AAE 538: Air-Breathing Propulsion

Lecture 26: Inlet Starting and Isolators

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Inlet Starting Example

More detail on the Shock 'Swallowing' Process

- To demonstrate the shock swallowing process in more detail, we consider a numerical example.
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  - This is a rather large Mach number for a supersonic inlet (with all normal shocks as opposed to some oblique shocks), but it serves as an effective example for understanding this process.
- At the critical Mach number ($M_0 = 4.0$),
  - The Mach number behind the shock is obtained by
  - The corresponding throat area, which is choked at this inlet Mach number, is
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- At this Mach number, we compute the results for placing the shock at a series of locations between the inlet and the throat:

Example

The Shock Location in a Converging Duct				
Shock Area	M_u	M_d	Required Throat Area	Available Throat Area
1.0	4.050	0.4336	0.6707	0.6723
0.9344	3.974	0.4356	0.6291	0.6723
0.8689	3.893	0.4379	0.5874	0.6723
0.8034	3.806	0.4405	0.5456	0.6723
0.7379	3.713	0.4435	0.5037	0.6723
0.6724	3.612	0.4469	0.4617	0.6723

- Column 1 shows the location where the shock is placed in the convergence, normalized by the inlet area.
- Column 2 is the Mach number in front of the shock, determined by the isentropic relations while Column 3 is the Mach number downstream of the shock.
- Column 4 indicates the throat area required to pass the flow with the shock at this location.
- Column 5 simply indicates the available throat area, per the design (compute previously)

Example

- The results show that when the shock is placed within the inlet, the throat area is _______________than it needs to be for the flow rate to be supported.

- The result in the table, however, show that as the shock wave moves farther into the nozzle, the required area becomes _______________so that it cannot sit at the inlet lip.
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- Once inside the nozzle, the location of the shock is determined by the back pressure and the Mach number in the inlet remains supersonic until it reaches the throat.
  - In other words, the flow decelerates supersonically (and isentropically) in the converging portion of the inlet and then accelerates again in the divergent section.

Example

- For this particular case, the Mach number at the throat is the one given by the upstream Mach number

- Once the shock has been swallowed, the inlet has been 'started'.
    - At this point, it takes a significant amount of deceleration to cause it to be disgorged.

- If the Mach number is now reduced below 4.05, the Mach number at the throat decreases continuously, but it remains supersonic!
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- The remains true until the free-stream Mach number is reduced to the point that the shock is actually brought back to the throat.
    - The free-stream Mach number that places the shock at the throat can be found by iteration.

Example

Example

Example

Example

Variable Geometry

- If the inlet has variable geometry capability, the shock strength inside the nozzle can be reduced by changing the inlet throat area.
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- In an ideal situation, the inlet throat area can be chosen such that the converging inlet section is fully-supersonic, but decelerated to the sonic speed at the throat.
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Variable Geometry

- Practically speaking, placing the nozzle this close to unstart is not wise because any small perturbation would cause the shock to be disgorged.
    - The inlet-starting process would have to be repeated.

- To circumvent this, inlets with variable area will generally keep the shock location at a low-supersonic Mach number so that, if a perturbation is encountered, the resulting shock disturbance will remain inside the divergent section and the inlet will remain started.

Introduction to Isolators

- Supersonic combustors require an isolator to de-couple (to some extent) the inlet and the combustor.
  - As fuel flow is increased, pre-combustion pressure rise also increases and, effectively, changes the exit conditions M_3 and P_3 from our analysis of inlets.
- Isolators function to manage the shock train leading into the combustor

Introduction to Isolators

Shock-Boundary Layer Interactions

- The flow in an isolator is separated due to the inevitable shock-boundary layer interactions

Shock-Boundary Layer Interactions

- Think of the near-wall process as a shock-refraction, rather than a reflection.

Isolators

- We are most interested in oblique shock trains for any isolator
- For a given flight condition, the isolator permits a range of backpressures at the same mass flow rate

Isolators

- Real isolator design is very complex due to the strong dependence on boundary layer developed and shock-B.L. interactions.
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- In general, the performance trend is something like the following:

Isolators

- Often described by correlations for canonical conditions, the Walthrop and Billig correlation is valid for ____________________.
    - The shock train length is described by: