Turbofan Engine

By: Lancert Foster

Turbofan Presentation Overview

- Description of Turbofan and Turboprop
- Performance
- Turbofan History and Noise Considerations
- UHB turbofan
- Variations Modern Applications

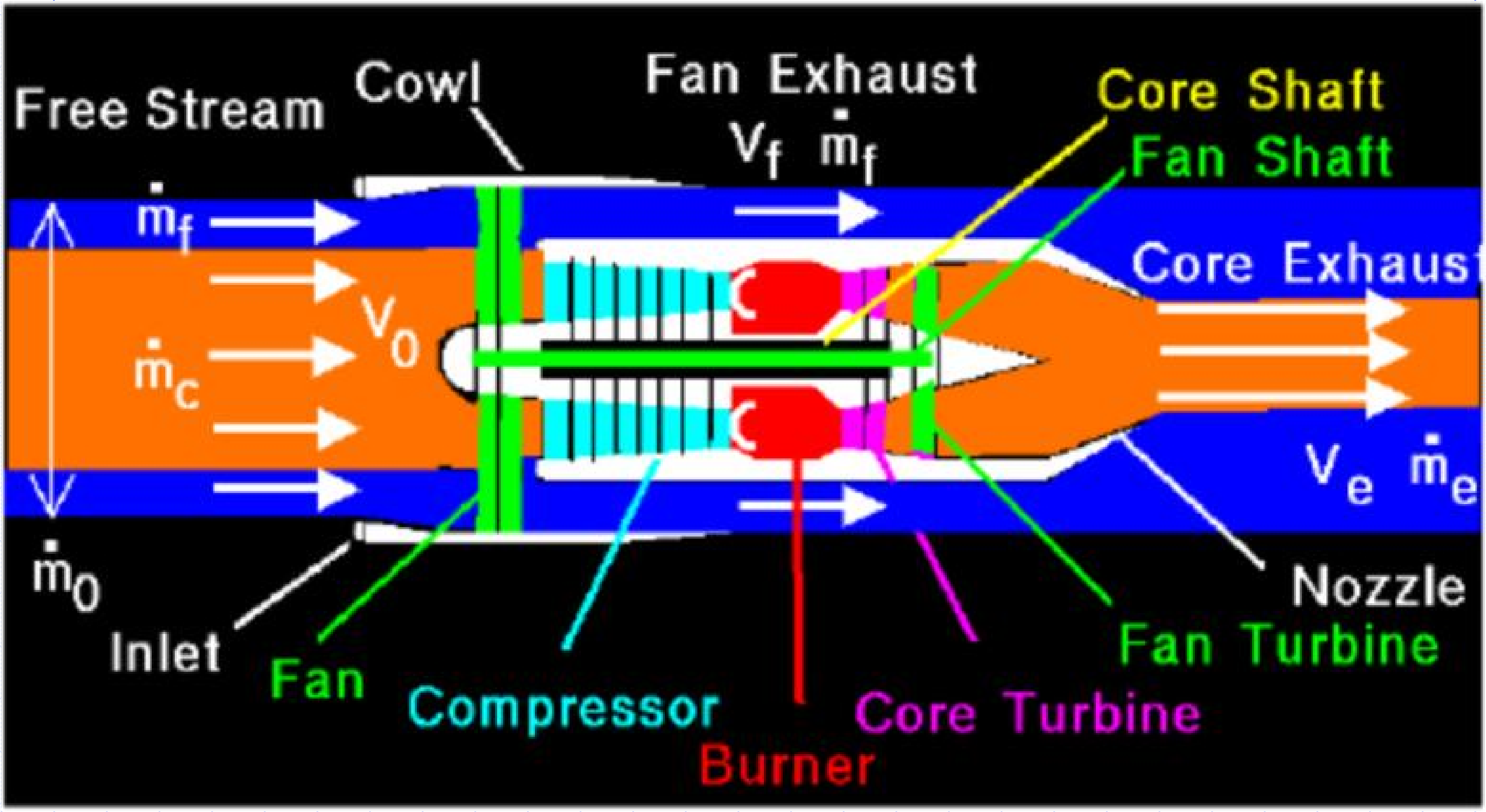
Benefits of Turbofan over Turbojet

- Reduced fuel consumption (for given thrust)

  OR

- Increased thrust (for given core mass flow)
- Increased propulsion efficiency
- Reduction in noise

Turbofan Components

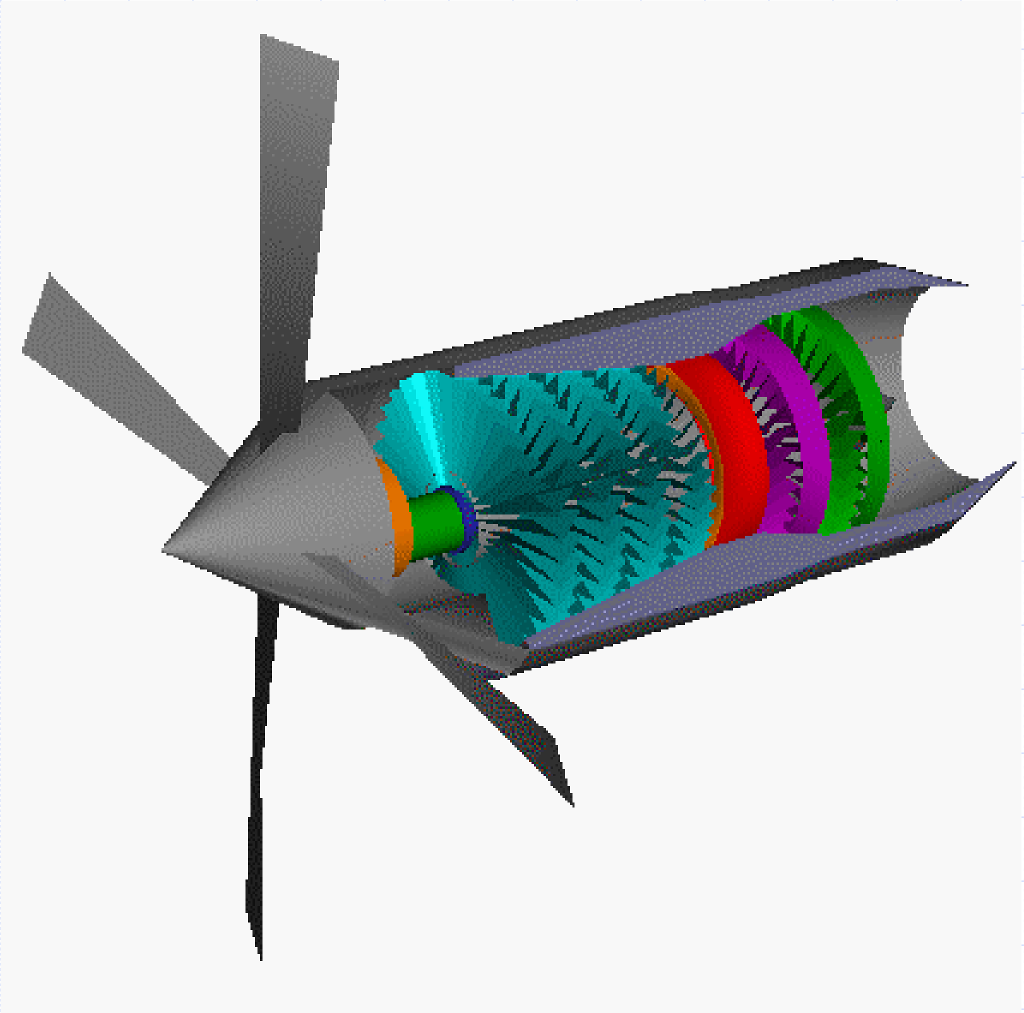


Thrust and TSFC equations

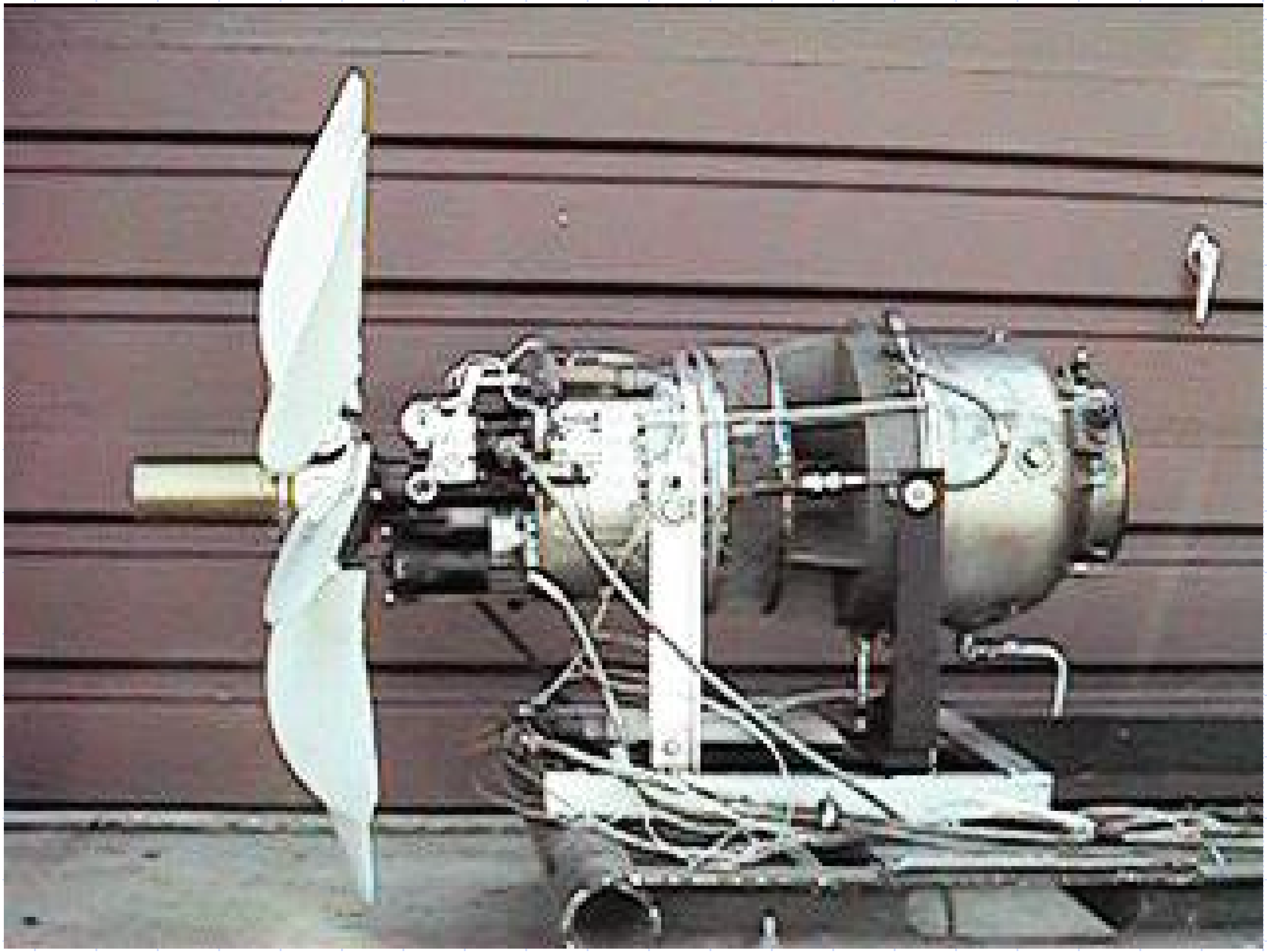
$$\frac{T}{m_a} = (1+f)u_e + \beta u_{ef} - (1+\beta)u_e$$

$$TSFC = \frac{m_f}{T} = \frac{f}{(1+f)u_e + \beta u_{ef} - (1+\beta)u}$$

Turboprop Engine



Turboprop Engine



Turboprop Engine (cont’d)

- Propeller power turbine is mechanically independent of gas generator rotor elements
- Large speed reduction unit (having a speed ratio of perhaps 15:1) required
- Weight may be 1.5 times that of conventional turbojet with same size gas generator

Turboprop Thrust Equation

$$T = T_{pr} + T_n$$

Tpr = propeller thrust
Tn = exhaust nozzle thrust

Turboprop Propeller Thrust

$$T_{pr} = \frac{\eta_{pr} * \eta_g * \eta_{pt} * \alpha * \Delta h * m}{U}$$

ηpr = propeller efficiency
ηg = gear efficiency
ηpt = power turbine efficiency
α = fraction of Δh used by isentropic turbine
Δh = net work
U = flight velocity

Turboprop Nozzle Thrust

$$T_n = m(u_e - u)$$

$$T_n = m\left(\sqrt{(2*(1-\alpha)*\eta_n*\Delta h)} - u\right)$$

Turboprop Thrust Maximization

$$T = \frac{\eta_{pr} * \eta_g * \eta_{pt} * \alpha * \Delta h * m}{u} + m\left(\sqrt{(2(1-\alpha)\eta_n \Delta h)} - u\right)$$

Maximum thrust occurs when:

$$\alpha = 1 - \frac{u^2}{2\Delta h}\left(\frac{\eta_n}{\eta_{pr}^2 \eta_g^2 \eta_{pt}^2}\right)$$

Propulsion Efficiency

- The ratio of thrust power (Tu) to the rate of production of propellant kinetic energy

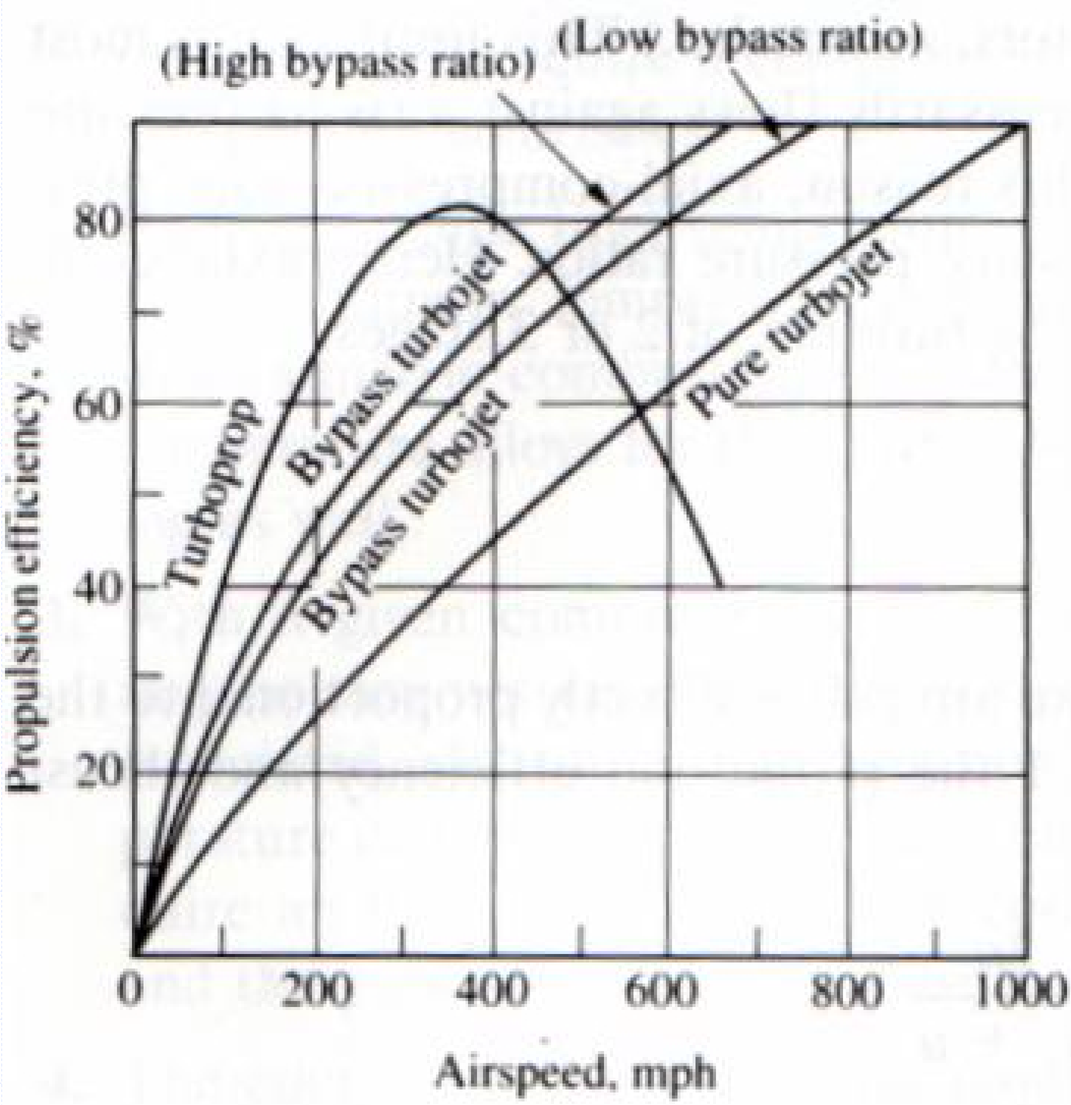
Propulsion Efficiency (cont'd)

$$\eta_p = \frac{Tu}{m_a\left[(1+f)\left(u_e^2/2\right)-u^2/2\right]}$$

If f << 1

$$\eta_p \approx \frac{(u_e-u)u}{\left(u_e^2/2\right)-\left(u^2/2\right)} = \frac{2u/u_e}{1+\left(u/u_e\right)}$$

Propulsion Efficiency v. Airspeed



Turbofan History

- In early jet engines, high velocity jet exhaust mixing with surrounding air is major source of noise
- In 1960’s, low-bypass-ratio turbofans introduced

Turbofan History (cont'd) LBR Turbofans

- Greater propulsion efficiency than turbojets
- Provided some noise relief
- Engine core and fan exhausts combined with help of internal mixers
- Reduced jet exhaust velocity, consequently reducing jet exhaust noise significantly

Turbofan History (cont'd)

- In 1967, NASA initiates acoustically treated nacelle program
- Engine ducts and inlets are lined with acoustic treatments
- Flight tested on Boeing 707 and DC-8
- Noise under approach path reduced by 15 PNdB
- Acoustic treatment proven effective and feasible

Turbofan History (cont'd)

HBR Turbofans

- Even greater jet noise reduction is achieved
- With further reduction of jet noise, fan noise becomes major noise source

Ultra-High Bypass Turbofan

- An ultra-high bypass turbofan is generally considered as any turbofan with a bypass ratio of 10:1 or higher
- Jet noise is no longer a major issue
- Fan noise is major noise source and thus, is being heavily investigated

UHB Savings Figures

- 10-20% fuel savings over conventional high bypass turbofan unducted propfan engine
- Weight reduction causing fuel savings of 7-15% over heavier aircraft

Fan Noise Causes

- Inlet boundary layer or inflow distortion interacting with the fan
- Self noise from the fan
- Fan wakes interacting with stators or struts

Fan Noise Categories

- Broadband Noise
- Tone Noise

Broadband (or Random) Noise

- Tends to be caused by inflow turbulence interacting with the fan or fan turbulent wakes impinging on stators and struts

Sources of Broadband Noise Generating Turbulence

- The boundary layer in the outer wall of the inlet duct
- Wakes shed by fan blades
- Atmospheric inflow turbulence (not normally significant in production of broadband noise)

Broadband Noise Solutions

- Acoustic treatment duct liners

Tone Noise Sources

- Rotor alone
- Rotor/stator/strut interaction with flow distortions

Rotor-stator Interaction Noise

- The major source of tone noise
- Occurs at multiples of the blade passing frequency and its harmonics

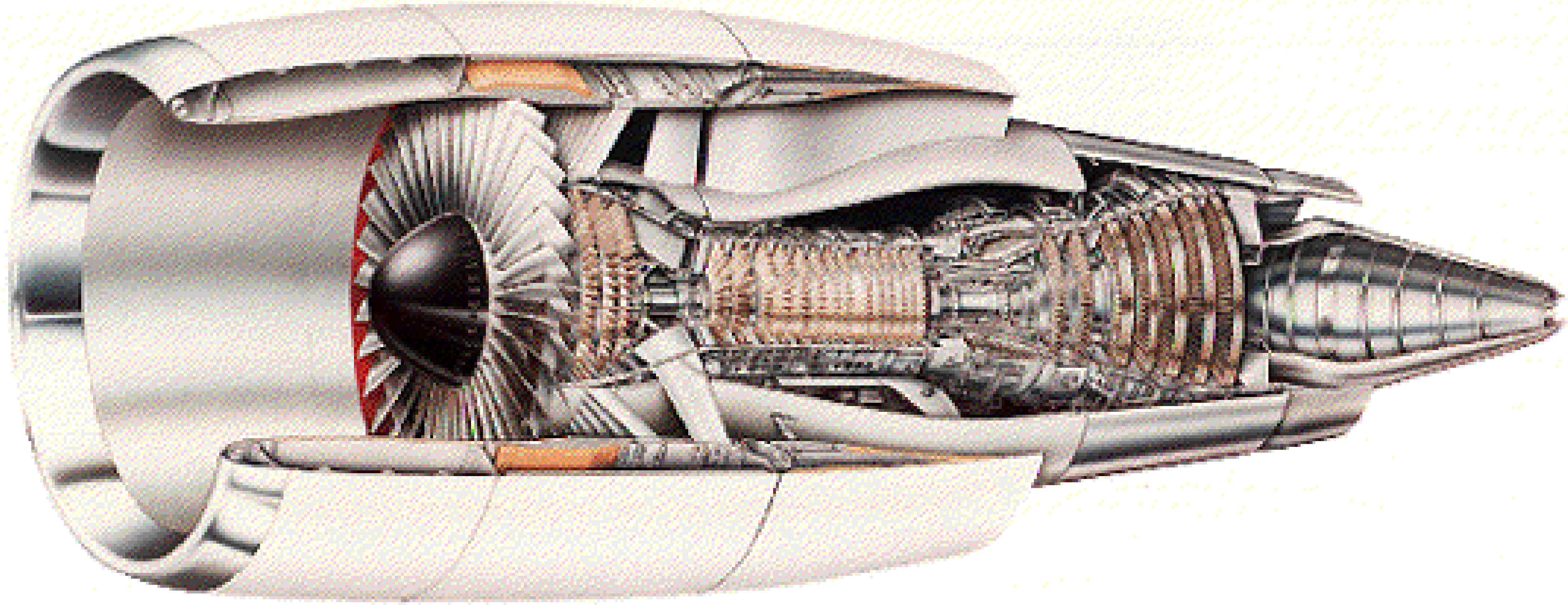
Tone Noise Solutions

- Actuators
- Aft Splitter

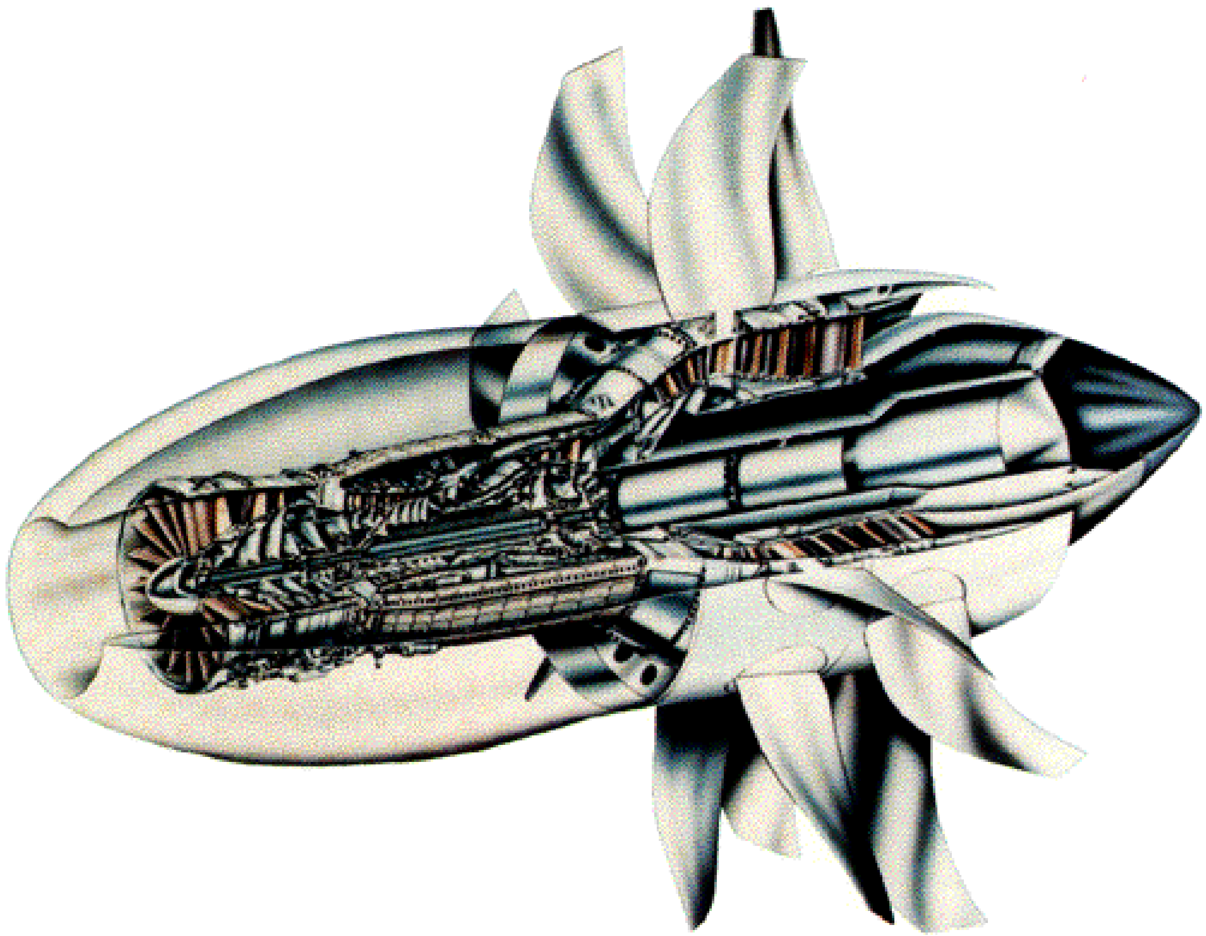
Bypass Duct Aft Splitter

- Consists of an acoustically treated splitter at mid-height of the bypass duct
- Acoustic treatment consists of honeycomb patterned Helmholtz resonator tuned to frequency of rotor-stator interaction noise
- Greatly increases L/H (length of acoustic treatment to duct height) ratio

CF6N Ducted Turbofan



Unducted Turbofan



F100-232 Afterburning Turbofan