By Barnaby Wainfan

Let's analyze the purported advantages of pusher configurations.

One of the often-cited reasons for using a pusher configuration is the perception that a pusher can be more efficient than a tractor. While this can be true, a pusher propeller operates in a more difficult aerodynamic environment. Let's look at a few considerations the designer of a pusher should keep in mind.

Propeller Wake

One advantage of a pusher propeller is that the slipstream aft of the propeller does not blow on the fuselage. A tractor propeller blows air backward onto the rest of the airplane, creating a built-in headwind. This is more significant for single-engine airplanes, on which the slipstream flows over the entire fuselage. While this effect is real, it is also relatively small. The slipstream velocity increase behind the propeller for a typical light airplane in cruise is less than 10 mph. The overall effect is small enough that it does not give the pusher a significant advantage.

Another advantage often cited for the pusher is that the propeller wake of a tractor configuration interferes with laminar flow over airplane components downstream of the prop. This is partially true. Experiments on the Rutan Amsoil racer showed that there was extensive laminar flow on the forward wing even in the propeller wake. What the experimenters found was that there was a momentary disruption of laminar flow each time a propeller blade passed the wing and the blade wake hit the wing. Between blade passages, the laminar flow reestablished itself. The overall effect was that the drag of the wing was slightly higher than it would have been with undisturbed air flowing over it, but still significantly lower than it would have been with fully turbulent flow.

Fuselage Drag

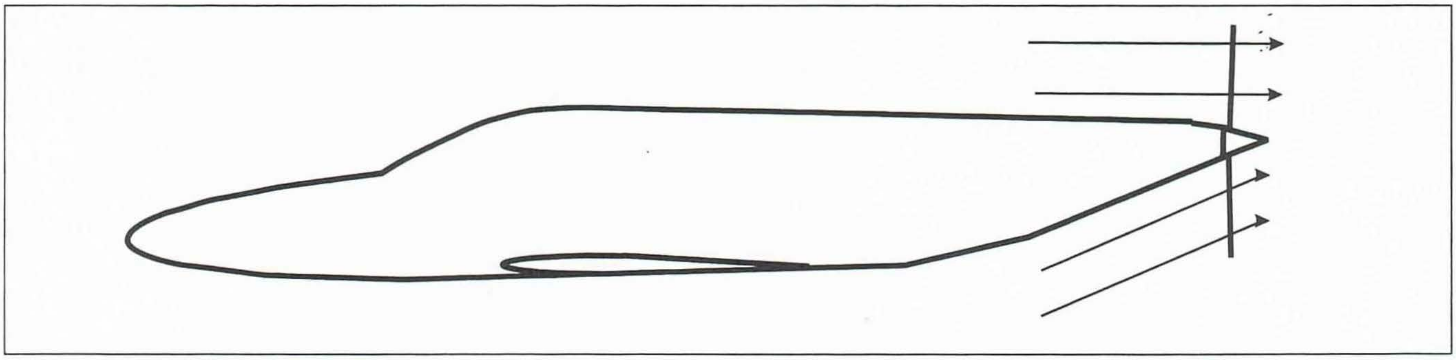
A pusher-engine installation frees the designer to shape the nose for minimum drag and good visibility. This means that the forebody can be shaped to sustain long runs of laminar flow and to have a smooth low-drag shape even if the flow is turbulent.

As we discussed in a previous article (June 2002), the pusher configuration makes the design of the afterbody more difficult. Integrating the engine tends to make the afterbody short and blunt, which increases the chance of significant separation and base drag. The cooling-air outlets on a pusher also tend to generate more base drag than a well-designed flush-ramp cooling-air exit on a tractor installation.

A poor afterbody design can increase drag far more than a good nose design can decrease it. This means that designing a low-drag fuselage for a pusher airplane can be tricky. But because the nose can be aerodynamically beneficial, the pusher does have the potential to have lower total fuselage drag if the designer gets the afterbody right.

Propeller Efficiency

The fuselage or nacelle can affect the airflow into both tractor and pusher propellers. For a tractor, the primary concern is the blockage of free airflow behind the inner portions of the propeller caused by the nose of the fuselage or nacelle. For airplanes with wide, blunt noses, as seen on many singles with direct-drive engines, this effect can be significant. The majority of this loss can be eliminated by using a modest-length prop-shaft extension to move the propeller forward of the cowling's front face and shaping the cowling to smooth the airflow.



On a pusher with an upswept afterbody, the blades on the lower part of the disk see a different airflow angle than they do at other points around the path of rotation. This makes the blades' angle of attack change as they rotate, causing inefficiency and noise.

ILLUSTRATION: BARNABY WAINFAN

A pusher propeller flies in the wake of everything upstream of it. If the afterbody of the fuselage or pod has significant flow separation, at least part of the propeller will be immersed in a low-energy, turbulent wake. This can dramatically reduce the propeller's efficiency. Even if the fuselage is smoothly shaped with a good afterbody, the propeller still must deal with the wake of the wing and sometimes the tail surfaces.

For maximum efficiency, the airflow into a propeller should be uniform and parallel to the propeller shaft's axis of rotation. This condition ensures that the blades are at the same angle of attack all the way around the propeller disk as they rotate. The blades can then be pitched to fly each portion of each blade at its optimum angle of attack. If the flow into the propeller is not uniform, the blade angle of attack varies as the blade moves around the path of rotation. This means that the blade will be at an off-optimum angle of attack part of the time, and therefore, it will be less efficient at producing thrust.

Distortion of the incoming airflow takes two major forms. The first is a non-uniform airspeed over the prop disk. This is caused by something upstream of the prop either accelerating or retarding part of the oncoming airstream. The most common cause of this type of distortion is flow separation on a surface upstream of the propeller. It can also be caused by a body, like a fuselage pod, that is not centered on the propeller shaft. A good example of this is an amphibian like the Seabee. The airflow immediately behind the fuselage pod will not travel at the same speed as the free air above it, and the propeller blade will see variations in airspeed as it rotates.

Cooling-air outlets, or any other internal-flow system that dumps a stream of low-velocity air upstream of the propeller, can also adversely affect propeller efficiency, particularly if the air impinges on the outer half of the propeller blades.

The other common form of airflow distortion into a propeller is angular distortion. In this situation, the airflow on one portion of the prop disk is not parallel to the airflow at another point in the path of rotation of the blades. Angular distortion can be caused by a misalignment between the propeller shaft and an otherwise uniform incoming airflow. This is typical for all airplanes in climb, as we tend to set the thrustline for best efficiency in cruise.

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Angular distortion can also occur when airplane components deflect the airflow differently at different spots. One such situation occurs with a highly upswept afterbody just upstream of the propeller. The portion of the blades directly behind the afterbody will encounter flow that has been deflected upward as it follows the skin of the airplane, while the blade on top of the rotation path will see airflow that is closer to parallel to the free stream.

Wings and tail surfaces upstream of the propeller can also affect the angularity of the flow into the prop. This can be particularly severe if there is an abrupt change in the wing shape (such as the end of a deflected flap) directly upstream of the propeller disk.

Noise and Vibration

The propeller generates a large portion of the noise that comes from a piston-engine aircraft. As anyone who has heard a Long-EZ, Skymaster or Starship fly by can attest, pusher propellers have a different sound than tractors. This is because the blades hit the wakes of the airplane's upstream components as they rotate. Each time a blade encounters the wake of the wing or tail surface, the airflow over the blade is momentarily disrupted. The disruption causes a pressure pulse that is heard on the ground as noise. It also generates mechanical vibration of the propeller that can be transmitted into the cabin as structure-borne vibration.

If more than one propeller blade is disrupted at the same time, the level of noise and vibration is increased. For example, if a two-blade propeller is placed directly behind a wing or tail surface, both blades hit the wing's wake at the same time. This produces a double-strength pulse twice per rotation. A three-blade prop in the same situation would produce six single-strength pulses per rotation, resulting in a softer, higher-frequency sound and vibration.

The situation can be further improved if the propeller axis of rotation is displaced vertically so that it's above or below the wing. If the shaft is in the plane of the wing, the whole length of a propeller blade hits the wake at once. If the shaft is above or below the wing, the blade moves into and out of the wake progressively. This lowers the maximum amplitude of the pressure pulse and makes it less abrupt, reducing noise and vibration.

As you can imagine, a propeller flying in a partially separated wake behind a poorly designed afterbody is really loud.

Blade Fatigue

Blade fatigue is a vital safety consideration when choosing a propeller for a pusher configuration. The blades of a propeller operating behind a wing get pulsed twice per rotation as they hit the wing's wake. This excites vibration of the propeller blade. It is important to make sure that the frequency of this excitation is far from any natural vibration frequency of the blade, particularly if the propeller is metal. If the two-per-rotation vibration frequency excites any natural vibration mode of the blades, they will fatigue rapidly and fail.

Similarly, the blades get pulsed any time they hit a wake. If the airplane has a pusher propeller in the extreme tail, then the pulse frequencies caused by hitting the wake of the fin and tail planes must also be considered.

FOD

Foreign-object damage (FOD), is the mortal enemy of pusher propellers. Because the prop is behind much of the airplane, it can get hit by any object coming from the airplane. It's particularly vulnerable to rocks or other objects kicked up by the nosewheel during takeoff and landing. It is a good idea to have a wheelpant or some form of fender or splash guard on the nosewheel if there is any direct path from the wheel contact point to the propeller disk.

Pusher propellers will also eat anything that comes off of or out of an airplane in flight. Losing the canopy in flight may be a major inconvenience in a tractor, but it can easily destroy a pusher's prop.

While the pusher configuration offers some attractive advantages, it is inherently harder on propellers than the tractor configuration. The designer of a pusher must pay special attention to make sure that the propeller is happy pushing instead of pulling.

Aerodynamic questions of a general nature should be addressed to "Wind Tunnel" c/o KITPLANES, 8745 Aero Dr., Suite 105, San Diego, CA 92123.