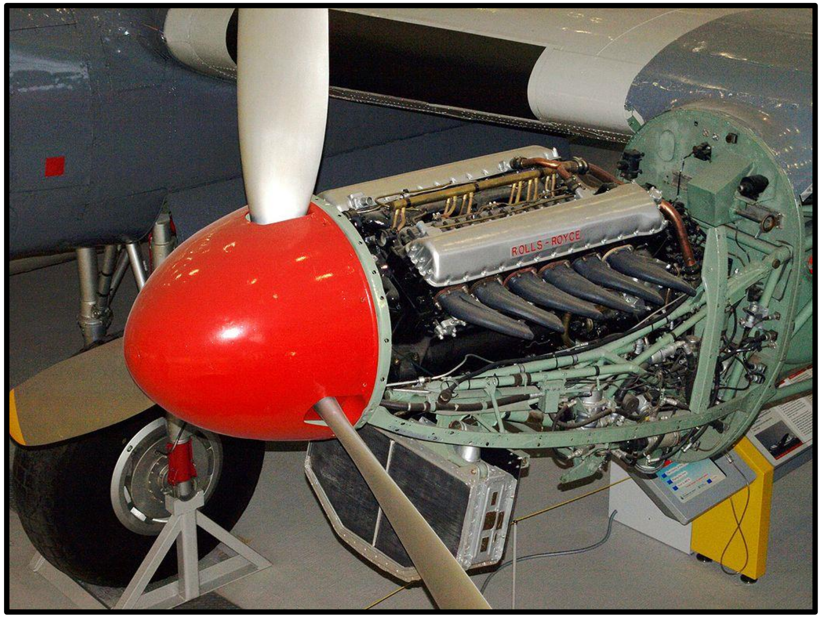
Aircraft Propulsion

Aircraft Propulsion

Reciprocating Engine / Propeller



The propeller is driven by the rotating shaft in the engine

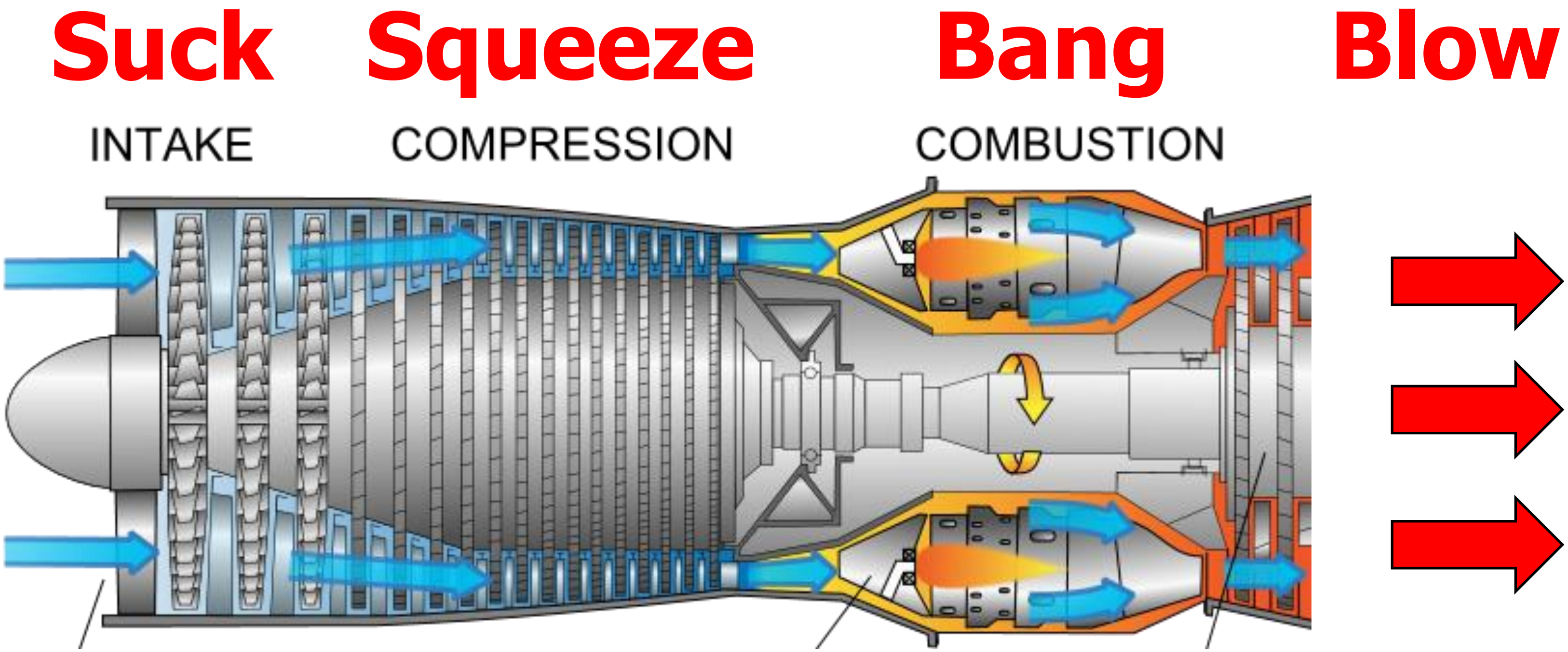
Supercharging can delay the loss of power at higher altitudes

Very efficient at slower speeds and lower altitudes

Used in general aviation aircraft

Largest manufacturers:
Continental
General Electric
Honeywell
Lycoming
Pratt & Whitney
Rolls-Royce
Williams International

Aircraft Propulsion



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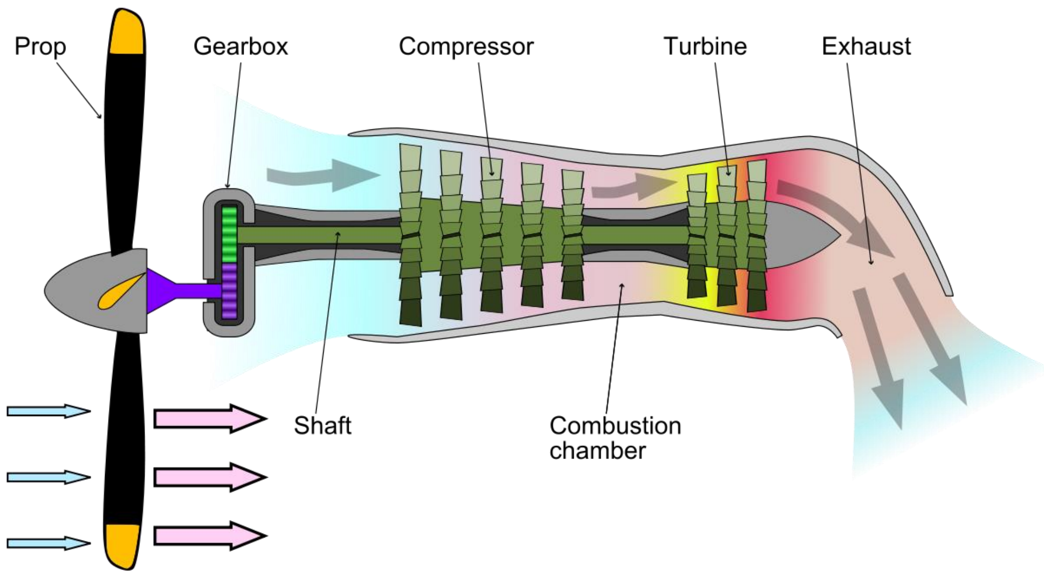
Aircraft Propulsion

Turboprop



The propeller is driven by the rotating shaft in the turbine engine via the gearbox

Almost no thrust is generated by the turbine engine

Very efficient at slower speeds and lower altitudes

Used in commuter aircraft

Largest manufacturers:
Honeywell
Pratt & Whitney
Rolls-Royce

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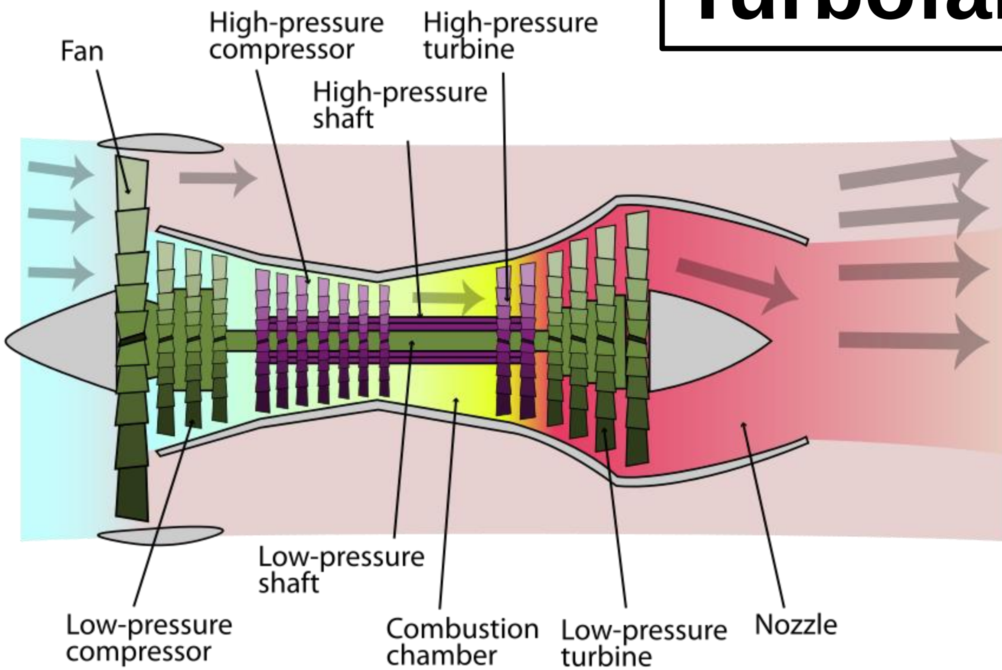
Aircraft Propulsion

Turbofan

$$\text{BPR} = \frac{\textbf{Bypass airflow}}{\textbf{Core airflow}}$$



Low-bypass turbofan engines have a bypass ratio BPR < 2 (modern fighter aircraft with A/B)

High-bypass turbofan engines have a bypass ratio BPR > 5 (airliners, military transports)

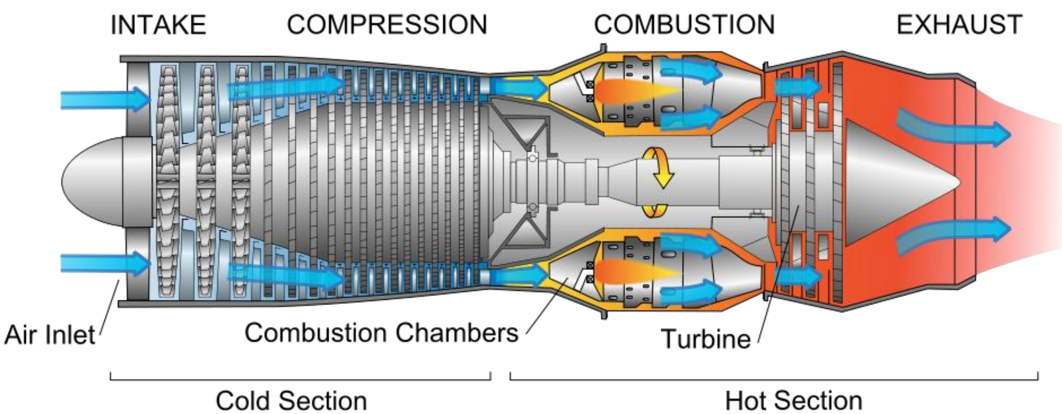
Core airflow drives the fan and contributes to overall thrust

Bypass airflow increases thrust, provides cooling, reduces noise

Largest manufacturers:
CFM International
General Electric
Pratt & Whitney
Rolls-Royce

Aircraft Propulsion

Turbojet



All of the intake air goes through the turbine (no bypass)

All of the thrust is generated by the engine exhaust

Efficient at supersonic speeds and higher altitudes, but is very noisy

Use of afterburners gets the aircraft to supersonic speeds

Used in cruise missiles and early fighter aircraft

Largest manufacturers:
General Electric
Pratt & Whitney

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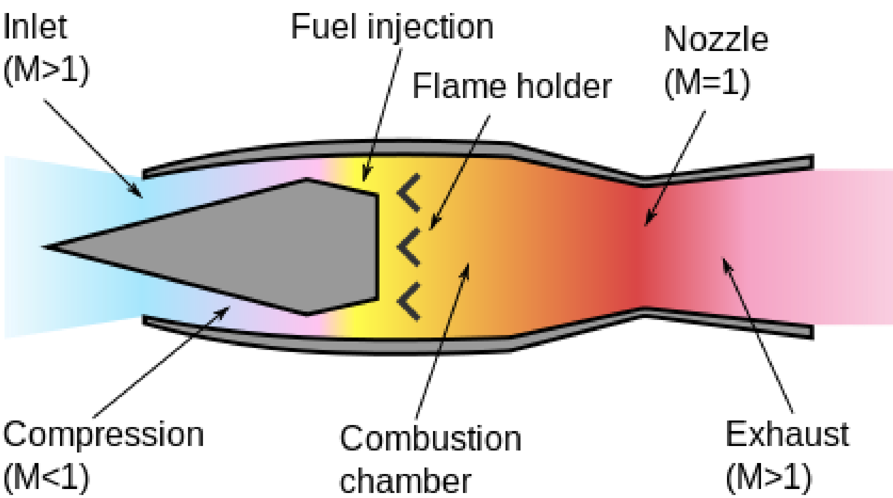
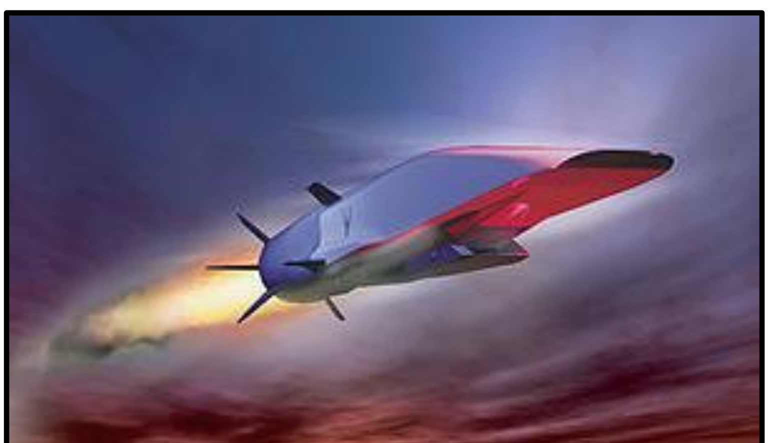
Aircraft Propulsion

Ramjet / Scramjet





Works best at Mach 2 to 6

Cannot produce thrust at slow speeds so the aircraft must be boosted to higher speeds

Manufacturer:
Aerojet Rocketdyne

Aircraft Propulsion

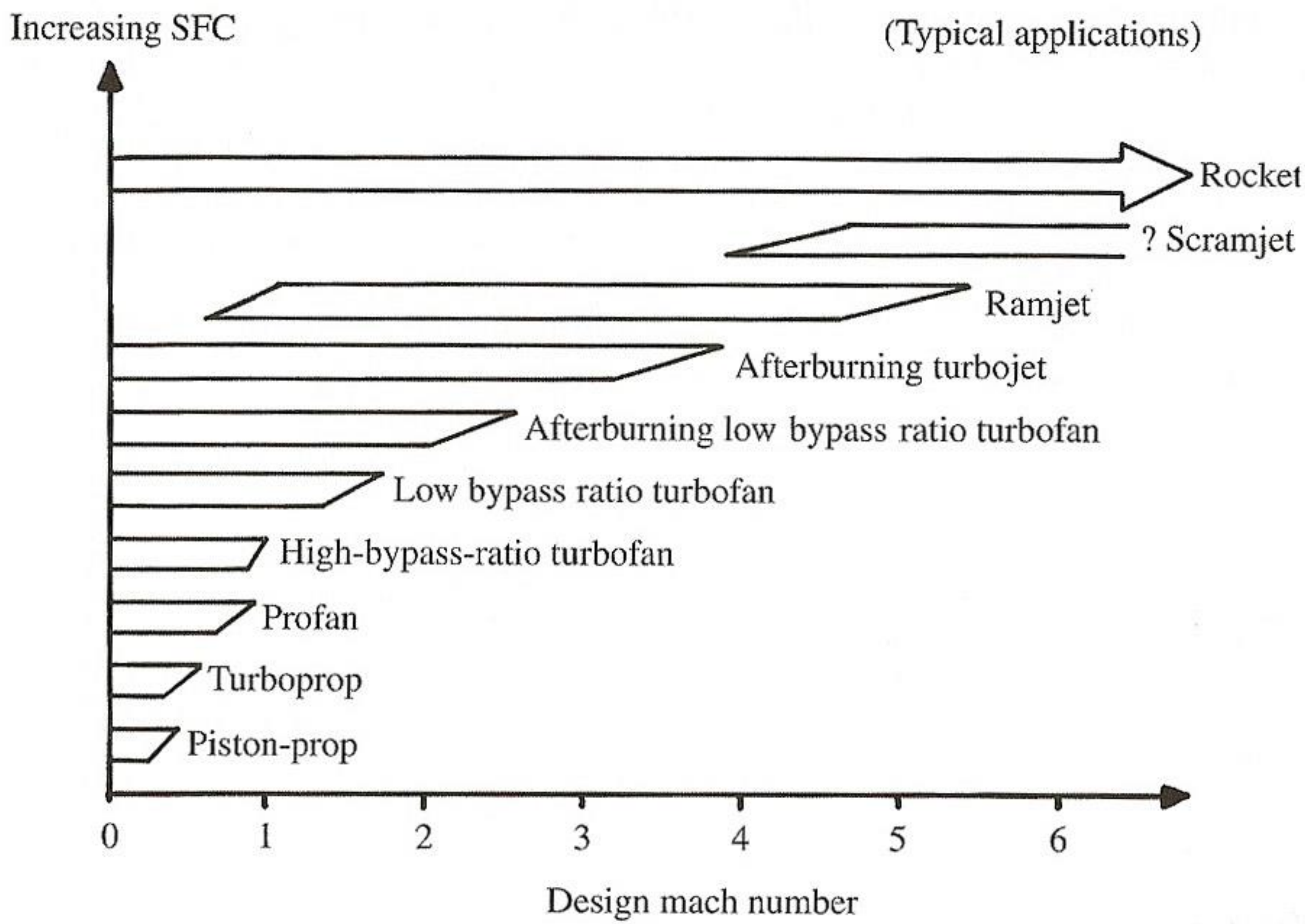


Fig. 10.2 Propulsion system speed limits.

"Aircraft Design: A Conceptual Approach" by Daniel P. Raymer, page 224

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Aircraft Weights

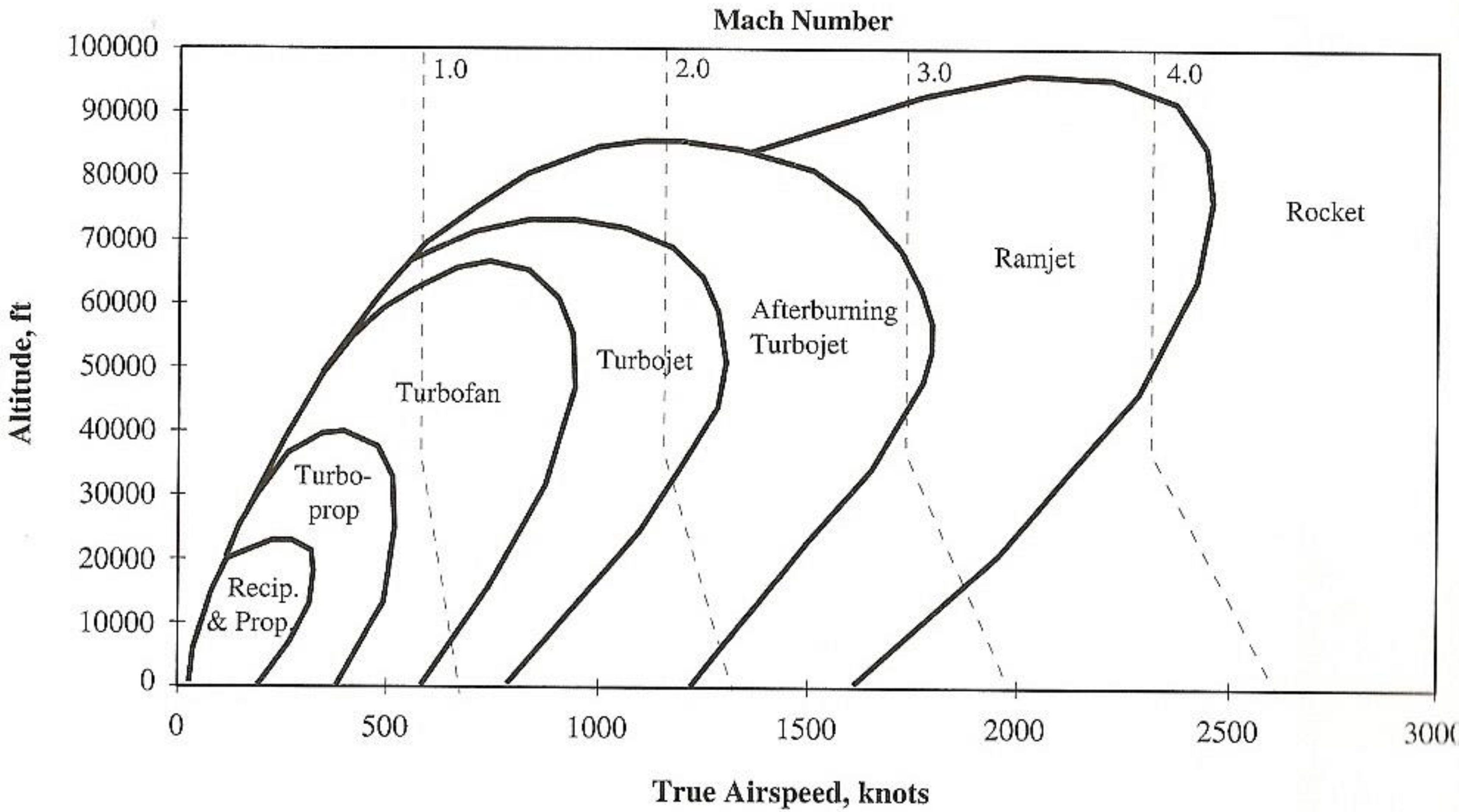

Fig. 5.4 Aircraft propulsion system operating envelopes (adapted from Ref. 2).

"Introduction to Aeronautics: A Design Perspective" by Brandt et al, page 178

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Aircraft Propulsion Definitions

Piston Engine / Propeller and Turboprop

Power = force x velocity = Thrust (lb) x Velocity (ft/sec)

Propulsive Efficiency (η_P)

$$\eta_P = \frac{\text{useful power available}}{\text{total power generated}} \qquad (0 < \eta_P \leq 1)$$

Shaft Horsepower (SHP) – sea level power rating

Effective (or Equivalent) Shaft Horsepower (ESHP)
- sea level power rating that includes jet power

$$1\ \text{HP} = 550\ \frac{\text{ft lb}}{\text{sec}}$$

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Aircraft Propulsion Definitions

Turbofan and Turbojet

Thrust Available (T_A)

– max thrust that can be produced by the engine

Thrust Required (T_R)

– thrust to maintain the current flight condition

Part Power Thrust

– any thrust setting less than max thrust

Specific Fuel Consumption (sfc or c)

– measure of engine efficiency

$$\mathrm{sfc} = \frac{\text{Fuel Flow } (\mathrm{lb_m/hr})}{\text{Thrust } (\mathrm{lb_f})}$$

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Aircraft Propulsion Modeling

Characteristic Equations (Theory)
Conceptual Design

Approximation Equations (Correlation)
Preliminary Design

Engine Computer Cycle Deck (ECCD)
Computational software model
Models the thermodynamic cycle of each engine stage
Detailed Design

Calibrated Engine
Ground test data correlated with cycle deck
Flight Test

Substantiated Data
Based on flight test results

Propulsion Characteristic Equations

Mass Flow

$$\dot{m} = \rho\, A\, V$$

Continuity

$$\rho_1\, A_1\, V_1 = \rho_2\, A_2\, V_2$$

Newton's 2nd Law

$$T = \dot{m}\left(V_j - V_\infty\right)$$

$$\eta_P = \frac{2}{1+\frac{V_j}{V_\infty}}$$

Jet Engine Thrust Equation

$$T = (\dot{m}_{air} + \dot{m}_{fuel})\, V_e - \dot{m}_{air}\, V_\infty + (p_e - p_\infty)A_e$$

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Aircraft Thrust

Piston engine / propeller $$T_A = SHP_{SL}\left(\frac{\eta_P}{V}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

Turboprop $$T_A = ESHP_{SL}\left(\frac{\eta_P}{V}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

High-bypass turbofan $$T_A = T_{SL}\left(\frac{0.1}{M}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

Low-bypass turbofan
Medium-bypass turbofan
& Turbojet $$T_A = T_{SL}\left(\frac{\rho}{\rho_{SL}}\right)$$

Afterburner $$T_A = T_{SL}\left(\frac{\rho}{\rho_{SL}}\right)(1 + 0.7\,M)$$

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Aircraft Fuel Flow

Piston engine / propeller	$\mathbf{FFR = SHP\ c}$
Turboprop	$\mathbf{FFR = ESHP\ c}$
High-bypass turbofan	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$
Low-bypass turbofan & Turbojet	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$
Afterburner	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$

Example Calculations

Turbojet $\mathbf{T_A = T_{SL}\left(\frac{\rho}{\rho_{SL}}\right)}$ $\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$

Example Turbojet Engine Characteristics:

$\mathbf{T_{SL} = 10,000}$ **lb / engine** $\mathbf{c_{SL} = 0.80\ lb/hr\ /lb_{thrust}}$

For an aircraft with 2 engines at 20,000 ft:

$\mathbf{T_{20k} = T_{SL}\left(\frac{\rho_{20k}}{\rho_{SL}}\right)}$ **x # engines = 10,000 x 0.5328 x 2 = 10,656 lb**

$\mathbf{c_{20k} = c_{SL}\left(\frac{a_{20k}}{a_{SL}}\right) = 0.80\ x\ 0.9287 = 0.7430\ lb/hr\ /lb_{thrust}}$

$\mathbf{FFR = T\ c_{SL}\left(\frac{a_{20k}}{a_{SL}}\right)}$ **= T** $\mathbf{c_{20k}}$ **= 10,656 x 0.7430 = 7,917 lb / hr**

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Homework Assignment

HW #4 – Propulsion
(due by 11:59 pm ET on Monday)
Reading – Chapter 3 in textbook

<u>HW Help Session</u>
Monday 1:00 – 2:00 pm ET

<u>Posted on Canvas</u>
HW #4 Assignment with instructions, tips, and checklist
HW #4 Template for data table in Excel

Questions?

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