Jet Aircraft Propulsion

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Lecture 35

Installed performance of Engines

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- Engine design process ends with sizing of the engine to achieve the required thrust for a given airflow ($\dot{m}_o$) through the engine, at the design point.
- When a powerplant is installed or attached to the body of the aircraft and flown with it the *Installed thrust* (**T_F**) as experienced by the aircraft, comes out to be different from the design *uninstalled thrust* (**F**) computed or bench tested for the isolated engine.
- The difference between **T_F** and **F** is often quite significant and may vary from one operating point to another of the engine or the aircraft.

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- The *uninstalled thrust, F* represents only the result of the internal flow of air inside the engine.
- Installing the engine outside the fuselage induces aerodynamic forces ($\mathbf{D_{engine}}$) that adds to the aircraft drag ($D_{a/c}$).
- This is the "self-drag" of the engine (for external mounting of the engine).
- The installed thrust, T, must be the sum of uninstalled thrust, **F** and self-drag, $\mathbf{D_{engine}}$, which is determined along with the initial engine size, (i.e. uninstalled thrust estimation).
- Thus very presence of the engine, its inlet, nozzle and exhaust stream actually influence the flow over the entire aircraft it is affects the instantaneous thrust.

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- From fundamental science, the engine performances favor higher bypass ratios, but the larger diameters and the resulting installation penalties prevent the final benefits.
- For high performance aircraft such as a fighter aircraft the engine is likely to be buried within the fuselage.
- The engine designer will be allowed to influence those parts that are believed to generate the bulk of the installation penalties, i.e. those affected by the inlet and exhaust flows.
- The inlet and nozzle external losses will be expressed as fraction of the uninstalled thrust, **F**.

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Installed Thrust available for flying

$$T_F = F - \Phi_{inlet} F - \Phi_{nozzle} F$$

Flying thrust available is less than Engine Design Thrust

Or, $$F = T_F / \left(1 - \Phi_{inlet} - \Phi_{nozzle}\right) > T_F$$

Where, Φs are the drag fractions of design thrust

$$\Phi_{inlet} = \frac{D_{inlet}}{F} \qquad \Phi_{nozzle} = \frac{D_{nozzle}}{F}$$

D_{inlet} : Drag due to engine inlet

D_{nozzle} : Drag due to engine nozzle

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- Note that Φ_{inlet} & Φ_{nozzle} will vary with flight condition and throttle setting for any engine, and vary from aircraft to aircraft slightly even for the same engine.

- Once the means of computing ϕ_{inlet} & ϕ_{nozzle} as a function of flight conditions (altitude, attitude and velocity) and throttle settings is found, the off-design computation method is used to "size" the engine.
- Starting from the "design point" engine and "mass flow", the engine is "flown" (i.e. simulated) off-design at each critical flight condition at maximum power in accordance with the rated requirement.
- Next, either the engine mass flow (or the size) is adjusted until the required and the available thrust are equal at all flight conditions.

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For each flight condition

$$\dot{m}_0 = \frac{F}{(F/\dot{m}_0)} = \frac{T_F}{(F/\dot{m}_0)(1-\Phi_{inlet}-\Phi_{nozzle})}$$

For a climbing and accelerating (general) flight

$$\dot{m}_0 == \frac{W}{(F/\dot{m}_0)(1-\Phi_{inlet}-\Phi_{nozzle})}\left[\frac{(D_{a/c}+D_{eng})}{W}+\frac{1}{g}\frac{dV}{dt}+\frac{1}{V}\frac{dh}{dt}\right]$$

In order to find which of the flight conditions is most "demanding", each $\dot{\mathbf{m}}_{\mathbf{0}}$ is multiplied by the relevant **(**$\dot{m}_{0design}/\dot{m}_{0\text{-}off\text{-}design}$**)** as obtained from engine off-design calculations. The largest product corresponds to the largest design of the engine, and hence the required engine size.

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- This newly re-sized engine will be too large for all other flight conditions and performance at the other operating conditions must be obtained by throttling $\dot{m}_0$, T_{04} (Turbine entry temperature) and T_{07} (nozzle temperature) until a new installed thrust is arrived at.
- This process needs to be completed before the installed behavior of the engine, i.e. its installed thrust and its installed fuel consumption rate is known with acceptable accuracy.

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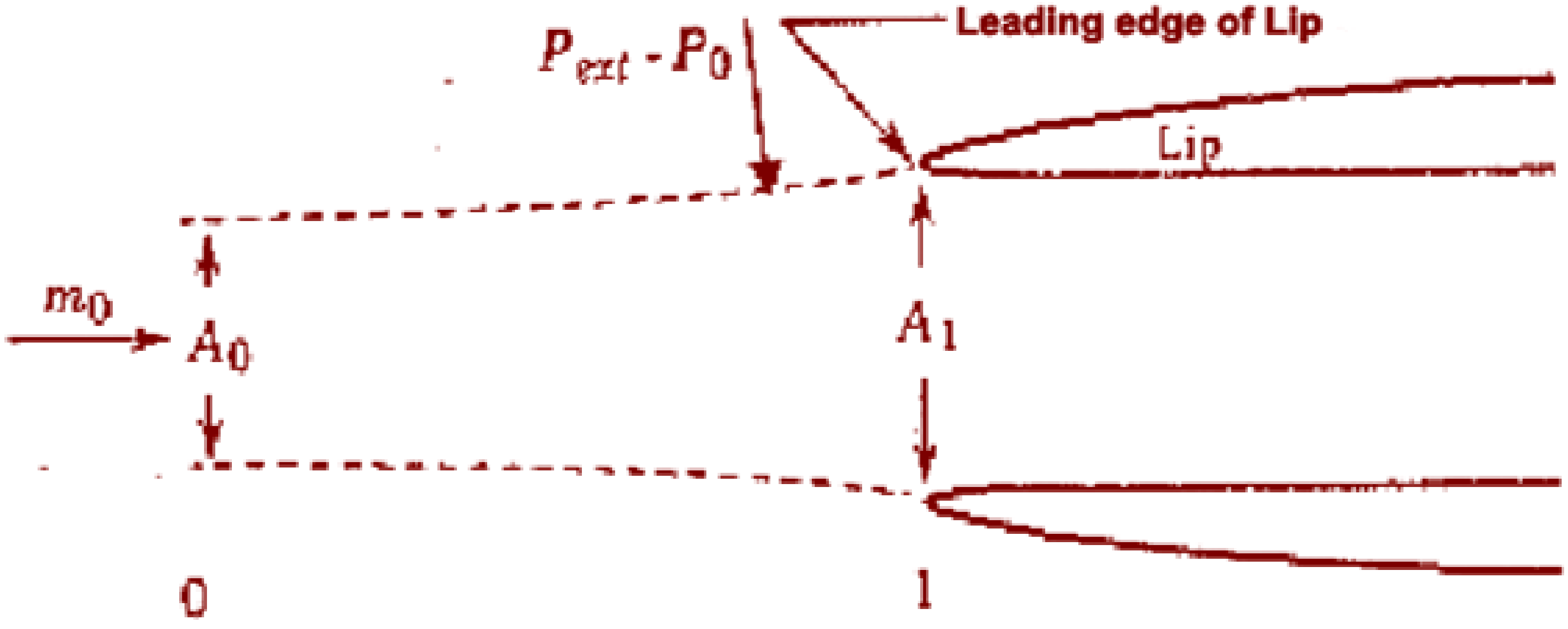
Subsonic Inlet Drag

There is always a positive drag acting on the stream tube which encloses the air entering the engine intake

$$D_{add} = \int^{1} (P_{ext} - P_0) dA$$



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This is known is "additive drag" (D_{add}) and is given as :

$$D_{add} = P_1 A_1 (1+\gamma M_1^2) - P_0 A_0 \left(\frac{A_1}{A_0} + \gamma M_0^2 \right)$$

Inlet Drag fraction

$$\Phi_{inlet} = \frac{D_{add}}{F}$$

$$\Phi_{inlet} = \frac{D_{add}}{\dot{m}_0 (F/\dot{m}_0)} = \frac{\left(\frac{M_0}{M_1}\right)\left(\sqrt{\frac{T_1}{T_0}}\right)(1+\gamma M_1^2) - P_0 A_0 \left(\frac{A_1}{A_0} + \gamma M_0^2\right)}{\frac{Fg}{\dot{m}_0} \frac{\gamma M_0}{a_0}}$$

Which can be evaluated for any set of values of M_0, M_1, a_0 and $F/\dot{m}_0$

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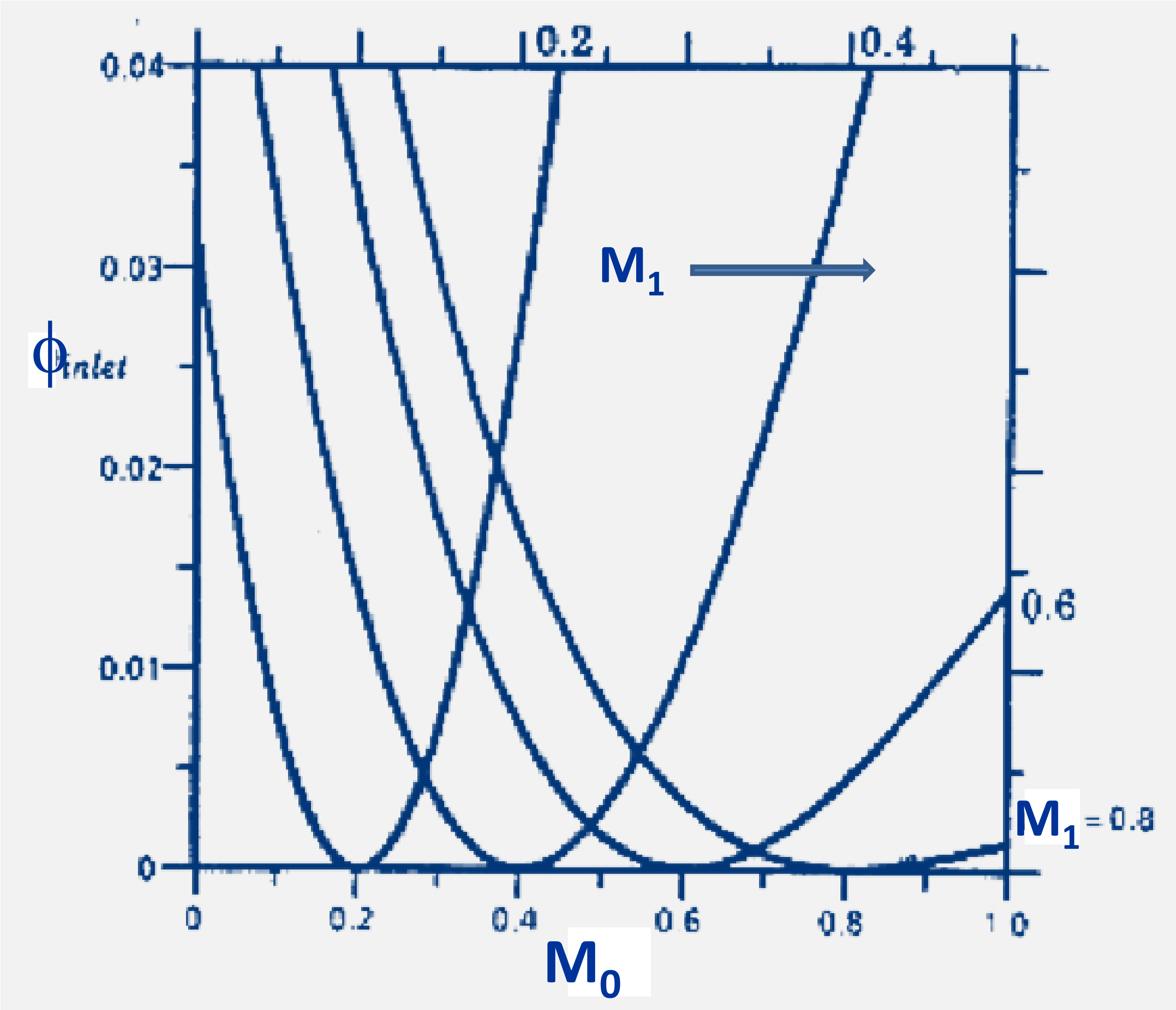
0.04
0.03
0.02
0.01
0
0.2
0.4
M1
0.6
M1 = 0.8
ϕinlet
0
0.2
0.4
0.6
0.8
1.0
M0

Conclusions on Intake installation drag:

- Φ_{inlet} is not large if M_0 is near M_1 and the entering stream tube experiences no change in flow area.
- For the usual range of subsonic flight, it is desirable to keep M_1 in the vicinity of 0.4-0.6
- High values of Φ_{inlet} occur at $M_0=0$, at Take off, is in the range of 0.5-1.

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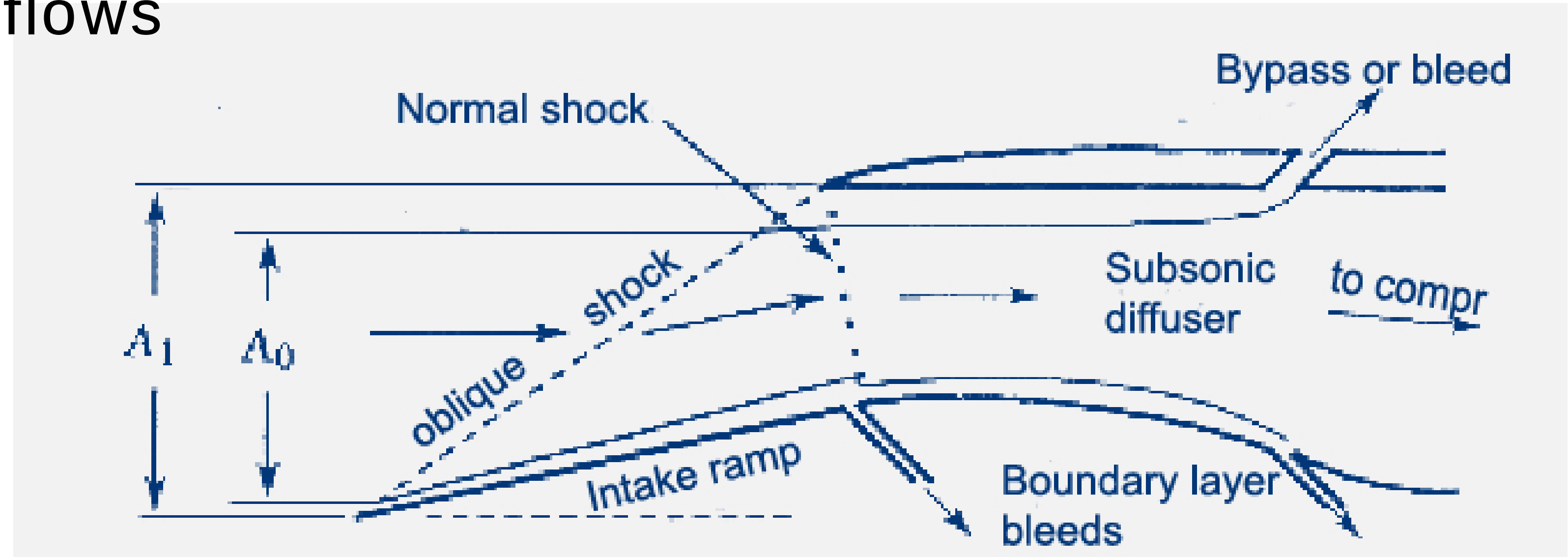
Supersonic Inlet Drag

The supersonic inlet drag is estimated to be equal to the momentum change of the bypass and bleed flows



Supersonic Inlet Flow Model

$$\Phi_{inlet} = \frac{\left(A_1 / A_0 - 1\right)\left(M_0 - \sqrt{\frac{2}{\gamma+1} + \frac{(\gamma-1)M_0^2}{\gamma+1}}\right)}{\left(Fg \;/ \dot{m}_0 a_0\right)}$$

Once A_1 has been selected, this equation can be directly evaluated at any given flight condition (P_0, T_0 and M_0) and engine power setting (i.e. A_0 and $F.g/m_0$). Note that ϕ_{inlet} approaches zero when (i) M_0 approaches unity and (ii) when A_0 approaches A_1 (sized), so that ϕ_{inlet} can useful when it is evaluated far from both the conditions.

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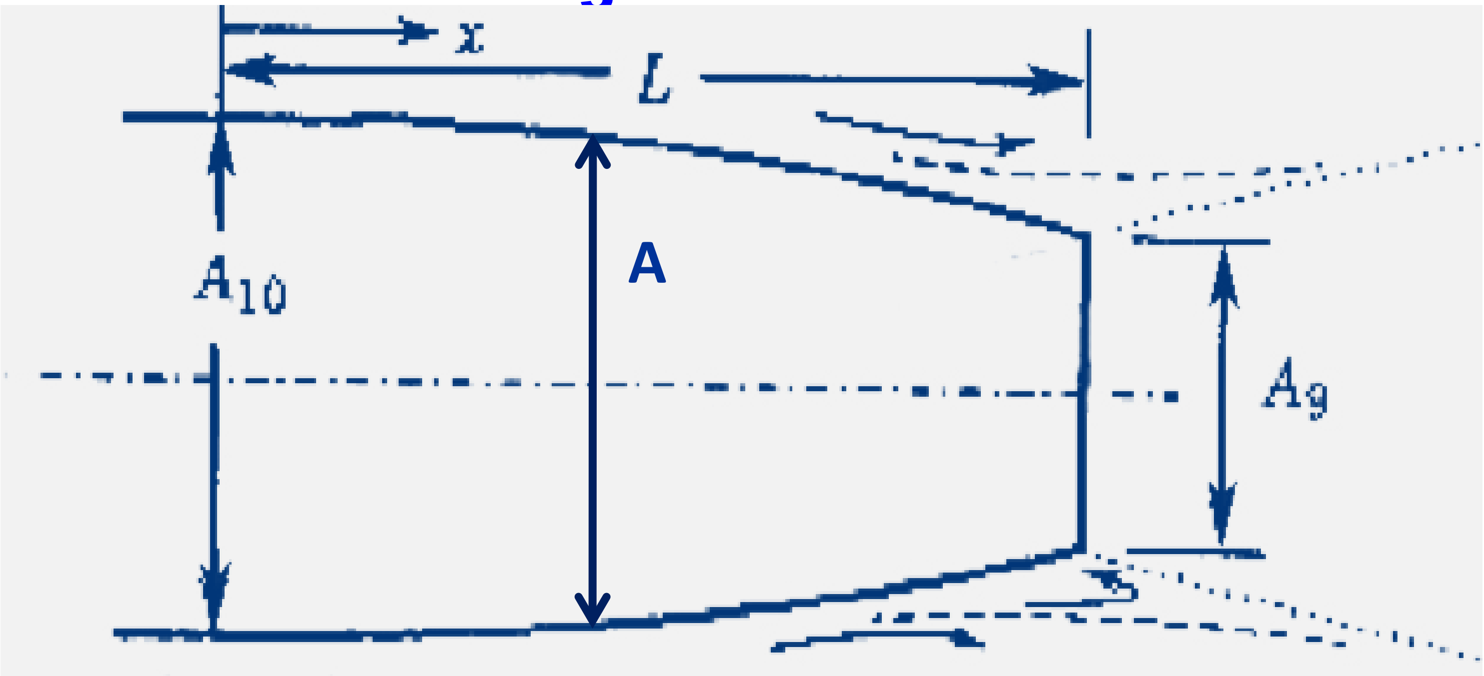
Exhaust Nozzle Drag



For predicting the exhaust nozzle pressure drag in subsonic and supersonic conditions correlation method has been developed based on "***integral mean slope***" "***integral mean slope***" is defined by the equation (*Integral mean slope captures the slope of the nozzle external surface contour*)

$$IMS = \frac{1}{\left(1 - \frac{A_9}{A_{10}}\right)} \int_{1}^{\frac{A_9}{A_{10}}} \frac{d\left(\frac{A}{A_{10}}\right)}{d\left(\frac{x}{R_{10} - R_9}\right)} d\left(\frac{A}{A_{10}}\right)$$

For Quick Practical solution

$$IMS \cong 1.8\left(\frac{D_{10} - D_9}{L}\right)\left(1 - \frac{D_9}{D_{10}}\right)$$

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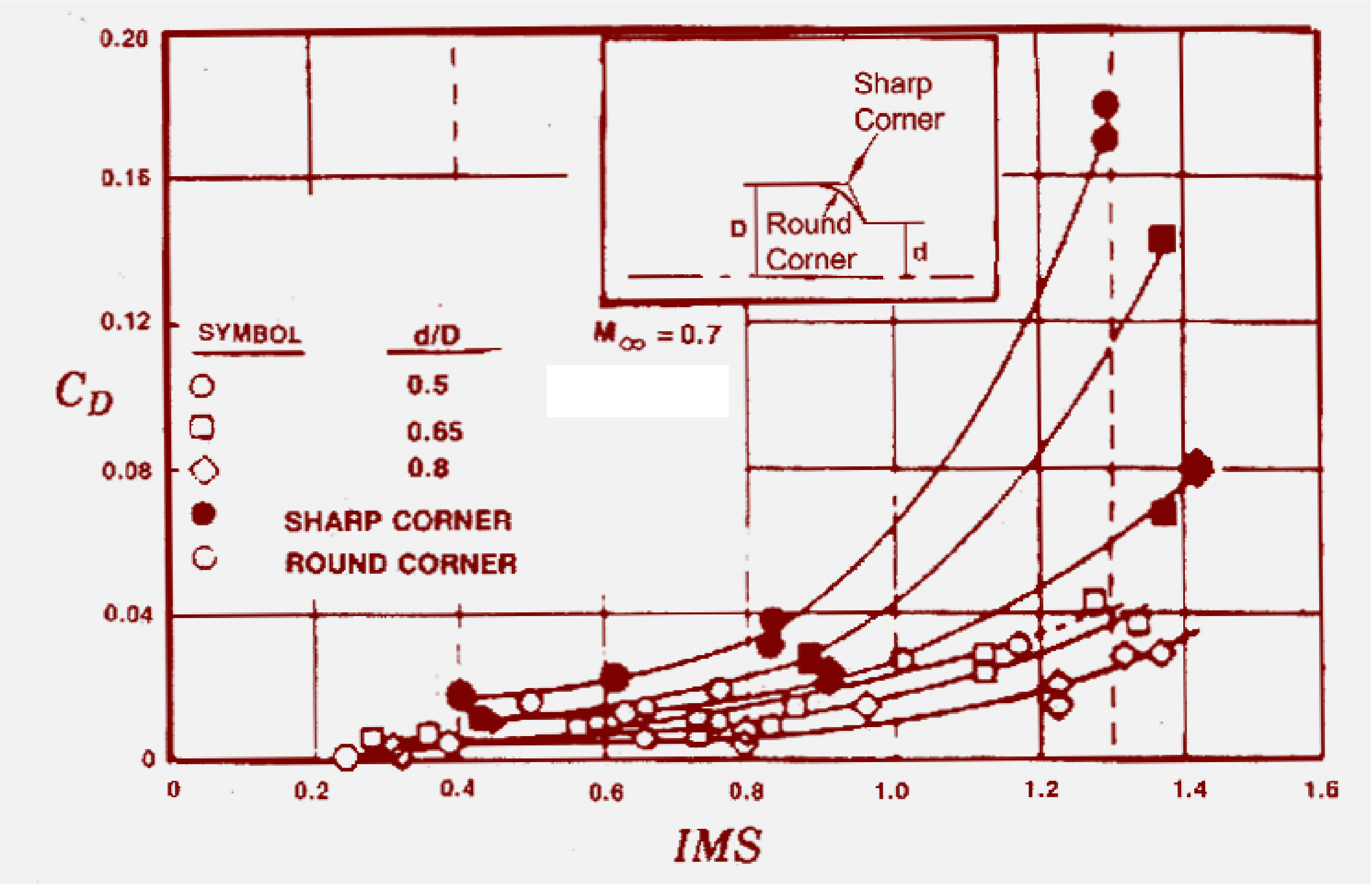

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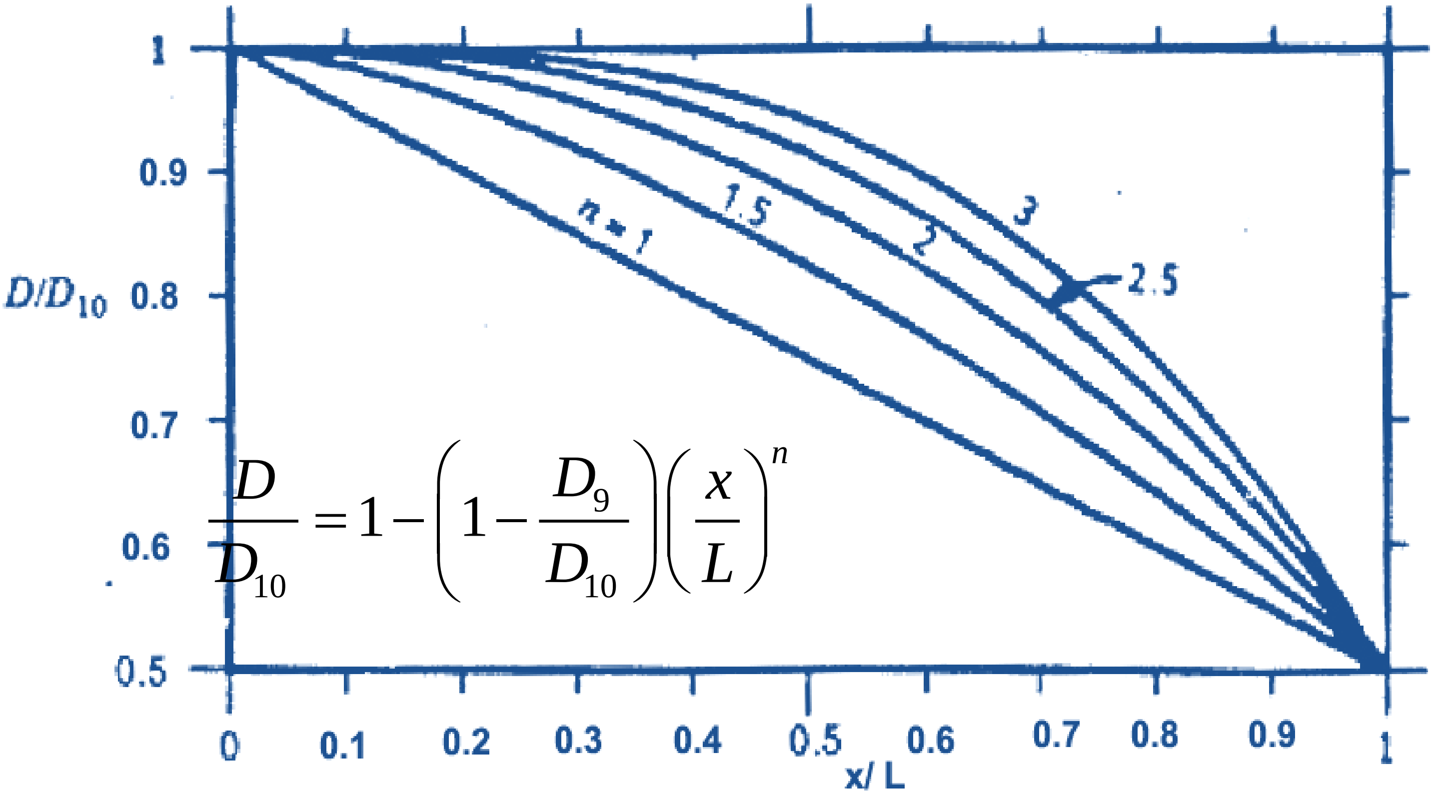

$$\frac{D}{D_{10}} = 1 - \left(1 - \frac{D_9}{D_{10}}\right)\left(\frac{x}{L}\right)^n$$

Nozzle installation penalty can be computed from

$$\Phi_{nozzle} = \frac{D_{nozzle}}{F} = \frac{q_0 C_D (A_{10} - A_9)}{\dot{m}_0 (F / \dot{m}_0)}$$

Next Class :

Problem solving for Engine matching and Tutorials

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