

ANATOMY OF A STOL AIRCRAFT

Designing a Modern Short Take-Off and Landing Aircraft

“Form follows function”

By Chris Heintz

The world truly seems to be smaller today, thanks in large part to aviation. This has created a renewed interest in many of us to see what is around us, and not just to dash as quickly as possible from one place to another. While recreational aviation certainly has its share of high-performance (fast) aircraft, I think that what continues to draw most of us to flying is the sheer excitement, enjoyment and freedom of being at the controls of our own aircraft. We want aircraft to give us the ability to fly cross-country, but we want to be able to see and visit the country we're flying over.

The popularity of aircraft like the Piper Cub has endured and grown over the years, not only on account of nostalgia, but because these aircraft are just plain fun and easy to fly and provide good grass field capability (most classic aircraft were developed in a time when paved runways were rare). However, because of their age, many of these older designs do not offer modern improvements that most of us take for granted, such as electrical systems, side-by-side seating, all-metal construction, steerable nosewheel, etc. And of course, classic airplanes are becoming scarce and require significant maintenance just to keep them airworthy.

For most of us recreational pilots, we're already where we want to be when we're in the air, and we therefore get the most enjoyment from flying an airplane that's easy and fun to fly, that provides good comfort and visibility, and that has low operating costs (who cares about miles per gallon – we want low hourly operating costs). When we do fly cross-country, the trip is as important (if not more) as arriving to the destination. A STOL (short take-off and landing) airplane gives us the ability to go to more places, especially in remote areas, where the world becomes your runway (this is an important safety feature too). With good payload, we have the ability to haul all the bags we want (camping equipment), or amphibious floats can give us the added capability and freedom to operate from water. Of course, a STOL airplane also allows us the opportunity to operate the aircraft out of our own “back yard.” Just



as sport utility vehicles (SUVs) have become very popular in the automotive world, many recreational pilots are also seeking maximum utility from their aircraft.

Ultralight aircraft provide an easy and inexpensive way to experience STOL performance, and the popularity of ultralights and other light kit aircraft has proven the demand for ‘low and slow’ flying, but ultralights, by their very definition, have many limitations – low speed, low payload, low comfort level, and wind limitations, to name a few of their inherent limitations.

Today, with the knowledge accumulated for nearly a century on aerodynamics, structural strength, on their relation in aerolasticity (flutter), on ergonomics and with the ongoing development of modern, efficient, reliable and lightweight engines, it is relatively easy for almost anyone curious enough to seriously study the above fields to design a light aircraft capable of carrying two to four occupants.

As a professional light aircraft designer and engineer I have done just that ... quite a few times. In the mid-eighties, I decided to design a light kit aircraft that combined the advantages of an ultralight aircraft with the characteristics of a modern ‘real’ airplane. Thus I designed the STOL CH 701 aircraft: It needed to offer outstanding short and rough field performance, acceptable cruise performance, good cross-wind capability, excellent visibility, comfortable side-by-side seating, and a durable all-metal airframe - that was easy to build and maintain. The STOL CH 701 design proved to be very successful (more than 400 STOL CH 701 aircraft flying) and I subsequently designed a 4-seat utility version, the STOL CH 801 (introduced in 1998).

My STOL designs have sometimes been called ‘ugly’ because of their unconventional shape. However, with form following function, a study of the unique shapes shows the inherent beauty of these aircraft in their interesting, unique and highly effective aerodynamic and design features. Following is an explanation of the basic design concepts that I have applied in designing my STOL aircraft:

POWER

Overpowering an existing aircraft is the easiest way to achieve short take-off performance (with enough power anything will take-off in a short distance!), but this requires a lot of fuel for acceptable endurance, and is an expensive, heavy, and inefficient way to obtain STOL performance, and does not provide good slow flight or payload due to the heavier engine weight and/or fuel load requirement. My experience tells me that I need 60 to 100 hp for a two-seat aircraft, or 150 to 200 hp for a four-seater capable of carrying 1,000 lbs. As an airplane designer and builder (and not an engine manufacturer), I design aircraft around existing and readily-available engines. For maximum flexibility and to keep costs low, a kit aircraft must be designed to accommodate different engine types so that owners can choose among existing (and new) powerplants.

WING DESIGN

To be practical, a STOL aircraft must be able to fly at very low speeds, yet it must also offer acceptable cross-country (cruise) performance. The next big challenge is to design a wing with a high lift coefficient so that the wing area is as small as possible, while take-off / landing speeds are as low as possible. Relatively short wings make the aircraft easier to taxi, especially when operating in an off-airport environment with obstructions, and requires less space for hangaring, while being easier to build, and stronger (less weight and wing span to support).

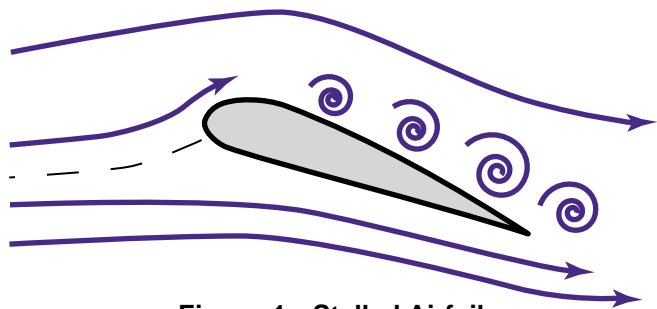


Figure 1 - Stalled Airfoil

The stall of the wing occurs at the highest lift coefficient on an airfoil, when the airflow can no longer go around the airfoil's nose (leading edge) and separates from the upper wing surface.

To delay the stall to a higher lift coefficient, many airplanes are equipped with flaps (on the wing trailing edge), and a few designs use slats (on the wing leading edge) to further lower the stall speed. The

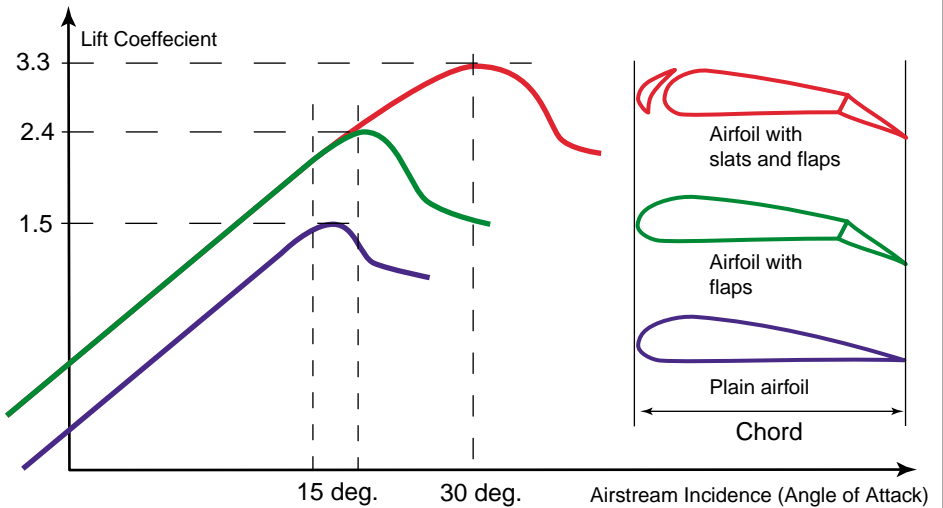


Figure 2 - Lift Coefficient vs. Airfoil Angle of Attack

following diagram illustrates the use of flaps and leading-edge slats to increase a wing's lift coefficient.

The lift coefficient can thus be effectively doubled with relatively simple devices (flaps and slats) if used on the full span of the wing.

Leading Edge Slats

Leading edge slats prevent the stall up to approximately 30 degrees incidence (angle of attack) by picking up a lot of air from below, where the slot is large (Figure 3), accelerating the air in the funnel shaped slot (venturi effect) and blowing this fast air tangentially on the upper wing surface through the much smaller slot. This "pulls" the air around the leading edge, thus preventing the stall up to a much higher angle of incidence and lift coefficient. The disadvantage of the leading edge slat is that the air accelerated in the slot requires energy which means higher drag. As the high lift is needed only when flying slowly (take-off, initial climb, and final approach and landing) the temptation for the designer is to use a retractable device which closes at higher speeds to reduce drag.

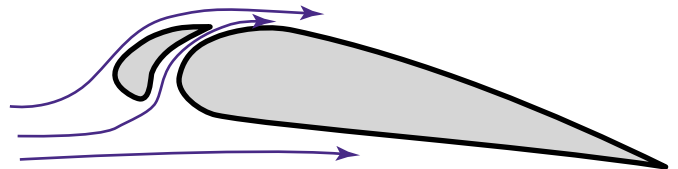


Figure 3 - Leading Edge Wing Slat

This can be done in different ways: The slats can be mounted on roller rails so that at high angles of attack they are automatically pulled out by the airstream around the leading edge, and in cruise (at lower angle of attack) they are pushed in. This is a relatively simple system and not too heavy to design, but it has one big disadvantage: in gusty weather only one wing slat may be drawn out while the other stays in, creating a potentially major problem for the pilot who now needs full aileron just to keep the airplane level...!

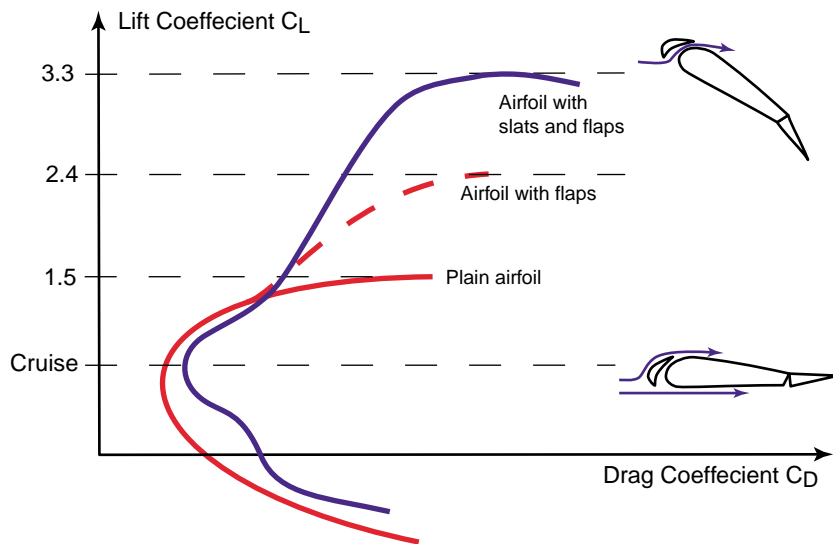


Figure 4 - Lift Coefficient vs. Drag Coefficient

So the safe way is to connect the right and left wing slats mechanically to prevent asymmetric extension. However, creating such an installation is heavy and more complex. The efficiency gained by the system must be very significant to compensate for the extra weight of the device (not to mention cost and complexity). A pilot controlled slat extension system is another approach, but has the same drawbacks: weight and complexity.

But there is a simple solution: The amount of drag increase created by the slot depends on the amount of air going through the slot in the whole range of flight. In take-off and landing configurations we want maximum lift, and in cruise we want minimum drag. By equalizing the amount of air pressure on the top and bottom of the wing at the leading edge (where the slat is located) in cruise configuration, there is no air flowing through the slot, and thus no lost energy (or extra drag created). Equalizing air pressure is easily achieved in cruise configuration with a slight trailing edge upward deflection of the wing flap. Figure 4 illustrates the lift coefficient and drag of such a wing design.

The illustration clearly shows that the wing with slats and flaps is the solution for slow flight where high lift is required, and also has little drag penalty in cruise. It is a light weight wing with no moving mechanical parts associated with the leading edge slats. A noticeable drawback is a relatively small low drag range, which means a narrow economical cruise speed range, but the overall configuration provides the best wing design for a STOL aircraft.

Thus, I have chosen this fixed slat configuration for the two-seat STOL CH 701 and the new four-seat STOL

CH 801. The wing is lightweight, yet yields a very high lift coefficient, making it a very reliable, simple, and a low-cost high lift device for these two designs.

I have also used a relatively thick wing chord on these designs to provide high lift. The thick wing chord, combined with a relatively short wing span, also provides maximum strength and low weight. With its constant chord (as opposed to tapered) the wing is also easy to build and assemble.

Wing Tips

For a long time, I've said that Hoerner wing tips should be used on most light

aircraft designs, since they increase the effective wing span from 8" to over one foot without having to carry any additional weight: As we all know, there is low pressure on top of the wing, and higher pressure on the bottom of the wing, with the pressure difference creating the lift that allows us to fly. Toward the tip of the wing, the high pressure 'feels' that there is less pressure on the top of the wing (just around the tip), and wants to go there to equalize the pressure, thus creating a secondary flow out toward the tip of the wing. This secondary outward flow generates a vortex (a circular motion) behind the wing, as illustrated below.

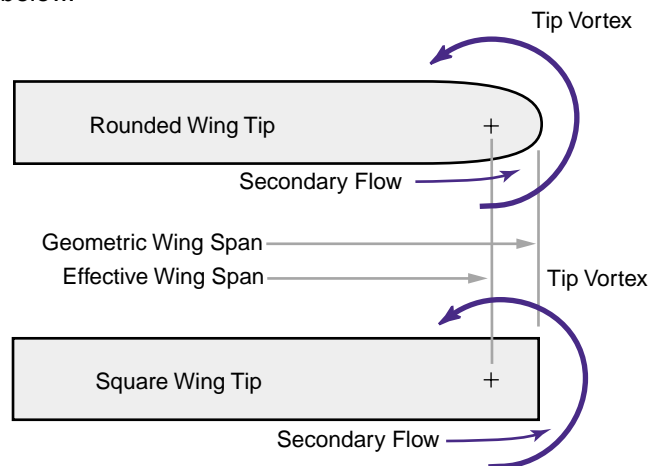


Figure 5 - Wing Tip Vortices

With a rounded or squared wing tip, the vortex is centered around the wing tip, as shown above

With drooped or raised wing tips, the vortex is forced further out. Drooped wing tips are often seen on STOL aircraft, but they create a weight penalty since they need to be added to the wing.

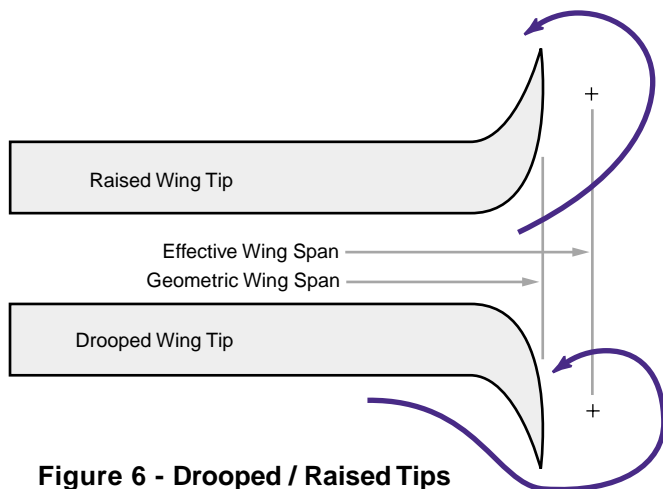


Figure 6 - Drooped / Raised Tips

If the wing tip is cut at 45-degrees with a small radius at the bottom and a relatively sharp top corner, the air from the secondary flow travels around the rounded bottom but can't go around the sharp top corner and is thus pushed outward.

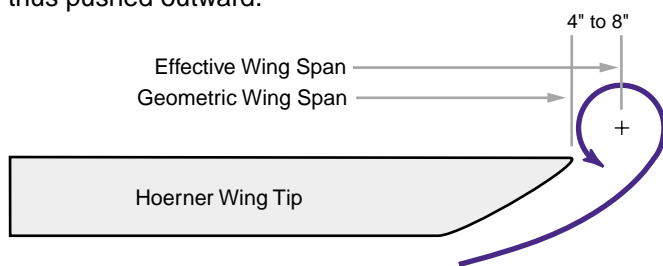


Figure 7 - Hoerner Wing Tips

The performance of the aircraft depends on the distance from the right to the left tip vortices (the effective wing span), and not the actual measured geometric span. Hoerner wing tips provide the largest effective span for a given geometric span or a given wing weight.

CONTROLS

Because a STOL airplane can fly at very low speeds, and is developed to operate in unimproved areas (often with obstacles), controllability of the aircraft at slow speeds is essential. This is one area that I've found to be lacking in many high-lift light aircraft designs – while many of these planes have a low stall speed, the pilot needs to fly the aircraft at a much higher speed in order to maintain control.

Flaps, Ailerons, and Flaperons

Full span ailerons, which also act as full span flaps, are thus used (called flaperons). The full span provides maximum high lift (flaps) for the entire wing and roll controllability (ailerons) at a minimal weight since both functions are shared by the same control surface (flaperon), with a simple mechanical 'mixer' controller.

We all know that close to the airfoil, the air is slowed down by friction. This slowed down layer of air is called the boundary layer. The boundary layer builds up thicker when moving from the front of the airfoil toward the wing trailing edge. Another factor is called the Reynolds effect, which means that the slower we fly, the thicker the boundary layer becomes. Friction and the Reynolds effect result in an approximately ½" thick boundary layer toward the rear portion of a 4 to 5 ft. chord wing designed to fly at low speeds.

A conventional flap or aileron thus would have 1 or 2 degrees of deflection with very little control effectiveness because it deflects in this not very aerodynamically active boundary layer. To avoid this loss of controllability, the flaperon can be designed as a separate small wing, moving outside of the wing's boundary layer and slipstream. Additionally, such a flaperon system (often called a "Junker" flaperon) is effective even at high angles of attack because it is positioned below the wing and thus continues to get 'fresh' undisturbed air even when the wing is at the extreme angle of attack (see Figure 8).

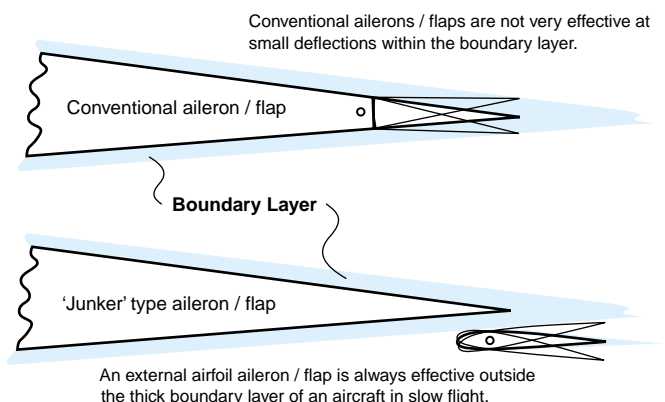


Figure 8 - Boundary Layer

Horizontal Tail

Also, because a high lift wing is designed to fly at an unusually high angle of attack (30 degrees compared to 15 to 17 degrees for a conventional wing) we need to achieve this high angle by pushing the tail down much more than with a conventional wing. Short of building a very large horizontal tail, we need a large negative lift coefficient on the tail. This is achieved first with an inverted stabilizer airfoil, and secondly with a virtual venturi. Let me explain: From an aerodynamics standpoint we know that a venturi provides lower pressure and higher speeds at the smallest section, as illustrated in Figure 9.

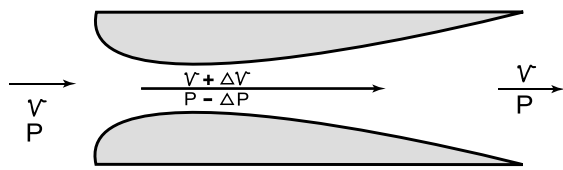


Figure 9 - Venturi

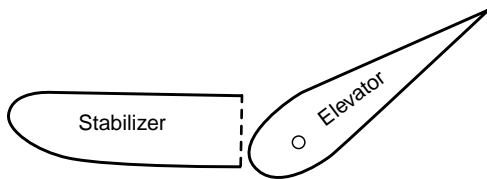


Figure 10 - One Half Venturi

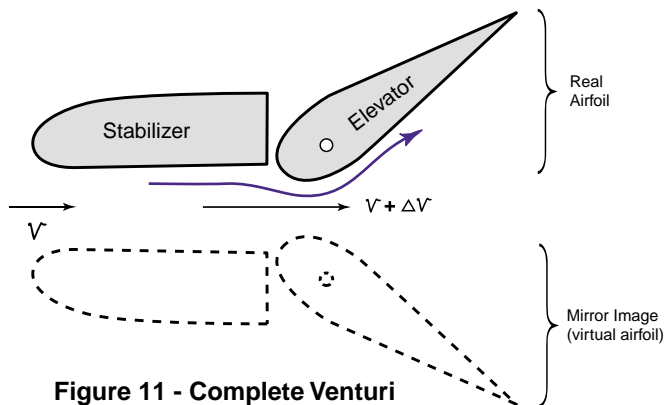


Figure 11 - Complete Venturi

The increased speed will overcome the tendency of separation when the flow is deflected. We also know that when we have a half venturi (Figure 10) the airflow creates a mirror image and follows the principles of a complete venturi (Figure 11), and thus the increased speed from the venturi effect follows the elevator of the horizontal tail even when deflected in the trailing edge down position (thus the virtual venturi effect).

Rudder

I've used the all-flying vertical tail (rudder) on my STOL designs that I've used on many of my earlier designs because it provides exceptional crosswind capability. With a STOL design, when the crosswind is higher than the aircraft's stall speed (this actually happens!) you can just face the airplane into the wind and literally take-off vertically (even if you have to face across the runway)! Another advantage of the all-flying vertical tail is that it is physically smaller (and shorter) than a corresponding conventional fin and rudder vertical tail, and thus lighter; and being a single piece it is easier to construct. It also provides excellent spin recovery capability because the actual moving part (rudder) is larger. The rudder itself is an actual symmetrical airfoil (and not just a flat 'board'), helping to make it effective and responsive even at lower speeds.

The main wings of the STOL designs taper at the wing root to allow undisturbed air to flow from the propeller to the empennage (tail sections). The position of the tail above the fuselage, with the direct undisturbed air from the prop, provides excellent and responsive control from the tail sections, compared to the sluggish response a conventional configuration provides at slow flight.

Short take-off / Landing

To best achieve short take-off performance, the wing's high angle of attack must be achieved at or near the ground, and we thus need a general aircraft configuration that permits this high angle of attack. We can do this either by using a very long main gear in tailwheel configuration (raising the nose) or by raising the rear fuselage (in tricycle gear configuration).

With the taildragger configuration, the whole cabin is awkwardly inclined on the ground, and the long gear legs mean that the landing gear structure is either weak or heavy (see Figure 13). The inclined cabin and high gear make access to the cabin difficult, especially for passengers or cargo loading, and can severely limit the pilot's forward visibility while on the ground (taxiing and take-off).

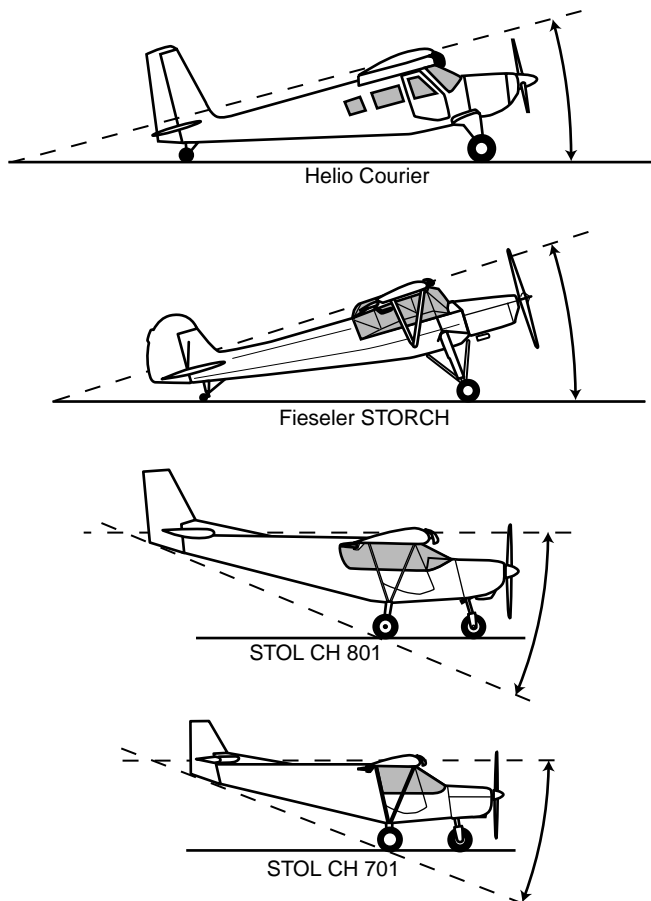


Figure 12 - Landing Gear Configuration

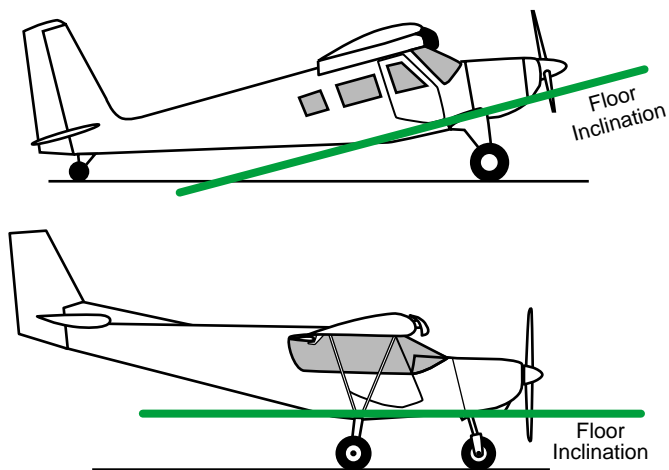


Figure 11 - Cabin Floor / Cabin Access

Most pilots today are much more comfortable (and safer) with a tricycle gear configuration, as nearly all trainers are tricycles. A tricycle gear is very stable on the ground, whereas a taildragger gear is not and needs continuous control input, especially in crosswind conditions. Aircraft insurance rates reflect this.

In a tricycle gear configuration, the wing is at a "neutral" angle of attack while the aircraft is on the ground, as opposed to a maximum lift angle with a taildragger (see Figure 12). Tailwheel airplanes are thus much more susceptible to the wind while taxiing the aircraft, or even while parked outdoors (this will be where the aircraft will spend the vast majority of its life, unless hangared).

Despite the many advantages of a tricycle gear system, many older aircraft designs (as well as many modern STOL designs) use a tailwheel configuration – this is mainly because the technology and expertise did not exist to build a lightweight and strong nosewheel system, and many designers today have little experience (or interest) in landing gear structures.

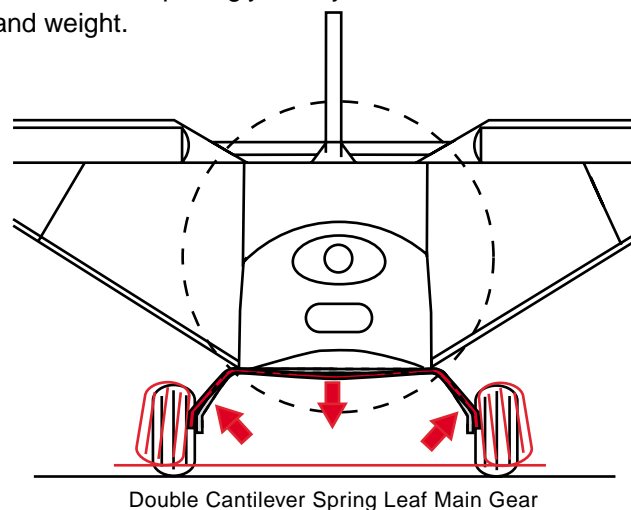
Off-airport operation dictates that a STOL aircraft have a durable and forgiving landing gear system. Landing gear systems seem to be a major weakness on many light aircraft designs, requiring that these aircraft be operated from paved runways, despite their capability to take off and land in short distances.

With my STOL designs, I have used a simple single-piece double cantilever spring leaf for the main gear. While it's not the lightest gear system around, it provides excellent rough-field capability when combined with large tires, and is very durable, simple and virtually maintenance-free. The nosewheel strut is steerable, with direct linkage to the rudder pedals, and uses a single heavy-duty bungee for shock absorbency. The STOL CH 801 borrows the nosegear assembly from the ZENITH CH 2000, my type-certificated production trainer design. The main wheels are also

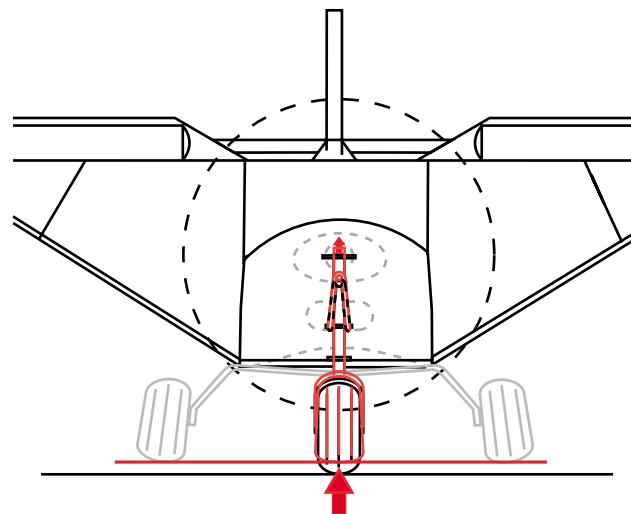
equipped with individual hydraulic disk brakes (activated with toe brake pedals) for exceptional ground handling. Experience has shown these landing gear systems to be well-suited for grass field operation, while being appropriate for low-time pilots. (Nosewheel system wear is minimized by reducing the pressure on the nosegear by using the appropriate elevator inputs – the effectiveness of the elevator makes this easy with my STOL designs).

FUSELAGE

The rectangular cabin offers maximum usable space for occupants and cargo. The 4-seat STOL CH 801 cabin is long enough to fit a stretcher along the right side of the aircraft across the folded co-pilot seat, while still providing adequate space for the pilot and one passenger, or two 50-gallon drums can be carried in the rear. Of course, for those using the STOL CH 801 as a sport utility plane, there's enough room inside for two to camp in, and more than enough baggage area for extended cross-country trips. The two-seat STOL CH 701 is surprisingly roomy for an aircraft of its size and weight.



Double Cantilever Spring Leaf Main Gear



Nose Gear Strut with Bungee

Figure 11 - Landing Gear Spring

The large doors offer easy access to the cabin for occupants and bulky baggage, and the aircraft can be operated with the doors removed for maximum visibility and 'outdoor' feel.

While it's maybe not the most aesthetically pleasing, the square fuselage is very simple to build and helps to provide good yaw stability and spin dampening (resistance) due to its flat sides and distinct corners.

CABIN / VISIBILITY

Pilot and passenger visibility is an important element of aircraft design, and is often overlooked by designers. Good visibility is especially important in a STOL aircraft – where the pilot needs to be able to see obstacles when “bush” flying. Passengers also need good visibility to enjoy “low and slow” flying – they don't want a small window the same size as in a commercial jetliner.

While an open cockpit provides unobstructed visibility, bugs, wind, and cold air all dictate an enclosed cockpit for a modern aircraft - to provide a minimum level of

comfort that we've grown accustomed to. An enclosed cabin also allows for good ventilation and heat, and protects avionics and baggage. Large doors provide easy access to the cockpit (and can be removed for better visibility and “ventilation” in flight).

A high-wing configuration provides the best downward visibility to enjoy the views provided by low and slow flying, and provides the pilot with the required visibility to be able to safely operate into unimproved areas – to be able to see and avoid obstacles. With my STOL designs, I've used an “above-cab” wing position, where the wing is located above the cabin. This design feature maximizes visibility for a high-wing configuration: Horizontal visibility is augmented by raising the wing over the pilot's head, and upward visibility is achieved by decreasing the wing thickness at the inboard end where it meets the cabin, and the top of the cabin can thus be fitted with a full window. A 'skylight' provides important visibility to the pilot in a highly maneuverable aircraft.

The additional benefit of this tapered “above cab” wing configuration chosen for visibility is also its smaller frontal area, which means less drag (a faster airplane with the same amount of power) and excellent controllability at low speeds because the air is directed without disturbance from the propeller to the tail.

As with most modern aircraft, I've chosen a side-by-side seating arrangement to maximize pilot and passenger comfort. Throughout, the cabin is ergonomically designed for pilot productivity, comfort and flexibility. The STOL CH 801 cabin interior is designed to provide comfort for four large adults, while being easy to convert for cargo-carrying applications. Large doors on either side allow easy access to the cabin from both sides. The adjustable front seats fold forward for easy access to the rear seats / cargo area. With anticipated applications for mission use, the rear seat area can be converted for cargo use (including 50 gallon drums), or the cabin can be reconfigured for a berth (patient on a stretcher) across the front and back right-hand seats, with the pilot in the front left seat and a doctor or nurse in the left rear seat. Recreational pilots can literally camp out of the STOL CH 801.

All-Metal Durability

Bush planes need to be rugged, reliable and simple to maintain. “Field maintenance” takes on a new meaning where the pilot literally needs to be able to perform basic maintenance and repair functions in the field.

Both the STOL CH 701 and STOL CH 801 are built of all-metal construction. I have over 30 years experience designing and building all-metal aircraft, and there is more than 60 years experience in the industry with stressed-skin, semi-monocoque construction.

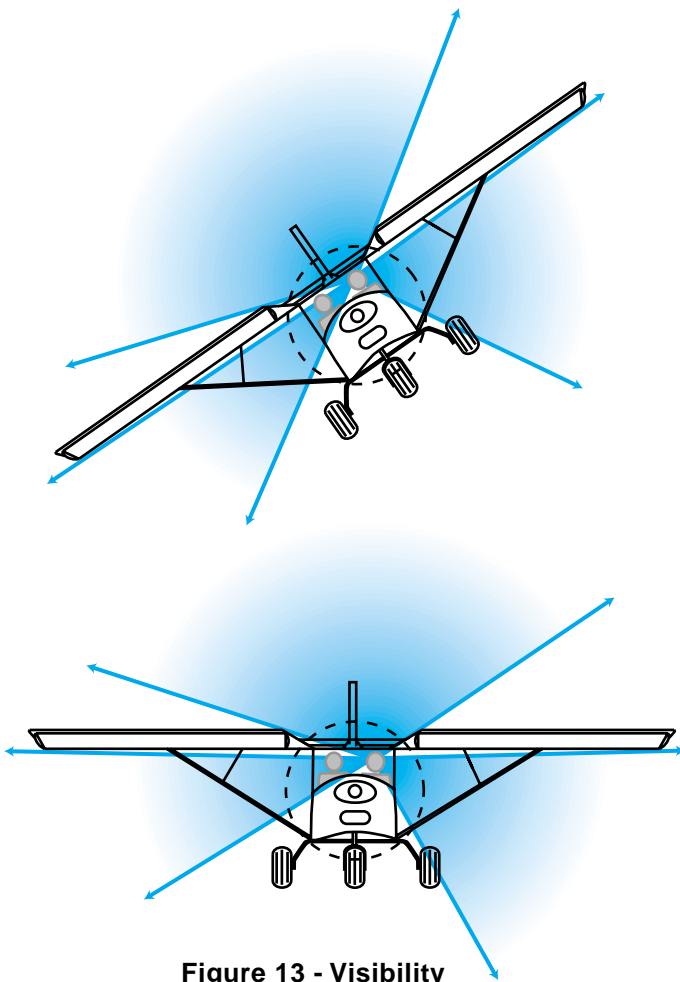


Figure 13 - Visibility

The tapered wing root and top window provides good visibility in turns. The wing design minimizes the frontal area in the propeller slipstream for increased performance, and also provides direct prop blast to the tail sections for superior controllability in slow flight.

Far from being obsolete, metal (aluminum alloy) construction continues to dominate as manufacturers' choice of construction. Aluminum alloys provide the following benefits:

- Low weight / high strength relationship;
- Corrosion resistance, especially with newer alloys and modern primers;
- Low cost and widespread availability;
- Proven durability, and resistance to sun and moisture exposure;
- Existence of vast amounts of empirical data on its properties;
- Easy to work with: requires simple tools and processes, and does not require a temperature-controlled or dust-free environment as with composites. Modern blind rivet fasteners have greatly simplified all-metal kit aircraft construction;
- Malleability: easy to form into many shapes, with almost no limit to the shapes it can be formed into;
Environmentally friendly: no health hazards to worry about when working with sheet metal; recyclable;
- Easy to inspect: construction or materials flaws are easily detected, as are defective parts and damage;
- Simple to repair: rivets and fasteners can be easily removed to replace damaged parts or sections, and individual parts can be replaced without having to replace or rework an entire airframe section.

Thus, aluminum-alloy construction provides the best airframe for a bush plane: 1) Suitable for continuous outdoor storage; 2) Durable and rugged, and; 3) Easy to inspect, maintain, and perform field maintenance. For example, a simple sheet-metal patch can easily be blind riveted onto a damaged area to fly the airplane home.

A well-designed sheet-metal aircraft also provides superior crashworthiness, as an impact's energy is absorbed by progressively collapsing (deforming) the metal structure, as opposed to splintering or shattering upon impact. The landing gear of my STOL aircraft absorbs a lot of energy. It then requires more energy to 'rip' it out, and the aluminum stringer frame and stressed-skin construction then need much more energy to start to bend, buckle and twist. The sturdy 'cabin frame' will protect the occupants even in an unlikely nose-over of a tricycle gear airplane where the wings, positioned quite a bit higher than the occupants' heads, will absorb the impact's energy. Another impor-

tant advantage often overlooked is the inherent lightning protection that a metal airframe offers.

As an aeronautical engineer, it's easy for me to design a complicated aircraft, and much more challenging to design a simple one. For a kit aircraft to be successful, it must be relatively simple in terms of construction, assembly and systems: Not only is a simple design easier and more affordable to build, but it will be well-constructed by the amateur builder, as there will be less opportunity for errors or poor workmanship. With a simple design, building time will be lower, and less tools and skills will be needed to put the aircraft together, equating to much higher completion rates than complex projects, and once completed, the aircraft will be easier to operate and maintain. Simple systems maximize reliability, while minimizing pilot workload. With 24 years experience designing and making kit aircraft for amateur builders, we've learned to develop aircraft specifically for the amateur builders and sport pilots, offering them complete kits that are quick and easy to build, with minimal tools and skills.

With form following function, my two STOL aircraft designs have an inherent beauty that is more than skin deep once one understands the aerodynamic and construction features that have gone into these designs, making them highly effective short take-off and landing aircraft, while being simple to build and maintain, and providing excellent durability and flexibility.

The STOL CH 701 offers excellent off-airport performance in a lightweight and very economical two-seat design that is easy and fun to fly, while the new STOL CH 801 is a true sport utility vehicle, with 1,000 lbs. useful load.



As a designer, it is truly rewarding to see how my designs have been put to use around the world, whether for mission or relief work in remote areas, or a recreational pilot writing me that the plane 'takes off like a cork out of a champagne bottle!'

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