# Jet Aircraft Propulsion

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## Lecture No. # 35

## Installed Performance of Engine

We are talking about component matching of aircraft engines. We also talked a little about sizing of the engines. Today we will look at what happens, when you take an engine that is been designed very meticulously, components have been matched very meticulously, and a certain amount of sizing has been done with reference to the design that has been done. So that it can go on an aircraft. What we shall see today is when you have this kind of a complicate completed engine installed on an aircraft, and flown the performance of the engine does not quite match that of what has been designed for. The installed performance of an engine quite often comes out to be somewhat different, and more often the not it somewhat falls short of the requirement of flying of the aircraft satisfactorily.

Now, this is a known phenomenon this happens with civil aircraft engines, which are meant for transport or passenger, this happens even more for military aircraft engines because there are number of issues here, where the installed performance of engine quite often differs from that of a well designed engine. We have seen in the case, when we were discussing very briefly about the sizing of the engine the component that need to be sized to begin with the intake and the nozzle, and we shall see today that after this sizing is done when the installed performance is estimated or when an engine is flown they may need to be resized, and this is something which needs to be estimated properly.

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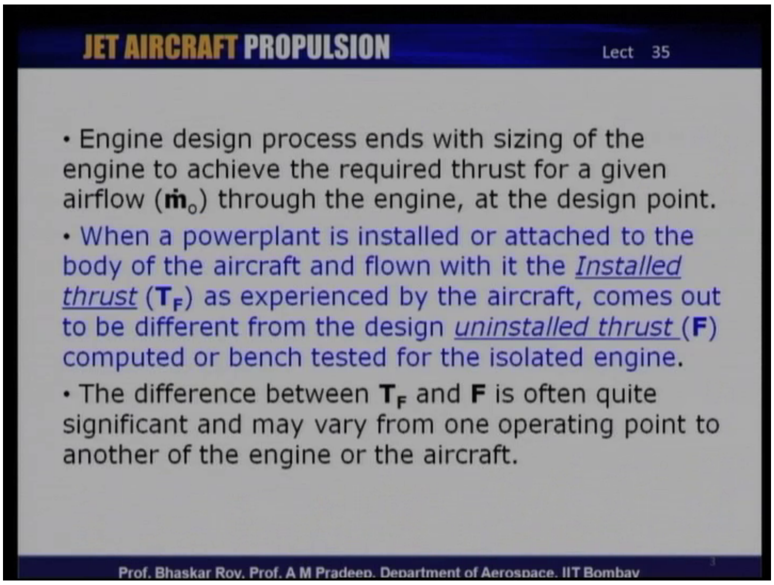

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- Engine design process ends with sizing of the engine to achieve the required thrust for a given airflow ($\dot{m}_0$) through the engine, at the design point.
- When a powerplant is installed or attached to the body of the aircraft and flown with it the *Installed thrust* ($\mathbf{T_F}$) 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 $\mathbf{T_F}$ 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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Let us take a look at what are the issues involved. The engine design process using some of the theories that we have done in this lecture series. It sort of comes to an end with the sizing of the engine to achieve the design thrust, and in the process of that we have arrived at a certain air flow mass flow through the engine at the design point which matches that of the aircraft operation at that particular point.

Once this is over we have some idea what was size of the engine, and the geometry of the engine should be, so accordingly when a power plant is installed or fitted to an aircraft, and flown with it, and this is often called the test flying of an engine; what happens is the installed thrust as experienced on board the aircraft comes out to be different from the designed uninstalled thrust.

Now, this design uninstalled thrust may have been very meticulously computed or even been bench tested in a test bed for the isolated engine even after those procedures are over, and one is satisfied that one is getting the design thrust this still remains the uninstalled thrust. Once it is attached to the aircraft, and flown with it the test flying often revels certain issues, and as a result of it the uninstalled thrust often comes out to be different from the installed thrust.

The difference between this installed thrust T F, and the uninstalled thrust which we have always called F is often quite significant. It is it could be significant at the design point, and when it is flown we also get to know its performance at various of design points and as a result we shall see that they vary from one operating point to another of the engine or of the aircraft.

If that is significant if this difference is significant we need to understand that the aircraft will never be able to fly in it is scheduled manner with this engine in case of a military aircraft this is quite catastrophic really, because the military aircraft are design for much more accurate flight spectrum, and if the thrust fall short of the design thrust for the aircraft the aircraft will never be able to carry out it is mission. As a result of which, a certain amount of estimation or understanding of what installed thrust is, and what an overall installed performance of an engine is is required to be carried out before the engine is finalized, and fabricated for flying.

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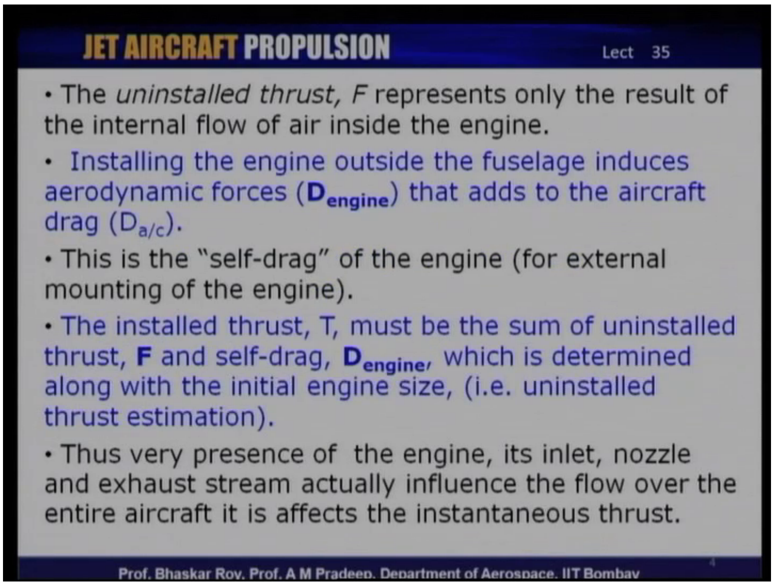

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- The *uninstalled thrust, F* represents only the result of the internal flow of air inside the engine.
- Installing the engine outside the fuselage induces aerodynamic forces (**$D_{engine}$**) that adds to the aircraft drag ($D_{a/c}$).
- This is 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, **$D_{engine}$**, 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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So let us take a look at some of the issues that are involved here. The uninstalled thrust or the thrust design thrust as we have called it before represents the results of the internal flow of air inside the engine. So, all aspects of the internal flow of air and after it is mixed with a fuel will often call it gas inside the engine through the various components of intake and compressor, and then combustion chamber where fuel is added, and then turbine, and nozzle have been done in some detail in this lecture series. All of that put together gives us a reasonably accurate notion of what the design thrust would be…

So, what we see now is this design thrust is essentially an uninstalled thrust. The installing of the engine if it is amounted outside on the fuselage induces certain aerodynamic forces which we often call drag, and this adds to the aircraft drag itself. So, there is something like an engine drag which adds to the drag of the aircraft which the aircraft designer may have computed very meticulously, and now this engine drag also comes into effect, which means that the thrust that needs to be created now is not only to over craft the aircraft drag which we call here D a c, but it has to also overcome it is own drag which we call now D engine.

And this is the cell drag of the engine and of course, we are talking about external per mounted engines we shall see later on that engines that are mounted inside also have a few such issues involved. So, what we see now is that the installed thrust must be the some of the uninstalled thrust F, and the self drag D engine, and this D engine needs to be determined along with the initials engine size.

So, we have a sizing that has been done of the uninstalled engine what we shall see as we go long today is that the engine would probably need to be resized, thus the very presence of the engine it is inlet, and nozzle which are the protruding elements or which are the covering of the engine. And the exhaust stream that comes out from the back of the engine influence the flow over the entire aircraft; depending on where the engine is actually mounted in the aircraft, and it affects the instantaneous thrust or a momentary thrust at the time of its flying.

So, what we see now is number of issues are involved here, which influences the instantaneous thrust created by the engine. So, what we see now is that a number of issues where once the engine is mounted, it is physical presence on the aircraft create certain differences with the design thrust, and hence the instantaneous thrust or the thrust obtained at the point of operation of the engine, and the aircraft needs to be taken into account as far as possible for a possible resizing of the engine.

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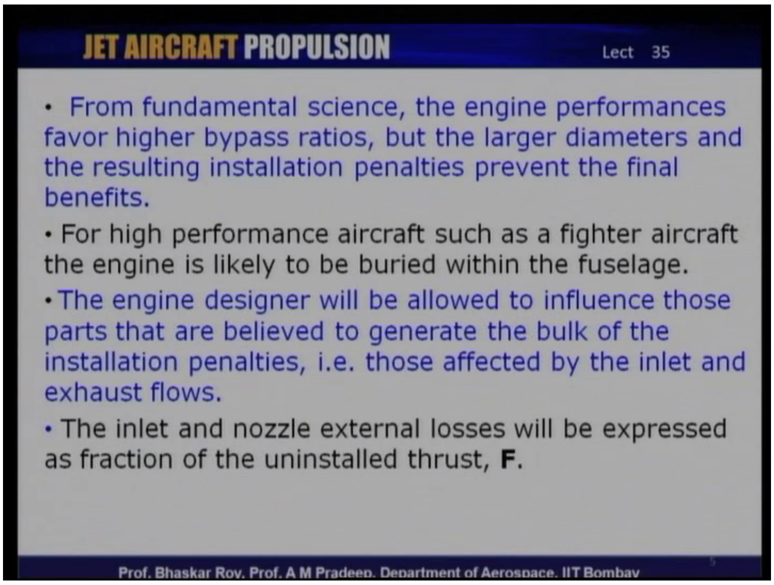

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- From fundamental science, the engine performances favor higher bypass ratios, but the larger diameters and the resulting installation penalties prevent the final benefits.
- For high performance aircraft such as a fighter aircraft the engine is likely 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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We have seen in the in this lecture series, that typically the modern aircraft engines specially the ones which are used for civil aircraft engines they often favor high bypass ratio. Now, we have seen number of issues earlier in this lecture series that higher the bypass ratio lower is the specific fuel consumption, and hence its economic to have high bypass ratio engines.

Now, it stands to reason that high bypass ratio engines would also have larger diameters and of course, they would have resulting installation penalties that we are talking about now, these installation penalties we shall see that prevent the final benefits that mean the benefits that you get from the high bypass ratio. So, if you have larger diameters it stands reason that they will produce more of self drag or D engine, and if you have more of D engine the engine itself would be called upon to create more thrust to overcome it is own drag.

So, higher the bypass ratio higher is this particular issue of self drag, and the need for creating more thrust by itself. Research has been done on this issue, and it is been found that after a certain high by bypass ratio an externally mounted engine reaches a certain point of diminution return, and there would be no point in increase in the bypass ratio any further. On the other hand, if we have a fighter aircraft or a military aircraft, where it is most likely the engine would be inside the fuselage of the aircraft. The effect of installation would be somewhat different we shall have a look at some of those issues, where some of the effects of the installation would have some small adverse effect on the thrust creating capability of the engine.

Now, what the engine designer needs to do is he needs to have some idea about these installation effects, and in which case he can then influence the design with this prior knowledge of the installation effect he can go on to resize the engine, and the installation penalties that we are talking about needs to be factored into the engine redesigned, and resizing. So, what we see now is that a number of issues which would require the engine to be finally, redesign notably some of the component that we have talked about in the recent lectures the inlet, and the nozzles and the corresponding exhaust flows. These are the once that effect the instantaneous thrust, and these are the components which would probably need to be looked into little more closely.

We have talked about the fact that the inlet is quite often designed not only with reference to the engine, but quite often with reference to the aircraft itself which means that if you have an engine used for different aircraft that aircraft may have a slightly different inlet or intake design.

Now, these are some of the issues that the engine designer would finally, have to factor in to get his final engine design. Also there are issues here which are aerodynamic issues not only just geometrical reconfiguration the inlet and the nozzle aerodynamics of the flow which is just before, the inlet or just after coming out of the nozzle influence the thrust creating capability of the engine the net thrust. The net thrust that goes on to the effect of flying the aircraft, so that net thrust gets affected by some aerodynamics that are happening in front of the inlet or intake and at the jet of the nozzle some of these need to be factored in with reference to the particular intake for a particular aircraft, because some of these things are a little aircraft specific and not only engine specific.

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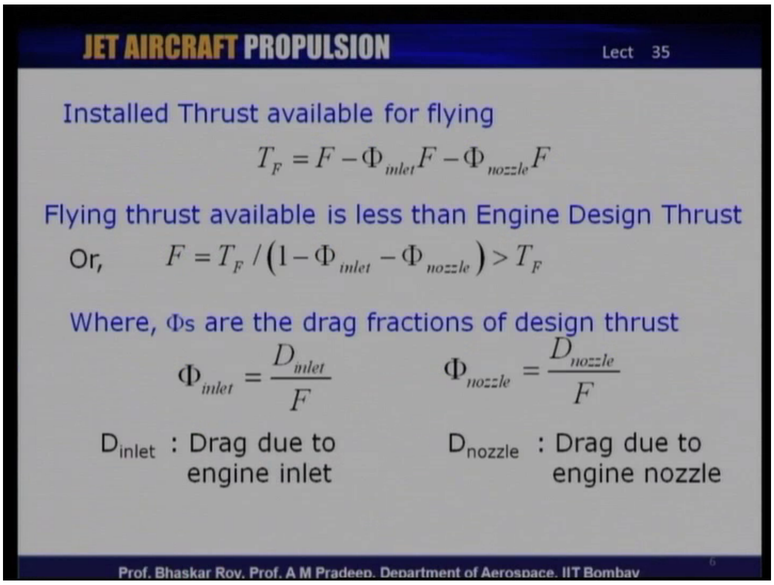

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Installed Thrust available for flying

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

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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Let us take a look at some of these issues the installed thrust that is available for flying now needs to be re-estimated, now that is going to be as we see here likely to be a little less than the so called design thrust, that had been meticulously arrived at and this is factored in by a couple of parameters that we are introducing here; one is called 5 inlet and other is called 5 nozzle, and these are what is called drag fractions. That means these are part of the drag created by the inlet, and the nozzle and fractions of the design thrust the original design thrust, and we shall see that if these are estimated or if these are made available or computable they would allow us to show that the design thrust often is fall short of the take off thrust or the necessary thrust of the engine, that is required for the aircraft to fly and as a result of which the engine design thrust would need to be reconfigure to higher values - and this higher value. Now, factors in the drag fractions 5 inlet and the 5 nozzle. So, we need to we see that the engine now needs to be redesigned with reference to a new engine design thrust, otherwise it is going to fall short of the required thrust.

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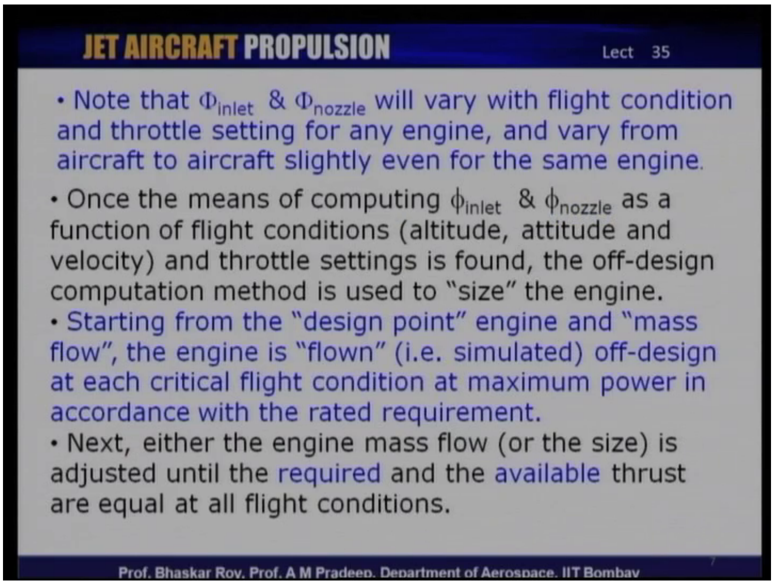

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- Note that $\Phi_{inlet}$ & $\Phi_{nozzle}$ will vary with flight condition and throttle setting for any engine, and vary from aircraft to aircraft slightly even for the same engine.
- Once the means of computing $\phi_{inlet}$ & $\phi_{nozzle}$ as 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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If we look at the 2 drag fractions that have been introduced here, it stands to reason that the true drag fractions the 5 inlet, and 5 nozzle would vary with fly condition and throttle setting of any engine. And it varies from aircraft to aircraft slightly even for the same engine and this is what we are talking about that if you put a let us say the same engine on 2 different aircraft, you would invariably get 2 different installed thrust requirements, because the 5 inlet specifically 5 inlet and may be even 5 nozzle will vary from one aircraft to another for the same engine.

So, we need to figure out a means of computing 5 inlet and 5 nozzle as a function of flight conditions. Now flight conditions include the altitude at which the aircraft is flying the attitude at which the aircraft is flying, which means it may be a climbing flight and not necessarily a cruse straighten level flight and the velocity at which it is flying the altitude of course, would give us the pressure and temperature at that altitude.

And in addition to the flight conditions we would need the throttle settings of the engine; that means the throttle setting that is exercised by throttling the nozzle of the engines typically, and these are the parameters that would influence 5 inlet and 5 nozzle. And many of these parameters are with reference to what we have been calling off design condition of the engine, and now we see now that many of these off design conditions refer not only to the off design of the engine but they often refer to off design of the aircraft.

So, as we see now when we are trying to figure out the uninstalled installed thrust with reference to uninstalled thrust, it is not only the engine, but often the aircraft is also coming into the picture and the resizing that needs to be done now factors in the various flight conditions of the aircraft.

So, we need to figure out the flight conditions of the aircraft we need to figure out the throttle settings of the engine and then find the installed thrust, so that we can resize the engine the number of things that need to be done is we start we have started with a design point. We first what did we do we first figured out what the design point is what the design point thrust requirement is we tried to design the components of the engine with reference to the so called design point, we match the components with reference to the design point, and we size the engines with reference to the design point, and after doing all this when we tried to put the aircraft and the engine together we find that the whole engine needs to be slightly resized.

This needs to be done, because as I mentioned earlier there is quite often a significant difference between the installed thrust, and uninstalled thrust and as far as possible this needs to be met before, the engine and aircraft actually starts flying on a regular basis each critical flight condition needs to be found out.

Now, some of the critical flight conditions of course, we know the take of condition the climb condition, if there are maneuvers necessary for military aircraft, we need to factor them in where there are dives and a pull outs, and those are the conditions at which the engine needs to be resized till we get the maximum power or the thrust in accordance with the requirement of the engine of the aircraft.

Our final goal is to make an aircraft fly to it is mission to it is actual purpose, and to do that it is necessary that the engine itself is very finely tuned to the needs of the aircraft one of the first things. Why we need to look at is what is the amount of air flow? What is going inside the engine, because that is what makes the thrust airflow that goes inside the engine is the working medium through which the thrust is produced.

So, the first thing we need to ensure is that the engine air mass flow is what is going inside the engine, and there is no miss match between what is required to create the necessary thrust and what is available for creating the thrust. So, this different between requirement and availability needs to be looked at very closely, and this needs to be done under all flight conditions now that is the important issue.

If you put a engine which is been designed meticulously at a design point, and fly it with an aircraft whether it meets all the flight conditions needs to be looked at very closely, because under all flight conditions it should match the thrust requirement otherwise one or the other flight condition will not be performed according to the design of the aircraft. So, if the engine does not create the necessary amount of installed thrust with the aircraft; the aircraft itself will fall short of it is performance requirement of its own design.

So, these are the issues that we need to look at very closely, let us move forward and look at some of the issues.

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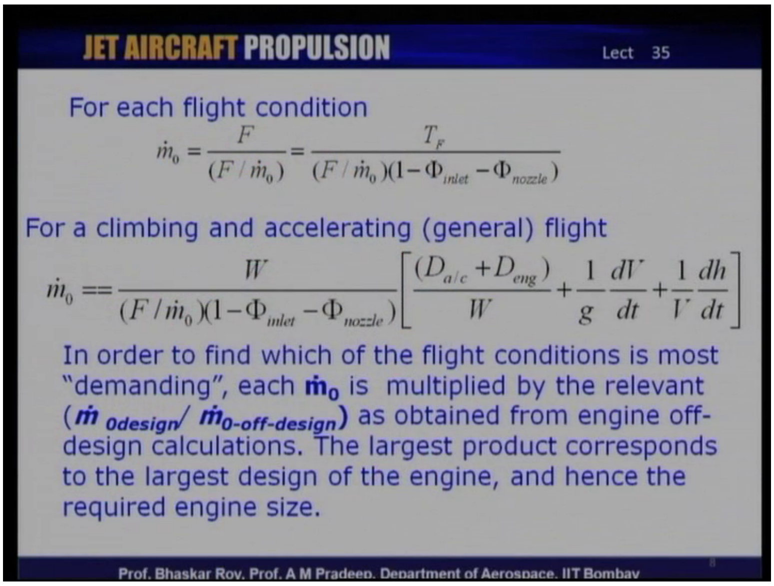

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For each flight condition

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

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 $\dot{m}_0$ 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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The first thing as I mentioned we need to look at what is the mass flow of air that is going inside. So, if we look at the mass flow of the air we see that it gets slightly redesigned or reconfigured with the change of the requirement of thrust from F to T F, that is from design thrust to the installed thrust, and here the 5 inlet and 5 nozzle the 2 drag fractions have been now factored in and having factored them in we get a new mass flow that needs to be allowed inside the engine.

Now, this needs to be done for each flight condition, if we take a climbing and accelerating flight as a general description of a flight condition or generalized description of flight condition M dot 0, that is the mass flow through the engine can be written down in terms of the weight of the aircraft, the instantaneous weight of the aircraft, the drag of the aircraft, the drag of the engine, the velocity of the aircraft. And the engine and the height at which the altitude at which it is flying or if it is experiencing a climbing flight and then of course, the drag fractions that we have defined, and introduced just a little while earlier.

Now in order to find each of the flight condition which of them is most demanding is needs a is needed to be founded out a priory as early as possible. So, each of these mass flow condition in needs to be multiplied by a relevant M dot design by M dot off design, because most of the flight conditions are indeed off design only one of them is a design point, and hence all those flight conditions which we are considering would have such a mass flow ratio off design to off design.

And this can be obtained from the detail engine off design calculations. We have done this before and the engine off design calculations need to be brought forth again for the purpose of estimating the installed performance.

The highest of these the largest product which corresponds to the largest design of the engine now comes out to be the required engine size. So, if you create an engine to meet the maximum performance that would be the largest size of the engine, and would be required for flying the particular aircraft. The question is whether this lager size of the engine is what you would like to have on one hand, if you do not have that size of the engine you do not get the thrust which is required at the most demanding flight condition, on the other hand at many other off design operating conditions you probably do not need that large engine.

So, this is where the decision needs to be taken whether the demanding condition is very critical demanding condition, if it is you would need to then go for that engine. And then of course, under off design conditions you need to throttle down the engine bring down the rotating speed of the rotating components, so that the engine gives you lesser amount of thrust with the same big sized engine.

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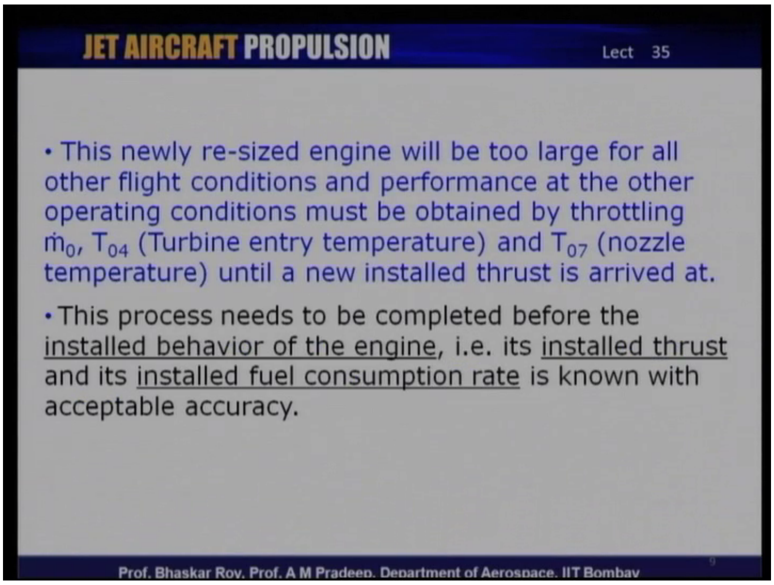

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- This newly re-sized engine will be too large for all other flight conditions and performance at the other operating conditions must be obtained by throttling $\dot{m}_0$, $T_{04}$ (Turbine entry temperature) and $T_{07}$ (nozzle temperature) until 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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So, the resizing of the engine that we are talking about now comes out of the most demanding condition of the flight as it is installed on an aircraft. What happens is as I was saying this resized engine could very well be a little too large for all flight conditions, and hence the performance at other conditions quite often is obtained by throttling the engine which is the mass flow is brought down to lower values. Then you can bring down the turbine entry temperature, then you can bring down the nozzle temperature, if it is an after burning engine you may like to switch off the after burner, and until a new installed thrust is arrived at for flying the aircraft at that particular operating aircraft flying condition.

Now this process needs to be done meticulously before the installed behavior of the engine or the installed thrust, and it is instantaneous fuel consumption rate is known with certain amount of accuracy.

So, the installed behavior of the engine includes installed thrust and installed fuel consumption rate and this need to be found out as accurately as possible so that, you can have a close matching between the engine and the aircraft.

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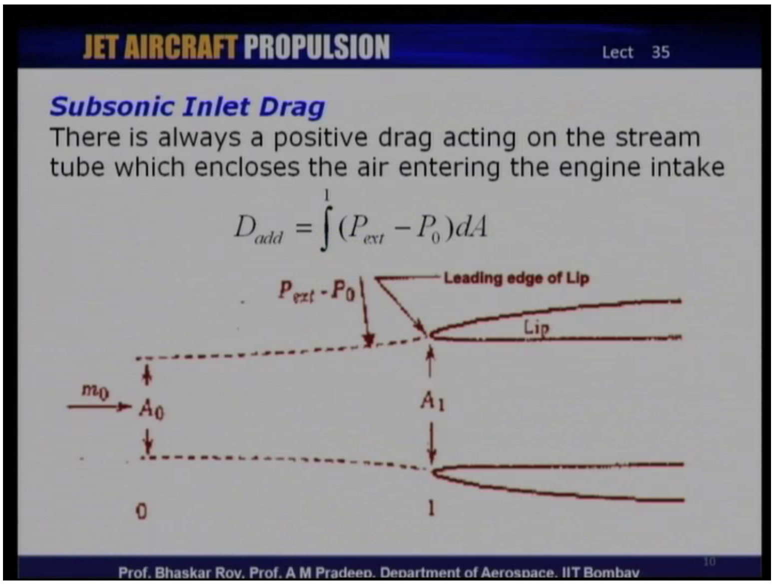

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**Subsonic Inlet Drag**

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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Let us take a look at some of the factors that govern the installed engine, when air is entering an intake, if we consider a to begin with a subsonic intake even before the air has entered the intake, because of the shape of the stream tube that it automatically takes before it enters the intake the pressure, that is shown here acting as P external minus P 0 P not being the pressure inside the stream tube, and this is quite often called the over pressure on the flow that is coming into the intake this.

Because of the shape of this stream tube, that it has a automatically taken shape it often means that if you integrate the all the over pressure over this shape of the stream tube, you would probably get a drag or a force which is acting in the direction parallel to the axis of the engine. And this is often an additional drag which comes out due to the over pressure of the stream tube that it automatically take shape.

Now, this is typically what we are seeing is a typical situation that happens probably during straight, and level flight during cruse a during takeoff, and many other operating conditions the stream tube, that it takes quite often could be extremely different quite different from this and under certain situation. For example, during takeoff the flow coming in would be accelerating flow, and would not be a slightly diverging or diffusing flow as we see here, and in that situation the problems that are encountered by the intake system is quite different from what we are looking at now.

So, now we are looking at a straight and level flight during which it looks that, if the stream tube takes this kind of a shape in which as we see. Now A 0 the far upstream stream tube diameter or area is slightly less than that of at the intake phase. You would end up getting a drag which is known as additive drag.

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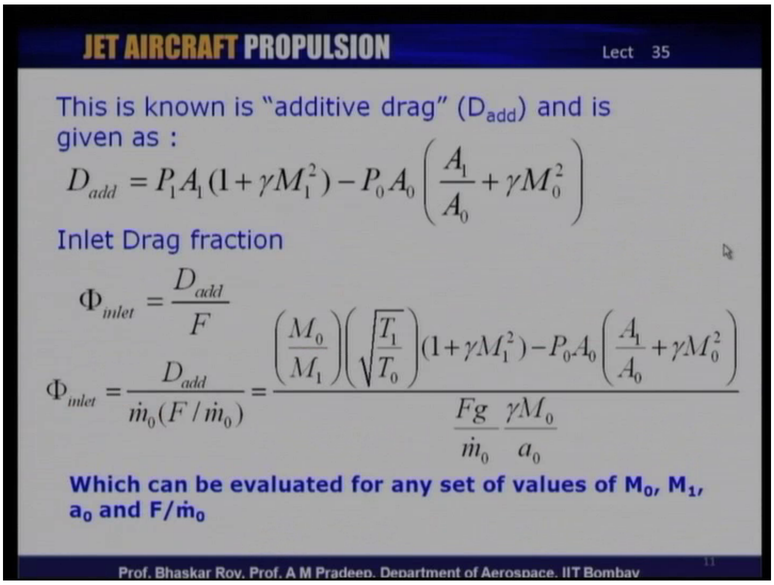

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This is known is "additive drag" ($D_{add}$) and is given as :

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

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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Now, if we to factor in this additive drag we can talk in terms of the parameters that the stream tube typically experiences the pressures P 0 and P 1, the areas A 0 and A 1 and of course, the mach numbers at station 0 and 1. And we can figure out at least theoretically a reasonable idea or notion of what this additive drag is going to be, and the point is this additive drag is happening even before the flow has entered the engine.

You have done in great detail what happens inside the intake what happens in other components of the engine, but this is happening outside the intake even before the flow has gone in the aircraft engine combine is experiencing an additive drag.

So, the inlet drag fraction, now takes a another shape that the additive drag essentially creates the inlet drag fraction this can now be written down as we have been doing with reference to the fundamental parameters the 2 Mach numbers the temperatures, and the areas, and the pressures at these stations before the intake system.

Now, this can be evaluated for any given set of values for M 0, M 1 A 0, which is the sonic velocity, and the thrust by a mass flow that is specific thrust as we have called it earlier. Now these are the issues that finally, determine what the inlet drag fraction is going to be and as we see this is happening before, the flow actually even enters the intake.

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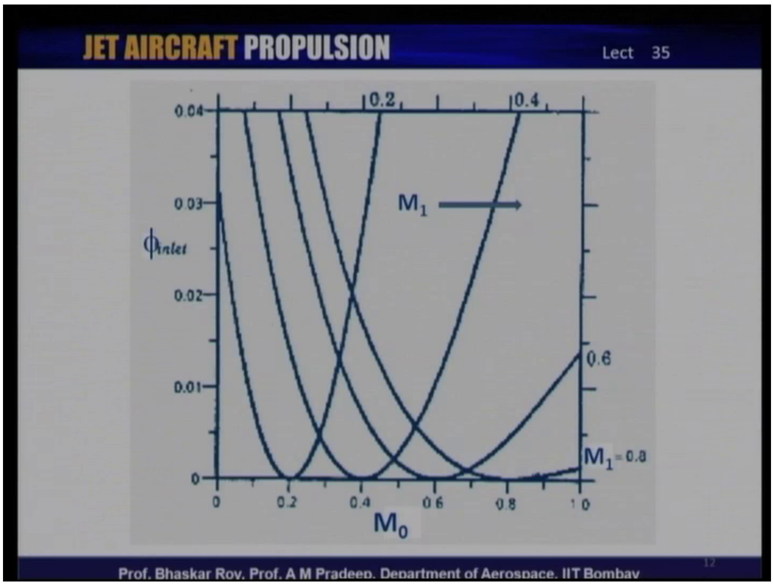

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If we try to plot this inlet drag fraction with reference to the two important parameters the Mach number upstream, and the Mach number at the inlet face. We see a typical pattern that emerges from which the inlet drag fraction can be computed a priory which means, if the two mach numbers available from the theory that we have established a certain inlet drag fraction can be computed or found out, and this can be factored into the installation of the engine.

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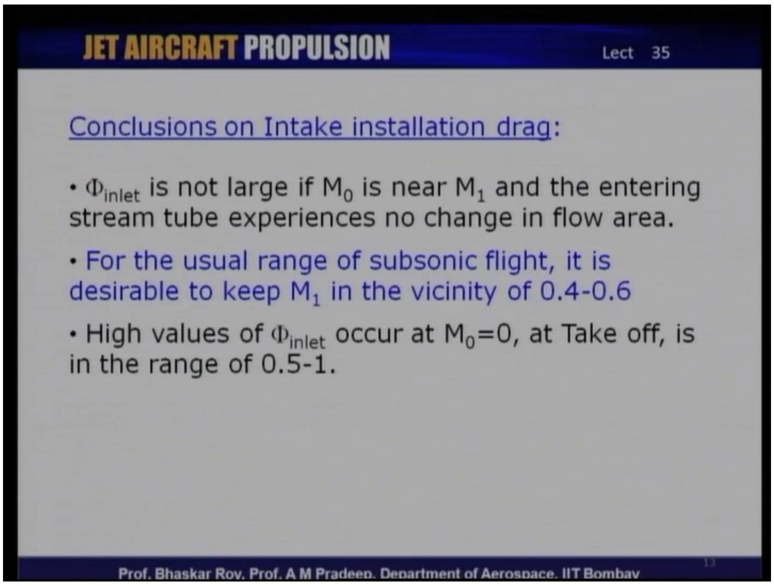

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Conclusions on Intake installation drag:

- $\Phi_{inlet}$ 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 $\Phi_{inlet}$ occur at $M_0$=0, at Take off, is in the range of 0.5-1.

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So, what we learn from this intake installation is that the drag fraction phi inlet is not very large if M 0 is almost equal to M 1, and that the entering stream tube experiences no change in flow area that is A 0 is equal to A 1.

In such a situation as we have seen before it stands to reason, if you look at the earlier diagram, that if a not is equal to A 1 this shape is going to be a cylindrical flat cylindrical shape, and hence the installation drag would essentially be 0 or pretty close to 0.

The other thing is that the usual range of subsonic flight which is a normally of the order of a point 8 the value of M 1, that is at the inlet face or intake face is often of the order of point 4 to 0.6 which means a certain amount of a pre diffusion we call it before, it enters the intake may be allowed to happen. The high values of phi inlet occur at mach number 0, that is a takeoff and it is in the range of point 0.5 to 1. Now, as we have seen this is not due to the diffusive flow that we have seen in the picture, but it is due to highly accelerating flow that enters the engine from all sides to cater to the engine mass flow requirement, and in the process it creates a very large 5 inlet during the process of take off.

So, these are the issues that the engine designer would need to reconsider to create engine, that needs its installed thrust requirement as closely as possible. Let us take a look at what happens when you have a supersonic intake.

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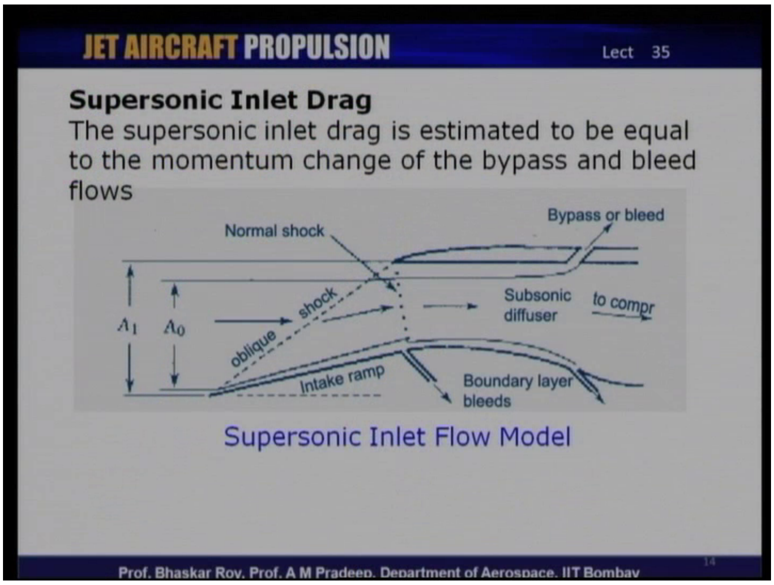

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**Supersonic Inlet Drag**

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

Supersonic Inlet Flow Model

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The inlet drag fraction that we have been talking about for supersonic inlet can be estimated from the momentum change that takes place due to the bypass, and the bleed. Now these bleeds we know and you have done in case in your lecture series that these are often required for various engine purposes, and when all these are factored in certain amount of supersonic inlet drag essentially comes through which needs to be factored into the resizing of the engine, and essentially are those things that come out of the installed engine performance.

Now, as we see here typical supersonic inlet flow model would give you at least one oblique shock, and then you might have a boundary layer bleed to control the inlet flow, and then you may have a bypass or a bleed which may be required for engine servicing or many other purposes within the engine or the aircraft. And one of the bleeds a may be occurring during the flow inside the intake which is supersonic at the other of the bleed may be occurring when the flow inside the intake is actually subsonic.

Now, if these bleeds are essentially been made to control the mass flow through the intake, and through the engine they would entail certain amount of a drag penalty when they come out from the size sides of the engines. And these are the drag penalties that need to be factored into resizing of the engine, because these drags would bring down your thrust calculation, and hence the installed thrust would be less than that of the design thrust.

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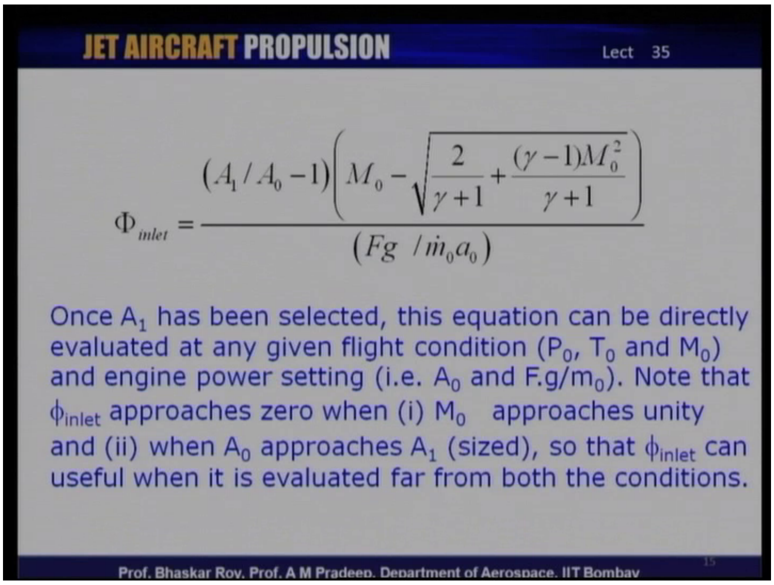

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$$\Phi_{inlet} = \frac{(A_1/A_0 - 1)\left(M_0 - \sqrt{\frac{2}{\gamma+1} + \frac{(\gamma-1)M_0^2}{\gamma+1}}\right)}{(Fg\ /\dot{m}_0 a_0)}$$

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 $\phi_{inlet}$ approaches zero when (i) $M_0$ approaches unity and (ii) when $A_0$ approaches $A_1$ (sized), so that $\phi_{inlet}$ can useful when it is evaluated far from both the conditions.

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The typical supersonic drag fraction inlet drag fraction can be written down again in terms of the areas, that we have looked at the Mach number, and of course the A 0 or the local speed of the flight.

Now, once this value of A 1 has been selected the intake area, we can use this theoretical derived equation directly into evaluation for any flight condition what the drag fraction should be… So, once the flight condition is known that is the atmospheric pressure temperature and a mach number and the engine throttle setting or power setting that is the area of the intake, and the thrust setting we can find out what the drag fraction for this condition flight condition, and engine condition could possibly be and this theoretical finding can be factored into the inlet redesign or resizing.

Now what we see here that a when this drag fraction approaches value, it approaches a value 0 when M 0 approaches unity which is the sonic speed or when A 0 approaches A 1, which is a sized value, so which means that the drag fraction 5 inlet can be useful when it is evaluated far from both this conditions at these conditions the 5 inlet is likely to be theoretically determined to be 0.

So, under those conditions the drag fraction ah finding could be a little misleading for a installed thrust creation, so at other off design operating conditions the drag fraction that one gets out of this theory is likely to be reasonably accurate for installed performance evaluation.

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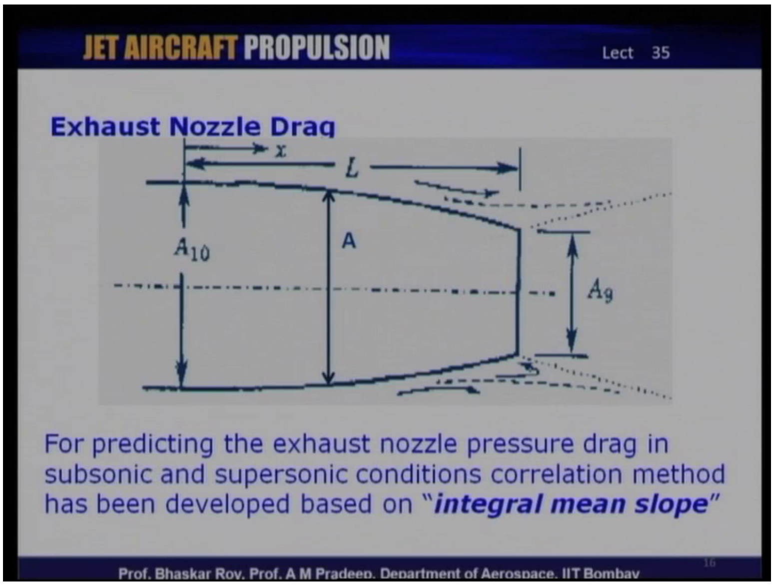

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**Exhaust Nozzle Drag**

For predicting the exhaust nozzle pressure drag in subsonic and supersonic conditions correlation method has been developed based on "***integral mean slope***"

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If we now look at the contribution of the exhaust nozzle to the installed thrust re-estimation, we see that a typically exhaust nozzle would have a certain contour you have done in great detail what is happening inside the nozzle. We will take a look at what is happening outside the nozzle on the outer surface of the nozzle, because for a engine to be created we need to know what is the shape, and dimension of a the nozzle external surface. And we see here, we need to figure out what the value of A 10 should be and what the value of A 9 should be because that is where the nozzle get's shaped, and then of course what the length of the nozzle.

And if we try to find out all that what happens is under certain conditions these nozzles would create, what is known as pressure drag under either supersonic or subsonic flight conditions, and one of the methods by which the shaping can be created is through a parameter called integral mean sloop which essentially defines the shape of the nozzle.

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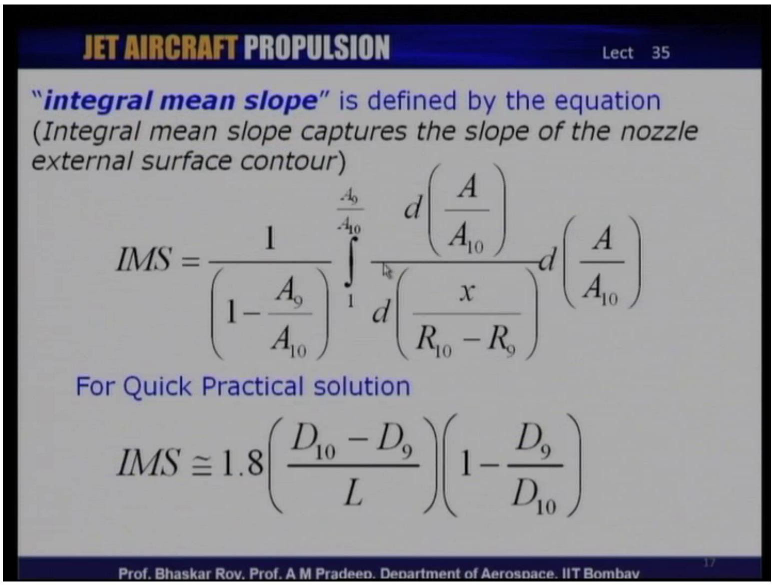

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"***integral mean slope***" is defined by the equation
(*Integral mean slope captures the slope of the nozzle external surface contour*)

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

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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Now, this integral mean sloop can be defined in terms of an equation which essentially takes into account the areas, we are talking about and the radii we were talking about and the length A is a area at any point on the intake length, and the integral mean sloop can be found at any point on this intake shape. So, A is at any point of the intake shape, and this can be A the integral mean sloop over here can be found using the simple definition that we have put down here.

For a very quick practical solution quite often integral mean sloop can be written down in terms of the diameters, and the length that one is being one is conceiving, and it gives a first cut notion of what the integral mean sloop is should be.

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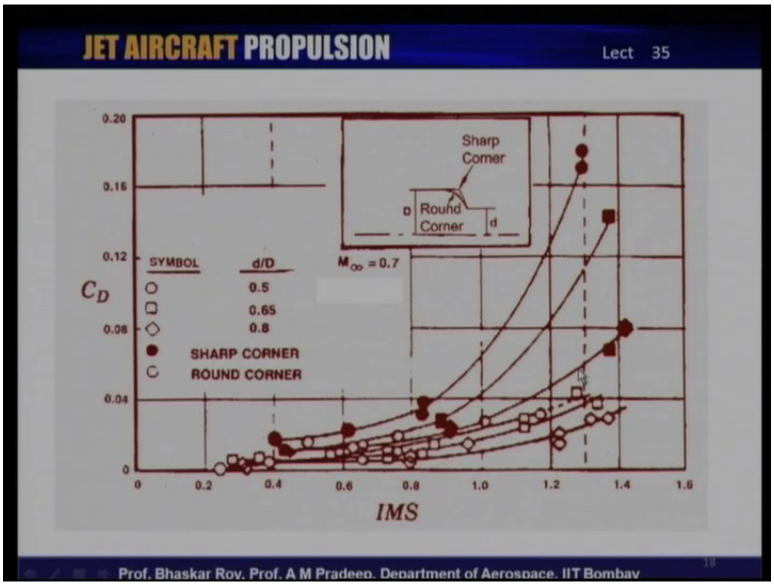

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If we put this integral mean sloop as one of the important parameters, what we see here is that a the drag that is created by this nozzle shaping can be connected to the integral mean sloop or IMS and it is dependent on the shape of the outer shape of the nozzle.

Now, the number of nozzle shapes have been factored in here we can have a rounded corner or we can have a sharp corner, and the plots have been created here for sharp and a rounded corner. The sharp corners are once with a filled out a symbols, and the rounded corners are one once with a hollow symbols, and we can see here what stands to common sense that the rounded corners would have lower drags, and the sharp corners would have higher drags under different kinds of IMS values.

Now, sharp corner is something which is obviously then an avoidable thing, and if you have to create a rounded corner, and then the question is we have certain values of a small D by D which is the area ratio between the exhaust. And the supply a first area from which the flow ensues into the nozzle and this diameter ratio is one of the parameters that come out as an important issue in figuring out what the nozzle shape.

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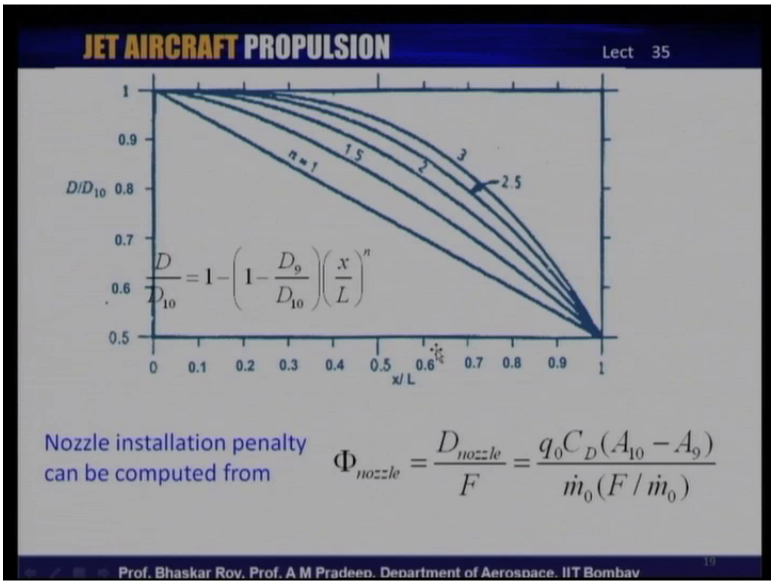

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$$\frac{D}{D_{10}} = 1 - \left(1 - \frac{D_9}{D_{10}}\right)\left(\frac{x}{L}\right)^n$$

Nozzle installation penalty can be computed from

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

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If we now look at the rounded shapes, we realize the rounded shape is better than the sharp shape. There are various ways the rounded shape can be factored in, and again if we look at the D by D ratio and factor that with the x by L; there are number of a rounded shapes n is the parameter here which is been plotted here. And one can find out what the shape should be and then one can find out what the nozzle installation penalty can be from this computation.

Now, these are the issues that engine designer would typically need to be aware of he needs to factor in what the nozzle external shape should be, and then he needs to figure out what the nozzle external shape should be if it is rounded shape which here has been shown in terms of the values of parameter n which comes out in the diameter ratio. And if this is available then we can figure out what the nozzle drag penalty is going to be, and then that gives us the nozzle drag fraction which can be then factored into the reconfiguration of the installed thrust of the engine, this gives us a this puts us together theoretical method of estimation of the nozzle drag fraction for a priory estimation of the installed thrust.

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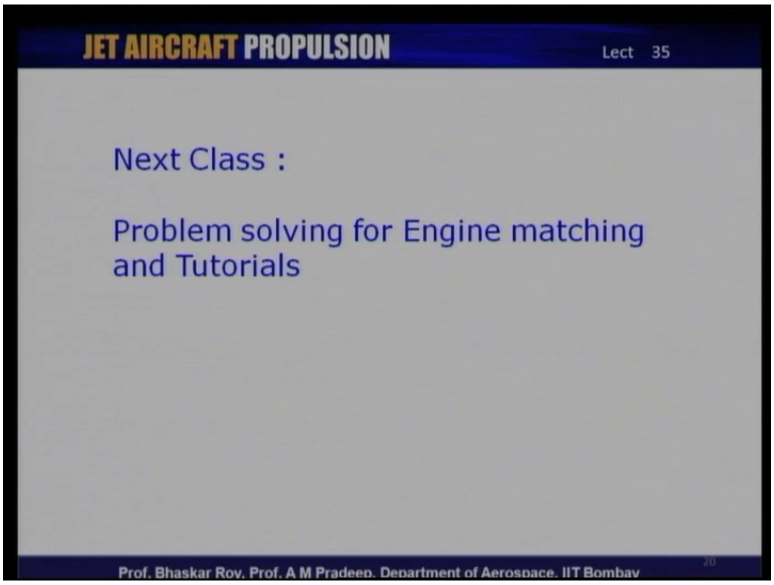

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Next Class :

Problem solving for Engine matching and Tutorials

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We will put together all these things in the nozzle, and in intake resizing which then tells us that if we do all this the engine would need to be resized, and the resized engine would eventually meet the thrust requirement of the aircraft under various flight conditions, and as we see the thrust requirement needs to be met under various flight conditions, and under various engine throttle conditions.

If we put them all together, and we put together this simple theory that we have introduced in this lecture it gives us an a priory notion of what the installed thrust reconfiguration would require, and what the engine resizing needs to be done, so that it meets the installed thrust under all flying conditions of the aircraft.

In the next lecture we will take a look at some of these theories that we have done over the last 3 or 4 lectures, and try to see whether some of these theories can be utilized to solve some practical problems that are typical to aircraft engine matching. So, in the next class we will try to solve some practical problems form with reference to aircraft engine matching.