

Optimization of Aspect Ratio for Cooling Channels in Rocket Engines

A Parametric Study on the RL10 Engine

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Introduction

- **Objective:** Find the optimal mass flow rate and aspect ratio (AR) for the cooling channels at the throat section of the RL10 engine.
- **Context:** Importance of aspect ratio in enhancing cooling performance and minimizing pump power loss.

Methodology

- **Parametric Study:** Conducted to determine the optimal AR by varying mass flow rate and observing the resulting pressure drop and power loss.
- **Design:** Channel height constant, width is twice the rib thickness.

Key Equations and Concepts (1/2)

- **Aspect Ratio (AR):** Ratio of channel height to width.
- **Heat Transfer Coefficient:**
 - Coolant: Explained through the Dittus-Boelter correlation for the Nusselt number
 - Hot gas: Bartz correlation
- **Wetted Perimeter and Hydraulic Diameter:**
Their role in pressure drop and heat transfer.

Key Equations and Concepts (2/2)

(1) Pressure drop: $\Delta p_0 \sim \frac{G^2}{D_h}$

(2) Channels hydraulic diameter: $D_h = \frac{4A}{P} = \frac{4A_{tot}}{P_{tot}}$

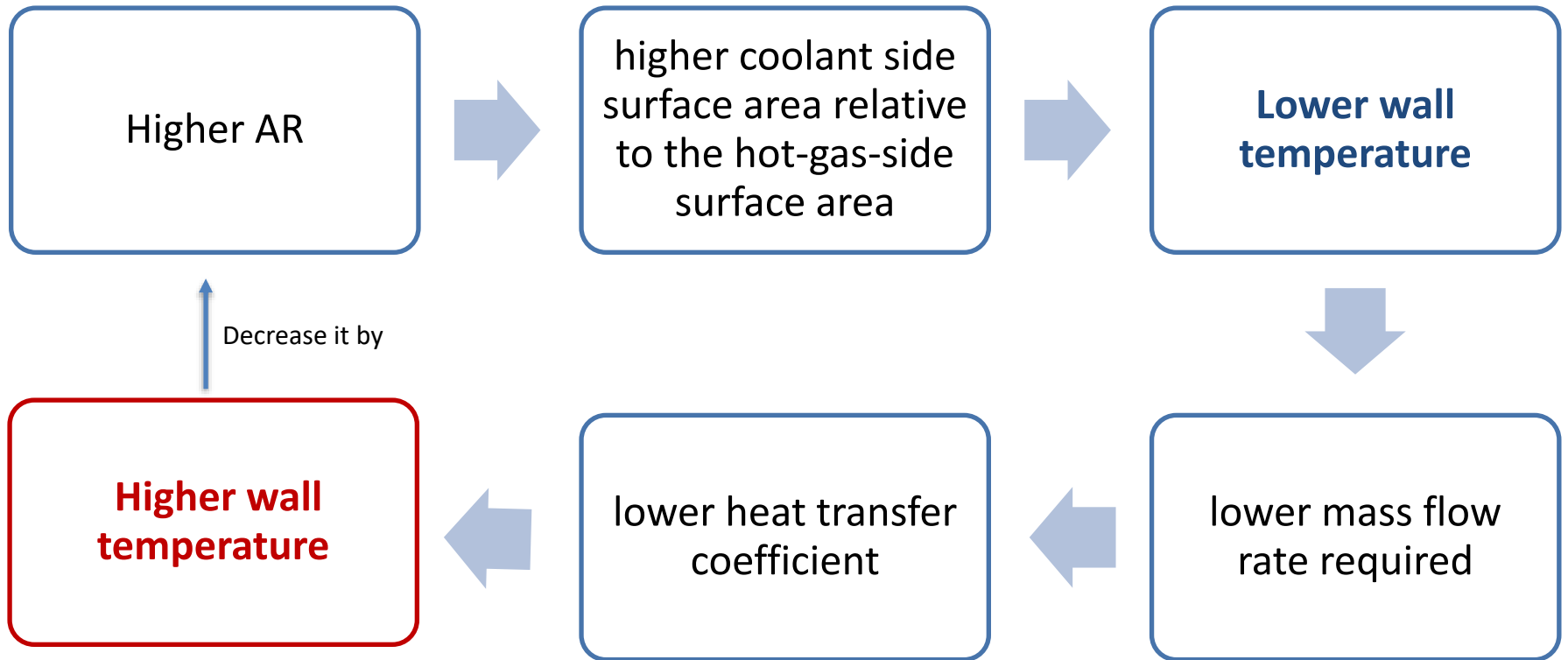
(3) Coolant heat transfer coefficient: $h_w \sim \frac{G^{0.8}}{D_h^{0.2}}$

- For a given coolant mass flow rate, the wall temp can be reduced by increasing the coolant-side surface area relative to the hot-gas-side surface area. This means increasing the wetted perimeter (P_{tot}), which means more cooling jackets.
- Increasing P_{tot} will decrease the hydraulic diameter, and consequently increase the pressure loss. (equations 1 and 2)
- The heat transfer will decrease if the hydraulic diameter increases.

Note: G is the mass flow rate per unit area [kg/s/m^2]

Reference: Pizzarelli, Trade-off analysis of high-aspect-ratio-cooling-channels for rocket engines.

Need for a parametric study



Requirements (ref.[2])

- Cooling jackets outlet pressure: 5.6 Mpa
- Wall temperature $< 880\text{K}$
- Coolant is subsonic in the cooling channels

Algorithm

1. Geometry inputs, define $P_{pump_{fin}}$, $T_{pump_{fin}}$, $P_{pump_{oxin}}$, $T_{pump_{oxin}}$

For loop: Aspect ratio = 1: 20

For loop: mass flow rate = 3: 6

While loop: error > tolerance (bisection method)

2. Define bounds, $P_{IN,l}$, then $P_{IN,u}$ for the cooling jacket inlet pressure

3. Calculate average $P_{IN,mid}$

4. Determine P_{out} with *regen_cooling_rl10.m* function

5. Error = $(P_{IN,mid} - P_{IN,l}) / P_{IN,l}$

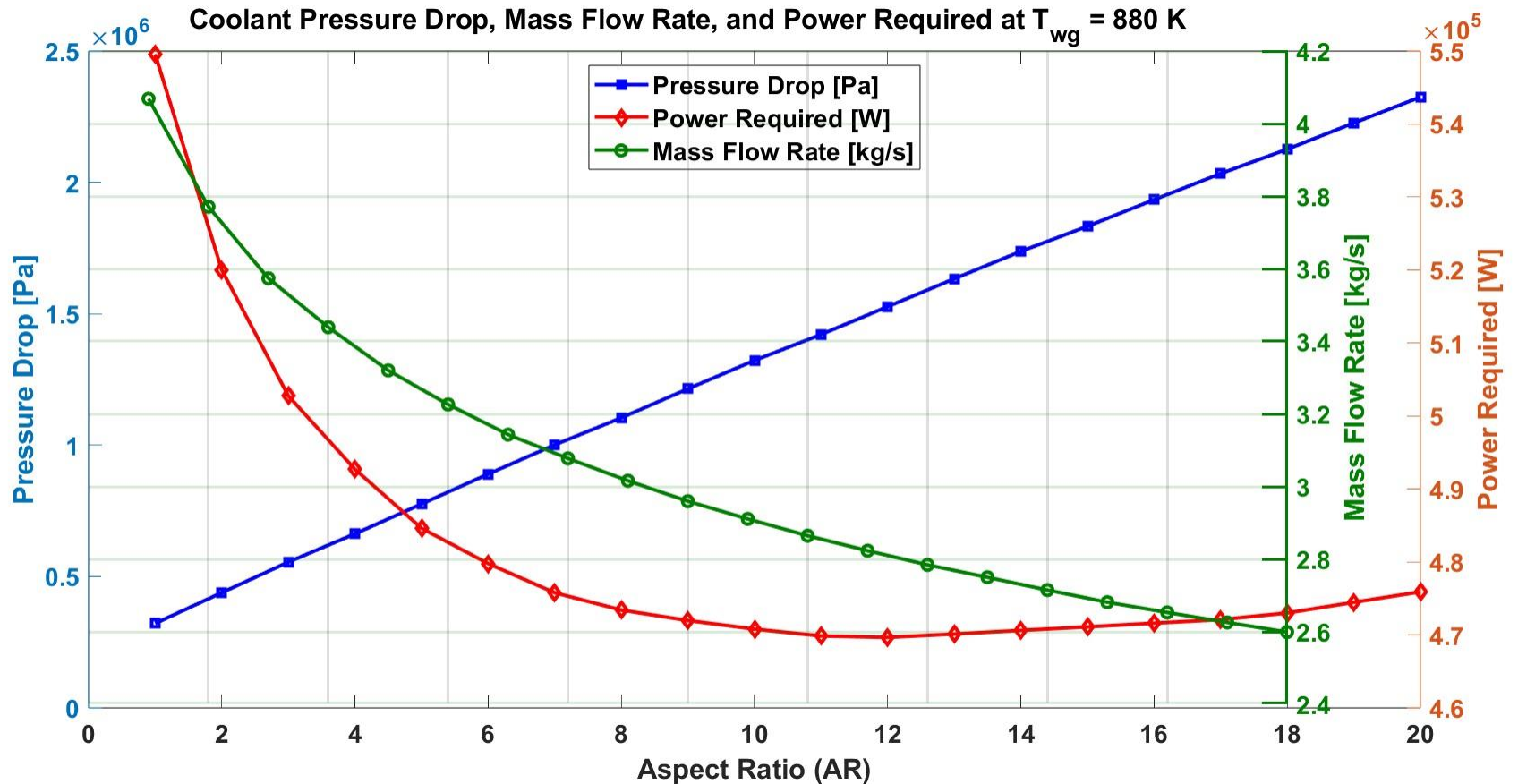
6. Bisection interval boundaries update

end

Results Overview

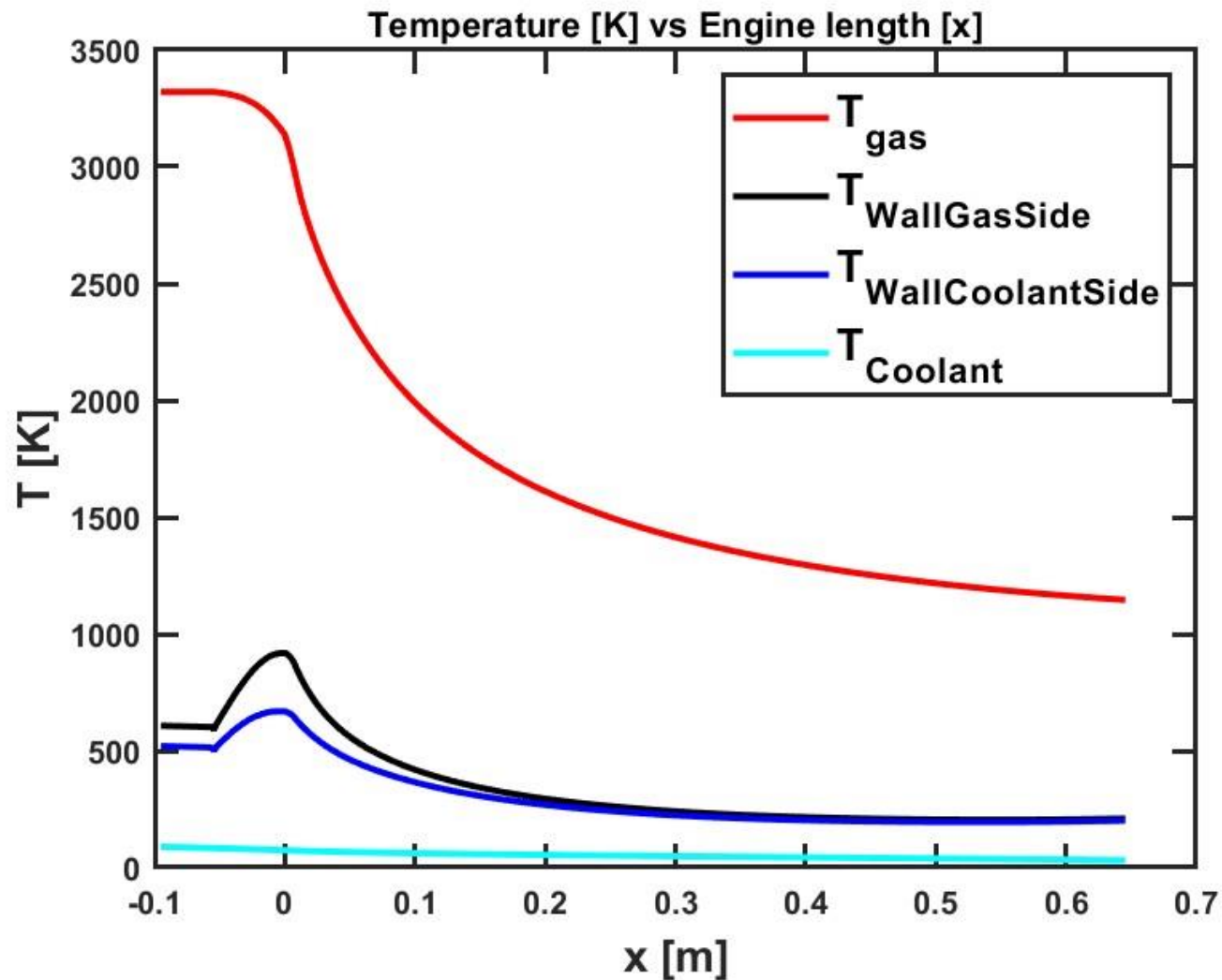
- Minimum pressure drop at AR=1, minimum power loss at AR=12.
- Current RL-10
 - H₂ mass flow rate = 2.7 kg/s
 - Power consumption: 0.50 MW
- Optimized RL10
 - Hydrogen mass flow rate = 2.6 kg/s
 - Power consumption = 0.47 MW
- Power saving with optimized AR: 6%

Graphical Results



Coolant pressure drop, mass flow rate, and power required as a function of AR.

Temperature distribution in the engine



Discussion

- **Trade-offs:** Higher AR improves cooling but increases pressure losses.
- **Manufacturing Considerations:** Challenges in achieving high AR with conventional machining.

Conclusion

- **Optimal AR:** Identified as $AR=12$ for minimizing power loss while maintaining acceptable cooling, and subsonic flow in the channels
- **Future Work:** Suggestions for further parametric studies with more variables.

References

1. Pizzarelli, Trade-off analysis of high-aspect-ratio-cooling-channels for rocket engines.
2. Binder, RL10A-3-3A Rocket Engine Modeling Project
3. Haberbusch, Modeling the RL10 with Densified Liquid Hydrogen and Oxygen Propellants.
4. NASA SP8107, Turbopump systems for liquid rocket engines.
5. Bartz, Technical notes.

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