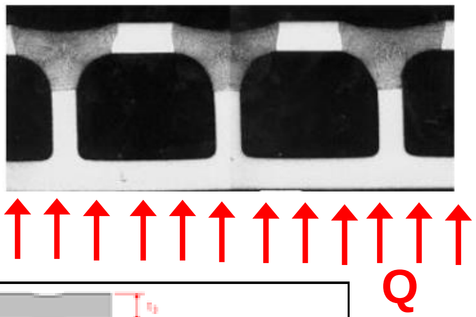
  - heat load
  - wall temperature
  - Reynolds number
  - fuel grade
  - pressure level

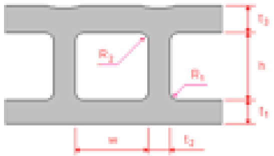
Methodology

  - Design and commission a test rig for conjugate heat transfer studies according to specs and perform trials
  - Supported with numerical studies

Specifications





										
#	Material	Heat flux (MW/m²)	Pressure level (bar)	Inlet temperature (K)	w (-)	h (-)	t_1 (-)	t_2 (-)	t_3 (-)	Length (-)
1	21-6-9 Carpenter 40	~6...7	40...160	270...655	0.16	0.16	0.06	0.1	0.08	0.75
2	21-6-9 Carpenter 40	~3.5...4.5	40...160	270...655	0.16	0.26	0.06	0.1	0.08	1
3	21-6-9 Carpenter 40	~1...2	40...160	270...655	0.3	0.26	0.06	0.1	0.08	1
4	Inco600	~6...7	40 bar	270...655	0.28	0.48	0.06	0.06	0.06	1

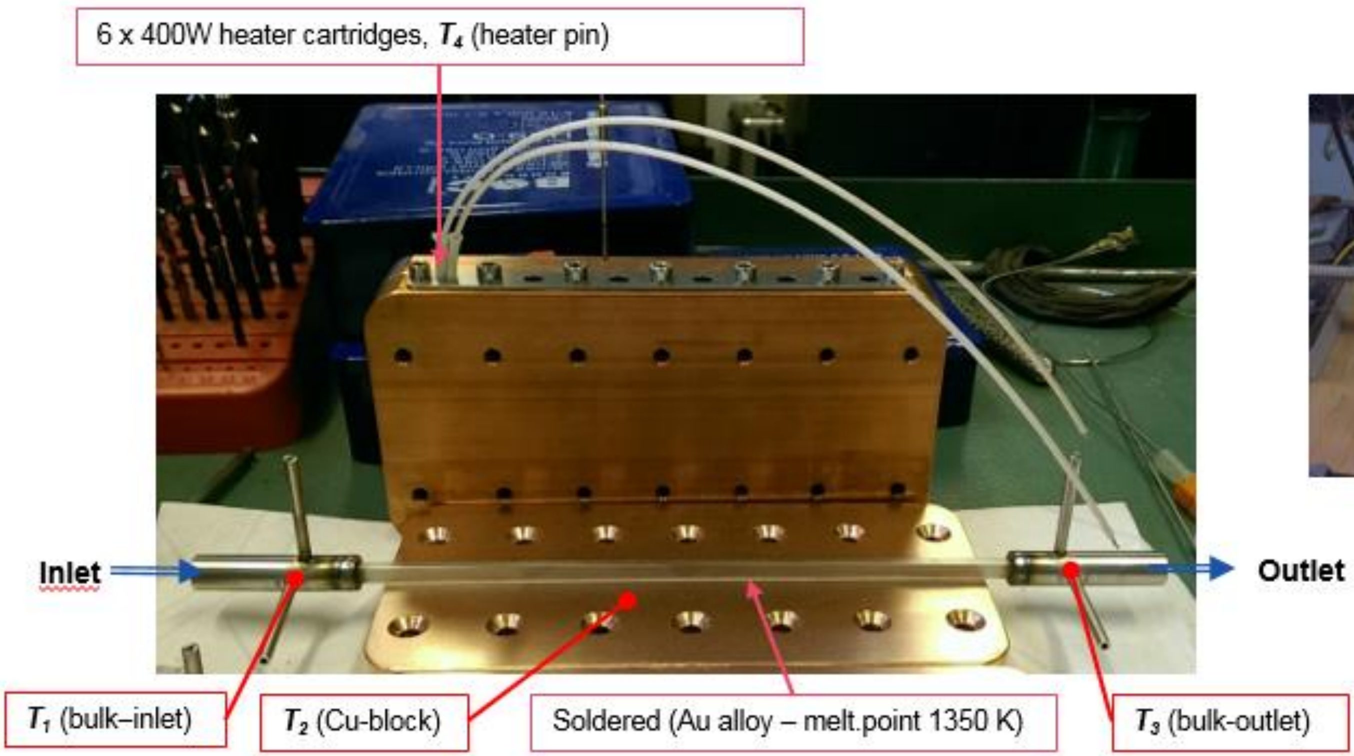
- Channel outlet temperature: < 800 K

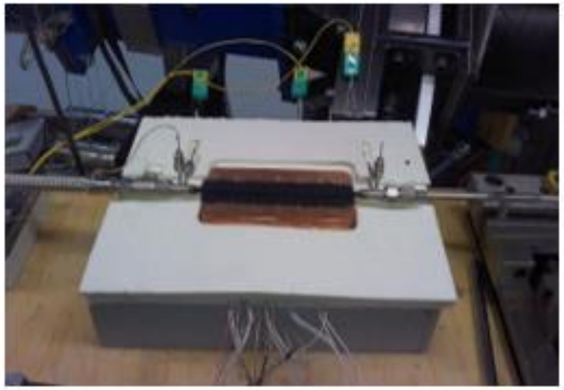
MERiT - Project plan

NRFP 3 - MERiT — Today

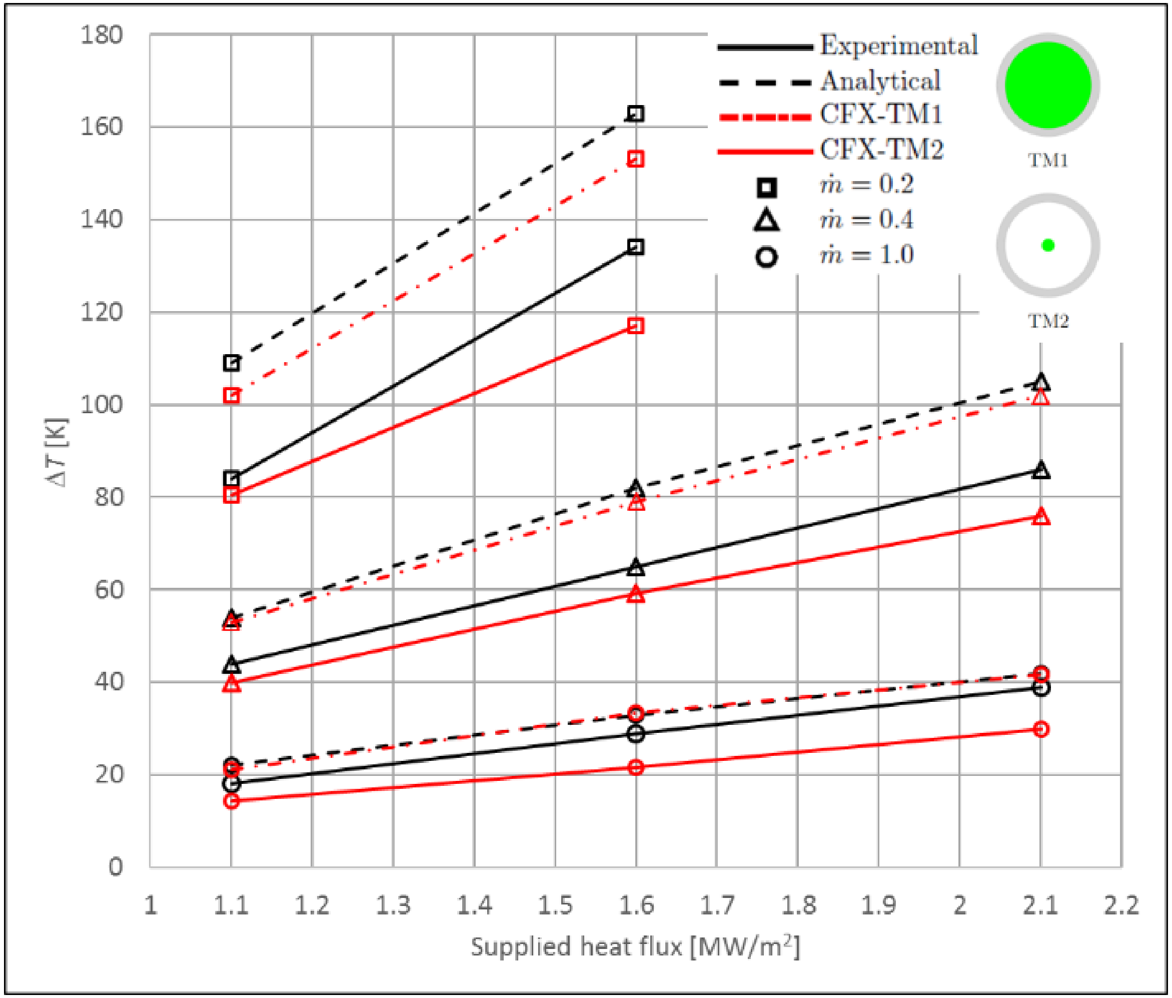
Work packages	**Description**	20160901 - 20161130	20161201 - 20170228	20170301 - 20170531	20170601 - 20170831	20170901 - 20171130	20171201 - 20180228	20180301 - 20180531	20180601 - 20180831	20180901 - 20181230	share
WP 0	Project lead										5%
WP 1	Conceptual study & heater tests										10%
WP 2	Design test rig										20%
WP 3	Infrastructure, risk assesment										20%
WP 4	Commissioning test rig										10%
WP 5	Test campaign										25%
WP 6	Synthesis of results										10%
Deliverables											Responsibility
D 0	Reference group meetings, minutes	x	x	x	x	x	x	x	x	x	GKN
D 1.1	Report – conceptual study		x								KTH
D 1.2	Report – heater tests		x								KTH
D 2	MSc thesis (optional)			x							GKN
D 3	Test facility installed, risk assessment report				x						KTH
D 4	Technical report, commissioning									x	KTH
D 5.1	Test & measurement plan								x		KTH
D 5.2	MSc thesis (optional), internship								x		GKN
D 5.3	MSc thesis (optional), internship								x		KTH
D 6.1	Technical report, test campaign									x	KTH
D 6.2	International paper, results							x		x	KTH/GKN
D 6.3	Final report, technical/economical									x	KTH/GKN

WP1: Inert (air) tests – Inco600 (4x6x180, t0.6)

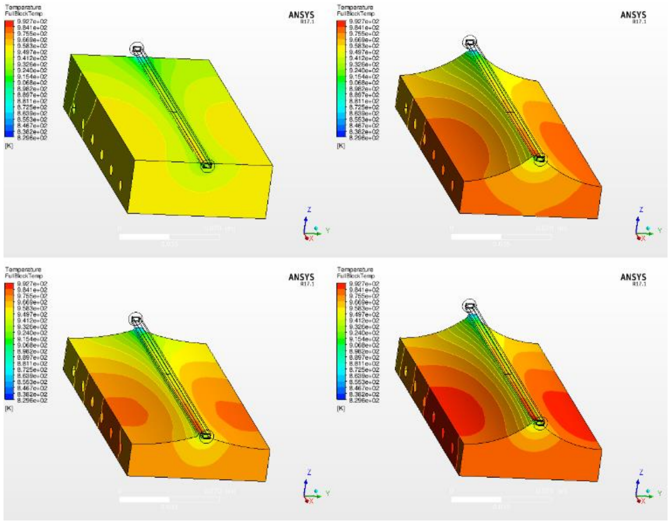


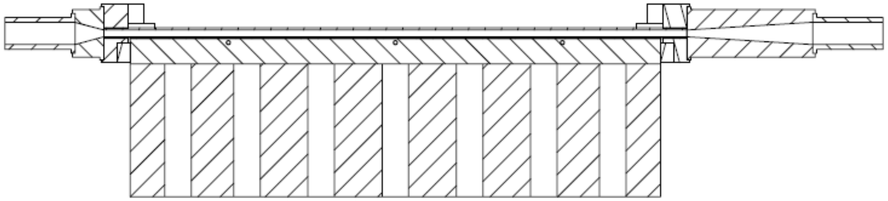


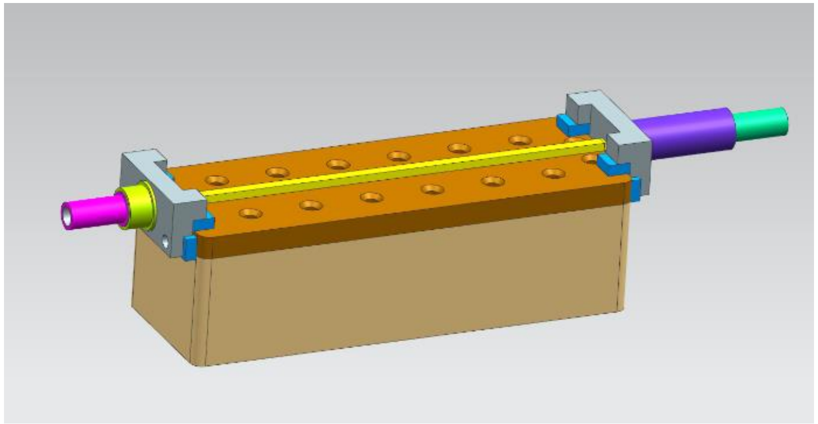
WP1: heater trials EXP / 1D / 3D CFD



Final Heater Design (WP2)



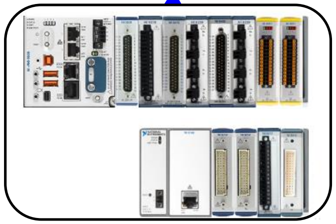


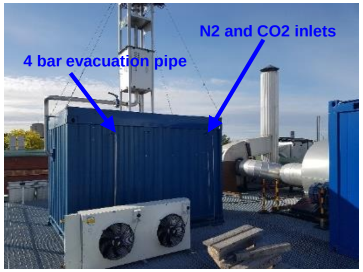


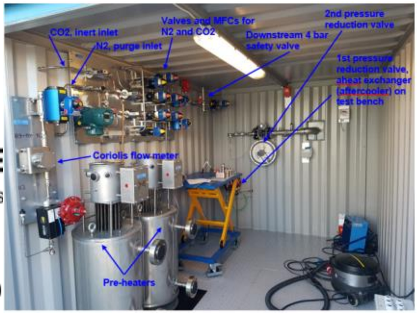
Targets:
Maximize the heat pick-up
Minimize the maximum block-temperature

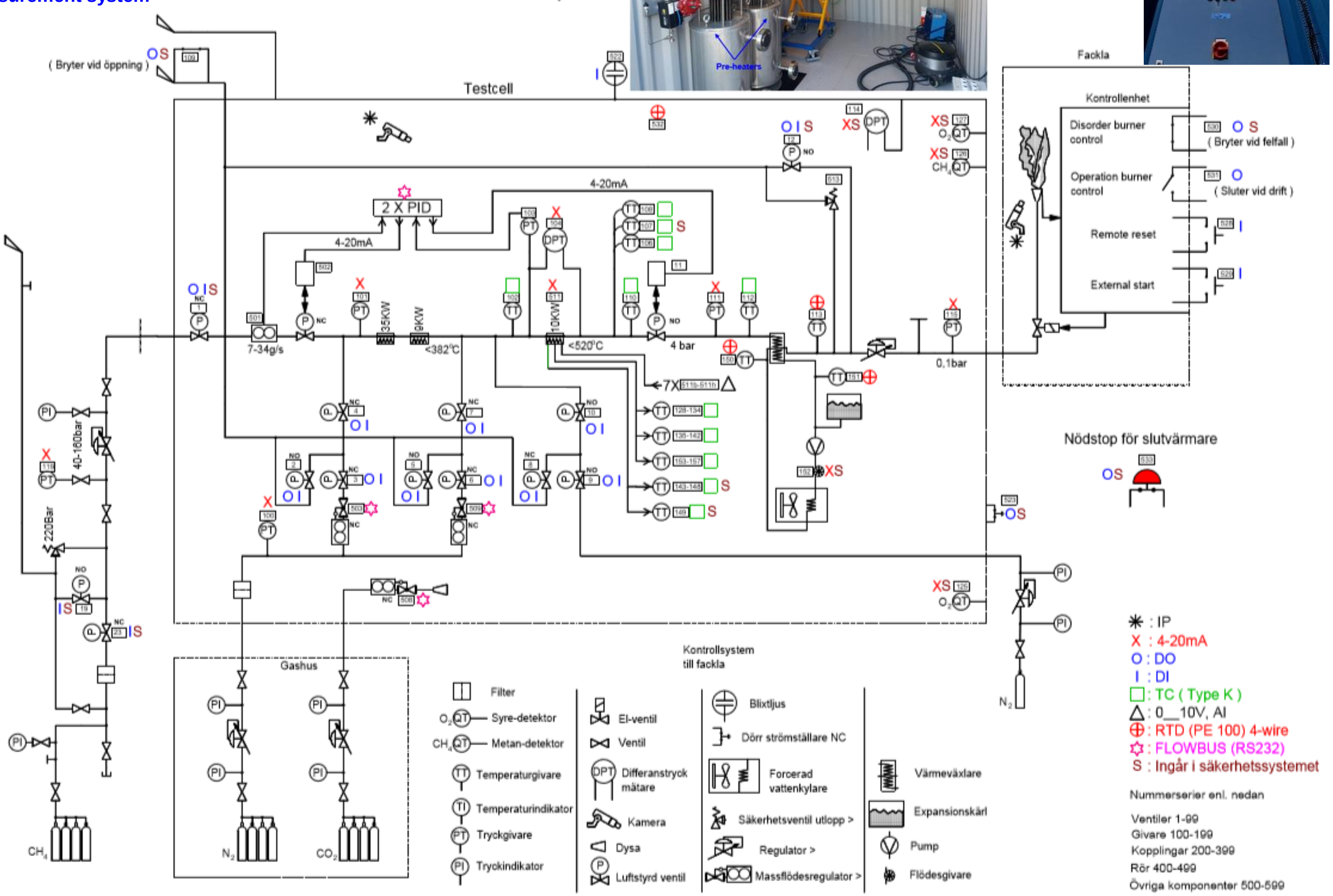
Infrastructure (WP3)

NI cRIO: Control & Measurement system



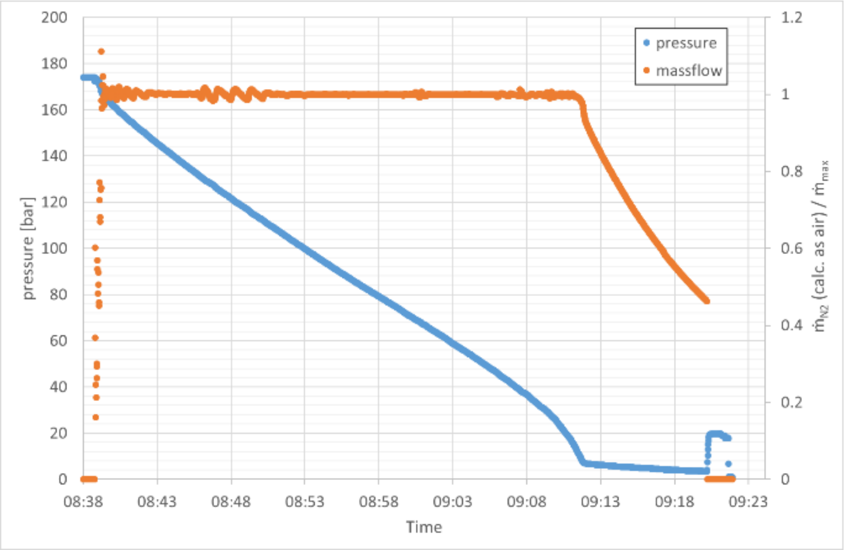






Commissioning (WP4)

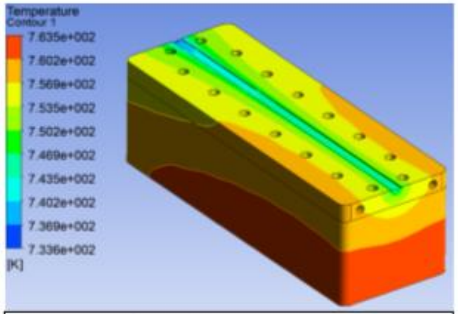
- Risk assessment
- Gas supply system
  - April 2017
- Flare system
  - Dec 2017
- Process
  - ....



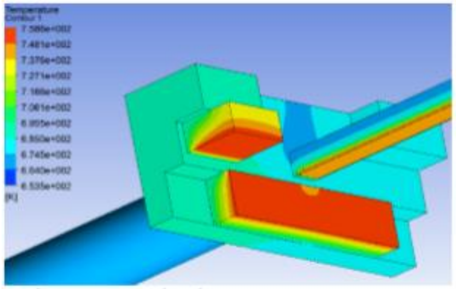
Test plan preliminary trials (WP5)

Limited due to economical and time restrictions

Test ID	channel #	q (MW/m2)	PTI (bar)	TTI (nor	m (-)	DPT_est (norm)		TTO_est (norm)		MO_est (norm	
						1D	CFD	1D	CFD	1D	CFD
D301	3	1,5	40	0,687	low	0,008	0,012	0,654	0,659	0,2	0,22
D302	3	1,5	100	0,687	low	0,003	0,005	0,651	0,655	0,08	0,08
D303	3	1,5	160	0,687	low	0,002	0,003	0,650	0,653	0,05	0,052
D304	3	1,5	40	1	medium	0,092	0,144	0,845	0,856	0,8	0,76
D305	3	1,5	100	1	medium	0,038	0,056	0,845	0,848	0,28	0,28
D306	3	1,5	160	1	medium	0,024	0,036	0,844	0,846	0,18	0,18
D307	3	1,5	60	1	high	0,178	0,284	0,834	0,849	0,92	0,9
D308	3	1,5	100	1	high	0,108	0,164	0,834	0,839	0,5	0,5
D309	3	1,5	160	1	high	0,068	0,104	0,834	0,836	0,3	0,3
D201	2	3,5	40	0,5344	low	0,032		0,604		0,4	
D202	2	3,5	100	0,5344	low	0,012		0,594		0,14	
D203	2	3,5	160	0,5344	low	0,008		0,588		0,08	
D204	2	3,5	60	0,687	medium	0,224		0,615		0,88	
D205	2	3,5	100	0,687	medium	0,134		0,615		0,46	
D206	2	3,5	160	0,687	medium	0,084		0,614		0,26	
D207	2	3,5	80	0,7634	high	0,546		0,653		1,46	
D208	2	3,5	120	0,7634	high	0,366		0,653		0,74	
D209	2	3,5	160	0,7634	high	0,278		0,653		0,52	
D101	1	4	40	0,458	low	0,068		0,525		0,6	
D102	1	4,5	100	0,458	low	0,024		0,528		0,22	
D103	1	4,5	160	0,458	low	0,014		0,515		0,12	
D104	1	6	60	0,458	medium	0,354		0,446		1,36	
D105	1	6	100	0,458	medium	0,2		0,443		0,62	
D106	1	6	160	0,458	medium	0,12		0,438		0,34	
D107	1	7	100	0,458	high	0,58		0,413		1,28	
D108	1	7	130	0,458	high	0,44		0,414		0,8	
D109	1	7	160	0,458	high	0,35		0,414		0,6	



20g 655K 40bar Configuration 3



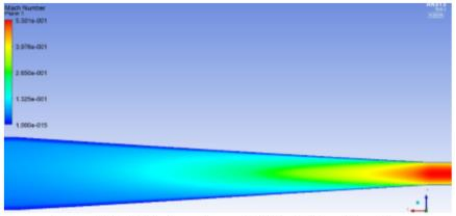


Figure 17 Outlet Mach number map in high velocity configuration

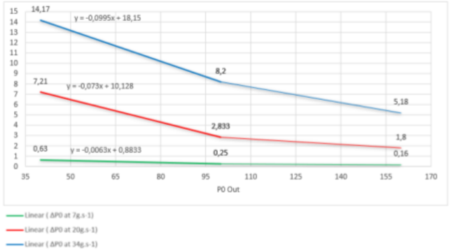
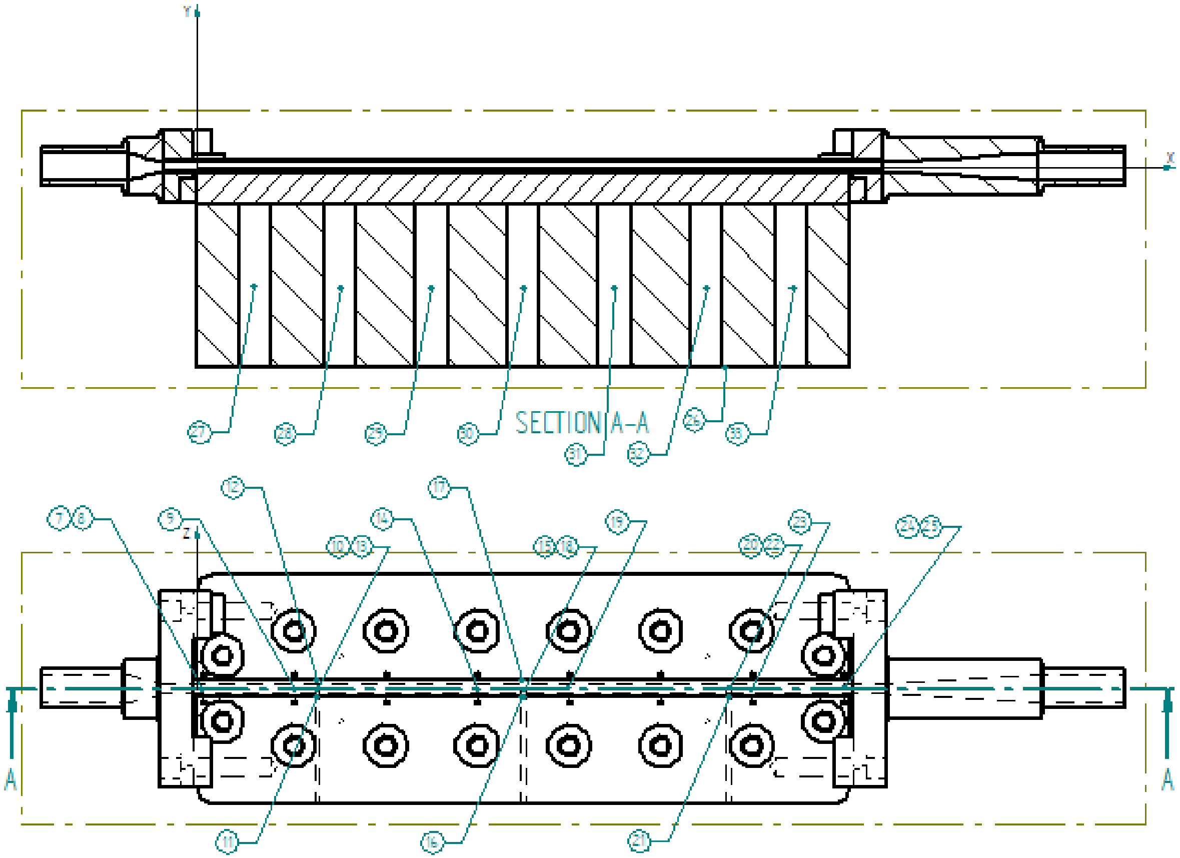


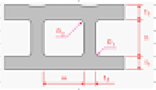
Figure 19 Pressure loss as a function of back pressure with constant mass flow rate

Test Measurement points



Heat transfer:
TC measurements

e.g. TWCXD1
T: Temperature
W: wall (E: embedded)
C: cold side (H: hot, M: middle, B: bottom)
X: channel (1...4, 0 heater block)
D: repr. Z-location (0...2)
1: repr. X-location (1...9, 10..17 heater block)



#	Point ID	X	Y	Z	Signal ID	Description	Note
1	TTI	~-130	0	0	102	Total Temperature Inlet	see process chart for location
2	PTI	~-30	0	0	103	Total Pressure Inlet	see process chart for location
3	DP1	~-70...250	0	0	104	Differential Pressure	see process chart for location
4	TTO1	~280	-2,75	0	106	Total Temperature Outlet rake	see process chart for location
5	TTO2	~280	0	0	107	Total Temperature Outlet rake	see process chart for location
6	TTO3	~280	2,75	0	108	Total Temperature Outlet rake	see process chart for location
7	TWHXD1	2	-1,95	0	135	Temperature Wall Hot	
8	TWCXD1	2	2	0	136	Temperature Wall Cold	
9	TWHXD2	30	-1,95	0	137	Temperature Wall Hot	
10	TEHXD3	37	-4,2	0	138	Temperature Embedded Hot	
11	TWM1D3	37	0	-2,5	153	Temperature Wall Middle	
12	TWM2D3	37	0	2,5	154	Temperature Wall Middle	
13	TWCXD3	37	2	0	139	Temperature Wall Cold	
14	TWHXD4	86	-1,95	0	140	Temperature Wall Hot	
15	TEHXD5	100	-4,2	0	141	Temperature Embedded Hot	
16	TWM1D5	100	0	-2,5	155	Temperature Wall Middle	
17	TWM2D5	100	0	2,5	156	Temperature Wall Middle	
18	TWCXD5	100	2	0	142	Temperature Wall Cold	
19	TWHXD6	134	-1,95	0	143	Temperature Wall Hot	
20	TEHXD7	168	-4,2	0	144	Temperature Embedded Hot	
21	TWM1D7	168	0	-2,5	157	Temperature Wall Middle	
22	TWCXD7	168	2	0	145	Temperature Wall Cold	
23	TWHXD8	[illegible]	-1,95	0	146	Temperature Wall Hot	
24	TWHXD9	198	-1,95	0	147	Temperature Wall Hot	
25	TWCXD9	198	2	0	148	Temperature Wall Cold	
26	TWBXD10	168	[illegible]	0	149	Temperature Wall Bottom	hot spot, supervision
27	TELCD11	18	-86	0	128	Temperature Electric cartridge 2	
28	TELCD12	48	-86	0	129	Temperature Electric cartridge 5	
29	TELCD13	[illegible]	-86	0	130	Temperature Electric cartridge 8	
30	TELCD14	100	-86	0	131	Temperature Electric cartridge 11	
31	TELCD15	128	-86	0	132	Temperature Electric cartridge 14	
32	TELCD16	156	-86	0	133	Temperature Electric cartridge 17	
33	TELCD17	182	-86	0	134	Temperature Electric cartridge 20	

Outcomes...up until 2018-11-15

- Test build design
  - Conceptual and design report
  - 1 MSc thesis (NUM)
- Infrastructure design
  - Risk assessment report
  - 2 Internships (EXP, NUM)
  - Third party audit documentation
- Commissioning and Trials
  - Test and measurement plan report
- Conf.paper (SP2018)

Summary / Outlook

Summary

- A world-unique test rig for high pressure (200 bar), high temperature (800 K / 1023 K) and fuel thermal power < 1.8 MW heat transfer studies for channels have been designed, manufactured, installed...partly verified & commissioned
- Tight time plan to build a very complex infrastructure (high press, high temp.) → 6-8 months delay compared to the original plan → unrealistic to manage first base trials with CH_4 before 2019

- Acknowledgements to project funding organizations:
  - Rymdstyrelsen (NRFP3)
  - ESA (FLPP)
  - KTH, EGI Dept.(KTH)

Outlook

- Nov-Dec 2018 – Infrastructure installed
- Dec 2018...Jan 2019 – Commissioning, Inspection, authority clearance