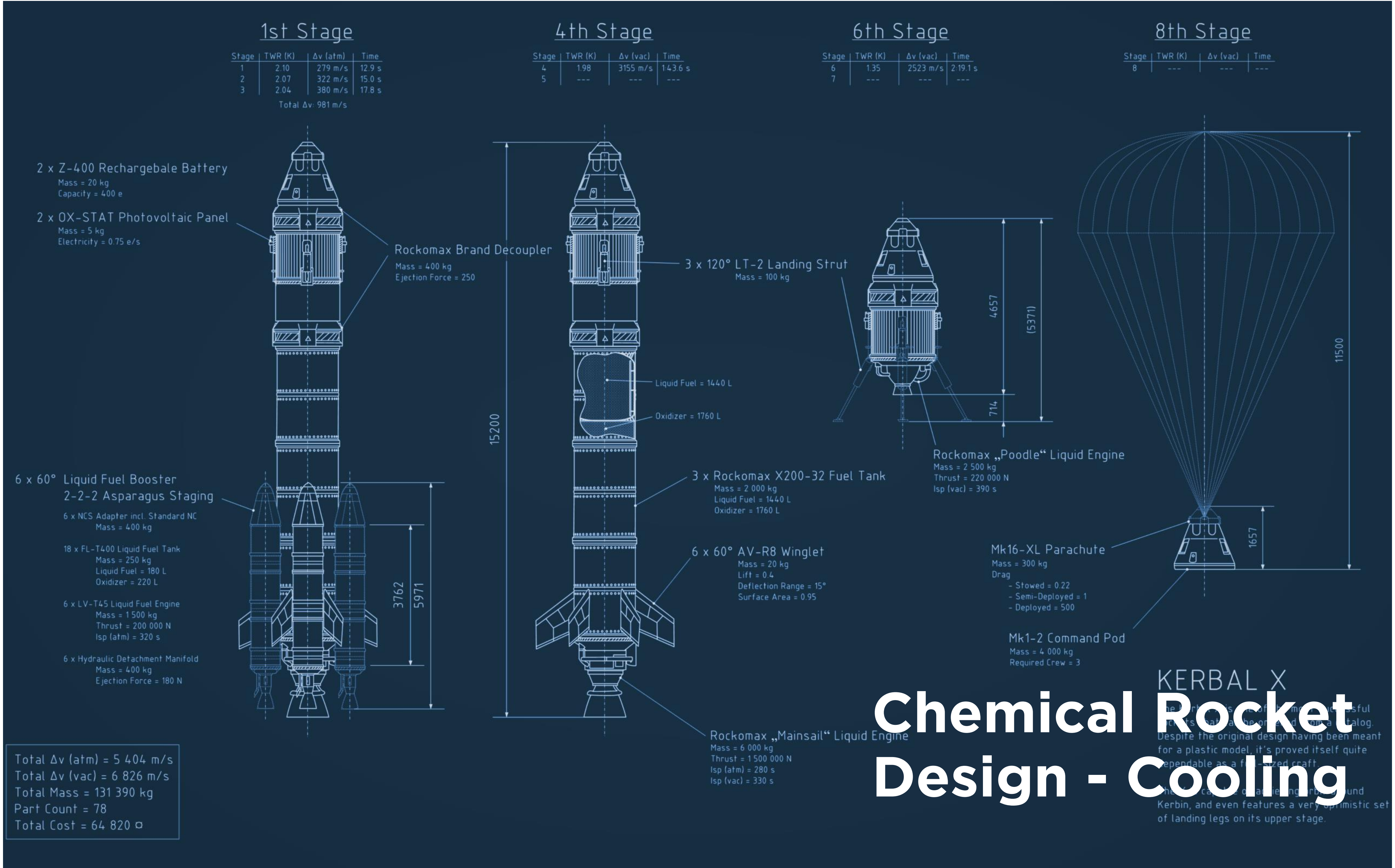
Chemical Rocket Design - Cooling



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*.

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.

6 Cooling Methods

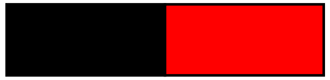
- Fluid Cooling: Circulate cold liquids along walls.

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

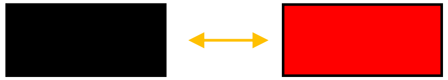
Heat Transfer

- Three phenomenons:

- 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:

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

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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).

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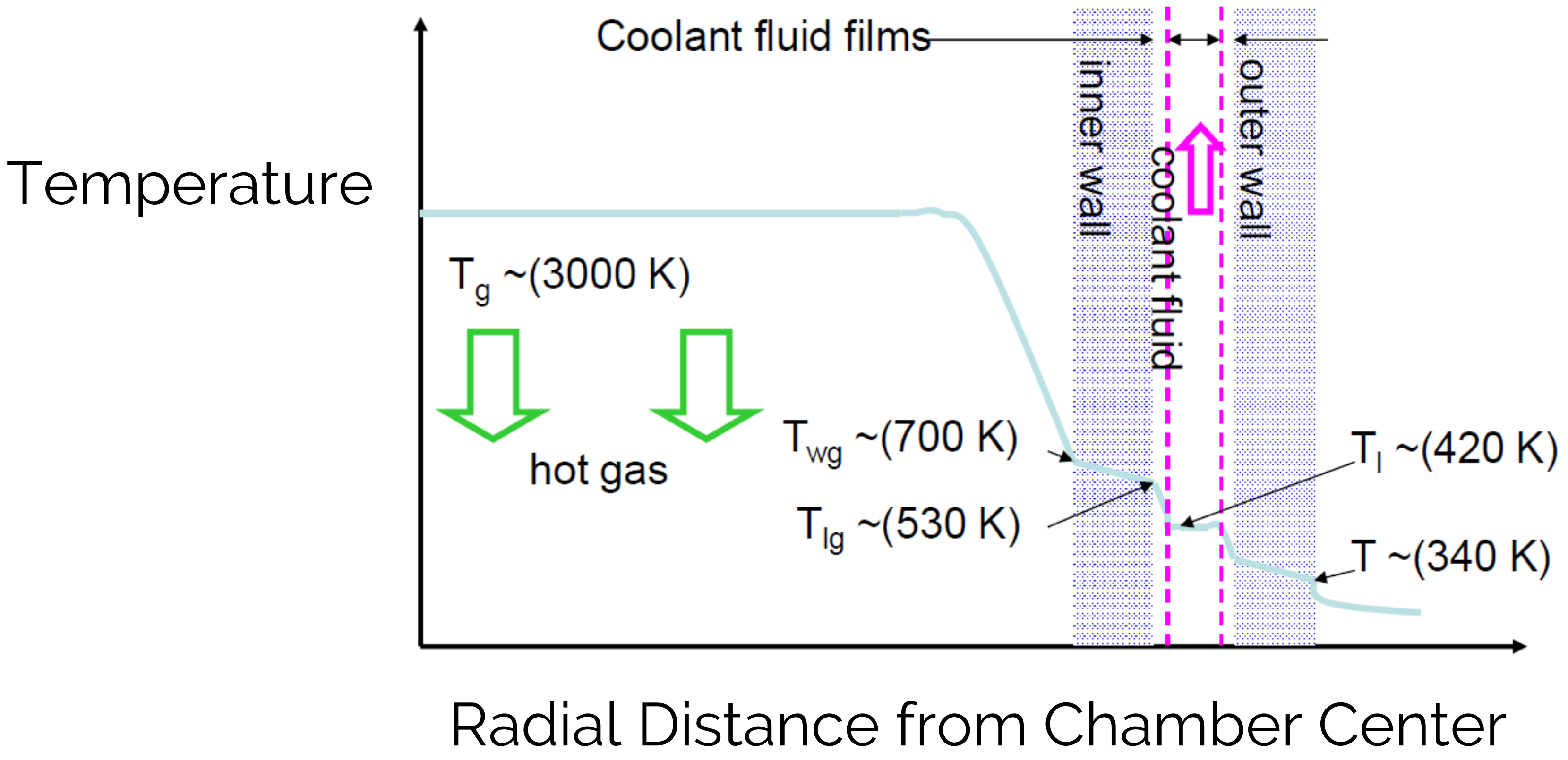
Temperature through a Regenerative Engine



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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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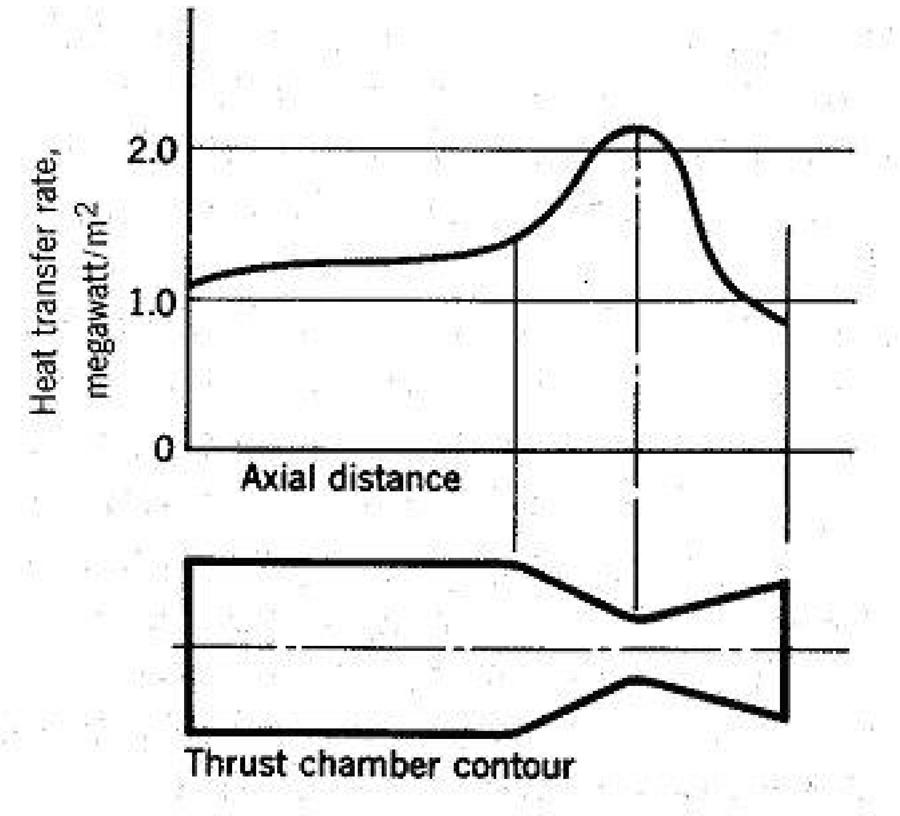
Typical Variation of q



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