Jet Aircraft Propulsion

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Lect-39
In this lecture...

- Components of ramjets and pulsejets
- Ramjet combustors
- Types of pulsejets: valved and valveless, Pulse detonation engines
Ramjet engines

- Ramjet engines consist of intakes, combustors and nozzles.
- The entire compression process is accomplished in the intake of the ramjet.
- Intakes therefore form a very important component of ramjets.
- After the intake, the compressed air goes into the combustor.
- The combustion products are then expanded through the nozzle to generate thrust.
Ramjet intakes

• Ramjet intakes are usually of the supersonic, variable ramp geometry.
• The ramp position will be adjusted depending upon the operating condition.
• The intake usually employs 2-3 oblique shocks followed by a normal shock for decelerating the flow.
• After the normal shock, the flow that is subsonic is further decelerated using a diffuser.
Ramjet combustors

• Unlike other jet engines like turbojets, turbofans etc, there are no rotating components in ramjets.
• The temperatures in the combustion chamber are therefore much higher than the conventional jet engines.
• Maximum temperatures as high as 3000K are common in ramjets.
• Ramjet combustors are similar to the afterburners used in turbojet engines.
Ramjet combustors

• Combustors have flameholders for stabilizing the flame within the combustor.
• The length of the combustor depends upon the fuel used, the injector characteristics and the flame holders.
• Though flameholders are essential to ensure stable combustion, they also lead to total pressure losses.
• Designers would need to optimize the blockage due to flameholders.
Ramjet combustors

Schematic of a typical ramjet combustion chamber
Ramjet combustors

Intermittent spark

Flame front

Continuous spark
Ramjet combustors

Operation of a flameholder in a ramjet combustor
Ramjet combustors

- Even in the absence of frictional drag due to the flameholders, the heating process in a constant area duct will lead to stagnation pressure loss.
- Let us consider a one-dimensional flow in an afterburner.
- The flow entering and leaving the combustor are assumed to be uniform.
- The flameholders exert a total leftward drag, $D$, on the flow.
Ramjet combustors

Simplified combustion chamber flow
Ramjet combustors

\[(P_2 - P_4)A - D = \dot{m}_4 u_4 - \dot{m}_2 u_2\]

or, \[P_2 - P_4 = \rho_4 u_4^2 - \rho_2 u_2^2 + K\left(\frac{1}{2} \rho_2 u_2^2\right)\]

where, \(K\) is the ratio of pressure drop due to friction.

Since, \(M^2 = u^2 \left(\frac{\gamma P}{\rho}\right)\)

We can express

\[
\frac{P_2}{P_4} = 1 + \gamma M_4^2 - \gamma M_2^2 \frac{P_2}{P_4} + K \frac{\gamma M_2^2}{2} \frac{P_2}{P_4}
\]

or,

\[
\frac{P_2}{P_4} = \frac{1 + \gamma M_4^2}{1 + \gamma M_2^2 \left(1 - \frac{K}{2}\right)}
\]
Ramjet combustors

In terms of the total pressure ratio:

\[
\frac{P_{04}}{P_{02}} = \frac{1 + \gamma M_2^2 \left(1 - \frac{K}{2}\right)}{1 + \gamma M_4^2} \left[ \frac{1 + \frac{\gamma - 1}{2} \gamma M_4^2}{1 + \frac{\gamma - 1}{2} \gamma M_2^2} \right]^{\gamma/(\gamma - 1)}
\]

If we assume that \( \dot{m}_4 = \dot{m}_2 \) and that \( P = \rho RT \)

\[
\frac{P_2}{P_4} = \frac{u_4 T_2}{u_2 T_4} = \frac{M_4}{M_2} \sqrt{\frac{T_2}{T_4}} = \frac{M_4}{M_2} \sqrt{\frac{T_{02}}{T_{04}}} \left[ 1 + \frac{\gamma - 1}{2} \gamma M_4^2 \right] 1 + \frac{\gamma - 1}{2} \gamma M_2^2
\]

The stagnation temperature ratio can be expressed as,

\[
\frac{T_{04}}{T_{02}} = \frac{M_4^2}{M_2^2} \left[ \frac{1 + \frac{\gamma - 1}{2} \gamma M_4^2}{1 + \frac{\gamma - 1}{2} \gamma M_2^2} \right] \left[ 1 + \gamma M_2^2 \left(1 - \frac{K}{2}\right) \right]^2 \left[1 + \gamma M_4^2 \right]^2
\]
Ramjet nozzles

- Nozzles expand the combustion products coming from the combustor and generate thrust.
- Nozzles in ramjets are usually of the converging-diverging type.
- They are normally axisymmetric with or without provision for geometry variation.
- Variable geometry is required for optimum operation under various operating conditions.
Variants of ramjet engines

- Ramjets can be designed in a variety of configurations.
- Conventional ramjets: Can type ramjets (CRJ)
- Solid fuelled ramjets (SFRJ), Liquid fuelled ramjets (LFRJ) and Gaseous fuelled ramjets (GFRJ).
- Integral rocket-ramjets (IRR): SFIRR, LFIRR and GFIRR
- Combined cycle: Air-turboramjet (ATR)
- Ejector Ramjets (ERJ)
Pulsejet engines

• There are two types of pulsejet engines: valved-type and valve-less type.
• Valved-type pulsejet have been the more popularly used versions.
• In valved type engines, the pulsing is accomplished using a set of valves.
• The combustion in the engine is self-sustaining.
• The valves operate when the fuel-air mixture ignites in the combustor.
• The combustion products are expelled through the tailpipe to create thrust.
Valveless pulsejet engines

- The main disadvantage of valved pulsejet engines is the use of mechanical valves.
- Wear and tear, reliability and noise problems can be partly overcome by valveless pulsejets.
- These engines do not have mechanical valves, but have aerodynamic valves.
- One of the most successful valveless pulsejet engines, Lockwood-Hiller engines, have a “U” bend.
- The intake and exhaust pipes face the same direction.
Valveless pulsejet engines

Schematic of a valveless pulsejet engine
Valveless pulsejet engines

• Combustion process generates two shock wave fronts.
• By appropriately tuning the system, a stable, resonating combustion leading to be considerable thrust generation, can be achieved.
• Because of the deflagrating nature of the combustion, valveless pulsejet have a rather clean combustion.
• Valveless pulsejets have been successfully demonstrated for powering small sized as well as very large sized aircraft.
Valveless pulsejet engines

An aircraft with a valveless pulsejet engine
Pulse Detonation Engines

- Pulse detonation engines (PDE) have been demonstrated conceptually.
- It is expected to deliver efficiencies higher than conventional gas turbine engines.
- Pulse detonation engines also have no moving parts like a ramjet.
- PDE detonate rather than deflagrate their fuel.
- Detonation involves supersonic combustion of the fuel.
Pulse Detonation Engines

- PDE are envisaged to be used for supersonic flights.
- PDEs use intermittent detonation waves to generate thrust.
- PDE operation is not governed by the acoustics of the system.
- This renders better control of the engine unlike conventional pulsejets.
- PDE generate higher specific thrust than a comparable ramjet even at lower subsonic speeds.
Pulse Detonation Engines

- PDE may be used as a stand-alone engine, combined cycle or as a hybrid engine.
- Pure PDE simply have an array of detonation tubes to generate thrust.
- Combined cycle PDE involve adding a PDE to the flow path of a ramjet or scramjet enabling operation from subsonic to hypersonic speeds.
- Hybrid engines involve use of PDE along with a conventional jet engine.
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