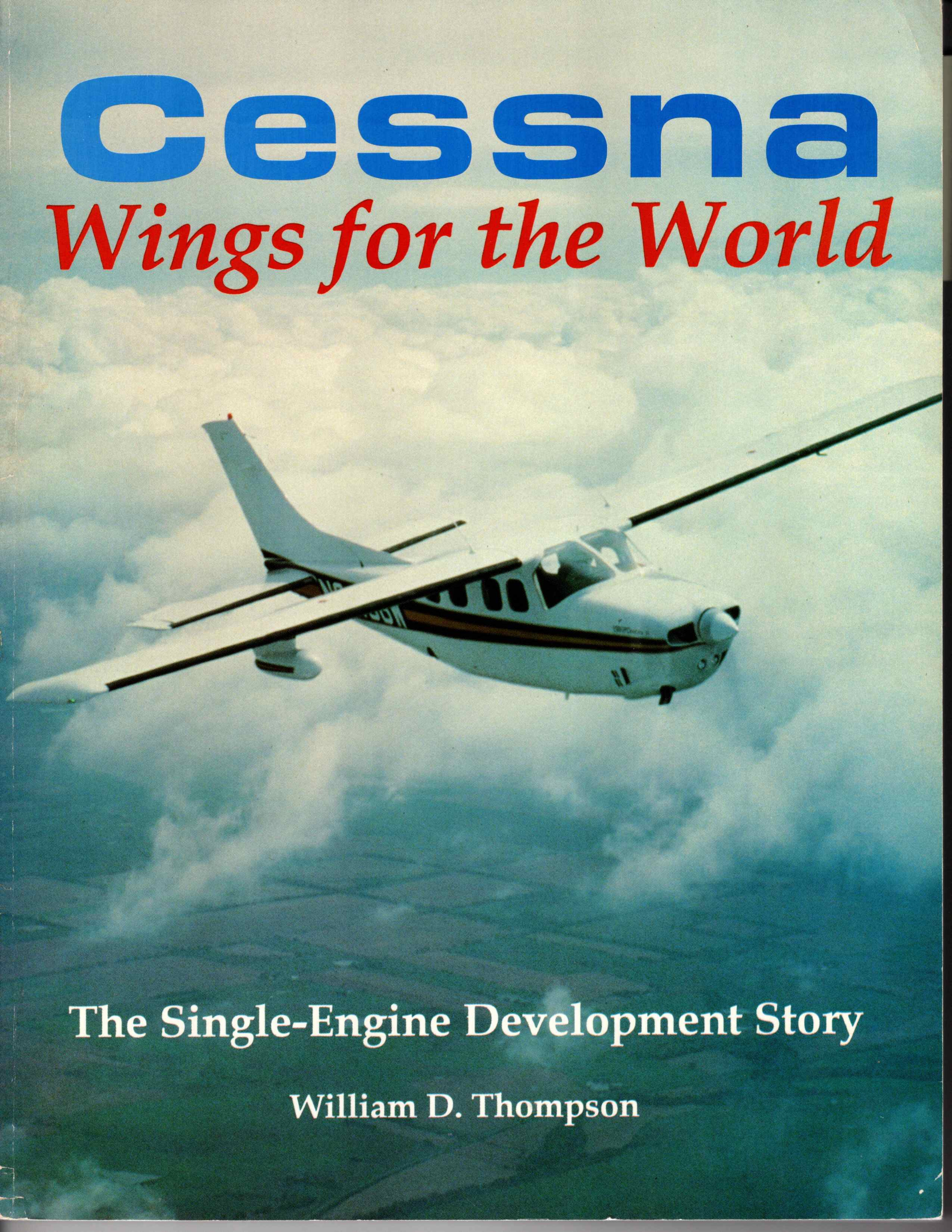
Cessna
Wings for the World



The Single-Engine Development Story

William D. Thompson

The C-170 Story

After WWII it was widely believed that most aviation-minded veterans would start a family and eventually want a family airplane. Cessna publicized a "Family Car of the Air" project during the war years as evidence of this expectation—a project that was shelved and then reactivated in the form of a lower cost airplane called the Cessna 170.

With the astounding success of the C-140, it is understandable that a new 4-place design would be in that image, although aimed at the cross-country flying mission more than local flying that is so typical in the trainer mission. This meant more cabin comfort, especially in the rear seat where, traditionally, leg room was usually inadequate. Thus the challenge to the preliminary design engineer, Mitch Zurawinski, was achieving the *largest* center-of-gravity range in the largest cabin and smallest, lowest-powered airplane imaginable. That was a tough task, and it meant providing adequate longitudinal stability, stall, and spin characteristics at seldom-seen most rearward C.G. positions approaching 40% mean aerodynamic chord (compared to a normal 30% MAC). Similarly, sufficient elevator power would be needed to get the tailwheel on the ground in a 3-point landing at a 10-12% MAC loading (compared to the usual 15-20% most forward loading). The horizontal tail areas and length were sized to accomplish these objectives at the expense of rather heavy elevator stick forces at the forward C.G. position.

To keep the selling price down (while exploring this market) the fabric covered C-140 wing structural design was adopted by lengthening the inboard sections. This resulted in ailerons that were sized for the C-140 instead of the larger C-170. Predictably, aileron control was a bit sluggish in rough air at slow speed just before landing touchdown. Unlike the tricycle gear landing task, tail dragger pilots had to endure prolonged floating to bleed off enough speed to get near a stall for the 3-point touch-down. I recall much gusty air "floating" where the control wheel was rotated stop-to-stop (90° each way) to correct for wing-dropping in severe gusts. Adding wing-low drift correction in crosswinds made this even more awkward.

Some brave pilots performed wheel landings, which were usually unpredictable if bouncing commenced. After a series of crow-hop bounces with four people and baggage aboard, I gave up wheel landings on Cessna spring gears. It is amazing that some pilots *always* use wheel landings by pushing the control wheel forward very abruptly (and with vigor) just at touchdown. This is tough on old flight instructors and passengers watching that procedure and fearing a propeller strike with the runway.

Mitch addressed the problem of poor over-the-nose-in-taxi-visibility (that was common in tail draggers) by lowering the engine and sloping the upper cowling downward rather sharply. As the prototype was being built I wondered if pilots could establish a glide without the usual prominent cowl line as a reference with the horizon. Later we did find this to be a problem until the pilots became used to glancing more frequently at the airspeed indicator.

Another concern during the prototype's construction was the enormous amount of leg room for rear seat passengers in such a small airplane. That meant a *really far aft* C.G. position to be FAA-certified, and Hank Waring and I would be under the gun in developmental flight testing. As always, the production tooling was well underway before the maiden flight.

In June of 1947 the company rented a new 165 HP Stinson from a dealer in Detroit, and I was asked to ferry it back to Wichita for comparative testing with the C-170. My impressions of the rear seat room are reflected by a recent statement by a Skyhawk owner:

> "...We use the Skyhawks on floats as a ride airplane and as an instruction airplane. They work out beautifully. The thing I really like is the roominess. We were running a Stinson for rides, and the Skyhawk is cavernous by comparison..."

Another innovation was the extremely wide cabin doors in the C-170 for easier ingress and egress. These large doors presented a problem on the ground in Wichita's typical 20-30 mph winds, but we soon learned to open them carefully (and hang on to them) to avoid wind damage. They also proved very worthwhile in loading suitcases more easily over the rear seat back to the baggage compartment.

The seats were constructed with no-sag (zigzag pattern) springs covered by rather skimpy amounts of foam rubber and fabric upholstery material. For a cross country airplane, we had to admit to our competitors that those early interiors were a bit austere—after *two* 3-hour flights one was ready for relaxation in the nearest hot tub! However, interiors are expensive and heavy, and the success of the C-170 depended on keeping the price and empty weight at a minimum.

The maiden flight was made uneventfully by Hank Waring on November 5, 1947 using a typical solo loading at a 25% MAC c.g. location. As one can see in the photograph section, the configuration is strikingly similar to the C-140. Also shown is the instrument panel with the rather austere arrangement of instruments and avionics. Note the infamous G.E. AS1B low frequency radio at the right side where a glove box door normally is located. Out of view is the wing flap handle between the two front seats.

We looked forward to expanding the C.G. envelope sufficiently to make this an *honest* "4-place-and-baggage" airplane. Testing at forward C.G. with power off and flaps down showed inadequate elevator power for a 3-point landing. To correct this the angle of negative incidence for the horizontal stabilizer had to be changed to -4°. This, of course, had to be counteracted in cruising flight with down-elevator, creating some drag. In addition, it produced a greater out-of-trim condition in a balked landing climb, requiring a more rapid application of nose-down trim and/or flap retraction. However, these were small penalties to pay for such a far-forward C.G. limit. As expected, the elevator control forces were significantly greater than in the C-140 and C-195.

The rather large vertical tail produced excellent controllability in crosswind landing approaches and landing rolls. I can't recall any landing problems in the notorious cross-winds and gustiness at the Cessna test flight strip that is so close to the large factory structures. Tailwheel steering and differential braking were good enough to overcome any weathervaning tendencies during long crosswind taxi runs. In contrast, the Stinson, with its enormous vertical tail and its weak brakes, weathervaned strongly into a 20-30 mph direct crosswind.

Stalls and spins were also excellent with no abnormal amount of wing dropping at the stall or delayed recoveries in the spins. The spin attitude was steeply nose down and rotation was rapid.

The small ailerons were not as effective in limiting wing dropping motions in stalls as the later C-170A/B ailerons, but they gave reasonable (if not spectacular) control in normal flight maneuvers. As mentioned previously, they were only marginally effective at landing touchdown in real gusty air. With the C-170's longer wing, and, consequently, its greater damping-in-roll, the airplane was not as pleasant to maneuver as the C-140 and C-195. However, for the cross-country mission, it appeared quite acceptable.

The quest for greater climb performance continued in the C-140 tradition with a seemingly endless number and types of propellers. We proved that wooden or composite propellers (fixed or controllable) were no match for McCauley's propellers having thin aluminum blades. Of course the metal propellers were vulnerable to high stresses and possible fatigue failure near the tip. Stress tests were performed at Dayton, Ohio or in Wichita, using strain gauges cemented in various locations on the blades. These gauges were connected electrically via a slip ring assembly to an oscillograph which recorded voltage traces (and, hence, strain in psi) on a roll of graph paper. Analysis of these traces would indicate stress levels and, most importantly, the engine speed that produced the highest stress. In some cases, a critical RPM range would be marked with a yellow arc on the tachometer dial.

McCauley engineers surprised me by placing a propeller on a bench in a darkened room, attaching an excitation device (like a huge loud speaker) to the blade via a needle-like element, and observing the blades' flexing motions with a strobe light. By varying the excitation frequency, they could make the blade undulate a surprising amount in a wide variety of forms. For example, at one frequency the tips would move one or two inches, while another frequency would hold the tips in place but cause the blades to flex in a sine wave or a "snaking" pattern. The strobe light allowed us to observe this flexing in slow motion. The truly shocking part of this demonstration is that these flexing excursions occur in *every revolution* of the propeller. Thus I became an instant-believer in filing out nicks in propeller blades, since they are notorious stress-risers.

Our chief engineer, Tom Salter, was adamant about keeping all oil lines internal in the engine, and we did all in our power to avoid an external oil cooler. Cooling tests indicated good cooling for the cylinder heads and bases in contrast to poor cooling of the oil in the "wet sump" C-145 engine. In my memory is a series of six or eight consecutive cooling climbs following a series of minor baffle changes directed by Tom on one busy Saturday. His patience was extraordinary while mine was getting thin. Eventually we barely passed the requirement. This pattern of oil temperature testing followed in all successive models of Continental-powered C-170's and C-172's. Tom's reasoning was that oil temperature limits were established by Continental Motors in the days of poor oil quality. As oil composition has improved over the years, the limits can rise accordingly. This is illustrated (in hindsight) by limits of 200°F for the WWII Jacobs engines, 225°F for the early Continental engines and 245° for the later Lycoming's used by Cessna. Therefore, he was relatively unconcerned at oil temperature indications near the red line in climbs in 100° weather.

Another argument was the extremely conservative testing method required by the FAA. This consisted of a full throttle stabilizing run (often 10-15 minutes) at low altitude, followed immediately by a full throttle climb until the temperature peaked. Added to this conservatism is the FAA's unrealistic temperature correction method to a 100° day. To get the most favorable result we often flew to hot climates rather than attempt a cooling climb in Wichita during the winter time. Ideally, we preferred to test in 100° + conditions at sea level.

The above "Salter reasoning" has been vindicated by almost a complete absence of high oil temperature complaints over the years in Continental-powered C-140's, C-170's and C-172's. However, the slightly higher power Lycomings in C-172's did require oil coolers, making life a lot easier for Cessna test pilots.

A 1,000 hour accelerated service test was flown, dawn to dusk, by the same pilots who had previously flown the C-140 service test. As expected, they exhibited poor airspeed control in landing glides on initial check-outs. However, when instructed to monitor the airspeed indicator more frequently, they didn't seem to miss the traditional cowl reference with respect to the horizon. Even though many were low-time (100 hour) pilots, I can't recall any hard landings or overshot landings to the 1800-foot Cessna landing strip. They were asked to perform five landings per hour (some crosswind) and, again, no ground loops were reported.

Unlike the C-140 service test, the C-170 was flown periodically on extended cross-country flights (VFR). I recall accompanying FAA test pilot, Jerry Davidson, and their manufacturing inspector on an FAA function & reliability surveillance trip through the midwest as far as Dayton, Ohio. In the winter time temperatures, we soon realized that cabin heat in the rear seats was marginal, if not totally inadequate. Subsequently, more internal radiating surface was added to the muffler to more than double the heat output at the back end of the "tunnel". Otherwise the airplane performed very well.

In side-by-side take-offs, climbs, top speed and cruise speed runs, and landings with the rented Stinson, the C-170 excelled despite its 145 vs 165 horsepower comparison. In fact, the C-170 actually put it and most other competitors' models out of business. Evidence of its superiority is shown by the great number of C-170's still flying some 30 years later.

I had the pleasure of delivering several C-170's to Cessna dealers in Central and South America where the airplane was very popular. On one memorable flight in November 1947 with a "no-radio" airplane to Bogota, Colombia an overnight stop was made in Ixtepec, Mexico near the Golfa de Tehauntepec. The wind came up in this isthmus between the Atlantic and Pacific oceans, and it was still blowing 50-65 mph when we arrived at the airport. Fortunately the airplane was facing the wind at a solitary tie-down in front of a rudimentary control tower. After a difficult negotiation with the tower operator and the fixed base operator (in my broken Spanish), we agreed that the airplane would be untied with two men holding the wing tips down. When the anemometer showed a "lull" in the wind velocity to 45-50 mph, the operator was to give my wife a thumbs-up hand signal visible to her co-pilot seat position. Then I would apply full throttle with the wing men running forward with the airplane. In reality, they took only two steps before the airplane lifted almost vertically out of their outstretched hands.

Later in that trip while flying from Costa Rica to Panama into a strong headwind my planned late afternoon arrival was delayed until after dark. Knowing that night flying was strictly forbidden after dark without a radio, I ducked into the first available airport (Howard Field) using light signals from the tower. We were met with a FOLLOW ME jeep loaded with U.S. soldiers carrying machine guns. The commanding General later grilled me for an hour while my wife wondered if we would spend the night in a military jail. However, we were allowed to take the airplane on to the international airport at Panama City with some pre-arrangements over the telephone. After this humbling experience, the really difficult part of the flight to Bogota airport (nearly 8,700′ elevation) became an anti-climax.

The C-170A, featuring an all-metal wing (designed by O.D. "Ozzie" Mall and Don Simon) with single lift struts and a dorsal fin, was developed in 1948 and offered as a 1949 model. The unique aileron nose shape was a drastic modification of the well-known Frise aileron having a "downward protruding nose" when the surface is deflected upward. This adds aerodynamic balance and drag to the inside of the turn in hopes of reducing adverse yaw. The Cessna nose shape was intended to exaggerate this "pro-yaw" objective while, at the same time, not overbalancing or *snatching* the aileron near maximum deflection. This attempt to minimize adverse yaw (to reduce demand for rudder/aileron coordination) was partially successful at the expense of rather poor aileron centering in cruising flight. The latter item hampered low-cost wing leveler (auto pilot) operation in later years. However, pilots appreciated the lower aileron forces in maneuvering flight and its effectiveness in preventing wing dropping in stalls. Obtaining the optimum length and shape of the protruding lip on the aileron was a flight test task. This lip also served as a mounting base for the aileron balance weights that are necessary to prevent aileron flutter.

The semi-tapered wing planform compromised the excellent stall characteristics obtained with the rectangular planform used in the 1948 Model C-170 with fabric-covered wings. Therefore, washout (wing twist) in the amount of -1° was built into the C-170A wing outboard of the wing struts. My recollection is that this change was made in two steps to -3° on the C-170B, and it was perhaps the most difficult phase of the flight test program. The decision to use landing lights in the left wing's leading edge caused another source of left-wing-dropping at the stall which had to be corrected by smoothing the plexiglass frame's juncture with the wing surface.

Rigging of the wing was obtained by rotating a cam at each rear spar wing bolt location. When full adjustment was unable to correct wing heaviness, we sometimes had to replace ailerons that were slightly deformed during fabrication. In later years, we were surprised to learn that production test pilots had a trick of tabbing (re-forming) a portion of the ailerons trailing edge. Fortunately this was not noticeable to the owner because the aileron already incorporated a transition from a NACA 2412 airfoil shape to a symmetrical airfoil shape at the tip. This was a concession to production engineers who wanted interchangeability between left and right wing tips.

Since very strong torsional strength could be built into the all-metal wing it made sense to use a single lift strut attached to the front spar of each wing. In addition, it permitted the wide cabin doors to be opened wider for easier access to the cabin. Contrary to published conjectures, this was *not* done to obtain "load-relieving" wing twist in a sharp pull-out from a graveyard spiral dive. In fact, in-flight observations of upper wing surface smoothness in wind-up, high-g turns does not show any abnormal wing skin wrinkling.

The extruded, oval-shaped lift struts were designed to accommodate flat bearing plates (internally) at each extremity. One can see the aerodynamic penalty for the lack of streamlining by flying through a light rain. Water droplets move aft to about 50% chord and simply remain there at cruising speed. We had always planned to measure the speed penalty, but never got around to it, thinking that the production department would never accept a fully streamlined strut configuration.

The dorsal fin, borrowed from the C-195, was added to the C-170A to prevent abnormally large angles of yaw with full rudder deflection in flight. An FAA regulation for positive directional stability in the critical balked landing climb configuration caused problems with the larger flaps. In addition, an optional floatplane version was planned, and that would be even more critical in directional stability. To pass the test after the release of full rudder pedal travel, the airplane would have to return to close to the original heading. The addition of the dorsal fin would not be noticeable to the pilot except for a slight deterioration in rudder control during taxi operations. As often happens, the airplane suffers a weight, cost, and operational penalty simply to meet an ill-conceived FAA regulation on directional stability in the balked landing climb configuration.

To satisfy customers' requests for a floatplane version, we searched for a float size that would permit retention of the landplane's gross weight of 2200 pounds. However, a new rule for 80% reserve buoyancy left Edo without an available float for this project. Consequently, we had to accept an Edo Model 89-2000 float that permitted a gross weight of only 2106 pounds. Thus the floatplane became a 2-place or, at the most, an overloaded 3-place vehicle. The top speed was only 115 mph compared to 140 mph for the landplane. A photograph of the prototype floatplane on its first take-off from a dolly is shown among the photographs.

Despite the presence of the dorsal fin we could not pass the aforementioned directional stability tests because of (1) destabilizing effects of the floats and (2) a high amount of water rudder cable friction which prevented the air rudder from returning to neutral. We lubricated all pulleys and fairleads in both the air rudder and water rudder systems with little success. Then we loosened all cable tensions to a minimum value and tried rather weak rudder centering springs before presenting the floatplane to the FAA. The alternatives were (1) auxiliary seaplane fins that would create unwanted weathervaning tendencies in crosswind taxi runs and (2) much stronger rudder centering springs that would wear out the pilot in correcting yaw in climbs and, possibly, in cruising flight. Of more importance is the frequent need for *full rudder travel* in most taxiing operations, and the floatplane pilot would not tolerate heavy rudder pedal forces.

Aside from directional stability problems, oil cooling was next in importance. As illustrated in a photograph, we had to install an oversized cooling lip on the lower cowl. From this "plowing" photograph one can understand why cooling is critical in floatplanes, especially in the take-off runs which often last a full minute or more.

We were most fortunate to get an experienced floatplane pilot, Joe Tymczyszyn (the flying alphabet), from the Kansas City FAA regional office to conduct the final FAA certification tests. Having flown many floatplanes in the Seattle area, he knew first hand the pros and cons of a too-large vertical tail as previously described. To his credit, he agreed with our bending the rules and took responsibility for those actions. This is a rare trait for a bureaucrat, but, after all, Joe had been a WWII P-47 pilot who was used to making decisions. His favorite expression was "what do you expect for $2200 a year?"

Joe's obsession for getting the best possible airplane to the market place (despite any hindering FAA regulations) led to his extraneous research on spins during normal certification testing. Claiming that someday he was going to write a book on the subject, he had me perform many additional spins with unusual entry and recovery techniques. Then he would record such items as stabilized spin turns, recovery turns, aileron usage, character of spin, altitude loss, etc, for his records. He indicated that similar data was being obtained from other manufacturers on a bootleg basis. However, his talents and good common sense were diverted to the demanding tasks of certifying the first jet transport airplane (Boeing 707) and then the Douglas DC-8 among others. I suspect that the "spin analysis" book remains uncompleted.

Skiplane testing on the C-170A was performed in 1949 using the Federal A2500/A2500A skis and tail ski. As with the C-140 and C-195 skiplanes, development consisted mainly of determining the correct ski-positioning-bungee strength and obtaining a shimmy-free tail ski that gave adequate steering in various snow depths.

Among the demonstration flights to potential customers was one to the legendary Alaskan bush pilot, Sig Wien. He was looking for a floatplane capable of hauling fish. Having been used to much larger floatplanes, Sig manhandled the small C-170 in an uncoordinated manner. It was obvious that he hadn't learned the fine points of flying in his bush flying exploits, but maybe that wasn't important in Alaska!

The 1952 C-170B featured new slotted flaps that could offer extra lift for take-off and far more lift and drag for landing. We referred to the design as the NACA "2h" configuration, since the wind tunnel performance curves had been presented as Figure 2h in the NACA report. A clever internal flap track design was designed to provide an obstruction-free lower wing surface. This would be especially valuable in the high-wing C-170's where people walking beneath the wing would not bump their heads on external hinge brackets.

We had some misgivings over the effect of these more powerful flaps on increasing the nose-down pitching moments and making 3-point landings more difficult. Happily, these pitching moments were counteracted to a large extent by a nose-up tendency resulting from the stronger wing down-wash striking the horizontal tail. Thus, very little retrimming was required from an 80 mph *flaps up* glide to a 70 mph *flaps down* glide. I recall project engineer, Web Moore, being overjoyed at this finding. We were always puzzled when magazine writers criticized a transient nose-up motion with initial flap extension. To Cessna pilots it was practically unnoticeable, probably because we extended the flaps smoothly and evenly. Jerking the flap handle upward would produce the momentary nose-up motion. However, the overall result was far superior to other airplanes of that era (and this era).

Our marketing people coined the phrase "para-lift flaps", implying that they allowed the airplane to descend like a parachute. Although the advertising program was committed, we caused some consternation in those circles by reminding them that the airplane descended more *rapidly* with the flaps *extended* than with them *retracted.* As an example of the power of advertising, we heard no public outcry over this inaccuracy (or deception).

These slotted flaps have been highly successful, and have been carried forward into all succeeding Cessna models with strut-braced wings. In the C-170B they permitted a 10% shorter ground run at 10° deflection, but that advantage was lost in the climb to a 50-foot obstacle. In later more powerful Cessna models they also proved to be useful in total take-off distance over the 50-foot obstacle.

In looking back over the C-170/A/B flight tests, I am reminded of a few amusing incidents such as the time that a rivet sheared with a loud pop as we reached a dive speed about 10-mph over red line speed. It sailed through the cabin and lodged in the hair of FAA test pilot, Jack Hurley. We had anticipated some windshield or cabin door distress, but not a solitary rivet. Of course we were really looking for flutter, following "raps" of the control wheel (aileron and elevator) and the rudder pedals. As in all other Cessna prototypes, we were unable to induce any control surface flutter. Much to our chagrin, the missing rivet location was never found. However, Jack approved the dive test and vowed to wear a cap on the next one.

Another amusing (if not frightening) test was at Strother Field near Winfield, Kansas, where we were attempting to find the friction adjustment limits for the swiveling mechanism in optional oversized tailwheels. To simulate a high-elevation airport and resulting high touchdown speeds, we conducted these landings in a 10-15 mph tailwind. When shimmy was encountered, the whole airplane shook violently until it was decelerated to only 10-20 mph with heavy braking. This period of ear-shattering noise seemed endless in the prototype which had no soundproofing, no upholstery, and no rear baggage compartment curtain. We felt absolutely helpless and thought, surely, that the tailwheel assembly would depart the airplane—it never did. Years later on a vacation flight to Mexico City, at 7339 feet elevation I experienced tail wheel shimmy on a take-off run in 90° temperature. However, in that case I was able to lift the tail prematurely and stop the shimmy. No doubt, pilots who operate from high-elevation airports keep the friction adjustment at a high setting at the expense of easy swiveling with differential braking.

In conclusion, the C-170 models, priced at only $5,475 in 1948 and $8,295 at the end of production in 1956, were an immediate and enduring success. Production quantities were 730 C-170's, 1,536 C-170A's, and 2,907 C-170B's for a total of 5,173 airplanes over a nine-year span. They allowed Cessna to continue to dominate the general aviation market and, perhaps most importantly, they served as the genesis of the most popular airplane of all time—the Cessna 172.

C-170 (309) BLC Research Airplane

The U.S. Naval Research Laboratory, in conjunction with Wichita University, had teamed up with Cessna as early as 1951 to explore the benefits of boundary layer control (BLC) on a highly modified C-170 called the C-309. The BLC technology was directed by Professor Kenneth Razak of W.U., while Cessna's Research Department, headed by Alex Petroff, spearheaded the Cessna participation. The project engineer was Jack Fisher, and Web Moore coordinated the airframe modifications. Other Research Department participants were Bob Wattson, Bill Wise, Allyn Heinrich, Marvin Gertsen, and John Smith among others.

The project consisted of modifying two sets of C-170 wings to (1) provide three-quarter span flaps with symmetrically-deflecting ailerons and (2), suck boundary layer air over the inboard flaps and discharge this air over the outboard flap segments and the ailerons. The second set of wings was installed on the original fuselage for the C-309C program. This method of controlling the boundary layer was invented by the Germans before World War II and was discovered in their research files by the Allies after their defeat. It is called the "Arado" system, and this was our country's first attempt to explore the concept. Details of the system are illustrated in a sketch presented at the end of this chapter. The program consisted of exploring various methods of pumping the "circulation control" air as listed below:

1. Jet (ejector) pump - compressed air and burner(309)
2. Axial fans - D.C. generator and motors (309A)
3. Jet pump - ethylene oxide (C_2H_40), (309B)
4. Jet pump - hydrogen peroxide (H_20_2) (309C)

In addition a fifth system was tested which, essentially, was a modification to the second listed above. It consisted of the same generator and motor-driven axial fans; however, the primary source of electrical power was storage batteries which were recharged by the generator.

The C-309 had an AiResearch auxiliary gas turbine engine to drive the pump. It was flown initially by Hank Waring on August 17, 1951, but soon thereafter, the project test pilot was E.B. "Fritz" Feutz.

The second model (309A) used a large belt-driven electric generator on top of the engine which powered four "motored" fans in the wings. Although this gave satisfactory operation, the resulting power drain from the engine significantly reduced the benefits from BLC in take-off performance. Subsequently, as described above, four batteries were installed to eliminate this degradation at a considerable weight penalty. This led to the development of a so-called mono-propellant fuel as a source of high energy gas for the jet pump. An ethylene tetra oxide-red fuming acid system was used in the C-309B aircraft, and a hydrogen peroxide system was used in the C-309C aircraft. The latter system used a platinum catalyst to generate high-pressure steam. With these early experiences with rocket fuel propulsion energy under the direction of the Rocketdyne Corporation, the flight testing challenges became much more formidable. Project test pilot, Fritz Feutz, describes some of those flights in the following paragraphs:

> "The 309C was ready first, and Rocketdyne Corp. had a crew with a truck to service the thing. I don't remember the airplane tank capacity, but it filled the whole back-end with the plumbing, valves, and everything else. As this was the beginning of "rocket" technology, sys-

disturbances near the wing root and undisturbed tufts over the ailerons, appeared ideal. As expected, however, it was obvious that most of the development would have to be performed on the prototype where surface roughness and scale effects would be major influences.

One of the first items to be tackled was an undesirable longitudinal trim change following the application of power in a balked-landing climb. Excerpts from the aforementioned SAE report are shown in the following paragraphs:

> "Out-of-trim push forces as high as 60-70 lb were obtained in this configuration. This excessive trim change was attributed mainly to the fact that the increase in power results in a significant increase in downwash behind the flapped wing. This increases the negative angle of attack, resulting in increased negative tail loads which must be offset by a change in stabilator deflection. This was verified by angle of flow measurements ahead of the tail which showed an increase in downwash angle of 5.5° with the application of power as compared to power off. The change in stabilator position to hold the same trim speed was noted to be essentially the same as the angle of flow change. This change in stabilator travel was naturally opposed by the anti-servo tab, thus resulting in the heavy stick forces. Heavy trim changes were found in other configuration changes also, although they were less likely to be encountered by the pilot in normal flying.
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> "A reduction in out-of-trim forces was obtained by reducing the tab-stabilator gear ratio, but this was also accompanied by an undesirable reduction in stability levels. Flight tests were made to evaluate the benefits of using artificial devices (bobweights and downsprings) to reduce the need for anti-servo action. These tests also included simulated changes in hinge line position of ±2% of the tail MAC. The evaluation of various changes showed that the out-of-trim forces were not appreciably changed by factors other than the amount of engine power that was used.
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> "Based on earlier unsuccessful testing of a stabilator with a tapered planform on a C-182, the C-177 prototype used a stabilator having a rectangular planform and a higher aspect ratio. This was done to provide as much area as possible outside the slipstream and also to provide a hinge line coincident with the 25% chord line along the tail span. The airfoils used on the tail were symmetrical, tapering in thickness from 12% at the centerline to 9% at the tip.
>
> "The ratio of the anti-servo action of the tab was varied over the range of stabilator travel to provide a maximum rate of change at full down stabilator and a minimum rate of change at full up stabilator. By this means, low landing stick forces could be achieved while still retaining high stability levels in cruise. In the normal cruise range the tab gearing is 1:1, but in the full up stabilator range, it was decreased to only 20% of this value."

The original anti-servo tab length of 90% of the stabilator span gave excessive longitudinal stability and maneuvering stability (55-85 lbs/g). Reducing the tab span to 55% gave a more reasonable 35-50 lbs/g and longitudinal stability levels comparable to the C-172 levels. In addition, the rather high landing-flare stick force of 35 pounds was reduced to a more typical 25 pounds at forward C.G. The out-of-trim stick forces in the missed-approach (balked landing climb) became no more than 25-30 pounds which were comparable to the C-172 values.

With the reduced tail arm length in combination with the wide-chord ailerons and the rather high 3° of wing dihedral, an excessive amount of adverse yaw occurred in sharp turns. This required 10° of rudder deflection (at low speed) for a coordinated turn. Thus it was necessary to reduce the wing dihedral to only 1.5° to minimize heavy rolling moments due to yaw. A more important change was an increase in vertical tail area of 20% with a slight increase in aspect ratio.

The original 40° wing flap setting produced a high rate of sink in the final-approach glide. This was attributed to drag-reducing extended wing skins along the flap gap, which, in turn, caused flow separation over the long flap span. In combination with the somewhat limited stabilator power at forward C.G. it was difficult to check the rate of descent in a flare at low speed. Consequently, for this and other reasons the maximum flap setting was reduced from 40° to 30°. This gave a stall speed penalty of only 1 mph, and it increased the total landing distance over a 50-foot obstacle by only 50 feet.

With the large, powerful flaps giving more than enough drag for a steep power-off descent, we had envisioned no need for forward slips for steeper descents. Crosswind landing approaches in sideslips were typically performed with only one-half flaps for better rudder control. However, we were disturbed with control in a sideslip as related in the following paragraphs from the referenced SAE report:

"A nose-down pitch was encountered during sideslips with flaps extended 40° in the normal approach speed range. This pitch-down was not evident at the rearward center of gravity locations and was not appreciably affected by airspeed. However, it became more noticeable as the center of gravity moved forward to positions within 5% of the most forward point on the envelope.

"Tuft studies of the rear fuselage area and of the horizontal tail showed that airflow direction became increasingly more negative on the low wing side as the sideslip angle was increased. On the opposite side of the vertical tail, the tufts showed a slight decrease in flow angle (more positive) which was attributed to the vortex from the inboard edge of the flaps being displaced along the tail span.

"Tuft studies of the lower surface of the horizontal tail showed that it was stalled in an area equivalent to approximately 40% of the semi-span of the tail. No stall was evident on the high wing side of the slip or the outer portion of the tail on the low wing side.

"The calculated angle of attack of the tail for trim at the most forward center of gravity at gross weight was -11° which compares to an estimated stall angle of 15° for the tail section. The tuft studies indicated flow angles well above this and the nose-down pitch, therefore, was attributed primarily to the loss in lift due to tail stall. In addition, some loss in lift could also have occurred due to a reduction in angle of attack (during sideslips) on the opposite side of the tail.

"The nose-down pitch characteristic was eliminated with 25° or lesser flap settings. It was considered mild with 30° flaps and, at this flap setting, it is felt in the controls as a heavy buffet at extreme sideslip angles and is easily controllable.

"In addition to this characteristic, the advantages of only 30° flaps (instead of 40°) were considered to:

1. Improve the landing characteristics because of excessively high sink rates with full flaps as discussed previously.
2. Provide easier flare-out capability.
3. Improve the rate-of-climb in the balked landing go-around."

For all of these reasons, the maximum flap setting was established at 30-degrees for initial production.

Despite the good stall characteristics predicted by the wind tunnel model, the prototype exhibited a rather sharp wing-dropping tendency at the stall. We had hoped that the more highly-cambered airfoil section at the tip and the 3° geometric twist in the wing would preclude this possibility. However, because of the relatively sharper nose of the 6-series airfoil (as compared to the 2412 section which is used on other Cessna single-engine models) it was found to be less tolerant of minor surface irregularities at the leading edge. Stall strips, therefore, were evaluated on this prototype. Flight tests showed that the strips could be used to insure that the inboard sections of both wing panels were well stalled prior to the outboard sections, thus resulting in good roll control at the stall. Because of the simplicity of the strips and since they were found to increase the stall speeds by only 1 mph or less for all flap deflections, they were adopted for production. The strips are 12 inches in length.

Several spanwise positions were evaluated and the final selected position was at a point on the wing corresponding to the outer end of the horizontal tail span. Locations more inboard than this did not provide as good lateral control and, in addition, caused excessive tail buffeting. Locations further outboard increased the stall speeds by a slightly greater increment than the final position.

Stall speeds for the C-177 were 7-mph higher than in the C-172 with flaps retracted at roughly the same weight. In the maximum flap condition, this penalty was only 4 mph. These penalties are attributed not only to the airfoil difference, but, also, to

In addition, the use of a maximum flap setting of 30° was established to insure good landing and control characteristics.

In the areas of performance, improvements were accomplished by the development of an optimum wing-fuselage juncture and fairings for the tubular landing gear. These improvements, along with the cantilever wing and other design features of the airplane to reduce drag, resulted in a minimum drag coefficient 10% less than a comparable airplane in the same performance class like the C-172.

Despite all of this good work and Cessna's heroic effort to produce as many as 12-airplanes per day (1164 units in its first year of production), we were disappointed to learn that production tolerances on smoothness of the wing and tail leading edges were quite variable. Occasionally, an airplane in Mort Brown's production flight test activity would exhibit the previously-described pitch-down motion in flaps-down sideslips. Some of our customers would experience this in a crosswind landing flare where the pitch-down would bang the nosewheel hard enough to deform the firewall. We were unable to duplicate this fault on the prototype. However, it had been reported by a few service test pilots on the first production C-177 which had been used for a 1,000 hour accelerated service test which included 5,000 landings.

Another problem was their approaching at excessive speed and over-controlling and porpoising in the landing flare. This, too, often resulted in a hard touchdown on the nosewheel and a wrinkled firewall. It became obvious that many Cessna owners had difficulty in making the transition from elevator control (slow pitch response) to stabilator control (quick pitch response). The occasional result was a pilot-induced-oscillation (PIO) in the landing flare by an embarrassed pilot.

This latter problem was described to the author by the manager of the Longhorn Flying Club at the University of Texas. They had damaged several Cardinals' firewalls due to porpoising. In the phone conversation, I asked if he could demonstrate the phenomenon for me if I made the trip to Austin. He insisted that he could show it quite easily. Upon my arrival in the service test Cardinal, we flew several of the flying club's Cardinals. To his surprise, this manager was absolutely unable to duplicate their porpoising problems—nor have I to this day. In fact, the problem essentially vanished as pilots became more accustomed to the rapid pitch response to stabilator movement.

The pitch-down motion in flaps-down sideslips was a more serious problem, however. Production test pilots became aware of a more noticeable waviness in some of the leading-edges of the wing, and occasionally, a 2-foot length of paint overspray that caused wing-dropping tendencies at the stall. This had to be corrected by applying body filler material on the leading-edge or rubbing compound to remove the almost invisible overspray. There was also questionable uniformity of the stabilators, giving as much as 15-mph deviations in minimum trim speeds. On some airplanes they reworked or actually replaced the stabilator with some improvement. This led to the decision to incorporate slots in the stabilators' leading-edges so that they could tolerate a steeper downflow of air without stalling the under-surface of the stabilator. This solved the problem, and a fleetwide "Cardinal Rule" retrofit was planned at no cost to the customer. In the meantime, a service bulletin called for a temporary installation of a simple sheet metal plate that would limit the maximum flap deflection to 15°. We were paying the price for these thin skins!

As these many improvements were added, the empty weight of the C-177 grew alarmingly. Very late in the development program an all-out war against excess weight was started. This included reductions in wing skin thicknesses as well as shaving excess thickness off many other structural and non-structural pieces and parts, and reducing the mass balance weight in the stabilator at the expense of some stabilator (and control wheel) motion in very rough air. This was a painful process for designers, and it resulted in an airframe that seemed rather flimsy when compared to the C-172. In particular, interior controls and cabin doors could not take very much abuse, and customers often complained about quality. Bruce Barrett remembers cruising across Arizona one bumpy afternoon when he experienced an almost explosive copilot's door opening. When the dust cleared he found all the maps formerly occupying the copilot's seat gone. One of the maps was wrapped around the stabilator leading-edge which he retrieved after landing at Flagstaff.