

1st Stage

Stage	TWR (K)	Δv (atm)	Time
1	2.10	279 m/s	12.9 s
2	2.07	322 m/s	15.0 s
3	2.04	380 m/s	17.8 s

Total Δv : 981 m/s

2 x Z-400 Rechargeable Battery

Mass = 20 kg
Capacity = 400 e

2 x OX-STAT Photovoltaic Panel

Mass = 5 kg
Electricity = 0.75 e/s

Rockomax Brand Decoupler

Mass = 400 kg
Ejection Force = 250

6 x 60° Liquid Fuel Booster
2-2-2 Asparagus Staging

6 x NCS Adapter incl. Standard NC
Mass = 400 kg

18 x FL-T400 Liquid Fuel Tank
Mass = 250 kg
Liquid Fuel = 180 L
Oxidizer = 220 L

6 x LV-T45 Liquid Fuel Engine
Mass = 1 500 kg
Thrust = 200 000 N
Isp (atm) = 320 s

6 x Hydraulic Detachment Manifold
Mass = 400 kg
Ejection Force = 180 N

4th Stage

Stage	TWR (K)	Δv (vac)	Time
4	1.98	3155 m/s	143.6 s
5	---	---	---

15200

Liquid Fuel = 1440 L

Oxidizer = 1760 L

3 x Rockomax X200-32 Fuel Tank

Mass = 2 000 kg
Liquid Fuel = 1440 L
Oxidizer = 1760 L

6 x 60° AV-R8 Winglet

Mass = 20 kg
Lift = 0.4
Deflection Range = 15°
Surface Area = 0.95

Rockomax „Mainsail“ Liquid Engine

Mass = 6 000 kg
Thrust = 1 500 000 N
Isp (atm) = 280 s
Isp (vac) = 330 s

6th Stage

Stage	TWR (K)	Δv (vac)	Time
6	1.35	2523 m/s	219.1 s
7	---	---	---

3 x 120° LT-2 Landing Strut

Mass = 100 kg

Rockomax „Poodle“ Liquid Engine

Mass = 2 500 kg
Thrust = 220 000 N
Isp (vac) = 390 s

Mk16-XL Parachute

Mass = 300 kg
Drag
- Stowed = 0.22
- Semi-Deployed = 1
- Deployed = 500

Mk1-2 Command Pod

Mass = 4 000 kg
Required Crew = 3

8th Stage

Stage	TWR (K)	Δv (vac)	Time
8	---	---	---

11500

1657

KERBAL X

Chemical Rocket Design - Cooling

Total Δv (atm) = 5 404 m/s
Total Δv (vac) = 6 826 m/s
Total Mass = 131 390 kg
Part Count = 78
Total Cost = 64 820 ¢

The first stage of the Kerbal X is a very successful design that has been used in a lot of projects. Despite the original design having been meant for a plastic model, it's proved itself quite dependable as a full-sized craft. The second stage is a very simple design that can be used to land on Kerbin, and even features a very optimistic set of landing legs on its upper stage.

More on Characteristic Exhaust Velocity

Using aerodynamic continuity around the throat of the motor, it is easy to prove that C^* :

- Goes up with higher chamber temperature T_c .
- Goes up with lower molecular weight.

We want to Maximise C^* .

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Why is Cooling so Important?

T_c can reach values easily higher than 3000°K (Sun's surface: 5778°K).

This is higher than the melting point of practical engineering materials: pure carbon melts at 3500K.

Chamber walls need to be cooled somewhat below melting point to prevent loss of performance associated with elevated temperatures.

Higher chamber pressures $\longrightarrow$ More cooling necessary

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6 Cooling Methods

- Heat Sink: Heat is simply absorbed but this is a heavy method.
- Radiation cooling: Need to use very high melting point alloys, high emissivity surfaces and good cold sink such as space.
- Ablative Cooling: Uses materials which evaporate and absorb heat doing so but this is short term.
- Film Cooling: Circulate cold gas along walls.

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6 Cooling Methods

- Fluid Cooling: Circulate cold liquids along walls.
- Regenerative Cooling: Fluid cooling but heated liquids feed back into the engines for combustion (best on big engines).

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Heat Transfer

- Three phenomena:
- Conduction: by direct contact of materials.



- Radiation: by electromagnetic waves (light) emission or absorption.



- Our main protagonist here convection:
Hot gases move towards the cooler walls through the thermal boundary layer:

$$q = h_g(T_g - T_{gw})$$



Convective Heat Transfer from Chamber to its Walls

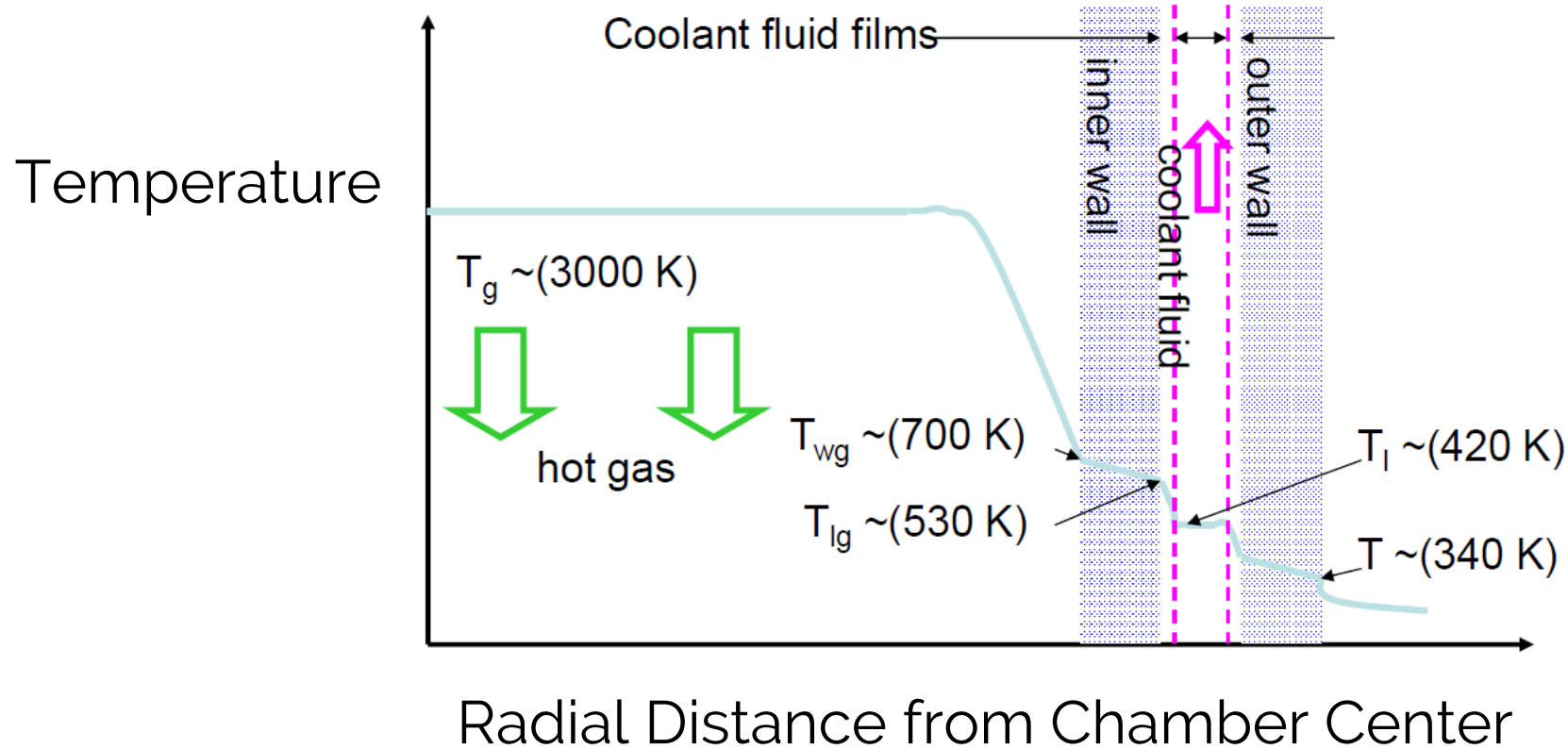
$$q = h_g(T_g - T_{gw})$$

T_g and h_g (heat transfer coefficient) are fixed by chamber temperature and the propellants used.

T_{gw} is set at the maximum value the wall's materials can withstand in order to minimise q (minimise heat going from gases to walls).



Temperature through a Regenerative Engine



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Materials Used

In the 60s, Nickel Alloys such as Inconel were used:

- Keep strength at high temperatures.
- Low thermal expansion.

Analysis showed that the use of weaker but more heat conductive copper was better:

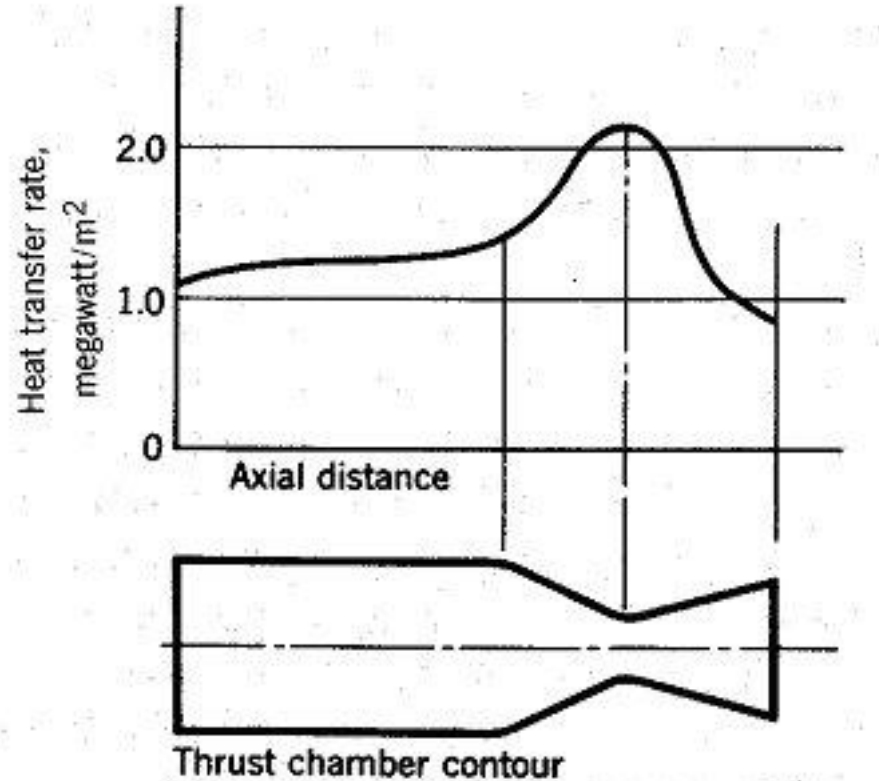
- Heat would move away quicker.
- Materials heated less.
- Overall lighter chamber.

Most modern engines use copper alloys such as SSME.

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Typical Variation of q



- Peaks at throat most common motor failure point.
- First estimates using pipe flow models.
- Computational Fluid Dynamics are used at later stages.

