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SESA2023 Propulsion

Lecture 10: Ramjets Introduction

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PROPULSION CONTENT OVERVIEW

Section 1: Introduction and Fundamentals	3 weeks, Ivo Peters
Section 2: Ramjets, Combustion, Rockets	3 weeks, Ivo Peters
Section 3: Gas Turbines, Turbojets, and Turbofans	2 weeks, Ed Richardson
Section 4: Turbomachinery and Propellers	3 weeks, Ed Richardson

THIS LECTURE

- Problems with high-speed flight
- Concept of a ramjet
- Operating limitations of ramjets
- Ideal ramjet introduction

SOME FLIGHT SPEEDS

- Modern jet fighters: max speed just above Ma = 2
- Some jet fighters with max speed Ma > 3, but only for a short duration
- A few exceptions exist…

MiG-25, Mach 2.8

1964 – 1984

MiG-35, Mach 2.3

2016 – present

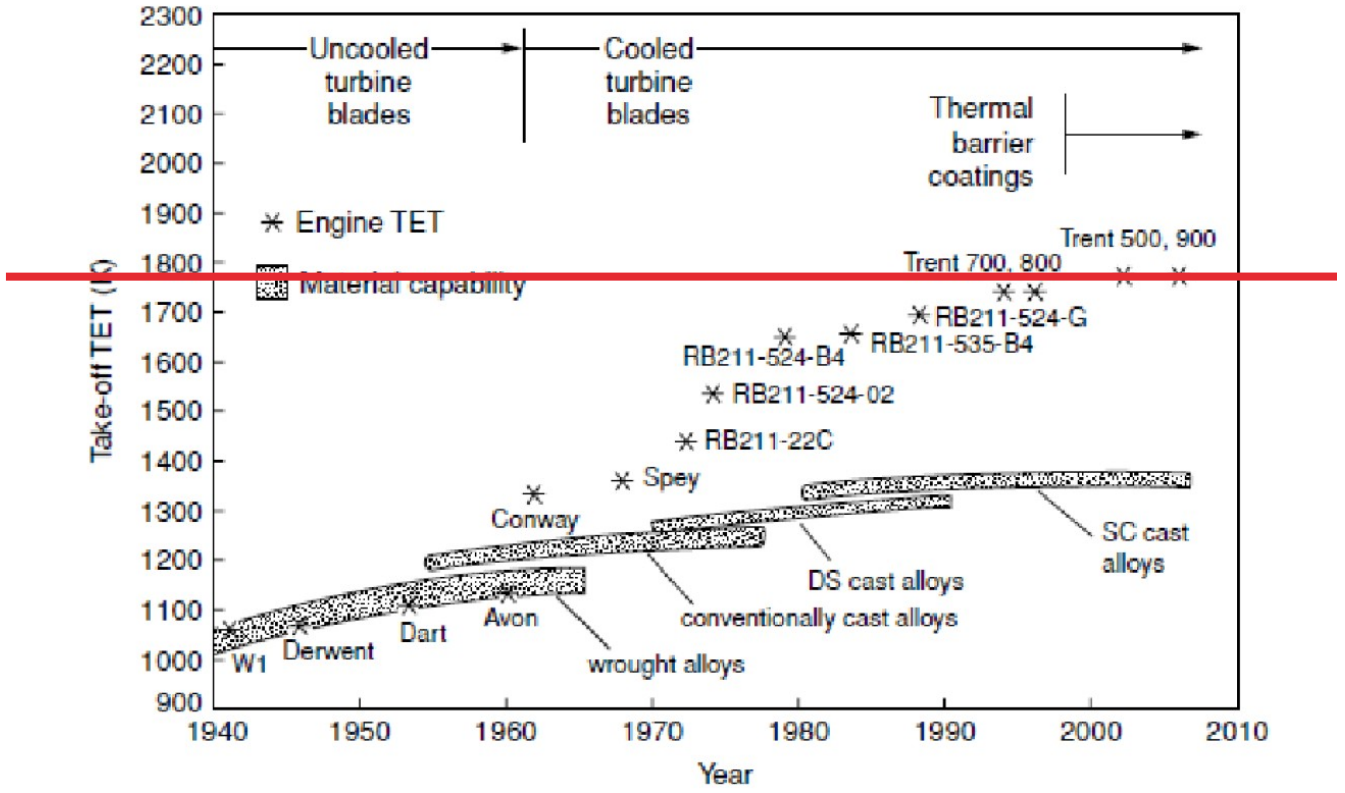
F22, Mach 2.3

1996–2011

F35, Mach 1.6

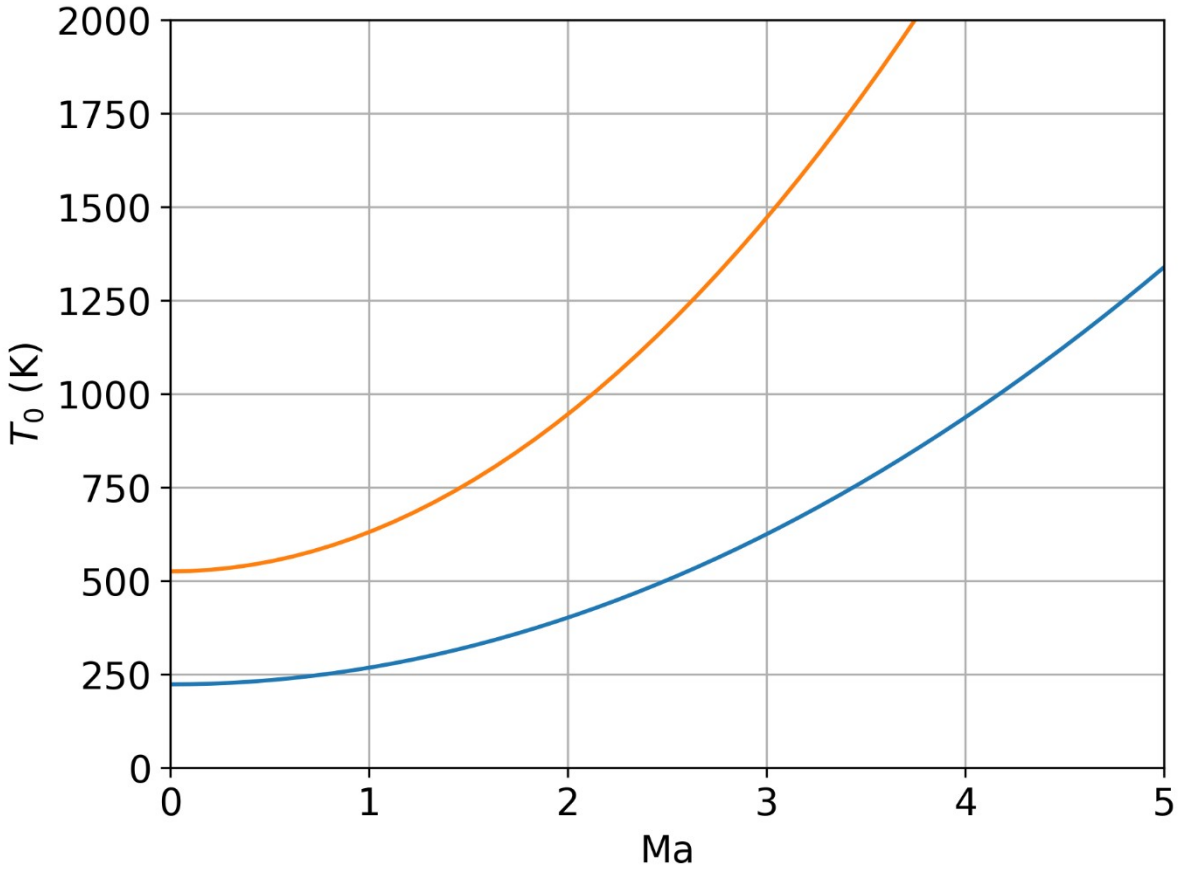
2006 – present

TEMPERATURE LIMITS



T-S DIAGRAM

TEMPERATURES: COMBUSTOR INLET



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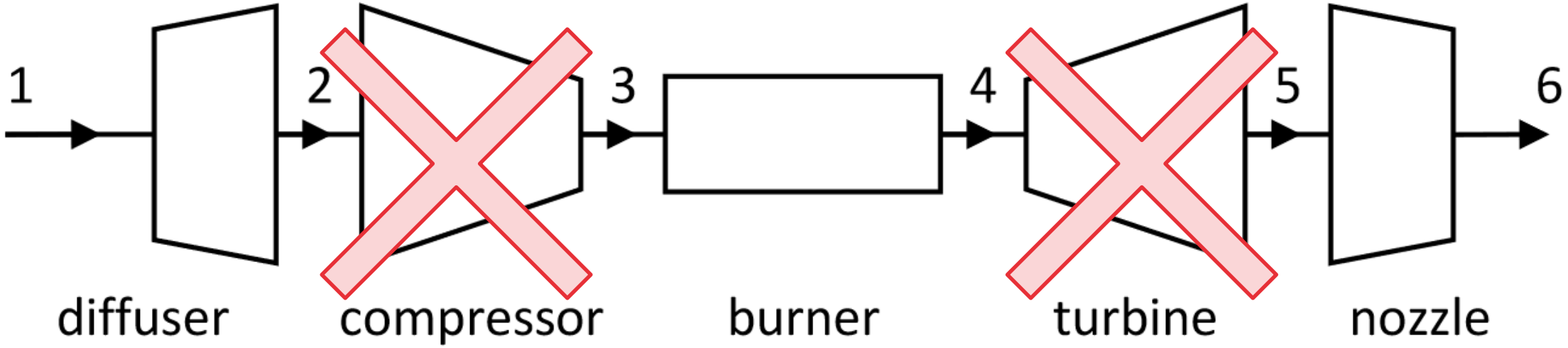
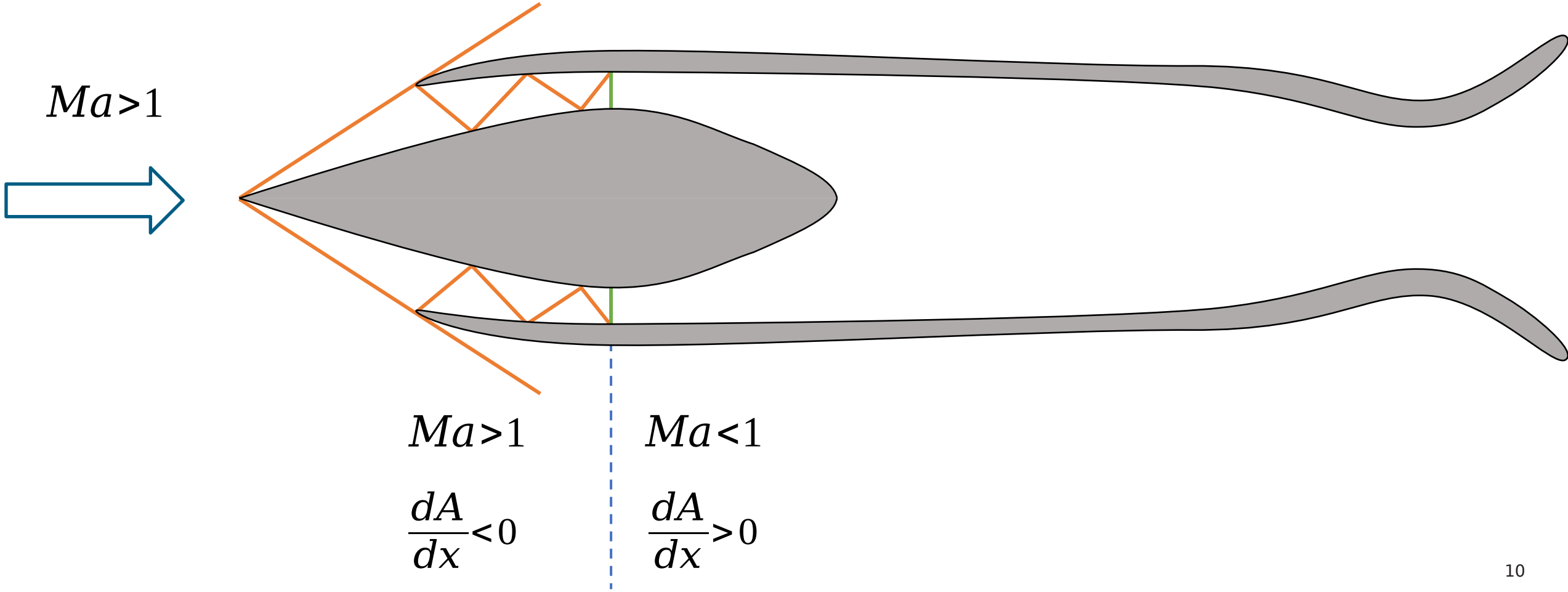
EXAMPLE: SR-71 BLACKBIRD

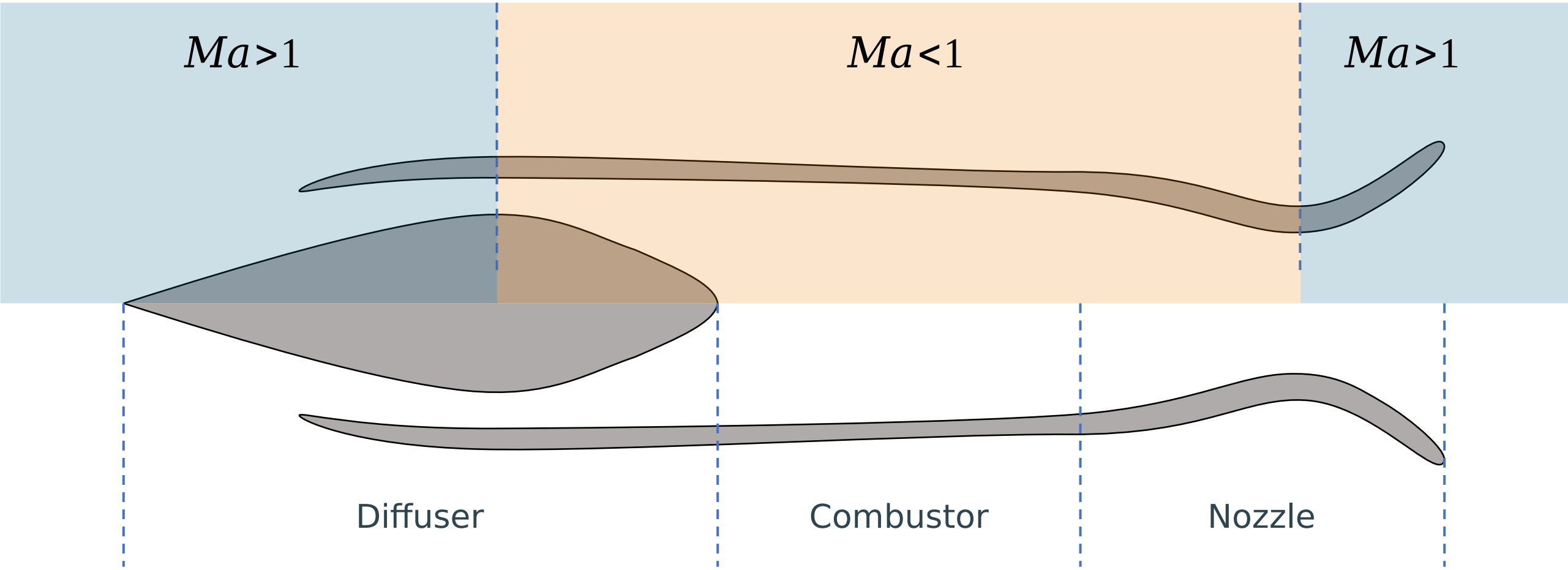
RAMJET CONCEPT



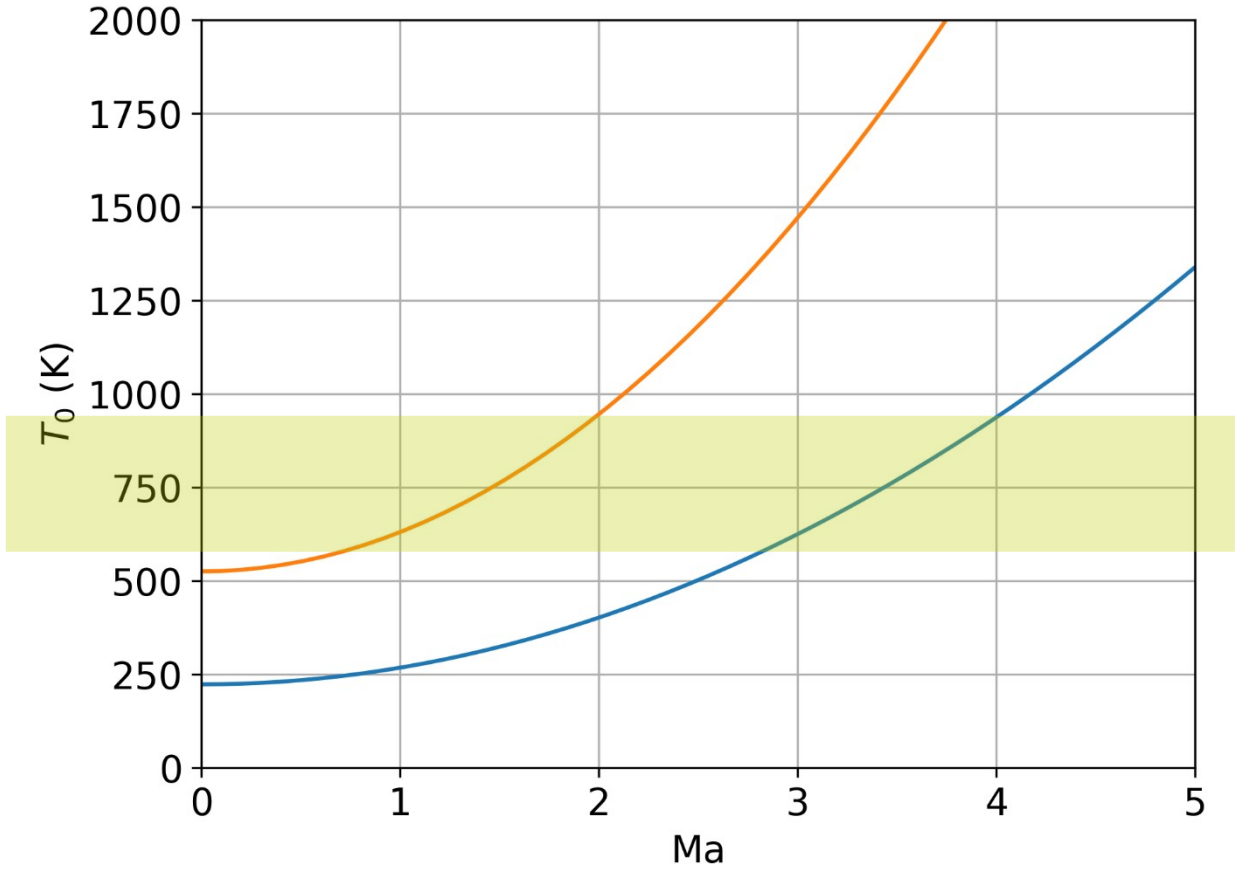
RAMJET CONCEPT: SUPERSONIC DIFFUSER



RAMJET CONCEPT

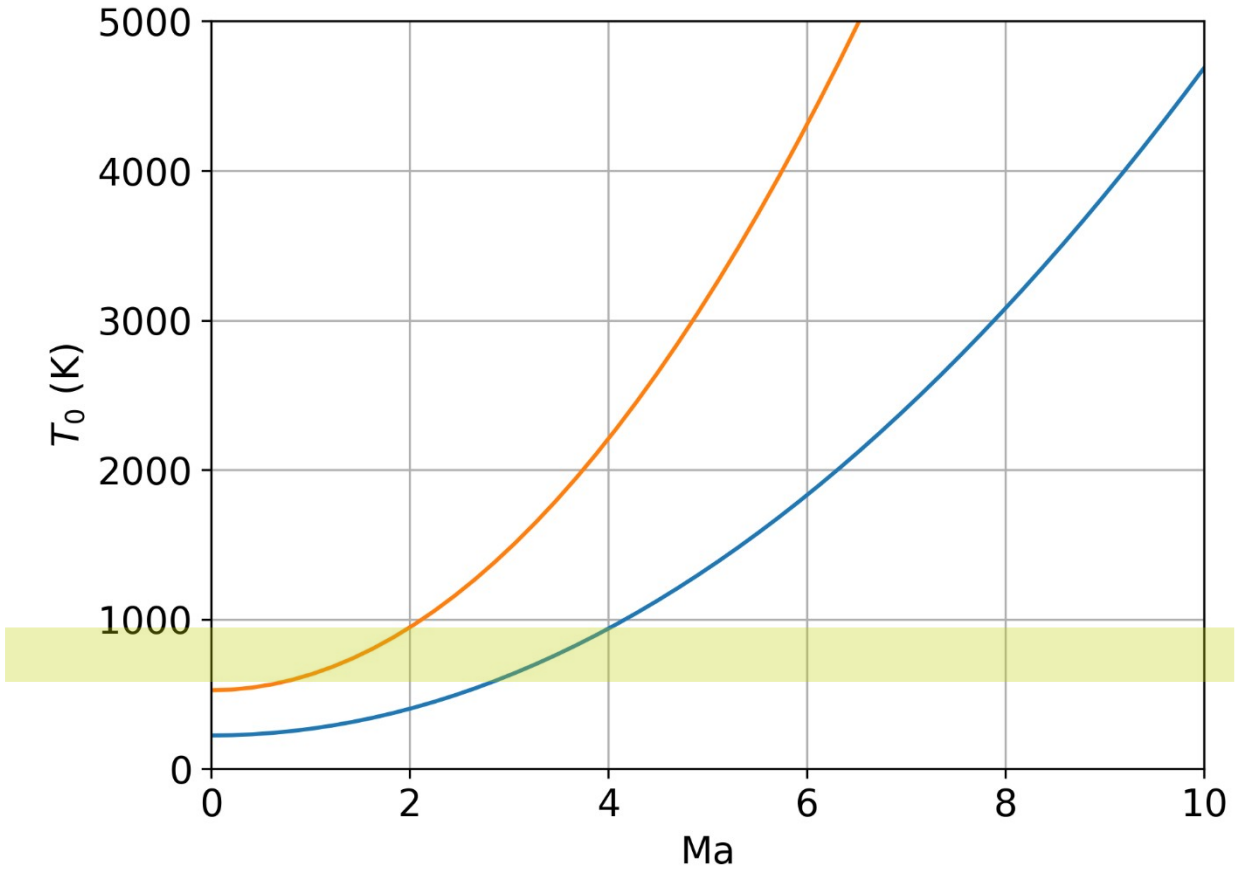


OPERATING LIMITATIONS: OPTIMAL RANGE

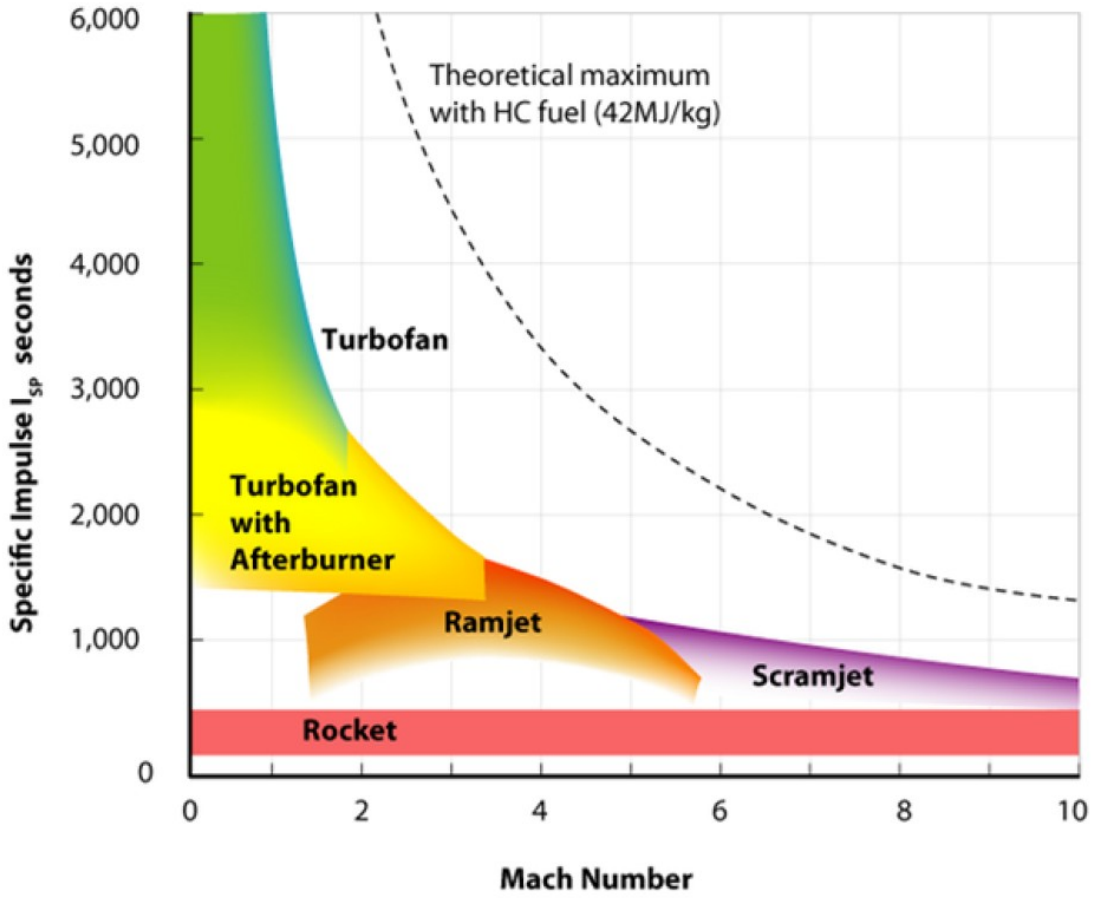


OPERATING LIMITATIONS: MA > 5

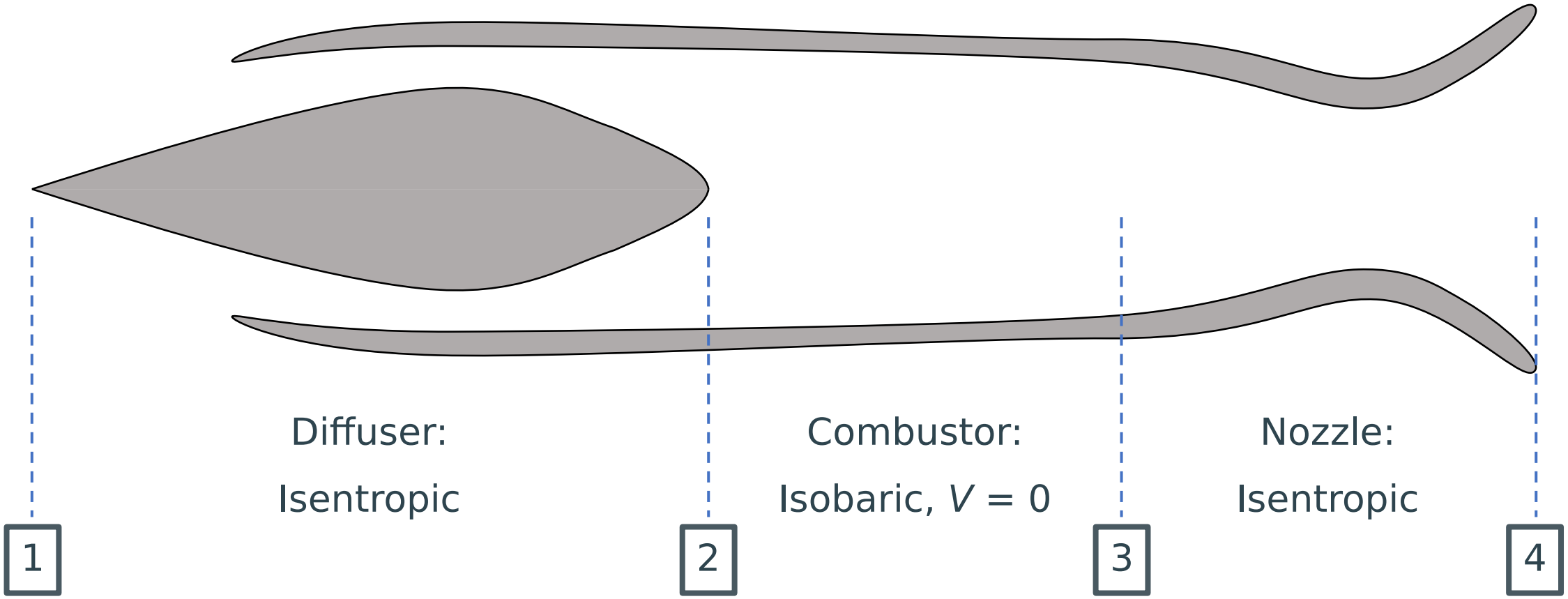
- Increased pressure losses
  - Reduced thrust
- Increased temperatures
  - Reduced combustion efficiency
  - Material limitations



RAMJET: PROPULSION SYSTEMS COMPARISON



IDEAL RAMJET



Stagnation pressure is constant!

THRUST

SUMMARY

- Limitations of turbofan and turbojet engines
- Concept of a ramjet engine
  - Diffuser, combustor, nozzle
- Operational range and limitations of ramjet engines
- Ideal ramjet assumptions, thrust and analysis

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Lecture 11: Ideal Ramjets

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THIS LECTURE

- Ideal ramjet component analysis
  - Diffuser
  - Combustor
  - Nozzle
- Example

DIFFUSER

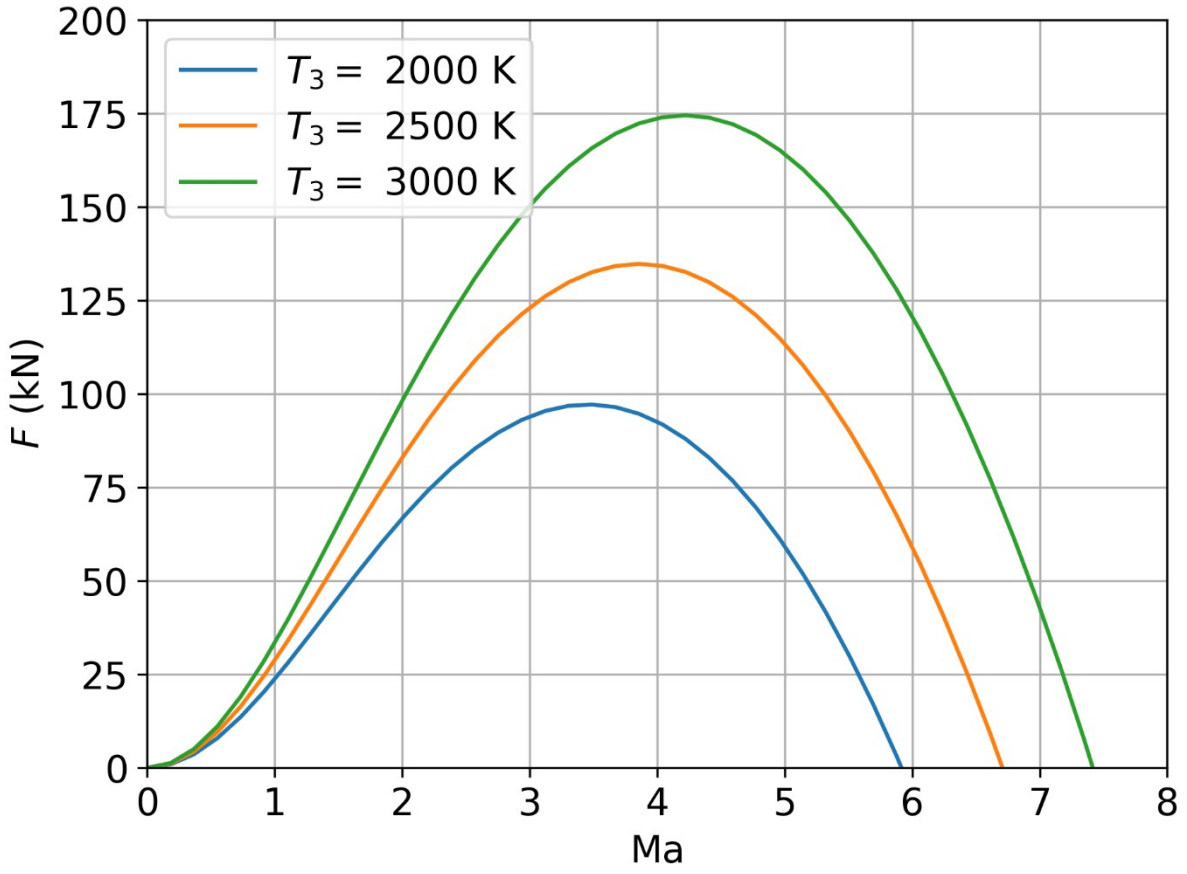
COMBUSTOR

NOZZLE

EXAMPLE

An ideal ramjet is operating at Mach 3. The local temperature is 250 K, and the local pressure is 10 kPa. With a maximum temperature of 2500 K and a fuel LCV of 42 MJ/kg, determine the specific thrust produced.

THRUST VS MACH NUMBER



SUMMARY

- Analysis of an ideal ramjet
- Diffuser: isentropic
- Combustor: isobaric
- Nozzle: isentropic
- Fuel consumption, thrust

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Lecture 12: Non-ideal ramjets and scramjets

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THIS LECTURE

- Non-ideal ramjets
- Influence on performance
- Scramjets

LOSSES IN REAL RAMJETS

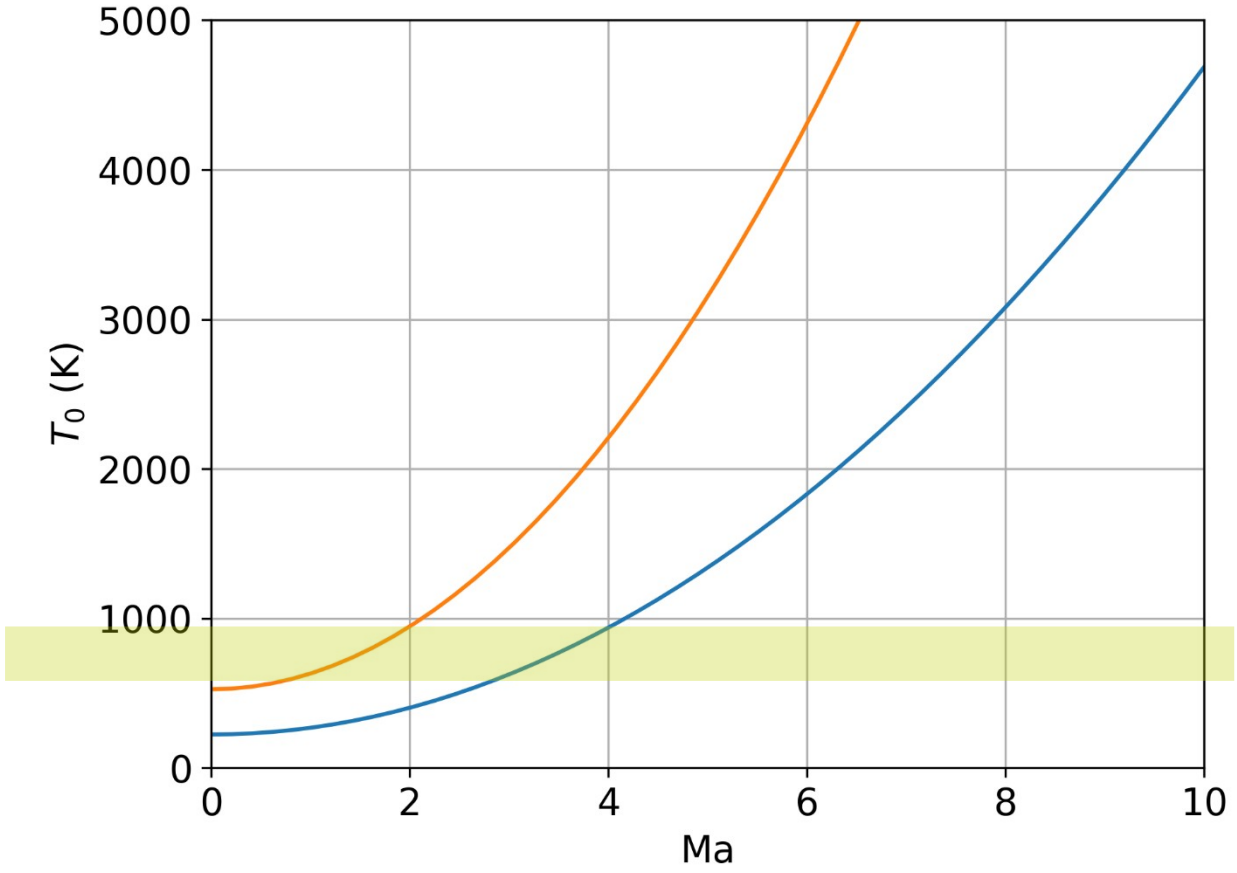
NON-IDEAL DIFFUSER

NON-IDEAL COMBUSTOR

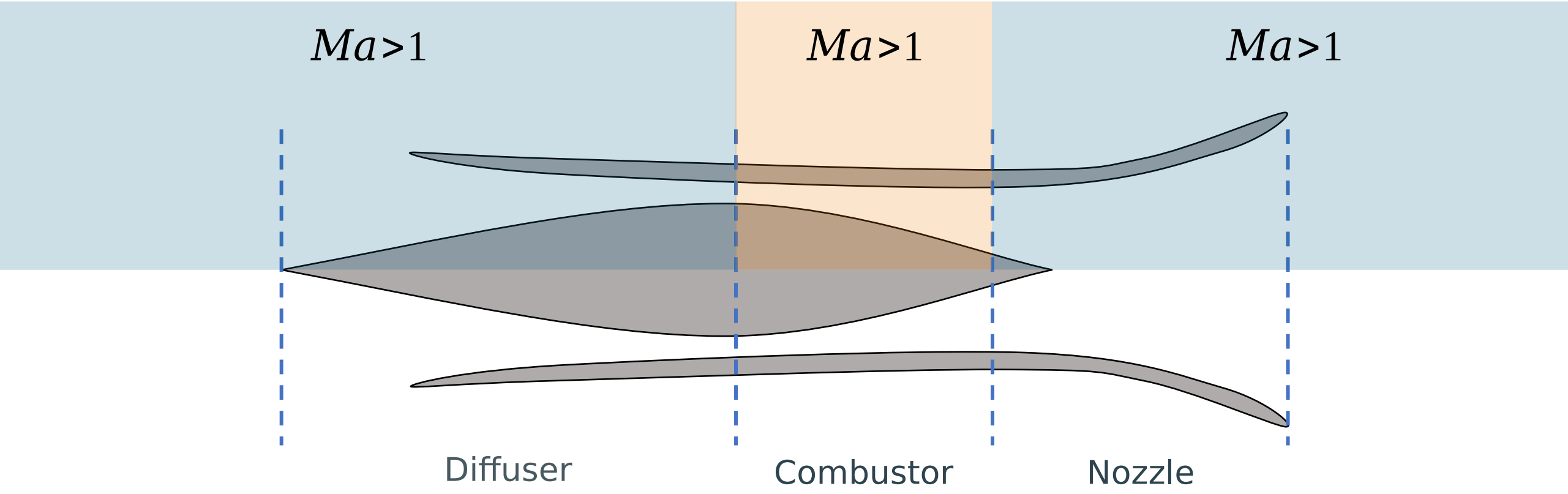
NON-IDEAL NOZZLE

REMINDER: OPERATING LIMITATIONS: MA > 5

- Increased pressure losses
  - Reduced thrust
- Increased temperatures
  - Reduced combustion efficiency
  - Material limitations



SCRAMJET: SUPERSONIC COMBUSTION RAMJET



NASA X-43A

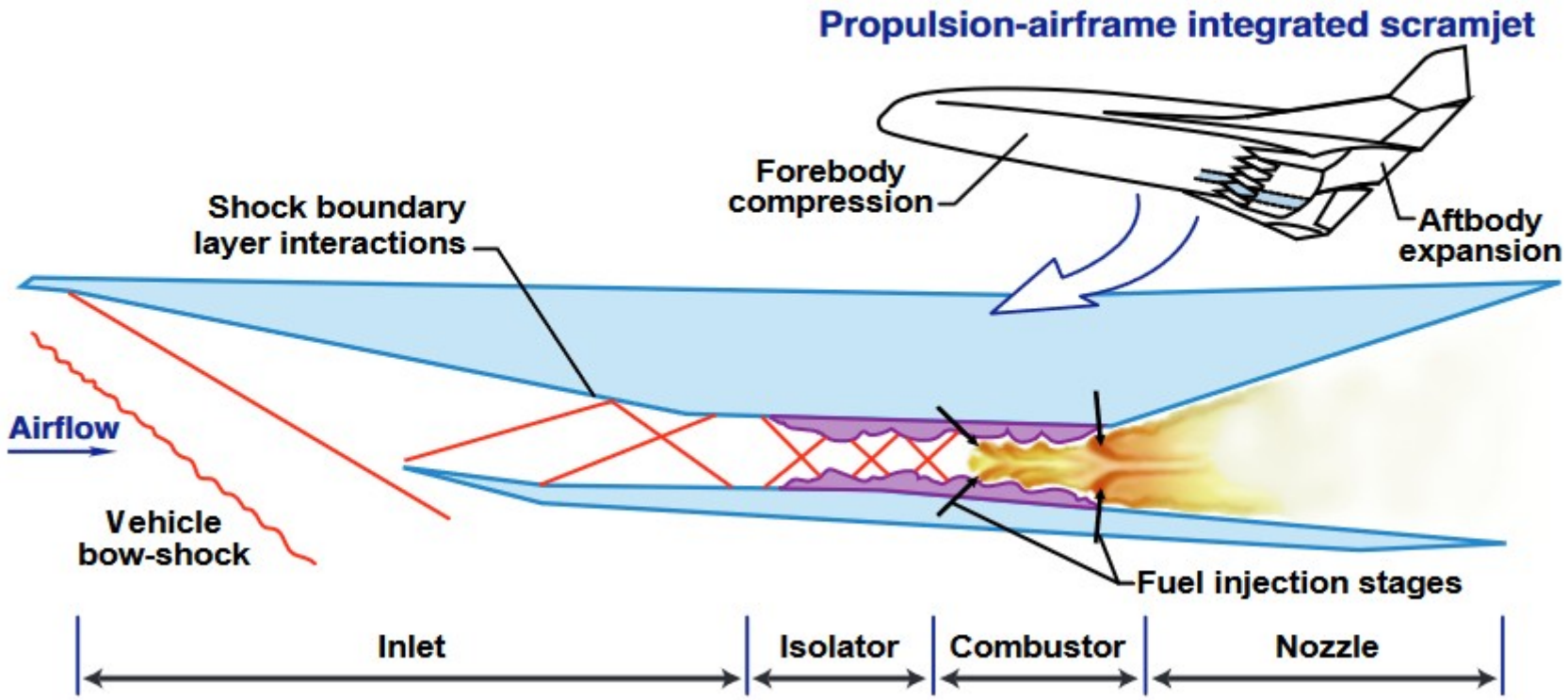


Figure: nasa.gov

NASA X-43A

SUMMARY

- Efficiency parameters for non-ideal ramjets
  - Stagnation pressure ratios
  - Combustion efficiency
- Influence on performance
  - Reduced exhaust velocity
  - Reduced heat input
- Scramjets
  - Operation at higher Mach numbers