Seth Anderson and his Honda Civic powered BD-5.

Photo Courtesy Seth Anderson

A CRITIQUE OF THE BD-5 CONCEPT

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(Part 1 of 2 Parts)

Next Month: Flying The BD-5

About the Author

Seth B. Anderson is a Research Assistant for Interagency Programs at NASA-Ames Research Center at Moffett Field, CA. Mr. Anderson has been with NASA and its predecessor, NACA, for over 40 years. He holds a MSE (aero) degree from Purdue University. He has served as a researcher and supervisor over a broad range of aeronautical disciplines. This includes performance, flight dynamics, and operating problems for a wide variety of aircraft from V/STOL to supersonic transport and has written over 80 reports and papers. He has specialized in defining handling qualities requirements for V/STOL and conventional aircraft and is the principal author of AGARD Report N. 577 on V/STOL Handling. His consulting activities include the FAA, Navy, Marine Corps, Air Force, Army and international organizations such as AGARD, the RAE, ONERA and DFVLR. He is a member of the NASA Aeronautics Advisory Ad Hoc Subcommittee on General Aviation Energy Efficiency and Utility, the AIAA General Aviation Systems Technical Committee, the Experimental Aircraft Association and holds a Commercial Pilots' License and Aircraft and Powerplant (A&P) License, and a U. S. Hang Glider Association Advanced (H-4) Pilot Rating. Mr. Anderson is an Associate Fellow of AIAA, a member of Pi Tau Sigma, mechanical engineering honorary, Sigma Delta Psi, national athletic honorary, and Sigma Gamma Tau, national honor society in aerospace engineering. His work has recently earned him the award of Distinguished NASA Aeronautical Researcher.

In recent years, Seth has been an annual participant in the Forums programs at Oshkosh, making presentations on his BD-5 project.

Introduction

Almost a quarter of one's nominal life span has elapsed since the idea of a high performance, low cost, easy-to-build, sport plane, **the BD-5** was introduced in 1967. The popularity of this concept was overwhelming when exhibited in the early 1970s, since, never before had such a sleek-looking, high performance aircraft been offered in kit form for less than $2000. The goals of the BD-5 program were credible . . . "to provide the amateur with a design configuration that has been thoroughly designed and tested to certified aircraft standards, one that possesses flying qualities and performance far superior to any available aircraft, and to make readily available, aircraft quality materials in one package to insure that the builder will have a safe, quality flying machine when he rolls it out for the first flight". The BD-5 never achieved these goals for reasons which may not be readily apparent.

Each year for the past ten years, I have talked about the BD-5 aircraft at the EAA Forums. I have been impressed with the sustained interest shown by a large audience comprised of builders and others interested in improving the basic BD-5 design. There is no question that it is an impressive aircraft not only on the ground but more so in the air giving the appearance of very high speed flight (it travels its own length in a short time). But why have only a small number (approximately 50) of the original 4000 kits sold been completed and flown? There's more to the story than . . . "Jim Bede not giving us all the parts". Were the original goals unrealistic for the technology available in the late 1960s? Is the BD-5 really difficult to complete for the average homebuilder and what about its safety record — is it difficult to fly, requiring a skilled pilot with thousands of hours in high performance aircraft?

I would like to attempt to answer these questions based on my experience in building and flying this unique design. One may hope that there is some merit in critiquing the total concept — both from the standpoint of helping current BD-5 builders have a safer aircraft and for others who still dream of designing a better pusher concept.

One must recognize that in critiquing any aircraft design, emphasis tends to be placed on "finding fault". Because there are so many good things about the BD-5 concept, I hope a fair balance of pros and cons result from this review.

In the following discussion, comments are made about design features which are somewhat unconventional but not totally unique to the BD-5 concept. These include: pusher propeller, mid-fuselage engine location, extended drive-gear reduction system, and side stick controller. In addition, design and construction details, aerodynamic features affecting performance, handling qualities (stability and control), and operating systems are reviewed.

Design and Construction — Primary considerations for selecting a given aircraft for most homebuilders are performance (speed, range payload, etc.), appearance, ease of construction, and cost. At its inception, the BD-5 probably scored a perfect 10 in all these areas — where else could you get a sleek-looking, 200 mph aircraft using a 40 hp (throw away) engine, with detailed, step-by-step building instructions — all for $1,850.00?

Regarding performance, obtaining high speed is no mystery from the aerodynamic drag standpoint. The configuration must be sized for low wetted area, use airfoils with laminar flow potential, and be lightweight to minimize induced drag — all these features were embodied in the BD-5 design. However, aircraft designers know very well the key to success or failure in achieving high performance is the powerplant. In the quest for superior performance many aircraft programs, both military and civil, have failed because the powerplant was not available at the power to weight ratio (P/W) advertised. The BD-5 clearly fell into this powerplant debacle. Early plans called for the use of a 32 hp Polaris snowmobile engine having high power/weight with relatively low cost. For several reasons the original goal to use two-cycle power was never achieved.

A repeated criticism of Jim Bede's program has been . . . "Why didn't he wait until he had an engine thoroughly checked out before selling the kit?" Using hindsight, the answer is that there was no available engine ideally suited for his concept. Even after 20 years, there still is no engine in today's market that fulfills the original 1970 goals of high P/W, good realiability and low cost. True, today's engines for ultralights have made great gains as installed on ultralights; however, when installed in a fuselage, with an alternator, starter, mounting structure, and proper exhaust system, the P/W is reduced considerably from the "one" value quoted by the engine manufacturers. And price? — almost as much as the original total BD-5 package.

Most experimental aircraft builders know that a much greater challenge exists in trying to develop both an experimental aircraft and experimental engine. The most succesful sport aircraft programs have used an FAA certified engine. But some people say . . . "Isn't that what experimental aircraft building is all about? . . . taking on new challenges?" Yes, but in my opinion, don't expect to feel comfortable flying a totally experimental aircraft over the Rocky Mountains. Jim Bede's BD-5 concept has certainly offered the opportunity to "discover" an optimum engine application. A wide variety of engines have been flown in the BD-5 ranging from a 40 hp Hirth to a 300 hp double row Mazda rotary.

A key to the success of using some types of engines is the speed reduction system. For most engines, high power to weight is achieved by running the engine at relatively high rpm — 6000-10,000 rpm for piston engines and much higher for turbine types. This requires a speed reduction to avoid large losses in propeller efficiency. The BD-5 drive provides a speed reducton of 1.60:1. Advantages of a long drive shaft system include locating the engine close to the CG for improved balance and a more ideal fuselage shape (small, circular cross sectional area) to minimize "boat tail" drag. This small fuselage area can also have a beneficial effect on propeller efficiency (5-7% improvement) since there is no blockage of flow to the propeller. To realize this gain, the propeller airfoil section shape must be retained close to the spinner.

As a point of interest, I carved a propeller optimized for the BD-5 with the generous help from a good friend, Ole Fahlin, the Master Propeller Builder. A supercritical MS-1 series airfoil was used to provide improved static thrust and minimum high speed tip losses. Henry Borst donated his propeller computer code program to derive the optimum chord and twist distribution for the blades. The performance of this propeller is far superior to others used on the BD-5.

The drive shaft system in the BD-5 uses a ribbed belt and pulleys. It was well-engineered, lightweight, efficient, and has had few problems when properly constructed. Because the center line of thrust is above the vertical CG, a nose-up trim change with reduction in power can be troublesome (discussed later). Of course, the high location provides good ground clearance allowing a larger diameter (more efficient) propeller to be used.

If for varous reasons a pusher design is selected, cooling can be a problem particularly when the engine is installed in the mid-section of the fuselage. Engine cooling problems on the ground are more severe in the BD-5 concept, because there is no benefit from propeller slipstream and convective and radiant heat dissipation characteristics are inadequate. In general, compared to a conventional tractor design there have been fewer successful "buried" engine installations. Air cooled engines have operated successfully when installed in the fuselage mid-section, however, a fan is usually required and because it is basically difficult to provide an efficient cooling air ducting system a large cooling drag penalty results. When the aircooled engine is located far aft as in Burt Rutan's VariEze design, inflow to the propeller provides a small benefit for ground cooling. The relatively blunt rear end is not an ideal aerodynamic shape and there is an associated drag penalty.

Logic suggests that the price paid for engine cooling can be potentially less for a liquid cooled engine if the heat absorbed from the engine by a radiator can be efficiently ducted to generate

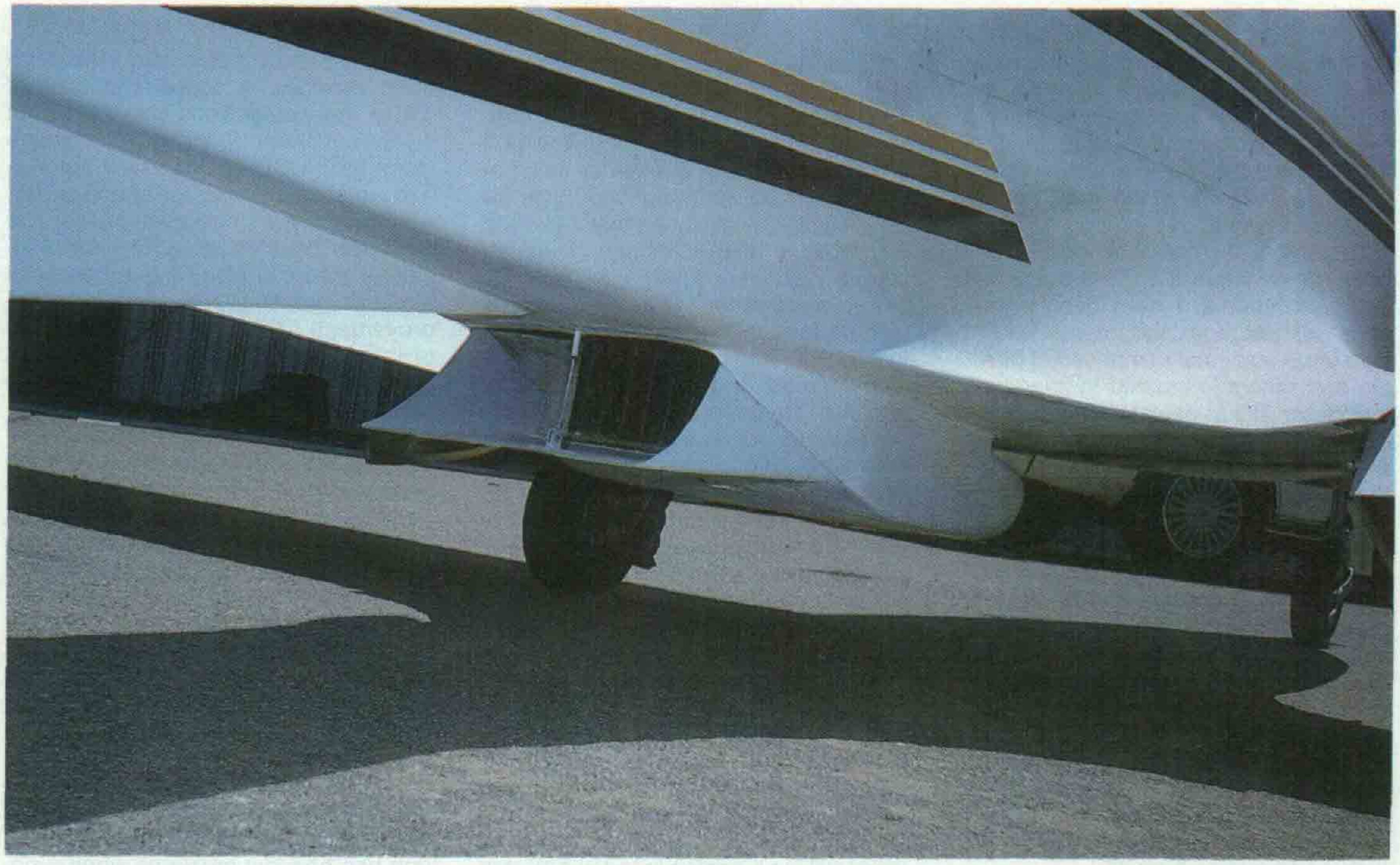

Photo Courtesy Seth Anderson

P-51 style coolant radiator on the author's BD-5.

thrust as it is exhausted into the airstream. A liquid cooled automotive engine is relatively heavy but can be used to good advantage by turbocharging. Fortunately, several automotive engines are rugged enough to handle the additional stresses of higher engine power (BMEPs). The weight of the turbo is offset in that no exhaust muffler is required. Since the exhaust energy is spent in the turbo, this results in a very quiet aircraft in the pattern. The most popular engine installation for the BD-5 thus far has been the liquid cooled Honda Civic 1237cc (aluminum block and head) EB-2 engine. Jerry Kibler (an early BD-5 distributor in Southern California) should be given credit for very successfully developing the turbocharged Honda engine installation for the BD-5. Dynamometer tests of the Honda EB-2 engine conducted by Andy Russell at Kansas State University, indicated that the horsepower of the basic engine could be almost doubled by supercharging. In addition, torque increased linearly with engine rpm rather than flattening out at 2500 rpm as it did with the normally aspirated engine. These good torque characteristics allow a high pitch (cruise) propeller to be used without an unacceptably long (low thrust) take-off run. Jim Bede knew about the Honda engine late in the development process, but elected not to use it for two reasons: (1) A stretch of the fuselage would be needed, and (2) he had no assurance, and rightfully so, that he could receive 4,000 engines from the Honda Company for use in an experimental aircraft.

A successful follow-on of the Kibler Honda design has been carried out by Keith Hinshaw in San Jose, CA, where the radiator is located in a vertical position just aft of the pilot's backrest. This forward location allows for a large-area radiator and a conventional cooling fan installation. Its major engineering drawback is that the hot air from the radiator flows back over the engine which prefers cool air from an outside source. In addition, it is very difficult to efficiently duct the air from the under side of the fuselage to the radiator since a sharp 90 degree turn is required and an optimum diffuser duct geometry cannot be made in the limited space available. The system does provide adequate cooling even on a hot day — albeit with considerable cooling drag penalty.

To provide a more efficient cooling system, the radiator in my BD-5 was installed behind and below the Honda engine using a ducting arrangement quite similar to that used in the P-51 Mustang. Wind tunnel tests of the P-51 cooling system showed essentially no increase in overall drag since the profile drag of the duct was offset by the thrust obtained from discharging the heated air at high velocity parallel to the airstream. To offset the rear CG shift due to radiator location, the Honda engine was mounted approximately five inches further forward than other BD-5 Honda installations. In spite of the close proximity to the cockpit, engine noise is minimal. This radiator installation does not readily lend itself to a ground cooling fan but has proven to cool very effectively once in the air. Several small NACA inlets located on the bottom of the fuselage provide ram air cooling to the engine, since even liquid cooled engines benefit to a large degree from air cooling.

The cockpit design of the BD-5 is well laid out with the side stick controller located conveniently at arm's length where one is predisposed to use only wrist motion. However, the cockpit is best for little people; the small width precludes overgrossing — fat pilots have no hip room. Tall pilots (I am 6' 3") require the back rest to be against the engine firewall. The semi-reclined posture (45 degrees in my aircraft) was initially disturbing. After overcoming the urge to sit up where you can **really** see — you find solace in knowing you automatically have extra G tolerance. Visibility is surprisingly good — forward through the very streamline windshield as well as downward and to the rear.

One serious deficiency for the BD-5 and other well known homebuilts is crashworthiness. The basic problem is that not enough space is available around the pilot to allow gradual deformation of the structure in a crash. Sitting on the bottom of the fuselage may be acceptable for gliders which have relatively low landing speeds and above average vertical flight path control. A crash landing in many high performance homebuilts is survivable only if both vertical sink rate and longitudinal deceleration can be low. The problem defies an easy solution when small wetted area is a design goal for high speed performance. Perhaps additional research and improved materials may help. One fact for sure — a 5-point seat belt is mandatory. In addition, good control of flight path must be maintained down to ground contact.

Wing design features and construction methods are of special interest because of the pronounced effect on performance and handling qualitites. The tubular spar construction method used in the BD-5 has several advantages including ease of wing removal, low cost, and simple airfoil rib assembly. Because the spar has a constant diameter spanwise, the tip airfoil section is relatively thick (18%) — a tradeoff made between cost of a tapered tube, drag and wing stall behavior (discussed later). Under aerodynamic load, the BD-5 wing skin buckles between ribs — not nice to look at and not helpful for achieving laminar flow. Many builders have added extra ribs (reduced rib spacing) and the BD-5J uses a thicker .025" wing skin thickness (nominally .020") to achieve a smoother in-flight airfoil contour.

Areas of concern in wing construction for many builders include minimizing twist in each wing panel and obtaining the correct leading edge contour and radius. Both of these items influence stall behavior. Hard tooling was used to drill and assemble the wing structure, thereby minimizing twist. The wing skin nose radius can very easily develop permanent creases due to handling and shipping. In addition, local deformities can occur where the skin is joined to the wing ribs since the ribs are discontinuous near the leading edge. As discussed later, these leading edge deformities can adversely alter both maximum lift (C_{Lmax}) and stall characteristics.

Because of known low speed deficiencies of the wing used on the BD-5, modifications were made to the 64,212 airfoil. Ray Hicks of NASA-Ames Research Center had developed a computer-aided airfoil program to improve C_{Lmax} for NACA series airfoils. One modification consisted of increasing the nose radius and adding upper surface camber. This was accomplished by using foam and fiberglass to form a "Mod B" airfoil section on the upper surface back to the 40% chord station and over the complete span except for a 20" portion near the mid-semispan where the fuel gas cap is located. An indirect benefit was elimination of skin wrinkling under aerodynamic loads. Advantages from this mod include: (1) lower stall speeds, (2) better stall behavior, and (3) improved lateral control (and roll damping) at high angle of attack (AOA). Improved stall behavior results from the fact that a strong vortex is shed from the leading edge discontinuity (at the mid-semispan) where the original and the modified airfoils meet. This alters the boundary layer flow on the outboard portion of the wing such that AOA for stall is increased about 8-10 degrees resulting in good lateral control long after separation has occurred inboard.

Photo Courtesy Seth Anderson

Seth Anderson's specially designed propeller for the BD-5 — featuring a supercritical airfoil.

In summarizing the BD-5 construction details, two points stand out in my mind. First, the BD-5 was not an **easy** aircraft to build even if all the plans and materials would have been supplied. There were too many small parts to fabricate and assemble. In addition, much more tooling was needed than originally projected. In addition to the usual small tools (files, tin snips, hand drill, etc.), a 3' metal shear, metal bending brake, drill press, disk sander, metal cutting lathe, milling machine, welding equipment and band saw were required. Instead of the projected 600-800 hours of construction time, I spent at least 3,000 hours — and I had an above average background of experience to draw on. Jim Bede was too conscientious — he more than beat the 51% FAA builder construction rule. True, he took care of the really hard parts (compound curve sections for the fuselage) but he failed to supply one of the more difficult components — the drive system. It took over six months of intensive effort to make and assemble mine. A second, and more favorable point is related to the methods developed for the aircraft assembly process. For the uninitiated in particular, the step-by-step, clearly stated construction and assembly process details helped the builder develop aircraft construction skills progressively so that the more difficult tasks could be undertaken with a high degree of confidence. The joy of building and feeling of accomplishment as each major component was completed was very gratifying. The Bede organization must be given due credit for this very successful approach to aircraft construction developed in the early 70s.

A conscientious effort must be made to minimize weight during construction if good cruise peformance and low stall speeds are to be achieved. The empty weight of my BD-5 was kept down to 500 lbs. — about 10% lower than other Honda equipped aircraft; but a far cry from the original projected empty weight of 310 lbs. Cruise performance at 10,000 ft. is 180 mph indicated using 30" Hg, 4800 rpm, and 3.5 gph resulting in a TAS over 210 mph — not bad for only 60 hp. Many BD-5 builders tend to overload their aircraft with "frills" that are not essential for the type of flying normally conducted with this aircraft. Examples include dual IFR equipment, RNAV, Loran C, cockpit heater, etc. In my opinion, it is not the type of aircraft to use on extended cross-country flights (no baggage room anyhow), but rather a day, VFR, close-to-the-airport sport aircraft that for the sheer fun of flying is surpassed only by a high performance fighter.

Photo Courtesy the Author
Seth Anderson's Honda powered BD-5.

A CRITIQUE OF THE BD-5 CONCEPT

Part 2

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Handling Qualities and Operating Problems

Next, what is the BD-5 really like to operate and fly? Does it require exceptional skill to safely operate this aircraft which **appears** to be short-coupled, oversensitive in pitch and difficult to land because you're sitting only 12 inches from the ground? Basically, the answer is no, although the BD-5 concept has some peculiarities which require attention. Some feeling for this reasoning can be obtained by going along for a typical flight. My comments are based on three flights in the BD-5J at Newton, KS and over 50 hours in my BD-5B based at Watsonville, CA.

First, do you have your crash helmet on? I'm a firm believer in head protection and would never fly in **any** small cockpit where your head is close to the canopy, particularly in high performance aircraft. After a routine ground preflight check, the BD-5B aircraft is pushed to a location where a short taxi run can be made to the active runway. Not only does this provide some needed exercise (the aircraft only weighs 500 lbs.), but it is necessary to minimize engine running time on the ground because of cooling constraints. For a normal temperature (75 degrees F) day my aircraft has only five minutes from engine start-up until coolant temperatures approach 200 degrees F — an arbitrary maximum limit for starting the take-off run. Ground cooling can be a problem for any pusher configuration because air flow from the propeller is minimal. Pusher designs with air cooled engines may be more forgiving because they don't have coolant to eject. In addition, on my aircraft, a relatively large torque load is applied to the engine immediately on start-up because a high pitch (48x77) propeller is used. A cooling fan would ease this operational problem but was not used because of the added weight and reduced cooling duct efficiency. A controllable pitch propeller would also alleviate the ground cooling problem because less torque is required in the low pitch setting to develop thrust for taxiing. However, available models would add almost 25 lbs. and cost almost as much as the original BD-5 kit. At the outset, ground cooling on my BD-5B may appear a formidable operational problem, but in fact, it's only a slight inconvenience. If incoming traffic unduly delays take-off, the engine can be shut off which removes the propeller torque load and the engine immediately starts to cool by convention and radiation.

Directional control when taxiing in a crosswind is difficult for the BD-5 configuration because of the lack of nose wheel steering, narrow gear, and low rudder effectiveness (no slipstream). Compared to the BD-5J, the weathercock tendency is accentuated in my aircraft by the addition of a ventral fin (tail skid) and large side force associated with the high pitch propeller. A successful operational technique to start taxiing in a strong crosswind is to not fight the weathercock tendency but rather help the aircraft turn into the wind and use the built-up rotational energy to rotate the aircraft through approximately 300 degrees heading change. Power is added for forward motion as the aircraft rotates toward the intended taxi direction.

Take-off techniques are somewhat different compared to a conventional GA aircraft (Cessna 150, etc.). First, because of the low seat height, apparent speed is accentuated and you think you're going 100 mph when the airspeed indicator shows 50 mph. Second, the side stick controller requires adaptation time — what position should it be held during the take-off run — neutral, yes, but where's neutral? One of the basic problems of the BD-5 is rotating for take-off at a reasonable speed. The problem is accentuated at forward CG locations and by the relatively high thrust line (about the vertical CG). In addition, for all pushers there is a lack of slipstream to increase pitch control effectiveness. The side stick controller should be held in an assumed neutral position with a relaxed grip until take-off speed (roughly 70 mph) is reached. Early application of nose-up control is not desirable since the added drag will increase the take-off run appreciably. In assessing take-off progress, I concentrate on watching airspeed, manifold pressure and engine rpm. If I see 40" Hg and 4000 rpm and the engine sounds okay — I go for lift-off. With 1/2 flap deflection and mid CG location, only a modest pull force is needed to rotate for lift off. Immediately after lift-off, brakes are applied, gear retracted, and engine power reduced to 30" Hg. Although other Honda-powered BD-5's have used as much as 60" Hg and 6000 rpm for take-off (which essentially doubles the hp), I feel more relaxed with lower power knowing that the engine and drive system are operating only slightly above their nominal design limits. Incidentally, I found the BD-5J take-off performance to be objectionably poor with take-off runs near 3000 ft. because of the low T/W (about 0.2) available. Even with a very high pitch propeller, my Turbo Honda configuration is airborne in about 1200 ft. Although initial acceleration is low, a marked increase in thrust can be felt at about 40 mph when the prop blade unstalls.

Pitch controllability of the BD-5 is a safety of flight concern if power is lost right after take-off because the nose-up pitch trim change can place the aircraft in close proximity to stalling AOA. This nose-up trim change with power reduction occurs for any aircraft (pusher or tractor) if the thrust line is above the vertical CG. The trim changes associated with gradual power changes are negligible in the BD-5 requiring only modest forces to maintain a given attitude. A **sudden** thrust change due to a failure in the drive system or engine stoppage is more serious because of the rapid pitch dynamics, characteristic of this short coupled (low inertia) configuration. The pilot's response is basically not quick enough to prevent a rapid increase in AOA and loss of flight path control can occur if the pilot fails to maintain a safe stall margin. During one of my early high speed taxi runs, the aircraft was lifted off and leveled out at about 5 feet altitude. Power was reduced to idle to land, however, the engine stopped and sure enough, even though I was prepared (mentally) for the pitch change, the aircraft achieved an altitude of about 10 feet in a semi-stalled wing-rocking condition. Fortunately, lateral control in my aircraft was adequate to make a safe touchdown.

What about Pilot Induced Oscillation (PIO) tendencies associated in part with adaptation to the use of the side controller? As with several well-known U. S. military jets, PIO is forever lurking in the background when high frequency pitch response is basic to the aircraft design. Throw in some undesirable mechanical control characteristics such as high friction, free motion in the control linkage, low pitch static stability (rearward CG position) — and a roller coaster ride could be experienced on your first lift off. I had "flown" the BD-5 simulator in my pre-flight checkout for the BD-5 jet flights and felt comfortable with the side stick controller after about 10 seconds of pitch control inputs. Even so, I encountered a slight PIO when I first flew the BD-5J. The PIO problem can be "triggered" by holding the controller too tightly when pulling the gear lever back (approximately 20 lbs. pull) for gear retraction. Not a serious problem if you merely relax your stick grip momentarily — after all, it is the pilot that is inadvertently causing the oscillation to persist.

Pausing a moment to comment about the side arm controller used in the BD-5 — it is **excellent**. PIO tendencies are non-existent on my BD-5B. The well-harmonized pitch/roll response is a positive feature that deserves honorable mention for the BD-5 designers. The crisp response and light forces are such that all one essentially has to do is *"think" about initiating a turn maneuver* and it happens essentially with no apparent control displacement. Combine this with the good forward visibility (no propeller disc) and you feel like a jet fighter pilot.

Continuing on to the handling qualities in climb-out and up-and-away flight, one quickly perceives that although the aircraft is very responsive to pitch control inputs, it is also well damped; in fact, almost deadbeat (a calculated damping ratio of about 0.7). The phugoid motion is only lightly damped but easily controlled since the period is over 30 sec. Stick free static stability (stick force variation with airspeed) is positive and quite satisfactory. Even though only a few pounds of stick force is needed to change airspeed over plus/minus 25 mph, precise control of airspeed is possible. Stick fixed stability (elevator position variations with airspeed) is positive also, but gives the impression of being neutral in that airspeed can be changed with no perceptible side stick controller displacement. In a sense, these "force" stick controller characteristics are similar to that used on the General Dynamics F-16A fighter.

A word of caution regarding flying the BD-5 with even small amounts of negative stability — it could be catastrophic! Although many types of aircraft have been flown successfully with negative pitch stability, exceptional pilot skill is required and the oscillatory period (time to double pitch attitude) must be relatively long. The BD-5 would be essentially uncontrollable if flown at negative static margins because its short period frequency response and small "apparent mass" make it too responsive. Even with the CG located within the nominal limits, adding a VOR antenna near the nose of the fuselage will deteriorate pitch stability to an unstable mode. In the same note, a high pitch propeller greatly improves static stability because of the added side force. At the same CG position, the BD-5J is less stable than the BD-5B.

Pitch trim changes due to gear or flap actuation are relatively small in an aerodynamic but not in a pilot-effort sense. The cleverly designed gear actuation system is completely mechanical requiring the pilot to use the inertia of the gear to counter the aerodynamic loads. However, to assure full extension or retraction, the gear handle must be moved briskly requiring an initial "break away" force of 20-25 lbs. This gear actuation technique, although acceptable, is different and requires some experience to feel comfortable.

Maneuvering flight characteristics are excellent because of the quick response and low stick forces required. The aircraft is stable throughout the load factor range with increasing pull forces required to increase G in the *linear relationship. These carefree* maneuvering characteristics were not completely without fault, however, as noted in the following incident. During a photo flight, I was overtaking the photo aircraft (Cessna 175) at a high closure

Photo by the Author

The author's modified BD-5 wing stalled behind the fuel cap where the airfoil was not altered in shape. The tufts remain in trail outboard of this area. It is easy to see how much the wing's leading edge was altered.

rate. I elected to reposition and reduce speed by executing a quick 360 degree turn. I banked sharply and abruptly applied back pressured — instantly all reality with the outside world disappeared and I "woke up" in a slightly banked, nose down attitude. I glanced at the G meter which indicated slightly over 3 G's. I thought, "What's going on here . . . I know I'm getting old, but . . ." There was no narrowing of field of vision, no grey-out — just instant loss of consciousness. The next day an article in Aviation Week discussed a **new** phenomenon known as GLC (loss of consciousness due to G) which had been experienced by fighter pilots in highly maneuverable aircraft such as the McDonnell Douglas F-15 and General Dynamics F-16. The loss of consciousness was attributed to the **rapid** rate of G onset without cues such as grey-out or blackout which occur when G's are applied slowly. The next week I flew the BD-5 in turning maneuvers and noted that I could go to about 3.5 G's before some narrowing of vision occurred. In these turns I tightened my stomach muscles and applied the G load gradually. However, when G's were applied rapidly, GLC effects set in as previously noted. Apparently the BD-5 with its inherent quick pitch response and low stick force gradient (approximately 2 lbs./G) was capable of simulating a basic problem encountered with some digital controlled fly-by-wire fighter aircraft. I wondered if some of the unexplained stall/spin BD-5 accidents could have resulted in part from the GLC phenomenon. I wouldn't suggest increasing the stick force gradient, but rather warn other "ordinary" BD-5 pilots of this phenomenon.

Lateral/directional stability and control characteristics of the BD-5 are straightforward with no surprises. Due to the short tail length and highly swept vertical surface (low lift curve slope), directional stability and control are relatively low. Excess aileron authority is always available in sideslip even at maximum rudder deflection which in effect could limit crosswind operation. Oscillations of the Dutch roll mode were lightly damped with yawing motion predominating in the BD-5J. These lateral/directional oscillations are most bothersome in landing approach in gusty air. The very light rudder forces make it difficult to damp the rough-air-induced yaw oscillations. A noticeable improvement in Dutch roll damping was noted with my BD-5B due to the addition of the ventral fin and a large side force associated with the high pitch propeller.

The spiral mode showed neutral stability (satisfactory behavior) over the speed range. Checking spiral stability in the BD-5 (as in all aircraft) requires proper trim characteristics, i. e., the aircraft flown wings level with controls free. Right wing heaviness was quite noticeable in early flights with my aircraft even though I had built the wings, tail and fuselage with hard tooling. Bending the ground adjustable aileron trim tab helped some but not enough at the higher airspeeds. When a six inch yaw yarn was placed on the windshield, an appreciable sideslip was noticeable over the speed range. Symmetry was restored by bending the trailing edge of the rudder slightly and the wing heaviness problems disappeared. The aileron trim tab wash re-set to zero deflection. Apparently, the vertical fin was slightly misaligned.

Roll control characteristics are satisfactory with the side controller. Only light forces are required over the speed range and control harmony (deflections and forces between pitch and roll) are considered excellent. Adverse yaw is noticeable only at low airspeeds. Abrupt coordinated (ball-in-center) rolls are somewhat difficult to execute due to a tendency to apply too much rudder because of the light rudder forces. At high speeds (above 200 mph IAS) a reduction of aileron control effectiveness is quite noticeable due to twist of the aluminum torque tubes which link the controller to the ailerons.

The low drag of the BD-5 becomes apparent in attempting to slow down for the landing pattern. Many people have the impression that the BD-5, being small and compact, would glide like a brick if engine power were lost. Quite the opposite — in the cruise configuration Lift/Drag (L/D) is relatively high (about 15). Power off landings are relatively easy to make once the pilot has learned to judge the effects of gear and flap position on flight path angle. In the BD-5J, a thrust attenuator is needed to get to gear-down speeds. Little trim change results and this in-flight thrust reverser provides additional flight path control. It is very important, however, to reposition it for forward flight when starting down for landing approach other-

Photo Courtesy the Author

Seth Anderson strapping in for a flight in his BD-5.

wise excessive sink rates would occur for landing. Increasing engine power to reduce sink rate (an intuitive pilot reaction) would, in fact, only increase rate of descent and give the pilot an impression he had lost engine power. Approach speed on finals for the BD-5B is 80 mph and touchdown about 70 mph. Landing approach and touchdown are not difficult to execute in either the BD-5J or BD-5B, after you have conditioned yourself to the pitch response and close proximity of the ground at touchdown. Too high an airspeed (nose-low touchdowns) can cause the nose wheel to retract unintentionally if the ground drag forces are large. Taxiing in with my BD-5B is different. It is necessary to taxi in at relatively high speeds (up to 40 mph) when conditions permit, to provide cooling flow through the radiator. Otherwise the engine may have to be shut-down to avoid excessive coolant temperatures.

Stall Warning and Stall Characteristics

This area is undoubtedly the most important from a safety standpoint for this aircraft concept and a more lengthy discussion is appropriate. Many BD-5 aircraft builders may not be aware that over 80% of the accidents that have occurred with the BD-5 are due to stall/spin. NTSB records show that the typical BD-5 stall/spin situation occurs at too low an altitude for recovery. The situation arises insidiously, the pilot does not expect to stall and seriously lacks proficiency for executing an optimum recovery technique. Although the BD-5 may appear to have a docile stall, there are fundamental reasons why it may be less forgiving when flight path control is lost in high AOA flight. A clearer understanding of the stall characteristics of the BD-5 can result in safer operation.

The BD-5 wing utilizes a NACA laminar flow airfoil section varying from 64,212 at the root to 64,218 at the wing tip. No twist (washout) is incorporated since the thicker section at the tip nominally stalls at a higher AOA than the root, thus providing unstalled airflow over the outboard portion of the wing when separation has initiated inboard. As previously noted, this airfoil series incurs a fundamental reduction in C_{Lmax} when Reynolds number (Re) is less than 3×10^6. The small wing chord of the BD-5 results in a Re of about 0.9×10^6 at landing speeds. This scale effect is not in itself a serious deficiency, resulting in only a modest (5-7 mph) increase in take-off and landing speeds. What is important are some adverse characteristics of the wing flow behavior at high AOA which are discussed next.

BD-5J Stall Characteristics

First, flying the BD-5J at high AOA is reviewed and then my BD-5B which has a modified airfoil. Stall warning in the form of buffeting or shaking of the aircraft and/or controls some 3 to 15 mph prior to stall departure has long remained the preferred cue for maneuvering safely near stall. The pilot prefers the warning to be consistent and repeatable in straight or maneuvering flight regardless of flight configuration (gear or flap up or down). The BD-5J possessed an acceptable degree of tactile (buffet) warning in slow approaches to stall as a result of inherent inboard flow separation. In rapid G onset maneuvers, however, the warning was more subtle and occurred too close to departure from controlled flight to be acceptable.

Stall departure was characterized by transient lateral (wing rock) oscillations at approximately 80 knots in the clean (flap and gear up) configuration. The lateral oscillations increased in magnitude and were more difficult to control with rudder and aileron as the stick was brought back to the full aft position. There was no "G break" evident, and airspeed increased about 10 to 15 knots. With the stick held full aft, the aircraft eventually departed abruptly rolling to an inverted, nose low attitude. With flap and gear down, the dynamic roll oscillatory behavior was still present although considerably less in magnitude. This would be expected since less pitch control power was available to obtain high AOA due to the increased nose down pitch trim moments associated with flap and gear extension.

In maneuvering flight stalls (pull ups or turns), stall warning was essentially non-existent and the roll-off became very abrupt and violent. In a 3 G turn, the aircraft "snapped" 360 degrees very smartly at stall. Two points were of interest: (1) no stall warning by buffet or shake of the aircraft was evident, (2) stall speeds were appreciably lower, and (3) stall behavior was improved. The only stall warning evident, flaps either up or down, was a mild wing rock or rolling oscillation which I consider only marginally acceptable. Increasing AOA resulted in increased amplitude roll oscillations although bank attitude never exceed plus/minus 30 degrees. It was always possible to keep the wings level with use of ailerons alone with stick full aft. Observations of tufts on the wing showed an initial trailing edge separation at the mid-semispan progressing forward quickly to leading edge separation in this unprotected area (original airfoil section). Flow outboard, ahead of the ailerons remained smooth (unseparated) up to the highest AOA tested (stick full aft). In general, stall behavior with flaps down was milder since as previously noted, available pitch control power limited the ablity to attain high AOA.

Stall recoveries were examined in detail on the BD-5B with the modified wing to compare with the "accelerated" stall problem previously noted with the BD-5J equipped with the normal wing. Similar trends were evident in that a relatively large increase in airspeed was required to avoid secondary stall during recovery. A closer examination of the stall and recovery characteristics was made to simulate the scenario for a typical stall/spin accident. At a safe altitude (over 5000 ft. AGL) with flap (1/2 down) and gear down, the aircraft was slowed down in a mild left bank simulating turning on to base or final approach. At the stall, the aircraft rolled mildly to the left or right at about 65 mph. For recovery, back pressure was relaxed to reduce AOA, nose down attitude increased and airspeed increased to approximately 80 mph. Since a steeper than desired nose down attitude existed, back pressure was increased somewhat abruptly to return to a desired (less steep) approach flight path angle. Sure enough, a secondary accelerated (higher airspeed) stall occurred with a much larger roll off and pitch down. The pilot's view of the ground approaching rapidly provokes a less patient attitude about waiting until airspeed builds up and another accelerated stall can set the scene for the classic stall/spin accident where there is not enough altitude for recovery.

Photo by the Author
Seth Anderson's instrument panel. Note the side stick.

Is this all-too-familiar stall/spin scenario worse for the BD-5 concept? Not necessarily, but there may be extenuating circumstances which require understanding. For stall recovery, most pilots are taught to add power and bring the nose down to level flight. These actions which help reattach airflow on the wing deserve closer scrutiny for the BD-5. First, with the pusher design, wing flow reattachment is not aided to any degree by increases in engine power since slipstream effects on the flow over the wing are essentially non-existent. Second, with the laminar flow airfoil used on the BD-5 , and by operating at low Re, stall occurs from the wing leading edge. This results in a relatively large hysteresis loop in AOA for flow reattachment. Compared to the AOA for initial flow breakaway, the AOA for flow reattachment must be decreased at least 5-7 degrees. This effect is accentuated if the builder has not been careful to avoid creases in the airfoil nose radius during handling and attachment of the wing skin to the nose ribs. Third, if engine failure has occurred, the aircraft must be accelerated by diving more steeply towards the ground to increase airspeed (and thereby reduce AOA). This would be true also for a conventional aircraft, but (and I am admittedly guessing at this point) the BD-5 pilot has a much clearer, unobstructed view of the approaching ground which may affect his timing and judgment for proper stall recovery in this high stress situation. Essentially, the average pilot may not have the patience to wait for enough increase in airspeed (low AOA) to provide a safe stall margin and the appreciation of the need to execute a **gradual** pitch change to avoid a secondary stall.

In Summary

What can be done to improve safety in high AOA operation for the BD-5 concept? First, the pilot must recognize when a potentially dangerous stall situation can occur, such as engine loss during take-off. This is particularly important for the low time pilot who has not flown a wide variety of aircraft and is in the initial checkout phase of the aircraft. Second, a clearer understanding of the causes of the problem should help improve stall recovery techniques with particular emphasis on the need for large increases in airspeed and **gradual** (low G acceleration) nose up flight path angle changes. Further, exposure to these stall characteristics at a safe altitude can be very educational. I doubt that many pilots practice this abused stall scenario. The addition of an AOA meter mounted next to the airspeed indicator on my aircraft is a great help in avoiding secondary stalls. Reducing the established aft stick travel value and favoring a more forward CG location will indirectly improve safety by restricting high AOA penetration without unduly compromising pitch control power for take-off or landing. Finally, airfoil modifications can be made to alleviate the tendency for leading edge flow separations. Some BD-5 builders have utilized the NASA LS0413 (GAW) airfoil which also provides improved max. lift at low Re and a favorable (trailing edge) stall separation pattern. It should be recognized that the GAW airfoil with the cusped trailing edge will reduce cruise performance on the BD-5 because it is optimized for a relatively high cruise C_L.

Modification of the airfoil as previously discussed will not only improve stall behavior but also spin characteristics. Extensive NASA-Langley stall/spin tests of a GA aircraft using leading edge protection similar to that incorporated on my BD-5B provided improved spin resistance. It was found, however, that autorotation characteristics were better when using only outboard protection compared to various full span leading edge modifications. Further work is planned for my aircraft to promote improved stall warning. A small leading edge stall strip inboard at the wing-fuselage fillet should provide ample buffet warning.

Concluding Remarks

Although the BD-5 design fell short of meeting many of its original design goals, it should be given credit for ushering in a new wave of popularity for homebuilts. Its sleek aerodynamic design is unique even today and is admired in the air and on the ground by the casual observer or the jet-set crew. It is not difficult to fly nor are there unsafe or hazardous characteristics for properly trained and adequately briefed pilots. Its short-coupled appearance is deceiving. Although very responsive in pitch and roll, adequate aerodynamic damping allows hands-off flying throughout the envelope. The cockpit arrangement and excellent control harmony provided by the side stick controller enhance the pure joy of maneuvering flight. Someday, an ideal engine will become available (perhaps the Rotary-Vee) and the BD-5 aircraft will realize its full potential.