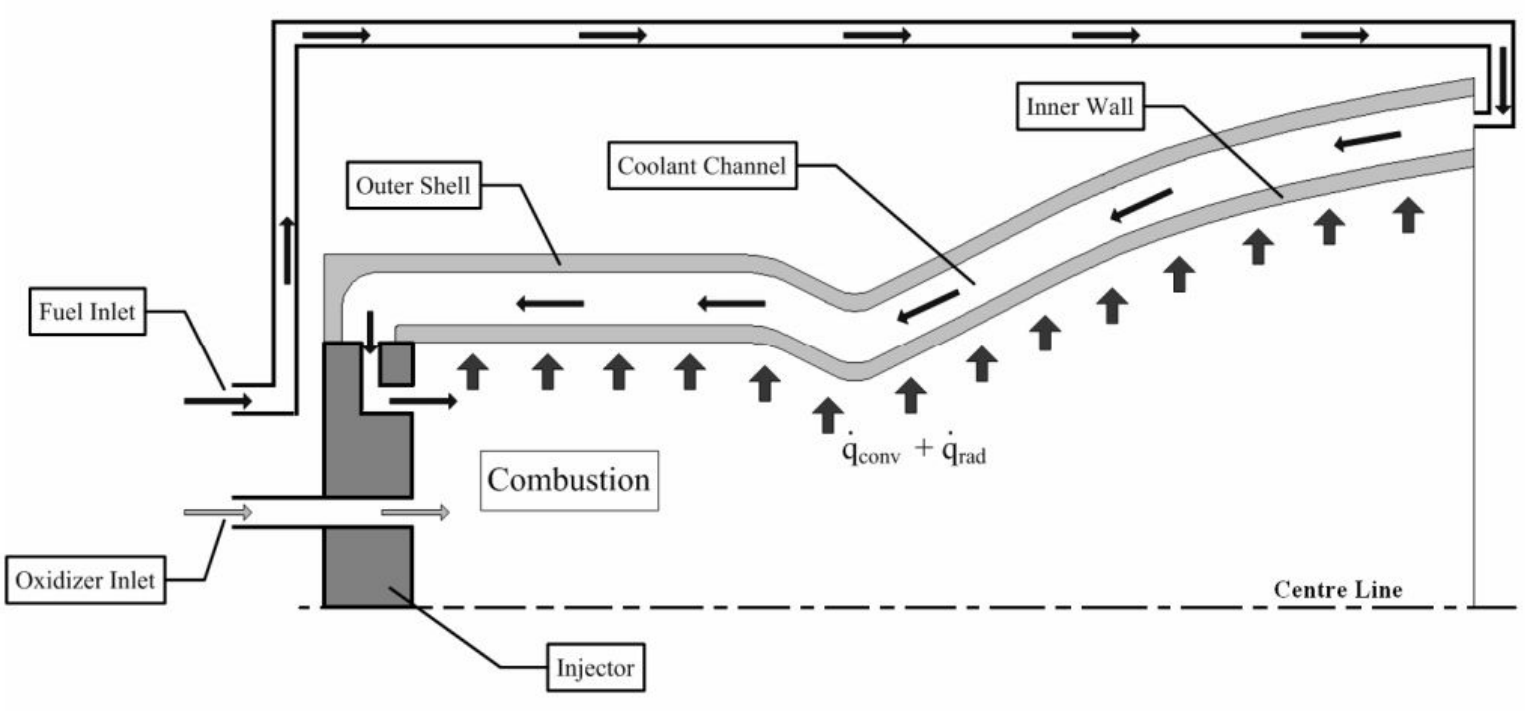
Rocket Engines

Optimizing Regenerative Cooling

Understanding the system



The question

MUST

Metal does not melt

# of tubes & flow rate are reasonable

SHOULD

Minimize mass

(↓ # of coolant tubes)
(↓ coolant tube surface area)
(↓ coolant flow rate)

Minimize cost

(↓ coolant flow rate)
(↓ operating temperature)

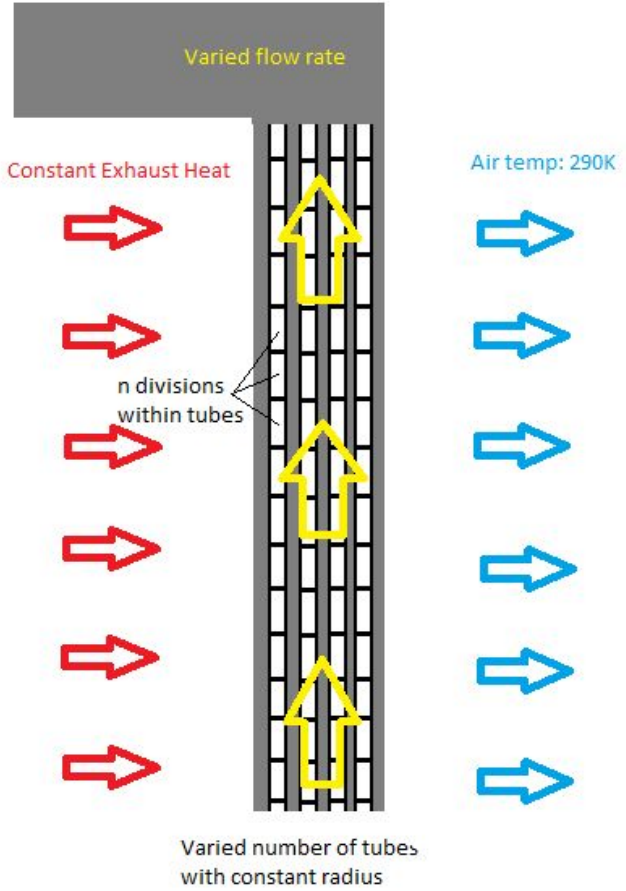
BY VARYING

Coolant flow rate
# of tubes

“How does the number of tubes and the total coolant flow rate affect the temperature of the engine?”

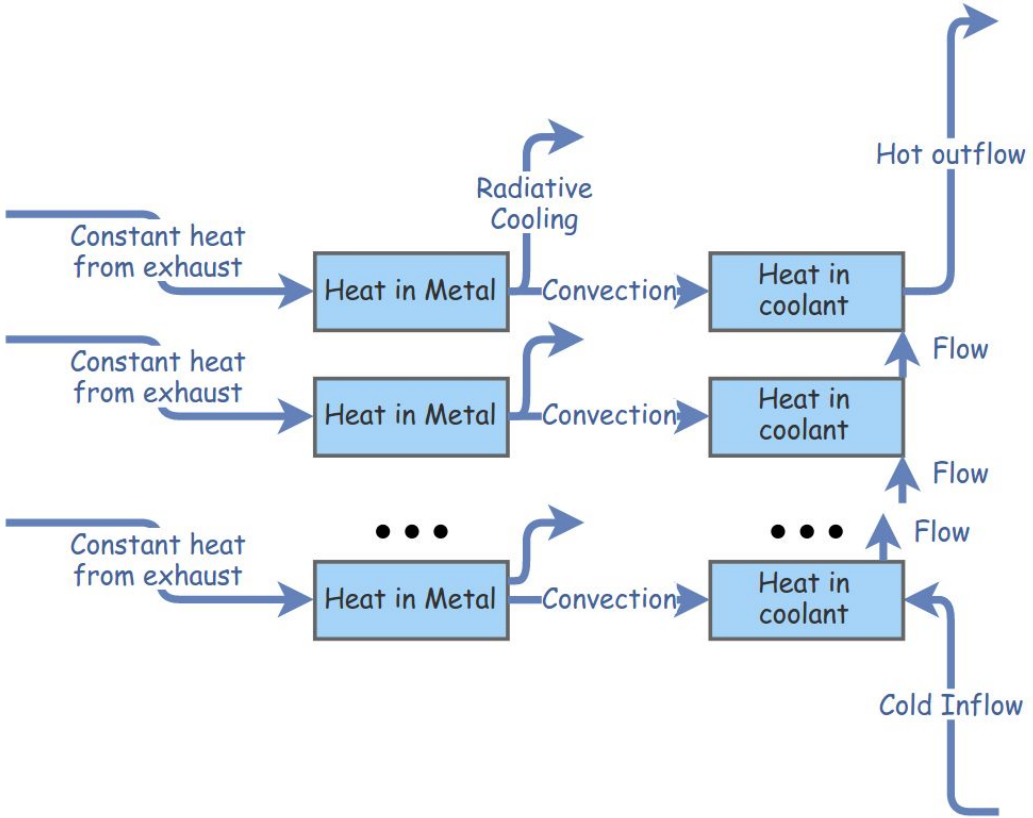
Our Model

- **Simplifications**
  - Chamber is a hollow cylinder
  - Exhaust temperature inside chamber is constant
  - Tubing is straight
- **Parameters**
  - Rate of fuel flow
  - Number of cooling tubes of equal radius
- **Assumptions**
  - Flows: radiative heating, fluid convection, air radiation
  - Tubes are divided into n divisions. Measure temperature within each division



Our Model (details)

Flow	Equation
Heat from Exhaust	*p.heat_flow_from_exhaust / num_fuel*
Radiation	*p.metal_radiative_emmisivity*SB* (p.metal_surface_area / num_fuel) * (metal_temp ^ 4 - p.air_temp^4);*
Convection	*p.heat_transfer_coefficient * (p. tubing_surface_area/num_fuel) * (metal_temp - fuel_temp);*
Flows fuel	*p.fuel_flow_rate * p.fuel_specific_heat * p.fuel_density * (fuel_temp - last_fuel_temp);*



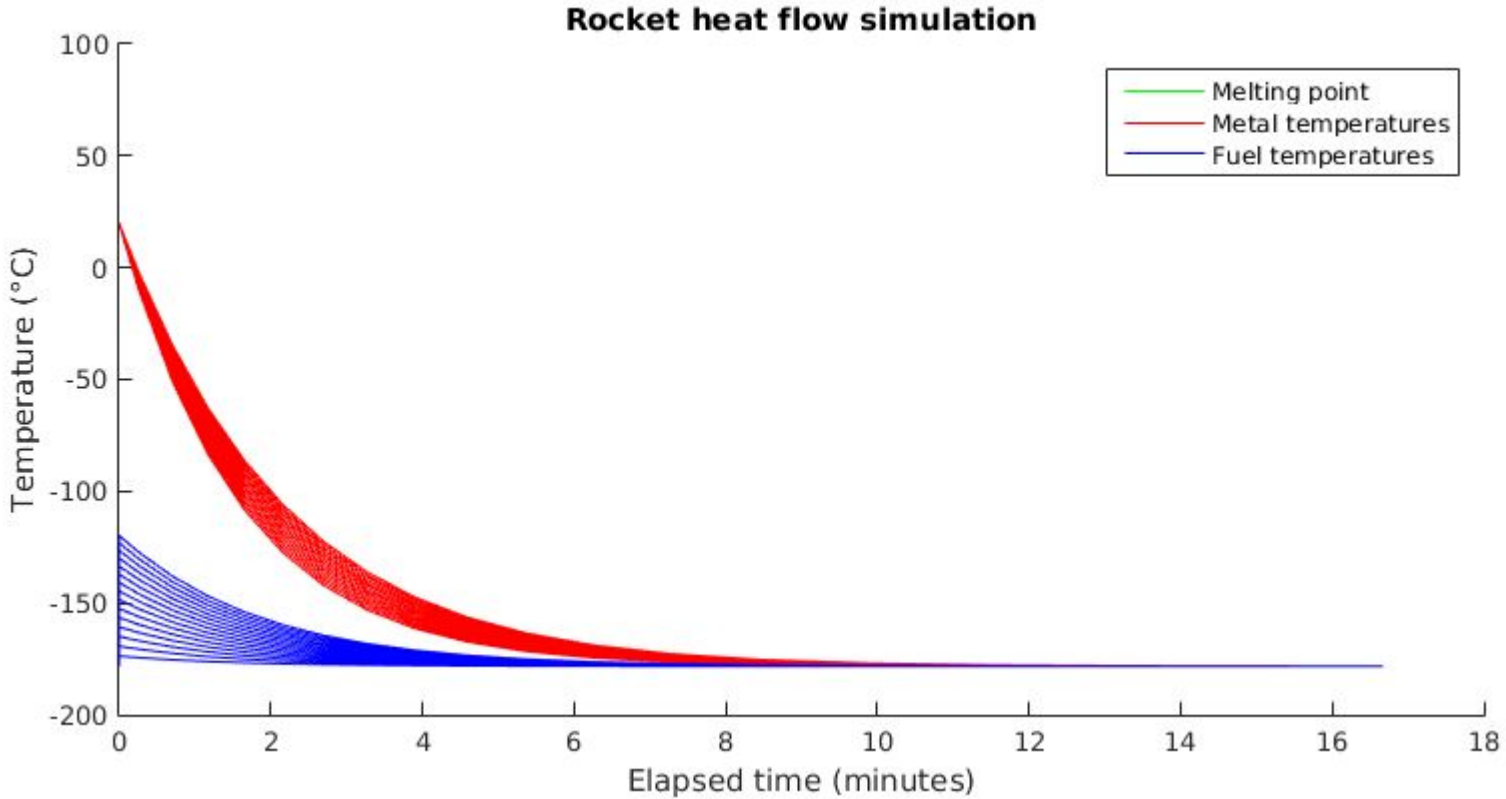
Our Model (default parameters)

Parameter	Units	Default value
air_temp	K	290
metal_specific_heat	J / (kg°C)	450
metal_initial_temp	K	290
metal_surface_area	m^2	8π
metal_density	kg/m^3	8890
metal_radiative_emmisivity	[unitless]	0.02
metal_melting_point	K	1053
number_of_tubes	[unitless]	300

Parameter	Units	Default value
tube_radius	m	0.5cm
fuel_specific_heat	J / (kg°C)	15000
fuel_cold_temp	K	91.7
fuel_density	kg/m^3	71
heat_transfer_coefficient	[unitless]	12000
heat_flow_from_exhaust	W	100000000
fuel_flow_rate	m^3 / s	0.3
num_coolant_stocks	[unitless]	15

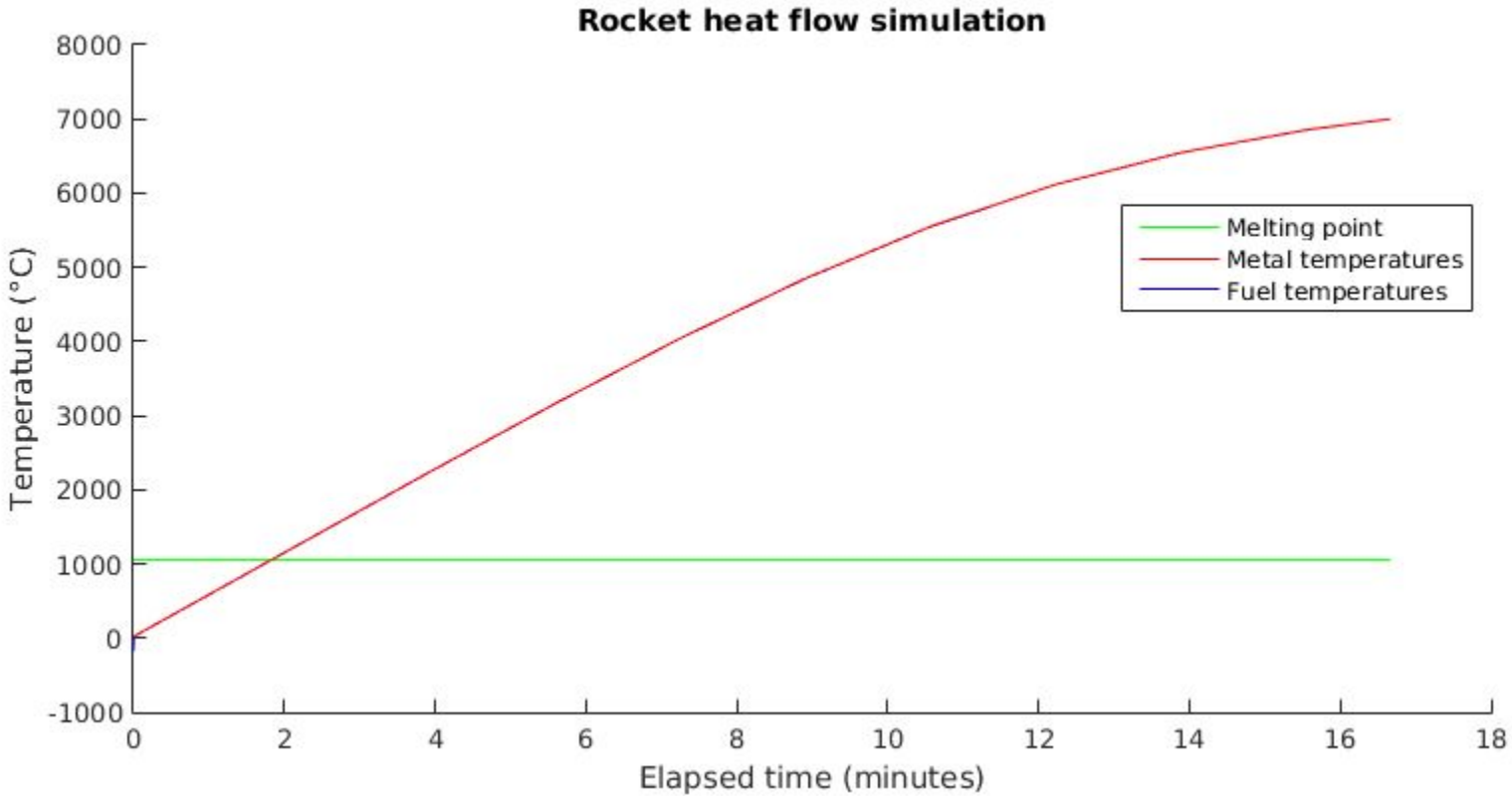
Limiting case #1: Engine off

heat_from_exhaust = 0



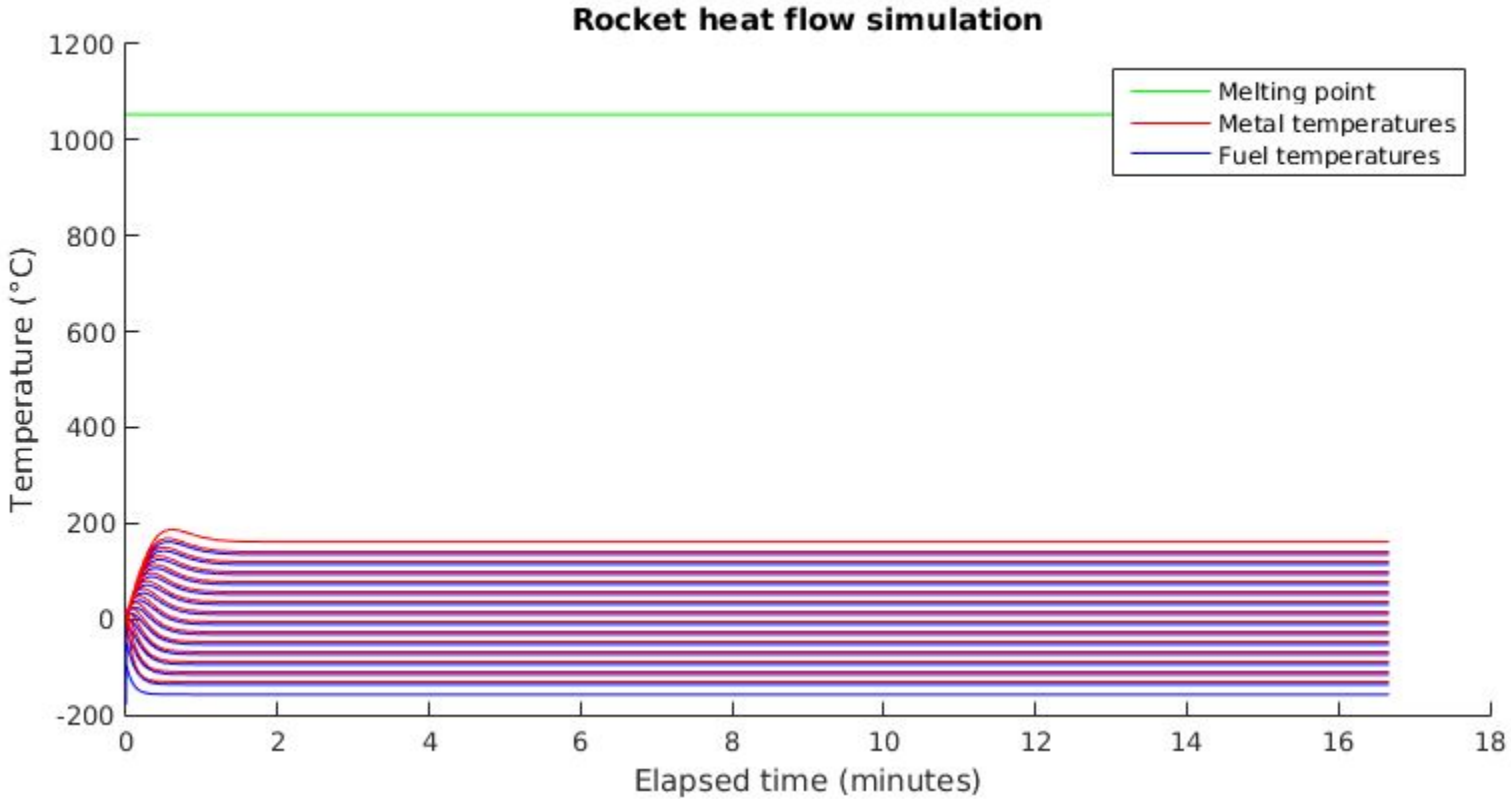
Limiting case #2: Coolant disabled

coolant_flow_rate = 0



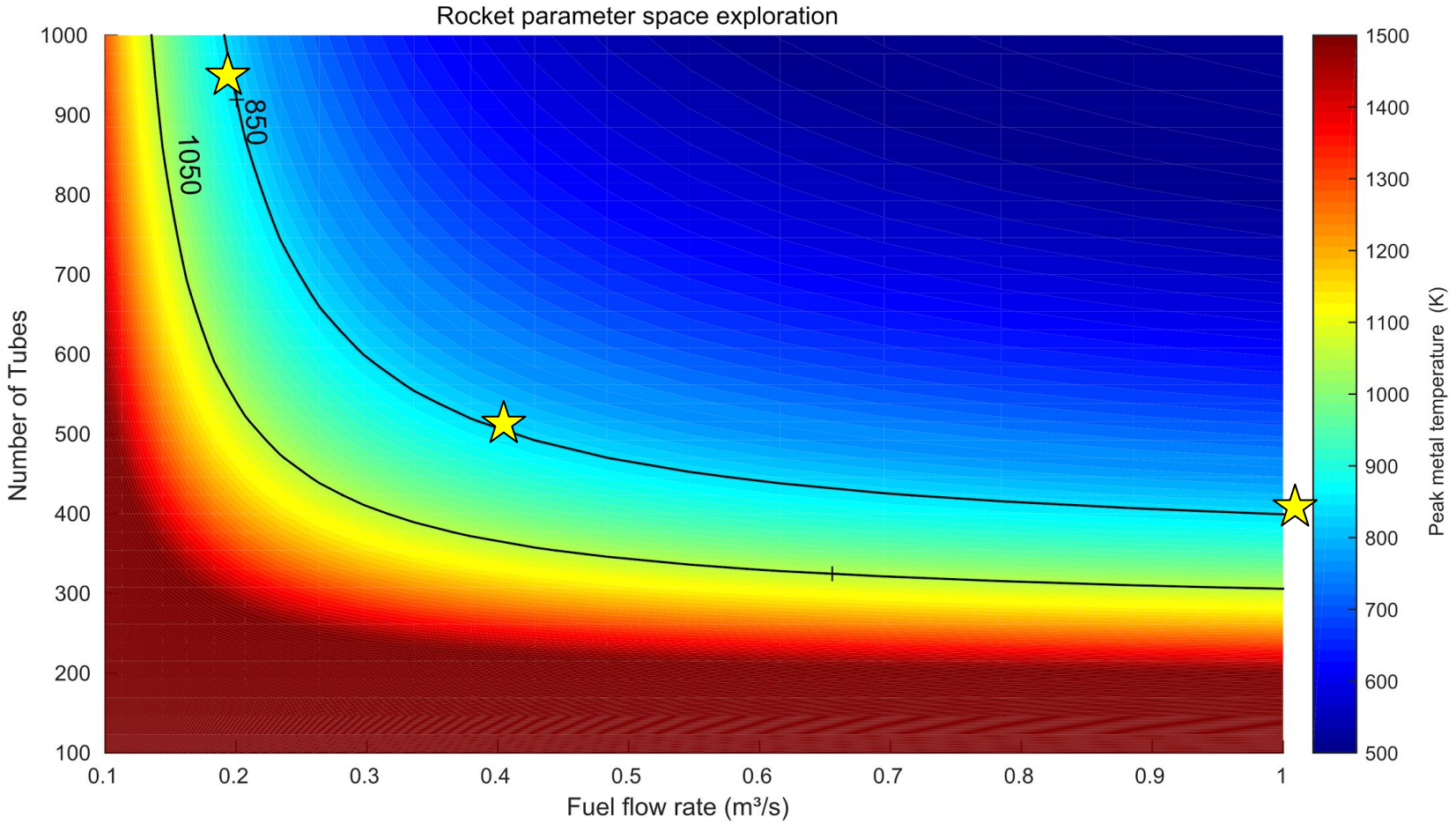
Limiting case #3: Many coolant tubes

number_of_tubes = 10^4



...drumroll...

Results


Rocket parameter space exploration
Number of Tubes
Fuel flow rate (m³/s)
Peak metal temperature (K)
850
1050
1000
900
800
700
600
500
400
300
200
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1500
1400
1300
1200
1100
1000
900
800
700
600
500

Additional Considerations

1: 500 tubes, 0.45 flow

2: 400 tubes, 1.41 flow

3: 900 tubes, 0.21 flow