Propellers and Ducted Fans

Lecture 5

Propellers vs. Ducted Fans

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Configurations

Open Propellers

The first, the most common and the most developed form of rotary-wing propulsion.

Shrouded Propellers

Specifically for low-speed applications, most often associated with sport aviation where it can bring additional safety benefits.

Ducted Fans

Most conducive to low-speed STOL and VTOL applications, often in embedded installations.

Also features in high-speed applications, typically turbo-fans where efficiency gains are available for transonic cruise.

Open Propellers

The most common form of propeller and the subject of all previous lectures in this unit.

Advantages:

- ✓ Most simple form of propeller
- ✓ Relatively insensitive to yaw and pitch
- ✓ Has little or no effect on aircraft lateral stability
- ✓ Noise !
- ✓ Affordable

Disadvantages:

- x Tip losses can be significant
- x Poor static thrust performance
- x Potential hazard to ground personnel
- x No containment in the event of "blade-off" failure
- x Noise !

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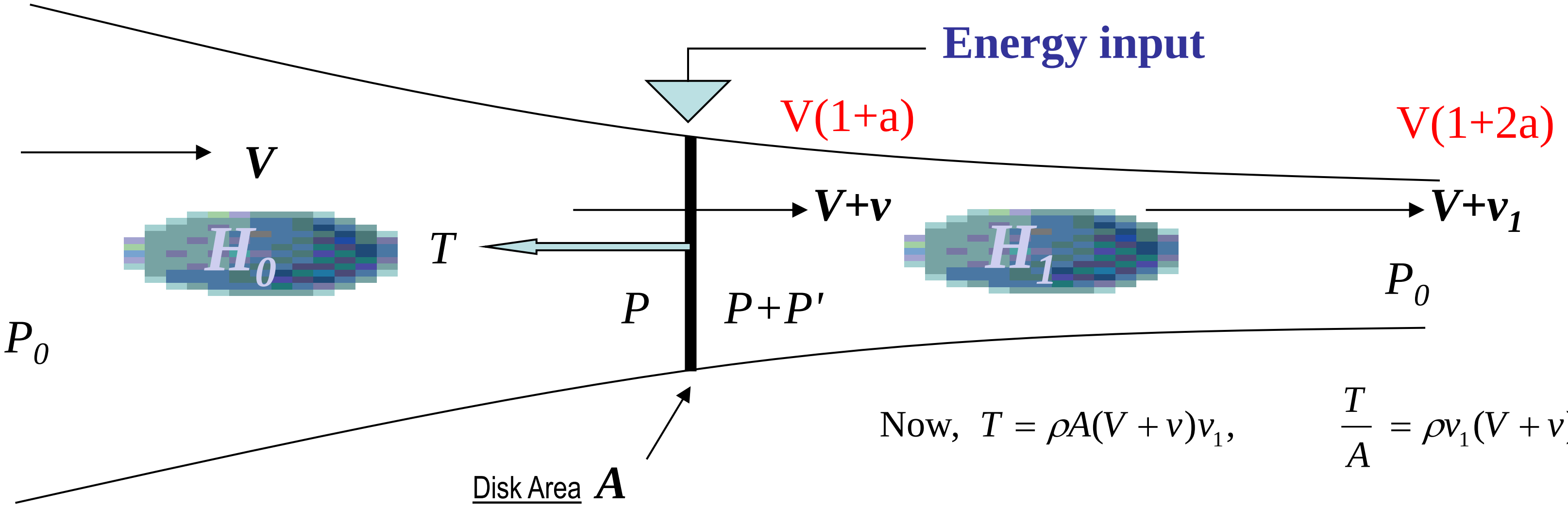
Tractor

Pusher

Tractor and Pusher

Open Propellers (Recall)



Now, $T = \rho A(V+v)v_1$, $\quad \dfrac{T}{A} = \rho v_1 (V+v)$

ρ Air density

A Disc area

$so\ \dfrac{v_1}{2} = v \qquad \therefore T = 2\rho A(V+v)v$

$$remembering\ \ that\ \ a = v/V$$

$$T = 2\rho A(V+v)v \ = \ 2\rho A V^2 (1+a)a$$

$$or\ \ (1+2a)^2 = 1 + \frac{2T}{\rho A V^2}$$

Open Propeller (Tractor propeller drag effects)

$$T = 2\rho A(V+v)v \;=\; 2\rho AV^2(1+a)a \quad (remembering\ \ that\ \ a = v/V)$$

$$or\ \ (1+2a)^2 = 1 + \frac{2T}{\rho AV^2}$$

The aircraft body (in wake) experiences this increased velocity *V(1+2a)* and hence the drag *D* which it would experience in a stream of velocity V is increased to a higher value D^*_{biw} according to the equation:

$$D^*_{biw} = D(1+2a)^2 = D\left[1 + \frac{2T}{\rho AV^2}\right]$$

Propulsive thrust T_P is the apparent thrust T minus the increased drag $(D^* - D)$ of the aircraft due to the interference of the propeller:

$$T_P = T - (D^* - D) = T\left[1 - \frac{2D}{\rho AV^2}\right]$$

Since the drag $D\ (and\ \ D^*)$ is proportional to the square of the velocity *V*, the propulsive thrust is a constant fraction of the apparent thrust. i.e. $\frac{T_p}{T} = constant$

Tractor

Pusher

"Propulsive Thrust" is a constant fraction of the "Apparent Thrust"

$$\frac{T_p}{T} = constant$$

This constant fraction is greater for the "Pusher" than for the "Tractor"

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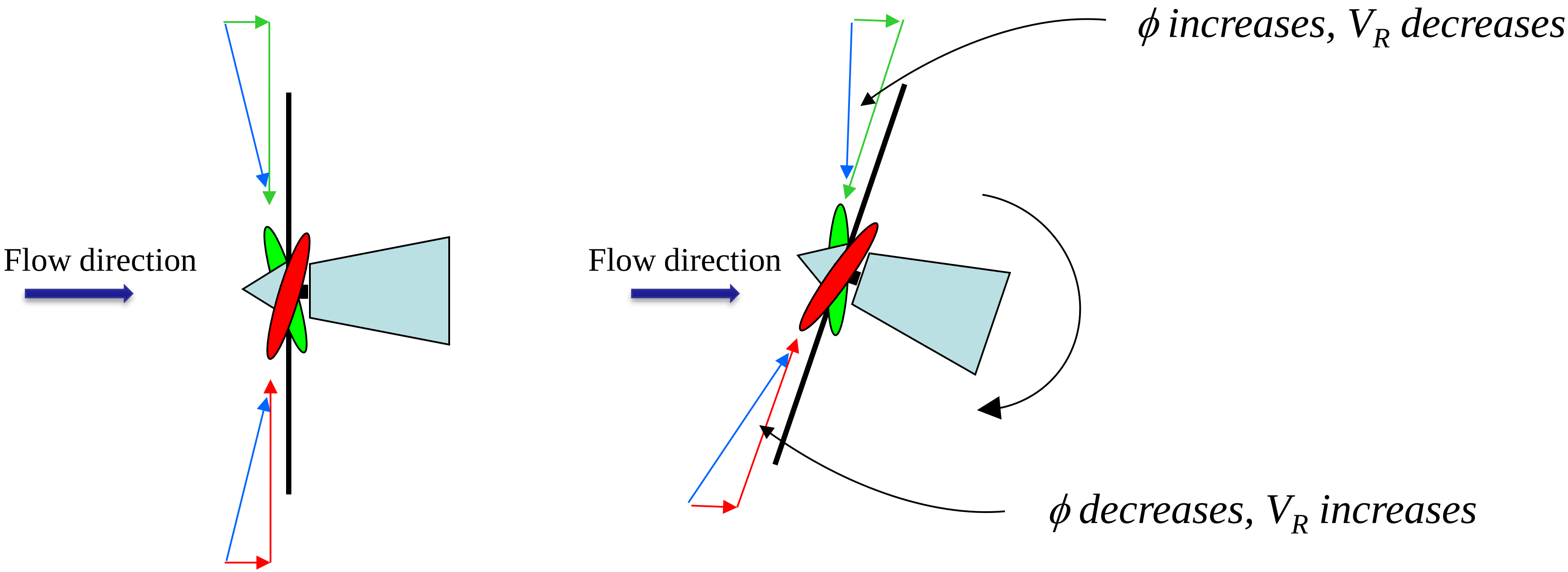

Cross-coupling, rather than destabilising - As the aircraft (and therefore propeller) pitches up or down, the flow into the propeller disk is subjected to asymmetric inflow which causes the propeller (and aircraft) to yaw to the right and left.

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Advantages:

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- ✓ Has little or no effect on aircraft lateral stability
- ✓ Noise ! (If lightly loaded and with “Q” tips)
- ✓ Affordable

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Open Propellers

You can easily make your own!

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- x Potential hazard to ground personnel
- x No containment in the event of "blade-off" failure
- x Noise ! (Particularly for close coupled "pusher" installations)

Shrouded Propellers

Gaining popularity in sport aviation. (Shrouded:- generally refers to a peripheral casing length that is substantially shorter than the propeller diameter)

Advantages:

- ✓ Tip losses significantly reduced
- ✓ Reduced hazard to ground personnel
- ✓ Static thrust greater than equivalent "open propeller"
- ✓ Relatively insensitive to yaw and pitch
- ✓ Has little effect on aircraft lateral stability
- ✓ Some containment in the event of "blade-off" failure
- ✓ Noise !
- ✓ Structural support for control surface

Disadvantages:

- x Lower static thrust efficiency than "open propeller"
- x Higher profile drag
- x Structural complexity

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Shrouded Propellers

Some protection from the spinning propeller but only marginal blade containment potential

Blade tip runs close to or even in slight contact with shroud

Fin / rudder supported in higher velocity field

Ducted Fans
(for Low Speed applications)

(Ducted:- generally refers to a peripheral casing stream-wise length that is close to the propeller diameter)

Advantages:

- ✓ Tip losses significantly reduced
- ✓ Reduced hazard to ground personnel
- ✓ Static thrust greater than equivalent “open propeller”
- ✓ Significant containment in the event of “blade-off” failure
- ✓ Conducive to thrust vectoring
- ✓ Noise !

Disadvantages:

- x Lower static thrust efficiency than “open propeller”
- x Very sensitive to pitch and yaw
- x May have significant effect on aircraft lateral stability
- x High profile drag
- x Structural complexity

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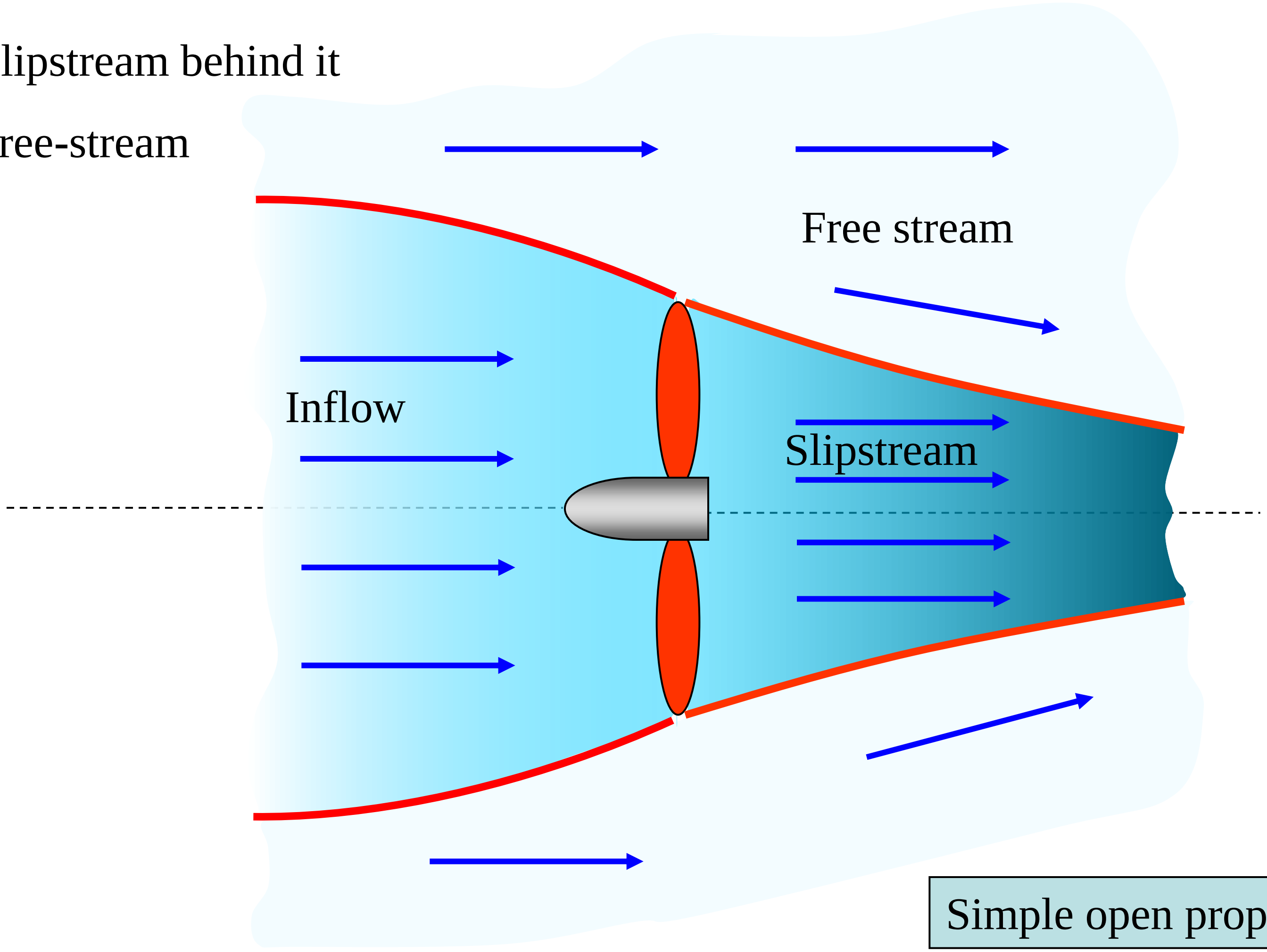
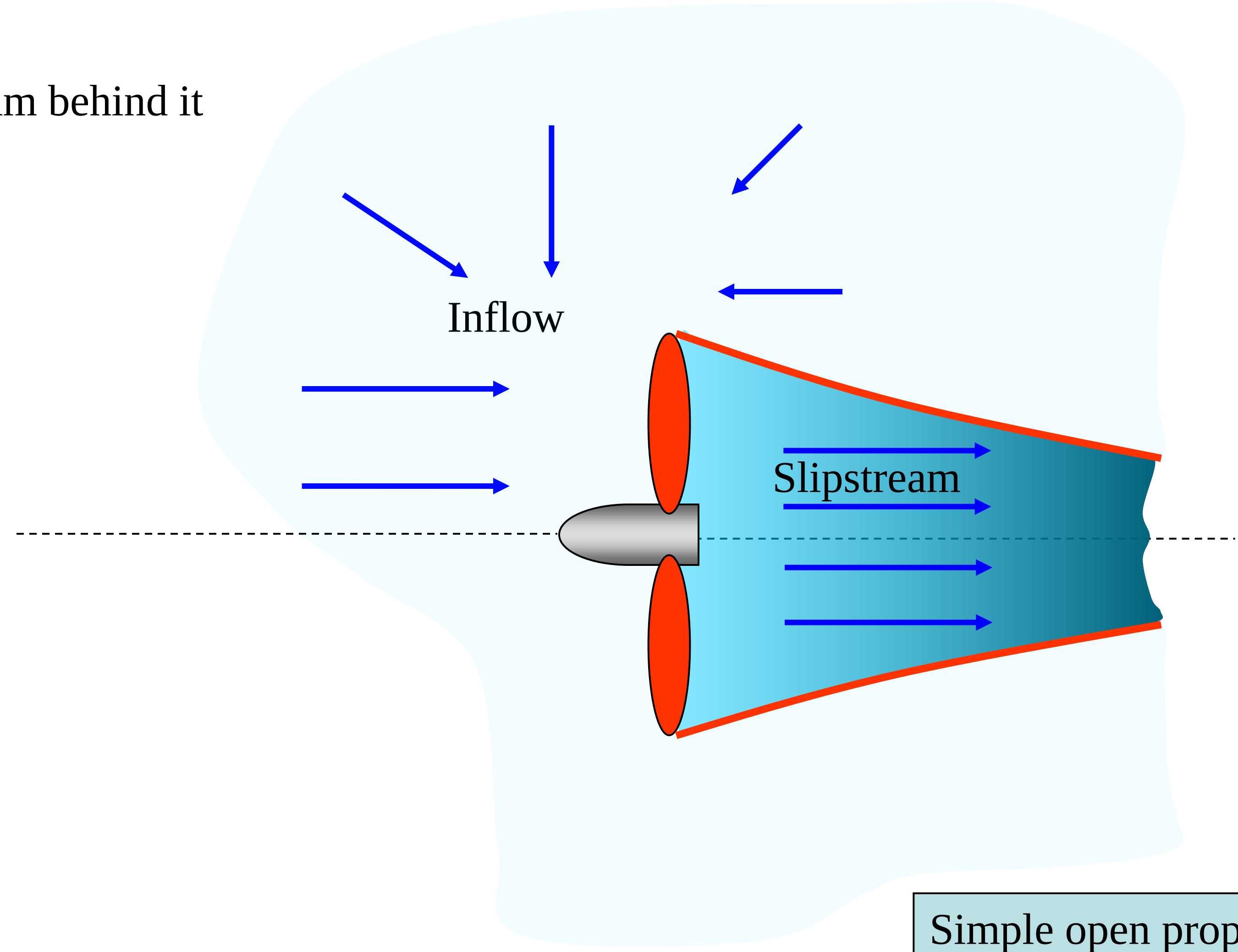
In steady cruising flight, the simple propeller has three distinct regions of flow:

- The inflow
- The slipstream behind it
- The free-stream



In static conditions, say prior to take-off there are only two flow regions:

- Inflow
- Slipstream behind it



Simple open propeller

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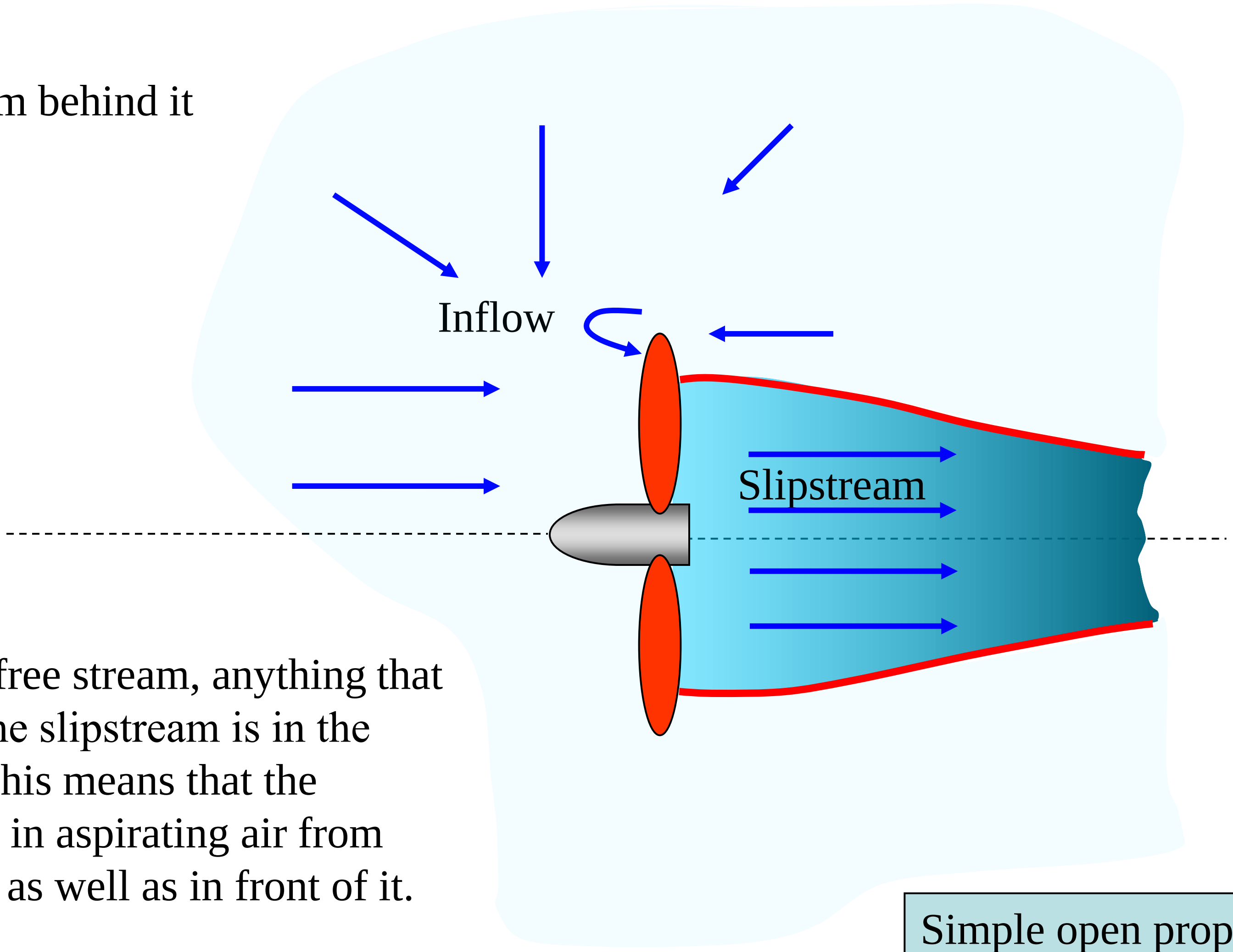


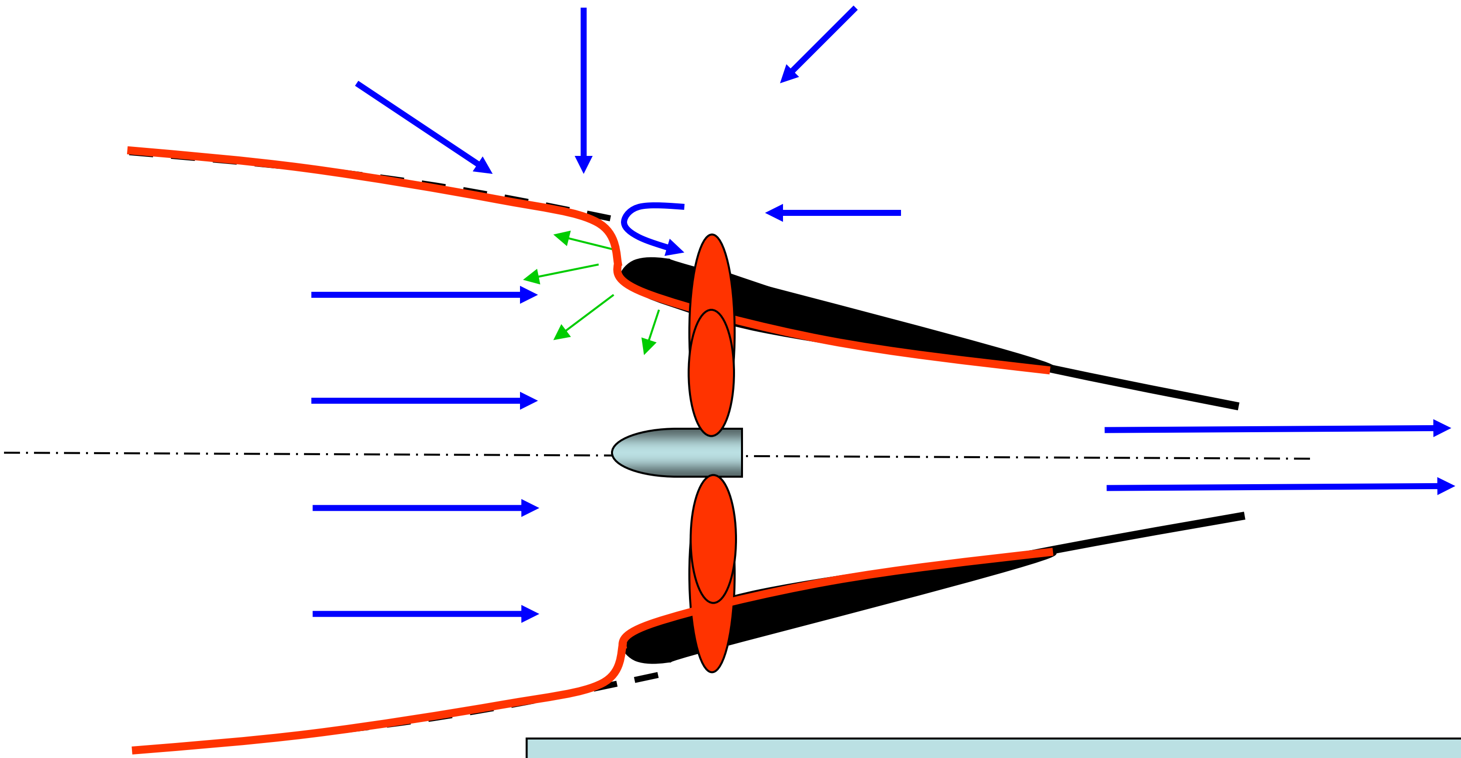
With no free stream, anything that isn't in the slipstream is in the inflow. This means that the propeller in aspirating air from behind it as well as in front of it.

Simple open propeller

For the ducted fan in static conditions, the solid boundary effectively presents the propeller with a flow not dissimilar to low speed cruise**:** a flow in just one direction.

The endplate effect of the duct, like the shroud allows thrust generation right out to the tip.

The duct lip can also generate thrust independent of the propeller system.



Low Speed Ducted Fan ~ 1.3D open propeller

Ducted Fans
(for Low Speed applications)

The main subject of this lecture. (Ducted:- generally refers to a peripheral casing stream-wise length that is close to the propeller diameter)

Advantages:

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Disadvantages:

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- x Very sensitive to pitch and yaw
- x May have significant effect on aircraft lateral stability
- x High profile drag
- x Structural complexity


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Noise

The duct can offer a number of advantages in noise suppression:

- Running the propeller under optimum flow and loading conditions eliminates the propeller-tip "buzz", a substantial component of the noise of propeller-driven aircraft.

- Enclosing the propeller in a duct allows various acoustic treatments to absorb noise before it can impinge on the ears of bystanders.

- By offering improved static and low-speed thrust, ducted fans make possible steeper climb-outs, which in turn reduces perceived noise levels at the airport boundary, an important public relations advantage.

Ducted Fans
(for High Speed applications)

The engine nacelle / casing of turbo-fan engines and the subject of previous lectures in this unit. (Generally associated with a peripheral casing stream-wise length that is equal to or greater than to the first stage fan diameter)

Advantages:

- ✓ Tip losses significantly reduced
- ✓ Natural flow conditioning to satisfy engine entry requirements
- ✓ Reduced hazard to ground personnel
- ✓ Total containment in the event of “blade-off” failure
- ✓ Noise !

Disadvantages:

- x Very Lower static thrust efficiency
- x Very sensitive to pitch and yaw
- x May have significant effect on aircraft lateral stability
- x High profile drag
- x Structural complexity and weight

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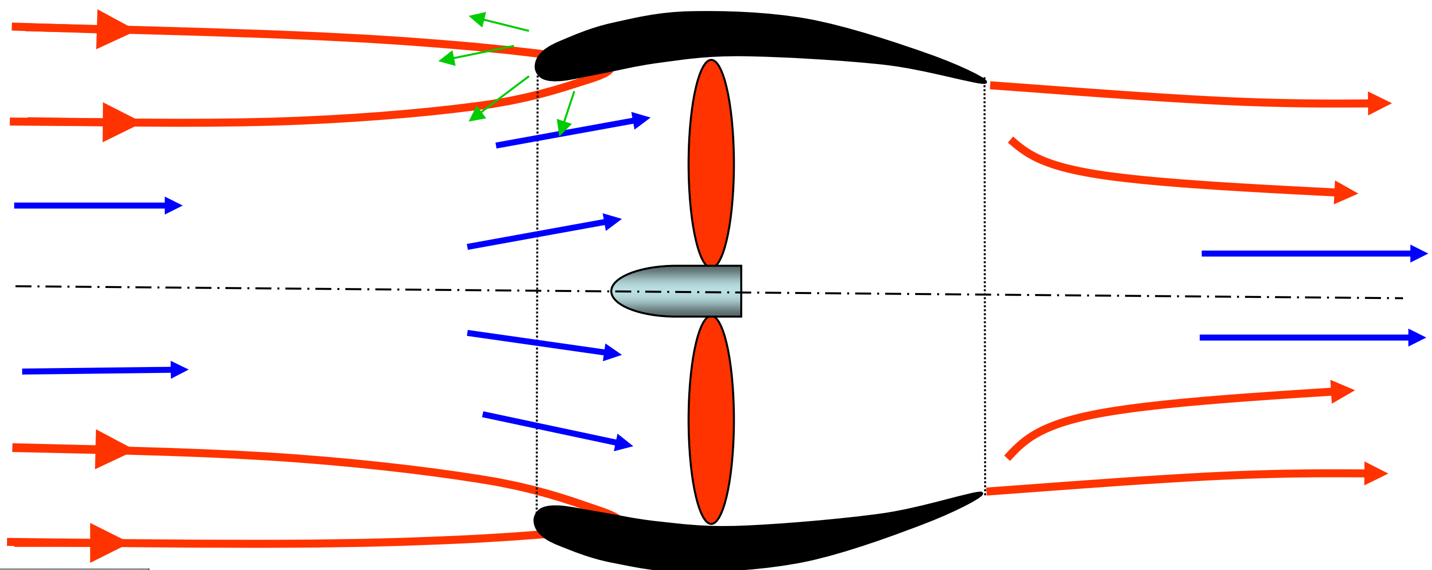
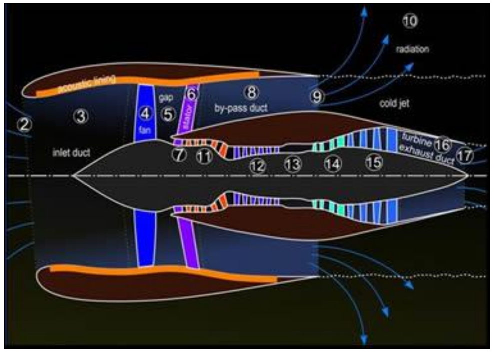
- x Structural complexity and weight

For the ducted fan at high speed, perhaps transonic flow, the divergent entry into the first stage compressor aids the increase in static pressure.

It also reduces the flow velocity to subsonic values.

The details of such designs are the subject of turbo-fan designs.





High Speed Ducted Fan

VTOL Applications

The non-convergent rear section increases the static pressure and reduces wasted kinetic energy.

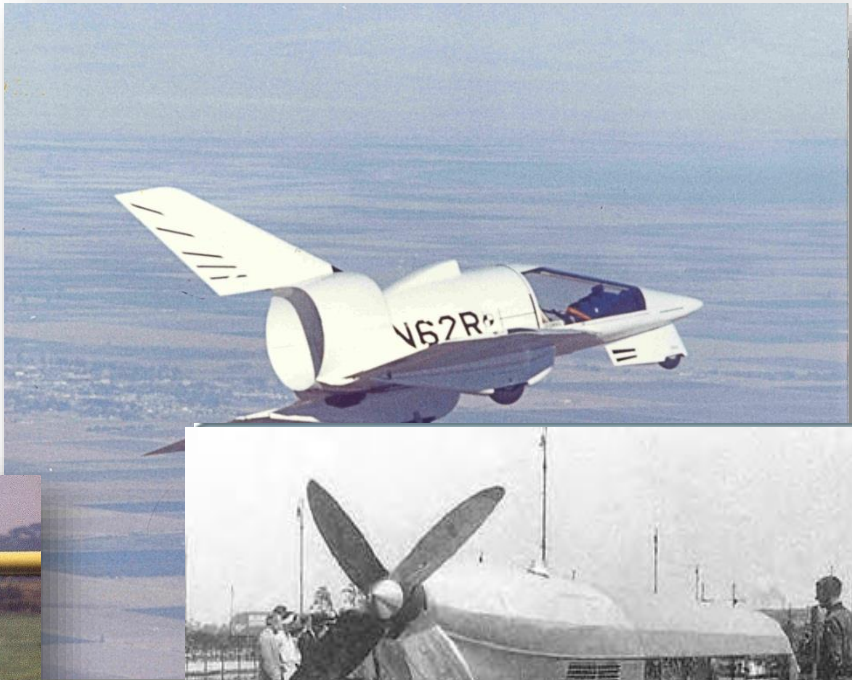
This is highly conducive to Vertical Take-Off and Landing flight modes.

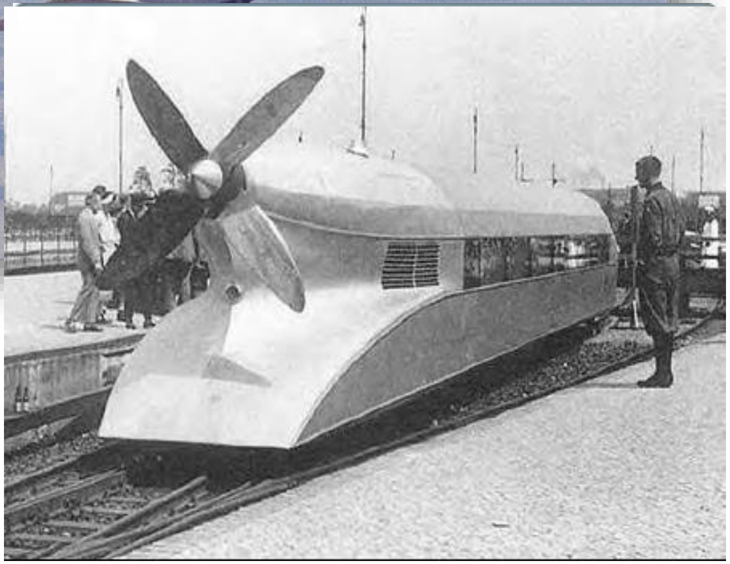
Care must be taken to avoid flow separation and the associated efficiency loss

VTOL Applications

Ducted fan as part of the design

Often the ducted fan is chosen for aesthetic reason (primarily on radio controlled models) or just as the only real option for power-plant integration





Aesthetics is important !