SPEED WITH ECONOMY

KENT PASER

EXPERIMENTAL AIRCRAFT PERFORMANCE IMPROVEMENT

WHAT OTHERS ARE SAYING ABOUT THIS BOOK

"I read [the] book, **Speed With Economy**, and liked it. It is well written, easy to read, and most informative. Anyone who is willing to put in the effort to improve the performance of his homebuilt will find a wealth of information in this book.

[The author] did not resort to formulas and high tech mathematics to describe his experiments and explain his findings. That sort of writing, I believe, intimidates and discourages even the most dedicated homebuilder."

"Kent's determination to enhance the performance of his Mustang-II is quite understandable. However, what does boggle my mind is the fact that he willingly devoted more than 23 years to the performance improvement of this one airplane, making modification after modification.., each carefully documented and tested."

Tony Bingelis, Author of several aviation books.

"I believe this book is great! It is something every homebuilder should read. Builders think of these improvements individually, but wonder if it is worthwhile. Seeing the total results is impressive."

Bob Bushby, Mustang-II Designer

"Improving the breed is a hallmark of the homebuilt movement, but it is nothing short of extraordinary for a builder to increase the top speed of his aircraft a whopping 64 mph...and cut the fuel consumption in half! Equally impressive is the way is was done: by guile rather than brute force...by aerodynamic and thermodynamic refinement rather than gobs of additional horsepower."

"It was my personal pleasure to greet Kent Paser when he brought his Mustang II to Oshkosh for the first time in 1971, and it has been a continuing fascination to see him bring it back year after year with yet another round of performance improvements. With the publishing of **Speed With Economy** the effort of all those years is compressed into a single volume that everyone can enjoy...and profit from. It's a must for anyone with a homebuilt project in their shop."

Jack Cox, Editor-in Chief, EAA Publications, and Editor/Publisher of Sportsman Pilot Magazine.

"Kent Paser's **Speed With Economy,** is an excellent reference manual for the amateur builder who wants to make his airplane go faster. You will find information in this book that, so far, very few have applied and only a handful of people have experimented with. In particular, his information on engine cooling, I have seen in no other literature. Kent has provided a contribution to economical flight which should serve as a hallmark to amateur builders of the future."

Ben Owen, Executive Director of EAA Information Services and Technical Counselor Program.

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BY KENT PASER

FIRST EDITION

PASER PUBLICATIONS, DENVER, COLORADO

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EXPERIMENTAL AIRCRAFT PERFORMANCE IMPROVEMENT

BY KENT PASER

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ABOUT THE AUTHOR

Kent Paser is a degreed Aeronautical Engineer, having received his degree from the Aeronautical University in Chicago, Illinois in 1957. He worked for Martin-Marietta Corporation in Denver, Colorado for 33 years. During that period, he worked on the Titan Family of Launch Vehicles, the Apollo Program, Skylab Program, several satellite programs, and the Mars Observer as Program Systems Engineering Manager. He has been a licensed private pilot since 1964. He is a member of the Experimental Aircraft Association and the Aircraft Owners and Pilots Association. He is a past President of EAA Chapter-301 and has served as Technical Counselor for Chapter-301 for several years. He has attended the EAA convention at Oshkosh, Wisconsin for 23 years with his Mustang-II Experimental Aircraft, which he completed in 1971. He has competed with his Mustang-II in the Oshkosh Pazmany Efficiency Contests, the CAFE-250 Race the Oshkosh-500 Races, and several local races. He has lectured at numerous AIAA and EAA meetings on the modifications he has incorporated on his Mustang-II. He has been a contributor to EAA's Sport Aviation magazine and continues to receive cards, letters and phone calls from people around the world who have read the magazine articles on his aircraft modification efforts. Kent is married, has four adult children and nine grandchildren. Kent and his wife, Sandra, regularly use their much-modified Mustang-II to fly around the country to visit their grandchildren.

ACKNOWLEDGEMENTS

At the risk of forgetting to mention individuals with whom I have discussed my ideas for performance improvement modifications, I would like to thank several friends and family members who have contributed significantly to the building, modification and testing of my Mustang-II and the publication of this book:

Bob Bushby, for designing a wonderful airplane;
Chris Hall, for original construction support;
Tom Armstrong, for original test flight support;
Jeff Paser, for modifications test flight support and photography;
Jim Herrington, for tuft testing support;
Dean Cochran and George Hite, for exhaust systems development support;
Jim Rushing, for radio antenna design;
Bill Cassidy, Norm Herz, and Bernie Warnke, for propellor development support;
Mark Brown, John Swearingen, and Larry Vetterman, for their performance improvement ideas;
Kathy Paser and Jenny Daiker, for typing, editing, and publishing support;
And my patient and understanding wife, Sandy, for construction, publishing, and moral support for the past 38 years.

FOREWORD

This book is a true and accurate account of my experiences in building, flying and maintaining an experimental Mustang-II (an original design by Bob Bushby). Over the past 23 years, I have experimented with many power plant and airframe modifications to my Mustang-II, in attempts to coax additional performance from my aircraft. As my modification program progressed, I entered the aircraft in numerous competition events (speed races, combination speed/efficiency races and efficiency contests). These competitions sequentially and progressively proved the success of my aircraft modifications efforts.

These modifications increased the aircraft's top speed by 64 MPH, the cruise speed by 60 MPH, and the climb rate by more than 800 feet per minute. In addition, the service ceiling was improved by 8,000 feet, and the fuel consumption was reduced by 50% for economy cruise. All of this was accomplished primarily by aerodynamic drag reduction and engine efficiency improvements, not by bolting in a larger engine.

While I do not encourage nor recommend any of the readers of this book to attempt to duplicate my experiments/modifications due to the risk to life and limb involved with test flying, I do believe my efforts show that considerable potential performance improvement is inherent in the Mustang-II design, and perhaps other experimental aircraft designs, as well.

DEDICATION

One night, at about 10:00 pm, after I had been working on the original construction of my Mustang-II for about three years, I was in the cockpit, installing the panel instruments. I suddenly felt that I was not alone in the garage. I turned around, to see my wife leaning against the garage door frame, her arms folded and a strange look on her face.

"Are you O.K.," I asked.

"You're really going to do it," she said, with a sound of awe in her voice.

"Do what," I said.

"You're really going to finish building and fly this airplane," she replied.

Here I had been pouring all of my spare time and family finances into the airplane for three years, and my wife, up to that point, had never believed that I would finish the airplane. Yet, she had gone along with the project, never complaining; knowing how important the airplane was to me and how happy I was working on it. My happiness was enough for her and it was sufficient to balance out the time and money that I was taking away from the family.

For this, and many other reasons, I am dedicating this book to my wife, Sandy.

WARNING-DISCLAIMER

The purpose of this book is to relate my experiences over the past twenty-three years with my experimental aircraft and to entertain the reader. The modifications made and procedures set forth in this book are not intended for use by the general aviation public. No modifications should be made to ANY aircraft without a thorough design review by a qualified aeronautical engineer familiar with your specific aircraft and the required FAA approval.

This book is designed to provide information in regard to the subject matter covered. It is sold with the understanding that the publisher and author are not engaged in rendering professional engineering services. If expert engineering assistance is required, the services of a competent professional should be sought. The author and Paser Publications shall have no liability nor responsibility to any person or entity with respect to any loss or damage caused, or alleged to be caused, directly or indirectly by the information contained in this book. The unthinking duplication of the modifications and procedures contained in this volume is more likely to turn the user into a casualty than into an expert on aeronautical engineering. Significant modification of the procedures and techniques used in this book may be required with the respect to a particular reader's experience, training and aircraft.

Every effort has been made to make this book as complete and accurate as possible. However, there may be mistakes both typographical and in content.

The inclusion of any design, design modification, procedure, method, practice or information in this book does not constitute endorsement of the same to be used by other individuals nor entities. In addition, nothing presented in this book is intended to substitute for specific information issued by the designer and/or manufacturer of any aircraft, aircraft kit, aircraft plans, engine, accessory, part or product. The designer and/or manufacturer always knows his product best and his design, instructions and operating guidelines should always be followed.

IF YOU DO NOT WISH TO BE BOUND BY THE ABOVE, YOU MAY RETURN THIS BOOK TO THE PUBLISHER FOR A [redacted] REFUND.

RASER

CHAPTER I

BUILDING MY MUSTANG II

Is there a more satisfying expression of your creativity than flying an airplane which you built at home?

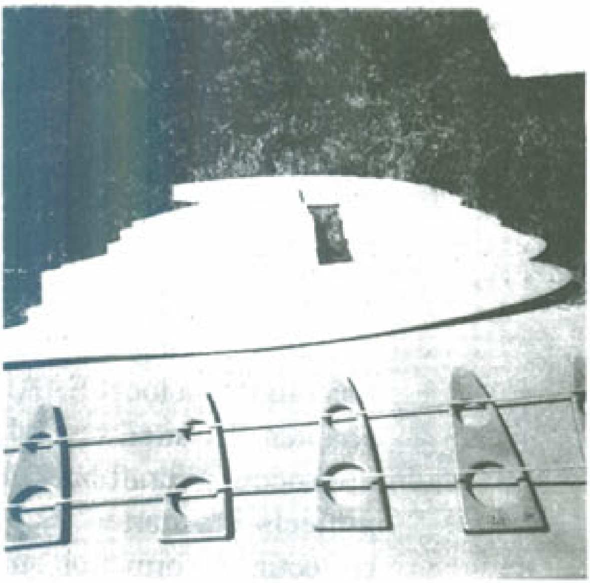
In January, 1967, I watched the first flight of a homebuilt airplane, an all-wood Piel Emeraude. I had earned my Private Pilot License earlier, in 1964. however, I didn't have much hope of buying my own aircraft. I was a young engineer concentrating on developing my engineering career. I had four young children and a large home mortgage payment. There just wasn't much money available to spend on something as non-essential as an airplane. At that time, I didn't know that the FAA allowed people to build their own aircraft. So, witnessing that successful first flight at our local airport (Columbine) was a real revelation to me. I was absolutely awestruck with the idea of building my own aircraft in my garage! I had built two hot rod cars as a teenager, and knew enough about myself to realize that I really enjoyed working with my hands on all kinds of building projects. I had worked part-time as a welder while going to school for my Aeronautical Engineering Degree, but did not know how to rivet. Nor did I have much sheet metal forming experience. As I found out later, these additional necessary skills were not very difficult to acquire.

Kent Paser, 8 years old, at the controls of his first experimental/ homebuilt aircraft.

I joined the Experimental Aircraft Association (EAA) and started attending the meetings of a local EAA chapter. I visited several in-process aircraft building projects and started collecting information and performance data on available experimental aircraft designs. I knew that a 2-seat design was a must, and I wanted cross-country capability with maximum cruise performance. I considered Steve Wittman's "Tailwind" design and John Thorp's "T-18" design. But Bob Bushby's "Mustang II" design had better performance specifications and its appearance seemed to strike a responsive chord in my psyche.

So, I sent off for the "Mustang II" plans. I was somewhat dismayed when all that arrived was the plan sheets for the outer wing panels. Bob and his draftsman had not yet finished the plans for the remainder of the design. However, I was enthusiastic enough about Bob's prototype aircraft that I believed Bob would complete the drawing set for the design.

I erected the wing jig in my single-car garage, and bought a 4' x 12' sheet of 2024T3 .025" aluminum stock from a local supplier.



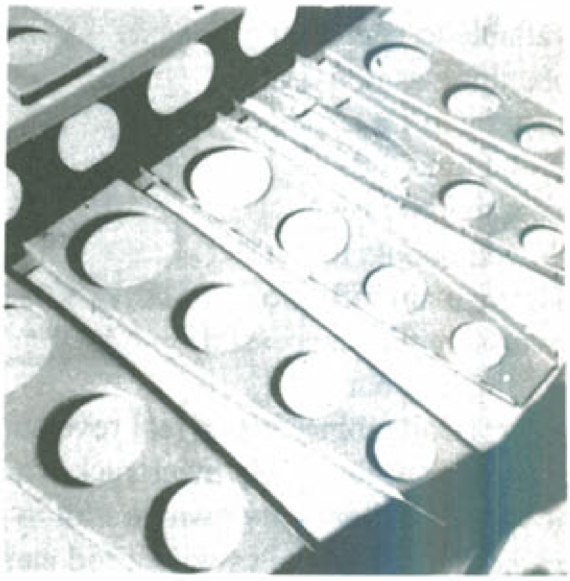
Wing rib form blocks.

I made the wing rib wood form blocks from ⅝" thick shop plywood and started buying tools that I knew I would need:

- right-hand and left-hand double action aviation sheet metal shears.
- an adjustable hole fly-cutter.
- assorted files.
- a drill bit set and 3/8" capacity hand held drill.
- I had a ½" capacity drill but needed a stand to convert it to a light weight drill press.
- a ½ horsepower air compressor.
- a vinyl/plastic forming mallet.
- a paint spray gun.
- a rivet gun and rivet sets.
- Cleco sheet metal temporary fasteners.

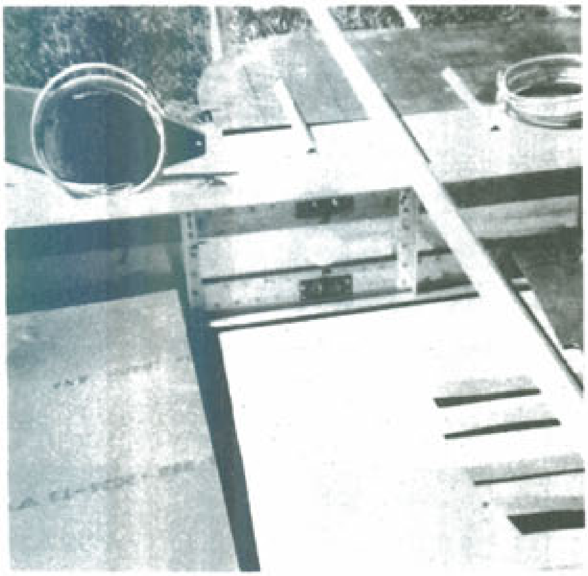
I made several tools:

- a disc sander.
- a 12 ½" capacity bending-brake.
- flange-forming pliers.
- flute-forming pliers.
- several rivet bucking bars.



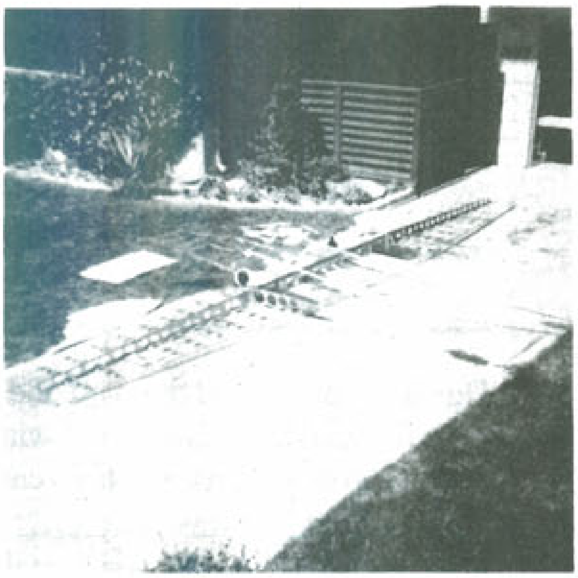
Formed aluminum wing ribs.

The first parts to be formed were the outer panel wing ribs cut from the .025" 2024T3 aluminum sheet, formed over wood form blocks, straightened with fluting pliers and flanged with hole hand-flanging pliers.



Wing center section spar and other parts and materials.

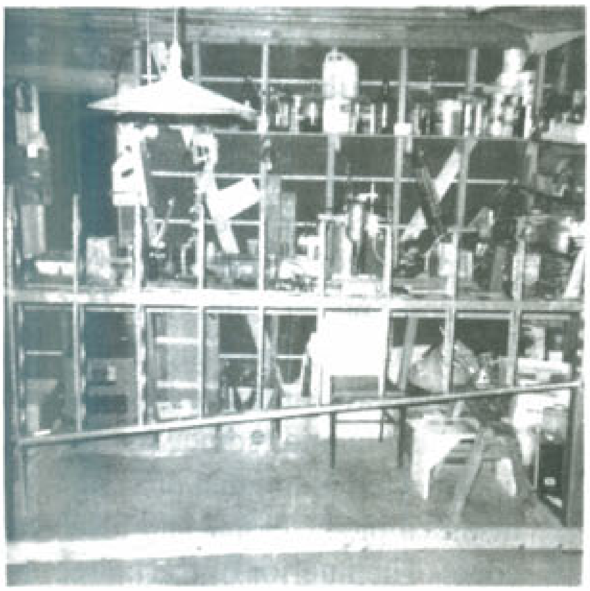
I then fabricated the main and rear wing spars. This is where I learned to rivet.



Wing spars, ribs and other materials.

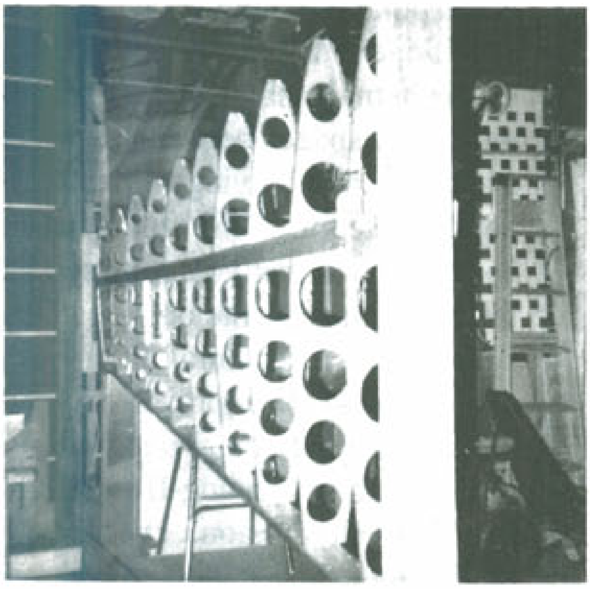
The wing main spar caps are laminations of 1/8" thick aluminum strips, all riveted together on the .040 thick spar shear web.

At this same time, I was working on the NASA Skylab Program and spending a lot of time at the NASA Johnson Space Center near Houston, Texas. During that time, I visited several local airports, and saw first-hand the effects of humid (somewhat salty) air on unprotected aluminum aircraft. I saw a disassembled Cessna-150 fuselage tail-cone. The interior of the tail-cone was bare aluminum and where the fuselage formers had been riveted to the aluminum skin, the corrosion was so bad that you could poke through the aluminum with your finger. This corrosion was caused by the humid salt air being drawn into the minute air spaces between the riveted surfaces (called faying surfaces) by capillary action. This type of corrosion is insidious in that you don't see it until it breaks through to the outside of the skin or has caused structural failure. Since I was getting a lot of pressure from NASA to move to Houston at that time, I wanted to protect my Mustang-II's airframe from that type of corrosion. I coated all aluminum surfaces with zinc chromate primer. I also coated all faying surfaces with military specification faying compound during assembly. The faying compound fills in the minute air spaces between the faying surfaces and prevents the capillary-action retention of moisture. This is especially critical for the wing main spar cap strips and all other



Right wing in the jig in my cluttered one-car garage.

Ribs and spars are riveted together for both outerwing panels.



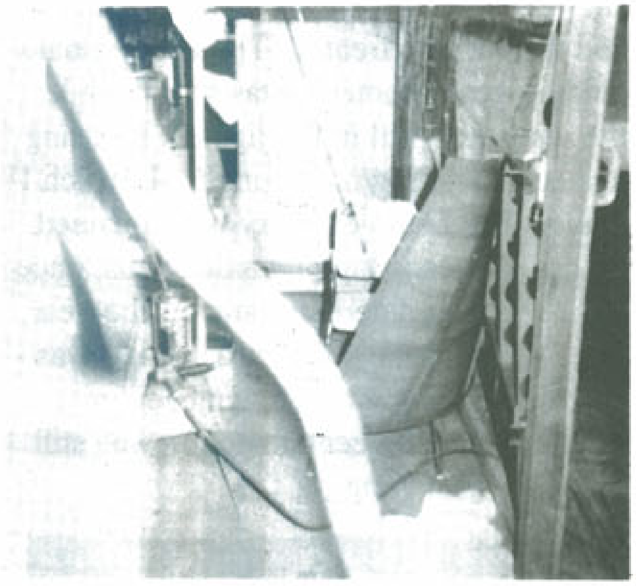
The wing jig puts in the right amount of wing twist.

Ready for the wing skin on both outer wing panels.

primary-load carrying structure.

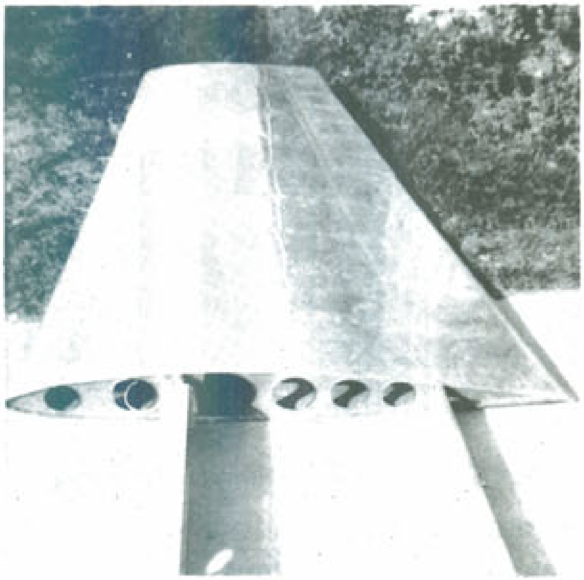
Once the wing spars were assembled, the spars and ribs were assembled in the wing jig and the wing skins were fitted and trimmed.

The skins were then dimpled and flush-riveted. During closure of the wing forward wrap-around skins, my ten year old daughter, Christine, was the only family member who had a forearm small

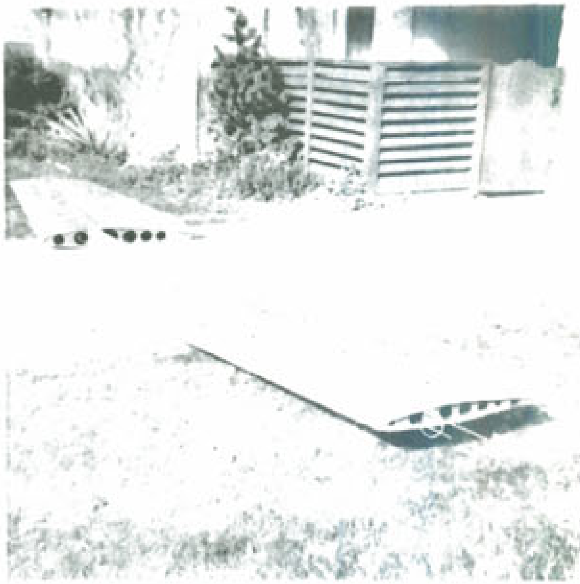


Riveting the skin on an outer wing panel.

The left wing panel is completely skinned.



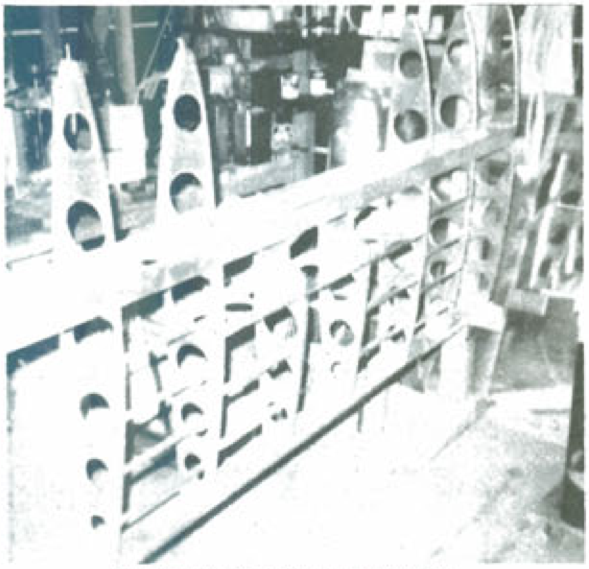
The right wing panel is completely skinned.



Both outer wing panels are now skinned and fitted to the center section spars.

enough to reach through the smaller spar lightening holes to buck the rivets. She did a good job, too! Once the outer wing panels were completed, I stored them in a frame along an inside garage wall.

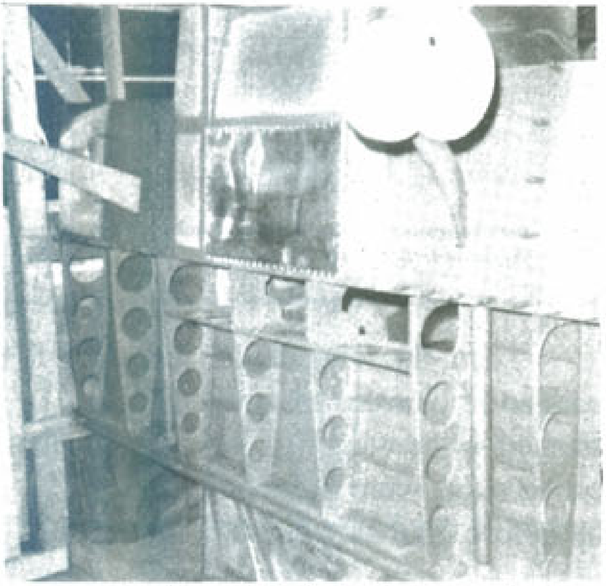
Then, the wing center section spars and ribs were assembled and fastened in the wing jig. The wing center section skins were fitted and trimmed. But before final skin closure, the landing gear torque tubes were assembled and fitted to the wing center section. The weak point of the torque tubes was strengthened by welding in steel gussets between the landing gear attach pad and the torque tube main spar attach fitting.



The wing center section in the wing jig.

This proved to be a good idea, since Bob Bushby eventually strengthened the torque tube design in this area.

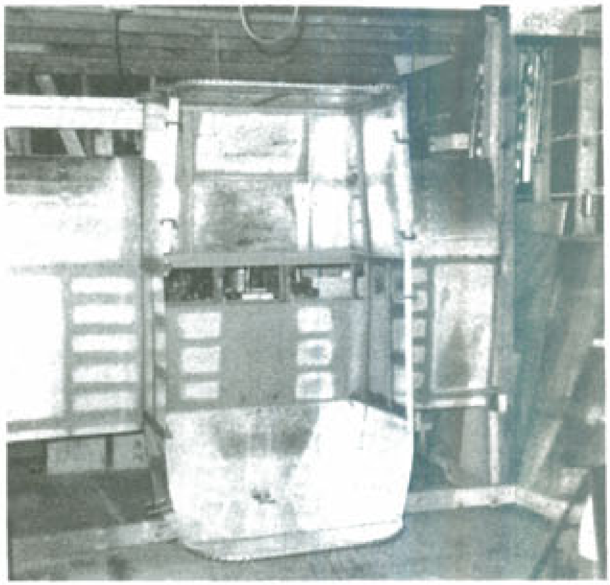
I made the landing gear legs from Cessna L-19 gear legs, which I



Landing gear is fitted to the wing center section.

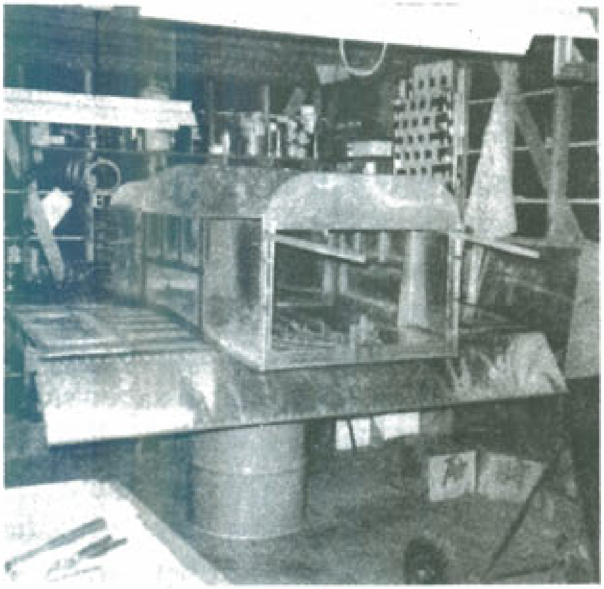
shortened and rebent the axle pad angle and then reheat-treated. The approximate landing gear geometry was set up while the wing was still in the jig, and by using a special bending/indicating tool, which I made. The final geometry was obtained by using Cessna tapered axle shims, once I had the completed airplane on-the-gear.

The fuselage forward section was assembled on and to the wing center section while the center section was still in the vertical wing jig.



The forward fuselage is built onto the wing center section while still in the jig.

The fuselage bulkheads/formers were formed over wood form blocks, similar to forming the wing ribs. The firewall was formed from ½ hard stainless steel. The fuselage longerons were bent from aluminum angle, using an aluminum forming-block and shaped to a full-size layout traced on the garage concrete floor with white drawing chalk. While still in the vertical wing jig, a plate was affixed to the garage ceiling rafters, to simulate the engine interface, relative to the firewall. The engine mount steel tubes were cut and fitted in this temporary, but accurate, engine mount jig. The tubes and mount fittings were tack-welded into place. Then the tack-welded engine mount was removed from the temporary jig and all welded joints were completed. To hold the dimensional tolerances during the finish welding, the 4-points of the engine mount engine interface were bolted to a plate and the 5-points of the engine mount firewall interface were also bolted to a plate. This arrangement worked very well, since when it came time to bolt the engine mount to the firewall and the engine to the engine mount, everything fit perfectly and the engine alignment to the fuselage was dead-on.



The wing center section and forward fuselage are now out of the jig.

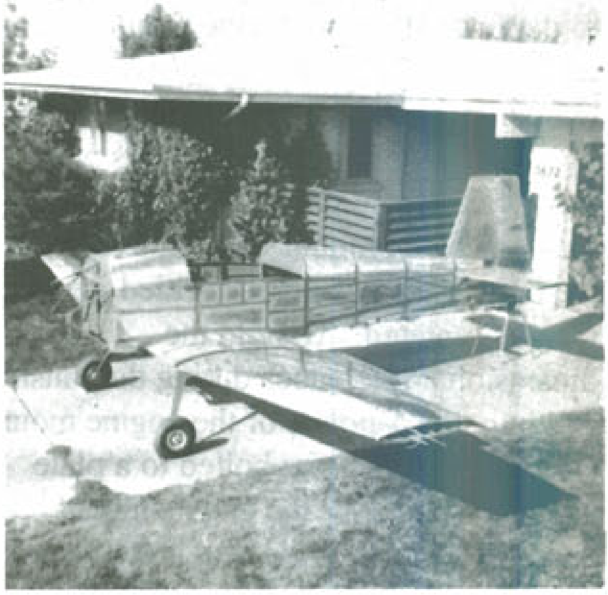
Once the forward fuselage section was wrapped with aluminum skin, the combined assembled wing center section/forward fuselage section was removed from the wing vertical jig and set up horizontally. The fuselage tail-cone belly-pan was fabricated and attached to the forward fuselage section.

The tailcone belly-pan and tailcone formers are added.

The tail-cone bulkheads were fabricated and attached to the belly-pan. The tail-cone was then wrapped with aluminum skin.

The fuselage tailcone is almost ready for skinning.

The fuselage longerons and lower engine bearers are fitted.



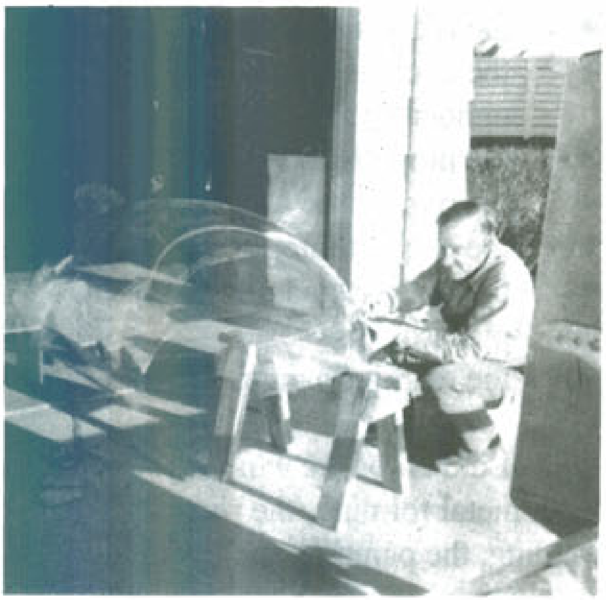
The aircraft is now on the gear-a significant construction milestone.

Here again, a family member was pressed into service to buck the rivets. I had my wife, Sandy, buck the rivets to close up the fuselage tail-cone. I laid boards and blankets inside the tail-cone and she crawled in and bucked rivets for three hours. She didn't wear any hearing protection, and her hearing was affected for several days afterward. She was also my quality control inspector. If she didn't like a rivet that we drove, she insisted that I drill it out immediately, and drive another rivet in its place.

The tail surfaces were then constructed right on the tail-cone. The horizontal and vertical stabilizer spars were bolted to their respective fuselage bulkheads. Then the stabilizer ribs were fitted into place. Then I prebent the stabilizer skins and fitted those skins into place. With all of the rivet holes drilled, the stabilizers were removed from the fuselage tail-cone and finish riveted. The movable tail surfaces were fabricated using a plywood sheet as a jig.

All steel fittings were cut and welded per the full-size drawings. When bolting/riveting the steel fittings to the aluminum structure, zinc chromate and faying compound were liberally applied to prevent dissimilar metals (electrolytic) corrosion between the aluminum and steel materials.

Building the canopy was a three and a half month project. Trimming the plexiglass canopy was a difficult and nervous job. I tried using a saber-saw, but the rapid blade movement heated the plexiglass too much and everything became soft and gummy and the plastic glued itself back together behind the blade. I wound up hand-sawing the plexiglass (a slow and tedious job.) When attaching the canopy and windscreen to their respective frames/mounts, I drilled over-size holes in the plexiglass to prevent cracks in the plexiglass at the rivet/screw mounting holes. The oversize hole approach was also used to attach the canopy skirt.

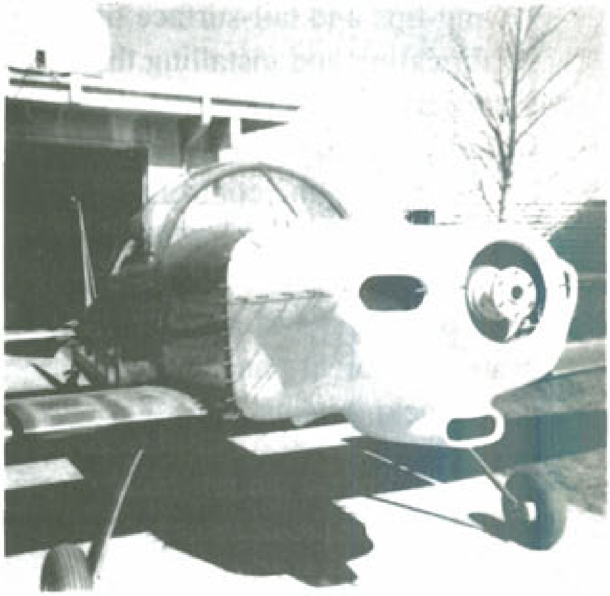


Canopy trimming is slow and tedious work.

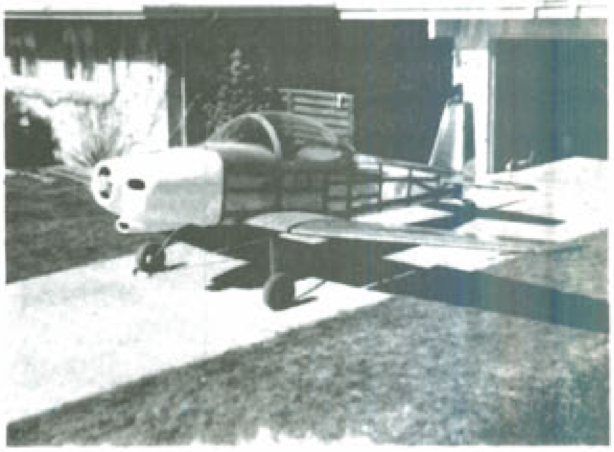
I didn't have an engine crane to mount the engine, so I used a different technique.

The canopy is trimmed and the engine is hung.

With the fuselage on the gear, I had two neighbor men lift the fuselage tail very high, which of course lowered the front of the fuselage to near the ground. The engine (on a dolly), was then maneuvered, on the ground, to match the angle of the engine mount and the engine mount rubbers and bolts were slipped into place. After the bolts and nuts were secured, the fuselage tail was lowered and the engine was now in its proper position on the engine mount.



The canopy is complete and the engine cowling is fitted.



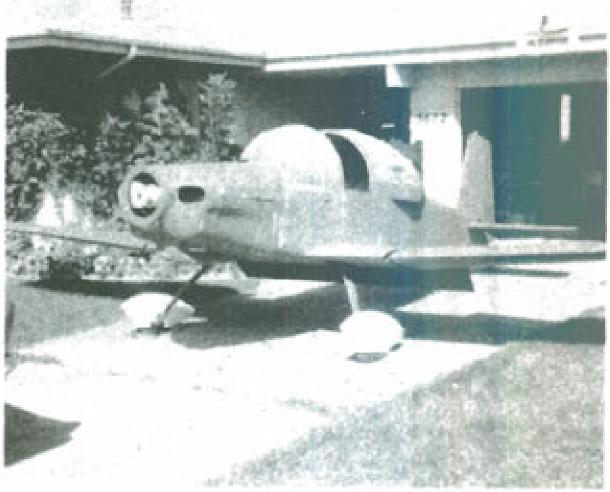
Beginning to look like a Mustang-II.

At this point in the building process, I thought that the airplane was 90% complete. Boy, was I ever wrong! Finishing the project took just as long as building the basic airframe! The finishing process included the following:

- fitting all of the fiberglass parts (engine cowling, wheel-pants, wing-tips and tail-surface tips).
- fabricating and installing the aerodynamic controls.
- the hydraulic/brake system.
- all of the engine controls.
- the engine cooling baffles and oil cooler.
- the electrical system.
- the instrument panel gauges.
- the cockpit vents.
- the fuel tank.
- the cockpit seats.
- the radio and antennas.
- the cockpit sound-proofing and upholstery.
- the propeller spinner.
- the pitot/static air system.
- the cockpit/interior painting.
- the cockpit and panel signs and placards.
- the exterior painting.

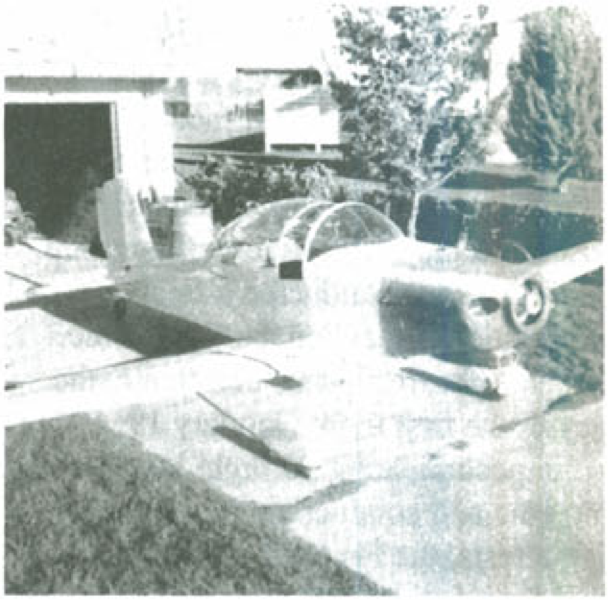
I did all of the work myself, the sheet metal forming, the riveting, the welding, the painting, the hydraulics installations, the electrical installations, and the radio installation. When I needed more hands, then family members, neighbors and friends pitched-in to help.

The engine compartment is now completed.



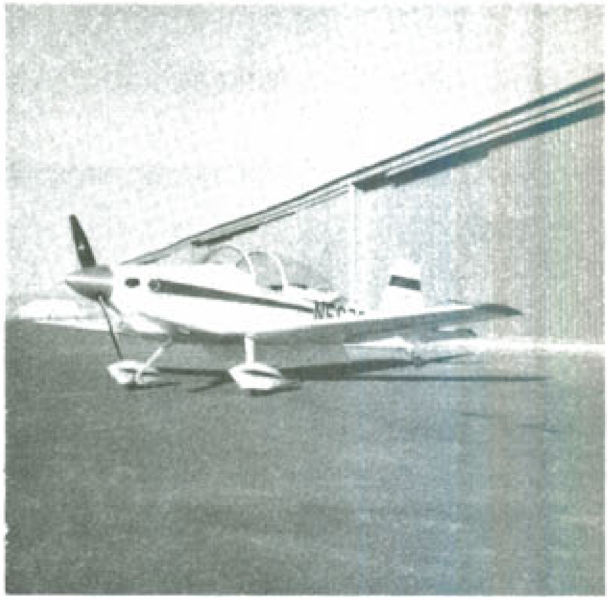
The zinc chromate primer is sprayed on the exterior.

The color coat being applied in my outdoors spray booth.



The white color coat is almost comlpete.

The blue trim paint is completed.



At Jefferson County Airport and ready for the first flight.

In December of 1970, the airplane was trailered to Jefferson County Airport, where I shared a hangar with Lamar Steen and Ray Parker for six months. During that six month period, the airplane was taxi-tested, the initial test-flights conducted, and the 50-hour restrictions were flown off. My friend and professional test pilot, Tom Armstrong, flew the first ten hours on the airplane, including basic aerobatic testing.

During the building and testing, the local FAA office was most cooperative. Before the closure of any structure, the FAA was called and they inspected the project for workmanship. The FAA also conducted a final completion inspection and issued the initial flight worthiness certificate, the day of the first flight (January 19, 1971). After accumulating 50 flight hours on the airplane and conducting the necessary flight tests, the FAA lifted the initial flight restrictions and issued a new flight worthiness certificate; just in time to fly

The 50-hour restrictions have been flown off and we are ready for our first cross-country.

the aircraft to the EAA convention at Oshkosh, Wisconsin in July 1971, where the airplane won the best Mustang-II trophy.

Heading for the experimental aircraft convention at Oshkosh, Wisconsin.

Parked at Oshkosh next to Bob Bushby's prototype Mustang-II

Some additional construction features which I feel are worth mentioning:

1. It is very important that the wing leading edge radius on the left wing is identical to the right wing at each rib station. If not, at stall, the aircraft will drop a wing to the side that has the sharper leading edge radius. To work out this problem on my aircraft, I made leading edge radius templates for each rib station. An adjustable "finger" gauge could also be used. A "sharp" leading edge can be broadened by gently tapping the front of the edge with a plastic/vinyl mallet. A "broad" leading edge can be sharpened with a block of wood held firmly below the leading edge while tapping the upper side of the leading edge with the mallet. This procedure should be used very slowly and cautiously, checking frequently with the template or finger gauge. However, the larger/broader leading edge radius will provide a slower/gentler stall.


"Arnold, it's Mr. Wimberly on the phone . . . He says the next time you buzz his house, he'll have his 12-gauge ready."

Sometimes the neighbors complain.

2. To hold the engine cooling baffles tight to the cylinder fins on the bottom of the cylinders, at the baffle gap, I used safety wire to hold the free edges together. I have seen small coiled springs used at this gap, which may not hold the baffles tight to the cylinder fins due to the high air pressure that builds up in the cooling plenum chamber above the cylinders.

3. All welded steel fittings will have a residual magnetism caused by the welding process. Any welded steel fitting within 3-feet of a magnetic compass will cause erroneous readings of that compass. To correct this, I removed the residual magnetism from the fittings by "degaussing" those fittings. I accomplished this by placing each fitting within the field of a very large coil of wire, then slowly building up the field and slowly collapsing the field using a "variac" (high capacity variable power resistor).

4. I also used brass machine screws and nuts to mount all of the gauges and instruments in the instrument panel, to prevent any magnetic material from affecting the compass.

5. To prevent battery acid liquid/fumes from corroding the battery box, I coated the interior of my aluminum battery box with several coats of epoxy paint.

6. My 25 gallon main fuel tank is between the firewall and the instrument panel, in the cockpit. To prevent any fuel overflow (when filling the tank) from flowing into the cockpit, I fabricated a filler neck well around the fuel tank opening, and sealed the well around the filler neck and the fuselage skin. Thus, the fuel tank fill opening is isolated from the cockpit interior.

7. To provide maximum shear load transfer from the propeller extension flange to the wood propeller hub, I had a set of six-extra long propeller flange shear load transfer lugs machined and pressed into the propeller extension flange.

8. I also had a 5/16" thick anti-crush plate machined for use under the propeller bolt heads, so that the necessary 18-20 foot-pounds (ft. lbs.) of torque could be maintained on the propeller attachment bolts.

9. There are definitely two schools of analytical thought on the controversy of whether to use toe-in or toe-out for wheel geometry. However, anyone who has actually experimented with wheel geometry on their aircraft agree that using toe-out results in squirrely steering characteristics. Which is exactly what I determined by experimentation on my aircraft. With even the slightest amount of toe-out, the aircraft has a tendency to dart from side to side and you really have to dance on the rudder pedals to keep the aircraft moving straight down the runway. Actually, the ideal geometry is to have the wheels exactly parallel to each other, but this is difficult to achieve and maintain. And the wheel geometry will change, depending on whether the aircraft is in the 2-point or 3-point attitude. So, I shoot for a slight amount of toe-in. First I spin the tires/wheels on their axles to make sure that the tire ribs run true. If they do, then I can measure the distance between the tire ribs, front and back. I try for a 1/16" to 3/32" shorter measurement in the front versus the back measurement. And I check these measurements with the aircraft's tail up and tail down. Ideally, the measurements should be taken with the aircraft at the weight that you normally fly, because the gear will flex and change the wheel geometry. If the tire ribs don't spin true, then I clamp a length of aluminum angle stock to each brake disc and measure between the angles, front and back. Also, before I take any measurements, I wheel the aircraft back and forth to make sure the landing gear flexure is normalized.

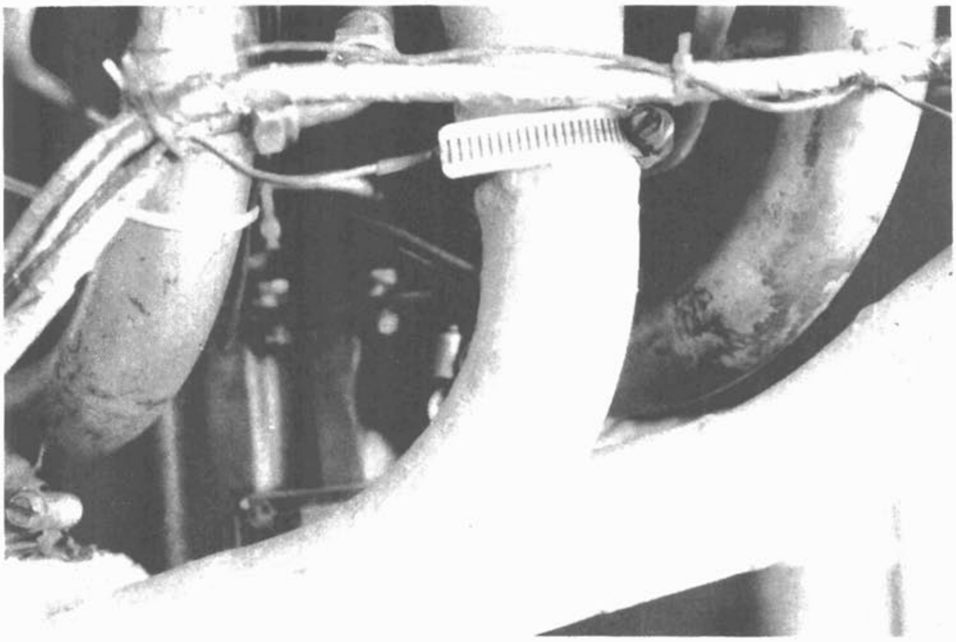

O.K. Which way did that Red Baron go?

10. To minimize cockpit glare, I sprayed the instrument panel with a black wrinkle-finish paint.

11. The Mustang-II canopy design includes a feature that provides steel fittings that protrude under the cockpit side rails on each side. I have found this to be a very important feature. On two occasions I have forgotten to securely lock the canopy prior to flight. Both times, the canopy opened about 3/4" and locked in that position, during flight, and I couldn't move the canopy any farther backward or forward. Apparently what happens is that the canopy is a lifting surface, and when the canopy is lifted off of the forward rollers, the under-rail steel fittings grip the side rails securely, and keep the canopy from being blown off. As I say, a very important design feature!

system, I fix the leak, then pump more fluid into the bleeder fittings. To make room for the additional fluid, I use a bulb syringe to suck the fluid out of the master cylinders reservoirs

13. Several features to control the extreme heat generated by the exhaust pipes in the cowling are as follows:



Aluminum tape wrappings protect heat sensitive wire and controls that pass close to high heat sources.

12. When filling the hydraulic brakes systems with fluid, I pump the fluid into the bleeder fitting at each wheel cylinder. This fills each hydraulic system from the bottom up, and all of the air is driven out of the system and completely replaced with hydraulic fluid. Of course, you need to check the fluid reservoirs in the master cylinders periodically, as you are pumping, to keep from overflowing the reservoirs. If I get an air leak in the

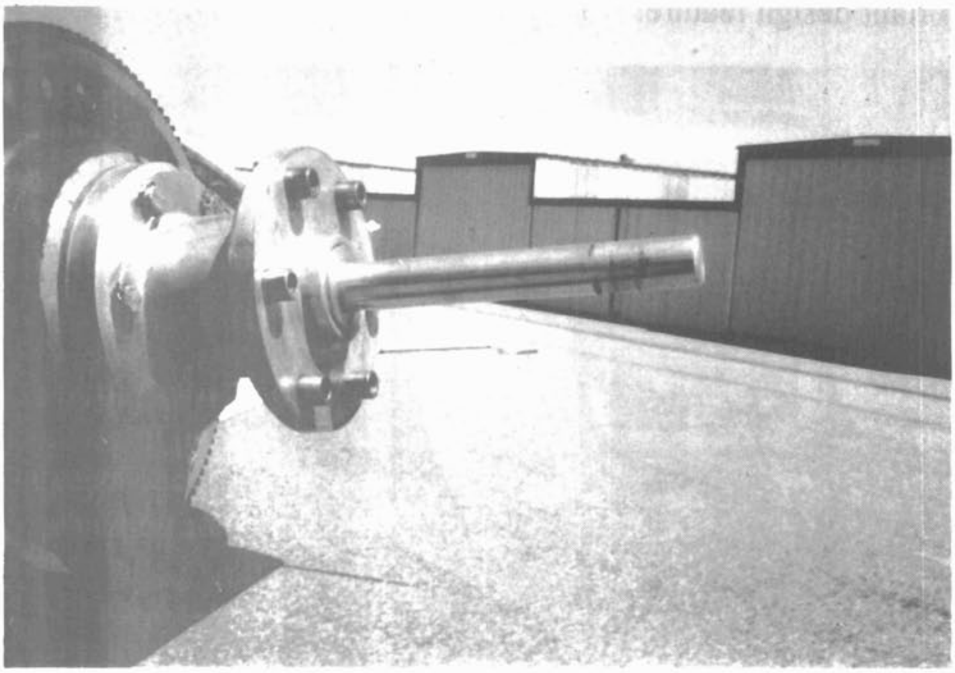
a) Since my exhaust pipes are now pointed aft, and some of the hot exhaust impinges on the belly of the aircraft, I protect the aluminum belly skin in the exhaust impingement area with galvanized sheet steel. And I sandwiched a sheet of asbestos between the steel sheet and the aluminum skin.

b) My cross-over exhaust pipes cross-over below the front of the engine. To keep the heat being generated from these cross-over pipes from cooking the alternator and starter, I placed a heat shield between the pipes and the alternator and starter. This heat deflector is also made from galvanized sheet steel.

c) I have a very tight fitting cowling, and the exhaust pipes run very close to the fiberglass cowling in two areas in the front. To protect the fiberglass in these two areas, I lined these areas with the sheet steel/asbestos sandwiches.

d) To protect the rest of the interior of the fiberglass cowling from engine and exhaust heat, I coated the interior of the cowl with a white, heat-reflective silicone rubber coating.

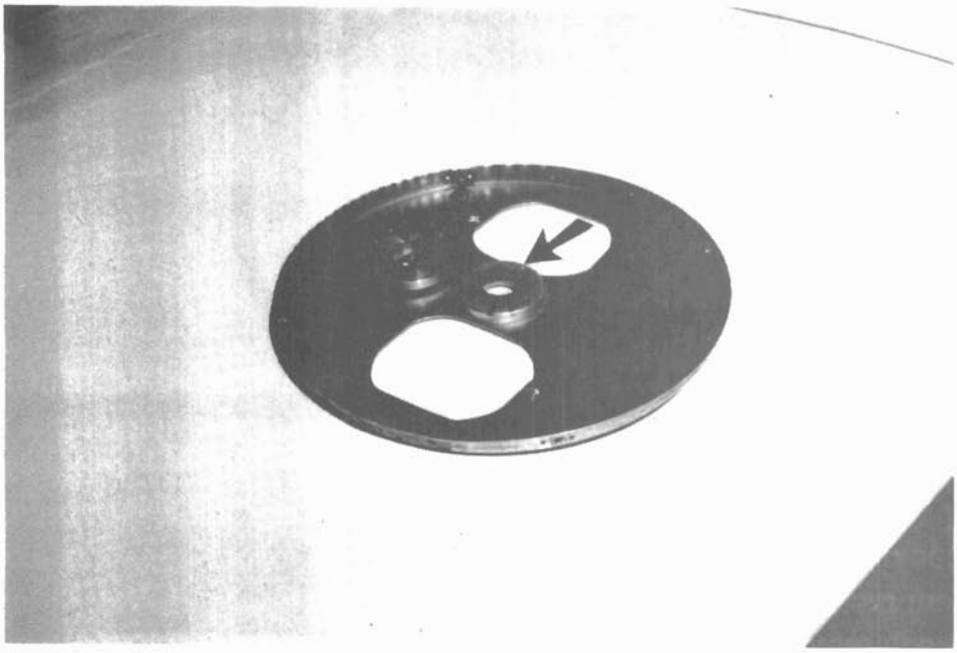
e) The spark plug wires to the lower spark plugs also run close to the exhaust pipes. To protect these wires and some other wires and controls from the exhaust pipe heat, I wrapped these wires/controls with heat-reflective, adhesive-backed, aluminum tape.



This one inch diameter aluminum spindle provides a rigid support for the spinner front bulkhead.

14. Several propellor spinner features are as follows:

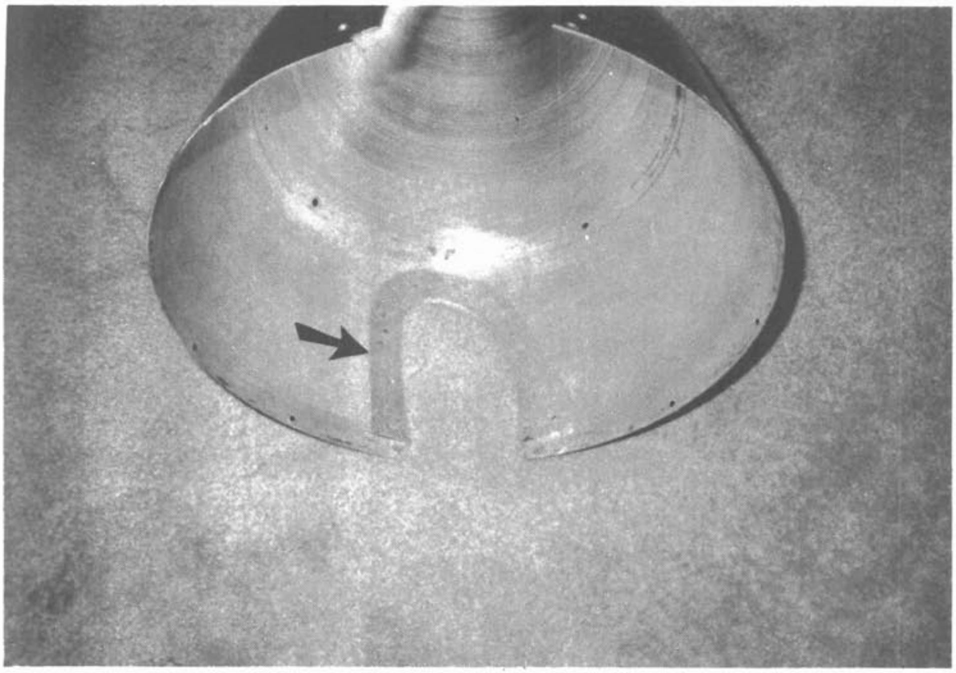
a) The propellor spinner is supported by an aft bulkhead and a forward bulkhead. The aft bulkhead is sandwiched between the propellor and the propellor extension flange. The front bulkhead is supported on a 1" diameter aluminum shaft that is pressed into the propeller extension. The front bulkhead is attached to the aluminum shaft via a rubber bushing. The rubber bushing is held in place by being sandwiched in a groove between two aluminum plates, and then riveted/bolted to the center of the front bulkhead. The grip-pressure of the rubber bushing on the aluminum shaft can be adjusted by tightening/loosening the 4 bolts that hold the grooved plates together.



Bolt-together plates on the spinner front bulkhead squeeze a rubber O-ring to grip the support spindle.

b) When the spinner shell is cut out to accommodate the propeller blades, this weakens the spinner shell. If cracks are going to develop in the spinner shell, they will start at these blade cut-out areas. To strengthen the edges of these blade cut-outs, I riveted a 1" wide strip of .060" thick aluminum, all the way around each cut-out on the inside of the spinner shell. These reinforcement strips terminate at the front face of the aft bulkhead. The ends of these strips are bolted, in turn, to aluminum angles (4-total) that are riveted to the aft bulkhead. This design allows the loads which are generated around the spinner blade cut-outs to be transferred to the aft bulkhead.

c) The spinner shell cut-outs fit closely (within 3/16") to the front of each propeller blade. However, to be able to slip the spinner shell over the propeller, the spinner shell cut-out behind each propeller blade must be made quite large, which leaves a triangular-shaped hole in the spinner shell when the shell is installed. I filled in these triangular gaps with the material cut out from the shell. These gap-fillers are held in place by riveting a back-up plate to the gap-filler. The back-up plate, in turn, is bolted to the edge of the blade cut-out in the shell. The aft end of this triangular gap-filler is bolted to the flange of the aft bulkhead. For extra security, I riveted what I call a "safety-strap" to the outside aft edge of the triangular gap filler. This strap overlaps the edges of the shell blade cut-outs at the aft bulkhead flange. A bolt at each end of the safety strap secures the strap and the edge of the spinner shell blade cut-outs to the aft bulkhead flange. Once I had added the blade cut-out reinforcement strips and the gap-filler safety straps, I had no further problems with spinner shell cracks. The spinner shell is attached to the front bulkhead with four 8-32 screws. Captive nuts must be used for these screws, since there is no access to the nuts, once the spinner shell is slipped over the propellor. Captive nuts for attaching the shell to the four aluminum angles on the aft bulkhead is also mandatory. However, captive nuts for the rest of the screws that attach the aft edge of the shell to the aft bulkhead is optional, since access to the nuts can be gained by removing the upper cowling half.



Aluminum plates riveted around the spinner shell propellor blade cutouts reinforce these inherently weak areas of the shell.

d) Exact centering of the spinner shell is necessary, since any off-center mounting of the shell will cause vibration which can be felt in the cockpit. Centering of the shell must be accomplished each time the shell is removed and reinstalled. After I reinstall the shell, I hold a felt-tip pen close to the shell (using a camera tripod to hold the pen). Then the propellor is rotated several times. The pen will mark the spinner shell high side. Removing a spark plug from each cylinder allows the engine to rotate smoothly. All the shell attachment hardware is loosened, the high side of the spinner shell (near the tip, at the pen marks) is slapped a few times with an open palm, and the attachment hardware is retightened. This procedure may have to be repeated a few times to exactly center the spinner, but it is worth it to eliminate any vibration from an off-center spinner.

The complete drawing set that I received from Bob Bushby was very detailed, with all of the fittings layed out full-size. The wing and tail surface ribs and all of the curved portions of the fuselage bulkheads were also layed out full-size, making it easy to transfer the patterns to the working material. Eventually, Bob sent over 80 sheets of drawings and continued to send additional sheets of changed design and drawing corrections for quite some time after I had completed the initial build of the airplane. During the initial building phase, I made few departures from the drawings. I carefully followed the drawing call-outs for the material type, alloy, thickness and heat-treat. The few instances where I did depart from the drawings are as follows:

- additional strengthening gussets for the portion of the landing gear torque-tubes that extend forward of the main wing spar.
- 1/4" diameter bolts instead of 3/16" bolts to attach the fixed tail surfaces to the fuselage.
- strengthening gussets to the elevator control bellcrank mounting, at the baggage compartment bulkhead.
- some additional stiffeners/stringers under the baggage compartment floor.
- an access door in the baggage compartment bulkhead for servicing the battery.
- extending the control tunnel housing forward to the firewall to protect the exposed rudder cables and battery cable.
- redesign of the wing flap control mechanism to provide positive latching at each flap position.
- thicker gauge materials and general strengthening of the wing flap mechanism.
- 0.004" thicker aileron skins, which necessitated more mass-balance weight (lead) for the aileron mass-balance arms (which caused the additional mass-balance weight to protrude slightly below the skin-

line of the wing-tips, at neutral aileron).

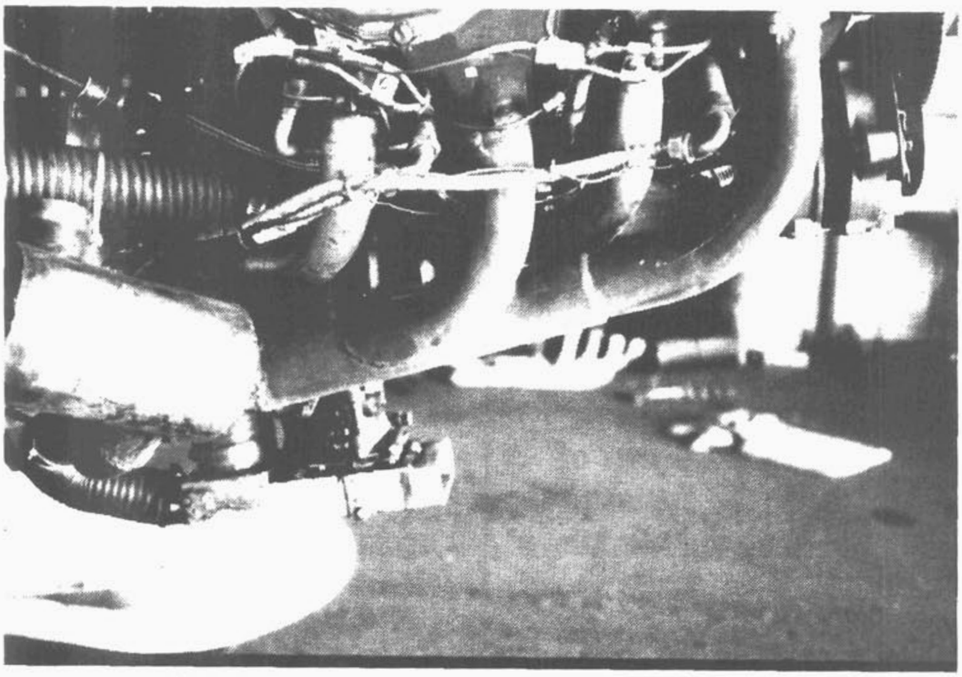
- overlapping aluminum sheets at the aft edge of the wind screen and forward edge of the canopy (makes for a near water and air-tight seal at the windscreen/canopy interface).
- a threaded-type canopy latch which allows me to really snug the canopy up to the windscreen.
- addition of a formed-aluminum tension-tie between the fuel tank supports to make sure that the fuel tank supports did not spread apart under heavy positive "G" forces.
- aluminum covers for the control stick wells in the cockpit, just aft of the wing main spar.
- I used a Ford automotive alternator and a Ford solid-state voltage regulator, which has an instantaneous response to fluctuating electrical loads, and with no arcing relay points, is maintenance and trouble-free.
- I acetylene gas-welded all of the steel fittings, except for the landing gear torque tubes. These I arc-welded with a nickel content rod, which gave good weld penetration into the 3/16" thick material. The nickel welding rod flows nicely, produces smoothly-filleted joints, doesn't under-cut the parent material, and holds weld-stress build-up to a minimum.

CHAPTER 2

ENGINE EXHAUST SYSTEM MODIFICATIONS

An engine's hot exhaust gases still have a lot of energy; harness that energy and put it to work.

The first type of exhaust system that I used on the engine were manifolds that collected the exhaust separately from the left bank of cylinders and the right bank of cylinders. That is, the cylinders on the right (#1 and #3) were manifolded together and the cylinders on the left (#2 and #4) were manifolded together. The exit ends of the manifolds were plumbed into a standard Piper muffler. The exhaust muffler had a single outlet that exited straight down, out of the cowling. Each manifold had a heat muff to provide carburetor heat and cabin heat. The exhaust muffler was braced back to the rear of the engine to prevent cantilever loads on the



Original exhaust system. Each cylinder bank flows into a common pipe.

manifolds. I used this exhaust system on the airplane for three years. After I had worked out the initial problems with the system, it did work satisfactorily. The problems consisted of the cracks in the aft ends of the manifolds and excessive heat from the muffler being absorbed by the gascolator. The manifold cracks were eliminated by bracing the muffler back to the engine. The excessive gascolator heating was solved with a simple heat shield over the gascolator. Not having any previous performance data to compare with, I was satisfied with this first exhaust system. However, I did notice that at full power near sea-level elevation, the engine produced objectionable vibration, which I initially thought was caused by the Aeromatic propellor that I was using at the time. I later discovered that #4 cylinder was exhausting into the manifold through only approximately a 1" diameter hole, causing the engine, at full sea-level power, to produce uneven power from all 4-cylinders, and vibrating heavily as a result. Opening up that 1" Diameter hole to the full 1 ¾" inside diameter of the exhaust pipe allowed the engine to produce smooth, balanced, full-throttle power.

Since I had been a hot-rod enthusiast and had built and experimented with two street-rods, I knew that most exhaust systems were very inefficient and that there was probably much room for improvement in my initial aircraft exhaust system. So began a whole series of experiments to see if I could increase my aircraft's performance by modifying the exhaust system.

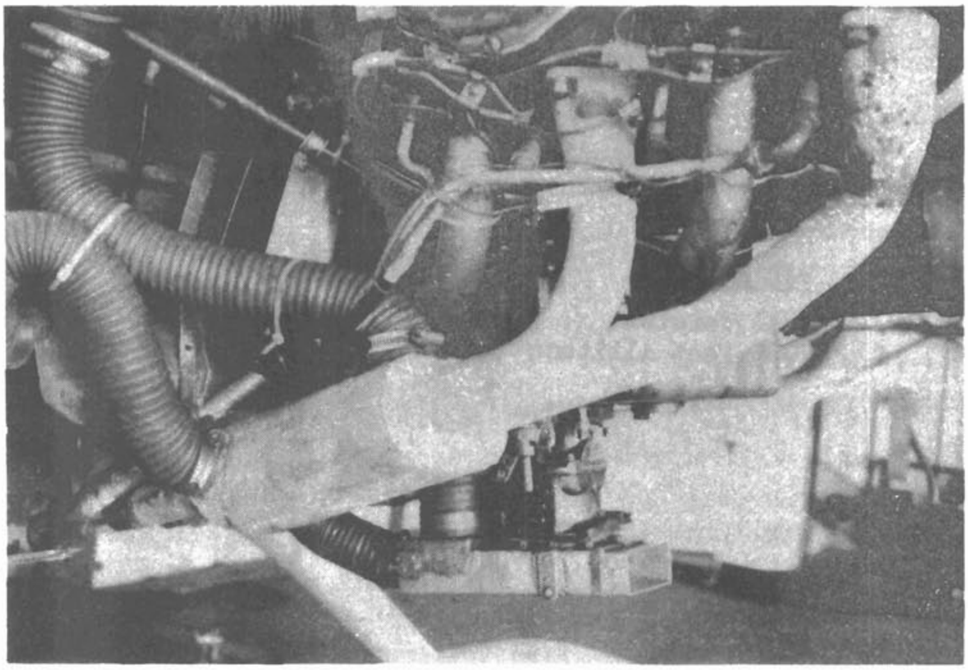
The first experiment was to see if eliminating the back pressure caused by the muffler would help much; so, I removed the muffler, and using 90° elbows, exhausted the gases from each manifold downward through the cowling. This did increase the aircraft's speed, but not as much as I had expected.

The next idea was to eliminate the drag caused by the downwards pointed exhaust plumes, by pointing the exhausts aft and maybe even benefitting some from the exhaust thrust. Using two more 90° elbows I jury-rigged both exhausts to point aft. This did produce an even larger speed increase. However, during the flight testing of this modification, the elbows rotated and the exhausts impinged on the aluminum belly-skin of the aircraft. Now, the exhaust is about 1600 degrees Fahrenheit and aluminum melts at about 1050 degrees Fahrenheit, so it didn't take long for the exhaust to burn through the aluminum skin, fill the cockpit with smoke from the burning floorboard insulation, and start giving me a real hot-foot! Fortunately, I wasn't far from the airport, with about 4,000 feet of altitude. So, I chopped the throttle, opened all cockpit vents and glided back to an uneventful landing at Arapahoe County Airport. The lesson I learned from the experience was that I needed to think through my planned experiments much more carefully, to recognize the risks of test flying, and to find ways to minimize those risks.

The positive results from the first two experiments served to whet my appetite for more experimentation. My next idea was to see what a separate exhaust pipe per cylinder would do. Using automotive exhaust tubing, elbows and fittings, I fabricated a set of 4 straight pipes, with only 1, less than 90° bend, per pipe. The pipes all pointed aft, but I was careful not to let them impinge directly on the aircraft's belly skin. Flight test results from this latest exhaust system configuration were very encouraging.

For some time, I had been searching for ideas to try on my aircraft. Sources for ideas were: hot-rod magazines, engineering texts, research by others on automobile exhaust systems, discussions with people who had raced automobiles and aircraft, and reports of research done by NACA (National Advisory Committee for Aeronautics) a government agency, predecessor of NASA. Most of my more successful ideas came from the old NACA reports.

The next idea to try did come from a NACA report: constrict the end of the exhaust pipes to accelerate the exhaust flow and realize even more jet-thrust. To constrict the ends of the 4 exhaust pipes, I first used exhaust pipe reducers, from 1¾" to 1½" diameter. Additional reductions in nozzle diameters were accomplished by fitting concentric rings of 4130 steel inside one another to eventually reach a diameter of 1" at the nozzle outlet (Figure 2-1). I performed a test flight at each increment



New exhaust system. Each cylinder has its own pipe, all the way to the end of each pipe outlet.

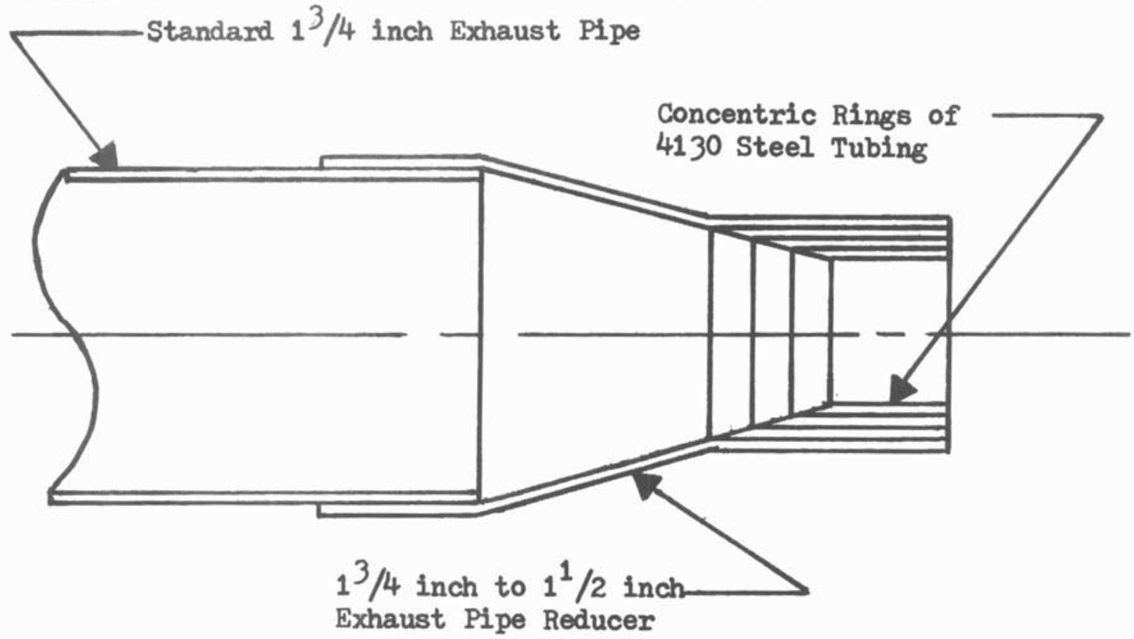


FIGURE 2-1
EXHAUST JET THRUST NOZZLE

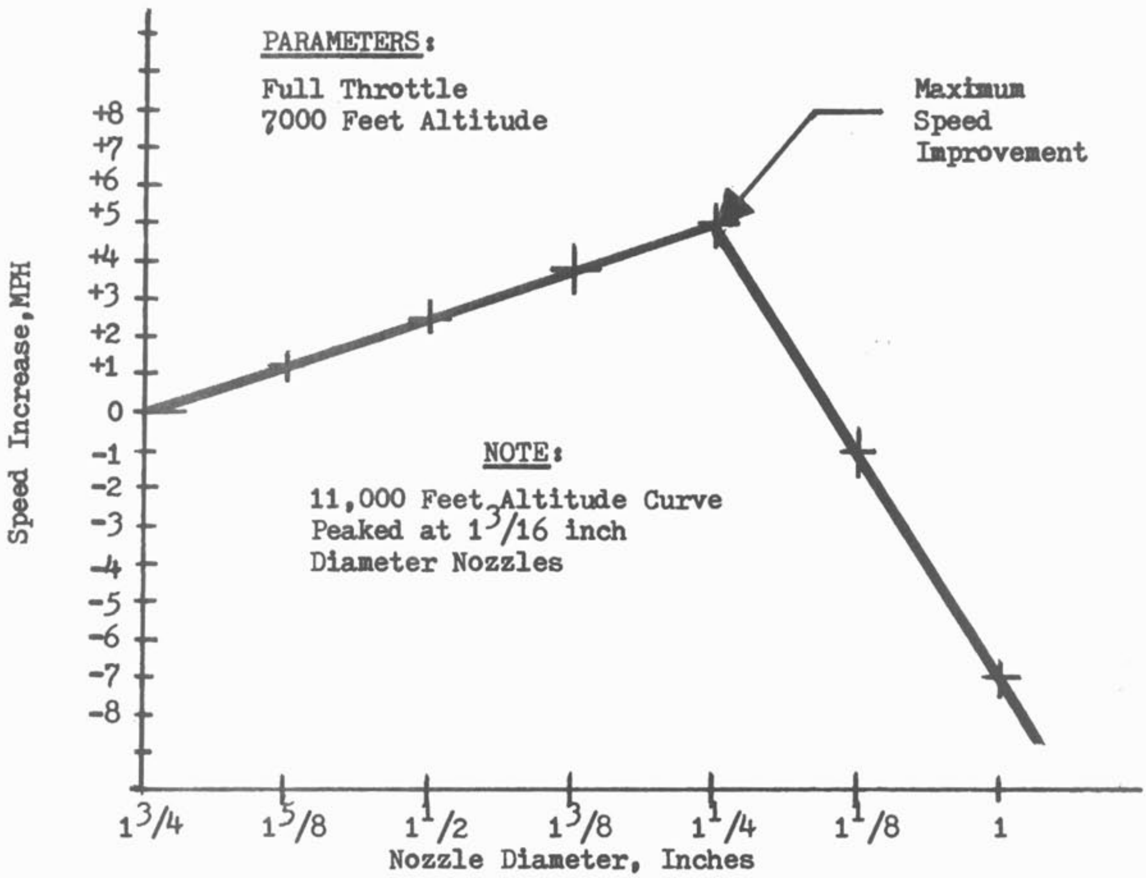
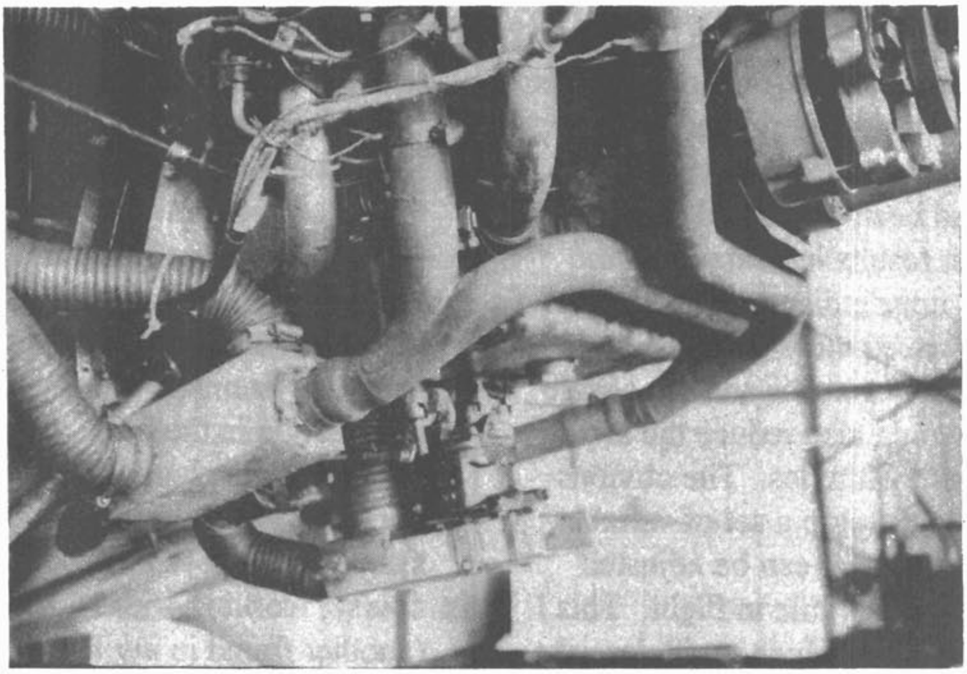


FIGURE 2-2, NOZZLE DIAMETER VERSUS BENEFIT of nozzle outlet reduction, so that I would know when the trade off between increased jet thrust versus reduced horsepower due to exhaust back pressure had been optimized (Figure 2-2). The test results indicated that the smaller the nozzle diameter, the larger the aircraft speed increase at the higher altitudes. However, the smaller nozzle diameters would also reduce the aircraft speed at lower altitudes. The obvious solution is to develop a set of variable exhaust nozzles that can be adjusted from the cockpit, while in flight. This I did at a later date, which I will describe later in this chapter. Nevertheless, the speed increases from the fixed diameter exhaust jet nozzles were significant. For my purposes, with my home airfield elevation at almost 6,000 ft., I chose the nozzle diameter of 1¼". This does cause a horsepower reduction at sea level, but doesn't hurt at 6,000 ft., and provides a significant speed increase at high cruise altitudes.

For some time I had been considering a cross-over exhaust system. A cross-over exhaust system manifolds together the two front cylinders (#1 and #2) and separately manifolds together the two rear cylinders (#3 and #4). All of the advertisements by cross-over system fabricators claimed that their system would develop more horsepower. About this time, George Hite, a friend in my local EAA Chapter #301, recommended that I read a book titled "Scientific Design of Intake and Exhaust Systems". This book was written by two researchers at the University of Edinburgh, Glascow, Scotland. I learned much about the theory of automotive intake and exhaust systems from this book, and I consider it required reading for anyone interested in experimenting with intake and exhaust systems. Anyway, based on the information in the book, it seemed likely that the claims of increased horsepower for the crossover exhaust system were possible. So, in due course, working with Dean Cochran (another friend in my EAA chapter), a cross-over exhaust system for my Mustang-II was fabricated. Some modifications to Dean's standard crossover design were necessary to fit the system inside my much-streamlined and tight cowling. But Dean was patient with me and the final results were well worth the effort. Flight testing indicated a significant horsepower increase, since the same fixed-pitch propellor was now turning almost 100 RPM faster in climb and even more in top speed. And the 1¼" diameter jet thrust nozzles worked equally well on the cross-over system. Dean Cochran also drew my attention to the subject of "exhaust anti-reversion". Specifically, a particular configuration to implement exhaust anti-reversion, that is, "anti-reversion cones." The theory of exhaust anti-reversion is to prevent hot exhaust gases from flowing backwards into the combustion chamber during the period

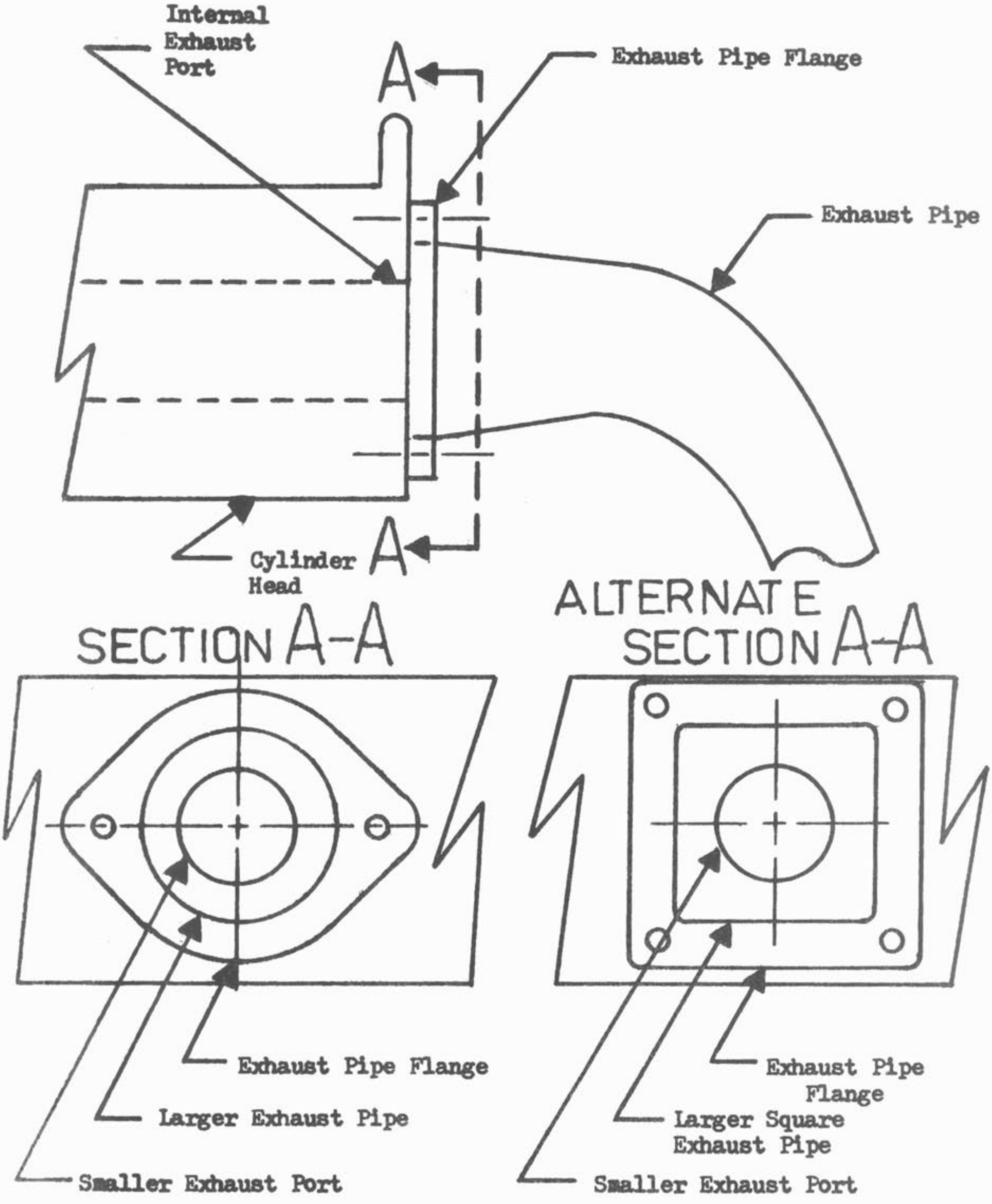


The cross-over exhaust system is aptly named.

of intake and exhaust valves being open at the same time. This is commonly called valve "overlap". Apparently, exhaust gases can actually back up into the intake pipe, as well. Obviously, anything that can be done to prevent or reduce this phenomenon should make the engine operate more efficiently (i.e.- more power, less fuel consumption, cooler running, etc.). It took a long time to convince myself that this would be a worthwhile modification to my aircraft's exhaust system. I had heard of port mis-matching before; this is where the cylinder head exhaust port is smaller in cross-sectional area than the exhaust pipe where it is bolted to the port (Figure 2-3). The auto racers have used this configuration for some time, with fair results. The anti-reversion cones configuration is basically port mis-matching, plus an inner truncated cone inside the exhaust pipe, where the pipe bolts to the head. After collecting all the data that I could on this configuration (which wasn't much; a hot-rod magazine article, and a look at "Cyclone" exhaust headers at a local auto speed shop), I finally decided that it was worth trying. Working with my 4-straight stack exhaust system, I replaced the first 2 inches of each pipe (where it bolts to the cylinder head) with a flared section of pipe, where the flared pipe is welded to the outside of the exhaust flange. Dean made a set of stainless steel inner truncated cones to fit inside the flared section of pipe (Figure 2-4). The flight test results were spectacular. While there was no appreciable increase in speed, nor decrease in engine temperature, fuel consumption, in cruise mode, dropped a full gallon per hour! This outstanding

FIGURE 2-3

EXAMPLES OF AUTOMOTIVE EXHAUST PORT MIS-MATCH



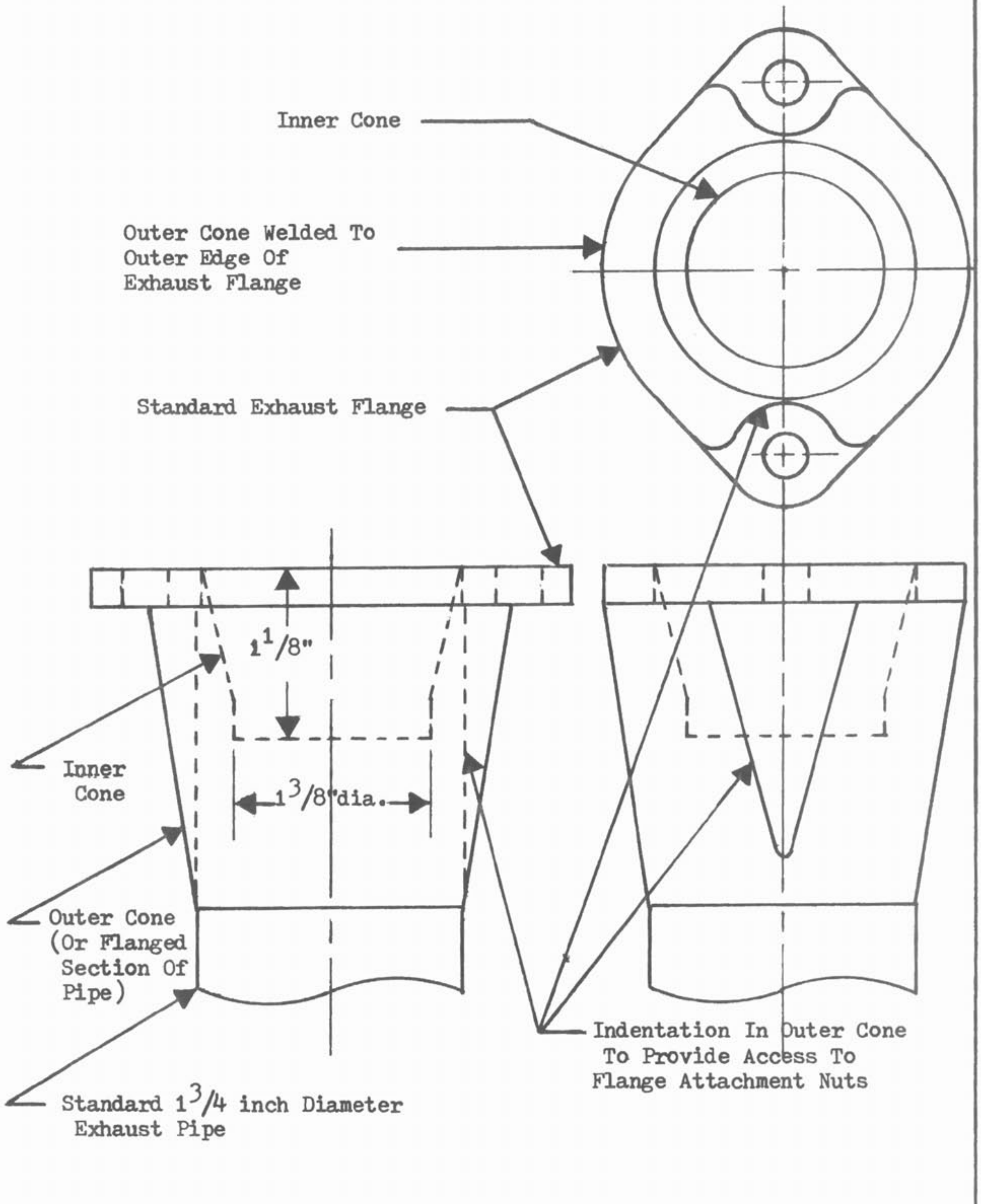
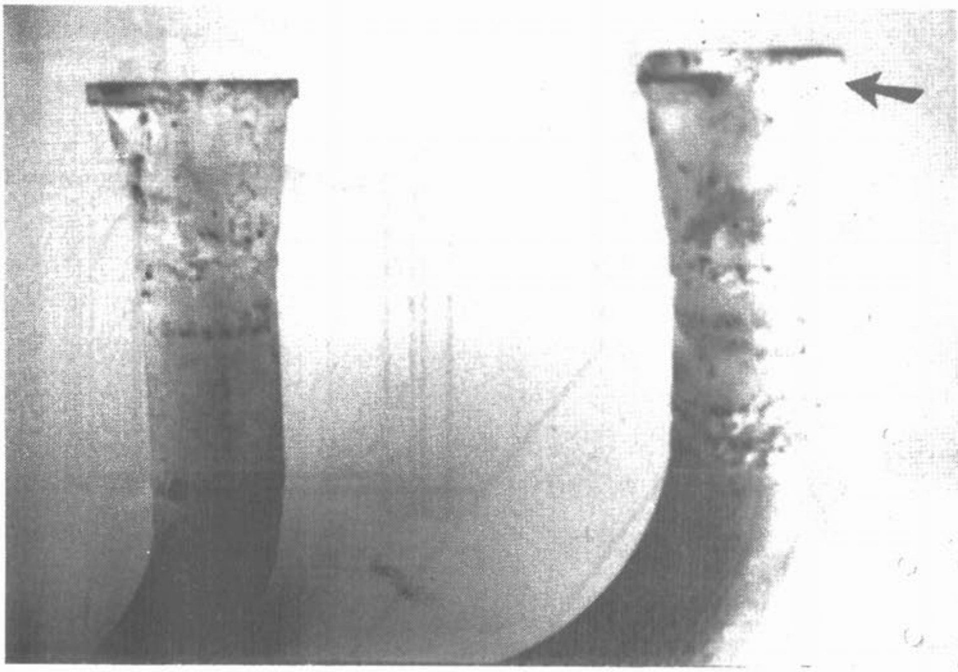
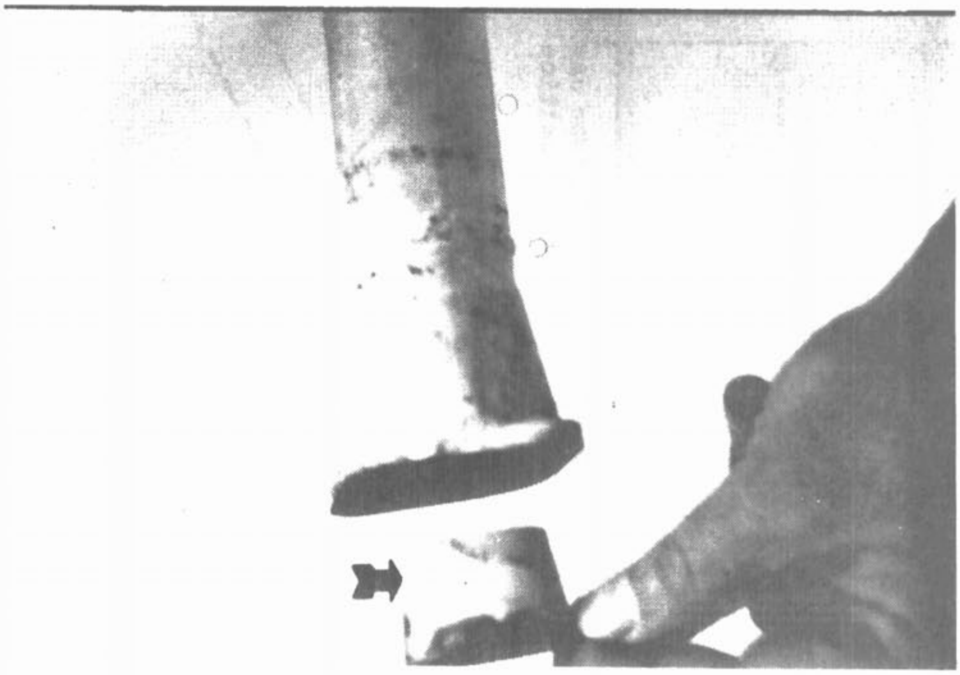


FIGURE 2-4

ANTI-REVERSION CONES EXHAUST SYSTEM



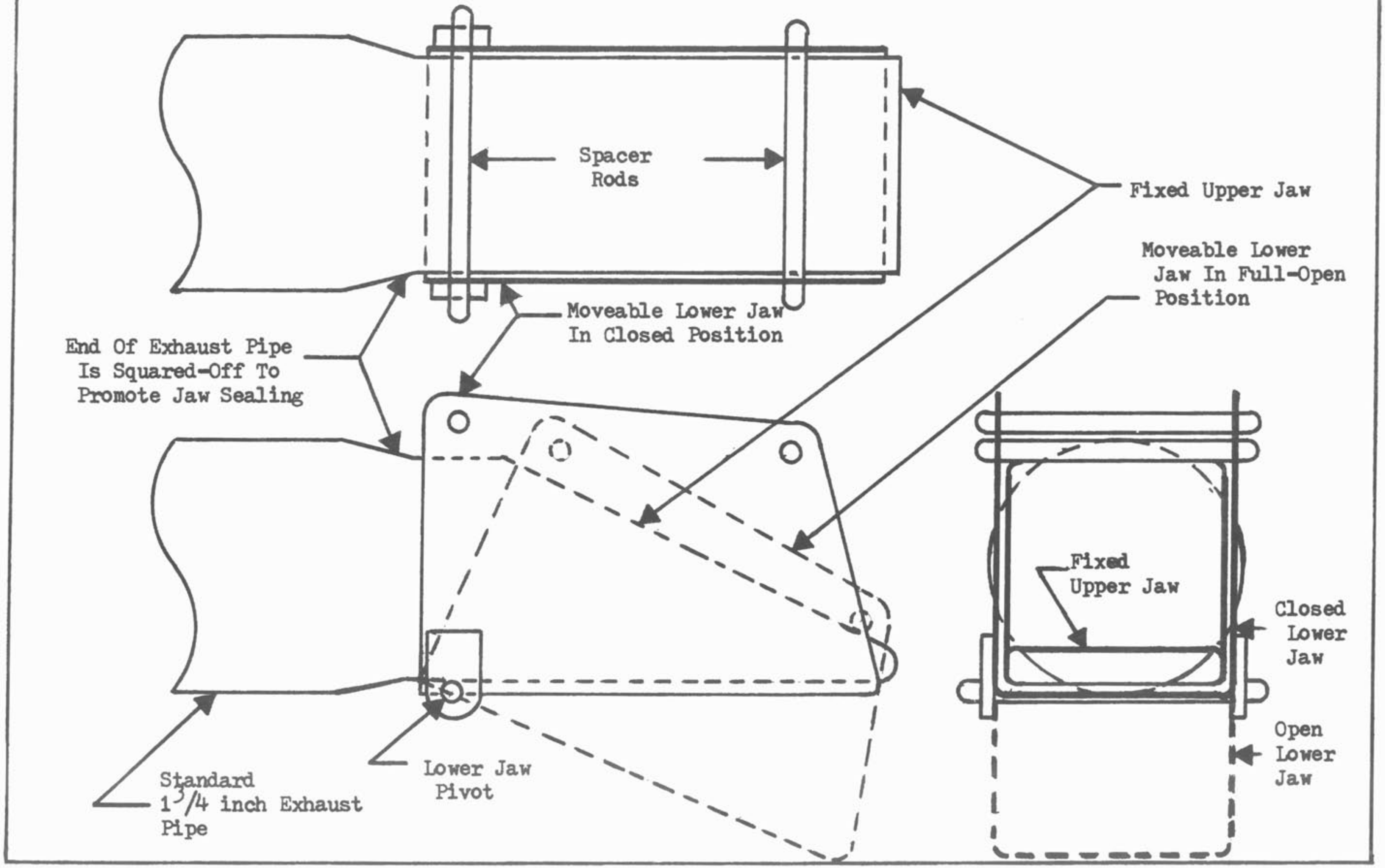
`For the anti-reversion system, the exhaust pipe upper-ends are flared and welded to the flange outer edges.



The anti-reversion inner-cone slips inside the exhaust pipe/flange.

performance improvement was shown by fuel flow meter readings and verified by numerous cross-country trips. I really wanted to use the crossover exhaust system, since it produced more power than the 4-straight stacks. So Dean, using an expandable mandrel, flared the crossover pipes, directly adjacent to the flange, to the approximate configuration that I had initially developed on the straight pipe system. Dean also made another set of

FIGURE 2-5, VARIABLE EXHAUST THRUST NOZZLE



inner cones to use with the crossover system. Again, flight testing showed the same spectacular decreased fuel consumption, plus the increased power of the crossover system.

I did give variable exhaust nozzles a try. The best configuration would be overlapping fingers, like the petals on a flower. Today's jet fighters have nozzles of a similar configuration on the ends of their tailpipes. However, the actuating mechanism to vary the diameter would be complicated and would have to operate in a very hot environment. The configuration I did fabricate was a clamshell-like device. The upper shell was fixed and the lower shell was hinged, to be able to vary the outlet area (Figure 2-5). Each of the two devices (one for each crossover pipe) was controlled by a vernier cable from the cockpit. I used the nozzles for about 6 months. The flight test results were fair. I could open the nozzles for maximum horsepower at sea level; and, I could close the nozzles for more jet thrust at altitude. However, I could not get the performance at altitude as good as the fixed diameter nozzles. I believe the poorer performance was due to the variable nozzle configuration. The configuration just did not provide for good exit flow when closed down to a smaller exit area. Also, due to the high vibration and heat environment, the nozzle hinges and lower ends of the vernier cables were worn to the point that operations were not reliable. I do think, that with more development work, a variable nozzle that is durable, reliable and that offers altitude performance comparable to a fixed diameter nozzle, could be developed. But, I had many more ideas in other areas that I wanted to try, and no further development of variable exhaust nozzles was undertaken.

So, after all of the research, experimentation, hardware configuration modifications, and flight testing, I have determined the best exhaust system configuration for my much-modified Mustang-II. I am currently flying Dean Cochran's stainless steel crossover exhaust system with 1¼" diameter jet thrust nozzles, port mis-matching, and anti-reversion cones. This configuration provides the highest performance (velocity) for the lowest fuel consumption.

RASER

CHAPTER 3

ENGINE INTAKE SYSTEM MODIFICATIONS

An efficient air intake system lets the engine really breathe and allows hidden horsepower to express itself.

My original thoughts on intake systems improvement included:

- Don't impede inlet air (air filter efficiency).
- Don't redirect inlet air anymore than necessary (change of direction).
- Keep inlet air as cool as possible (maximum fuel charge density).
- Maximize ram air (forward velocity/propellor augmentation).
- Improve plenum chamber utilization if air direction change is necessary.

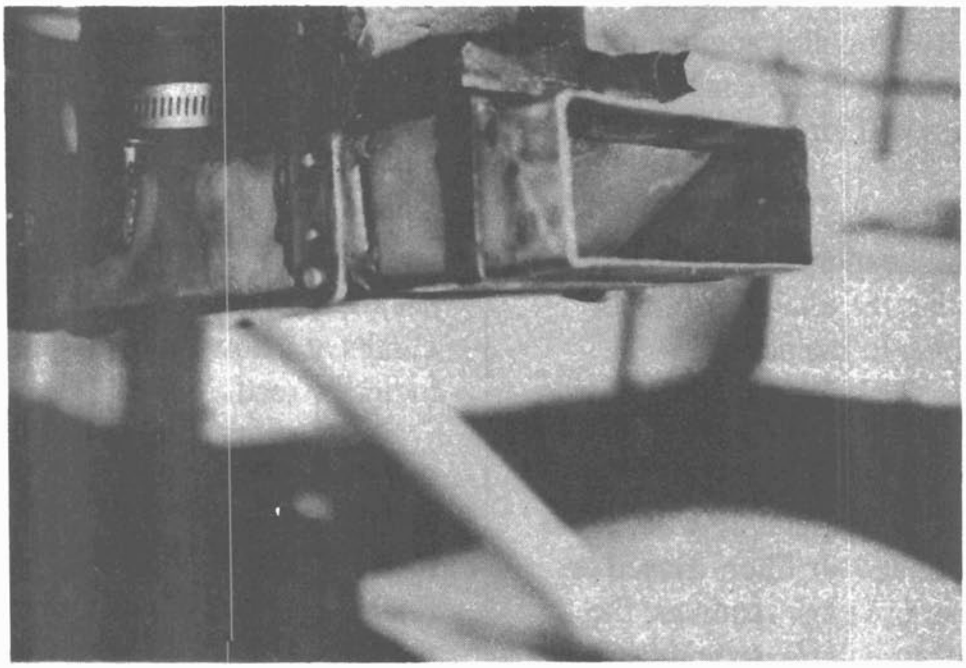
The first experiments were to determine what the intake system air filter was doing to the aircraft's performance. The original air filter was a standard aircraft flocked-screen filter. For the first test flight, I removed the flocked-screen filter, and flew the plane without any intake air filter. Based on manifold pressure gage readings, the manifold pressure increase without any air filter was slightly more than 1.0 inches of mercury. This is approximately what Mooney aircraft realize when they go from filtered air to unfiltered air. The aircraft's speed increase at altitude (7,000 ft.) was 3 MPH. At sea level, the speed increase should be 4 to 5 MPH. Since my home field elevation here in Denver is 6,000 ft., most of my performance data is at 7,000 to 12,000 feet. Occasionally, I collect some near sea-level data when I travel to Oshkosh for the EAA convention, or visit my brother in Chicago and my daughter in Topeka. I am always impressed, when I fly near sea-level, how short the take-off run seems, how much quicker the airplane climbs and how much more the airspeed indicator reads.

Anyway, since I had determined that the standard aircraft air filter was costing 3 MPH of top speed, I wanted to see if I could come up with an air filter media that would be better than the flocked screen. I tried an automotive filter (pleated, treated paper), but that was a step backwards in that both manifold pressure and speed were both less than when using the flocked-screen filter. Next, I tried an open-pore foam air filter. This was an improvement, but still not as good as using no air filter in the intake system.

It became obvious to me that the answer was to design a carburetor airbox that provided three air sources:

1. Filtered air,
2. Heated air,
3. Unfiltered, straight-ram air.

The carburetor airbox design which I developed utilizes two air gates (Figure 3-1). The main gate is directly under the carburetor inlet and allows me to select air either from the front or rear of the airbox. The front of the airbox supplies unfiltered, ram air to the engine. The rear of the airbox has another air gate which allows me to select either filtered air or heated air when the main gate is positioned to draw air from the rear of the airbox. The heated air is drawn from a heat muff on the right-side exhaust pipes. The heat muff itself is provided with pressurized air from the engine air cooler plenum chamber, atop the engine. The filtered air is drawn from a filter housing (Figure 3-2) which contains an open-pore foam filter. The foam filter is an Amsoil life-time automotive air filter. After trying the Amsoil air filter on my cars and realizing increased acceleration and decreased fuel consumption, I decided that the Amsoil air filter was the most efficient air filter that I could use on the airplane, also. The filter housing draws air from inside the cowling.



New airbox is all aluminum construction.

FIGURE 3-1, CARBURETOR AIRBOX NEW DESIGN

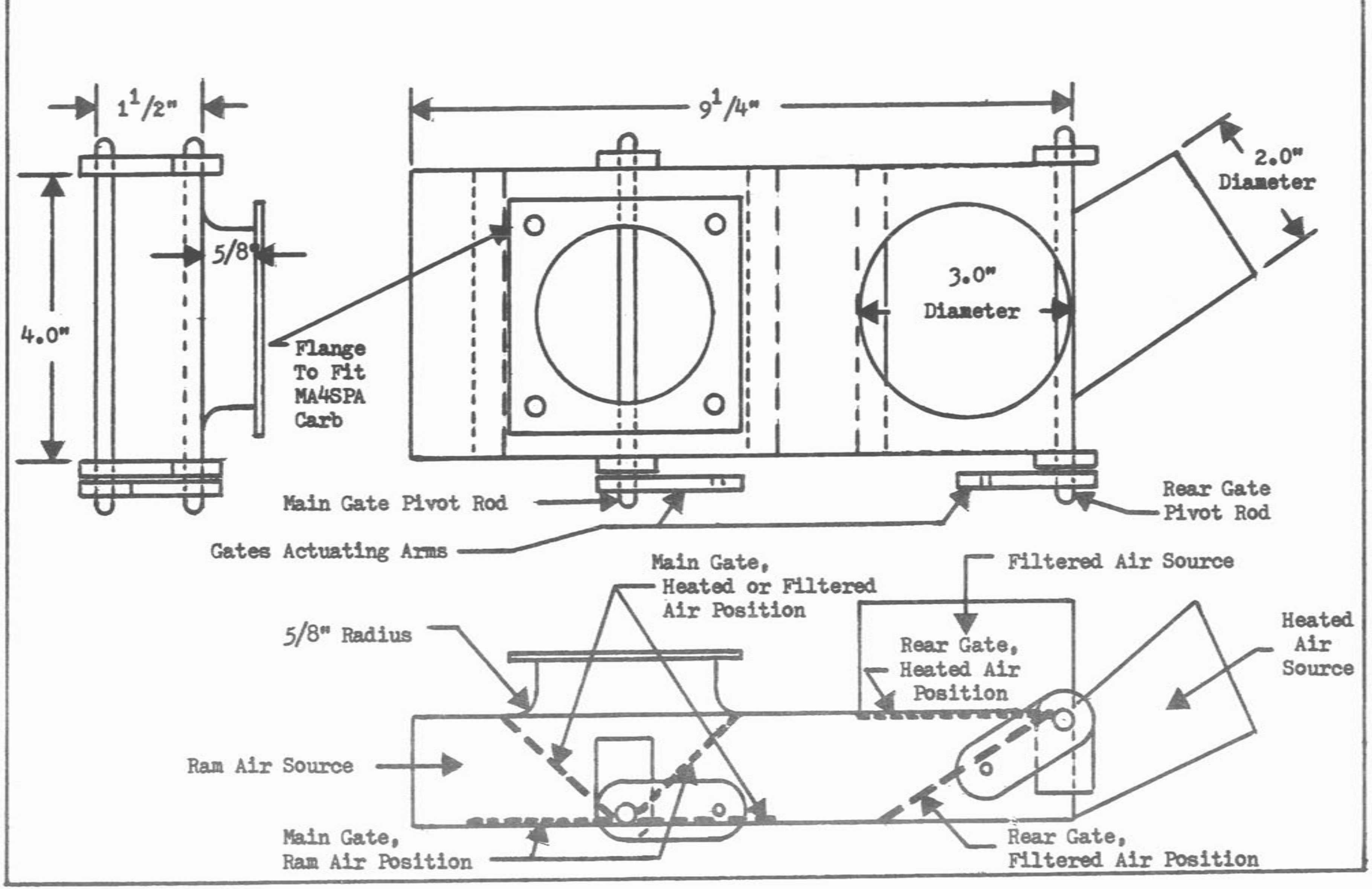
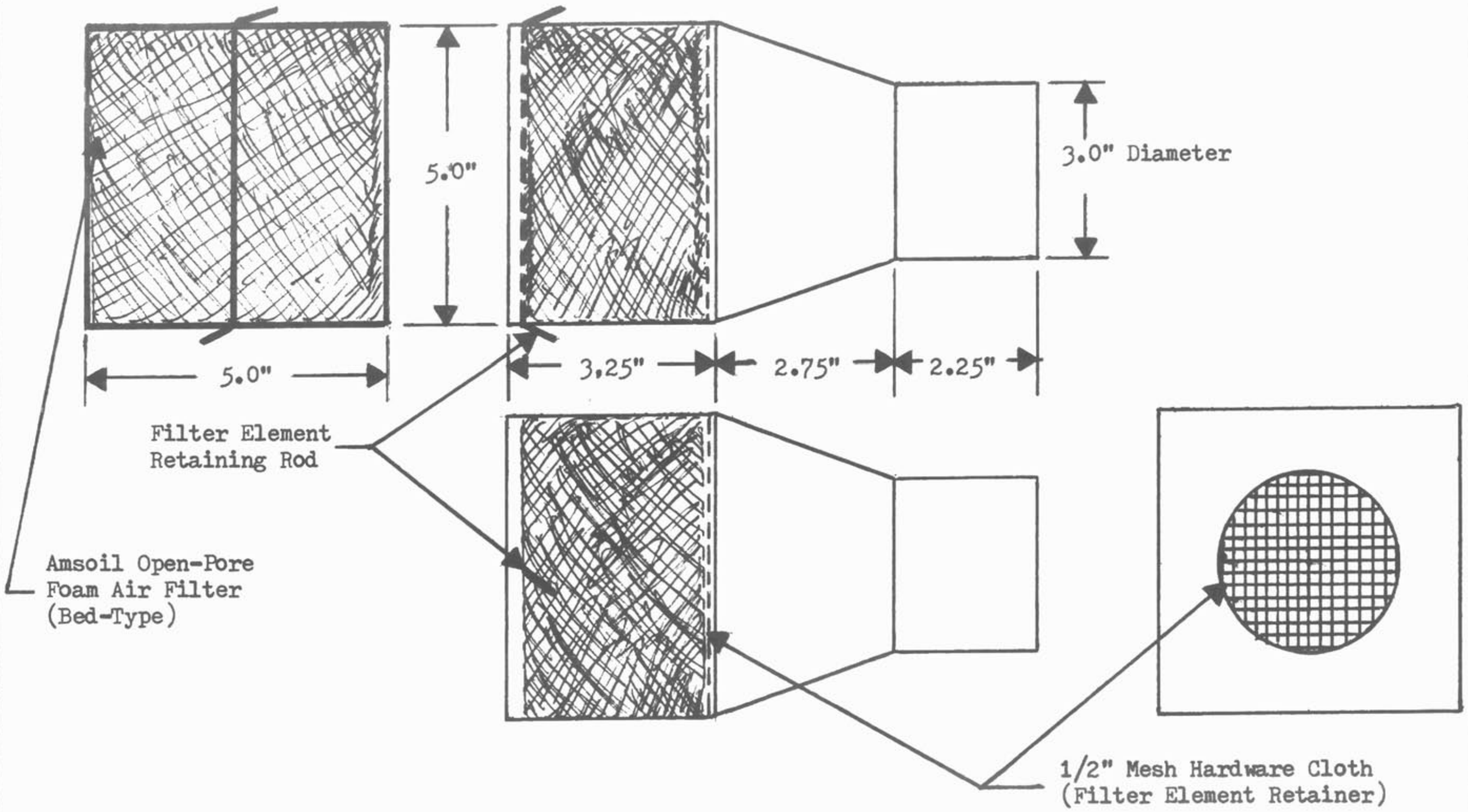
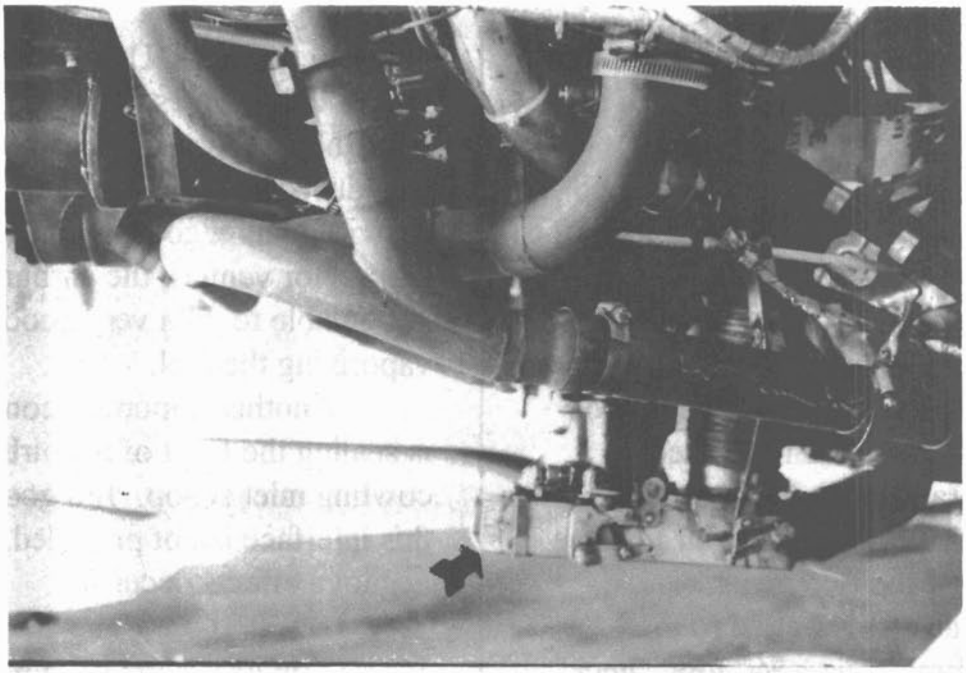
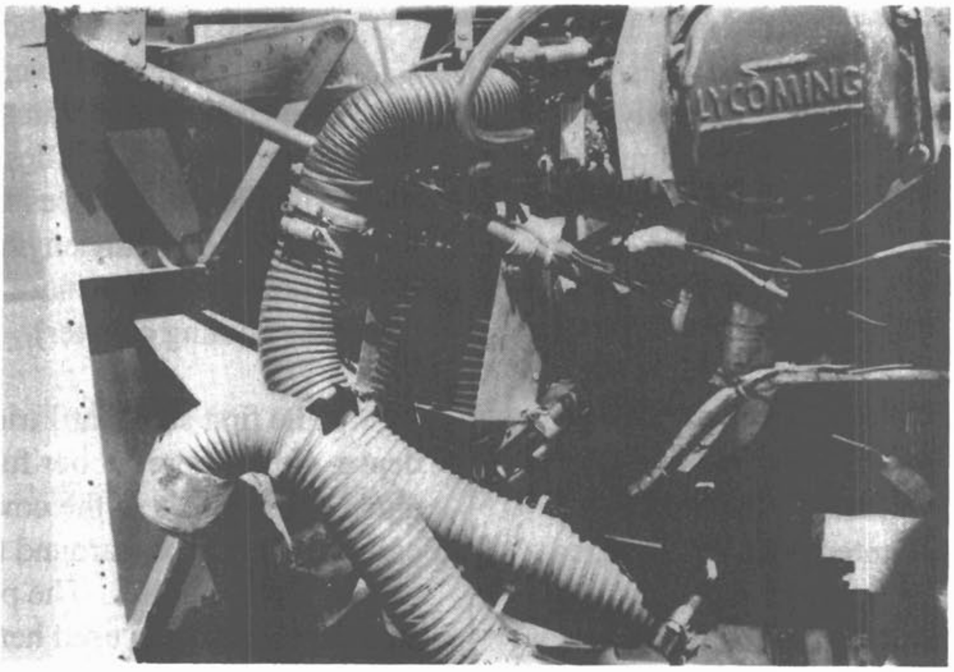


FIGURE 3-2, AIR FILTER HOUSING





New airbox has a shallow profile.



The carburetor air filter housing is mounted remotely from the carburetor airbox.

Pressurized air from the engine cooling air plenum chamber could be supplied to the air filter housing. However, I recognized that the more air I drew from the engine air cooling plenum chamber, the less efficient that the engine cooling system would be, and I opted for a strong engine cooling system. The flex hose from the heater shroud to the airbox is 2.0 inches in diameter. The flex hose from the filter housing to the airbox is 3.0 inches in diameter. These are considered minimum hose diameters, determined by flight tests. Some more details of the airbox itself:

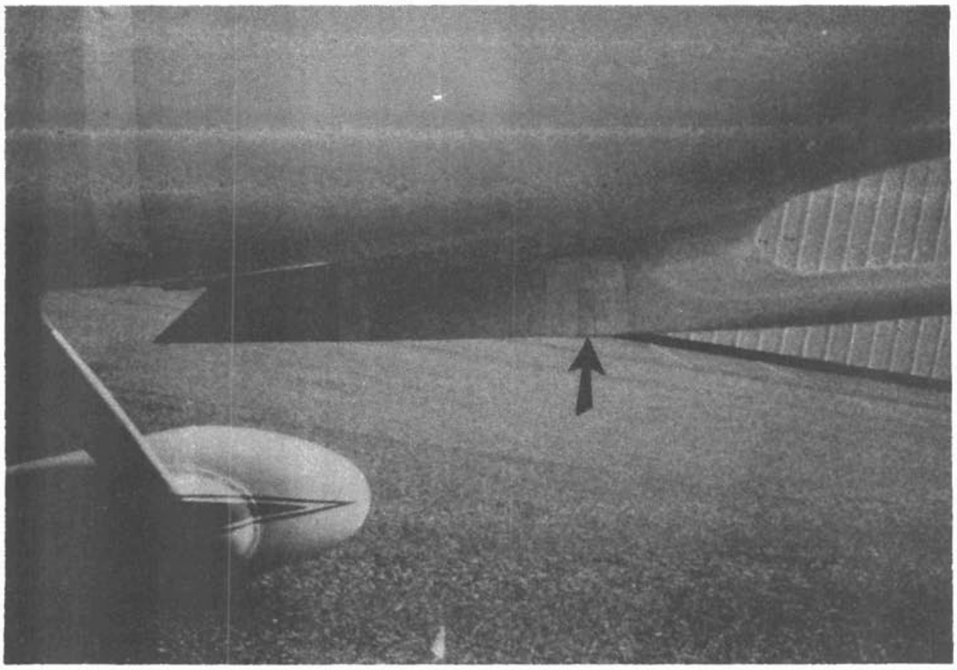
- The airbox is fabricated from aluminum sheet, plate and rod, and is riveted and welded.
- Tolerances are held as close as possible to minimize air leakage around the two gates.
- The airbox is bolted to the carburetor via a ⅝" long "neck".
- The neck, where it is welded to the top of the airbox, is flared to a ⅝" radius, all-around. The reason for this is that air is taken into the airbox horizontally and that air must then be redirected 90 degrees to be taken vertically into the carburetor. Now, air has mass and, at velocity, cannot turn a sharp 90 degrees.

When I first built the airbox and flight tested it, I was very disappointed in the aircraft performance. After considerable contemplation, I realized that I was asking the air going through the airbox to violate a law of physics by turning a perfect 90 degrees at high velocity. After I radiused the neck to airbox juncture, the aircraft performance improved significantly. Another feature that I added to the airbox at a later date was suggested by another friend in EAA Chapter 301, Larry Vetterman. That was to put a couple of air vanes in the airbox neck to keep the air from swirling as it was introduced to the carburetor. If the air is swirling as it goes through the carburetor venturi, the carburetor may not be able to do a very good job of vaporizing the fuel.

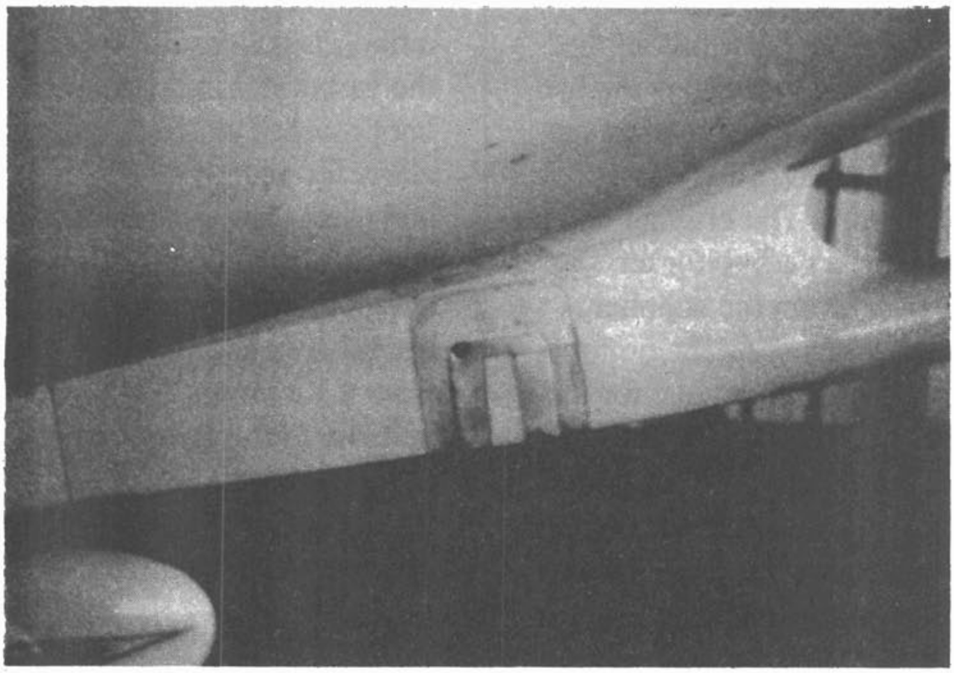
Another important consideration is sealing the front of the airbox to the cowling inlet scoop. If a good seal at this interface is not provided, two negative effects occur:

1. You lose ram air pressure to the carburetor.
2. The ram-air that should be going to the carburetor winds up pressurizing the lower cowl, which is downstream of the engine cooling baffles. This significantly reduces the efficiency of the engine pressure cooling system (more on this in the cooling chapter).

The first seal that I tried was a dense, closed-pore rubber foam that I glued to the inside of the cowling carburetor air scoop around the front of the carburetor airbox. The problem with any seal that is used here is that it must be flexible, due to engine vibration/shaking/movement relative to the fixed structure of the cowling. Also, access to this area inside the cowling is very limited. So, an air-tight yet flexible seal is very difficult to achieve. The foam, glued in place, did allow for engine movement, but was a very poor air seal. The most effective seal that I developed used an inner-aluminum liner, fixed in place inside the cowling carburetor air scoop, that was the same cross-section as the front of the airbox and ended ⅜" in front of the airbox. Then I cut access holes in the cowling so that I could wrap 3 or 4 layers of duct tape around the ⅜" gap between the front of the airbox and the end of the scoop aluminum liner. The holes in the cowl are then covered with a removable, formed aluminum access door.



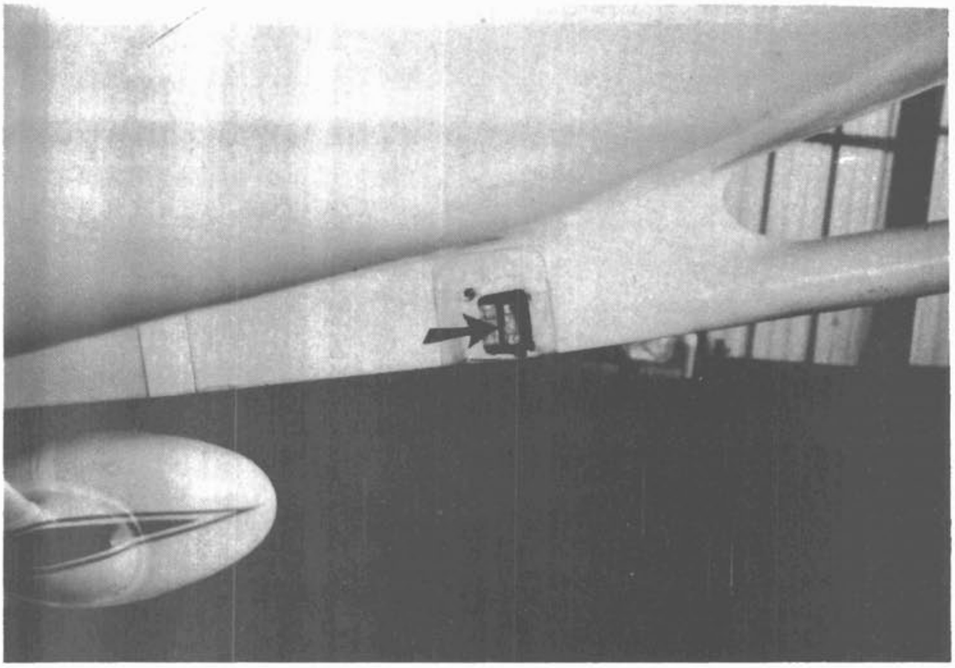
The carburetor housing access door is taped over.



The carburetor-housing access door covers three sides of the carburetor housing.

This design allows for engine movement and provides an absolutely air-tight seal. The only negative aspect of this design is that the tape must be removed and replaced each time that the lower cowling is removed and replaced.

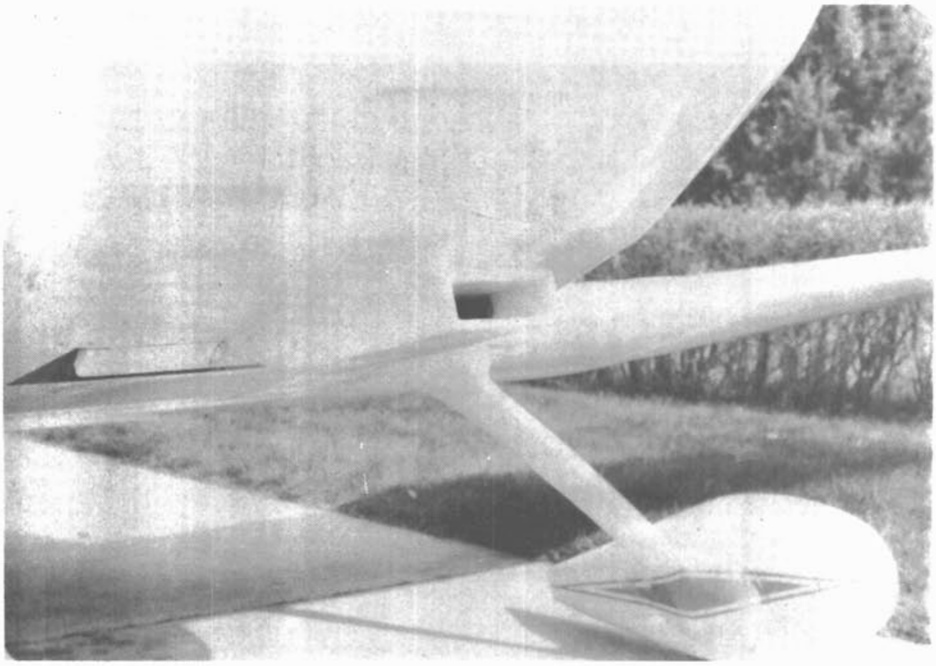
necessary to provide sufficient air flow for the carburetor. This resulted in a massive amount of air spilling back out of the scoop, causing a lot of totally unnecessary aero-dynamic drag. My first attempt to correct this situation was to completely remove this very large



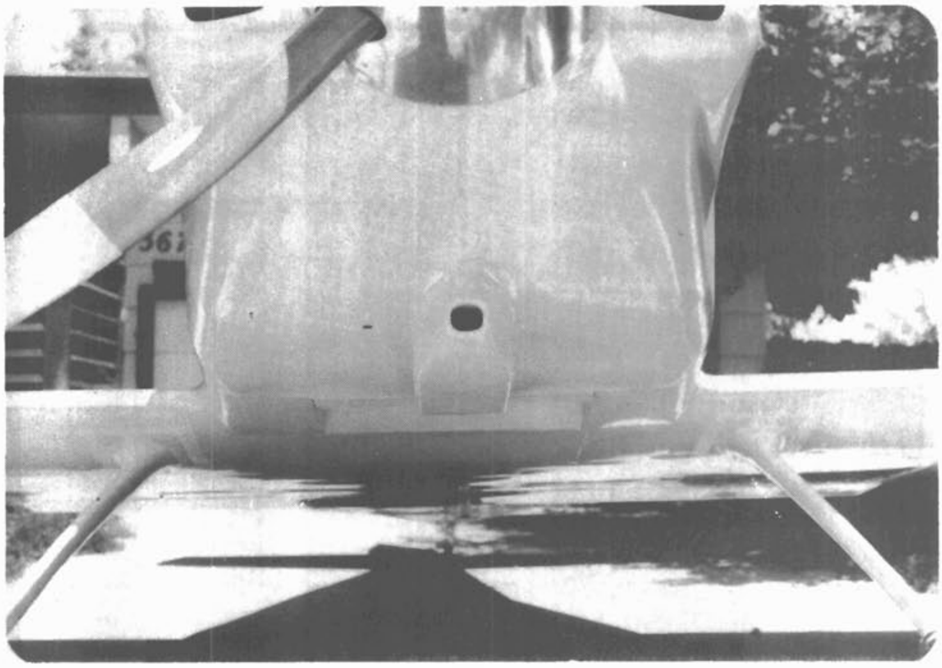
The carburetor airbox clears the scoop inner liner by 3/8".

Another idea which I discussed with John Swearingen (designer of the SX-300 experimental aircraft) is the use of propellor pressure pulses to augment the ram air flow into the cowl carburetor air scoop. The original cowl configuration for the carburetor air scoop (as received from the supplier) had a very large housing on the bottom of the cowl to provide clearance for the carburetor, carburetor airbox and carburetor air filter. The front of this cowl housing was the carburetor outside air scoop. The scoop had a very large opening. Probably an area 8 times that

carburetor airbox housing and fabricate a fiberglass housing which closely fitted the carburetor and carburetor airbox, but provided sufficient clearances to allow for engine movement and carburetor and carburetor airbox controls operation. This reduced aero-dynamic drag by reducing the aircraft's frontal area and reducing the air spillage from the carburetor air scoop. The opening to the scoop closely fit the front of the carburetor airbox and the area was about 3 times that necessary to provide sufficient carburetor air flow.

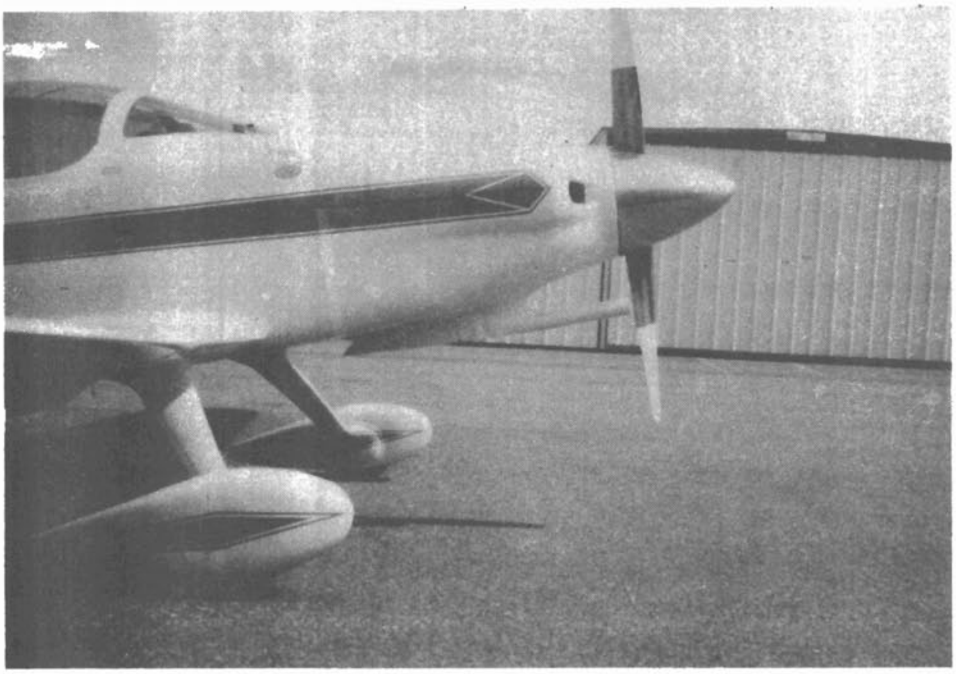


The first new carburetor air scoop was short in length and had a rectangular opening.

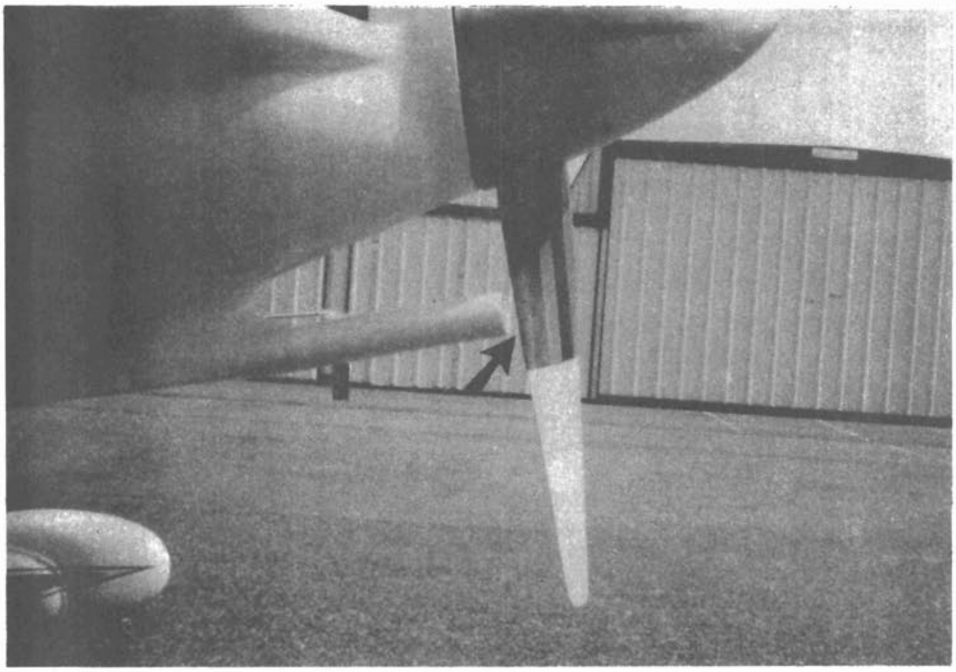


The next new carburetor air scoop was still short, but had a rounded and smaller opening.

This scoop was rectangular in cross-section. For the next scoop configuration, the scoop was extended forward about 8 inches, and the scoop opening was rounded-off with an inlet area reduced to about 1½ times that required for sufficient flow to the carburetor. Based on my discussion with John Swearingen, the final configuration for the carburetor air scoop clears the propellor by only ⅝ of an inch, with an inlet area only 10%



The final carburetor air scoop is quite long and retains the small, rounded opening.



The clearance between the long carburetor air scoop and the propellor is minimal.

larger than the venturi throat area of the carburetor. This configuration further reduces the aero-dynamic drag due to scoop air spillage, and takes advantage of the pressure pulses from the propellor each time that a propellor blade passes by the carburetor air scoop inlet.

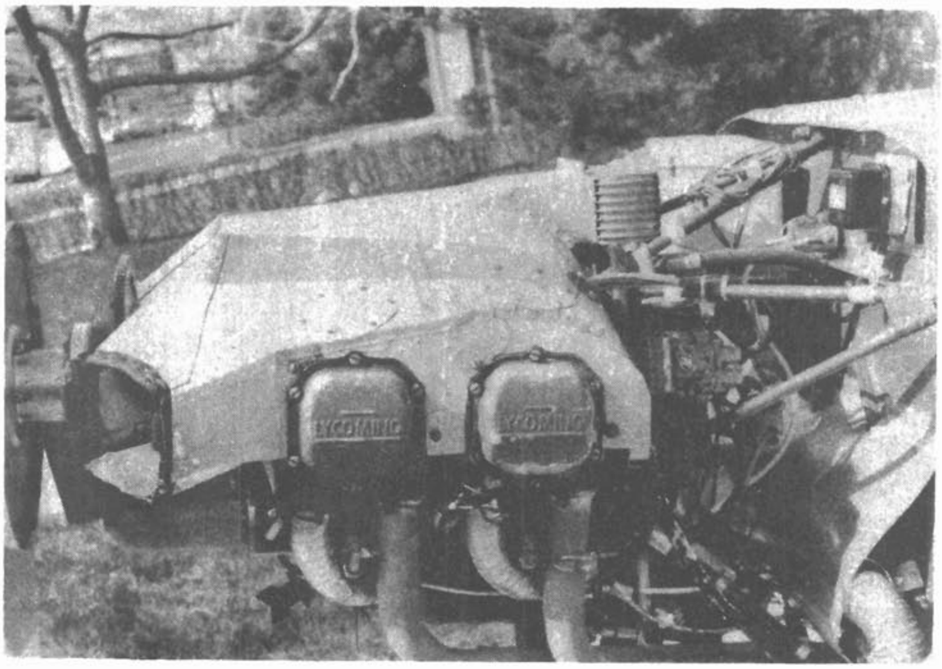
To take maximum advantage of this configuration, several features were necessary:

- The scoop inlet is cut at about a 10 degree angle into the advancing propellor blade. This is because the air coming off the propellor blade (very close to the blade) has a rotational component.
- The scoop inlet has a slightly bell-mouthed opening.
- The scoop has an inner liner that transitions the small, round scoop inlet to the larger, rectangular front opening of the carburetor airbox.
- The sides of this inner liner diverge at less than an 11 degree total angle. Any larger divergence angle and the flow in the scoop would go turbulent.
- The aft end of the inner liner is sealed to the front of the airbox with 3 layers of gray duct tape.

The timing of the pressure pulses is also very important. That is, the pressure pulses must occur when an engine cylinder intake valve is open. The propellor must be clocked properly on the engine propellor flange to achieve this important timing.

However, once that I had incorporated all of the necessary features, the performance improvement was well worth the effort. While I did not see any increase in manifold pressure, nor even a wiggle to the manifold pressure gage needle, I realized a 300 feet per minute increase in rate of climb at 7,000 feet altitude!

Another intake system improvement is to insulate the exposed intake tubes that run from the Lycoming oil sump to each of the engine cylinders.



The engine intake tubes are insulated with spun-glass mat and wrapped with aluminum tape.

The idea here is to keep the intake charge as cool as possible. The cooler the fuel/air charge, the denser that charge will be and the more power that the engine will develop and give better fuel economy, too, by giving the same amount of power at a reduced throttle setting. On a Lycoming, the intake tubes are directly below each cylinder, directly in the path of the heated air that is cooling each cylinder and emerging very hot from the cooling baffle gaps. On my engine, I have wrapped each exposed intake tube with fiberglass mat house insulation. The kind made from spun-glass and is backed with aluminum foil and is about 2 ½" thick when unrolled from the roll. When wrapped around the intake pipe, it adds about ¾" to the diameter of the pipe. I hold the insulation in place with a final wrapping of adhesive backed aluminum tape. This intake pipe insulation allows the engine exhaust gas temperature to run 50 degrees Fahrenheit to 75 degrees Fahrenheit higher before engine roughness occurs when leaning out the fuel mixture.

CHAPTER 4

ENGINE COOLING SYSTEM MODIFICATIONS

A cool-running engine and accessories promotes safety, reliability, and long life.

I believe that aircraft engine cooling is a subject that does not receive proper attention, emphasis nor discussion. Insufficient engine cooling is a problem that every aircraft suffers from, at some time during its useful life, to some degree. The negative effects of improper engine cooling include:

- accelerated and unnecessary engine wear.
- engine damage or failure.
- increased fuel consumption.
- reduced power output.
- potentially unsafe flight.

My aircraft experienced insufficient engine cooling on its very first flight. Both the cylinder head temperature and oil temperature went beyond recommended red-line values. The engine continued to operate, but it certainly wasn't very healthy to the engine and it introduced a dangerous condition into an already highly stressful situation - the first flight of a new and unproven aircraft.

To explain why this occurred: My original propellor was an "Aeromatic" automatic pitch-changing propellor that allowed the Lycoming engine to turn up to 2700 RPM for takeoff and climb out, thus delivering maximum available horsepower and, of course, requiring maximum cooling. I had fabricated a separate cooling plenum chamber atop each bank of cylinders that were not connected. The left plenum was fed air by the left cowling inlet and right plenum by the right inlet. Only the number four engine cylinder was instrumented to monitor cylinder head temperature (number 4 is normally the hottest running cylinder on a 0-320 Lycoming engine). The engine oil cooler was mounted on the firewall, right under the top of the cowling and had a separate scoop on the top of the cowl to direct cooling air through the oil cooler.

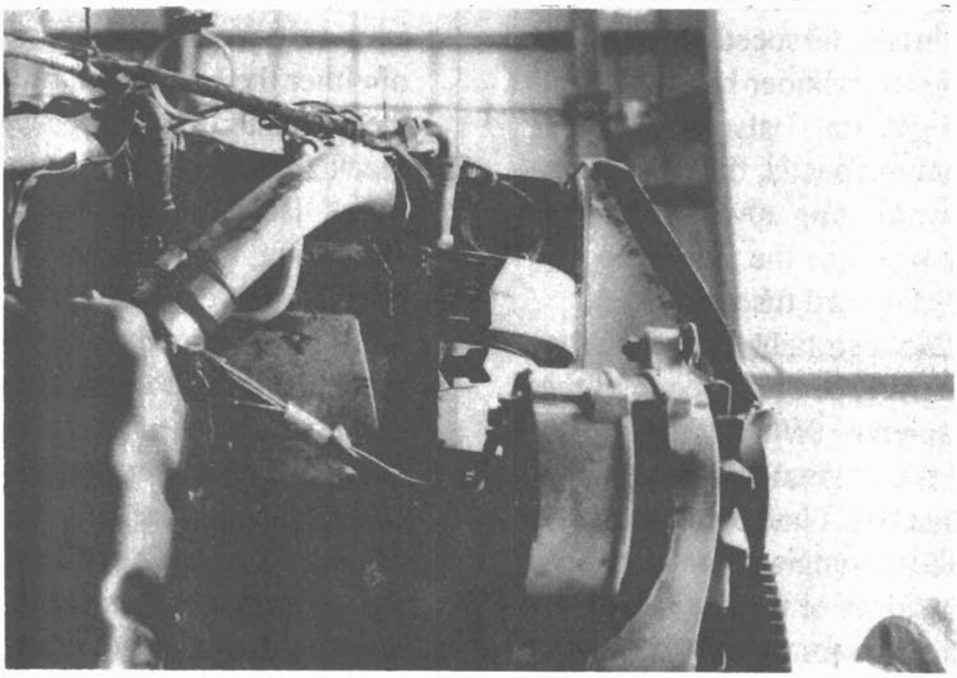
Now, we need to understand what is happening to the airflow around the cowling during a takeoff and steep climb out. The cooling air that is entering the two cooling air inlets on the front of the cowl, directly behind the propellor, is being affected by the rapidly rotating propellor. That is, the air directly behind the propellor is given a rotational directional component. The effect of this rotating mass of air on most aircraft cowlings, is to accelerate the flow of air into the cowling right air inlet and to decelerate the flow of air into the cowling left air inlet. So, if you have separate cooling plenum chambers atop the engine, the right bank of cylinders (numbers 1 and 3) will be receiving significantly more cooling air than the left bank of cylinders (numbers 2 and 4). This effect is so pronounced that even when a single plenum is being fed by both air inlets, the right bank cylinders will run cooler than the left bank - as we shall see later in this chapter. So that explains why my number 4 cylinder ran so hot on the first flight.

Now, the red-line oil temperature was caused by a different phenomenon. The separate oil cooler scoop on the top of the cowling was far enough aft of the propellor to not be affected by the rotating air mass. However, during a steep climb, the top of the cowl is inclined sufficiently to the relative air flow that the air flow over the top of the cowl becomes detached and goes very turbulent. Any air scoop on the top of the cowl under these conditions will experience very little air being taken in. In effect, that first prolonged climb was done with very little cooling air flowing through the oil cooler - hence, very hot oil. A Lycoming engine must have an effective oil cooler, especially under climb conditions.

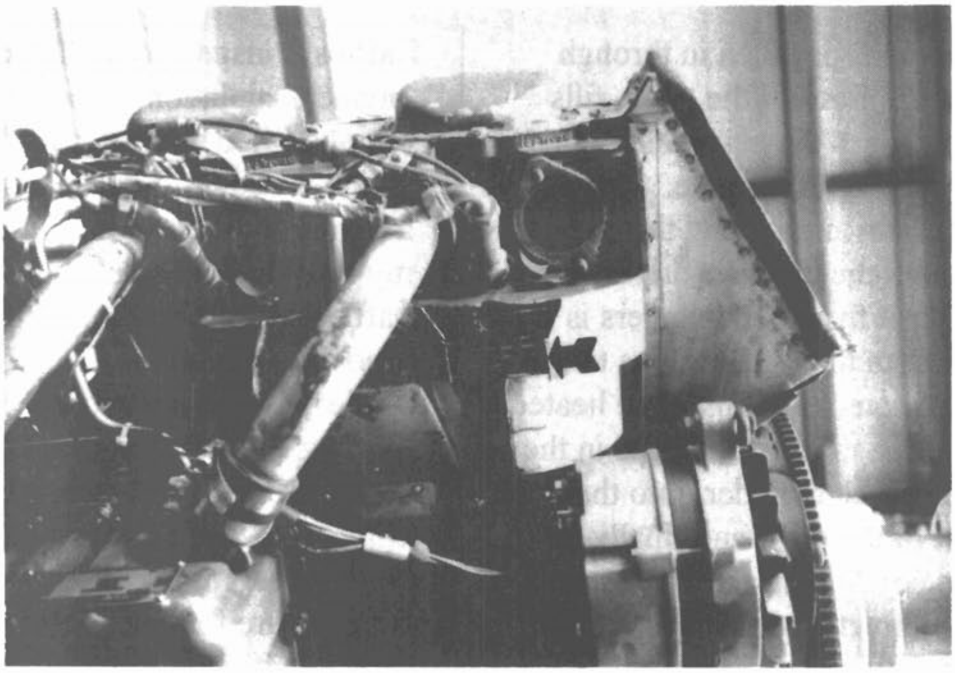
It took me awhile to understand why the high engine temperatures occurred during that first flight. However, for the next flight, I did change to one, common engine cooling plenum chamber and that did bring the number 4 cylinder head temperature down to red-line during a prolonged climb. Getting the high oil temperature under control took much longer to effect.

So, at this point I had a flyable airplane, as long as I did not climb too long and too steeply to cause an oil temperature problem. However, I knew that I could further improve the engine cooling system, and over the past 23 years, I have made a succession of modifications which have optimized the design of the system. That is, I have minimized the aerodynamic drag caused by engine cooling and maximized the effect of the cooling air taken into the cowling so that regardless of the flight regime, recommended engine red-line temperatures are <u>never</u> exceeded.

One of the areas of cooling air flow which I experimented with was the air exit gap dimensions between the baffles around each cylinder barrel and cylinder head. The purpose of these baffles is to direct the cooling air flow around the cylinders so that all of the cylinder barrel and head is bathed in a continuous flow of cooling air. The engine cooling air is taken in through the inlets in the front of the cowl, fills up and pressurizes the air plenum chamber on top of the engine. The air then flows down around and through the fins around the cylinder barrel and head. The heat from the cylinders is transferred from the cylinder fins to the air gushing through the fins. The heated air then escapes through the gaps in the baffles under each cylinder, into the bottom part of the cowl and finally through the cowling air exit. There is an optimum dimension for the baffle gaps. This optimum dimension is large enough so that a large enough mass of air is allowed to pass through the fins to carry off the heat from the cylinders. However, the gap must be small enough so that the cylinder is completely surrounded by cooling air, or hot spots will occur along the bottom of the cylinder barrel and head. Before I constructed the original engine cooling baffles, I inspected the Lycoming 0-320 engine installations in several different type-certified aircraft and measured the cylinder cooling baffle gaps. The average of all those measurements was my starting dimensions for my engine baffle gaps. For my experiments, I fabricated several sets of under-cylinder baffles, narrowing and widening the baffle gaps by ⅛" increments. For each set of baffles, I flew a test flight in climb, top speed and cruise flight modes, recording cylinder head and oil temperature for each flight for each mode. After a dozen flights and after correcting the flight data for ambient air temperature and density, I arrived at a set of baffle gaps dimensions which gave the lowest temperatures for the test flight modes. The cylinder barrel baffle gap was best at ⅞" to 1.0 inch. The cylinder head baffle gap was much more critical to controlling engine temperatures, but gave the best results



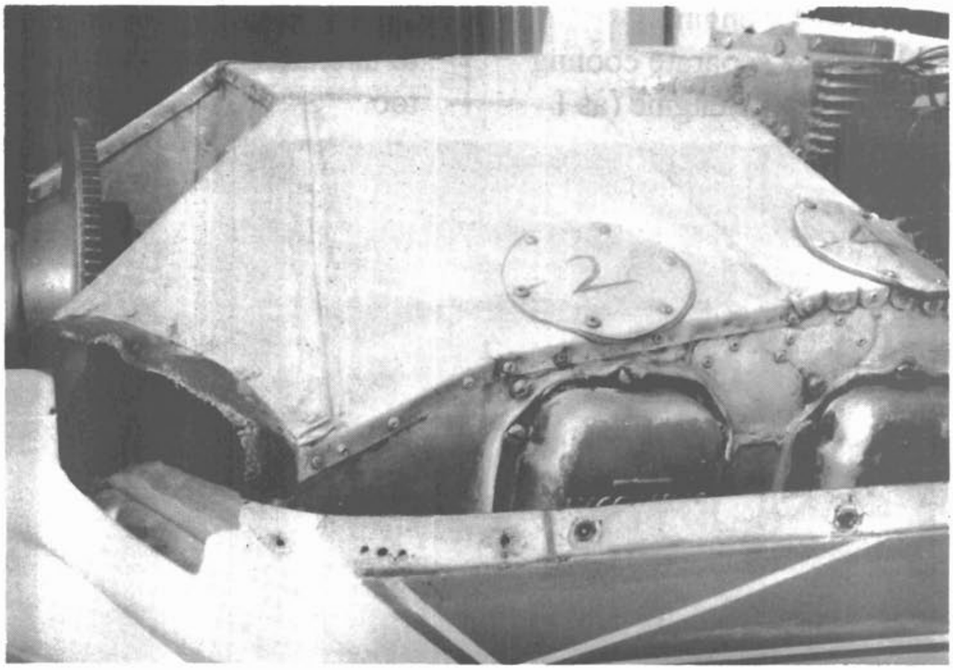
The cylinder barrel baffle gap is about one inch.



The cylinder head baffle gap is 2¼" and also flares out around the temperature probe well.

at a dimension of 2¼". These dimensions should hold true for most Lycoming powered aircraft, whether a high-speed or lower-speed aircraft, assuming all other factors which affect engine cooling have been optimized.

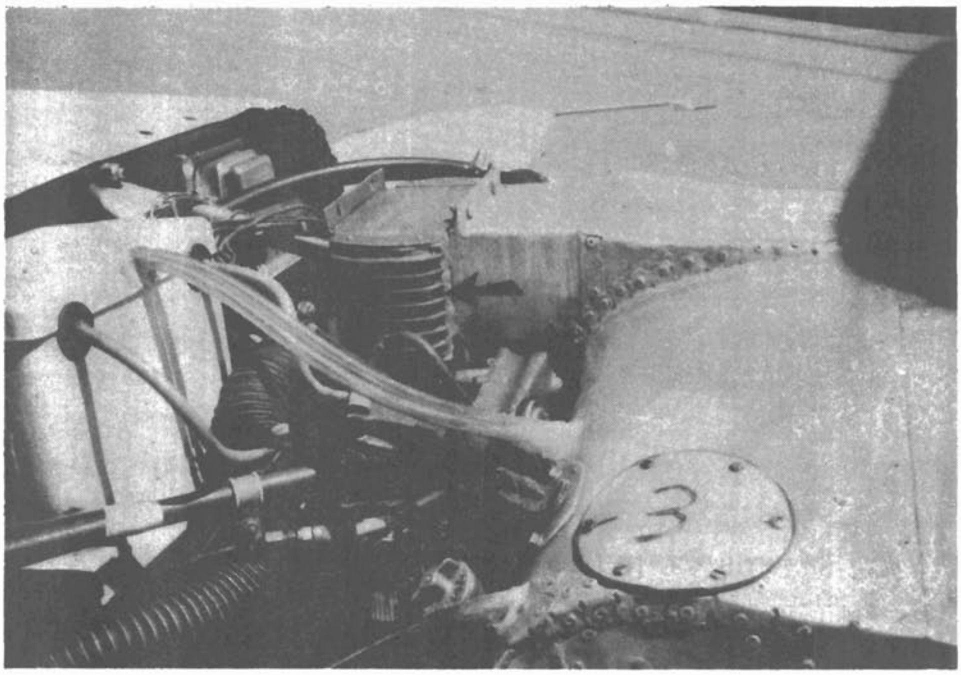
As the other modifications that I was making to the aircraft started producing higher airspeeds, I began seeing a higher cylinder head temperature, again. I also noticed that at the higher airspeeds, the top of the cowling was bulging upward. This was quite obvious, since the top of the Mustang-II forward fuselage is normally flat (a straight line) from the instrument panel to the aft edge of the propellor spinner. When I had fabricated the original engine cooling plenum chamber, I had again looked at certified aircraft engine compartments to get some ideas of how to fabricate a plenum chamber for my aircraft. Most installations affix aluminum sheet to the sides and back of the engine to form the sides and back of the plenum chamber and depend on the top of the cowl to form the top of the plenum chamber. The necessary flexible interface between the top edges of the aluminum sides and back and the top of the cowl is usually provided for by affixing strips of either the red silicon rubber sheet to the aluminum sheet edges, or using the black neoprene-impregnated asbestos sheet. But as my airspeeds started increasing, the pressure in the plenum chamber increased, the top of the cowl lifted away from the sides and back of the plenum and the air taken into the plenum, instead of going through the cylinder fins and cooling the engine, passed through the gap created between the sides and back of the plenum and the top of the cowl and out through the cowl air outlet! My early attempt to fix this bypass flow was to stiffen the top of the cowl with pieces of aluminum angle. This greatly reduced the cowling bulge, but the pressure in the plenum was so high that the flexible strips were being bent backwards and the bypass flow of cooling air was continuing. The final answer to this continuing problem was to eliminate the interface of the plenum with the top of the cowl. I riveted an aluminum sheet to the sides and back of the plenum, thus creating an independent plenum chamber atop the engine. However, the plenum still cowl, fitting into deep grooves around the inside of the cowling air inlets, With this configuration, the more pressure in the plenum, the better that the flexible strips seal the plenum air inlets to the cowl air inlets. I finished-off this plenum sealing effort by using silicone rubber sealant to seal all of the plenum sheet metal seams, the flexible strip attachment to the plenum air inlets and the entire plenum attachment to the engine itself. I now had all of the air that was going into the plenum doing useful work to cool the engine,



The engine cooling plenum chamber is totally separate from the top of the cowling.

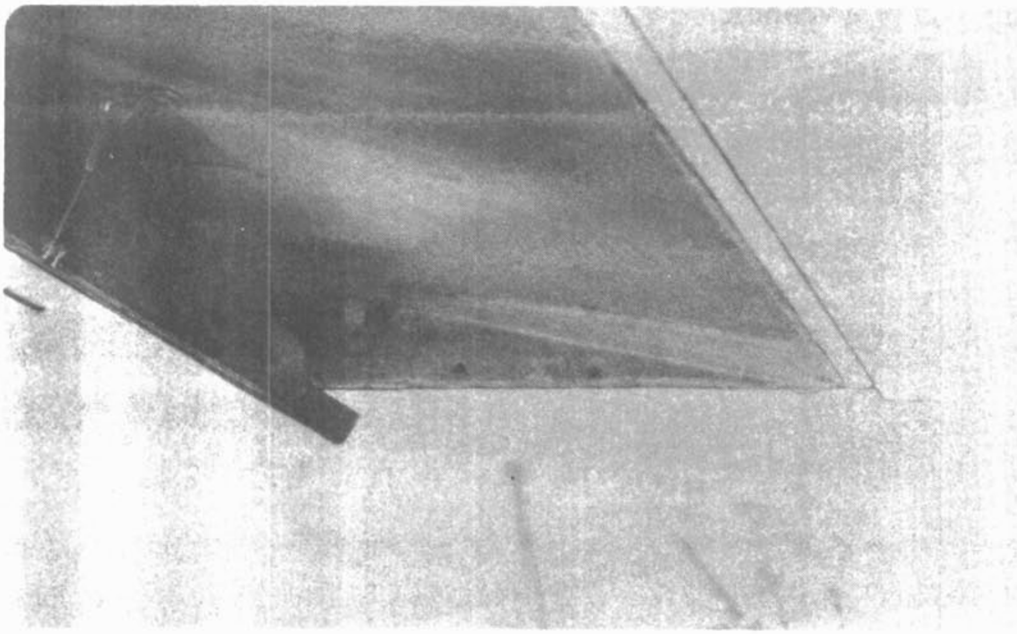
had to interface with the cowl at the air inlets at the front of the cowl, and, of course, this must also be a flexible interface. To prevent by-pass flow at this interface, I configured the inside of the cowl, at the air inlets, so that the flexible strips around the air inlets to the plenum were actually captured by the regardless of the speed of the aircraft or how much the pressure in the plenum increased.

At this point, I still had an oil cooling problem. A steep climb angle would always result in an excessively high oil temperature, because I had very poor cooling air flow into the separate oil cooler air scoop on the top of the cowl. The first modification eliminated the separate oil cooler air scoop, and I ran a 2.0" diameter flex hose to the firewall-mounted oil cooler. I also fabricated an air outlet diffuser for the oil cooler to get the air through the cooler more efficiently. I still didn't think that I was getting enough air through the oil cooler. So, I increased the diameter of the flex hose from the plenum to the oil cooler to 3.0" diameter. This configuration worked very well for many flight hours. Then I got a look at a Mooney engine compartment. I saw a separate cooling plenum chamber atop the engine (as I had developed for my Mustang-II). I also saw that the oil cooler was mounted directly on the back wall of the plenum chamber, providing direct, unimpeded, full air flow to the oil cooler! What a great idea! So, I proceeded to mount my oil cooler on the back of the engine, using two conveniently located bolts on the engine accessory case. Air from the plenum is now directly fed to the full inlet area of the oil cooler, in a rectangular configuration, just about as efficient as you can possibly get: no long flexible air hoses which formerly impeded the air flow to the cooler, and also, no long flexible oil hoses from the oil cooler to the engine accessory case. The oil lines can now be short and rigid, with only a small expansion loop. This really helps to unclutter the engine compartment, too.



The engine oil cooler is mounted on the rear of the cooling plenum chamber.

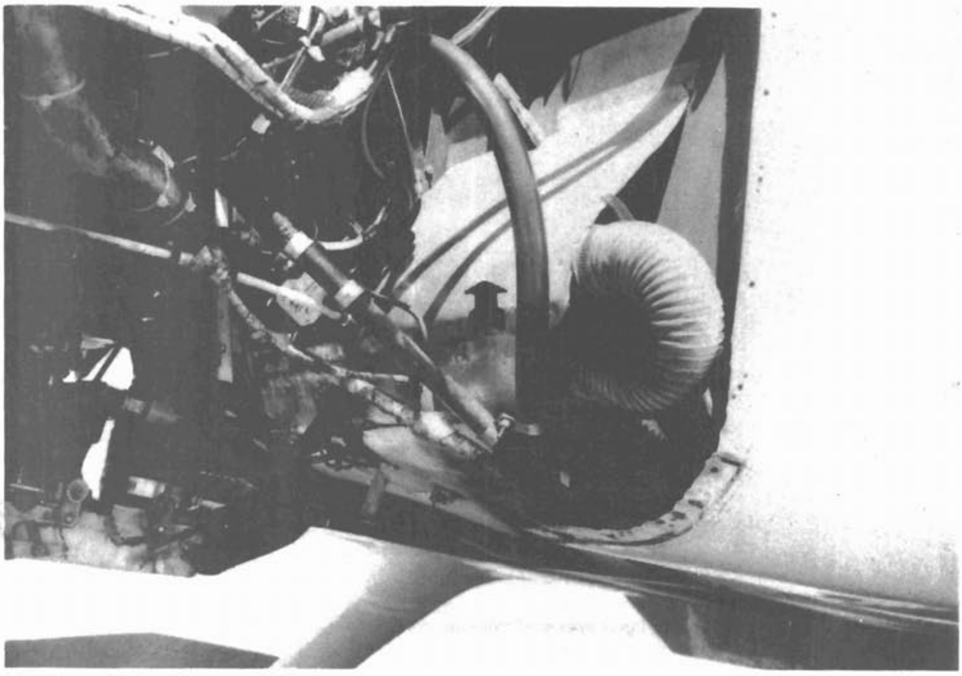
At this point, I turned my attention to the cowling air inlets and outlet. First the outlet. I wondered if a cowl outlet flap would be desirable. I tried various lengths and angles of a fixed outlet flap. Not much effect, except that they slowed the airplane down. I also tried a cockpit controllable outlet flap. Again, not much of an effect. Except that I noticed that the flap found its own position that it wanted to assume, which was about a 10° angle of deflection. In analyzing this phenomenon, I realized that the aft end of the cowling ended at the firewall. In this configuration, the air exiting the cowling was not perfectly parallel to the slipstream, but had a tendency to angle downwards, as well as aft. This exiting air plume was creating drag and slowing the airplane down. There were two ways that I could fix this. I could extend the cowl edge with a cowl flap, but I already knew that this only slowed the airplane even more. Why? Because the cowl does not hang down below the belly-line of the fuselage (only the carburetor air scoop does). Rather, the cowl air outlet is created by a recessed ramp in the fuselage belly, starting at the firewall. This ramp angles downward at about a 10° angle - sound familiar? (This is the angle that the cowl flap wants to assume, in flight!) The alternate fix to get the outlet flow parallel to the slipstream was to extend the upper edge of the outlet ramp forward. But I wanted the interface of the bottom of the firewall and the upper edge of the outlet ramp to be well-rounded. Remember, air has mass and at speed will not turn a 90° angle without going turbulent. I was able to accomplish both of these improvements by riveting one end of an aluminum sheet to the forward, upper edge of the outlet ramp, bending the free end of the sheet upwards and then riveting the upper end of the sheet to the



The cowl flap is operated from the cockpit by a Bowden cable.

firewall (Figure 4-1). The bend radius of the sheet is about 8". So, this allows the exiting air to make a gradual turn into the cowl outlet, and makes the air flow out of the cowl outlet within 10 degrees of parallel to the slipstream. Now, the configuration inside the cowl (approaching the cowl outlet) is like a converging duct or a venturi.

This gave me another idea. Why not use the exhaust flow out of the ends of the exhaust pipes to pump the cooling air out of the cowl, through the now venturi-like cowl outlet? I now had a configuration very similar to a "venturi-pump", or sometimes called a "jet-pump". All that I had to do was cut off the ends of my (at that time I was using the 4-straight stacks) exhaust nozzles so that the ends of the nozzles were just forward of the minimum cross-sectional area of the cowl outlet venturi (Figure 4-1). I did this by cutting off ¼" of each exhaust nozzle, then running a test flight, and recording the engine temperatures. I continued this procedure, ¼" at a time, until I saw a dramatic decrease in engine temperatures. The exhaust pipe/cowl outlet venturi pump was working!



The right-angle intersection of the firewall and fuselage bottom is rounded-off with a sheet of aluminum.

Well, with all of these modifications to improve the efficiency of the engine cooling system, the engine temperatures were now definitely on the cold side. I really didn't need all of that cooling air flowing through the cylinder fins and oil cooler. I could now reduce that air flow and reduce the aerodynamic cooling drag in the process! To do this, I could either decrease the cowl cooling air inlet area or the outlet area. However, since I had the exhaust pipe/cowl outlet venturi pump working so well, I decided to

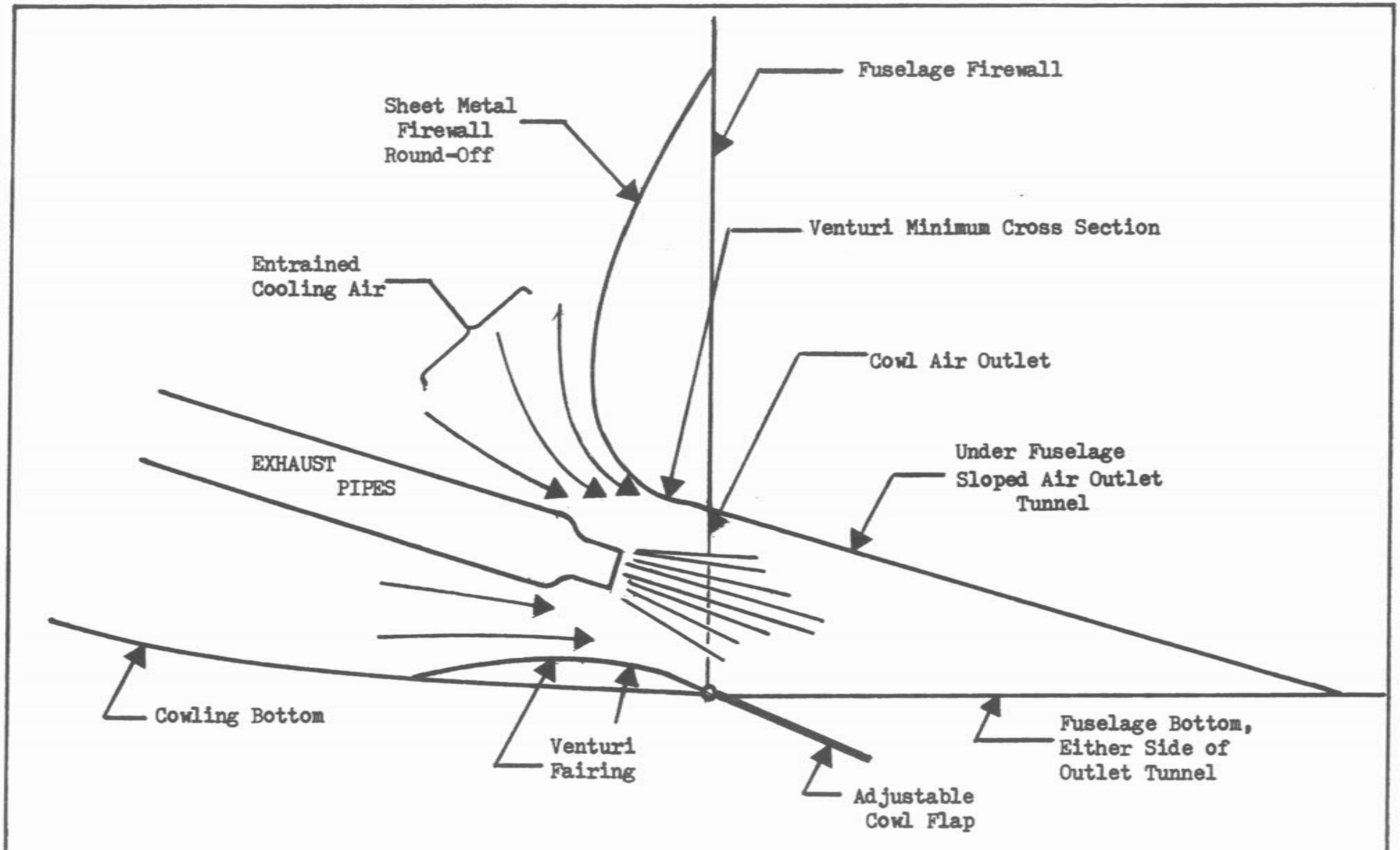
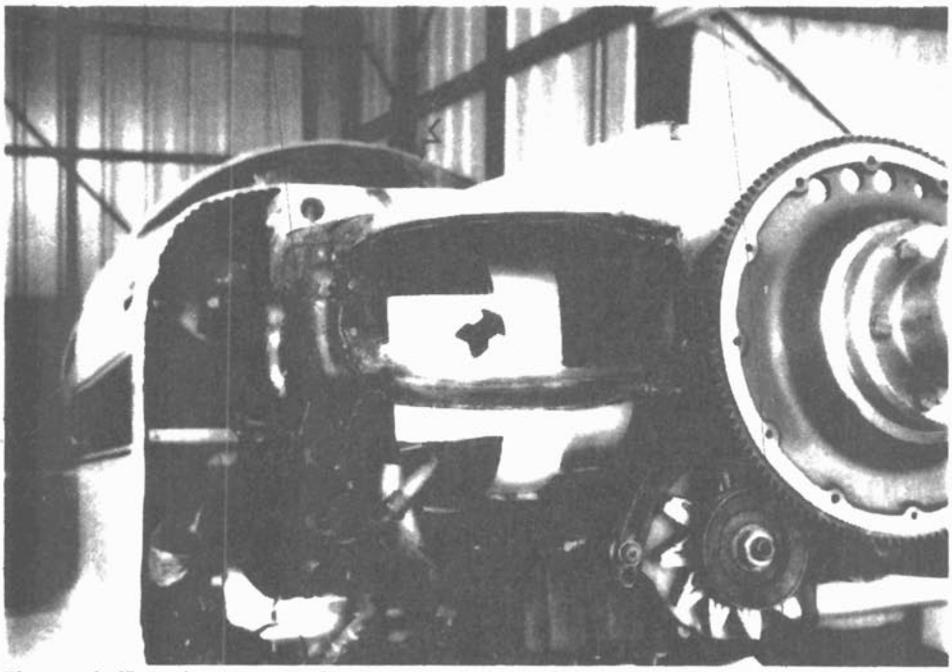


FIGURE 4-1, COWL AIR OUTLET VENTURI (SIDE VIEW) experiment with the cowl cooling air inlets. But how much should I reduce the inlet area to get the engine back to normal operating temperatures? The answer is to reduce the inlet area a little at a time and go fly the airplane. I fashioned some inlet blank plates from 0.040" soft aluminum sheet. I slit the center of the blanks so that each blank had an upper and lower flap that I could bend up or down to increase or decrease the inlet area. These adjustable inlet devices were then taped over the cowl air inlets, using common, gray duct tape (which by the way, will stay in place up to at least 270 MPH). I started out with an inlet area of 60 square inches. Reducing the inlet area by 4 square inches at a time, I test flew each inlet area reduction increment until I started seeing the bottom end of the temperature ranges recommended by Lycoming for the 0-320. At this point, I had reduced the cowl inlet area to 30 square inches. I don't know how much cooling drag that I saved, but it must have been appreciable, because the speed of the airplane was steadily improving as I made this series of cooling modifications.

Since I was regularly competing in the "CAFE" and "Oshkosh-500" races (which are really aircraft efficiency competitions), I was very curious to see how much that I could reduce the engine's fuel consumption. Up until now, I had only instrumented number 4 cylinder for cylinder head temperature (CHT) and exhaust gas temperature (EGT). I had noticed, that in leaning-out the engine, I would get to a lean setting where the engine started running rough, but I could lean quite a bit further before I encountered additional roughness and then still more leaning before the engine would shut down completely (of course, fine-leaning gradations can only be accomplished with a vernier mixture control). What this meant was that each cylinder was running at a different mixture ratio! Obviously, the only way that I could accurately tell what I would be doing with any future modifications to even out the mixture ratios, was to install 4-cylinder CHT's and 4-cylinder EGT's - which I did. Now I could really tell how well the engine was running. What an eye-opener the next flight was! Number 4-cylinder was running about 10 degrees Celsius hotter than cylinders 2 and 3. Number 1 cylinder was running 35 degrees Celsius cooler than cylinders 2 and 3. Cylinders 2 and 3 were running at the same temperature. The solution for number 4 cylinder was to gradually open up the number 4 cylinder cooling air baffle gaps to obtain more cooling air mass flow through those cylinder fins. Now I had three cylinders running at the same temperature.

The solution for cold-running number 1 cylinder was just the opposite. I had to reduce the cooling air mass flow to that cylinder. When I had been looking at type-certificated aircraft engine compartments, I had noticed on most aircraft an extra baffle on number 1 cylinder. This baffle covered much of the number 1 cylinder head cooling fins that were exposed to the direct blast of air entering the cowling right hand air inlet. Now I understood what that extra baffle was for! Remember, due to the propellor causing the air mass to rotate and increasing the air flow into the right inlet and decreasing the flow into the left inlet (especially in the climb mode), that number 1 cylinder was getting most of the cooling air flow and number 4 cylinder was not getting its total share the cylinder. I gradually increased the size (length) of this baffle until flight testing showed number 1 cylinder head temperature running the same as cylinders 2, 3 and 4. I was really surprised at how large I needed to make this baffle to raise the number 1 cylinder head temperature by 35 degrees Celsius. Another way to balance the flow of cooling air into both cooling air cowl inlets would be to put a protruding lip on the upper edge of the left air inlet. This would catch more of the rotating air mass, especially in the climb mode.



The extra baffle on the upper part of number one cylinder head was necessary to balance the cylinder head temperatures.

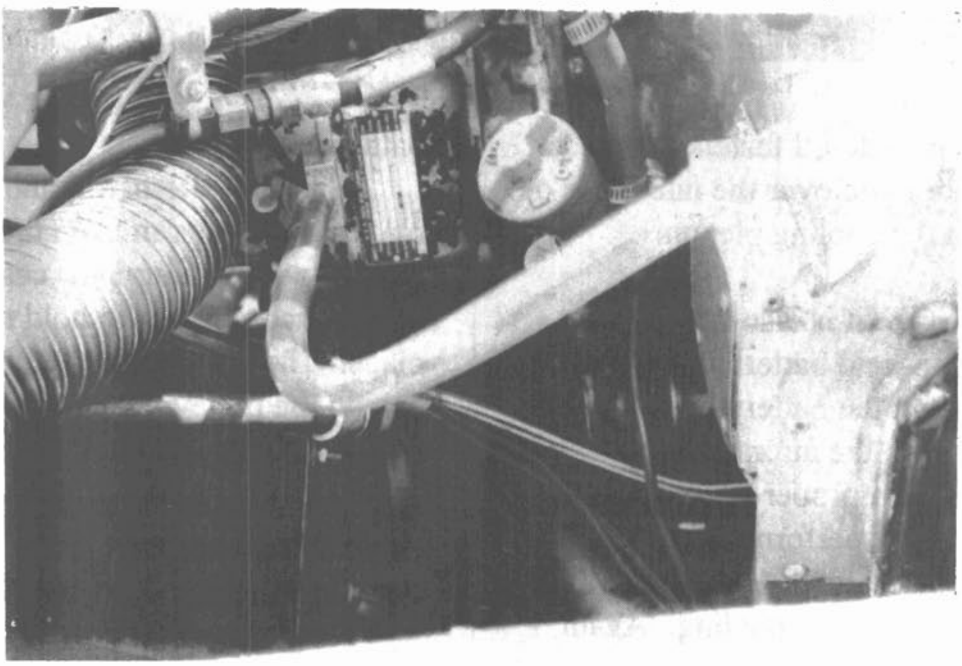
of cooling air (classically, on any air-cooled flat 4, 6 or 8 cylinder engine, the rear-most cylinder on the left side will run the hottest, unless adjustments are made). So, I made another baffle to cover more of the number 1 cylinder head cooling fins, on the upper side of

When I was doing a top overhaul on the engine and had removed the cylinders, I did a careful inspection of the cylinder cooling fins, looking for cracked, bent or broken fins. There is an area on each cylinder head, between the intake and exhaust valve chambers where the cooling fins go straight through the cylinder head, between the valve chambers. This is an important area of the cylinder head for cooling, due to the hot exhaust gases flowing through the exhaust valve chamber. On my number 4 cylinder, I found that this area of cooling fins was almost completely blocked off from air flow by "flashing" that was not removed after the cylinder head had been cast at the foundry. The other cylinders also had some "flashing" in this same area, but nothing like number 4. Using a small punch and files, I removed all of the flashing, from all of the cylinder cooling fins. This explained why my number 4 cylinder was wearing faster than the other 3 cylinders. And, when I reassembled the engine and test flew the airplane, sure enough, engine temperatures were even lower, especially number 4 cylinder head. Of course, now I again had to rebalance the 4 cylinder head temperatures.

I mentioned that I had also installed an exhaust gas temperature (EGT) probe on all four cylinder exhaust pipes. The test flight data that I collected from this instrumentation led to a whole new area of experimentation, study and analysis. When I installed the four EGT probes, I was using the 4-straight stack exhaust system. Test flight data showed that at lower engine RPM's the four EGT temperature readings were far apart. But, as the engine RPM increased (more throttle opening), gradually the four EGT temperature readings converged; until, at full throttle, the four EGT readings were the same value. I collected more flight test data, in different flight regimes, at different altitudes, on this phenomenon. Always the same result: the more fully-open the throttle position, the more alike the EGT readings. I reasoned that perhaps the position of the throttle "butterfly" plate in the carburetor had a strong effect on fuel-air mixture distribution to the 4 cylinders, when the throttle plate was anything else but fully open. This has been the conclusion of other people who have done research in this area. Apparently, Lycoming designed the 0320 engine to have equal mixture distribution at full throttle, but could not achieve the same result at partial throttle settings. Lycoming's fuel-injected engines give much better (equal) fuel distribution, at all power settings, and as a result, can be leaned-out further, and give a lower specific fuel consumption (SFC) than their carbureted engines.

I also tried the 4 cylinder EGT instrumentation on my cross-over exhaust system. Similar to the 4-straight-stack exhaust system, the more fully-open the throttle setting, the closer together the four EGT readings would be. However, unlike the 4-separate exhaust stack system, the four EGT temperature readings on the cross-over exhaust system never did completely converge, even at full throttle. I also noticed that the engine vibration was heavier with the cross-over system. After much analysis and study, I concluded that with the cross-over exhaust system, the engine did deliver more power (at the cost of higher fuel consumption), but it was unbalanced power. That is, two cylinders were producing more power than the other two cylinders. To explain why this is: Tuned exhaust pipe length at 2700 engine RPM is about 74 inches. With the cross-over exhaust system, engines cylinders number 1 and 4 effectively run about that tuned length exhaust pipes and as a result, produce more power than cylinders number 2 and 3 which have much shorter effective exhaust pipe lengths. This is corroborated by the EGT readings. EGT temperature readings for cylinders 1 and 4 run hotter than cylinders 2 and 3, even at full throttle. So, I found that while the cross-over exhaust system provides more engine power, with the 4-separate stack exhaust system (with its 4 more equal-length pipes) the engine can be leaned-out further, and gives better fuel economy. When I was competing in the CAFE and Oshkosh-500 efficiency competitions, I always installed the 4-separate stack exhaust system for an upcoming race.

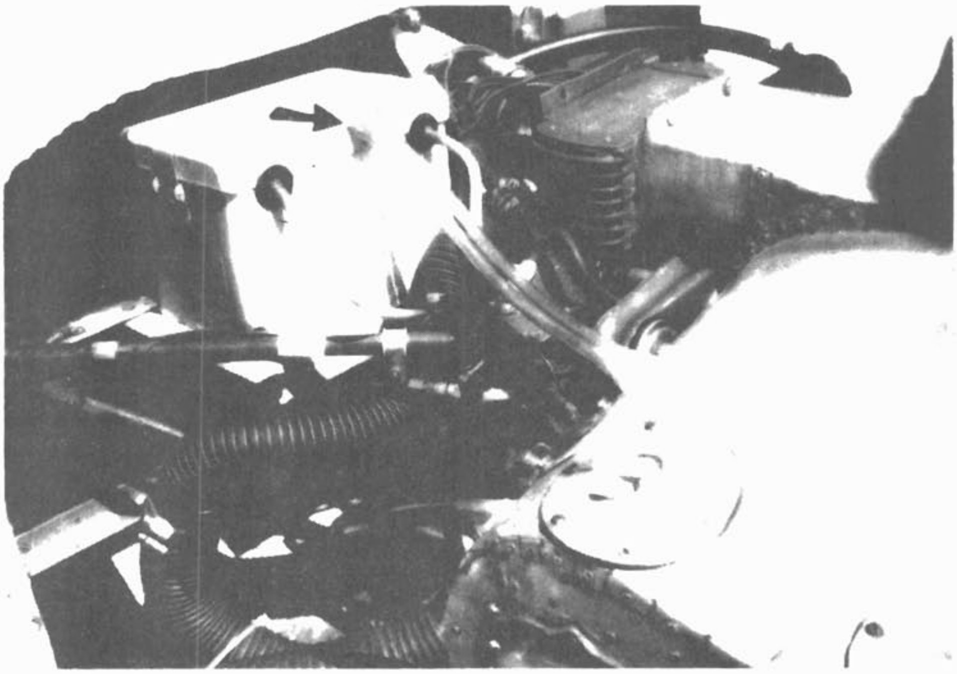
Although not exactly in the category of engine cooling, ensuring proper cooling of magnetos, battery, starter and generator or alternator is important to ensure proper engine systems operation and long life of those components. For keeping the magnetos cool, I installed a ½" diameter plastic tube to each magneto from the back of the engine cooling plenum chamber. Rather than having the tubes blast air onto the outside of the magneto cases, I reasoned that the cooling air was needed inside the magneto cases, since it was the magneto working parts (especially the coils) that I wanted to



Cooling air from the plenum chamber is fed into the magneto.

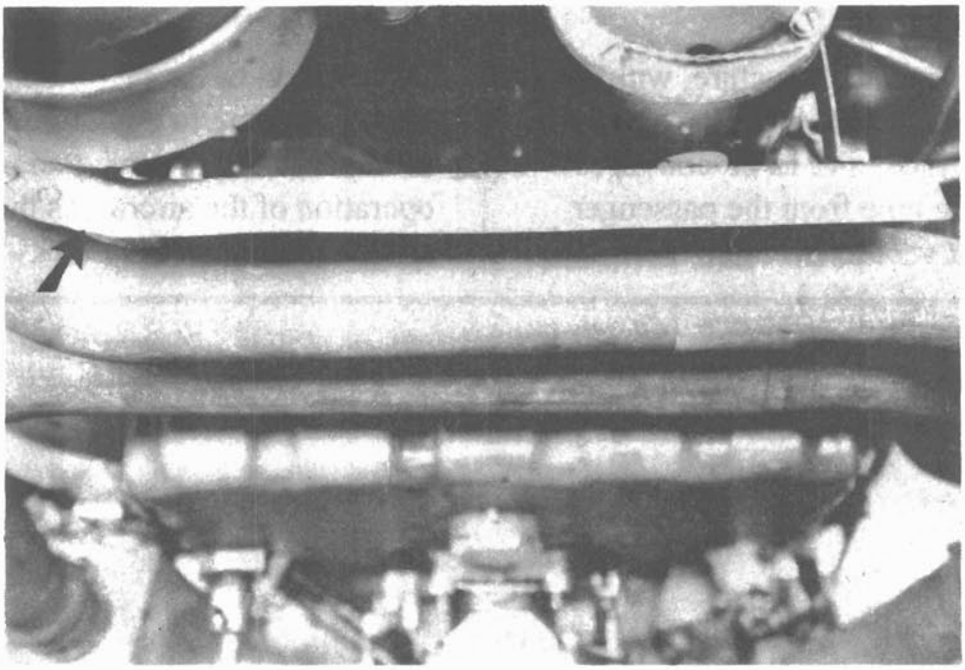
keep cool. So, removing the threaded plugs from the magneto timing/inspection ports, I used silicone rubber sealant to hold each end of the tubes in place. The opposite ends of the magneto cases have air vents, so the cooling air does flow through the magnetos. Wanting to keep dust/dirt out of the magnetos, I fastened a piece of open-pore foam over the inlet ends of the tubes in the cooling plenum chamber.

Excess heat is also sure early death for lead-acid batteries. Since I had to remount the battery on the firewall to keep the aircraft center-of-gravity (C.G.) in proper range (after making so many performance modifications to the airplane), the battery required extra cooling. Again, I ran two ⅜" diameter plastic tubes from the engine cooling plenum to the cover of the battery box, using silicon rubber sealant to hold the ends of the tube in place. The bottom of the battery box has a drain tube, so that drain serves well as a cooling air outlet, ensuring a good flow of cooling air over the battery.



Cooling air is also supplied from the plenum chamber to the battery case.

For the alternator, another ½" plastic tube was run from the plenum to the back of the alternator case. Again, using silicon rubber to hold the tube in place. The fan on the alternator, right behind the pulley, then pulls the cooling air through the alternator. In addition, to protect the alternator and starter from the heat radiated from the cross-over tubes of the cross-over exhaust system,



A heat shield protects the starter and alternator from the heat generated by the two cross-over exhaust pipes.

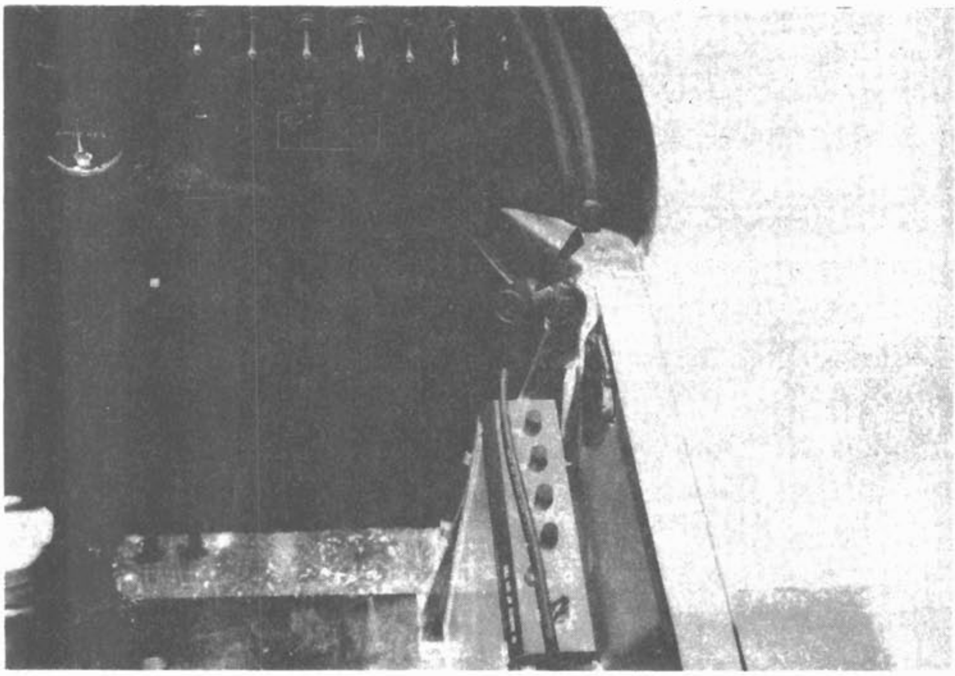
I fabricated a sheetmetal heat shield and suspended the shield between the alternator and starter and the under-slung cross-over exhaust pipes.

Does keeping these components cool pay off?

You bet it does! In 23 years of flying the airplane, I have:

- never had any magneto problems.
- replaced the battery only twice.
- replaced the alternator twice (using a Ford alternator)
- had only minor repair work done on the starter once (the starter still has the original brushes).

For cockpit cooling, I installed cockpit-adjustable vents on each side of



A swiveling nozzle on the cockpit sidewall/bulkhead directs cooling air to the face or upper body.

the cockpit fuselage structure, with swiveling nozzles to direct the air to the upper body/face. For radio cooling, I ran a cooling tube from the passenger side cockpit vent to the radio stack.

Of all of the modifications which I have made on/to the aircraft, none are as important to the safe and reliable operation of the aircraft as the cooling system modifications.

CHAPTER 5

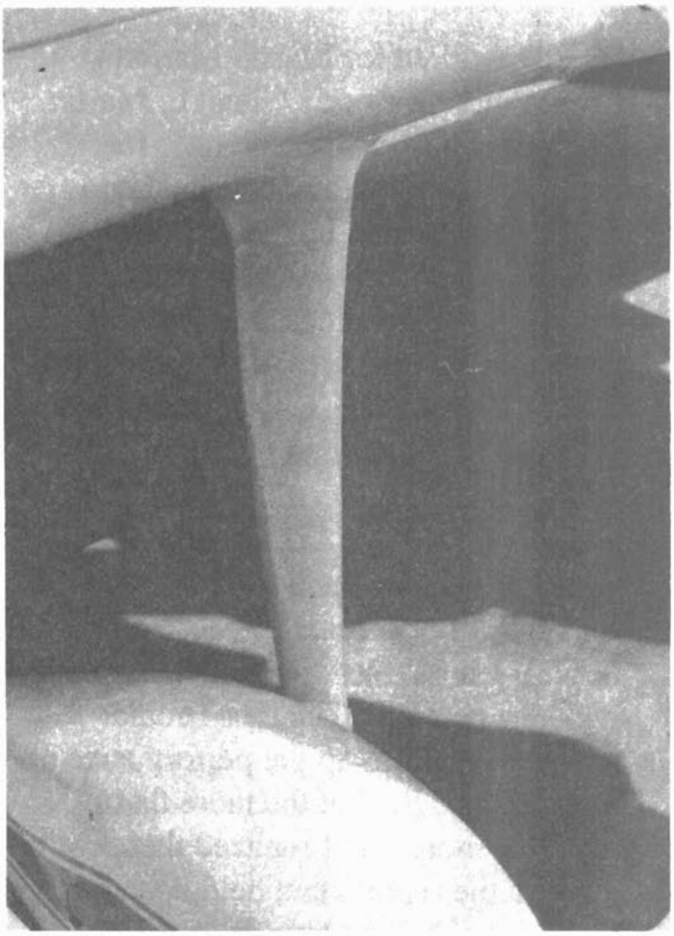
AERODYNAMIC CLEANUP AND DRAG REDUCTION

Air has mass; it takes energy to change the direction of mass in motion. Aerodynamic drag reduction is simply a matter of minimizing the redirection of air.

I worked for Martin Marietta Corporation (formerly Glenn L. Martin Company) in Denver, Colorado for many years. After lunch, each day, I would usually stop by the technical library to see what was new in the engineering disciplines, aeronautical and aerospace engineering in particular. After I built my Mustang-II and became interested in squeezing out more performance, I noticed that the library had all of the old NACA yearbooks, going all the way back to 1914. Initially, I thought that all those old NACA reports were just old history and wouldn't contain much that I could apply to cranking up the performance of my Mustang-II. But the more that I read, the more that I realized there were ideas in the reports that held potential for making the Mustang-II an even better airplane. Reports that investigated aeronautical subjects covered wing-root fairings, testing of different canopy configurations, exhaust ejector cooling, and exhaust nozzles for increased thrust. I had also been studying Hoerner's "Fluid Dynamics Drag" which is a very good book on determining minimum aerodynamic drag for various aircraft shapes, protuberances, scoops, etc.. From these two sources of ideas, I could see many areas on my Mustang-II that I wanted to experiment with that held potential for performance improvement. And, as I started making modifications to the airplane and realizing positive results, I started seeing additional areas of improvement that I wanted to try. Many of my ideas also came from my experiences as a hot-rod enthusiast during my high school and college years, especially in the areas of improving engine horsepower output and fuel efficiency. I had built several engines for street-rod applications; and, from that experience I could see areas of potential improvement for the Lycoming-0-320 in my Mustang-II.

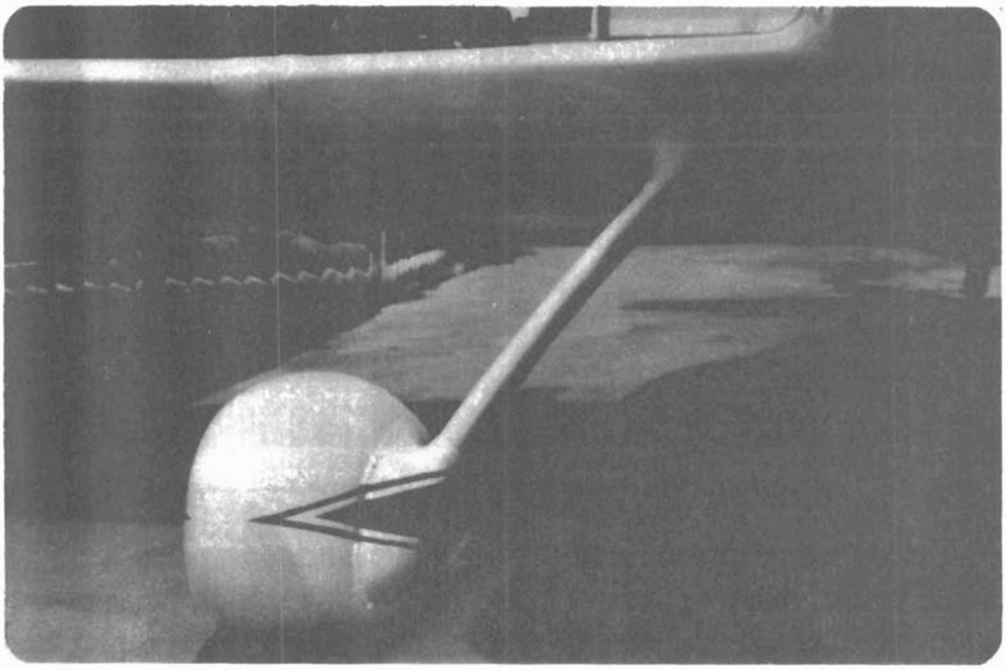
The most obvious drag-producing area on my airplane was the fixed landing gear. I thought that if I could retract the gear, I should be able to pick up a good 20 MPH in speed. So, I started to design a retracting gear system for the Mustang-II. Not an easy task, I found out. If I retracted into the wing, the wing wasn't thick enough to completely house the 500 X 5 wheel, tire and gear assembly (the wing center section is only 6" thick). Some of the gear would protrude from the bottom of the wing - not a good solution. If I retracted into the forward fuselage, I would have to cut out a considerable amount of existing fuselage structure and beef up the remaining structure. Also, my weight estimate indicated that I would add at least 100 lbs. to the aircraft empty weight (which is a considerable performance penalty, especially in the aircraft climb mode). In a small aircraft, as most current experimental aircraft are, excess weight is a real performance killer. The simpler that the aircraft is, usually the lighter it is, the less wing area is required, and the better the performance. When I considered how much weight that a retracting gear would add, how much less reliable the gear system would be and the potential damage from a gear-up landing (pilot caused or gear malfunction caused), I abandoned my gear redesign efforts, and concentrated on reducing the drag caused by the existing fixed landing gear.

The landing gear on the Mustang-II is the old style Cessna tapered slab steel gear leg. It protrudes from the wing center section at about a 60° angle. The approximate rectangular cross-section of the gear leg is not the worst aerodynamic shape (round would be the worse). But, according to Hoerner's "Fluid Dynamics Drag" (The aerodynamicist's "bible"), an aerodynamic fairing in the approximate shape of a tear-drop in cross-section, would minimize the drag caused by the gear leg.



Nonremovable landing gear fairing.

The tear-drop shape axes should be on the order of, 3.7 units long for each unit of width. For my Mustang-II gear legs, I had used L-19 gear legs (cut down, of course). The L-19 gear leg is not a straight leg, but has a slight curvature. As a result, I could not make the gear leg fairing from a simple bend-



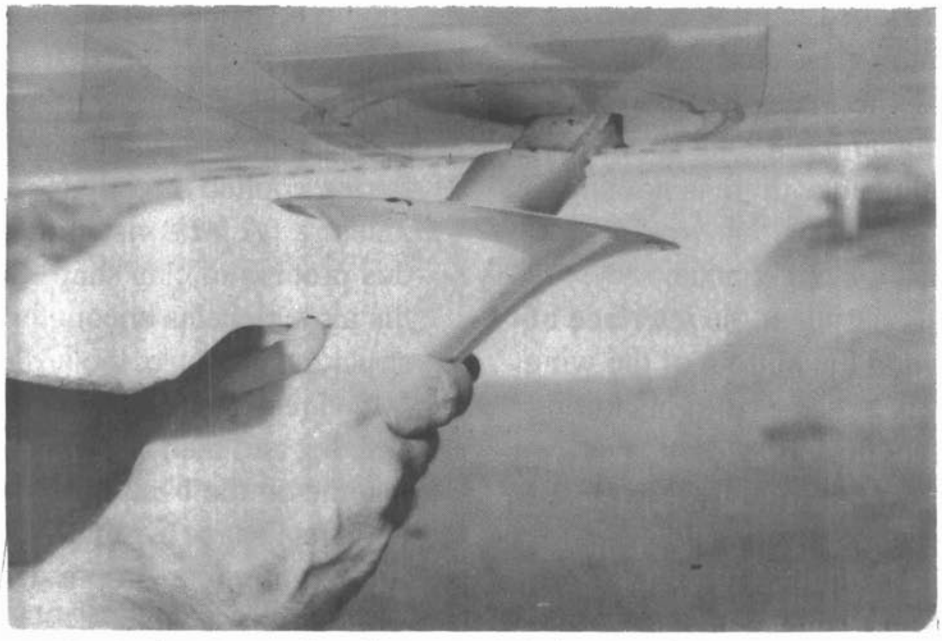
The slight landing gear curvature can be seen in this photo.

up of aluminum sheet. Instead, I glued blocks/sheets of rigid foam to the gear legs, sawing/sanding the foam to the ideal aerodynamic shape. I then covered the shaped foam with two layers of 10 oz. glass cloth, using polyester resin to make the fiberglass lay-up. The gear leg fairing is nonremovable, since there is nothing covered by the fairing that would require periodic maintenance.

For the fairing at the interface of the gear leg and the bottom of the wing, fiberglass was again used. This fairing serves to reduce the boundary layer interference drag caused by the 60° angle between the gear leg and the bottom of the wing. The fairing fills in the area of turbulent airflow and allows the air to flow smoothly (laminar flow) past this juncture. The fairing creates a 1½" radius between the leg and wing surface. This fairing must be removable to give access to the gear leg attach bolts and the landing gear torque tube attach bolts. This is an area that should be inspected and bolts retorqued at each annual inspection. To make this a removable fairing, common modeling clay is used to fill in the shape of the fairing applied directly to the leg/wing juncture. A little visualization is used in this process of clay shaping. Imagine the air molecules encountering this structural juncture, the airflow being forced to separate to flow around the gear leg and then the air flowing back together at the back of the gear leg. The ideal shape again being an approximate tear-drop in cross-section.

Fairing at the gear leg to wing interface reduces turbulent airflow at this juncture.

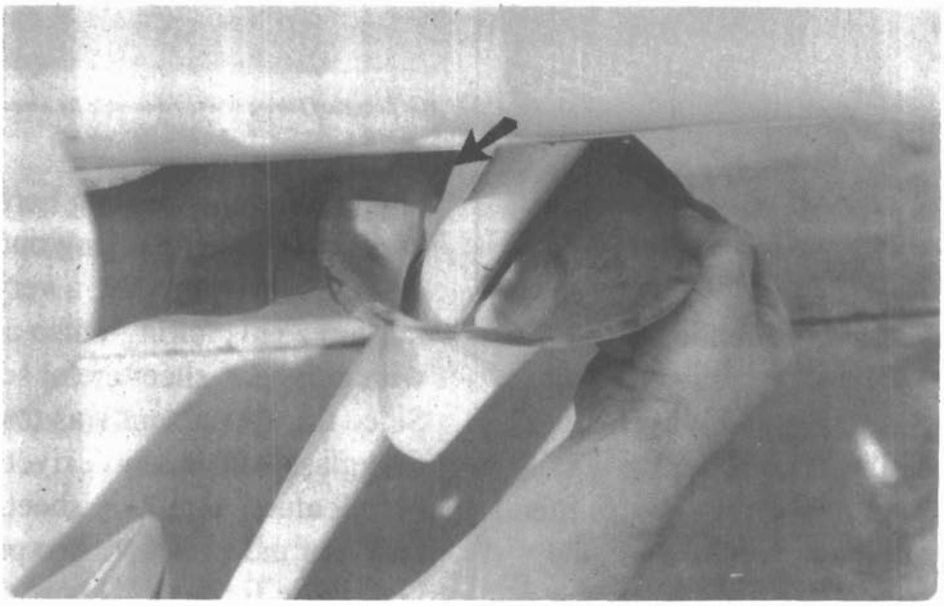
The air is smoothly forced apart by the rounded leading edge of the fairing, impact pressure keeping the air-flow attached (laminar). The airflow is then allowed to flow smoothly back together by the elongated tail of the fairing. Once the modeling clay is properly shaped, the area is coated with a release agent (paste wax). Two layers of 10 oz. glass cloth (impregnated with catalyzed polyester resin) are laid up over the area, smoothed to conform to the surface of the leg, wing and modeling clay shape. After curing, the fiberglass fairing is cut along the aft edge and popped off the modeling clay



This fiberglass fairing is removable to allow access to the landing gear and torque tube attachment bolts.

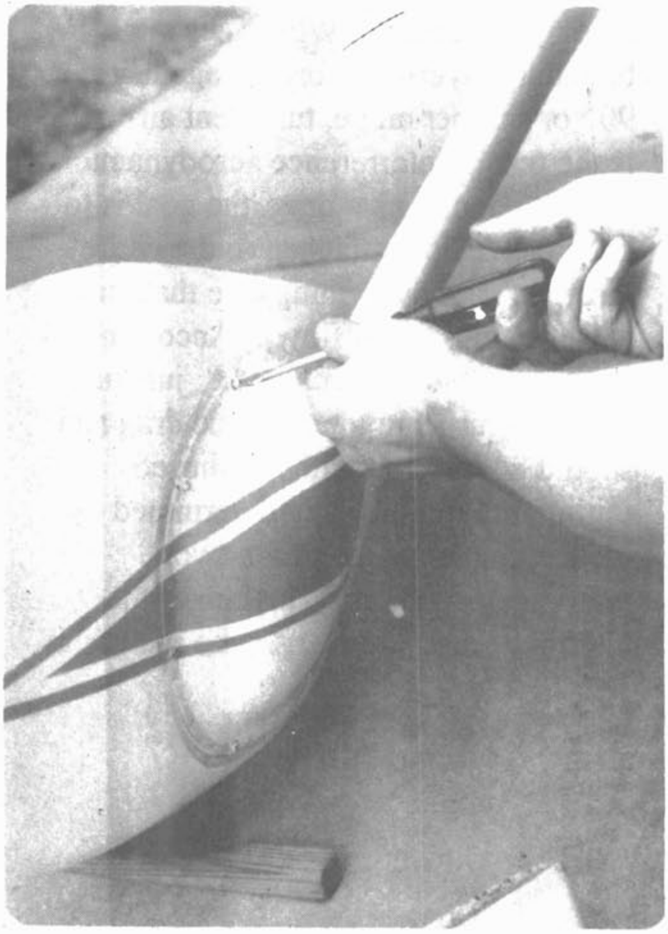
form. The clay can then be removed and the fairing trimmed and finished. I use ordinary sheet metal screws (pan-head) to attach the fairing to the wing. Machine screws and nut plates can be used. However, sheet metal screws have worked well for me for 20 years of flying. The cut aft end of the installed fairing is resealed with a strip of 1½" wide 3M brand 471 tape. This tape is used extensively by the racing fraternity and is commonly referred to as "go-fast tape". Properly applied to a clean surface, the tape will stay attached at speeds up to almost 300 MPH. I have left the tape in place for as long as 12 months and the tape can still be removed without leaving any adhesive residue on the surface. I have tried all brands of plastic and cloth tape and the 3M 471 tape is the only tape that I would recommend for this purpose.

The juncture of the gear leg and the wheel pant can also be at a very sharp (acute) angle. The sharper the angle, the higher the interference drag between the adjoining surfaces. This interference drag is caused by interaction of the two approximately ½" thick air boundary layers of the two adjoining surfaces. When these two air boundary layers are forced together at a 90° or sharper angle, turbulent airflow is the result (interference aerodynamic drag). To minimize drag, the goal is to keep the airflow attached to the entire airframe (and everything else that may stick out into the airflow). According to Hoerner's "bible", even a 90° juncture causes significant interference drag and should be covered with a radiused fairing; the radius being determined by the length (or chord) of the two interfacing surfaces. The longer the interface length, the larger the radius. It



This fairing is made from fiberglass and is split along the aft edge.

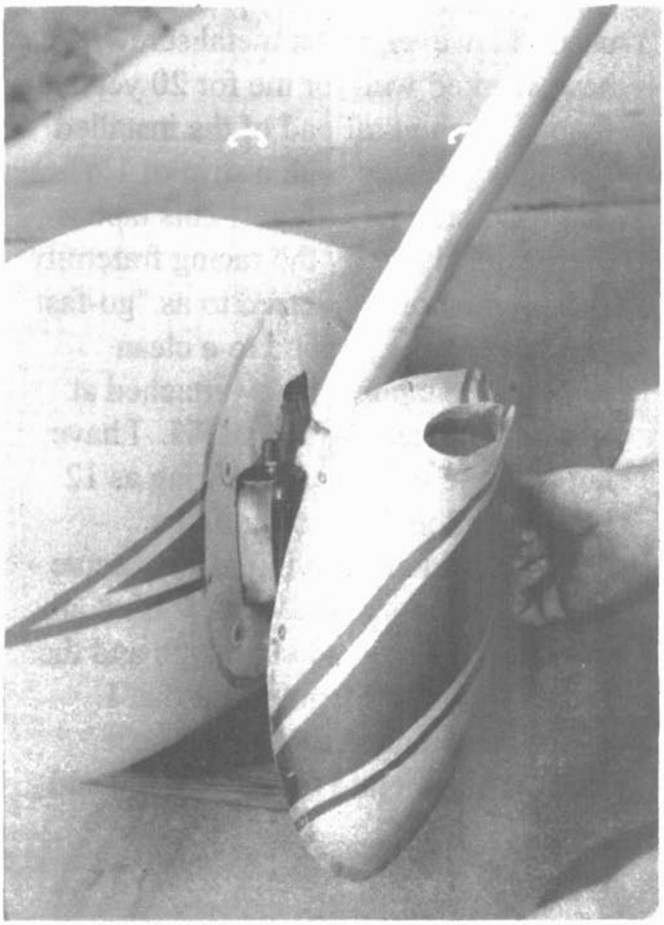
would be impractical to try to eliminate all of the interference drag of a juncture, so usually a radius is chosen that will eliminate 95% of the interference drag. Anyway, the fairing which I made for the gear leg to wheel pant juncture is similar to the leg to wing fairing.



The gear leg to wheel pant fairing also smooths-out the turbulent airflow at this juncture.

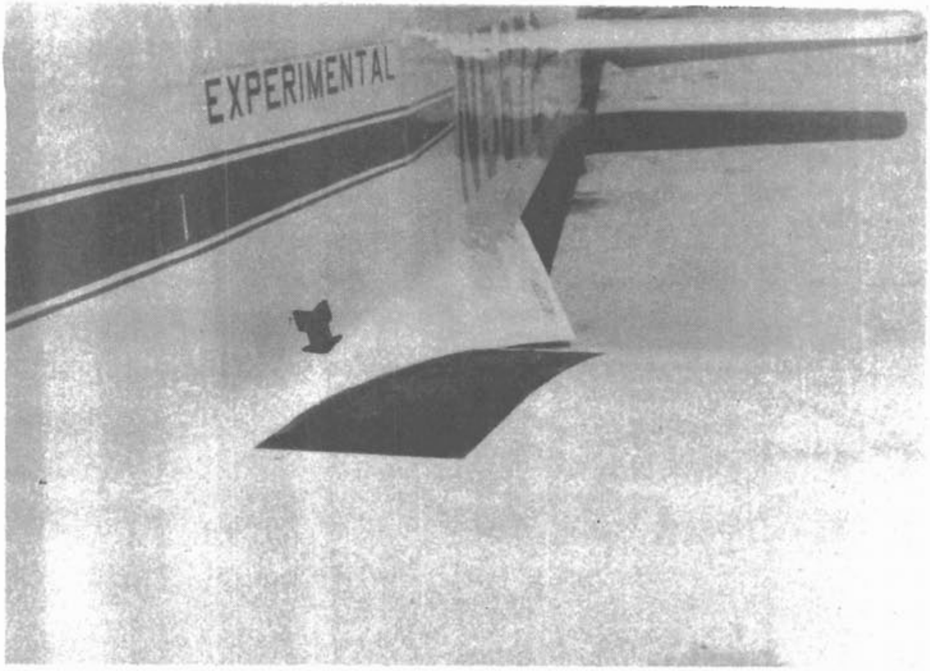
An application of modeling clay, shaped to the necessary minimum drag form, then covered with two layers of 10 oz. glass cloth. Again, this fairing must be removable to permit access to the wheel pant attaching hardware, the wheel axle attaching hardware and the wheel brake assembly for periodic maintenance and inspection.

Obviously, this fairing not only minimizes the interference drag of this juncture, but also eliminates the form



This fiberglass fairing is also removable for access to the axle attach bolts and brake cylinders.

drag of all that attaching hardware and brake hardware "hanging out" in that 200 MPH plus breeze (a very important fairing). This fairing I also attached with pan-head sheet metal screws. Since the attachment was to the fiberglass wheel pant, I riveted pieces of soft aluminum, .060 sheet, to the inside of the wheel pant to provide a better grip for the sheet metal screws. The split aft edge of this fairing, when

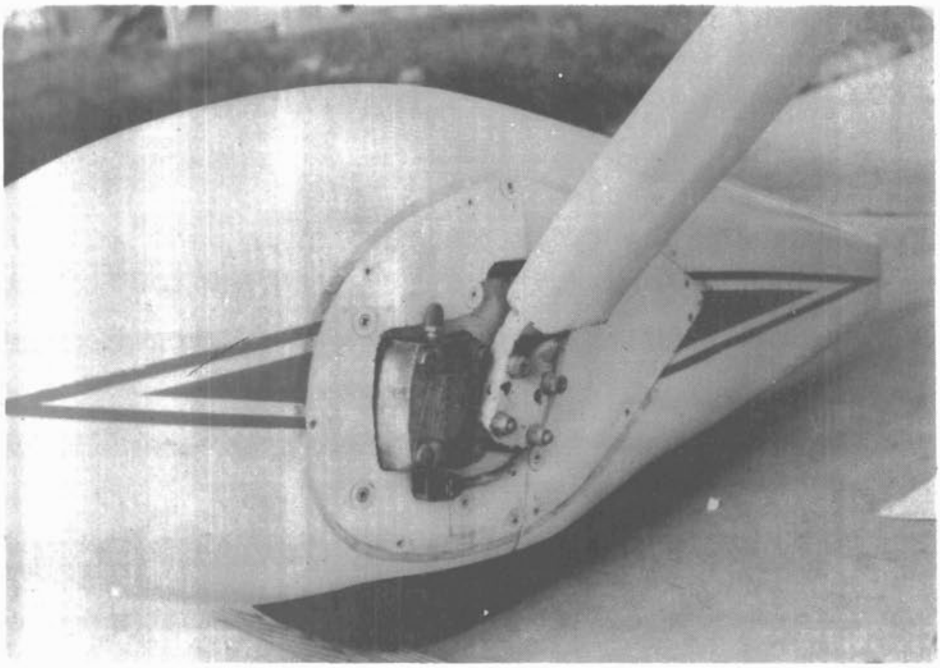


Wing-root radius fairing is made from foam and fiberglass and is nonremovable.

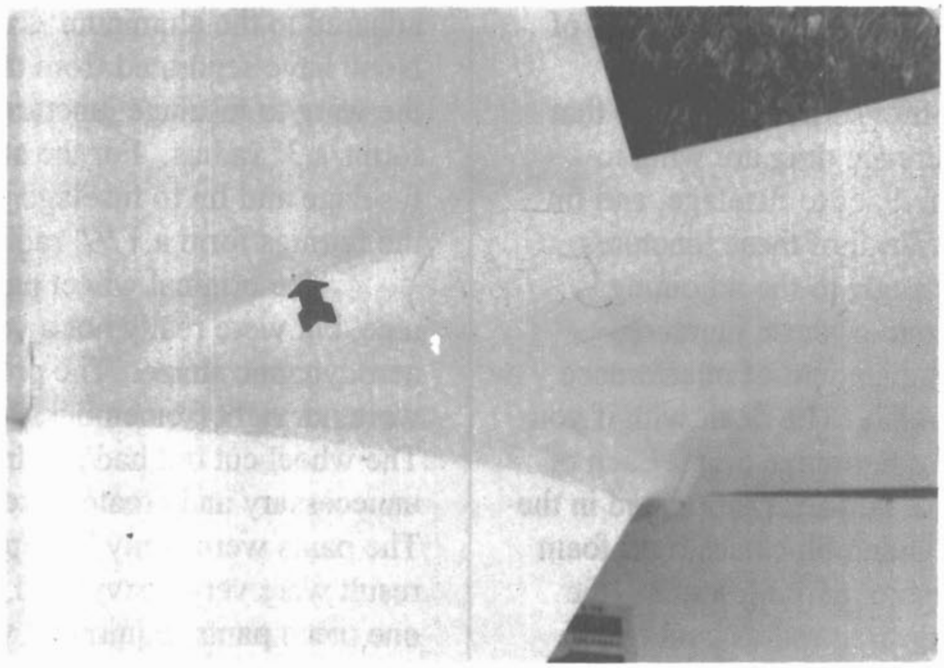
installed, is also sealed with a strip of 3M 471 tape.

The other surface junctures that cause interference drag are wing to fuselage, stabilizer to fuselage, and fin to fuselage. Each of these junctures forms a 90° angle to the adjoining surfaces. None of these junctures creates a huge amount of interference drag, but enough to be dealt with if you really want to minimize drag. Each of these juncture fairings I fabricated in the same way: gluing blocks of rigid foam into the juncture, carving/sanding the form to the desired radius, and over-laying the foam with two layers of 10 oz. glass cloth impregnated with catalyzed polyester resin. These fairings are nonremoveable, considering that nothing behind the fairings requires periodic maintenance. Incidentally, for these fairings, the fiberglass has adhered to the aluminum skin very well. None have separated from the skin. For the wing to fuselage juncture, the fairing forms a 3" radius. For the stabilizer to fuselage and fin to fuselage junctures, the fairings form a 1 ½" radius.

The original wheel pants looked nice, but were really not a very good aerodynamic shape. The proportions were not right (remember, 3.7 to 1.0). The wheel cut out had a skirt that was unnecessary and created excess drag. The pants were spray lay-up and as a result were very heavy; and, they were one piece pants requiring a very large opening in the bottom so that they could be installed over the wheels. When I was fabricating the gear fairings, I purchased a set of wheel fairings from John Monnet (of Sonerai and Monerai fame). These pants were almost ideal in proportion for minimum drag, were

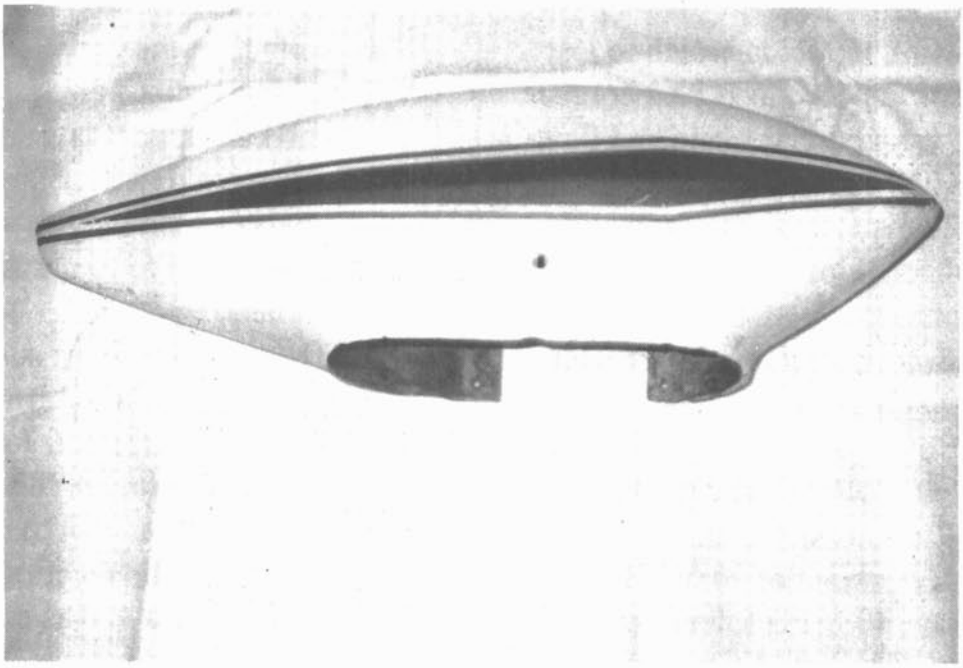


Without a fairing over this juncture, look at all the hardware that would disrupt the 200 MPH airflow.

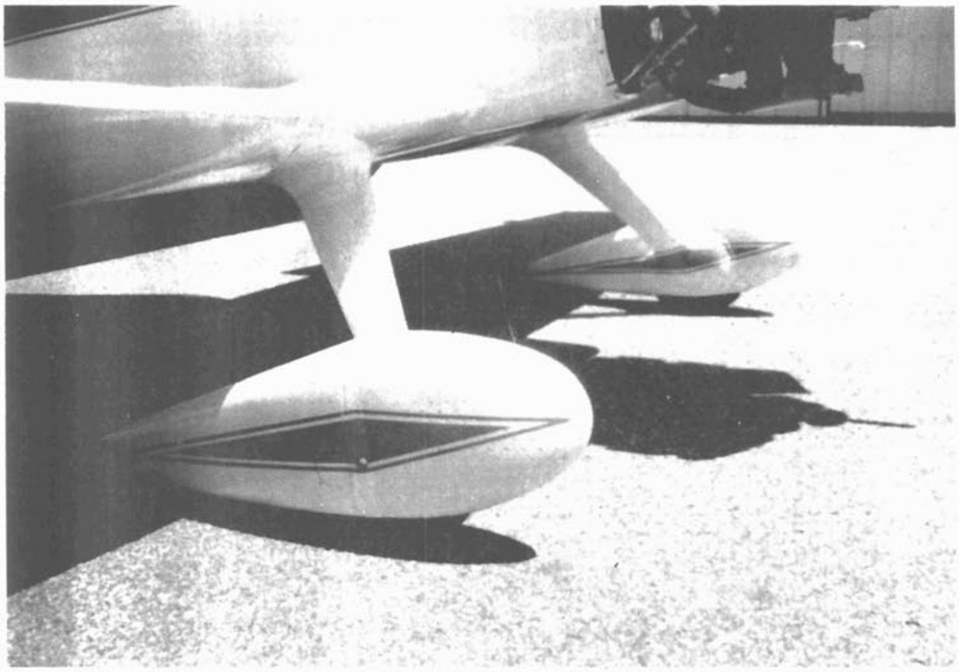


Tail surface root fairings are also foam and fiberglass and are nonremovable.

very light (but strong, being hand lay-up of glass cloth), were two-piece so they required a small opening in the bottom for the tire to protrude and could be fitted very closely around the tire (good for minimum drag). The joint of this two-piece pant I also sealed with the 3M 471 tape. When I flight-tested the airplane after the new landing gear fairings were all installed (including the new wheel pants), I found that the top speed was almost 20 MPH faster!



The original wheel pants were one-piece and had a large wheel opening.

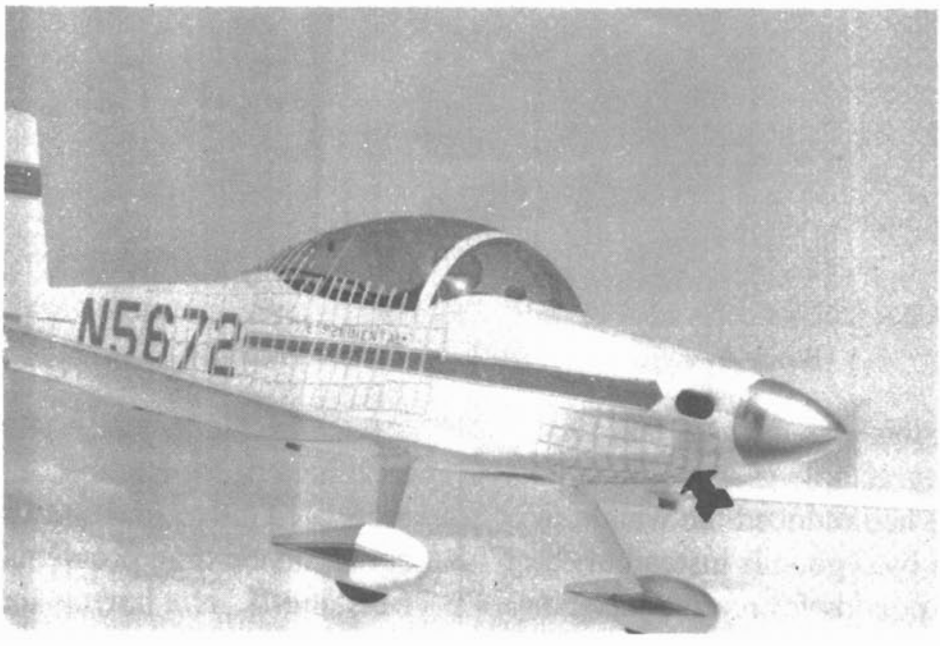


The current wheel pants are very light, two-piece, and have a small wheel opening.

Amazingly, this was the goal that I had set for the retractable gear modification! Better yet, I had reduced the weight of the airplane by 5 pounds instead of adding 100 pounds for retractable gear.

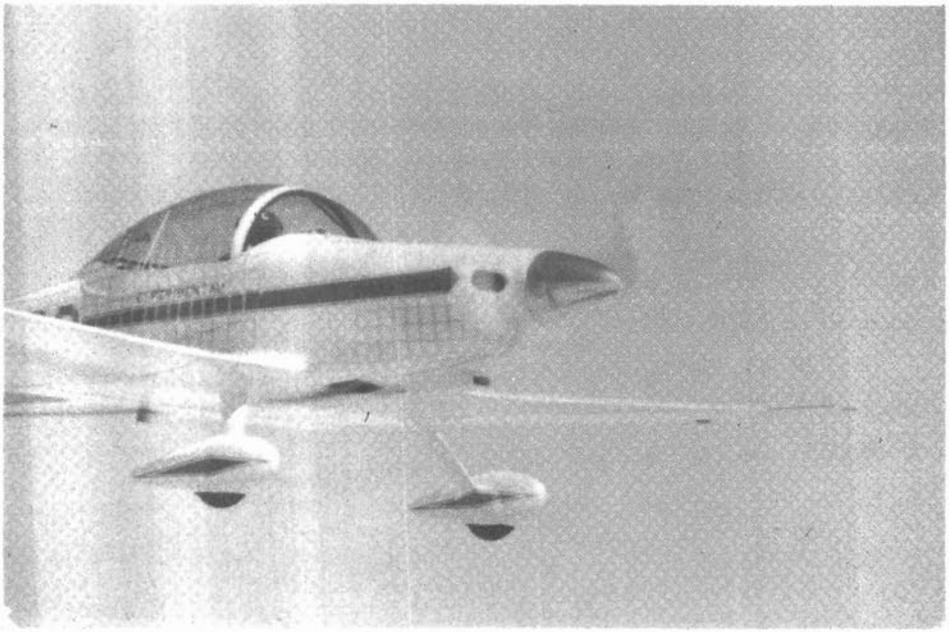
The highly successful fairing treatment of the landing gear really motivated me to find and fix other aerodynamic drag problems with my Mustang-II. Not having access to a large scale wind tunnel in which to test the airplane, I took the next best course of action. I tufted the airplane and flew formation with my friend Jim Herrington in his Comanche for a picture taking session. The tufts were 4" lengths of red yarn attached to the airplane with fresh masking tape. The tufts were spaced about 5" apart in each direction. Boy, did the airplane look scruffy with all that red hair growing all over it! We took two sets of photographs. One set at 90 MPH and another set at 180 MPH (about as fast as the Comanche could fly straight and level). The photographs very graphically showed additional areas where air flow could be improved:

1. Although the square jowls on the cowling did not show highly disturbed airflow, because air impact pressure was keeping the tufts pretty tightly held to the surface of the cowl jowls, I reasoned that I could reduce that cowl air impact pressure by removing those square cowl jowls (remember, air at velocity doesn't like to turn a square corner).
2. The tufts on the aft surface of the canopy were lifted from the canopy surface and Jim said that the tufts were wriggling like crazy. This meant that the airflow on the receding aft canopy surface was separated from the surface and very turbulent. Jim said that at times many of the tufts were actually pointing forward. Obviously, significant improvement could be made in that area of airflow. I reasoned that the canopy surface was receding at a greater angle (from the relative airflow) than what the airflow could stay

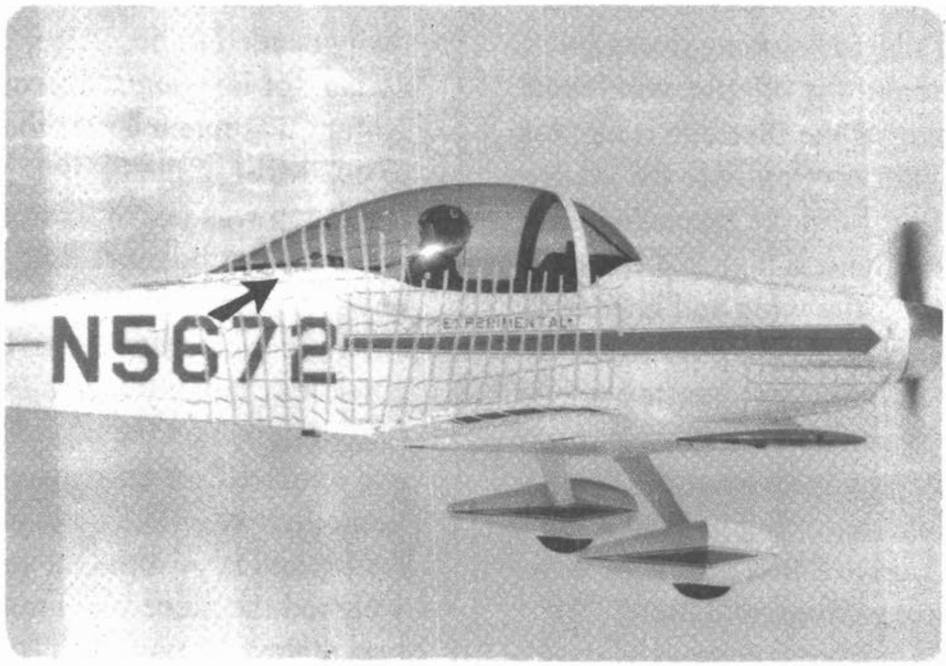


Cowling lower square jowls create high impact pressure in those areas.

attached; thus, creating a low pressure region on the aft portion of the canopy with actual reverse flow of air. I had heard that some people had cut slots in this receding canopy surface, intending these slots to be exits for cockpit air. But these intended air outlets actually acted as air inlets providing a cold blast of air on the backs of their heads! From my flght testing, I could see how and why this can occur.



Air flow doesn't look too dirty on the cowl square jowls, but can be improved.

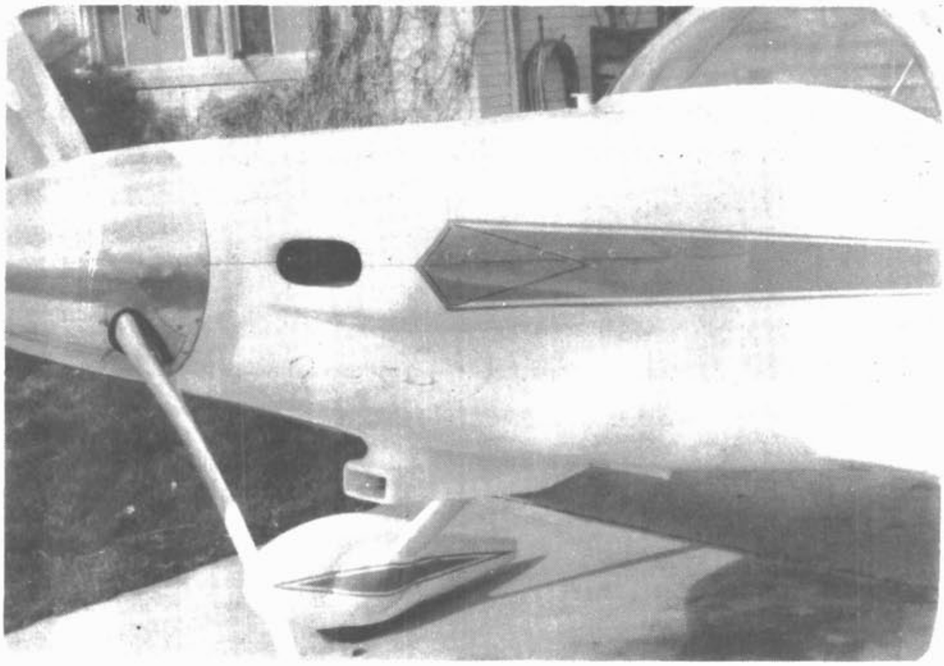


Very dirty airflow on the aft surface of the canopy and the interface of the canopy with the fuselage.

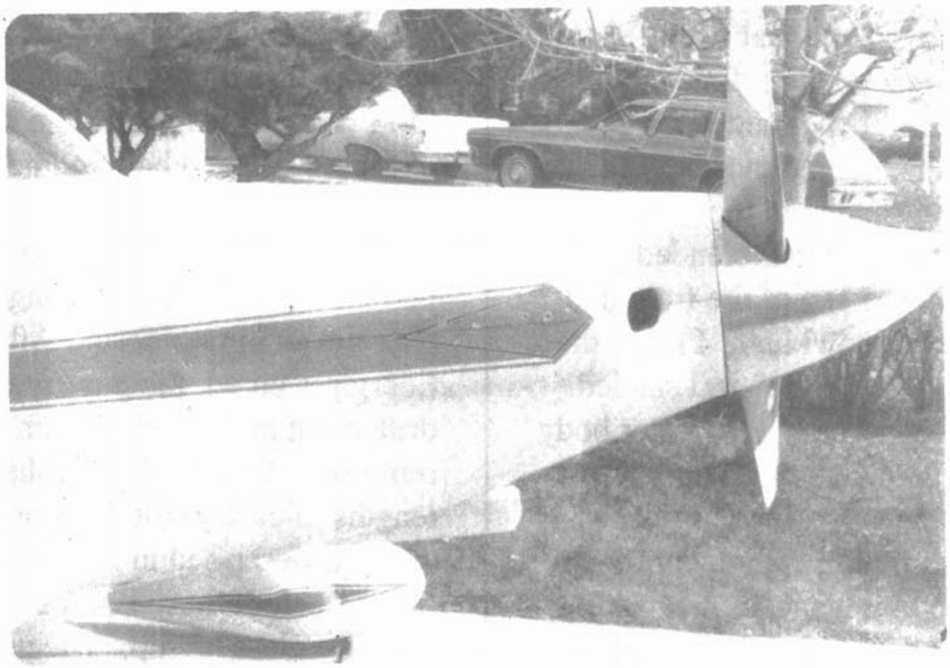
3 The tufts on the side of the fuselage, for 3 feet aft of the trailing edge of the wing, were pointing up instead of aft! The explanation for this phenomenon is that a low pressure region is being created in this area by the wing's airfoil sloping down (in relation to the relative wind) and the side of the fuselage is sloping in (again in relation to the relative wind) to form the fuselage tail-cone. There is higher pressure air under the wing and fuselage. The higher pressure air wants to flow into the low pressure region along the side of the fuselage. Hence, the tufts point up, even with the air trying to flow aft at 180 MPH! Must be a very strong pressure differential there. So now I had several areas of drag reduction to work on, with hopefully, commensurate increases in aircraft speed.

Look at those tufts pointing up on the side of the fuselage, aft of the wing trailing edge.

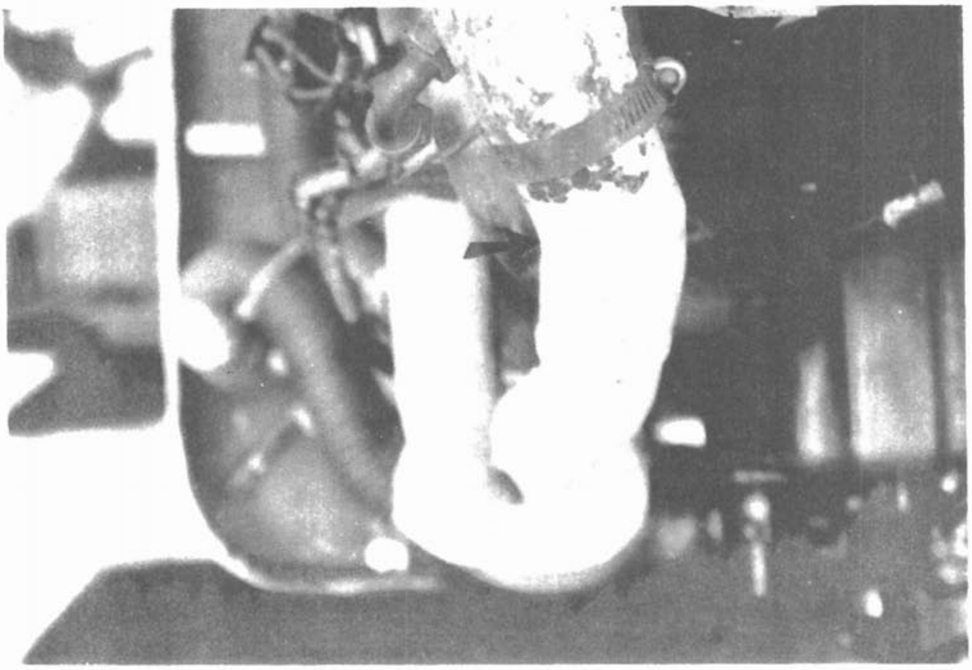
I had been looking at the square jowl on my cowling for some time, knowing that it was more draggy than it really needed to be. Also, the carburetor housing/scoop on the cowl bottom was much larger than it needed to be. Most of the air being taken in by the scoop was just spilling right back out and creating more drag. This was not going to be a simple modification. I cut away almost the entire bottom of the cowl, leaving only about 2½" of cowl ring right behind the propellor spinner and about 10" of cowl where it attaches to the firewall. The cowl is also a spray lay-up and is ¼" thick in some places. I weighed the piece that I cut out and it was almost 12 pounds! To get the smooth flowing shape that I wanted, I pop-riveted some pieces of aluminum sheet into place, then glued some sheets of rigid foam to aluminum sheets. The foam was then sanded to the gentle compound curvature that blended together what was left of the front and rear of the lower cowl half. I filled the foam pores with "Bondo" and sanded and waxed the "Bondo" (polyester body filler). Then, 4 layers of 10 oz. glass cloth (impregnated with polyester resin) were layed up over the aluminum/foam form, overlapping what was remaining of the lower cowl on the front, rear and sides. After the fiberglass cured, I drilled out the pop rivets and popped out the aluminum/foam form. For the new carburetor housing and scoop, I bent up some aluminum sheet to serve as a form. This form cleared the carburetor controls and airbox controls by only ½" all around (sides and bottom). Then this sheet aluminum form was pop-riveted to the new bottom of the lower cowl half and heavily waxed. Four layers of 10 oz. glass cloth were also used to fabricate the permanent fiberglass housing/scoop over the aluminum form. After the fiberglass cured, the pop rivets were drilled out and the aluminum form removed. Three different shapes and lengths of carburetor air scoops were tried, as described in the Intake Chapter (#3). Each of these scoops was a foam and fiberglass lay-up. The new cowl bottom was trimmed, sanded, filled and painted, and looked slick and fast even standing still. I did have to move the exhaust pipes for cylinders #1 and #2 in-board slightly to provide adequate cowl clearance. And, to provide heat protection for the new cowl bottom



No more cowling square jowls. The lower cowl now recedes smoothly, back from the spinner.

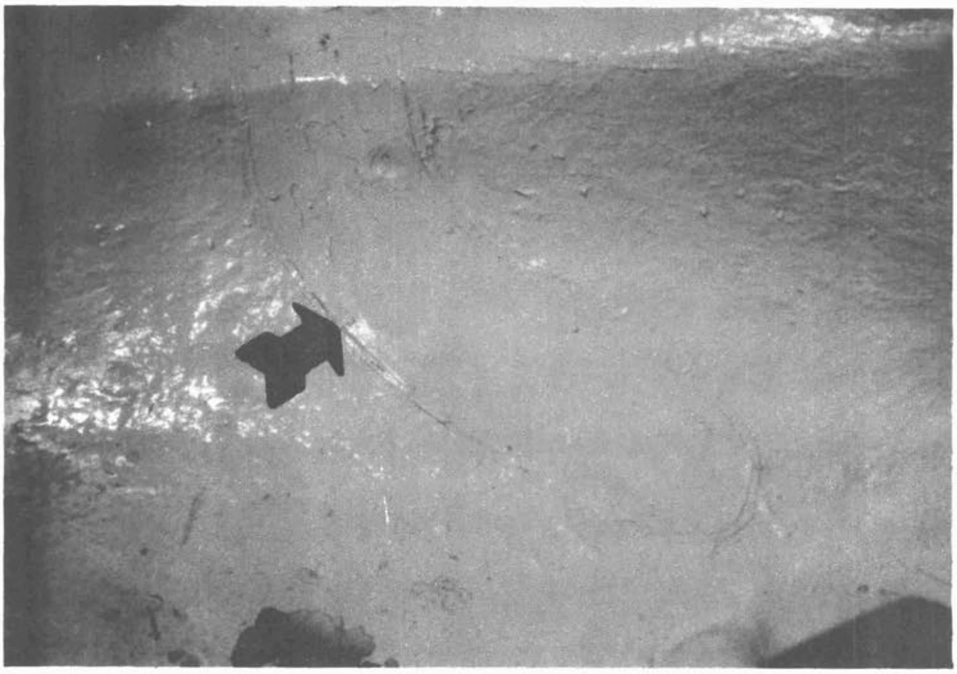


The high impact pressure on the cowl square jowls has been eliminated.



The number one exhaust pipe bends inward to clear the tight-fitting lower cowl.

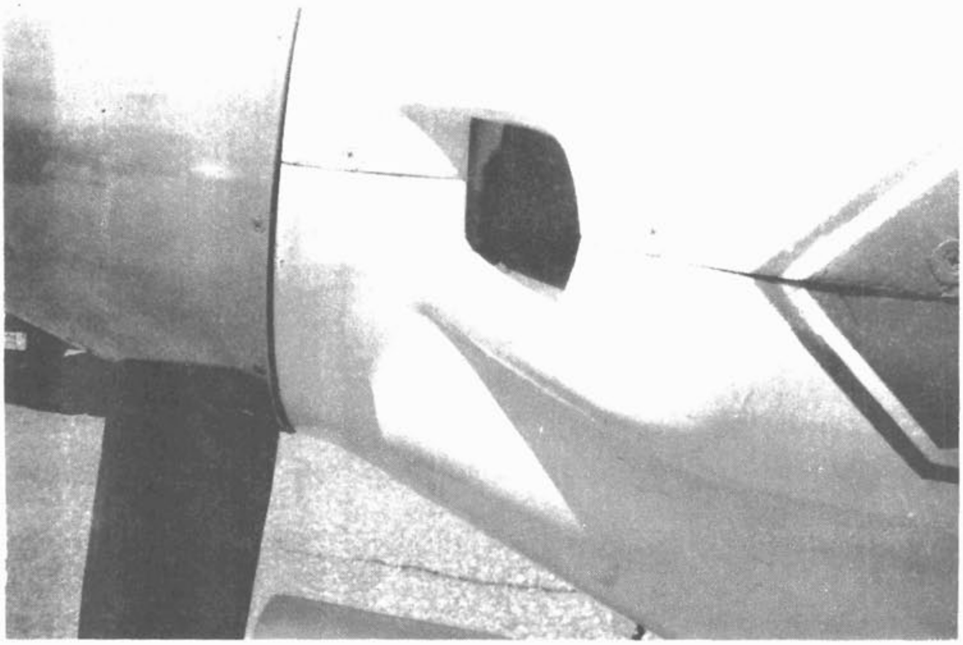
where the #1 and #2 exhaust pipes came close, I riveted a sheet of asbestos/sheet steel (.035-4130) heat shield patch to each side of the cowl bottom. It works well. I have not had any fiberglass softening or paint blisters.



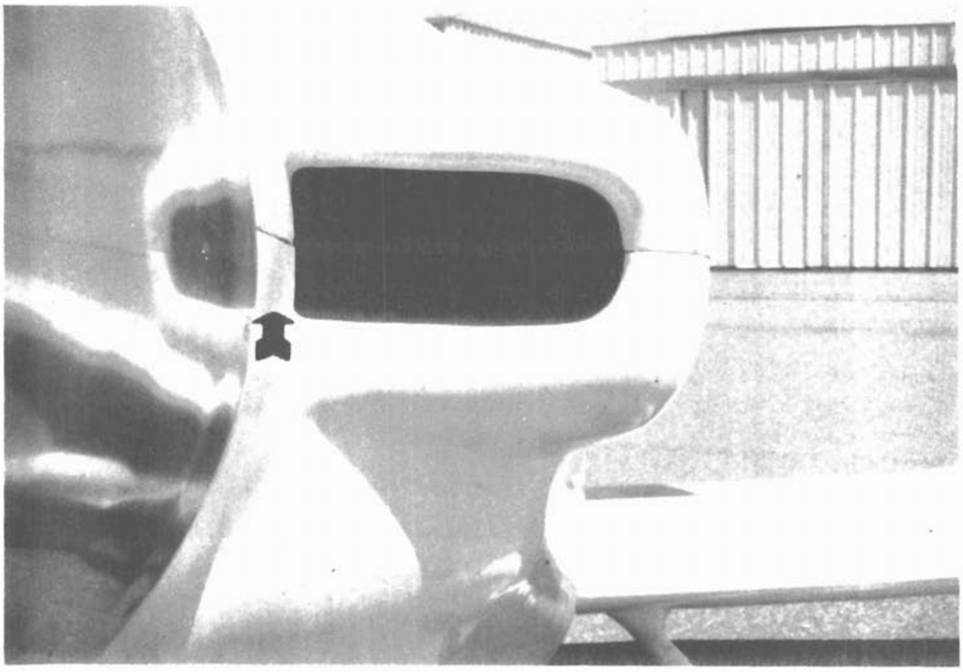
Tight-fitting lower cowl has heat protection plates to protect the fiberglass from the hot exhaust pipes.

As described in the Cooling Chapter (#4), the cowling cooling air inlets and outlet also were modified in several stages to not only improve engine cooling but to reduce aerodynamic drag, as well:

- The inlets area was reduced by 50%.
- The inlet edges were generously rounded.
- The portions of the inlets that are closest to the propellor spinner were cut in so that air coming off the spinner could flow directly aft into the air inlets instead of having to make a turn to enter the inlets.



Cowl air inlet edges are well-rounded.



Cowl air inlets allow air to flow straight back from the spinner and into the cooling plenum chamber.

The cowling air outlet did not require as much treatment to minimize drag. But since the cowling outlet aft edge was now lighter and more flexible, I installed a structural support (a standoff) from the bottom edge of the firewall (at the center line) down to the cowl outlet edge.

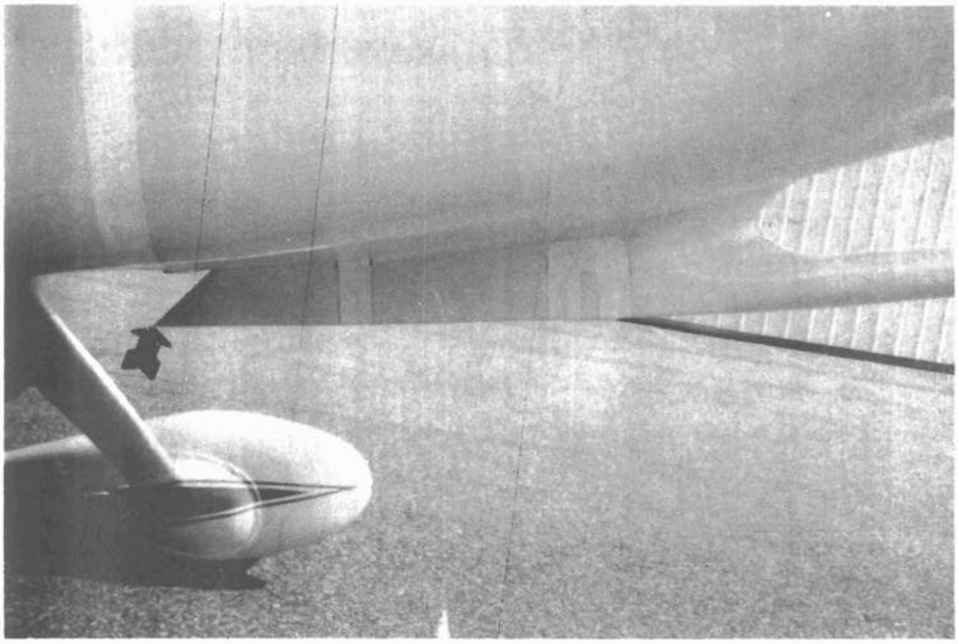
The cowl air outlet edge has structural support.

The one change that I did make (later) to the cowl air outlet was to continue the carburetor housing straight aft to the cowling air outlet. Previously, the carburetor housing sloped up sharply enough at the aft end that I am positive that the airflow detached from the sloped surface and became turbulent flow at the exact point where cooling air was trying to flow out from the cowl. A simple modification; but, it improved the cooling air outflow, and eliminated an area of turbulent outer airflow, besides.

that treated the problem of air transitioning from the wing to the fuselage (on low-wing aircraft). The wing-root fairings that resulted from those experiments reportedly:

1. Reduced a low-frequency structural rumble/airframe vibration.
2. Increased elevator effectiveness.
3. Increased the aircraft's speed.

The wing-root fairings which I fabricated were similar in configuration



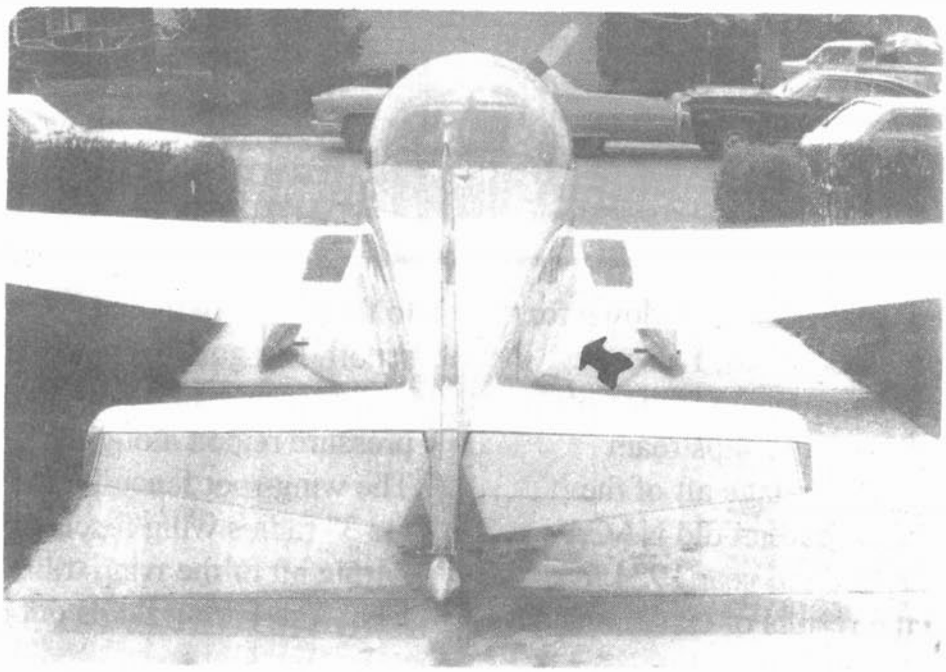
The cowl carburetor housing goes straight back and becomes part of the cowl air outlet.

While the airplane was down for the cowling modifications, I also fabricated some fairings to "fence-off" that adverse 90° to the slipstream airflow along the fuselage aft of the wing. I remembered that old NACA report from around the year 1924 that documented the results of experiments

to those shown in that 1924 NACA report. My goal being to "fence-off" the high pressure air below from the low pressure region along the fuselage sides. The wing-root fence/fairings continues the 3" radius wing/fuselage juncture fairing aft of the wing trailing edge for 3 feet. The fairing flares out at the wing trailing edge to about a 12" radius and then tapers back down to a gradually smaller radius to end in a tip or point, 3 feet aft of the wing trailing edge.

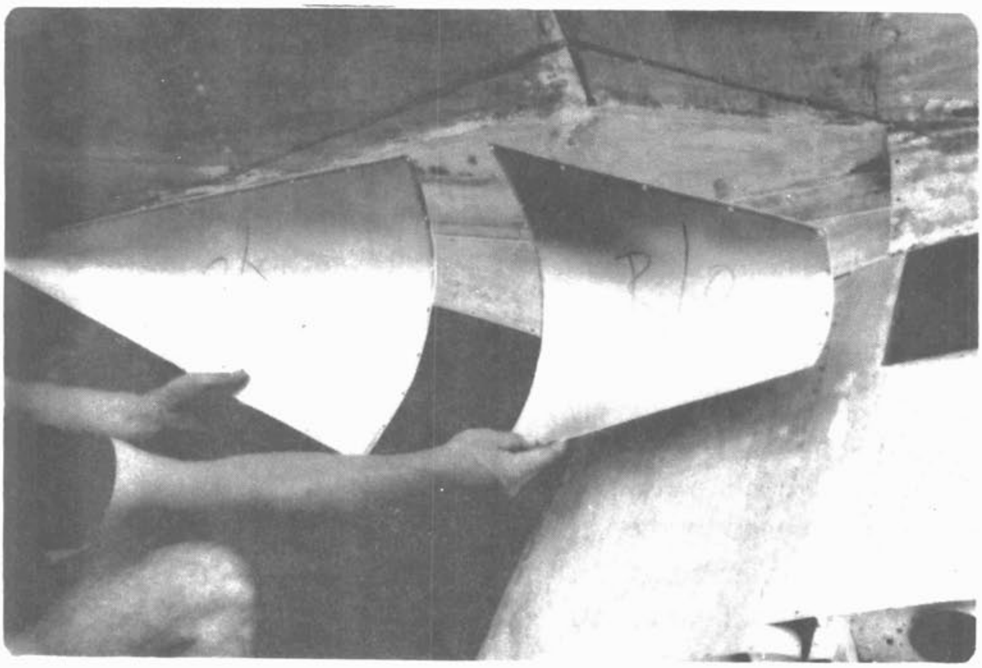
The original extended wing-root fairings were fabricated with an aluminum sheet belly pan riveted to the sides of the fuselage. Then, rigid foam blocks were glued in place to build up the fairings. The foam was sanded to the radius indicated, and then two layers of glass cloth were layed-up over the foam. I flew this configuration for some time.

The early design wing-root fence fairing had an aluminum belly pan and foam and fiberglass upper surface.

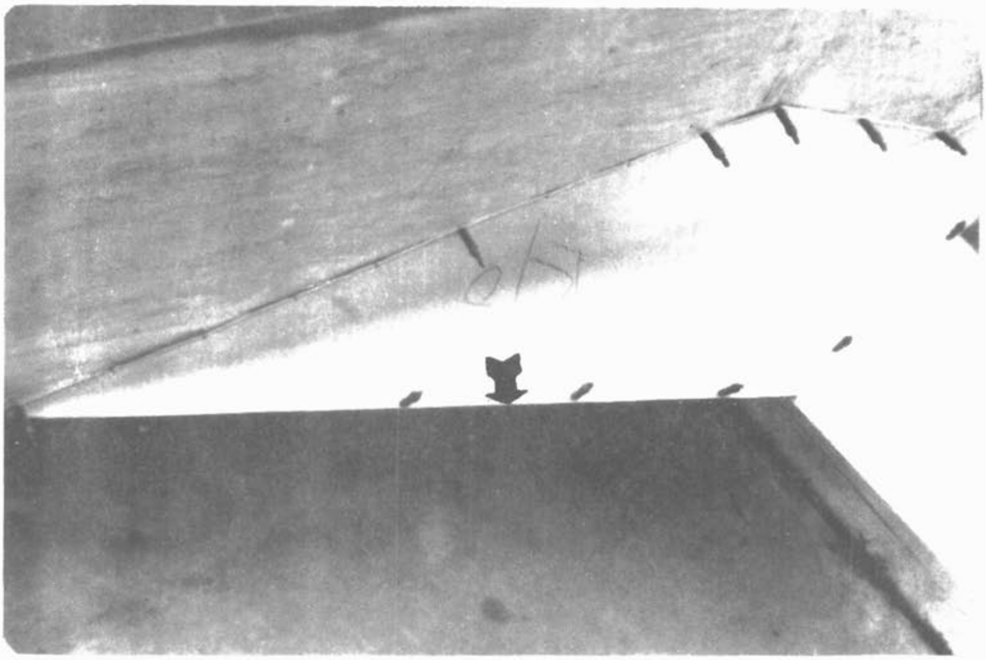


The wing-root fence fairings actually fence-off the high pressure air from the low pressure regions along the fuselage sides.

However, the outer fiberglass/aluminum sheet bonded edge of the fairings was very vulnerable, in that it was exactly the right height for adults to lean against and kids to kneel on when looking into the cockpit when I was parked. I was frequently rebonding this fairing outside edge. The upper-bond attaching the fairing to the fuselage side never did require rebonding. However, in the interest of minimizing aircraft maintenance, when I installed the fastback modification, I also made the upper surface of the extended wing-root fairings from formed aluminum sheet and riveted the free edge of the fairing.



Newer wing-root fence fairing surfaces are also made from sheet aluminum.



No more outer edge delamination with the riveted, all aluminum fence fairings.

This solved the debonding problem. The way that most aerodynamic fillets and fairings work is to fill in a region of turbulent airflow. Especially where you are asking the air to transition from one surface to another or to change direction or to depart from a flying surface and merge with free-stream air.

Anyway, the flight-test after the cowl and wing-root fairings modifications showed a top speed increase of between 7 and 8 MPH. I also noticed that the loud rumble that occurred with the wing flap extended for landing was significantly reduced. I did not notice any change in elevator effectiveness.

At this point in my quest for speed, it seemed that an easy way to pick up several more MPH's would be to eliminate the drag caused by the externally mounted radio antennas. Since the Mustang-II has an aluminum airframe, the only places to internally mount the antennas and still have acceptable radio operation are the wing tips, the engine cowling, or under the cockpit canopy. The fiberglass wing tips are not suitable because they are not long or wide enough for the VOR "rabbit ears" antenna; and, the communications antenna needs to be mounted vertically with a "ground-plane" mounting. I did try mounting both antennas inside the fiberglass engine cowling, but both NAV and COMM radio operations were unacceptable. The antenna pattern was badly pinched by the proximity of the engine mass and the electrical "noise" was very bad. This left the cockpit area for internally mounted antenna experimentation. I mounted the communications "mast" on the upper fuselage right side longeron where the seat back ties in. The longeron and seat back structure serves as a ground plane. The antenna is not perfectly vertical but

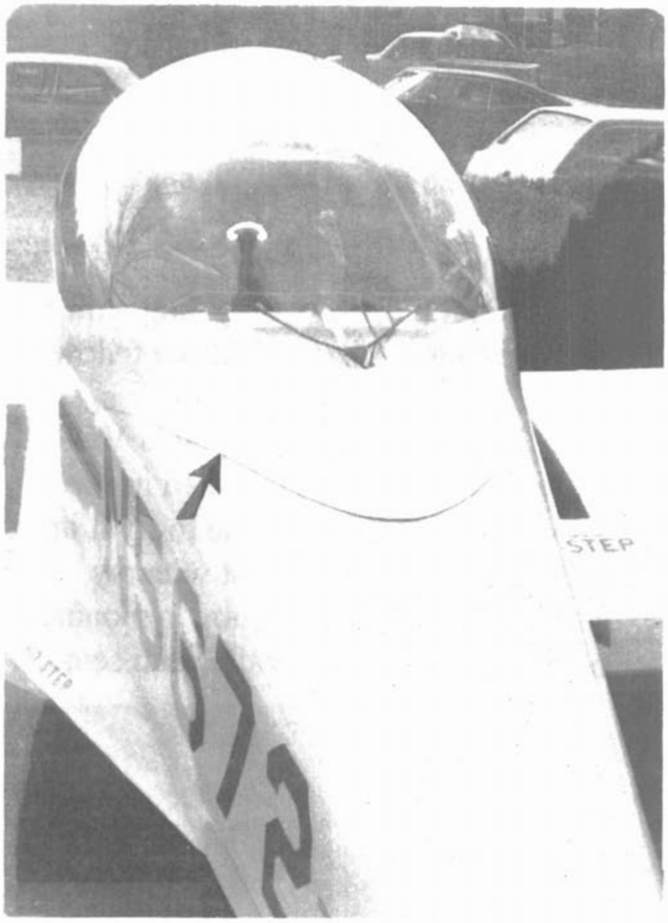
The communications antenna and Loran antenna are mounted on the upper seat-back brackets, inside the cockpit canopy.

slants inward to the fuselage centerline at the antenna tip. This is a very good location for that antenna. Transmitting and receiving radio operations are strong and noise free. The only disruption of the antenna pattern is to the right side of the aircraft, since the ground plane extends only a short distance in that direction.

I had been corresponding with Jim Rushing in Texas. Jim is a fellow Mustang-II builder and electronics engineer. Jim was developing a VOR antenna that could be installed inside the canopy, and wanted me to try it in my aircraft and compare it with my standard VOR antenna (now remounted on the belly of my aircraft). Jim sent his newly developed antenna to me and I installed his antenna inside my aircraft's canopy. I fabricated an RF switch so that I could easily switch back and forth between the two VOR antennas. For flight-testing, I flew cross-country to visit my daughter in Kansas. During the trip, I regularly switched back and forth between the two VOR antennas, testing the range of the navigation signal being pulled in and the clarity and strength of the audio signal. Jim's antenna showed about 20 miles more range flying to a VOR station; however, the standard VOR antenna was a little stronger flying away from a VOR station. This antenna difference was even more pronounced after I installed the fast-back modification on my Mustang-II. Even so, with Jim's new antenna, going to a VOR station, I was pulling in a reliable NAV signal from 80 miles away Flying from a VOR station, the signal would drop-out at about 50 miles from the station. These distances provide a

Jim Rushing's new design VOR antenna is attached with silicon rubber adhesive to the top of the plexiglass canopy inside surface.

combined 130 miles of reliable VOR NAV signal, much more than the average distance between VOR navigation stations. The audio signal also seemed better with Jim's new antenna. I believe that the aircraft structure aft of the canopy is affecting the signal when flying from a VOR station. And, with the raised, higher structure of the fast-back modification, the effect is even more pronounced although not really a problem for cross-country radio navigation. The top speed of the aircraft improved by about 5 MPH with the COMM and NAV antennas both installed inside the canopy and the outside antennas removed. I believe that the drag from the outside COMM antenna was costing about 2 MPH of top speed, and the drag from the outside NAV antenna was costing about 3 MPH of top speed. Jim later sent a sketch of his new antenna, and I am showing that sketch as Figure 5-1.



Interim attempt to smooth out the airflow at the canopy aft edge.

Much larger and tighter fairing at canopy aft edge helped to smooth the airflow, somewhat.

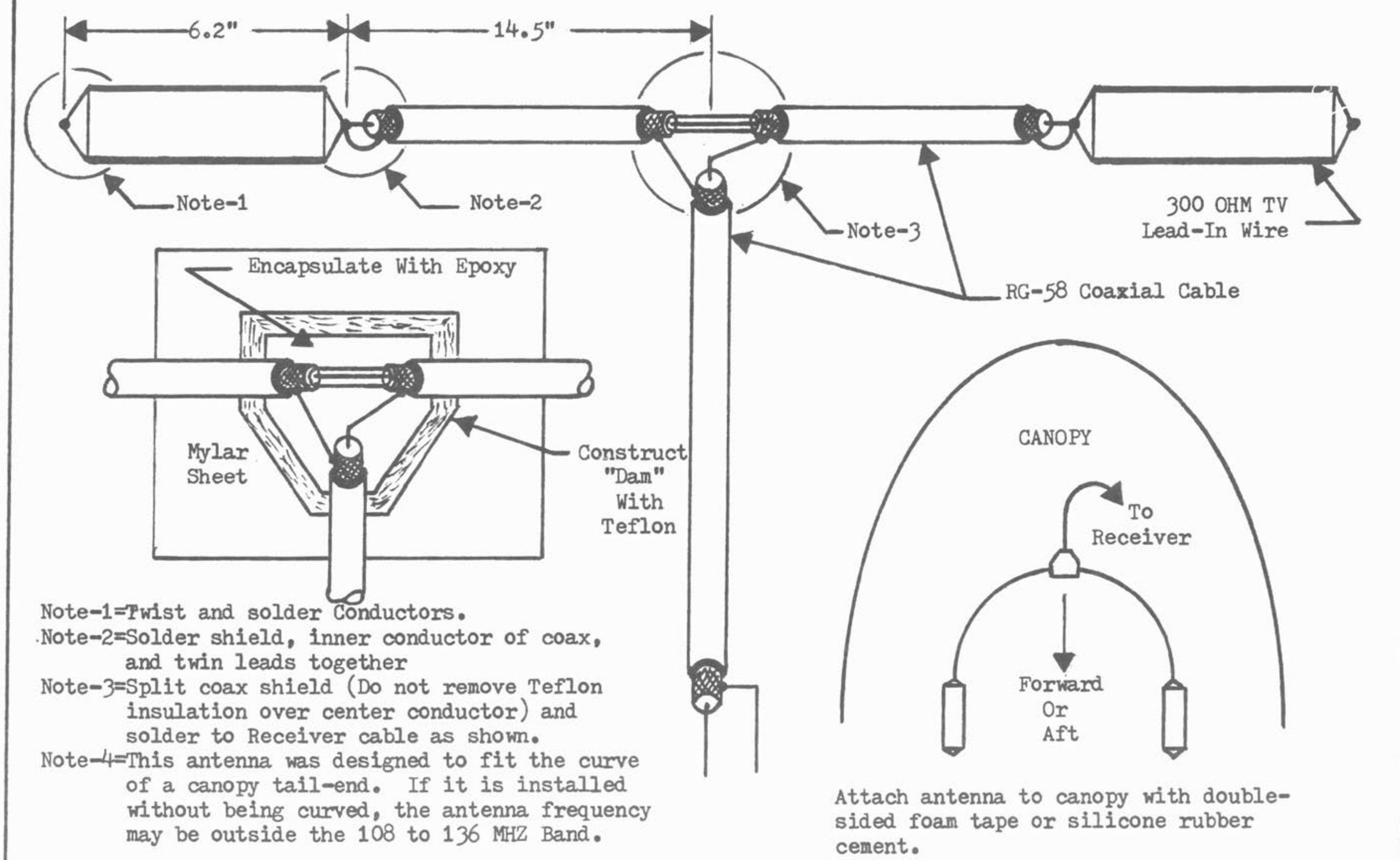


FIGURE 5-1, NEW DESIGN VOR ANTENNA

The next aerodynamic drag reduction modification was much more complicated in that the entire upper surface of the fuselage was involved:

- The rollover structure at the windscreen/canopy split was lowered by 3½".
- A new windscreen was installed.
- The entire canopy was extensively reworked.
- The baggage compartment fuselage bulkhead was raised by 11".
- The fuselage bulkhead at the fin leading edge was raised by 9".
- The heights of the other two intermediate fuselage bulkheads were raised to maintain a straight line between the fore and aft bulkheads.

I called this effort the "fastback" modification. I had been making sketches of the profile of the aircraft of various "fastback" configurations for 2 years prior to actually starting the hardware modification. I finally developed a configuration that reused the original canopy with much modification.

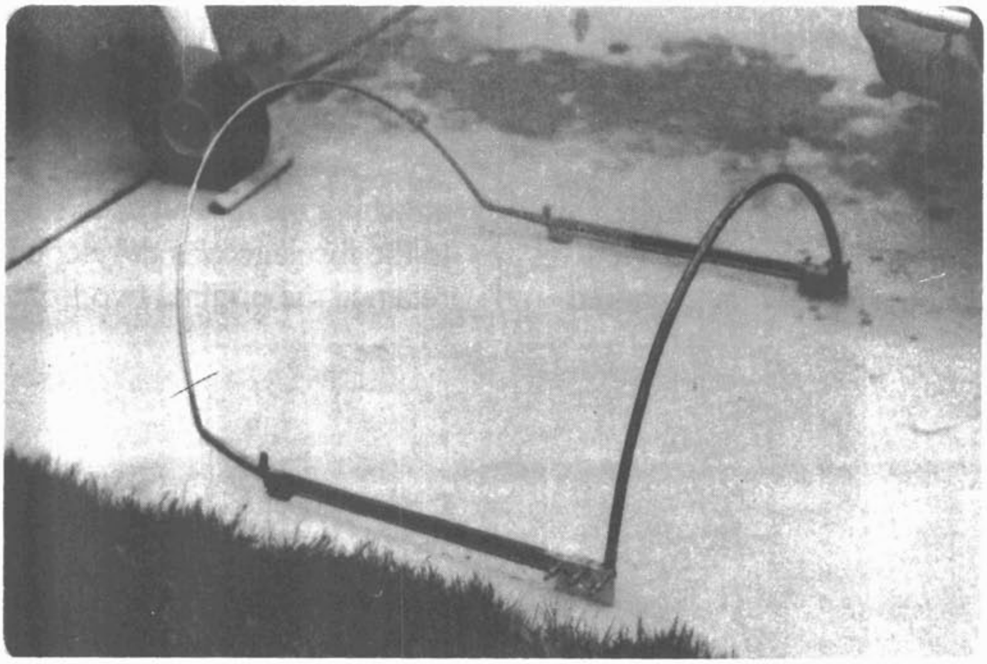
To begin the hardware effort, I removed the canopy, windscreen and rollbar. In the original configuration, the maximum height of the canopy was more than 12" ahead of my head when seated in the aircraft. The original canopy height would also accommodate a person 6'2" in height, whereas I am 5'9" in height. To minimize aircraft frontal area (another measure of aircraft aerodynamic drag) and still provide adequate head room for myself, I wanted the maximum height of the canopy to be at my head when seated in the aircraft. So, that was the starting point for the modification. I removed the chrome-moly tubing support

Original bubble canopy.

structure from the plexiglass canopy. Then, while I was seated in the aircraft, I had helpers position the canopy plexiglass "bubble" so that the previously stated maximum head height and head clearance requirements were achieved. Another helper then marked the trim lines on the plexiglass. Basically, what had happened in the canopy repositioning process was that the canopy was rotated at about my shoulder point with the forward part of the canopy being lowered and the canopy tail part being raised. Much of the canopy plexiglass was trimmed off: the canopy upper forward edge beyond the roll bar was removed; the lower forward side edges that now would overlap the fuselage sides was trimmed; and the entire, very thick, tail part of the canopy that was extending aft of the baggage compartment bulkhead was sawed off. A new chrome-moly tubing support structure for the canopy plexiglass was fabricated.

A new design for supporting and attaching the aft end of this new canopy to the fuselage was developed. I retained the original two front roller/longeron grip canopy attachment points. Then, another straight tube was added to the bottom of the canopy frame on each side. These tubes slide in fittings that are attached to the upper fuselage longerons at the canopy aft edge. So, now, I had a four point canopy attachment to the fuselage, 2 in front and 2 in back, a very secure mounting. Additionally, a complicated mechanism for supporting the canopy aft edge that would still allow the canopy to slide aft for opening was avoided. There is no outside structure to cause drag nor cuts in the fastback

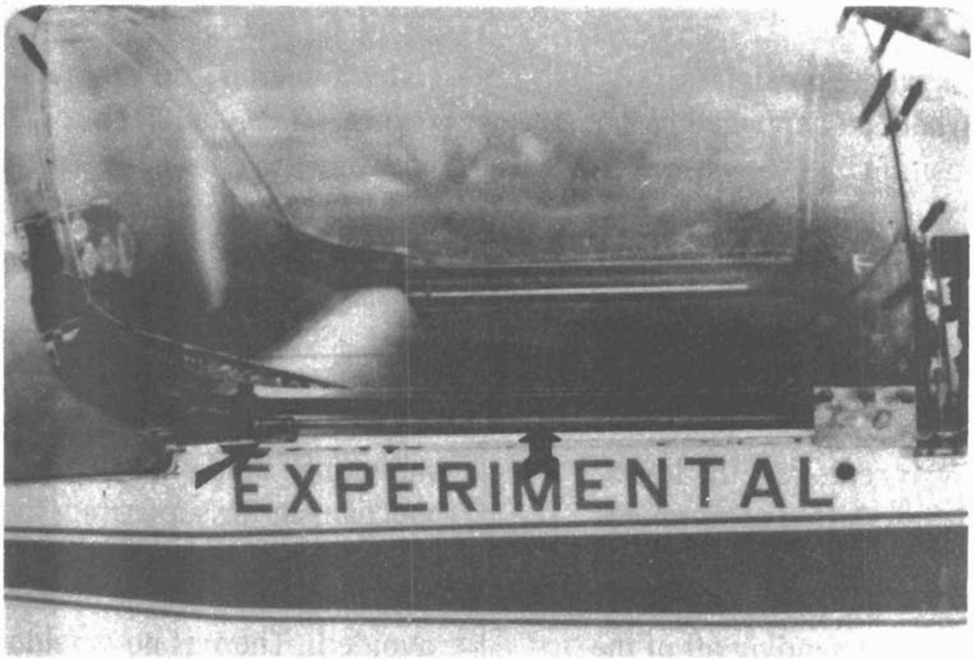
Only the center portion of the original bubble canopy was retained.



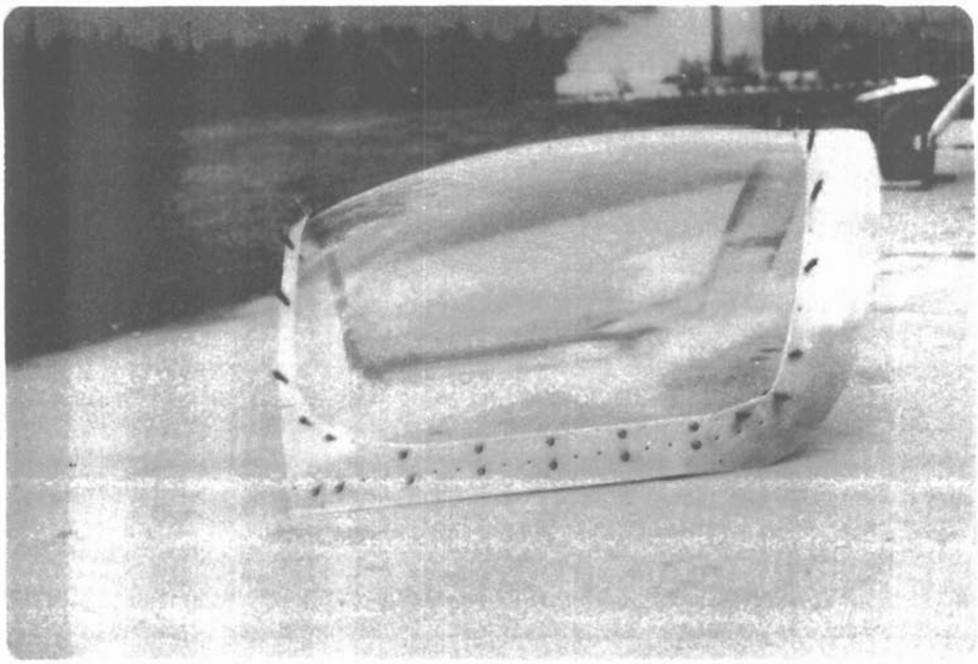
New canopy support structure.

skin to cause air or water leakage, nor slots in the fastback structure that would weaken that structure. All in all, a very neat design solution.

The ends of the roll bar tube were cut off sufficiently to allow the roll bar to match the lowered front edge of the canopy. The new windscreen is

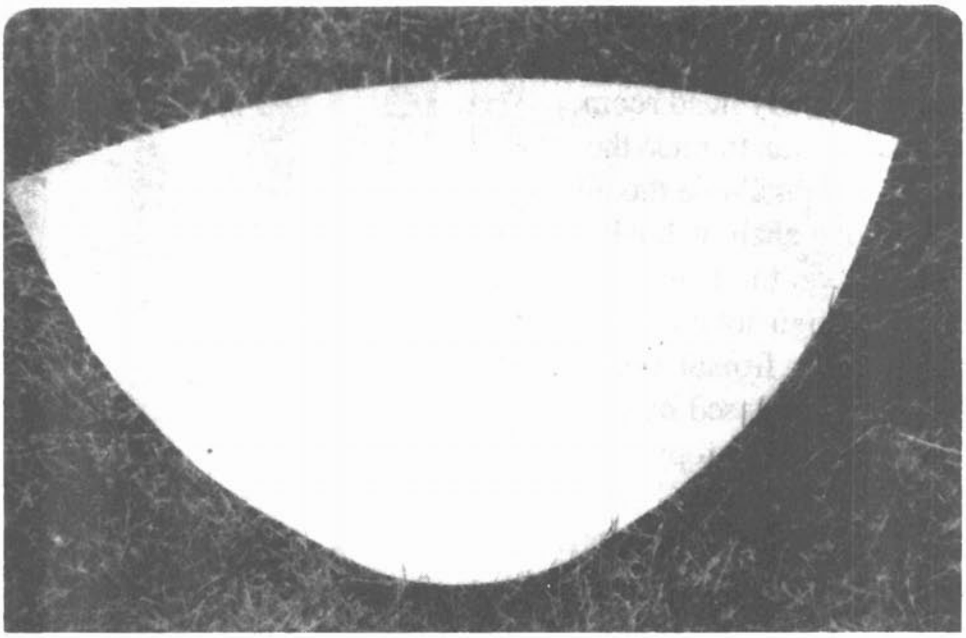


Canopy aft support fittings bolt to the upper fuselage longerons and the tube below the canopy frame slides through these fittings.

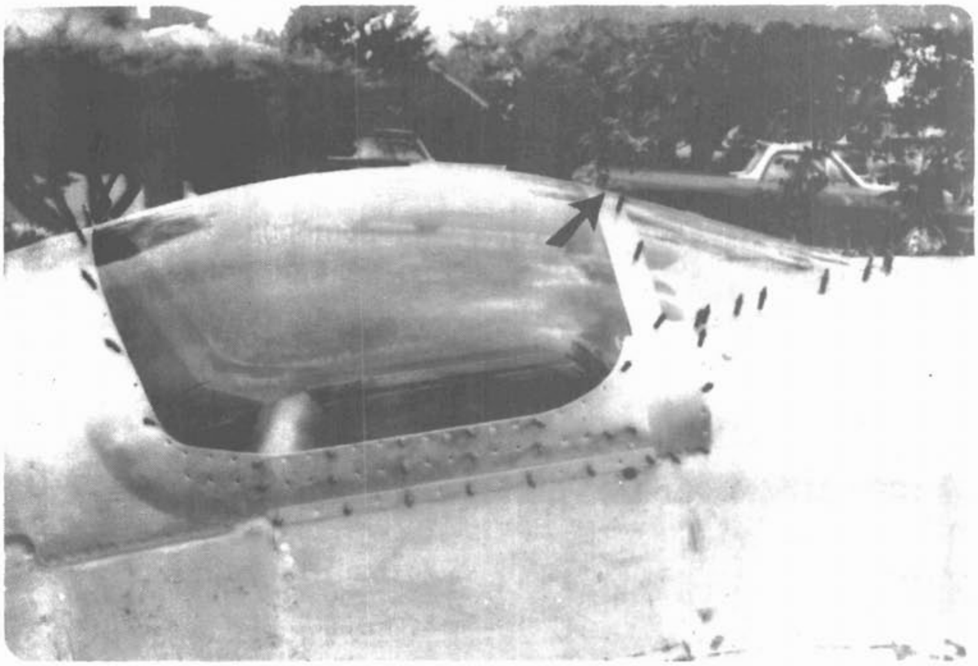


New canopy with aluminum edging and skirts.

simply a straight wrap of ⅛" thick Lexan plastic sheet. Since the Lexan flat wrap is quite curved, sufficient rigidity and impact resistance is maintained. The front edge of the new windscreen is extended forward so that the slope of the windscreen is now much shallower than previously. This accomplishes two objectives. First, the air impact pressure on the windscreen is now reduced. Second, the interface between the windscreen aft edge and the canopy forward edge is a smooth unbroken line.

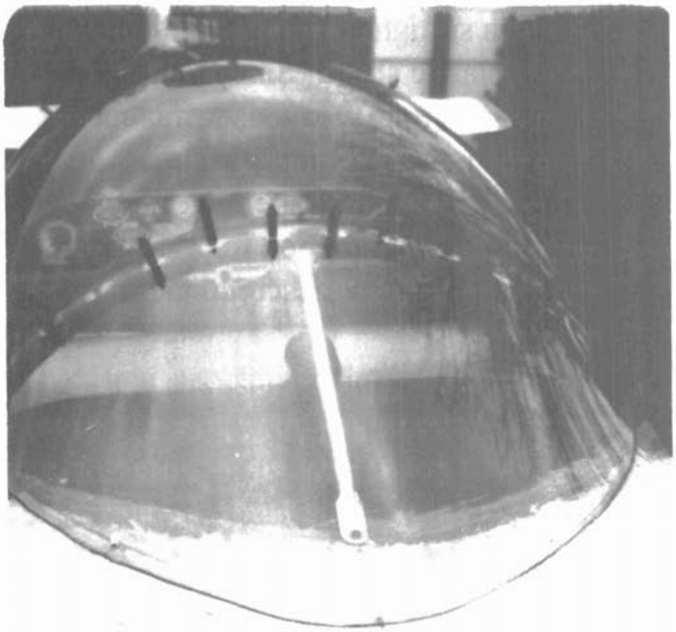


New Lexan plastic flat-wrap windscreen.



Smooth, unbroken line at the windscreen to canopy interface.

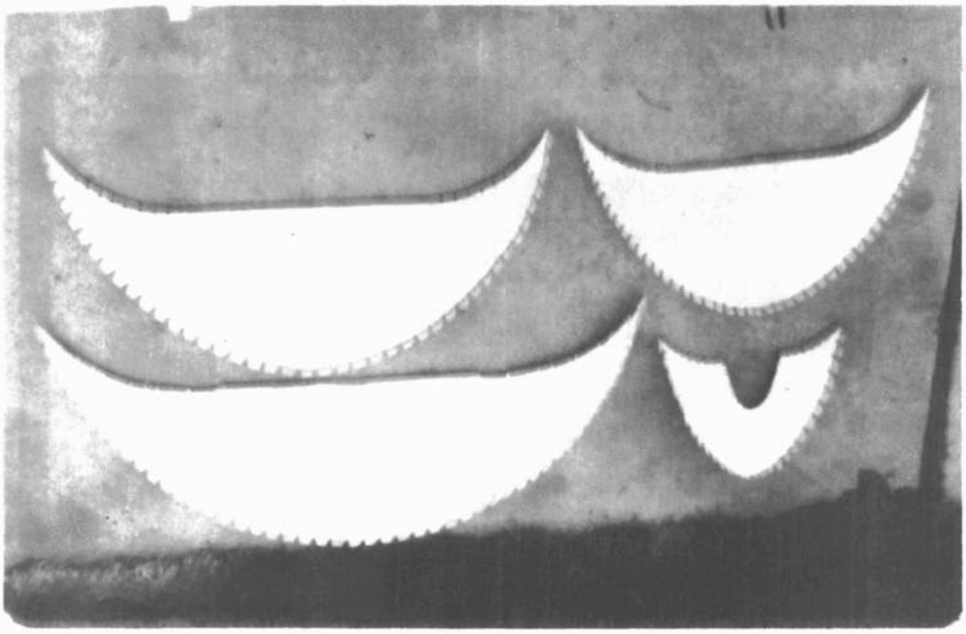
If this windscreen/canopy interface results in an angle, the airflow at this angled interface will go turbulent resulting in significant and totally unnecessary drag. To illustrate this point, during the second world war, when the F4U Corsair Fighter went operational, the taller pilots complained about inadequate canopy head room. The design solution was to raise the canopy plexiglass right above the pilot's head in the form of a shallow bubble. The designers were in for a surprise. Even though the design solution increased the aircraft's frontal area, the aircraft's top speed increased by 6 MPH! Apparently, that canopy "bubble" reduced or eliminated the turbulent airflow at the previously sharp edged interface between the canopy and windscreen.



Flat-wrap Lexan windscreen being fitted.

With the new canopy/windscreen in place, I could now concentrate on the design of the raised structure aft of the new canopy. This fastback structure is basically a large aerodynamic fairing. It carries no primary structural loads, since I left the old tail cone upper skin in place and totally intact. This fastback fairing is quite simple. It consists of four new raised bulkheads pop-riveted to the four existing bulkheads in the fuselage tail cone, and then a wrap of aluminum skin which I also pop-riveted to the new bulkheads and existing tail cone skin.

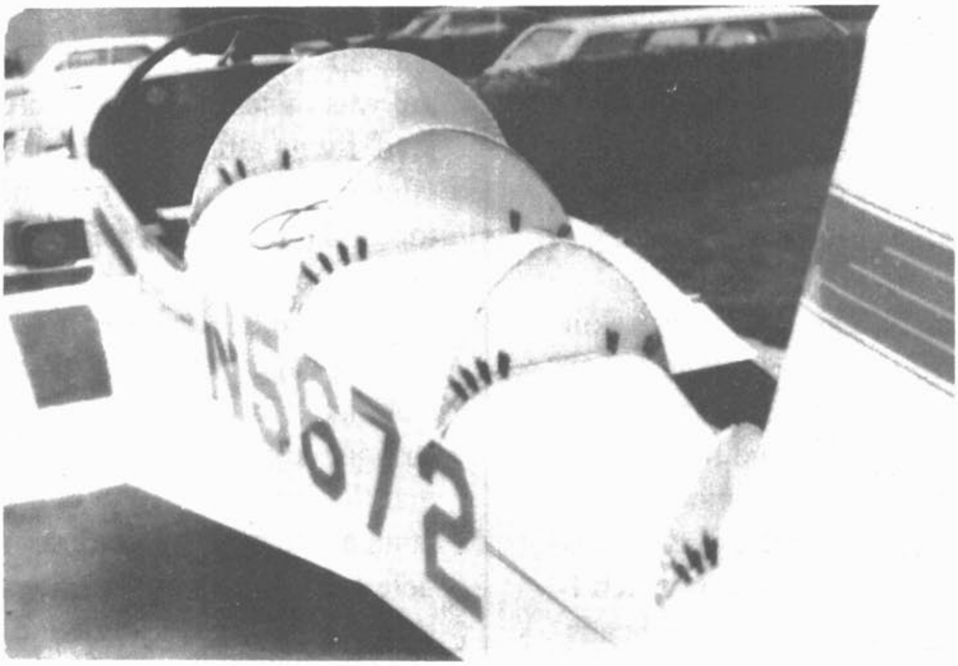
and taped in place. Then, the aircraft's tail was raised so that the aircraft was in level flying attitude. A long straight edge was placed with one end on the top of the temporary new bulkhead (at the canopy aft edge) and the other end of the straight edge was held at the leading edge of the fixed vertical stabilizer (fin). The position on the straight edge at the fin was adjusted so that the straight edge declined to the fin at an angle of 7½ degree. This determined the height of the new add on bulkhead at the leading edge of the fin (9"). This 7½ degree slope of the



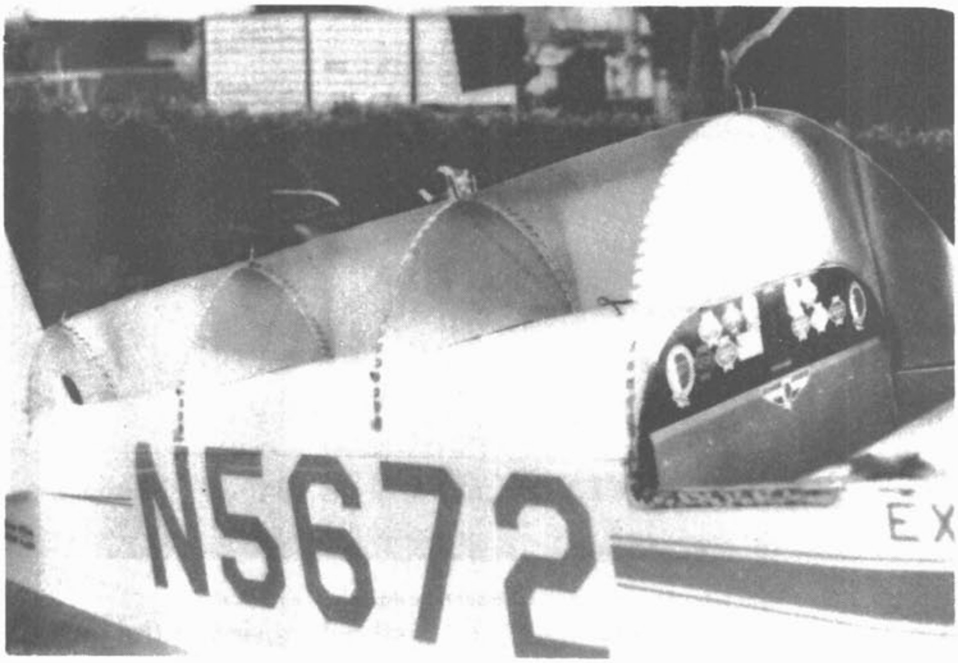
Four new add-on fuselage bulkheads were designed and fabricated.

I used flush monel pop-rivets through out the new fairing structure. In designing the new add on bulkheads, the bulkhead at the aft edge of the new canopy was defined by the aft edge of the canopy itself. A temporary form of the new bulkhead for this fuselage station was constructed from cardboard

fastback fairing is the maximum departure angle for the airflow to remain attached (laminar) to the skin. This maximum angle was determined during testing of new fighter designs during World War II. This data also holds true for airflow through internal divergent ducts. For internal ducts



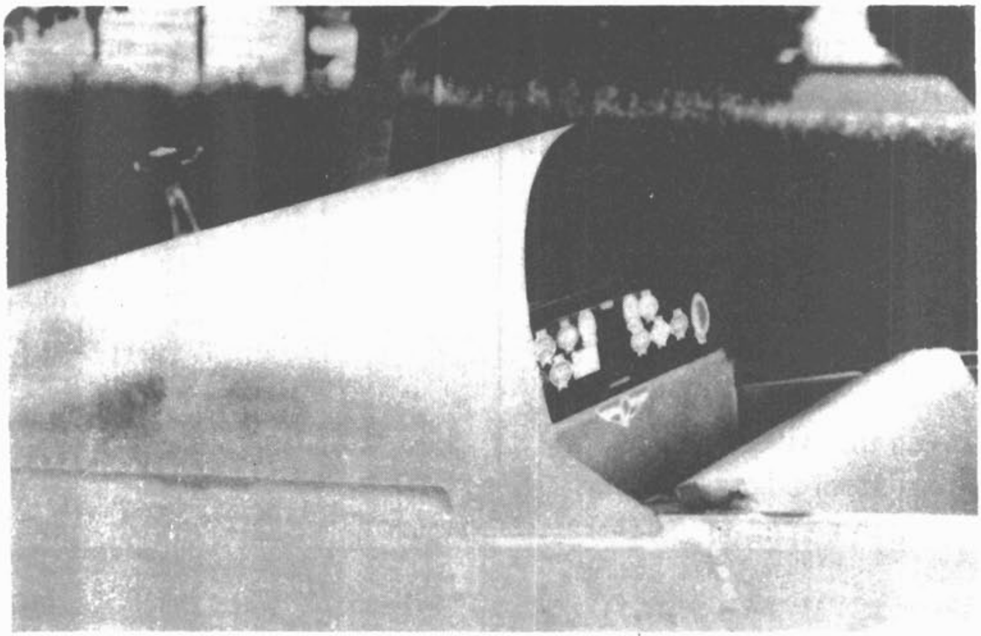
These new bulkheads were then fitted and attached right over the original bulkheads and outer fuselage skin.



The new fuselage skin was attached in two pieces.

where one side is parallel to the airflow and the opposite side is divergent, a maximum departure angle of 7½ degrees for the divergent side was observed before the airflow separated and became turbulent. For divergent ducts where two opposite sides are divergent and the other two sides are parallel, a maximum sum total divergence angle for both diverging sides of 11 degrees was observed before the airflow in the duct became turbulent. This data becomes a handy rule of thumb when designing free stream aerodynamic fairings. From Hoerner's "bible", when designing a fairing for a protrusion from an existing aerodynamic form (like a bolt head), the nose and tail parts of the fairing should each be 6 times the height of the fairing, or a total fairing length of 12 times the height, for minimum drag.

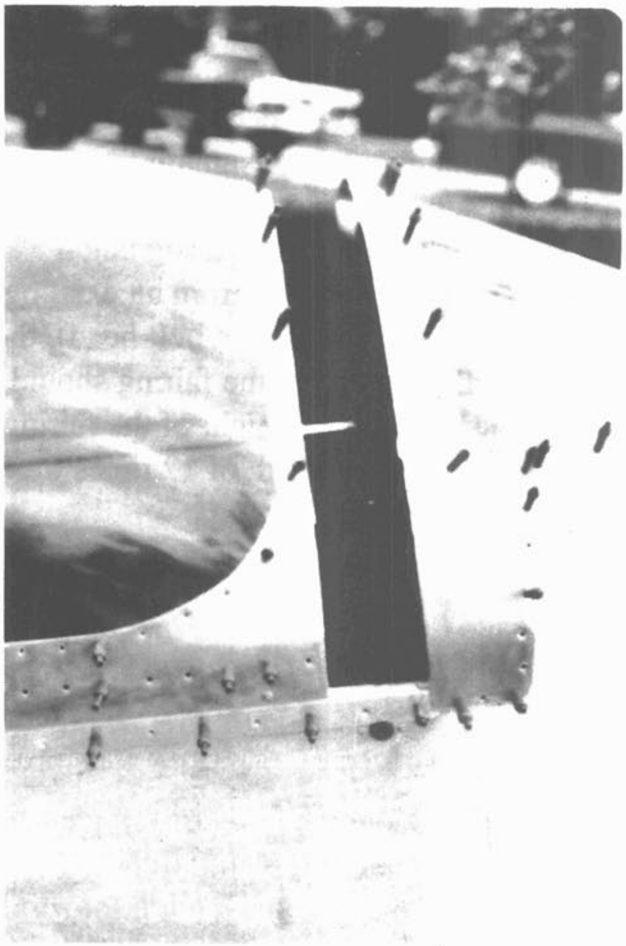
form of the two intermediate add on bulkheads was determined. Each of these add on bulkheads was mocked-up from stiff cardboard. The cardboard forms were then traced on the plywood to make wood forms over which the final aluminum bulkheads were formed. The new fairing skin was attached in two pieces to the new bulkheads with the sheet metal seam running longitudinally down the fuselage center line (for ease of construction - since the



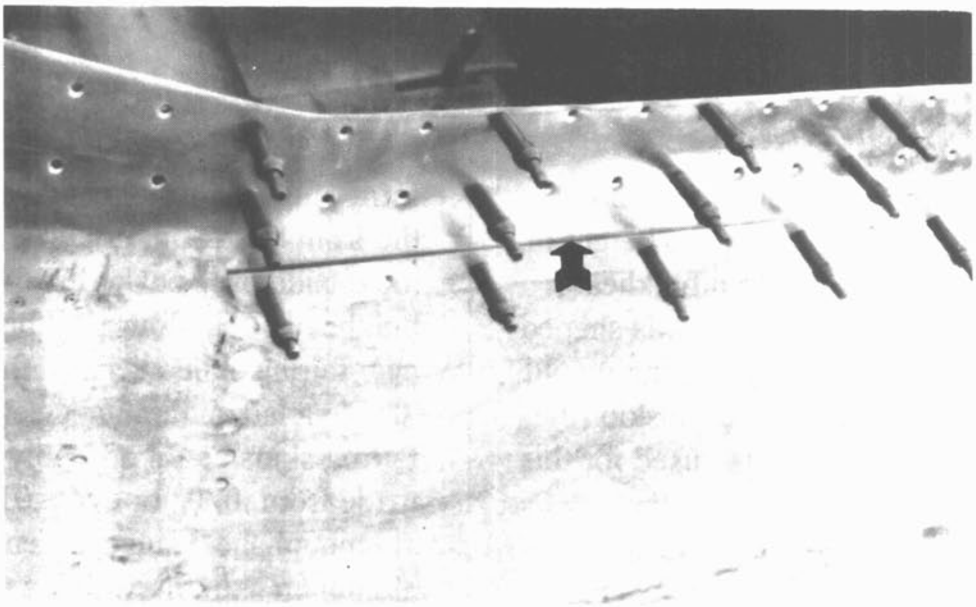
The new fastback fairing carries no structural loads, since the old structure was left in place.

Back to the development of the fastback fairing. Knowing the height of the fin leading edge add-on bulkhead, the form of the fin bulkhead was shaped so that the skin line of the fairing would blend in smoothly with the fin skin (the long straight edge was also used for this determination). Again, using the straight edge between the baggage compartment and fin bulkheads, the

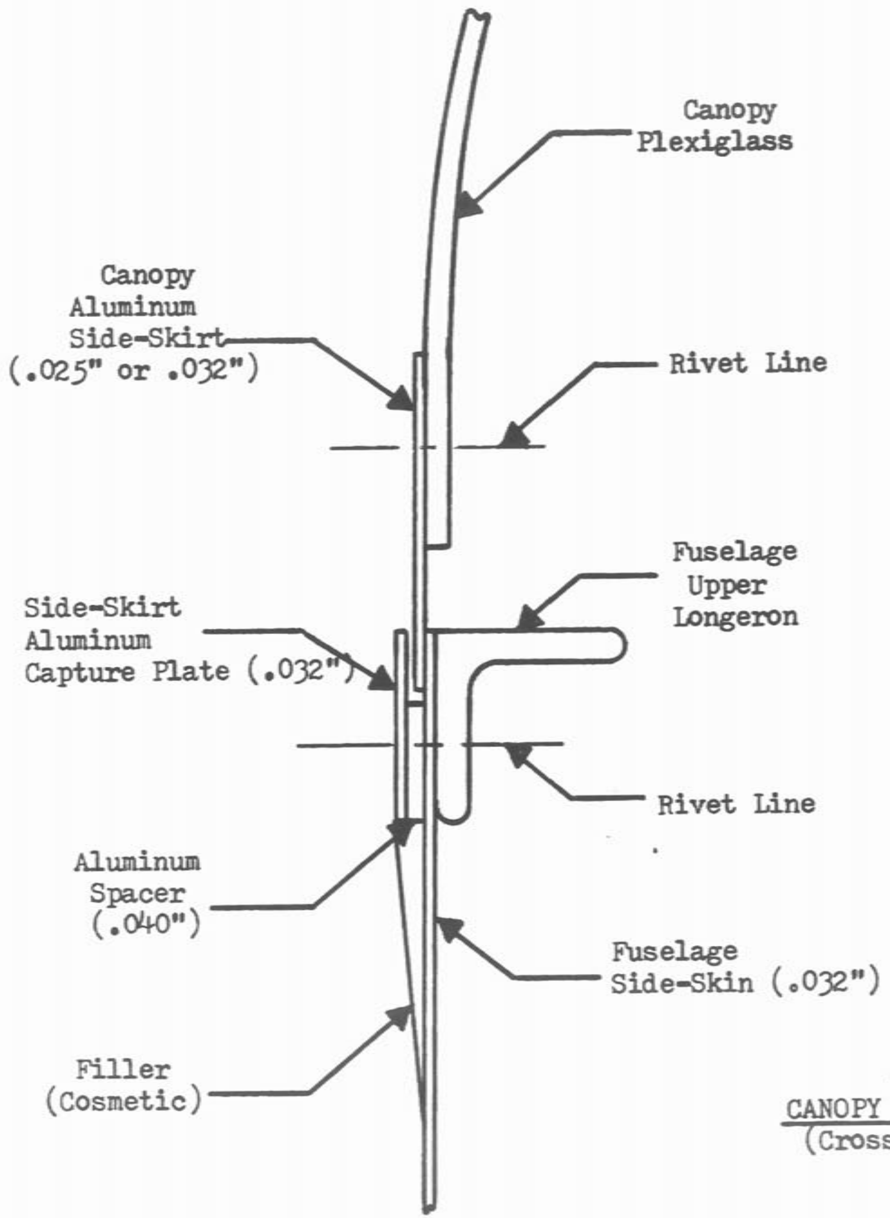
form of the new bulkheads was round at the front bulkhead, gradually changing to considerably peaked at the aft bulkhead). The four new bulkheads and new fairing skins were all formed from .025" alclad aluminum sheet. The fairing skins could probably have been made from .020" or even .016" aluminum sheet since, when curved, aluminum skin of even this thickness becomes quite rigid and stiff and is highly resistant to "oil-canning". With the fastback fairing structure in place, I could then fabricate a "skirt" all the way around the new canopy to close the gap between the canopy and the existing fuselage sides and new fairing. The skirt between canopy aft-edge and new fairing structure was made of fiberglass layed-up in place for a perfect transition fit between the curved canopy and fastback fairing. The canopy side skirts were made from .025" aluminum sheet. The side skirts are "captured" in a .040" slot on either fuselage side (see Figure 5-2). This "capture" is highly recommended, since at 200 MPH the canopy side skirts will lift away from the fuselage sides at least ¼". The higher pressure cockpit air gushing out from under the canopy skirt creates a significant amount of "air-plume" drag. The slot between the windscreen aft edge and canopy front edge is sealed



Overlapping aluminum trim on the windscreen aft edge and the canopy forward edge provides a very tight closure and significantly reduces wind noise in the cockpit.



Capturing the canopy side-skirt keeps cockpit air from blowing out from under the canopy side-skirts.



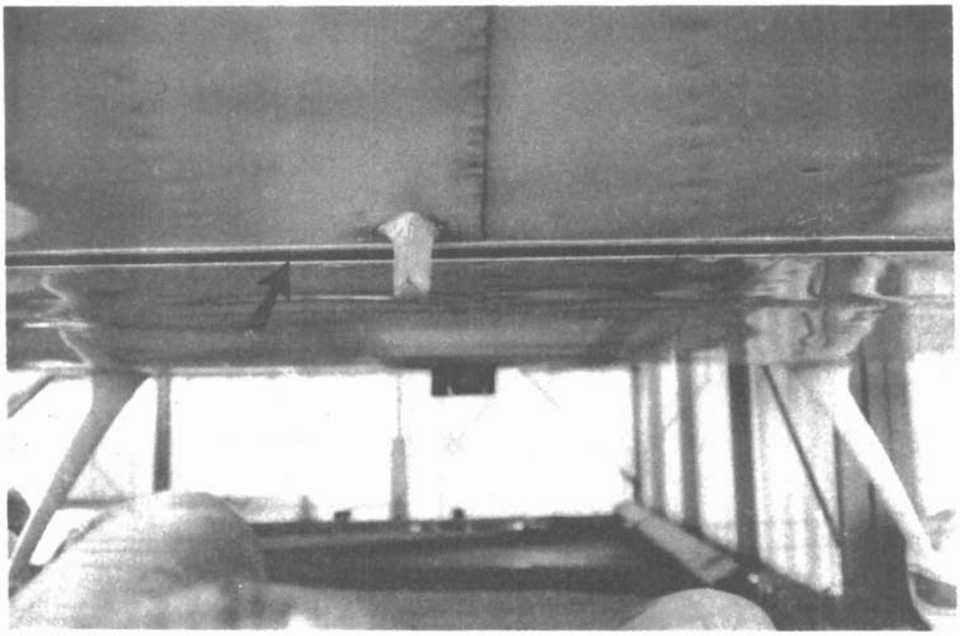
NOTE:
Some dimensions enlarged for clarity (not to scale)

FIGURE 5-2

CANOPY SIDE-SKIRT CAPTURE
(Cross-Sectional View)

with overlapping aluminum skirts. A careful forming of these two overlapping skirts will produce an almost air tight and water tight seal. The only air noise in my cockpit now comes from the cockpit air inlets on either side of the fuselage. When these vents are closed, there is no air noise in the cockpit. In the original configuration, there was as much air noise in the cockpit as there was noise from the 4-straight exhaust stacks! One time, when flying in the original canopy configuration, I felt somebody tugging on my left shirt-sleeve. The air gushing out from under the lifted canopy side skirt was strong enough to suck my shirt-sleeve through the gap! Now, there are no cockpit drafts whatsoever except in the summertime when the cockpit vents are open.

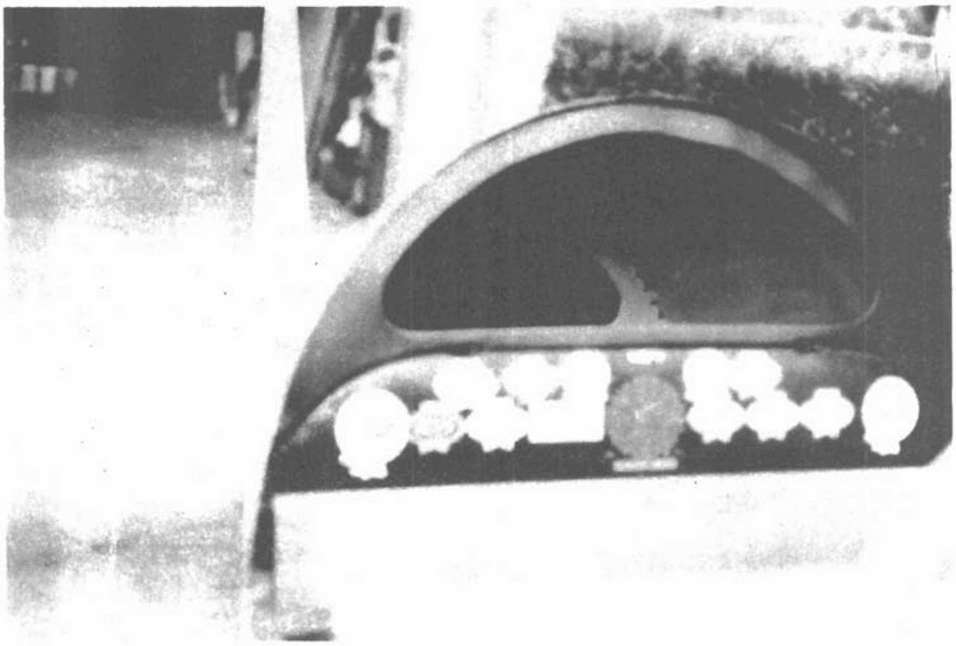
To prevent the higher pressure air from flowing out of the cockpit through the open structure around the control stick assemblies, all of that open structure is sealed with ¾" thick, closed pore, rigid foam sheets glued in place. This is also important since, if not controlled and directed, this cockpit outflow air will eventually find its way to the gaps around the aircraft's control surfaces and flaps and cause a significant amount of "air-plume" drag and decreased controls effectiveness. My cockpit air is now directed out through a ½" gap between the flap trailing edge and the fuselage bottom. This gap is actually a tunnel that directs the cockpit outflow air straight aft, thus minimizing air-plume drag from this source. When the new canopy is now slid into place, it produces a very satisfying "thunk" sound (like a tight car door), as it is captured by the skirt on the aft edge of the windscreen. Of course, the canopy can also be locked



The cockpit air outlet is a narrow opening between the flap trailing edge and the fuselage bottom.

in closed position both internally and externally. Incidentally, I did cut large lightening holes in the four new add on bulkheads. This not only lightened the add-on structure but also created an additional baggage area for relatively light, long objects like fishing rods, skis and ski poles and even a spare propellor, if going to a race site. Of course, you must be careful not to create an out-of-range aft center-of-gravity condition. And, speaking of weight, I did weigh all of the material/items that I removed from the aircraft (like the very thick and heavy plexiglass from the old canopy tail piece

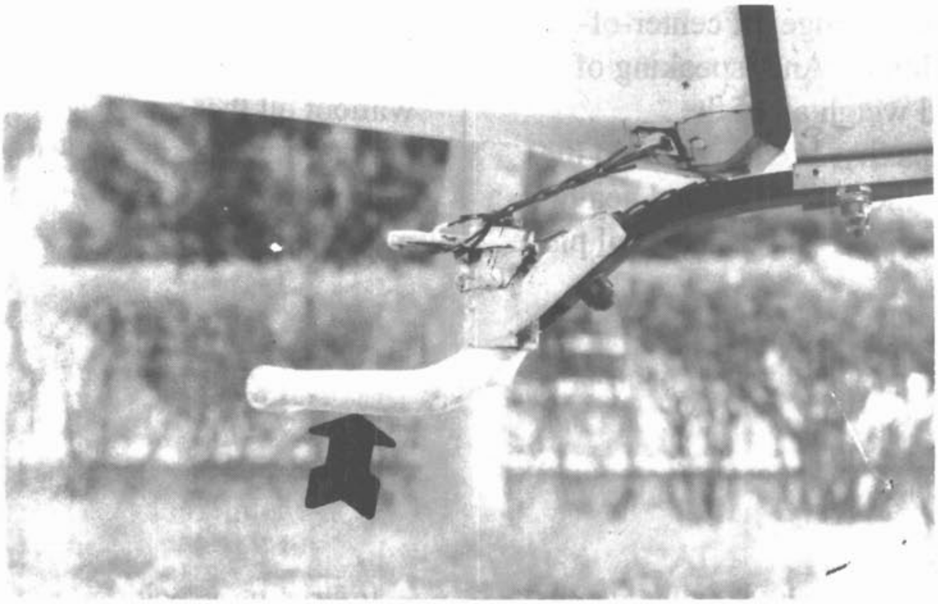
pounds from the aircraft empty weight! Now, for the most significant performance improvement. When I conducted the test flight after the fastback conversion, the top speed had increased by 12 MPH! The cockpit was much quieter. I didn't have a draft on the back of my head and neck and other drafty air currents blowing around the cockpit, picking up loose papers, dust and other light items. It's warmer in the cockpit during wintertime flying, without all that drafty air blowing around the cockpit. All-in-all, a very satisfactory and satisfying aircraft modification!



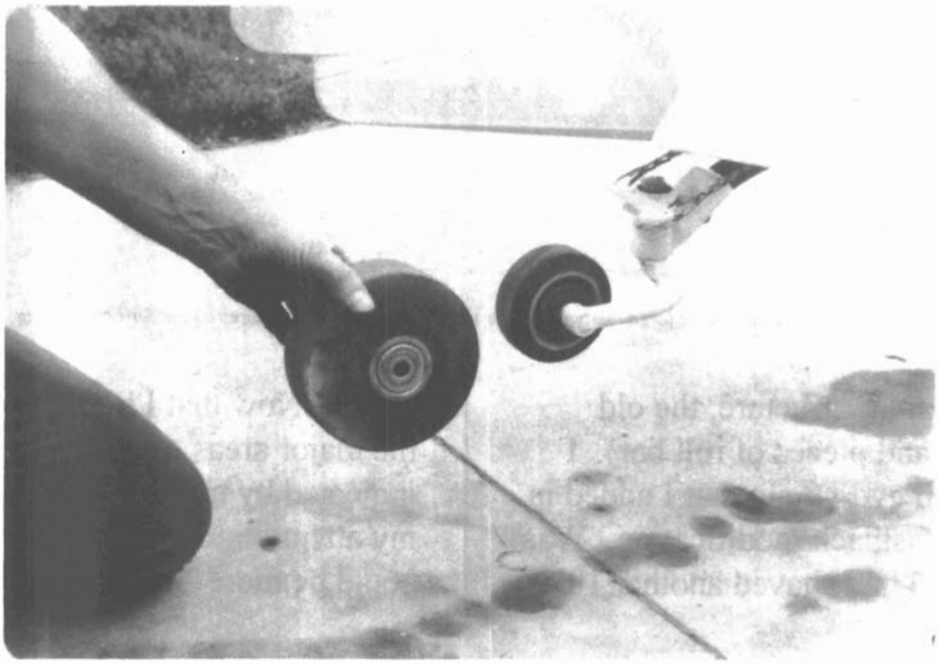
The add-on bulkheads have large lightening holes which creates more baggage volume for light or long items.

and steel support structure, the old windscreen and pieces of roll bar). I also weighed everything that I added in making the fastback modification. Was I surprised! I had shaved another 10½

Now that I had corrected all of the major areas of turbulent airflow (as indicated by my tuft testing), I turned my attention to the smaller items that could be more streamlined. The tail wheel assembly stuck out like a sore thumb. The tail wheel assembly was originally a standard Maule 6" diameter super-soft wheel and fork unit. The Maule unit was mounted on a 2 leaf spring assembly. My first step to reduce the drag of this area was to bend the tail wheel arm (or fork) so that it trailed directly aft of the unit pivot point. Heating the arm to a cherry red allowed me to bend the arm without rupturing the material. I used a carbon arc torch to do the heating. Then I substituted a 4" diameter wheel for the 6" diameter super soft Maule wheel and tire. The 4" diameter tailwheel was obtained from Bob Bushby (the designer of the Mustang-II).

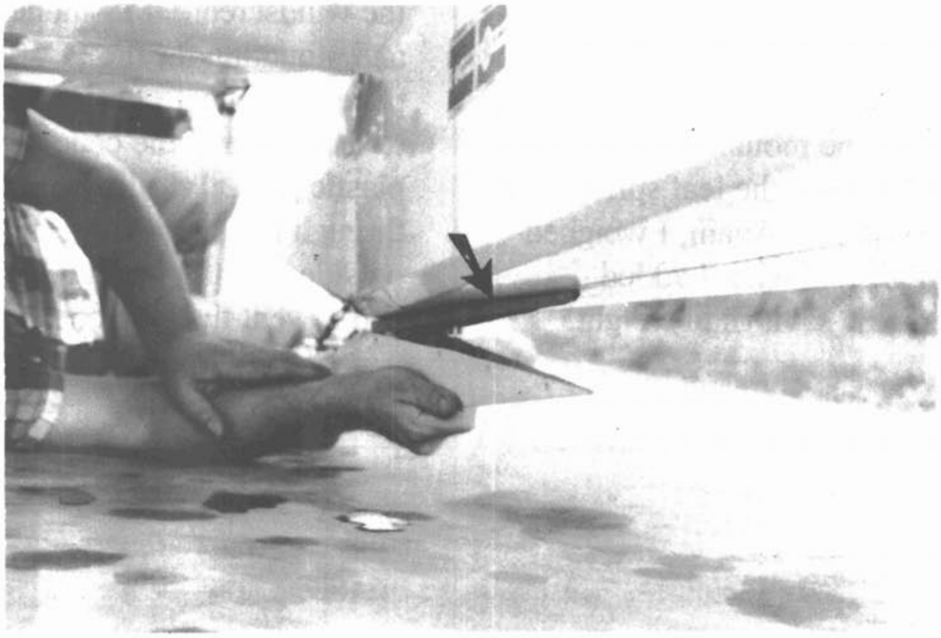


The tailwheel fork was bent to trail directly aft.

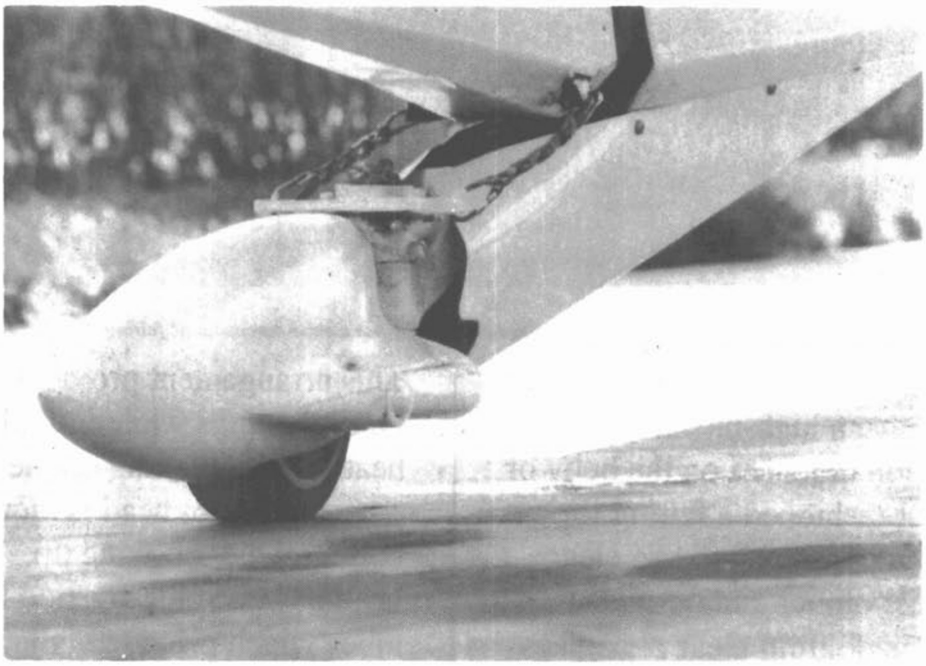


The 4 inch tailwheel is also much lighter than the 6 inch maule tailwheel.

Then, I fabricated a small wheel pant for the tailwheel. I fashioned the form for the wheel pant from a rigid foam block. Four layers of 10 oz. glass cloth were layed-up over the foam form. Between the second and third layers of glass cloth, I inserted aluminum plates to strengthen the load points through the pant. I also inserted a .060" aluminum mounting tab in the front of the pant. I drilled and tapped a hole in the bottom of the pivot portion of the arm to provide an attachment for the pant forward mounting tab. This still left the



Tailwheel spring fairing attaches to a plate sandwiched between the spring and the fuselage structure.

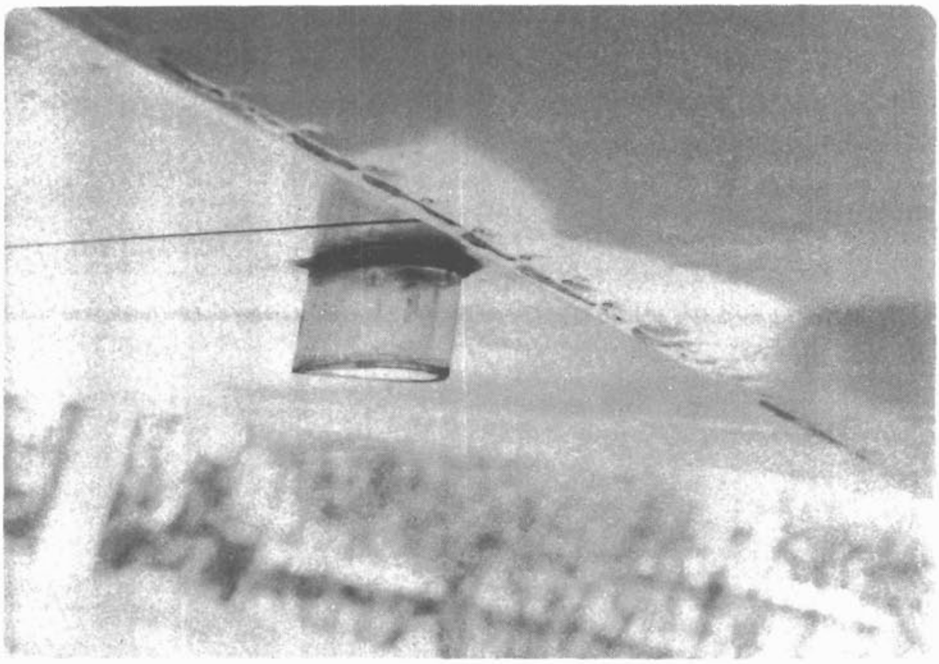


A very clean tailwheel installation.

leaf spring and tailwheel mounting bracket hanging out in the breeze. So, I fashioned a fairing from sheet aluminum to aerodynamically cover the leaf spring, it's attachment brackets and hardware, and the tail wheel mounting and its attachment hardware. The fairing is a simple bend up of the aluminum sheet and is attached to a mounting plate with pan-head, sheet metal screws. The mounting plate is sandwiched between the leaf spring and the fuselage bottom. Again, I weighed what I removed and what I added - another 2 pounds savings in weight!

and attached to the beacon dome with clear silicon rubber sealant. The clear celluloid was wrapped around the two end plates and attached with clear silicon rubber sealant.

I had an outside air temperature (OAT) probe sticking out forward from the windscreen. I fashioned a housing and mounting for the OAT probe from plexiglass sheet. I attached this housing to the inside of the canopy with clear plastic glue. I drilled angled holes through the plexiglass canopy to admit outside air into the OAT probe housing and to vent the air from the housing.

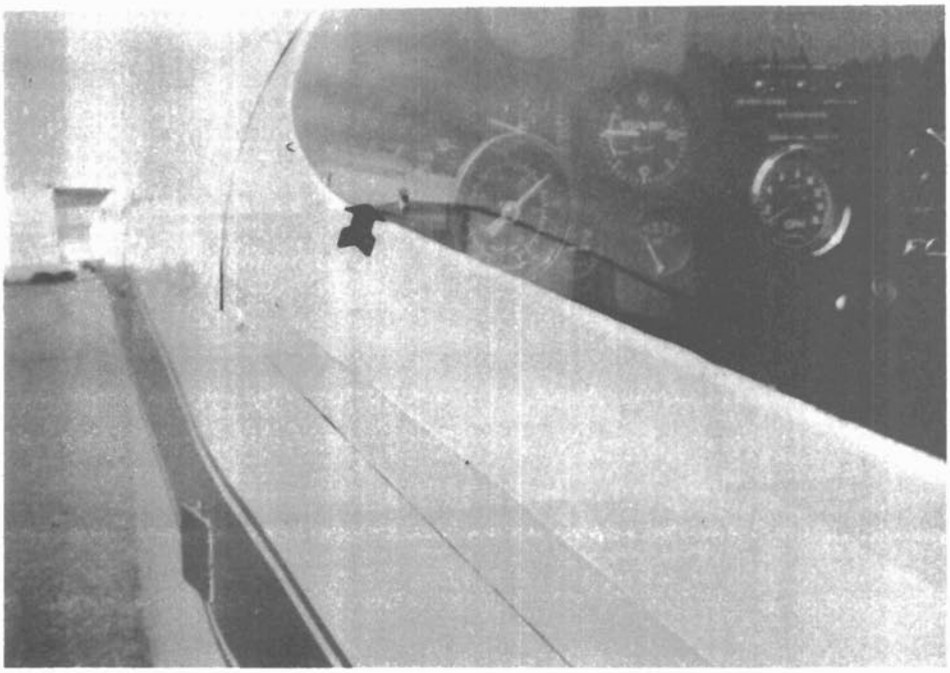


The flashing beacon on the fuselage bottom also has a clear aerodynamic fairing.

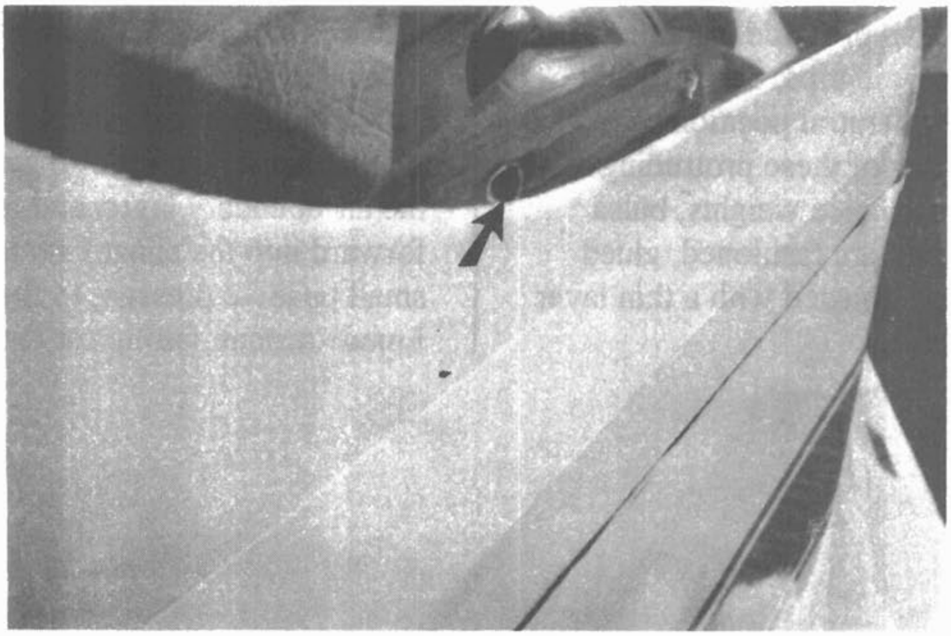
Several other protuberances were faired in. I have a high-intensity flashing beacon mounted on the belly of the aircraft. I fashioned a fairing for this beacon from plexiglass and clear celluloid sheet. Inner and outer end plates were made from clear plexiglass

This arrangement provides accurate OAT readings while in flight, but does heat up when sitting on the ground.

My pitot head is mounted on a boom on the left wing tip. The pitot head has two side-by-side ¼" diameter tubes which provide both ram and static

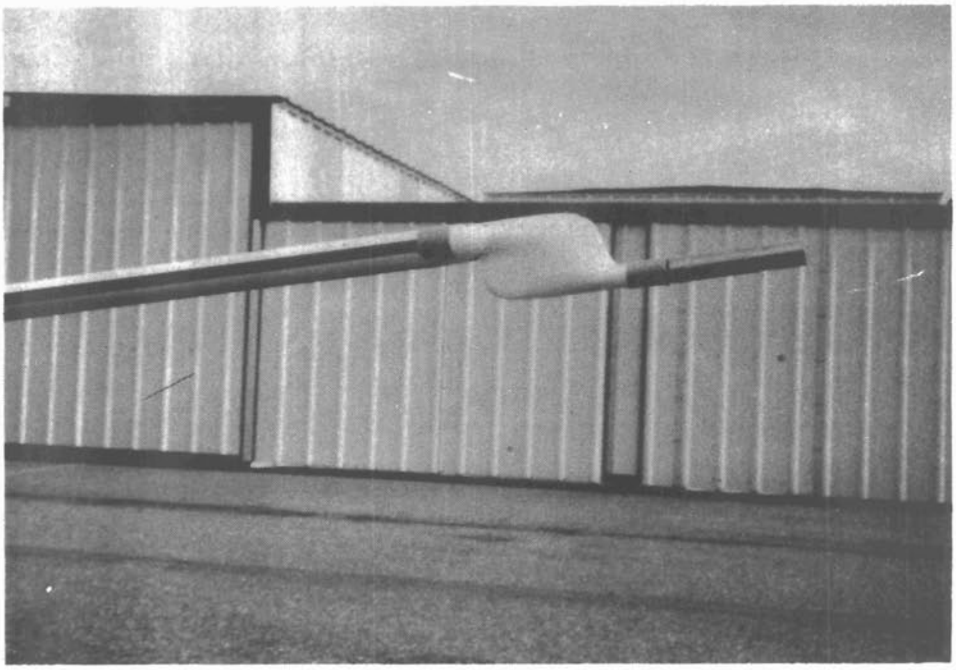


The outside air temperature probe is mounted in a housing on the inside of the canopy.



Two holes, drilled at an angle in the canopy plexiglass, allow outside air to flow through the OAT probe housing.

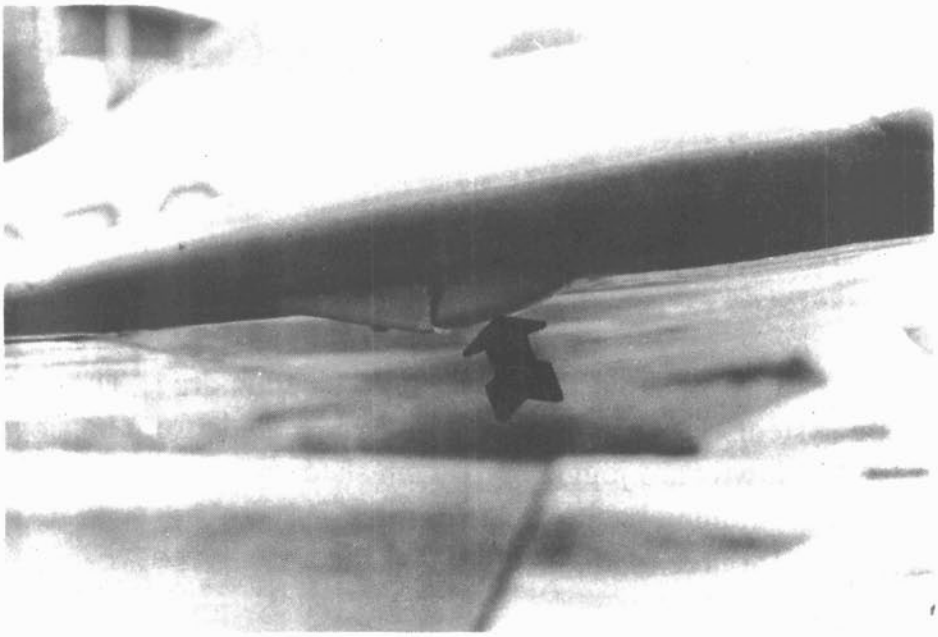
pressure to the cockpit instruments and is a very accurate system. However, the two tubes have a downward joggle to prevent water from draining back into the tubes - a small source of aerodynamic drag. The fairing for this joggle is made from balsa wood and finished with a thin layer of polyester filler.



The pitot tube head joggle is faired-in with a balsa wood fairing over the two side-by-side ¼" tubes.

My aircraft's aileron mass balance weights protrude from the bottom of the wingtips, even when the ailerons are at neutral position. To reduce the drag of these protruding aileron mass balance weights, balsa wood fairings were fashioned, glued into place and finished with a thin layer of polyester filler.

The aircraft's main fuel tank vent is a ¼" diameter aluminum tube which protrudes from the fuselage at the forward edge of the windscreen. The tube sticks up about 2" to get it above the air boundary layer, and is then bent forward into the slipstream to provide a small positive pressure to the fuel tank. I made a small fairing for the vertical

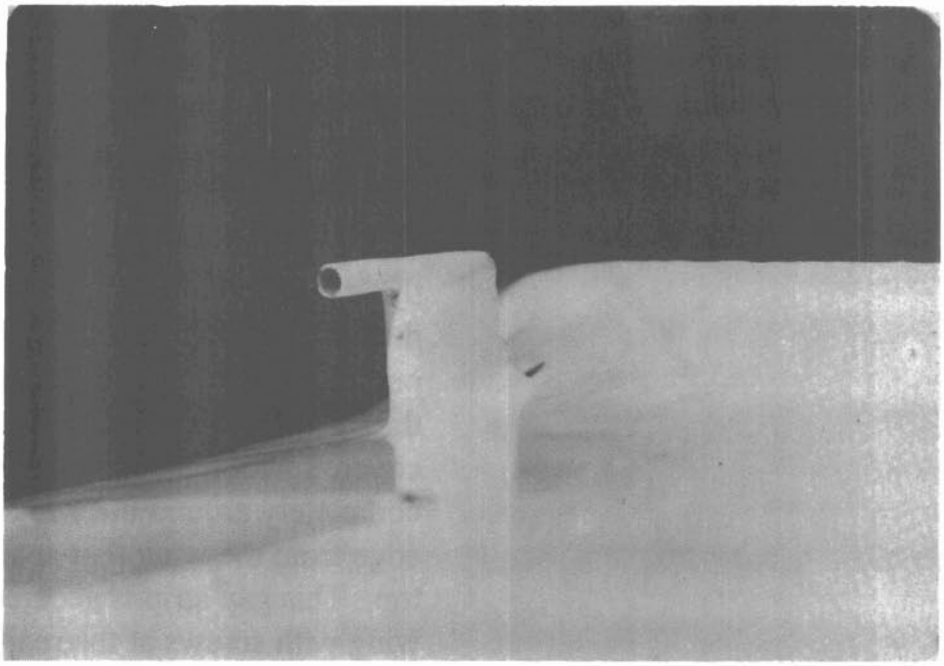


The protruding aileron mass balance weight, at the wingtip lower surface has a balsa wood fairing.

portion of the vent tube. Again, the fairing is made from balsa wood, glued in place and finished with a thin layer of polyester filler.

For reasons of structural strength, my aircraft has a double row of protruding head rivets on the bottom of the wing center section. I faired in these rivet rows with a layer of polyester filler which extends for the entire width of the wing center section.

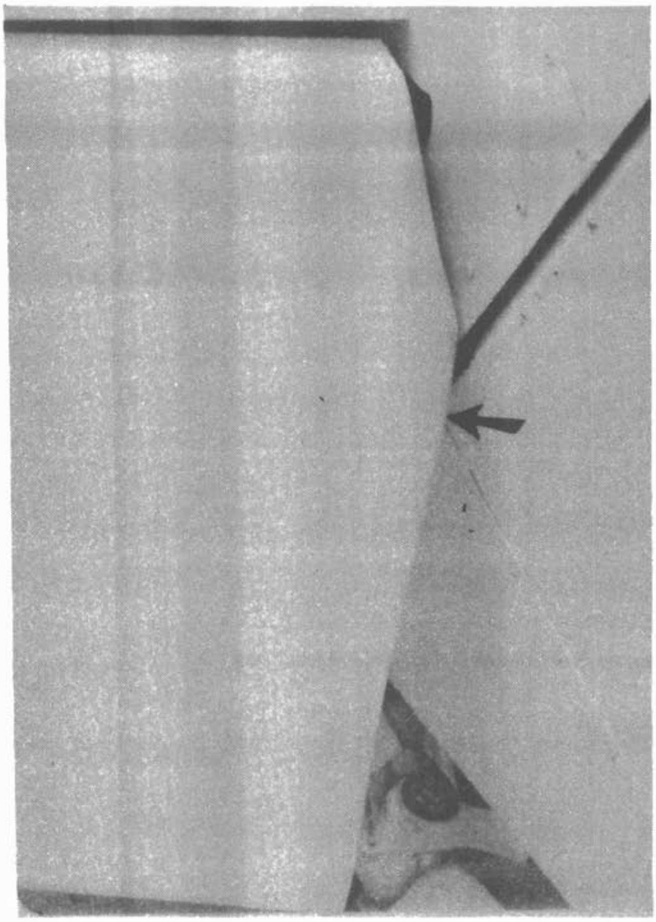
The root end of each elevator half



The ¼" tube fuel tank vent doesn't produce much drag, but produces even less when faired-in with balsa wood.

The row of protruding-head rivets on the bottom of the wing center section can't be seen because they are also faired-in.

had structure (root rib and skin attachment rivets) that were exposed to the slipstream. I made rigid foam fairings for these exposed elevator roots. These being somewhat larger foam fairings, I did cover the foam with one layer of 10 oz. glass cloth.

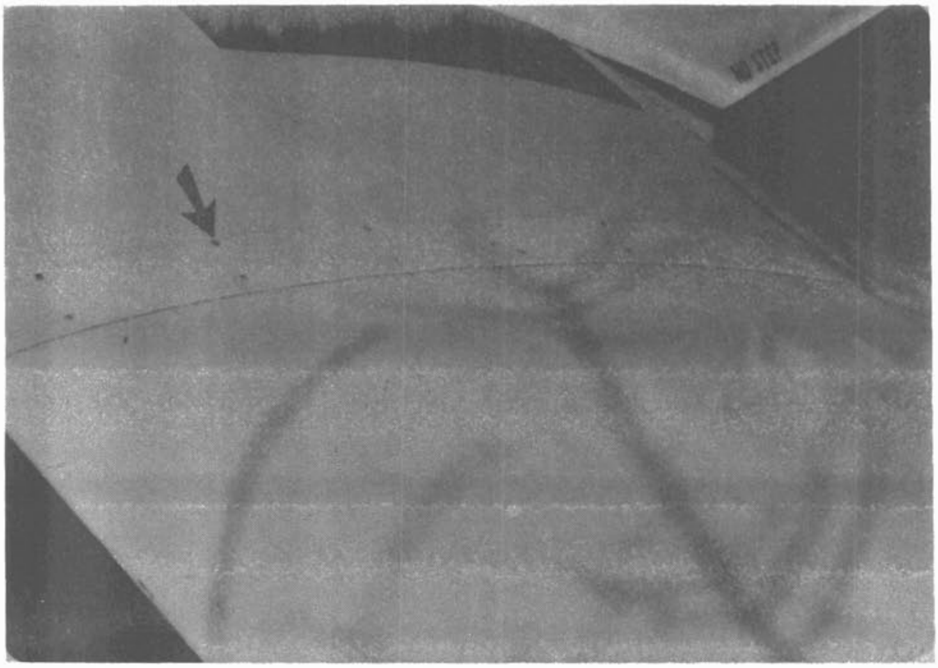


The elevator ends next to the rudder are filled with foam and covered with fiberglass.

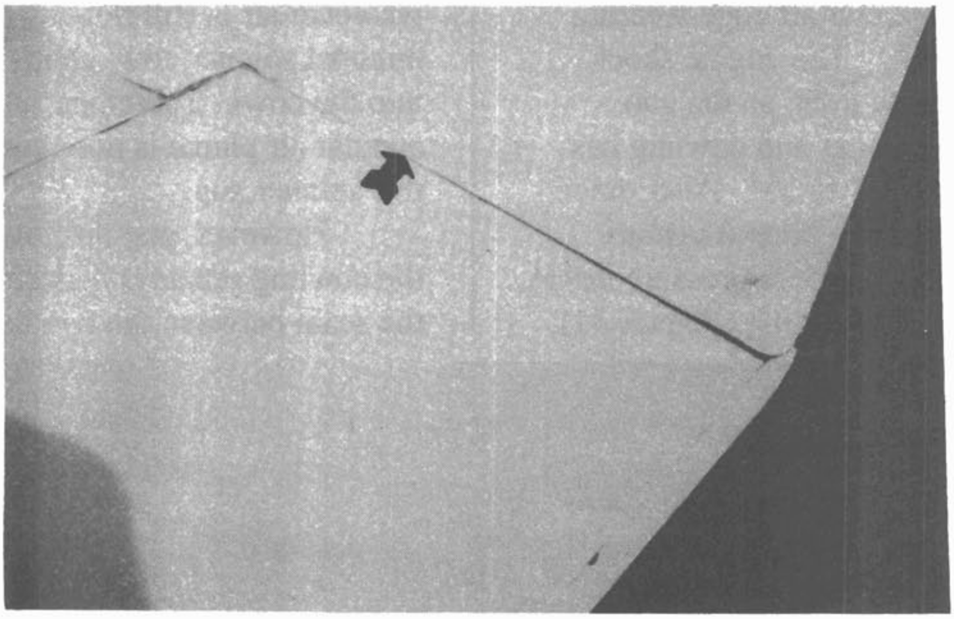
The propellor spinner cut outs for the propellor blades provide ⅛" to 3/16" clearance (gaps) around the blades. Also, this juncture of the propellor blades with the spinner is approximately a 90 degree angle of adjoining surfaces. To prevent air from flowing through these gaps and reduce interference drag at these 90 degree surface junctures, a ⅜" radius fillet of silicone rubber sealant is provided at these gaps/surface junctures. The radius in the silicone rubber is easily formed with a finger tip if the fingertip is first dipped into liquid dish washing detergent.

The Mustang-II wing is constructed in three sections. A fixed center section and removable outer wing panels. There is an approximate 1½" gap between the wing panels at these dihedral gaps to provide access to the attachment bolts, the aileron push-pull tubes, the instrument air lines and the tip light wires. These gaps are covered with aluminum strips that wrap completely around the wing leading edge from the wing rear spar, bottom to top. This gap strip is secured to the wing with screws at the rear spar, top and bottom. In flight, I have seen this gap strip lift off the upper wing surface by as much as ¼" to ⅜". There is air-flowing out from under these gap strips, creating air plume drag and decreasing the wing's lifting capability. To solve this problem, I secured both edges of the gap strip with flush head sheet metal screws at 6" intervals on the top of the wing and 12" intervals on the bottom of the wing. The edges of the gap strips are then sealed with 3M 471 tape.

There was also a movement clearance gap between the ends of the wing flap (which is mounted on the wing center section) and the wing outer panels. Air will flow through this gap



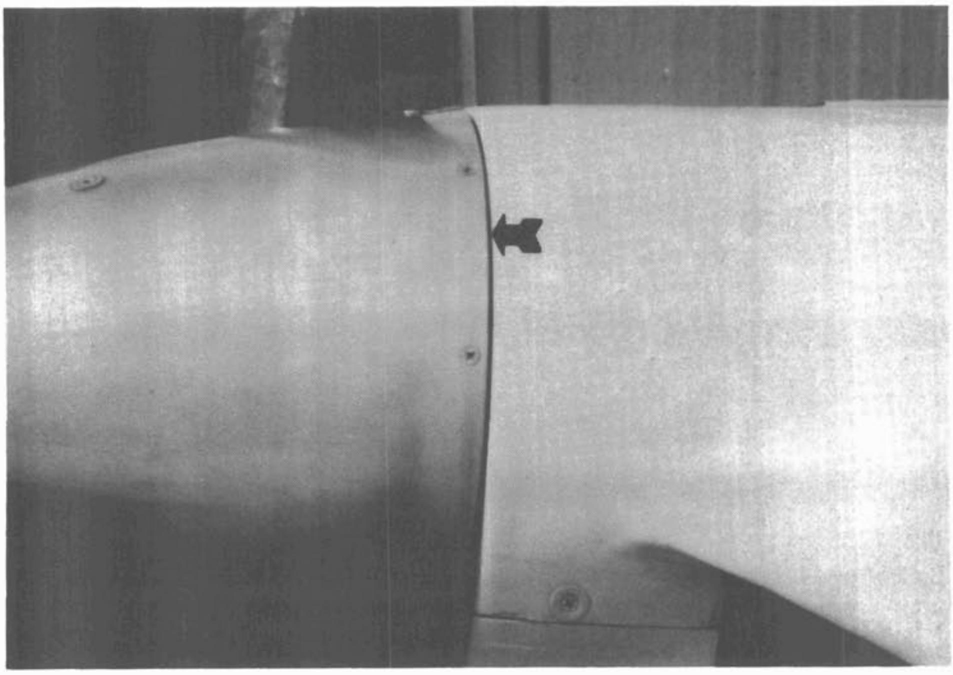
The wing dihedral gap covers are secured with flush-head sheet metal screws at 6" intervals.



The gap between the ends of the flap and outboard wing panels is covered on the upper surface.

from the high air pressure region on the bottom of the wing to the low air pressure region on the top of the wing. Since the wing flap only swings down, a fixed cover was installed on the top of each wing to prevent adverse airflow through these gaps. The covers are riveted to the outer wing panels.

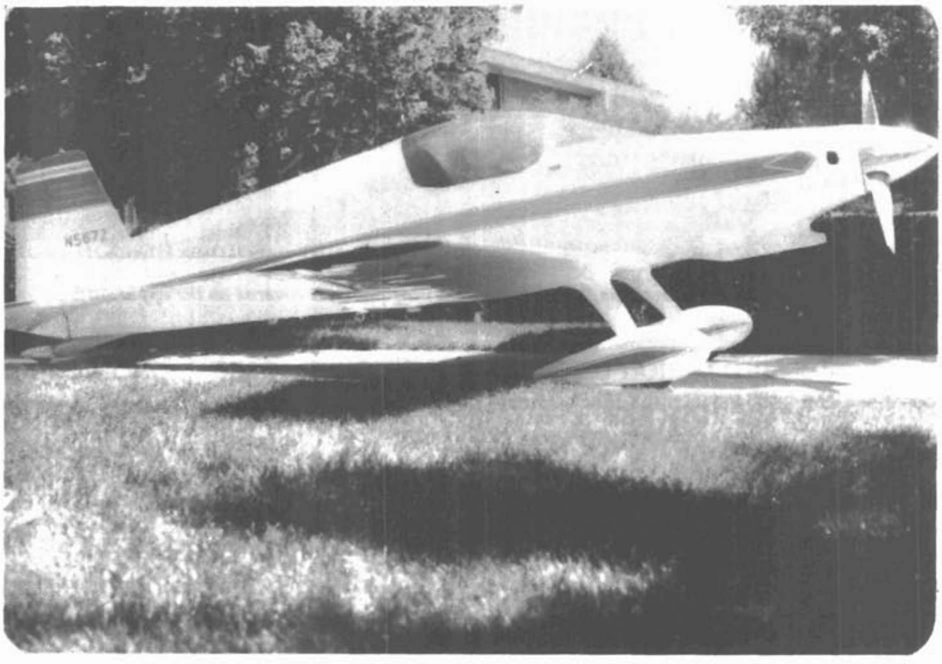
The propellor spinner to cowling clearance is held to a minimum. Actually I set up this interface to be a slight interference fit and let the gap



Minimal gap between the propellor spinner and the engine cowling.

form by the spinner aft edge wearing into the cowling. The engine shock mounts are quite tight, so the gap between the spinner and cowling has stabilized at 1/16" to ⅛". Also, since the exhaust cooling air exit venturi pump creates a negative pressure inside the cowling (see Cooling Chapter #4), whatever air is still flowing through the minimal spinner/cowl gap is flowing into the cowl. Therefore, an external annular air plume is not being created at this spinner gap.

However, any air flowing through the cowling seams is undesirable. So, the seam between the two cowling



Filled sheet metal seams and rivet heads make a smooth exterior surface.

halves, the seam where the cowl attaches at the firewall and the two cowling access doors are all sealed with 3M 471 plastic tape. Before each race, I would also seal each control surface gap/hinge line with 1½" wide 3M 471 plastic tape. To finish off my aerodynamic drag clean up efforts, I filled all of the external flush head rivets and sheet metal seams with polyester body filler. It never fails to make me chuckle when people ask what the aircraft is constructed of , wood or fiberglass, since they say they can't see any rivets or seams! Flight testing after installation of all these small fairings and fillets, adverse airflow correction and surface friction drag reduction resulted in another 6 to 7 MPH increase in top speed. This may seem like a small incremental speed increase for a lot of attention to small items, but once the racing competition bug bites you, you will work long and hard to increase your speed only 1 MPH! Incidentally, the difference in speed of my Mustang-II between a dirty exterior surface and a cleaned and polished surface is a good 5 MPH. I use "Star-Brite" aircraft polish. It does an excellent job and is the easiest to apply of all the silicone polishes that I have tried.

RASER

CHAPTER 6

PROPELLOR EXPERIMENTATION AND DEVELOPMENT

My work with aircraft propellors has probably been the most exciting and challenging of all my modification efforts, but also the most frustrating and dangerous.

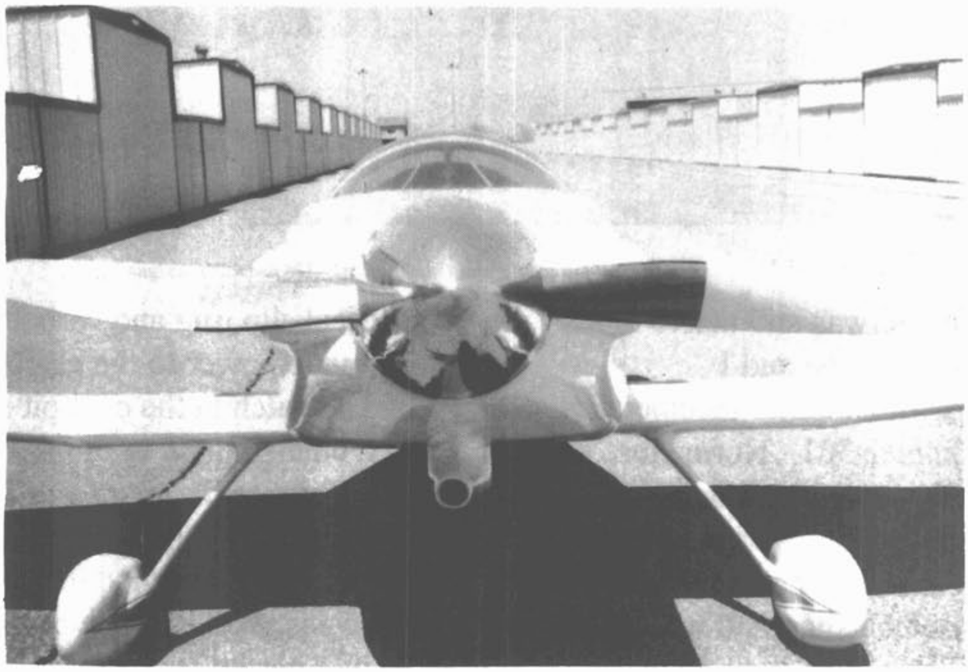
The first propellor which I installed on my Mustang-II was an "Aeromatic". The Aeromatic propellor has laminated wood blades, each lamination being about 1/16" thick. The blades are plastic coated and the leading edges are armored. The blades are held in a metal hub and are free to rotate in the hub between the high and low pitch stops. The model that I used was 73 inches in diameter and weighed 32 pounds. This self-adjusting feature is accomplished by balancing off centrifugal force against aerodynamic pressure on the blades. The centrifugal force is generated by weights attached to the ends of counterweight arms on each blade shank. The balancing of forces is accomplished by adding or removing weights from the counterweight arms. Aerodynamic pressure on the blades is trying to force the propellor into low pitch while centrifugal force is trying to force the propellor into high pitch. So, if you wanted less RPM, you would add weights to the counterweight arms. In operation, you would adjust the weights so that at full throttle for take off and climb, the engine would turn at 2700 RPM. Once you had reached cruise altitude and pulled the throttle back for cruise operation, the Aeromatic would automatically increase it's pitch and reduce engine RPM. When landing, at reduced forward speed and minimal engine power, the

The aeromatic propellor performed well when the aircraft was in the original configuration.

Aeromatic would reset itself to a lower pitch setting, thus, allowing maximum engine RPM/power to be available if a go-around became necessary. Adjusting the weights could be tricky; and, in actual operating conditions in Denver (6,000 ft. airport elevation), some compromise between engine RPM for take off and climb and cruise RPM was necessary. Also, if you visited an airport that was more than 1,000 feet higher or lower in elevation than your home airport, additional weights adjustment would be necessary for proper RPM control for the next flight. In normal operations, since my propellor spinner had to be removed to adjust the counterweights (not an easy task), I would seldom adjust the weights. Instead, I would control engine RPM with slight throttle adjustments and actually became quite adept at getting the Aeromatic to change pitch by using various combinations of engine power, forward speed and altitude. The Aeromatic was a satisfactory propellor for my Mustang-II when the aircraft's top speed was 180 MPH, since, in standard form, the Aeromatic's blades would be against the high pitch stops at 180 MPH. But, for each 10 MPH over 180 MPH, the engine would gain 100 RPM. For example, if I took off, climbed to altitude, reset the propellor to high pitch, then nosed-over to let the forward speed build up to 210 MPH (true airspeed) the engine RPM would increase to 3,000 RPM.

As the aircraft's speed capability was steadily being improved by my performance improvement modification efforts, I had to do something with the Aeromatic to keep from regularly over-speeding the engine beyond it's 2700 RPM redline. After much study of the Aeromatic's theory of operation, I started to experiment with the angular relationships of the blades, the hub and the counterweight arms. I made a large, adjustable protractor so that I could readjust both blades to exactly the same angle, and also for readjusting the counterweight arm angles. After many angular adjustments and test flights after each adjustment, I was able to expand the Aeromatic's pitch range to provide automatic pitch change up to 200 MPH for my Mustang-II. However, my other modifications were pushing the aircraft's top speed well beyond 200 MPH.

Fortunately, at about this point in time, Bob Bushby told me about another individual in the Denver area, by the name of Bill Cassidy, who was interested in developing propellors for experimental aircraft. Bill and I met, and very quickly realized that our goals were complementary and we started to work together to develop a suitable wood propellor for my speedy Mustang-II. The technical library at my place of employment (Martin Marietta Corporation) provided numerous old NACA reports on propellor theory, research and development. Bill and I duplicated many of those early NACA propellor development efforts. We tried various airfoil shapes (Clark-Y, RAF-6, Symmetrical, Undercamber - the RAF-6 was best), various blade planforms, various tip shapes (round, square, turned-down - I almost didn't get off the ground with the turned-down tip propellor model), various airfoil thicknesses (the thicker airfoil was best for take off and maximum climb rate, but the thinner airfoil was best for maximum speed). We incorporated experimental aircraft besides the Mustang-II. For my Mustang-II, we settled on a propellor with a diameter of 68 inches and a true pitch of 82 inches, weighing 12½ pounds. With this propellor, my static RPM is only 2,000. However, at top speed, at sea level, I can turn this propellor to 3,300 RPM. I consider this propellor to be a high-cruise propellor for my high-performance Mustang-II, since the airplane will cruise at 200 MPH and the engine is turning at only 2450 RPM.



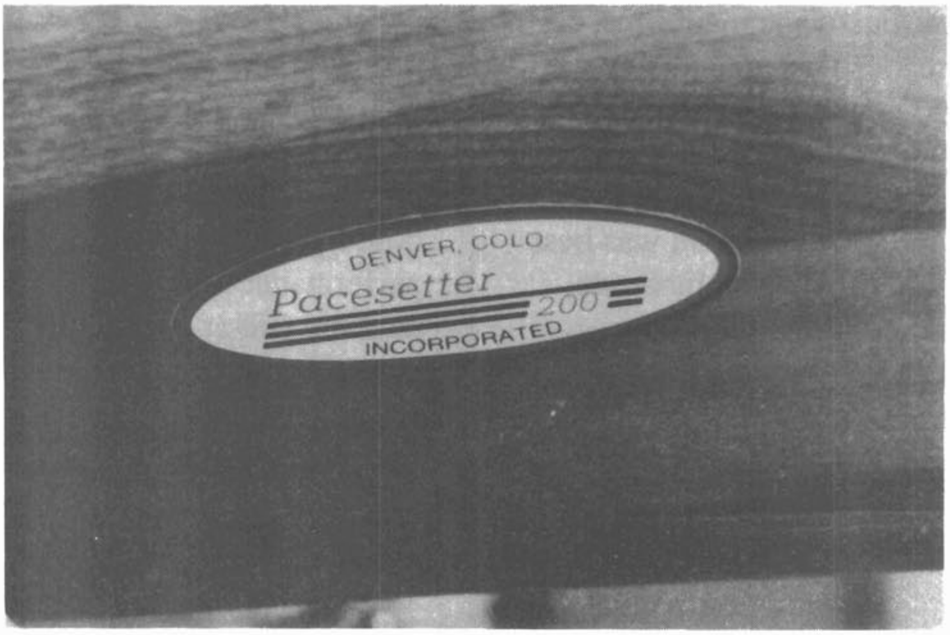
Bill Cassidy's propellors give excellent performance on high-speed aircraft.

those ideas that worked best for our purposes and, of course, discarded those ideas that did not. We tested all of those truly experimental propellors on my Mustang-II. Eventually, we were able to develop an entire line of wood, fixed-pitch propellors that were suitable for a large range of speed applications and for many other

Bill Cassidy eventually began supplying propellors for experimental aircraft all over the world. Bill's "Pacesetter-200" propellors became world famous for their performance, quality, reliability and ruggedness. Bill ran his propellor business successfully for many years before illness forced him to sell the business. However, his "Pacesetter-

200" propellor designs are still being marketed under the same trade name and are still very popular.

electric motor and gear train which was mounted on the front of the hub. We fitted my engine's flywheel with an

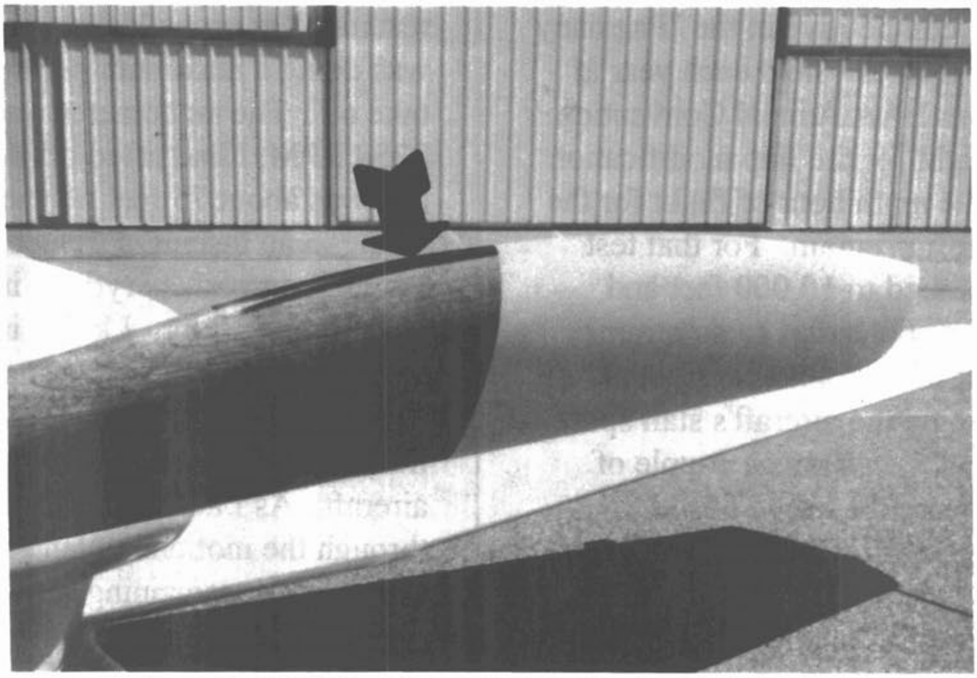


Bill Cassidy built a successful business around his Pacesetter-200 propellor designs.

While Bill was still active in his propellor business, he and I collaborated with another member of our EAA Chapter-301. Norm Herz was a mechanical engineer and had some ideas for developing a variable pitch propellor. Norm had access to a well equipped machine shop and was an excellent machinist. Bill and I contributed our ideas to the basic design, but the major design work was done by Norm. Bill made the laminated wood blades. Norm made the hub and all the operating mechanisms; and, I did the flight testing on/with my Mustang-II. The prototype propellor weighed a total of 18½ pounds, while each blade weighed only 3½ pounds. The pitch-changing mechanism was driven by an electrical slip ring and carbon brushes to provide power to the electric motor. I had a switch in the cockpit so that I could change pitch in flight.

Prior to the first test flight, I did a "failure mode and effects analysis" (FMEA). I determined that the only truly catastrophic failure mode was the loss of a partial or complete blade in flight. Since each blade only weighed 3½ pounds, my analysis indicated that if a complete blade did depart, insufficient force would be generated to completely rip the engine from the airframe. However, for safety purposes, I did install a safety cable to keep the engine with the airframe, in the event of a total failure of the engine mount. The first test flight was uneventful and the propellor worked very well and so I proceeded to expand the test program to "wring-out" the propellor. Over the course of the test program, I flew 14 test flights and over 9 flight hours. The aircraft's performance with this propellor was outstanding. A very short ground run for take off, better than 2500 FPM rate-of-climb and I could reduce the RPM during a 200 MPH cruise and realize a lower fuel consumption rate. The propellor itself continued to work very well during the test program. The only problems were with the slip-ring brushes. They wore out very rapidly. But a change of brush material solved that problem. While I was running the propellor test program, I was still making other performance improvement modifications to the airplane. One of those modifications at that time was to modify the wing flap mechanism to provide an additional notch of flaps. The intent was to make the airplane even more competitive in the "Pazmany Efficiency Contest" held each year at the Oshkosh EAA Annual Convention. The test flight for the flap modification was also the ninth hour of flight for the propellor test program. For that test flight, I climbed to 10,000 feet and performed a stall series to determine what effect the extra notch of flaps would have on the aircraft's stall speed. And the stall speed was a couple of MPH slower. But, when I tried to retract the flaps, I couldn't. That huge barn door flap was stuck in the full down position! Initially, I wasn't too alarmed. I had 4,000 feet of altitude and the airport was not that far away. However, that extra notch of flaps creates a tremendous amount of extra drag, and the airplane was literally falling out of the sky. I was down to 500 feet AGL and the airport was still several miles away. Now, I started getting anxious and started thinking about an off-airport landing. I had all of the throttle pushed in and was watching the cylinder head temperature and oil temperature rapidly climb to redline values and beyond. After several more anxious minutes of flight, I did make an uneventful airport landing, but the engine was very hot. I fixed the stuck flap problem, but gave no thought to the fact that the very hot engine was also heat-soaking the propellor hub which stayed very hot for a long time, insulated as it was by the propellor spinner. The stage was now set for disaster. The very next flight, I resumed the propellor test program. I was doing a maximum performance take off. The tachometer was indicating 2750 RPM, I had lifted off the runway and was about 75 feet off the ground when, in an instant, a tremendous vibration turned everything in the cockpit into a blur. I knew immediately what had happened. A catastrophic propellor failure had occurred and most, if not all, of one blade had departed the aircraft. As I automatically went through the motions to land straight ahead on the remaining runway (and the adrenalin was really flowing, because all of this seemed to be occurring in slow motion). I was thinking incredulously that this couldn't be happening, since I had developed a lot of confidence in the new propellor. My confidence had lulled me into a false sense of security. Actually, I had precipitated a failure that was only going to happen later anyway. It was only a matter of operating time, as many months of simulated flight testing would later prove. We tried many different designs to retain the blades in the hub, but each one, after between 40 to 50 hours of ground testing with a flight simulation tester, would fail. Each failure occurrence was the same mode. The wood around the shank of the blade would shear with the grain of the wood. The only retention design which we couldn't test was the long lag screws that the successful Aeromatic propellor uses. These lag screws were no longer available. I learned later, from the local FAA office, that other designs of wood blade variable-pitch propellors were regularly starting to throw blades in flight. And, the failure mode was always the same as what we had determined from our ground testing. So ended our efforts to further develop a wood blade variable-pitch propellor. A project that initially held much promise.

My most recent propellor effort was to send my back-up Cassidy propellor (68" diameter x 79" pitch) to Bernie Warnke to have a plastic leading edge installed. While the propellor was there, I also had Bernie thin down the blade section. This reduced the propellor weight from 12½ pounds to 11 pounds. This thinner blade section did improve the aircraft's top speed and RPM. So, I sent my 68 x 82 Cassidy propellor to Bernie for a plastic leading edge installation and asked Bernie to thin out the blade section even further than the first one that I had sent to him.



A propellor plastic leading edge prevents edge erosion when flying in the rain.

Bernie's efforts reduced that propellor's weight from 12½ pounds to 9 pounds, an additional 2 pounds more weight reduction than the first propellor. This propellor also exhibited an improved top speed and RPM. However, I had told Bernie to thin it out too far because my take off performance suffered somewhat. This is consistent with the development work which Bill Cassidy and I had done. The thinner blade sections give the best top speed performance, but not the best low speed performance. My friend, Dean Cochran, using a Pacesetter-200 propellor on his T-18, had the blade section thinned and lost considerable take off performance. My theory on this phenomenon is that, at low forward speed, a high-pitched propellor blade is almost totally stalled-out. However, a thicker airfoil section blade will have less air flow separation than will a thinner blade section. Just like most other areas of aircraft design, propellor design is also subject to performance trade offs. You can maximize one performance parameter, but another performance parameter will probably suffer.

PASER

CHAPTER 7

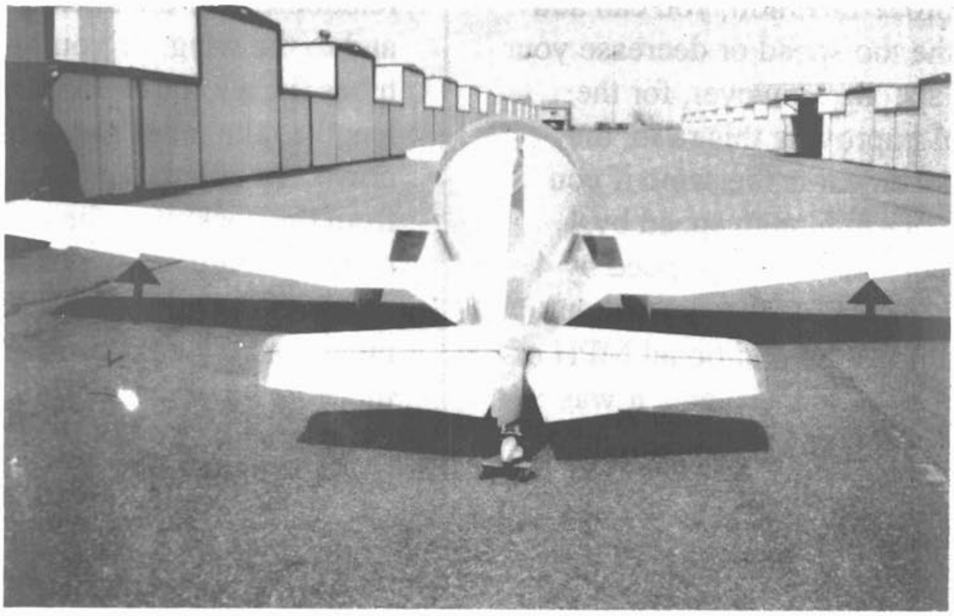
MISCELLANEOUS PERFORMANCE IMPROVEMENT MODIFICATIONS

Even very small and obscure performance improvement increments can be significant if enough increments are gathered together.

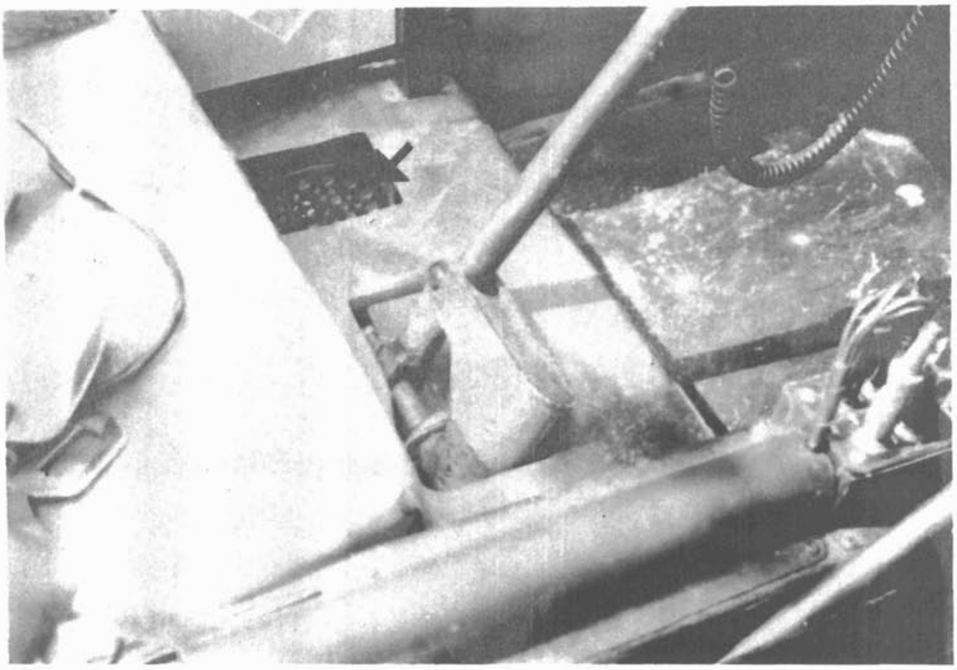
This chapter collects all of the other performance improvement modifications which can't be categorized as exhaust, intake, cooling, aerodynamic or propellor.

DROOP AILERON MODIFICATION

In the Pazmany Efficiency Contest, some of the factors that are taken into consideration are top speed, minimum speed and the ratio between top and minimum speed. For my Mustang-II that ratio is better than 4 to 1. To improve this ratio, you can add speed to the top speed or decrease your minimum speed. However, for the purpose of improving this ratio, the ratio improvement is the same if you decrease your minimum speed by 1 MPH or increase your top speed by 4 MPH. Once that I had squeezed out every fraction of an additional MPH of top speed out of the airplane, it was time to see if I could make the airplane fly slower. One of the ways to reduce stall speed is to improve the slow-speed lift characteristics of the wing; and, one of the ways to do that is to add flaps to the trailing edge of the wing. The Mustang-II already has a large wing flap across the entire wing center section. But how about the ailerons? If both of the ailerons can be made to both droop at the same time, they will act as wing lift improvement devices. On the Mustang-II the ailerons are controlled via push-pull tubes. If you change the length of the tubes from the cockpit control stick out to the aileron bellcranks, you will change the relationship of the ailerons to each other and to the wing. If you shorten the tubes the ailerons will go up. If you lengthen the tubes the ailerons will go down. In effect, the push-pull tubes from the cockpit to the aileron bellcranks are really one long tube that connects the aileron bellcranks to each other, and the control stick just swings this long tube back and forth to move the ailerons. So, if you shorten this long tube, anywhere along the tube's entire length, both ailerons will be displaced upward. Conversely, if you lengthen this long tube, both ailerons will be displaced downwards. To be able to vary this long tube's length, I inserted a thumbwheel into the tube where it passes under my left leg when I am seated in the cockpit, where I can easily reach the thumbwheel. Rotating the thumbwheel in one direction will droop both ailerons and rotated in the other direction will reflex both ailerons upward. The thumbwheel is a steel disk 4 inches in diameter. A right-hand threaded rod is welded to the center of the disk on one side, and a left-hand threaded rod is welded to the disc on the other side. I sawed a section out of the aileron push-pull tube. To the ends of the aileron tubes that remained in the cockpit, to one tube end I welded a right-hand thread nut and to the other tube end I welded a left-hand thread nut. Of course, the size and pitch of the nut threads matched those of the threaded rods welded to the thumbwheel disc. The threaded rods are then simultaneously threaded into both the right and left-hand threaded nuts. The threaded rods are long enough so that the ailerons can be run up against the up and down stops without the threaded rods dropping out of their respective nuts. Of course, in flight, I don't run both ailerons against the stops simultaneously, since some amount of aileron differential action must be maintained for aircraft lateral control. The test flight for this modification showed a stall speed reduction of 2 MPH. This aileron adjustment feature is also useful for providing a small amount of lateral aircraft trim, like the lateral weight difference between flying solo or carrying a passenger. Or, it can also be used for exactly centering the ball in the turn and bank indicator. Incidentally, reflexing both ailerons upward on my Mustang-II does not increase top speed like it will for some other airfoil sections.



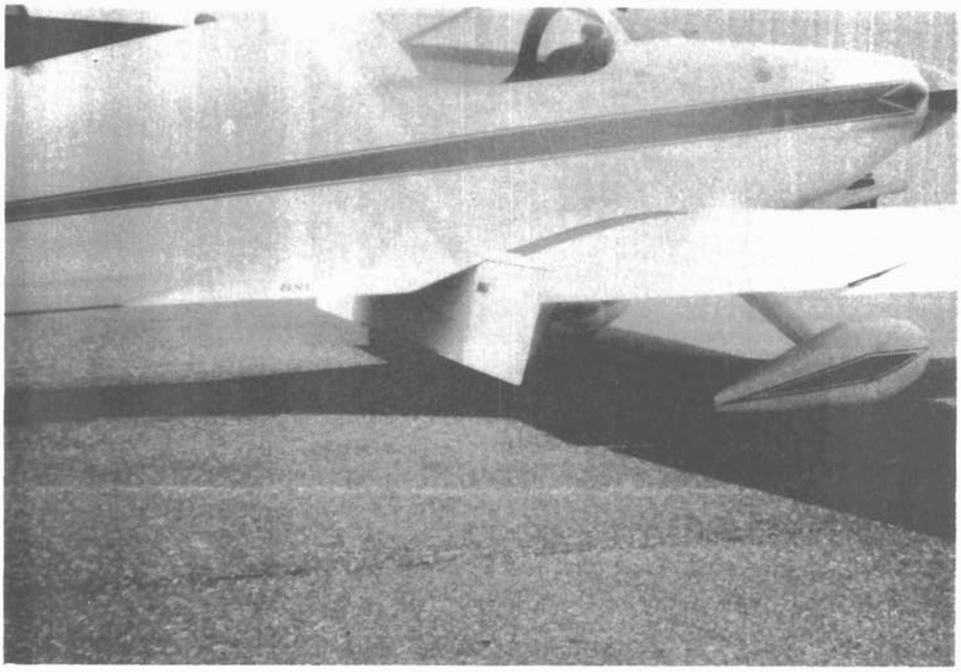
Both ailerons can be seen to be drooped in this photo.



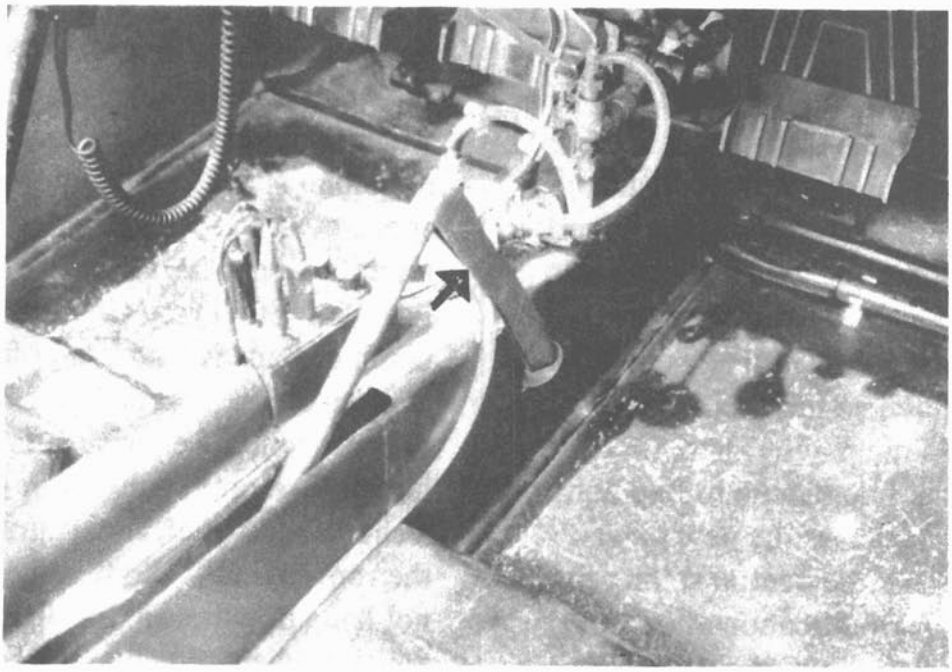
The aileron adjustment thumbwheel protrudes through the control well cover.

WING FLAP MODIFICATIONS

Also, as part of the effort to reduce the aircraft's stall speed, I incorporated a modification which allows me to drop (or rotate downward) the wing flap farther. I accomplished this with some changes to the flap actuation mechanism. I lengthened the flap handle pawl so that I could put an extra notch in the pawl. Then I lengthened the flap handle to flap horn pushrod. This causes the new pawl notch to become the neutral setting for the flap. This modification allows me to rotate the flap down to 60 degrees. When on the ground in the three point attitude, the flap now hangs almost straight down. Test flight data shows an additional 2 MPH decrease in stall speed for this modification. This extra notch of flaps produces much more aerodynamic drag. So, I can now carry more engine power and propellor RPM for augmented air flow over the wing when flying in ground effect at minimum speed. This reduces the stall speed even further. This makes the aircraft even more competitive in the Pazmany Efficiency Contest. The extra notch of flaps is also useful for steepening the approach for landing in the case when the airplane is high and hot on final approach, or for getting into a short field which has obstructions off the runway ends. So that the flap does not hang down even the slightest amount when in the neutral position, I have installed a bungee cord to slip over the flap handle to keep the flap very tight to the belly of the fuselage, thus preventing any unnecessary aerodynamic drag.



Flap modification now allows 60 degrees of flap.



Flap handle bungee cord holds the flap tight to the belly of the fuselage.

ADDITIONAL MAGNETO ADVANCE

To gain additional fuel efficiency (for competing in the Oshkosh-500 and CAFE races), I experimented with advancing the magnetos beyond the 25 degree BTDC recommended by Lycoming. I advanced the magnetos 1 degree at a time, leaving the magnetos at each incrementally advanced setting for several flying hours. I have actually run the engine (on the ground only) with the magnetos set at 45 degree BTDC. However, at this setting, the engine was shaking badly and making ominous noises. I currently have the magnetos set at 30 degree BTDC. I am uncomfortable with any further permanent magneto advance setting, believing that I have reduced the margin between normal engine combustion and combustion detonation, as far as I dare, for my engine. This practice can be very dangerous as other engines, even other Lycoming 0320, may detonate with that much magneto advance. Especially if a variable-pitch propellor is being used that will allow the engine to develop full, rated power for take off at sea level. Incidentally, I burn 100 octane low-lead gasoline exclusively.

MAGNETO CUT OFF SWITCH

When running 30 degree BTDC advance on the magnetos, starting the engine can be very hard on the starter. The left magneto has an impulse coupling which retards the spark from that magneto for starting. However, normally, the right magneto does not have an impulse coupling. Should the right magneto produce a spark at 30 degree BTDC during engine start up and cause combustion in a cylinder, the resulting engine kick-back is violent and could damage the starter. To prevent this from occurring, I have installed a separate switch on the instrument panel for cutting-out the right magneto during engine start up. Actually, the switch selectively grounds out the right magneto. Once the engine is running, I flip the switch up to unground the right magneto and bring it on-line. Just for starting, the right magneto can also be grounded by proper wiring of the bendix key switch. However, I am still doing some experimentation with magneto advance settings and the ability to ground out the right magneto during flight is necessary for my tests.

ALTERNATOR CUT OFF SWITCH

A normal aircraft or automotive alternator, when operating at it's rated output, can draw as much as 3 or 4 engine horsepower to operate. This is not caused so much by the mass of the armature because the armature rotates in ball or needle bearings; and, once the mass of the armature is spun-up, it doesn't require much energy to keep it spinning. Rather, most of the energy (horsepower) required to spin the armature is due to the armature spinning within the magnetic field created by the field coil windings. In an alternator, the field windings must be energized by an outside source of DC current (the battery) for the alternator to start producing an electrical output. I have installed a separate switch on the instrument panel so that I can cut off the current to the alternator field windings; thereby, freeing up as much as 3 or 4 engine horsepower which can then be used to either increase the aircraft's speed or decrease the aircraft's fuel consumption. Of course, when I shut off the alternator, I also minimize other current draw from the battery so that the battery doesn't discharge completely during the race. Actually, since the engine's ignition is provided by the magnetos (which require no outside electrical power source), no electrical draw from the battery should be required during a race unless the race format requires radio communication during the event.

ENGINE ADDITIVES

One of the prizes that I won, when competing in the Oshkosh-500 races, was a case of "Microlon." Microlon is a reciprocating engine oil and fuel additive designed to reduce internal engine operating friction. The composition of Microlon is a microscopically fine particulate of teflon (PTFE) in a petro-chemical cleaning solution. According to the manufacturer, Chem-lon, the cleaning solution cleans out the surface porosity of the engine's bearing/wearing surfaces and then the microscopic particles of teflon are imbedded in the cleaned out pores of the bearings, journals, guides, stems, cylinder walls, etc. I never believed very much in the claims by engine oil additive manufacturers. However, since Microlon had been tested and approved by the FAA for use in aircraft engines, I thought that Microlon was worth a try. I applied the product per the manufacturer's directions (a quart in the engine crankcase and ½ pint in the fuel tank and then fly for 2 hours). The results of the test flight to determine the effects of the Microlon was a genuine surprise. My Mustang-II showed an additional 6 MPH of top speed! I can't verify all of the claims made about Microlon, and other teflon oil additives, but I do believe my flight test data. My Mustang-II was definitely faster and had a better climb rate after using Microlon. I treated all of my family's cars with Microlon. They all got better gas mileage. I tried Microlon in my well worn lawn mower. My lawn mower didn't smoke anymore. Was I impressed! I was impressed enough to become the Rocky Mountain Distributor for Microlon for many years. The DOT tested Microlon in their automotive laboratories and found that the product significantly reduced the major components of automobile exhaust emissions.

HIGH COMPRESSION PISTONS

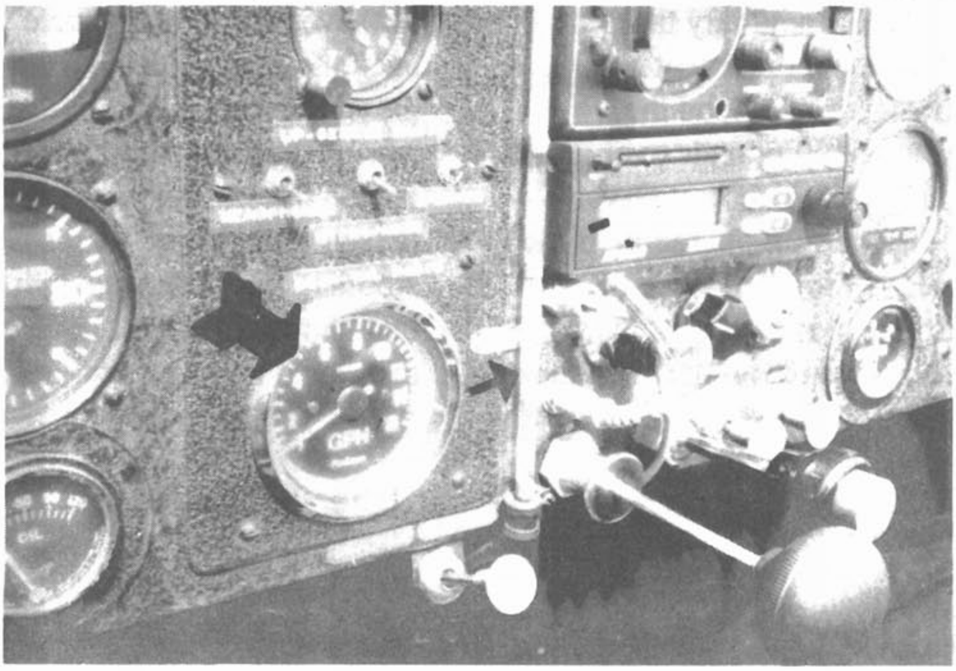
I had been studying Lycoming's specifications on their various 0320 engine models. Per their data sheets, their 7 to 1 compression 0320 engines have a fuel consumption rate of .53 pounds per horsepower per hour and produce 150 horsepower at rated RPM (2700). Their 8½ to 1 compression engines have a fuel consumption rate of .48 pounds per horsepower per hour and produce 160 horsepower at rated RPM (again, 2700). The difference between the two sets of 0320 Lycoming engine models is the pistons. There are other differences in the engine models, but the higher compression is produced by high compression pistons. Swapping my set of low compression pistons would give me 10 percent less fuel consumption and almost 7 percent more horsepower. Sounded good to me. So, during my engine's first top overhaul, that's what I did. I also went to ½ inch stem diameter sodium-cooled exhaust valves, different exhaust valve rockers, and different wrist pins. Using these newer parts pretty well matched Lycoming 160 horsepower 0320 engine parts make-up. "Firewall Forward" in Fort Collins, Colorado, did the parts procurement and machine work for me. Firewall Forward can raise the compression ratio of an 0320 Lycoming to 10 to 1. But, more than parts swapping is necessary (crankcase machining is required). A 10 to 1 compression increase will certainly reduce fuel consumption and increase horsepower even further; but, I believe that engine reliability and longevity would be decreased and have not opted for any higher engine compression. Also, 8½ to 1 compression ratio and 30 degree advance on the magnetos is really a practical limit for the use of 100 octane gasoline. Incidentally, with 8½ to 1 compression ratio, and conscientious fuel mixture leaning, I have had no problems with spark plug lead fouling from using the higher lead content 100 octane low-lead gasoline (higher lead content than 80 octane fuel).

FUEL FLOW METER AND FUEL SIGHT GAUGE

Most of the races that I have competed in have utilized fuel economy as a factor in determining race results. In the Oshkosh-500 race, you were allowed to burn a specified amount of fuel for the entire 500 miles. If you burned less than the specified amount, you were given extra credit. The less you burned the more extra credit you received (in terms of MPH added to your actual average speed). However, if you burned more than the specified amount, you were disqualified from the race. So, it was very important to know, during the race, how much fuel remaining and the rate that you were burning your fuel. You could determine how much fuel that you had burned for the first quarter or half hour of the race and extrapolate a fuel burn rate. But, even that approach requires an accurate fuel quantity gauge. The original fuel quantity gauging system in my Mustang-II was a float type sensor in the tank and a needle gauge in the instrument panel. This system was failure-prone (3 failures in 3 years) and was anything but accurate (the panel gauge having only empty, one-quarter, one-half, three-quarters and full markings on the face). I needed to know within a gallon how much fuel was in the tank. The Mustang-II has a 25 gallon fuel tank mounted between the instrument panel and firewall over the rudder pedals. With the tank so accessible and close to the instrument panel, a fuel sight gauge was the easiest and most accurate solution available. I tapped into the vent fitting at the top of the tank and the outlet fitting at the sump on the bottom of the tank. A ¼" diameter clear plastic tube was strung between those two fittings. The tube was run in front of the instrument panel and from the bottom of the panel at an angle forward to the tank sump fitting. The aircraft's tail was then raised to level flight attitude. Fuel was added to the empty tank in exact 3-gallon increments and the tube was marked at each 3-gallon increment. This is a simple, but very effective and accurate fuel gauge. It is easy to interpolate intermediate amounts of fuel between the tube 3-gallon incremental marks. Almost like being able to measure the amount of fuel directly with a dip-stick. This type of fuel gauge also adds a measure of safety when stretching your fuel supply. This type of fuel gauge does not lie. There should be no valid reason for running out of fuel if your airplane is equipped with a fuel quantity sight gauge.

I also opted for a fuel flow meter. There were automotive fuel flow metering devices available, but I wanted better reliability and ruggedness. A marine system was the answer. Flo-scan is the trade name of the instrument. It consists of a flow sensor, a surge chamber and the readout gauge. The sensor has an internal rotor which revolves as the fuel impinges on the rotor blades. The rotor blades, in turning, interrupt a beam of light which is sensed by a photo-cell. The electronics in the gauge head counts the pulses over time and converts the pulses into electrical current which drives the readout needle. The gauge face is marked in ½ gallon-per-hour increments, which makes it easy to interpolate within ¼ gallon-per-hour. Fuel delivery from the tank to the engine is normally by gravity flow. However, for the flow meter, the fuel passes through a small orifice in the fuel flow sensor. So, to provide enough fuel flow for the engine, I had to add an electric fuel pump. I use a 35 gallon-per-hour automotive unit. Should the pump fail, I can switch back to gravity flow to the engine. Since the sensor fuel orifice is so small and critical to gauge accuracy, I added an in-line fuel filter just ahead of the sensor. I have calibrated the gauge. The gauge readout is close to linear and reads about 10 percent higher than actual flow. A relatively accurate system. With the fuel sight gauge and the fuel flow meter, it is very easy to prevent overburning my fuel in a race. The fuel flow meter adds another measure of safety to cross-country flying. My Loran radio gives my ground speed, the fuel sight gauge tells me fuel quantity, and the flow meter tells me how fast I am burning the remaining fuel. Not much left to chance these days!

beyond your allowable fuel burn. Nick Jones, the race organizer, promoter and sponsor, didn't want anybody running out of fuel during the race! However, the Mustang-II standard tank only holds 25 gallons. This meant that I had to have an auxiliary fuel tank. I only needed one more gallon. But, it was hardly worth building and plumbing a 1-gallon auxiliary fuel tank. Besides, more aircraft range (for the cross-country trips I was making) was highly desirable. I could have modified the wing leading edge to carry fuel. But, that would have been a lot of work to

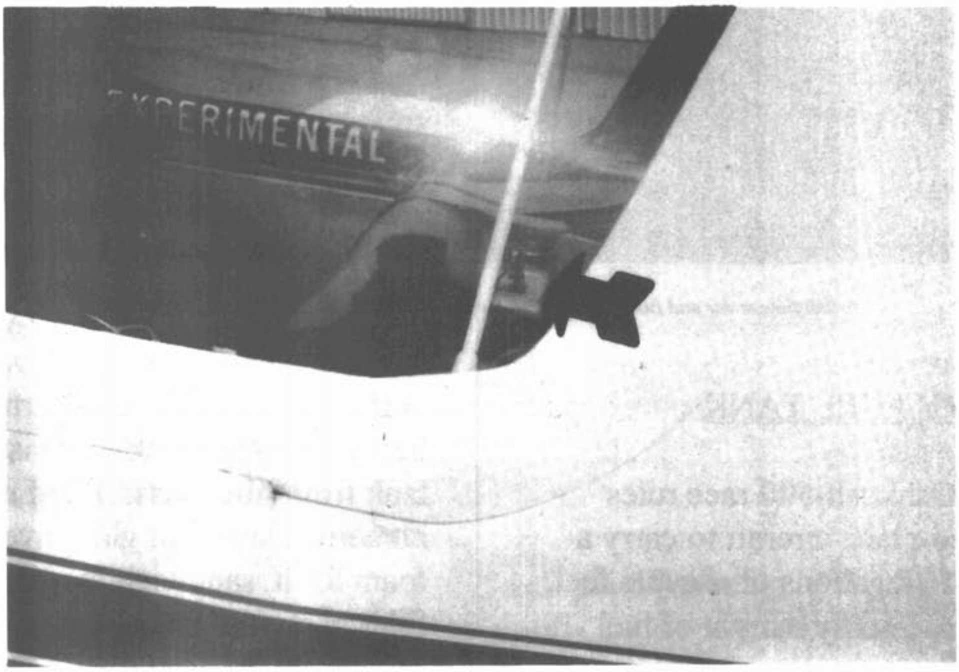


A fuel flow meter and fuel tank sight gauge are valuable cockpit fuel useage indicators.

retrofit. The easy way out was to put a tank in the baggage compartment, right behind the seat back. I constructed the tank from fiberglass. I laid up numerous layers of glass over a rigid foam form, sandwiching outlet, vent and filler neck fittings between the glass

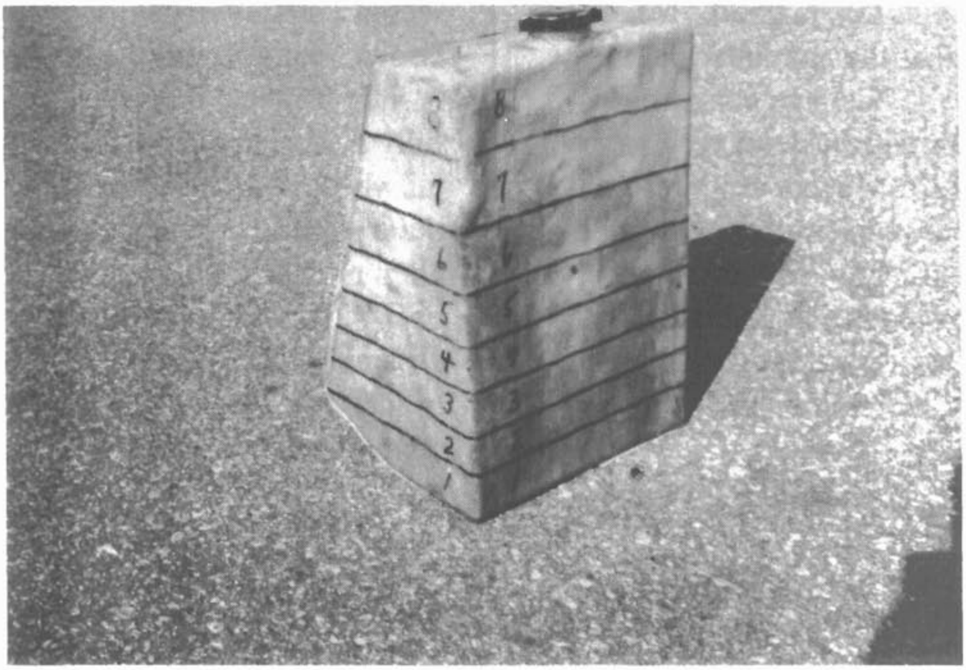
AUXILIARY FUEL TANK

The Oshkosh-500 race rules required two-place aircraft to carry a minimum of 26 gallons of useable fuel, which gave a goodly margin of fuel layers. All of the fittings are at the top of the tank (if fiberglass tanks are going to leak, it will be around the fittings). The outlet fitting at the top attaches a standpipe that picks up fuel from ⅛" of the tank bottom. The tank interior is sealed with two applications of slosh sealing compound (I slosh sealed the aluminum main fuel tank and have not had a leak, seep or weep in over 23 years of flying). The auxiliary tank holds 8-gallons of fuel and is shaped to form-fit neatly behind the seat back. This arrangement uses up very little useful volume of the baggage compartment. This auxiliary tank is located aft of the aircraft's center of gravity. However, I can load the aircraft to almost 100 pounds over gross weight, and the C.G. does not travel beyond the aft limit. In operation, if the airplane is heavily loaded, since the main tank is ahead of the C.G., I will usually start drawing from the main tank then empty the auxiliary tank into the main tank and continue drawing from the main tank (this keeps the center of gravity in range). I have the system plumbed so that I use the flow meter fuel pump to also draw fuel from the auxiliary tank. Actually, with the way I have the entire fuel system plumbed, there are numerous ways to supply fuel to the engine - gravity feed from the main tank, pump feed from the main tank, pump feed directly from the auxiliary tank, or pump from the auxiliary to the main tank then gravity feed from there. The latter is preferable for several reasons. I have very accurate gaging on the front tank; gravity feed to the engine is more reliable (gravity never fails); and the engine doesn't quit when the auxiliary tank runs dry (boy, that is a real heart-stopper. My wife was with me when that happened; and, I have been instructed to never let that happen



The auxiliary fuel tank tucks neatly behind the seat back.

again. At least, not when she is in the airplane!). The auxiliary tank adds about 300 miles to the aircraft's range, at high-cruise power settings, and high altitude. Actually, the airplane now has considerably more range than I do. The airplane still has plenty of fuel remaining when I have to land and empty my personal tank! However, I do carry an empty quart mason jar in the baggage compartment, if time doesn't allow for a creature-comfort landing.



The auxiliary fuel tank is shaped to fit the slope of the seatback.

BATTERY ON THE FIREWALL

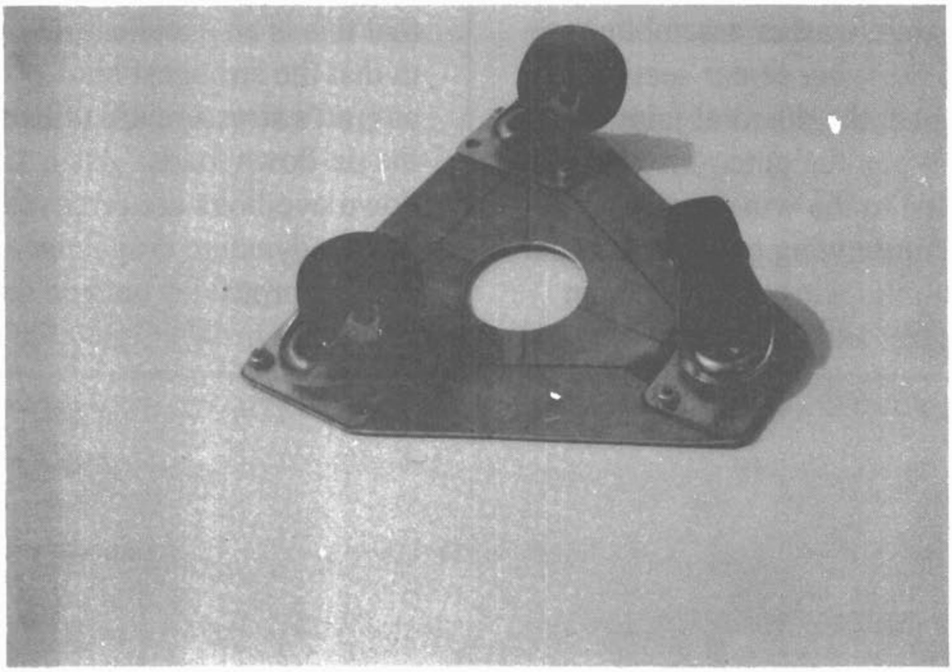
With all of the modifications that I have made on/to the airplane, I have had to be very careful to keep the aircraft's center of gravity in range. Some modifications reduced weight and some modifications added weight. But when I replaced the 30 pound Aeromatic propellor with the 12 pound Pacesetter-200 propellor, that really drove the C.G. aft. In fact, when that modification was added to several other aft-shifting C.G. modifications, I could not carry a passenger without exceeding the aft C.G. limit. Definitely not a recommended procedure. In a standard Mustang-II, the battery is mounted far aft, behind the baggage compartment bulkhead. To solve my aft C.G. problem, I moved the battery to a position on the firewall. I had to put a firewall strengthening aluminum angle member on the firewall to distribute the point load that the battery represented. I extended the battery box drain out of the cowl air outlet so that any battery effluent would not contaminate the engine compartment. Also, since the engine compartment is a very warm environment for a lead-acid battery, I had to supply forced-air cooling to the battery box (see Cooling Chapter #4). However, this new battery installation also had some positive considerations. The aircraft's C.G. problem was corrected, the battery would get serviced more frequently, and the cable from the battery to the starter was now much shorter. There wasn't as much line voltage drop and the engine turns over much faster when starting. Currently, my Mustang-II is slightly nose heavy; but, that is good, considering that the auxiliary fuel tank is located in the baggage compartment. Talking about weight, I am very happy that the aircraft's current empty weight is still very close to its original weight. Especially since I have added a fuel tank, more instrumentation, more controls, an intercom, and 4 additional radios with 2 more antennas!

CASTORING TAILWHEEL DOLLY

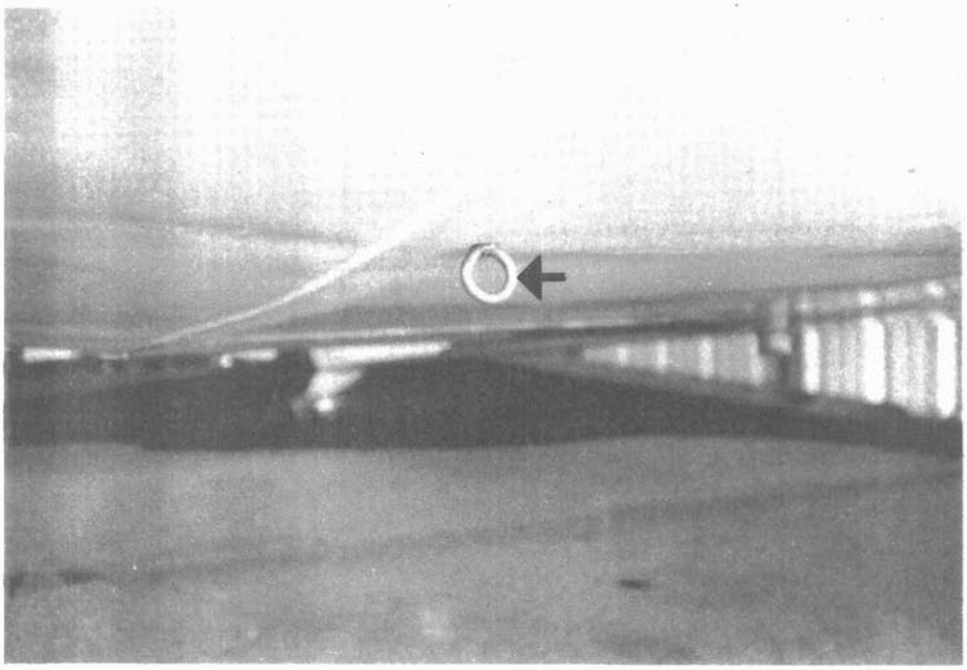
My Maule tailwheel assembly originally was a fully castoring unit; and, when I wanted to push the airplane backwards into the hangar, the tailwheel and tailwheel fork would easily swivel around and trail the pivot point on the tailwheel assembly. However, when I put the wheelpant on the tailwheel and the fairing over the tailwheel spring and the front of the tailwheel assembly, this prevented the tailwheel assembly from fully swiveling around. The tailwheel will still swivel to 90 degrees either side of center, so I can still pivot the airplane around on one wheel by locking that wheel brake. But, I could no longer push the airplane backwards into the hangar when the tailwheel was on the ground. I had to pick the tail up and pull the airplane into the hangar. Not really all that difficult since the airplane's weight on the tailwheel is only 40 pounds. However, it is still easier to push the airplane than pull and carry the tail backwards. A friend and fellow Mustang-II builder, whom I share the hangar with, Mark Brown, came up with a neat solution. A little 3-wheel dolly that provides the fully castoring action which the tailwheel no longer can. The dolly is quite simple. A triangular sheet of aluminum or steel, about 8" or 10" on each side, with a small castoring wheel assembly bolted to each corner of the triangular sheet. A hole is cut in the center of the sheet for the tailwheel to nest in. Now it is very easy to push the airplane backwards again. The castoring dolly allows the airplane's tail to swing back and forth quite freely to position the airplane accurately in the hangar. I used very small wheels for the first dolly - about 1" diameter plastic wheels. These small wheels would be easily stopped from rolling by even very small pieces of gravel on the hangar floor. I switched to 2" diameter, hard rubber wheels which will ride right up and over the hangar floor debris and keep on rolling instead of skidding along. I normally leave the dolly in the hangar. However, the little dolly is small and light enough to carry in the airplane's baggage compartment (I used a .060" thick aluminum sheet for my dolly).

AIRCRAFT TIE-DOWN FITTINGS

I designed and fabricated a set of tie-down fittings that pick up the wing center section spar fittings at the dihedral joints. I bought some steel



The tailwheel dolly works very well, even on rough surfaces.



Tie-down fittings. The tie-down fittings pick up the main spar lower fittings at the dihedral joint.

hex-stock that is ¾" wide at the flats. This hex-stock is drilled and threaded for a 3/8" bolt. I cut off a 1½" length of this hex-stock for each tie-down fitting. I welded a steel washer over each end of each 1½" long hex-stock piece. These hex-stock/washer assemblies are slipped into the wing center section lower fittings at the dihedral joint on each side. When the outer wing panels are assembled to the wing center section, the outer wing panel lower spar ends slip into the wing center section dihedral fittings and hold the tie-down fittings in place. A ½" hole was drilled in each wing dihedral fairing in line with each tie-down fitting. A ⅜" threaded eye-bolt can then be threaded into the hex-stock fittings whenever the aircraft needs to be tied down. I feel that this is an excellent tie-down design in that the strongest hard-points in the aircraft's structure are utilized to accept the tie-down loads. Also, since the tie-down eye-bolts are removed for flight, no aerodynamic drag is incurred since nothing protrudes outside the skin-line of the wing.

CHAPTER 8

PERFORMANCE IMPROVEMENT RESULTS

Twenty years of modification efforts has produced significant improvements in all performance categories.

Now for the results of all this modification effort. However, I should first talk about the instrumentation used to measure the performance results and the calibration of those instruments. The performance improvement results are measured in terms of:

- Increased top speed and cruise speed.
- Increased rate of climb.
- Decreased fuel consumption.

For speed measurement, the airspeed indicator is the primary instrument with Loran as a secondary indicator. Calibration of the pitot/static system and the airspeed indicator is of prime importance. My first attempt at calibration was to build a manometer. The construction of which was shown in an article in Sport Aviation Magazine. The magazine article was well written and included a chart that correlated inches of water pressure to airspeed readout. However, I could not get consistent results using the manometer. The methodology that did produce consistent results was timed, two-way runs over a measured course. I used a 2½ mile measured course, about 5 miles from my home airport, which has a control tower that supplied me with wind velocity and direction. I flew the course in both directions for each speed measurement and averaged the back and forth speeds. The most consistent results were obtained when the wind was directly along the line of flight of the 2½ mile course (i.e. - either a direct headwind or tailwind). I flew the course at 500 feet while my copilot ran the stop watch and recorded the elapsed time for each run. Average times were obtained for each 10 MPH increment of indicated airspeed from 80 MPH to 180 MPH. From this flight data, I constructed an airspeed indicator calibration chart to convert indicated airspeed (IAS) to calibrated airspeed (Figure 8-1). Later, after I bought a LORAN radio, I used the same 2½ mile course to fly 2-way calibration runs using the LORAN airspeed readout and a stop watch to get average speeds over the course. Correlation between the LORAN data and the stop watch data was very good and, again, the most consistent data was with the wind either as a direct headwind or tailwind.

Calibration of the rate-of-climb instrument was obtained by using a stop watch to time the aircraft between 1,000 ft. increments of altitude. Two sets of data were taken. Between 7,000 and 8,000 ft. and between 12,000 and 13,000 ft. Each 100 FPM increment of rate-of-climb was calibrated, starting at 500 FPM. The readout of the rate-of-climb meter proved to be quite accurate. The meter was reading 25 to 50 FPM lower than the stop watch data through-out the range of data taken. Most of the calibration runs were made early in the morning when the air was cool and stable and the instrument needles could be accurately read for both airspeed and rate-of-climb calibration flights.

My fuel flow meter is a "Flo-Scan" unit. The unit was designed for marine applications and as a result is quite rugged. The unit operates by passing the fuel through a small orifice. The fuel impinges on a four armed rotor. The rotor arms interrupt a light beam. The light pulses are counted and converted to a needle readout. Calibration of the unit was obtained by using a valve to control the output flow, collecting the output flow over a period of time, measuring the output volume and comparing that volume with the meter reading. Over the useable range of the instrument (3-GPH to 15-GPH), the meter reads approximately 10 percent too high. This was corroborated when I flew the Oshkosh-500 races. The fuel burned, during the race, was measured by weighing the aircraft before and after the race. Again, the fuel burn by weight was always about 10 percent less than what I calculated from my fuel flow meter readings. Since my fuel tank quantity is measured by a very accurate sight gauge, I can also correlate fuel burn readings (over time) between the sight gauge and the flow meter during climb and cruise. During cruise, I usually expect to see a drop of fuel quantity in the sight gauge of 1 gallon per each 10 minutes of flight, while the flow meter is reading about 6.5 GPH (or about 10 percent too high).

I also calibrated the cylinder head temperature (CHT) gauge and oil temperature gauge. This was done by placing the thermocouples in a pot of heated oil along with a thermometer of known accuracy. Comparing the readings on the CHT and oil temperature gauges, with the accurate

INDICATED AIRSPEED (IAS)	INDICATED AIRSPEED CORRECTION	CALIBRATED AIRSPEED (CAS)
70 MPH	SUBTRACT 4 MPH	66 MPH
80 MPH	SUBTRACT 3 MPH	77 MPH
90 MPH	SUBTRACT 2 MPH	88 MPH
100 MPH	SUBTRACT 1 MPH	99 MPH
110 MPH	NO CORRECTION	110 MPH
120 MPH	NO CORRECTION	120 MPH
130 MPH	NO CORRECTION	130 MPH
140 MPH	ADD 1 MPH	141 MPH
150 MPH	ADD 2 MPH	152 MPH
160 MPH	ADD 3 MPH	163 MPH
170 MPH	ADD 4 MPH	174 MPH
180 MPH	ADD 5 MPH	185 MPH
190 MPH	ADD 6 MPH	196 MPH
200 MPH	ADD 7 MPH	207 MPH

FIGURE 8-1

AIRSPEED INDICATOR
CALIBRATION/CORRECTION

thermometer, proved that these gauges were reasonably accurate over their operating ranges. When I first started making test flights, I recorded a minimum amount of data:

- Flight date
- Engine hours
- Modification being tested
- Aircraft weight
- Altitude
- Outside air temperature (OAT)
- Manifold pressure
- Engine RPM
- Indicated airspeed (IAS)
- Calibrated air speed (CAS)
- True airspeed (TAS)
- Cylinder head temperature (#4 cylinder only)
- Oil temperature

An example of this early data sheet is shown as Figure 8-2.

Whenever I performed a test flight, I would always reset the altimeter to 29.92 inches of mercury prior to recording any test data. In this way, the pressure altitude would be the same for all flight test data sheets (normalized to standard pressure conditions). Later, I added an exhaust gas temperature (EGT) gauge to #4 cylinder, and this EGT reading was added to the data sheet. A later flight test data sheet is shown as Figure 8-3. As time went on, I continued to add instrumentation and this additional data would be recorded for each test flight:

- A fuel flow meter reading in gallons per hour (GPH)
- All four cylinders CHT
- All four cylinders EGT

This may seem like a lot of data, but it is all very valuable. Many times I have made a modification with a specific improvement in mind. Then, during flight test, I would see an unexpected change in oil temperature or CHT/EGT or GPH. In fact, seldom would a modification affect only one flight parameter or instrument readout. Many times I have come back from a test flight, puzzled by the test flight data, and then the mystery is cleared up by comparing and studying all of the data elements on the current data sheet and previous data sheets.

The performance of the original configuration of the aircraft is shown as Figure 8-4. At that time, I had not added all of the additional instrumentation, and was still in the process of calibrating the existing instrumentation and gauges. But, I later went back and added the CAS column and corrected the TAS column data.

As I made the modifications, I resolved to run a flight test after each individual modification to make sure that the modification helped and not hurt the performance. For all of the major modifications, I accomplished

ALT	TEMP	MP	RPM	IAS	CAS	TAS
7,000	0	22.4	2625	158	161	175
8,000	-2	21.5	2550	156	159	176
9,000	-4	20.6	2500	153	155	175
10,000	-6	19.8	2475	150	152	175
11,000	-8	19.0	2450	147	149	174

ALT=ALTITUDE IN FEET

TEMP=OUTSIDE AIR TEMPERATURE IN DEGREES CENTIGRADE

MP=MANIFOLD PRESSURE IN INCHES OF MERCURY

RPM=ENGINE REVOLUTIONS PER MINUTE

IAS=INDICATED AIRSPEED IN MILES PER HOUR

CAS=CALIBRATED AIRSPEED IN MILES PER HOUR

TAS=TRUE AIRSPEED IN MILES PER HOUR

CONFIGURATION: AEROMATIC PROP AND NEW DESIGN AIRBOX

LOADING: PILOT ONLY, 20 GALLONS GAS, 6-QUARTS OIL, NO BAGGAGE

DATE: 1 JANUARY, 1975

FIGURE 8-2

EARLY FLIGHT TEST DATA SHEET

ALT	OAT	RPM	MP	IAS	CAS	TAS	ET	CT	OT	GPH
12,000	12	2800	18.8	170	174	218	1500	200	200	9.5
		2750	18.4	166	170	214	1500	200	200	9.0
		2700	17.9	163	167	210	1500	200	195	8.5
		2650	17.5	160	163	205	1500	200	195	8.0
		2600	17.0	156	159	200	1475	195	195	7.5
		2550	16.5	153	156	196	1475	195	190	7.0
		2500	16.0	151	153	192	1450	190	190	6.5
		2450	15.5	148	150	188	1450	190	190	6.0
		2400	15.0	145	147	185	1425	185	185	5.5
		2350	14.5	143	144	181	1425	185	185	5.0
		2300	14.0	140	141	177	1400	180	185	4.5
11,000	14	2825	19.3	172	177	221	1525	200	200	9.8
10,000	16	2850	20.2	178	183	223	1525	200	200	10.0
9,000	18	2875	21.0	182	188	225	1550	205	205	10.2
8,000	20	2900	21.9	187	193	227	1550	205	205	10.5
7,000	22	2925	22.8	190	197	229	1575	210	210	10.7
6,000	24	2950	23.8	196	203	231	1575	210	210	11.0

ALT = ALTITUDE IN FEET

OAT = OUTSIDE AIR TEMPERATURE IN DEGREES CENTIGRADE

RPM = ENGINE REVOLUTIONS PER MINUTE

MP = MANIFOLD PRESSURE IN INCHES OF MERCURY

IAS = INDICATED AIRSPEED IN MILES PER HOUR

CAS = CALIBRATED AIRSPEED IN MILES PER HOUR

TAS = TRUE AIRSPEED IN MILES PER HOUR

ET = EXHAUST GAS TEMPERATURE IN DEGREES FAHRENHEIT

CT = CYLINDER HEAD TEMPERATURE IN DEGREES CENTIGRADE

OT = OIL TEMPERATURE IN DEGREES FAHRENHEIT

GPH = FUEL CONSUMPTION IN GALLONS PER HOUR

DATE = 1 MAY, 1982. 68x79 PROP, PILOT ONLY, 20 GALLONS FUEL, CROSSOVER EXHAUST SYSTEM, 1¼" EXHAUST NOZZLES, 6-QUARTS OIL, ALTIMETER CORRECTED TO 29,92, AIRFRAME DIRTY AND BUG-SPLATTERED, ALL TAPED JOINTS ROUGH, TACH = 513,84.

FIGURE 8-3

LATER FLIGHT TEST DATA SHEET

ALT	OAT	RPM	MP	IAS	CAS	TAS
17,000	-20	1800	14.2	69	73	95
16,000	-17	2100	14.9	103	103	134
15,000	-15	2400	15.6	117	117	149
14,000	-12	2475	16.3	123	123	152
13,000	-10	2500	17.0	126	126	155
12,000	-8	2525	17.8	131	131	159
11,000	-5	2550	18.6	135	136	163
10,000	-2	2575	19.4	137	138	167
9,000	-1	2600	20.2	146	148	171
8,000	0	2625	21.0	150	152	175
7,000	+1	2650	21.8	156	159	179

ALT = ALTITUDE IN FEET

OAT = OUTSIDE AIR TEMPERATURE IN DEGREES FAHRENHEIT

RPM = ENGINE REVOLUTIONS PER MINUTE

MP = MANIFOLD PRESSURE IN INCHES OF MERCURY

IAS = INDICATED AIRSPEED, MILES PER HOUR

CAS = CALIBRATED AIRSPEED, MILES PER HOUR

TAS = TRUE AIRSPEED, MILES PER HOUR

ALL DATA TAKEN AT FULL THROTTLE.

AIRCRAFT WAS IN ORIGINAL CONFIGURATION WITH AEROMATIC PROPELLOR

DATE = 26 November, 1971

FIGURE 8-4

ORIGINAL CONFIGURATION TOP SPEEDS
AND SERVICE CEILING

this, and can tell you what the performance increase was for that modification. However, for many of the smaller individual modifications, I could not see any appreciable performance gain, and have grouped several of the smaller modifications together to show an improvement using some engineering judgement and test data interpretation.

Figure 8-5 lists all of the individual modifications and gives a performance improvement in terms of top speed MPH. Figure 8-6 provides a power modifications summary. Figure 8-7 lists the modifications by category and ranks the categories from most significant to least significant. Figure 8-8 is an actual performance data sheet that reflects the aircraft's current performance. Figure 8-9 compares the aircraft's original performance with its current performance. Some additional charts and curves are provided that deal with specific performance parameters or categories. Figure 8-10 gives aircraft stall speeds in various configurations and conditions. Figure 8-11 gives fuel consumption data at various speeds. Figure 8-12 provides EGT/CHT curves for various RPMs and speeds. Figure 8-13 provides various propellor performance curves. Figure 8-14 is an actual early flight test data sheet from the Cassidy Pacesetter-200 propellors development period.

19 MPH

- LANDING GEAR LEG FAIRINGS
- NEW WHEEL PANTS
- GEAR LEG TO WING FAIRINGS
- GEAR LEG TO WHEEL PANT FAIRINGS
- WING-ROOT RADIUS FAIRINGS
- WING-ROOT FENCE FAIRINGS
- STABILIZER AND FIN RADIUS FAIRINGS

12 MPH

- FASTBACK FUSELAGE FAIRING
- MORE SLOPED WINDSCREEN
- LOWER CANOPY
- CANOPY SIDE-SKIRT CAPTURE

7 MPH

- SMALLER COWL COOLING AIR INLETS
- ROUNDED COWL COOLING AIR OUTLET
- RADIUSED COWL COOLING AIR INLETS
- COWL AIR INLETS STRAIGHT BACK FROM SPINNER
- COWL OUTLET EXHAUST VENTURI PUMP
- OPTIMIZED ENGINE COOLING BAFFLES
- COWL CARB HOUSING & INLET SIZE REDUCTION
- SMOOTHED COWL SQUARE JOWLS

6 MPH

- TAILWHEEL PANT
- TAILSPRING FAIRING
- BEACON LENS FAIRING
- FLAP TRAILING EDGE FAIRING/AIR OUTLET
- WING UNDERSIDE PROTRUDING RIVETS FAIRING
- AILERON BALANCE WEIGHT FAIRINGS
- FUEL TANK VENT FAIRING
- ELEVATOR INNER-END FAIRINGS
- PITOT TUBE HEAD FAIRING
- FLAP GAP COVERS
- DIHEDRAL JOINT COVERS SEALING
- RIVET HEADS AND SEAMS FILLING
- AILERON ADJUSTMENT FEATURE
- TEMPERATURE PROBE TUNNEL/HOUSING
- TAPING OF JOINTS, SEAMS AND HINGES
- CONTROL WELL SEALING
- WINDSCREEN TO CANOPY OVERLAPPING SEAL
- MINIMUM SPINNER TO COWL GAP
- PROPELLOR TO SPINNER SEALS

5 MPH

- COMMUNICATION ANTENNA INSIDE CANOPY
- VOR ANTENNA INSIDE THE CANOPY
- LORAN ANTENNA INSIDE THE CANOPY

FIGURE 8-5
AERODYNAMIC IMPROVEMENTS LIST

MODIFICATION	SPEED INCREASE	
New Design Exhaust System	3-MPH	At 8000 feet
Exhaust Thrust Nozzles	5-MPH	
Crossover Exhaust System	2-MPH	
New Design Carburetor Airbox	3-MPH	
Higher Compression Pistons	2-MPH	
Total Speed Increase	15-MPH	

FIGURE 8-6

POWER MODIFICATIONS SUMMARY

19 MPH = LANDING GEAR DRAG REDUCTION AND ROOT FAIRINGS

15 MPH = ENGINE EFFICIENCY IMPROVEMENTS

12 MPH = FUSELAGE FAST BACK MODIFICATIONS

7 MPH = COWLING AND ENGINE COOLING DRAG REDUCTIONS

6 MPH = NUMEROUS SMALL DRAG REDUCTIONS

5 MPH = RADIO ANTENNAE DRAG REDUCTIONS

---

64 MPH = TOTAL TOP SPEED INCREASE AT 8,000 FEET

FIGURE 8-7

SPEED IMPROVEMENT, BY CATEGORY

ALT	OAT	RPM	MP	IAS	CAS	TAS	ET-1	ET-2	ET-3	ET-4	CT-1	CT-2	CT-3	CT-4	OT	GPH
12,000	10	2850	18.7	180	185	232	1475	1475	1475	1475	195	195	195	195	185	9.2
		2800	18.3	177	182	228	1475	1475	1475	1475	195	195	195	195	185	8.8
		2750	17.9	174	178	223	1475	1475	1475	1475	190	190	190	190	180	8.4
		2700	17.5	171	175	219	1475	1475	1475	1475	190	190	190	190	180	8.0
		2650	17.1	167	171	214	1425	1425	1425	1425	185	185	185	185	180	7.6
		2600	16.7	164	167	209	1425	1425	1425	1425	185	185	185	185	180	7.2
		2550	16.3	161	164	205	1425	1425	1425	1425	185	185	185	185	175	6.8
		2500	15.9	158	161	202	1425	1425	1425	1425	185	185	185	185	175	6.4
		2450	15.5	155	158	198	1425	1400	1400	1425	180	180	180	185	175	6.0
		2400	15.1	151	153	192	1425	1400	1400	1425	180	180	180	185	175	5.6
		2350	14.7	148	150	188	1425	1400	1400	1425	180	180	180	185	170	5.2
		2300	14.3	144	145	181	1425	1400	1400	1425	180	180	180	185	170	4.8
		2250	13.9	141	142	177	1400	1375	1375	1400	175	175	175	180	170	4.4
12,000	10	2200	13.5	137	138	173	1400	1350	1350	1400	175	175	175	180	170	4.0
11,000	11	2875	19.4	183	189	233	1500	1500	1500	1500	195	195	195	195	185	9.6
10,000	12	2900	20.2	188	194	235	1500	1500	1500	1500	200	200	200	200	185	10.0
9,000	13	2925	21.0	194	200	237	1500	1500	1500	1500	200	200	200	200	190	10.4
8,000	14	2950	21.9	198	205	239	1500	1500	1500	1500	200	200	200	200	190	10.9
7,000	15	2975	23.0	203	210	241	1525	1525	1525	1525	205	205	205	205	190	11.4
6,000	16	3000	23.9	209	216	243	1525	1525	1525	1525	205	205	205	205	195	12.0

DATE = 28 JANUARY, 1992. PILOT ONLY, 24 GALLONS FUEL, 6-QUARTS OIL, TACH = 879.56, ALTIMETER CORRECTED TO 29.92, CROSSOVER EXHAUST, $1\frac{1}{4}$" NOZZLES, ANTI-REVERSION CONES, 68x82 PROP, NO TAPE ON SEAMS, EXTENDED CARB AIR INTAKE, ALTNTR SWITCH ON, FASTBACK.

FIGURE 8-8, RECENT FLIGHT TEST DATA SHEET

TOP SPEED

	MPH	ALT	IMPROVEMENT
ORIGINAL	175	8,000	+64 MILES PER HOUR
CURRENT	239	8,000	

CRUISE SPEED AND FUEL CONSUMPTION

	MPH	GPH	RPM	ALT	MP
ORIGINAL MAXIMUM CRUISE	159	8.0	2700	12,000	17.8
CURRENT ECONOMY CRUISE	173	4.0	2200	12,000	13.5
CURRENT HIGH CRUISE	198	6.0	2450	12,000	15.5
CURRENT MAXIMUM CRUISE	219	8.0	2700	12,000	17.5

CLIMB RATE

	FPM	ALT	IMPROVEMENT
ORIGINAL	1,200	7,000	800+ FEET PER MINUTE
CURRENT	2,000+	7,000	

SERVICE CEILING

	SERVICE CEILING	IMPROVEMENT
ORIGINAL	17,000	8,000 FEET
CURRENT	25,000	

FIGURE 8-9, PERFORMANCE IMPROVEMENT RESULTS

POWER-OFF STALL SPEEDS				
FLAP POSITION	IAS	OAT	ALTITUDE (FEET)	ENGINE RPM
0-FLAP	69	23	9,000	IDLE
1st NOTCH	67	23	9,000	IDLE
2nd NOTCH	65	23	9,000	IDLE
3rd NOTCH	63	23	9,000	IDLE
POWER-ON STALL SPEEDS				
FLAP POSITION	IAS	OAT	ALTITUDE (FEET)	ENGINE RPM
0-FLAP	67	23	9,000	1300
1st NOTCH	65	23	9,000	1325
2nd NOTCH	63	23	9,000	1375
3rd NOTCH	61	23	9,000	1500
SLOW FLIGHT IN GROUND EFFECT				
FLAP POSITION	IAS	OAT	ALTITUDE (FEET)	ENGINE RPM
3rd NOTCH	58	27	5,800	1500

IAS = INDICATED AIRSPEED, MILES PER HOUR
OAT = OUTSIDE AIR TEMPERATURE (CENTIGRADE)

DATE = 5/29/76, TACH = 286.79, PILOT ONLY, 12 GALLONS FUEL, 7 QUARTS OIL, NO BAGGAGE.

FIGURE 8-10

STALL SPEEDS

ENGINE RPM	TRUE AIRSPEED (Miles Per Hour)	FUEL CONSUMPTION (Gallons Per Hour)	FUEL MILEAGE (Miles Per Gallon)
2850	232	9.2	25.2
2800	228	8.8	25.9
2750	223	8.4	26.6
2700	219	8.0	27.4
2650	214	7.6	28.2
2600	209	7.2	29.0
2550	205	6.8	30.1
2500	202	6.4	31.6
2450	198	6.0	33.0
2400	192	5.6	34.3
2350	188	5.2	36.2
2300	181	4.8	37.7
2250	177	4.4	40.2
2200	173	4.0	43.3

FIGURE 8-11

FUEL ECONOMY/MILEAGE AT 12,000 FEET

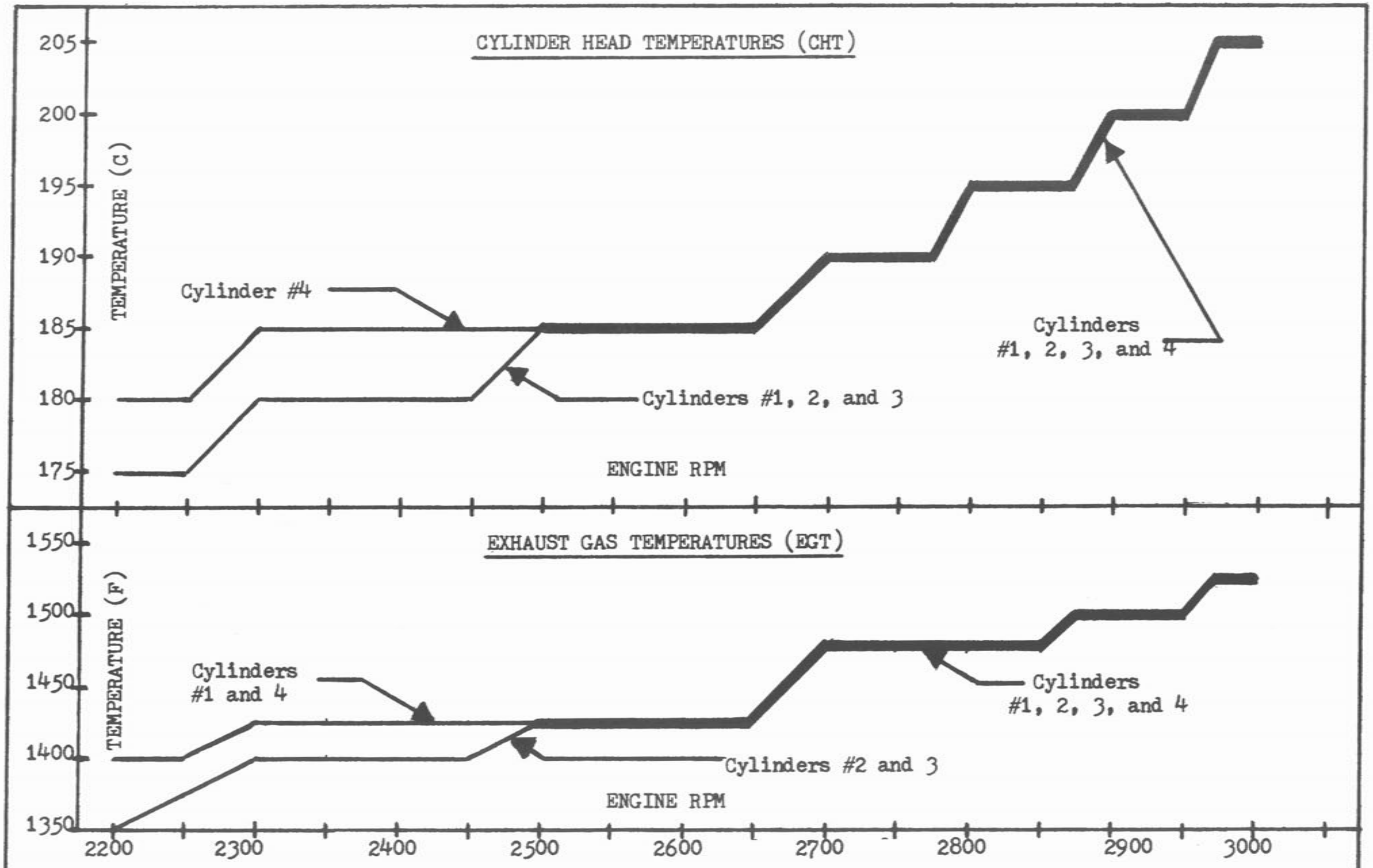


FIGURE 8-12, CHT AND EGT CURVES

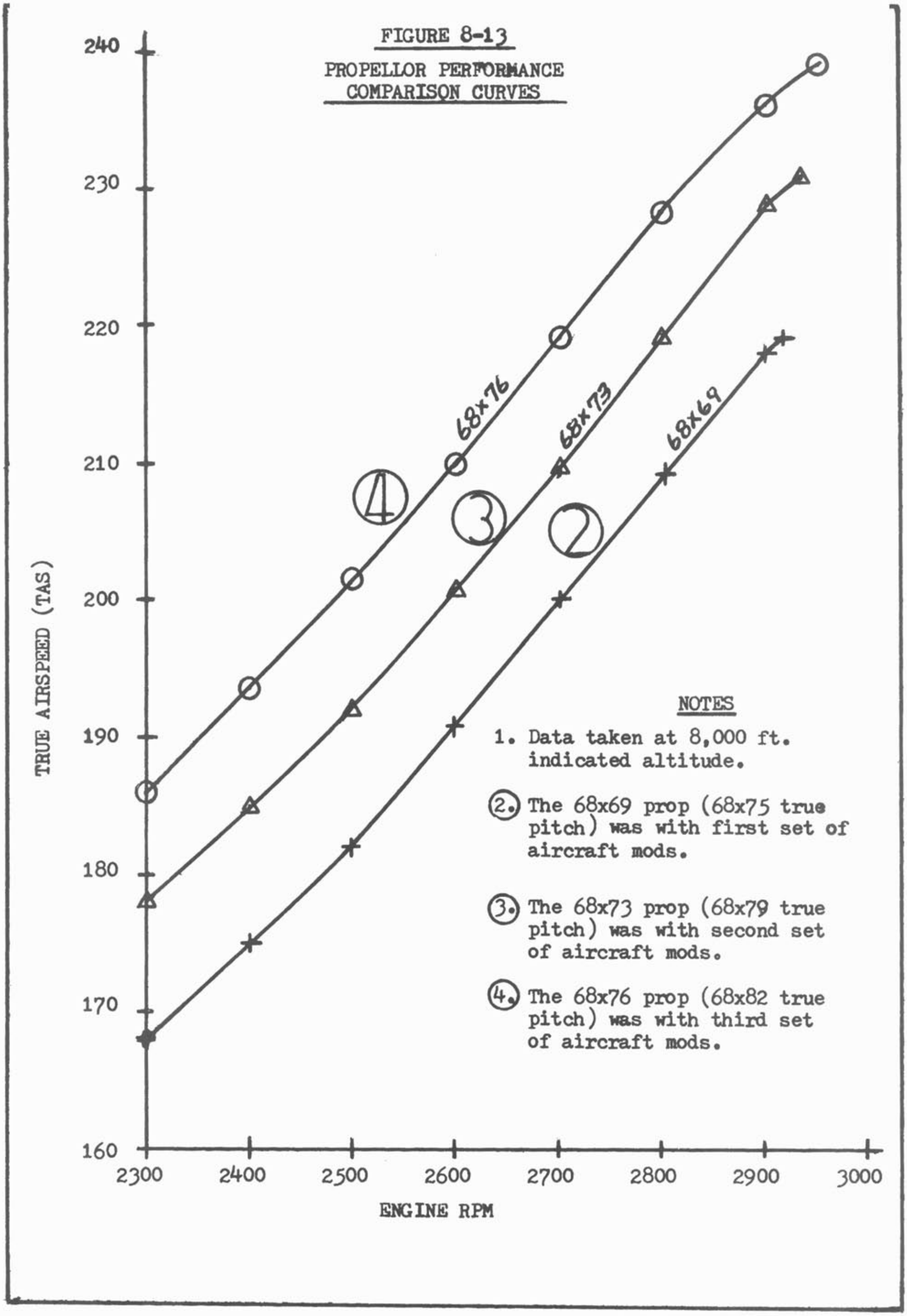


FIGURE 8-13
PROPELLOR PERFORMANCE
COMPARISON CURVES
240
230
220
210
200
190
180
170
160
TRUE AIRSPEED (TAS)
2300
2400
2500
2600
2700
2800
2900
3000
ENGINE RPM
68x76
68x73
68x69
4
3
2
NOTES
1. Data taken at 8,000 ft. indicated altitude.
2. The 68x69 prop (68x75 true pitch) was with first set of aircraft mods.
3. The 68x73 prop (68x79 true pitch) was with second set of aircraft mods.
4. The 68x76 prop (68x82 true pitch) was with third set of aircraft mods.

4th PERFORMANCE TEST WITH WOOD FIXED PITCH PROPS DESIGNED AND BUILT BY BILL CASSIDY. THIS WAS A BRAND NEW PROP WHICH BILL CUT FOR DEVELOPMENT TEST INSTALLATION ON MY AIRPLANE. THE DIAMETER IS 68" AND PITCH IS 69" (TRUE PITCH 75"). PROP SPINNER IS INSTALLED. DATE: 5 APRIL, 1975

ALT	RPM	OAT	IAS	CAS	TAS	MP
7,000	2775	+18°C	172	176	202	22.1
8,000	2750	+14°C	167	171	200	21.3
9,000	2725	+11°C	164	167	197	20.5
10,000	2700	+8°C	160	163	195	19.8
11,000	2675	+6°C	156	159	193	19.1

STATIC RPM = 2125 AT 5,800 FEET, GROUND LEVEL

PARTIAL THROTTLE CRUISE DATA:

100 IAS = 1775 RPM AT 7,000 FT.
110 IAS = 1900 RPM AT 7,000 FT.
120 IAS = 2025 RPM AT 7,000 FT.
130 IAS = 2150 RPM AT 7,000 FT.
140 IAS = 2275 RPM AT 7,000 FT.
150 IAS = 2400 RPM AT 7,000 FT.
160 IAS = 2625 RPM AT 7,000 FT.
170 IAS = 2750 RPM AT 7,000 FT.

CLIMB:

8,000 FT = 1400 FPM AT 2400 RPM AT 120 IAS
9,000 FT = 1300 FPM AT 2400 RPM AT 120 IAS
10,000 FT = 1200 FPM AT 2400 RPM AT 120 IAS
11,000 FT = 1100 FPM AT 2375 RPM AT 120 IAS

CONCLUSIONS:

THIS PROP IS GOOD; EXCELLENT SPEED, NO VIBRATION, TERRIFIC CLIMB RATES, GOOD STATIC RPM, AND AMAZINGLY ENOUGH, DECREASED FUEL CONSUMPTION. I FLEW FOR A TOTAL OF 1.2 HOURS TODAY WITH THIS NEW PROP AND BURNED ONLY 6.0 GALLONS OF FUEL.

FIGURE 8-14

CASSIDY PROPELLORS DEVELOPMENT TEST DATA SHEET

PASER

CHAPTER 9

COMPETITION RESULTS AND OTHER AWARDS

Competing for numerous years in several speed and efficiency contests has proven the effectiveness of my aircraft modifications.

Human nature being what it is, I believe it is safe to say that much, if not most, of the advancement in almost any field of endeavor is the direct result of competition. And so, it has been with the modifications to my Mustang-II. The desire to do well in various forms of competition was a strong motivation to continue to find ways of making the airplane faster and more efficient. The competition phase of my flying experience began in 1971 and ended in 1993, a span of over 20 years. Although, in the earlier years of my modification efforts, before the competition "bug" bit me hard, my motivation was mainly an engineer's desire to find better ways of doing things. The flying competition phase of my experience started in 1976 and finished in 1986. A total of 11 years of actually pitting my aircraft against other aircraft in flying contests of speed and efficiency.

During the years from 1971 through 1975, the aircraft won numerous local and regional awards and competitions and one national award. The local and regional awards were for non-flying categories like best homebuilt, best workmanship and best finish. The national award in 1971 was Bob Bushby's Best Mustang-II at Oshkosh 1971. After the initial set of modifications, the aircraft again won Bob Bushby's Best Mustang-II trophy at Oshkosh 1976. I believe my aircraft is the only Mustang-II to have won Best Mustang-II at Oshkosh on two separate occasions.

Oshkosh 1976 was also the beginning of my serious flying competition. The Pazmany Efficiency Contest had been held at Oshkosh for several years. However, 1976 was the first year in which I entered that contest. The contest was intended to measure an aircraft's efficiency relative to other aircraft. Several factors were taken into consideration like aircraft weight, wing area, horsepower, top speed and minimum flying speed. The top and minimum speeds were measured by actually flying the aircraft through a speed "trap" set up on the north/south runway at Oshkosh. In that 1976 competition, my Mustang-II won first place for experimental homebuilt aircraft and second place overall. My maximum speed was 222.31 MPH and minimum speed was 59.23 MPH. These results were reported in the July 1977 issue of Sport Aviation magazine. In the 1977 Pazmany Efficiency Contest, my aircraft turned in the highest speed ever recorded in the Oshkosh Pazmany Efficiency Contest (for all years) of 229.66 MPH. These results were reported in the June 1978 issue of Sport Aviation magazine.

The January 1977 issue of Sport Aviation magazine featured my aircraft as the magazine's cover story. This article provided the results of my aircraft modification efforts, up to that date. In the March 1979 issue of Sport Aviation magazine, my aircraft again received feature story attention in the article titled "Honing a Winner". This story again discussed my aircraft's modifications and the results of the Pazmany competitions at the EAA Oshkosh conventions.

In 1979, the Oshkosh 500 races were begun at the Oshkosh convention. These races were flying competitions over a measured course of 500 miles. Each aircraft was allowed a specific amount of fuel for the 500 miles and if you used more than that amount of fuel, you were disqualified. The Oshkosh 500 was actually 3 races in 1 event. Awards were given for fastest average actual speed for the entire 500 miles, fastest actual speed for 1 lap of the race course, and fastest adjusted speed for the entire 500 miles. The adjusted speed was calculated by adding 1 MPH to your actual speed for each pound of your fuel allocation that you did not use. The Oshkosh 500 race was conducted each year from 1979 to 1986. The race was eventually eliminated from the EAA convention format due to the cost of race insurance. I competed in the race each year that it was run and my race results are shown in Figure 9-1. As can be seen, due to my many aircraft modifications, my aircraft's actual and adjusted speeds improved steadily each year, until the last year of the race, when the only aircraft to finish at a higher actual speed was A.J. Smith's aircraft which was designed and constructed specifically to compete in the Oshkosh 500 races. Over the years, my aircraft won numerous second and third place finishes (for 2-place aircraft) except in 1984 when I experienced engine stoppage during the race, due to fuel contamination, and did not finish the race. During the races, I also won several special awards - Most Improved Performance, Most Innovative Modification, and Most Consistent Lap Times. In addition, my money winnings, each year always covered my race expenses, at least.

In 1981, I also competed in the inaugural running of the CAFE races in Santa Rosa, California. My aircraft finished a respectable eleventh out of 50

YEAR	ACTUAL SPEED (MPH)	FINISH (2-PLACE AIRCRAFT)	ADJUSTED SPEED (MPH)	FINISH (2-PLACE AIRCRAFT)
1986	202.13	2	214.13	3
1985	196.65	3	212.15	4
1984	192.65	DNF	DNF	DNF
1983	178.62	4	197.72	5
1982	176.78	3	192.68	3
1981	172.68	4	191.70	2
1980	167.84	2	178.62	2
1979	165.62	2	175.74	2

DNF = DID NOT FINISH; LANDED AFTER 4-LAPS; ENGINE INTERMITTENT DUE TO CONTAMINATED FUEL. HOWEVER, 192 MPH AVERAGE WOULD HAVE TAKEN 3rd PLACE.

PERSONAL RACE HISTORY SUMMARY

OUT OF 14 RACE FINISHES:

- FINISHED 2nd 6 TIMES
- FINISHED 3rd 4 TIMES
- FINISHED 4th 3 TIMES
- FINISHED 5th 1 TIME

NOTICE THAT MY AIRCRAFT'S ACTUAL SPEED AND ADJUSTED SPEED INCREASED WITH EACH RACE; A TESTAMENT TO MY CONTINUING PERFORMANCE IMPROVEMENT MODIFICATION PROGRAM.

FIGURE 9-1

OSHKOSH-500 RACE PERSONAL FINISH HISTORY entrants. The format of the initial CAFE-250 race varied significantly from the Oshkosh-500 race format, in that the CAFE-250 required numerous climbs and descents of several thousand feet. This race feature favored the smaller, lighter, and lower-powered "Quickie" and "Varieze" aircraft, which dominated the race. The only aircraft of comparable configuration to my Mustang-II to finish in the top 10 of the race was the factory "Glass Air".

I should also mention that at Oshkosh 1977, my aircraft won the Stan Dzik Outstanding Design award for Performance Increase Modifications.

From 1976 to 1993 my aircraft has continued to win awards at various chapter and regional fly-ins around the Rocky Mountain Geographical Region - Best Homebuilt, Best All Metal, Most Unique Homebuilt, Most Popular Homebuilt, and Ladies Choice.

CHAPTER 10

FLYING AND MAINTAINING MY MUSTANG-II

Twenty three years of flying and maintaining my Mustang-II has produced preferred practices and procedures which have enhanced the safety and fun of owning a delightful airplane.

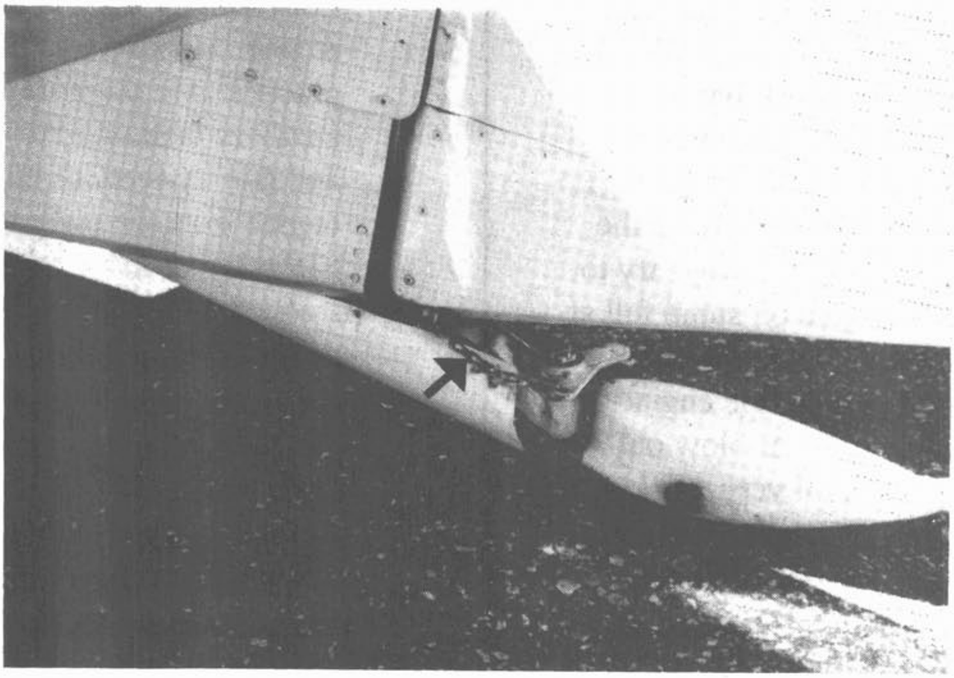
Originally, I had not intended to put any of my flying techniques or maintenance frequencies into this first edition. However, at Oshkosh 1993, many of the people who stopped by at the airplane on the flight line and at the Mustang booth encouraged me to do so. These people were all anxious to hear about the operating techniques and maintenance frequencies which I have developed over the past 23 years of successful and safe flying of my Mustang-II without serious incident or accident.

First, my personal flying techniques or operating practices:

- When I first started flying the airplane, I would always try to keep the engine oil sump full at the 8-quart level. However, for whatever reason, the engine would consume or blow out 1 to 1½ quarts of oil very quickly, then oil consumption would stabilize at about 10 hours per quart. So, now I try not to put or keep the oil sump at much more than 6½ quarts and don't add another quart until the sump is down to 5½ or 5 quarts. Just about everyone that I have talked to about this has had the same experience.
- My airplane has a 25 gallon main or header fuel tank which will gravity-feed to the engine. I also have an 8 gallon auxiliary tank, from which I must pump-feed the engine. However, the safest practice is to pump-feed the auxiliary tank into the main tank and gravity-feed all fuel to the engine from the main tank. Electrical or mechanical pumps frequently fail, whereas gravity never has.
- Also, since my auxiliary tank does not have a sump from which I can sample the fuel, I will pump a small amount of fuel from the auxiliary to the main tank during

the preflight, then sample the main tank at the gascolator. The idea is that if there is any water that has settled to the bottom of the auxiliary tank, pumping it to the main tank will get rid of it when I sample the main tank/gascolator.

- I do not use springs in the links between the rudder steering arms and the tailwheel steering arms. Rather, I use chain for the links and keep the chains adjusted slightly loose. I don't like the mushy, nonresponsive feel of springs in the links. There are times during gusty crosswind landings when I want the immediate steering response which the chain links provide.
- On my 5.00 X 5 main tires, I try to keep the tire pressure at 30 to 32 PSI gauge reading. That reading seems to give the most hours of wear from the tires.
- My Lycoming engine has natural harmonic frequencies at 700 RPM multiples (i.e. - 700, 1400, 2100, 2800 RPM). I try not to run the engine continually at any of those RPMs, especially 2100. In fact, many Lycoming powered aircraft are placarded not to run continuously at 2100 RPM. It can be a destructive propellor/engine frequency. On take off and climb out, I usually hold the nose of the aircraft down to let the speed pick up as quickly as possible, to pass through 2100 RPM very quickly to get to my 2300 RPM best rate-of-climb.
- When I put fuel into my auxiliary tank, I always use a funnel with a porous membrane incorporated in the funnel. This will stop any water from going into the auxiliary tank. The fuel passes through the membrane.

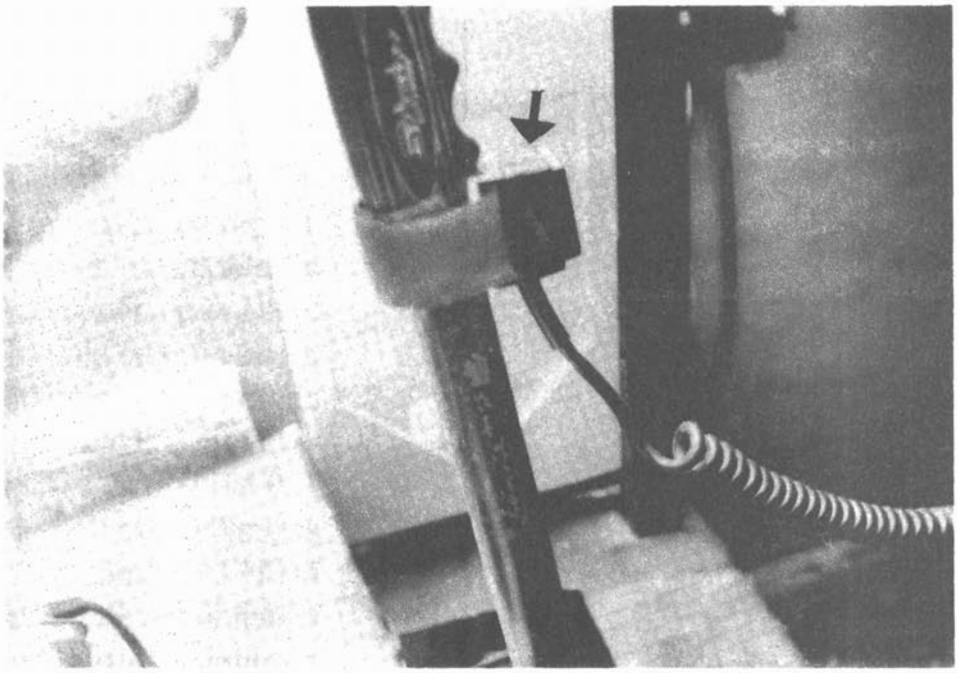


Direct chain tailwheel steering links give immediate steering responses.

This membrane-funnel will filter-out any water or other particulate contaminates in suspect fuel.

However, the water just beads up and rolls around on top of the membrane.

- When transferring fuel from the auxiliary tank to the main tank, I run the fuel through the fuel flow meter. The meter will then indicate when fuel transfer is completed. I also have a fuel filter in that fuel line.
- I have mounted the radio push-to-talk switch on the control stick, right below the stick hand grip, where I can activate the switch with my little finger.
- On take off, I bring the tail of the aircraft up as soon as possible, with full forward stick. This provides good forward visibility and provides maximum rate of acceleration. I accelerate to 70 MPH indicated airspeed, then rotate and the aircraft will start to climb with a good steady rate. I maintain a shallow climb until 120 MPH IAS. Then, raise the aircraft's nose to maintain 120 MPH IAS (and 2300 RPM) which is the aircraft's best rate-of-climb. This will usually peg my 2,000 feet-per-minute rate-of-climb meter up to about 8,000 feet altitude.
- Also, on lift-off I pull the carburetor ram-air handle which by passes the carburetor air filter and admits unfiltered ram-air directly to the carburetor. When the handle is pulled, the aircraft will surge ahead, as if I had kicked in an after burner. When landing, I will go back to filtered carburetor air, once I have the airport in sight.
- I enter the landing pattern at 100 MPH IAS and pull on the first notch of flaps. Turn base at 90 MPH IAS and pull on the second notch of flaps. Turn final at 80 MPH IAS and pull on the third notch of flaps. Hold 80 MPH IAS to the runway threshold, flare and touchdown. I usually make tail-low wheel landings. If



The push-to-talk switch mounted on the stick leaves the right hand free to operate other cockpit controls.

you try to stall-land the Mustang-II, the tailwheel will hit first and then slam the main wheels down to the runway and then the airplane will go bouncing down the runway - most embarrassing. Actually, during the flare, I will usually "feel" for the runway with the left main wheel (depending on the crosswind), then plant the right main on the runway. From experience, I have found it near impossible to find the runway surface with all three wheels, simultaneously. Sometimes with two wheels simultaneously. But, very consistently with the left main first. After I have both main wheels planted, I hold the tail up with forward stick, as long as possible, on the landing roll out. Then, when the tail wheel is planted, I bring the control stick full aft. Again, this promotes good forward visibility during most of the landing roll out.

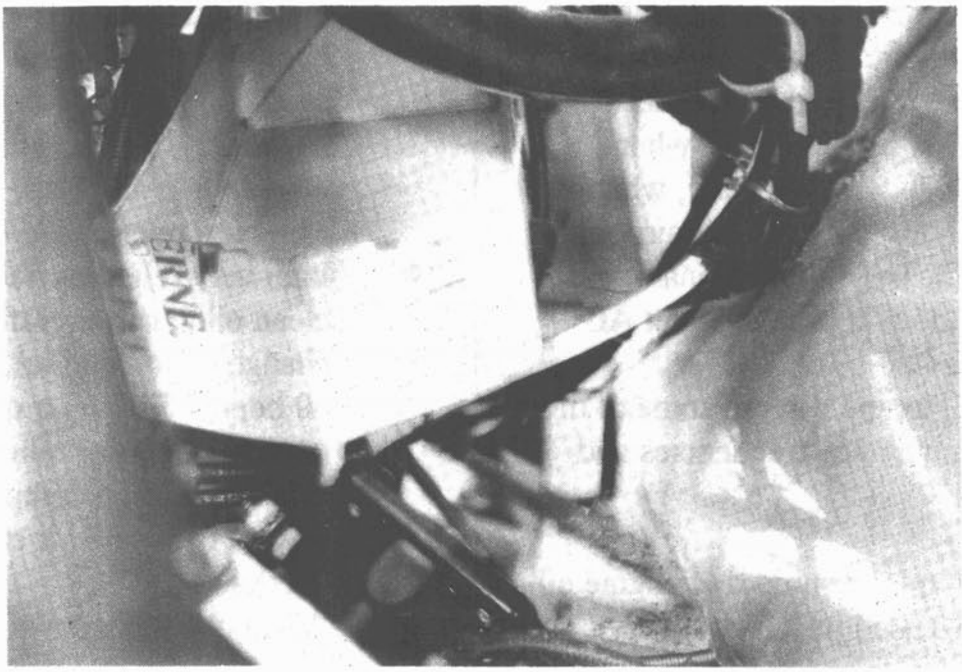
- When flying cross county, I like to fly at a high altitude to take advantage of the improved fuel economy and the stronger westerly winds. However, it does require extra fuel to climb to those higher altitudes. If the trip leg is 500 miles or so, the climb to higher altitude is certainly worthwhile. The reduced fuel flow for 2½ hours at altitude will more than compensate for the extra fuel burned to climb to altitude. But, if the trip leg is only 100 or 200 miles, a climb to only 1,000 or 2,000 feet above ground level can be justified, from a fuel consumption standpoint. Of course, if I am headed in a westerly direction and there is a strong air flow from the west, I don't want to climb very high into an even stronger west wind. However, I always want to climb high enough to be above the rough air caused by air flow over irregularities on the earth's surface. Also, with the higher land elevations here in the western part of the country, rough air caused by rising hot air (thermal activity) in the summer, is another consideration. On really hot days, the rough air caused by thermals can be as high as 13,000 or 14,000 feet. So, in the summer, most of my flying will be done during the cooler morning hours. Here, in Denver, we also have a 30 nautical mile radius Class B control area to deal with. So, of course, these requirements are the first consideration when flying locally. Usually, when I am flying to visit local airports in the Class B area, my maximum altitude will be 1,000 feet AGL or less.

Now, let me discuss some of my aircraft maintenance frequencies and techniques:

- First, on the subject of engine oil. I have used just about every brand and type of engine oil available. It seems that each type of engine oil had advantages and disadvantages. Rather than give a complete history of oils that I have used, just let me say that I prefer a multi-weight, synthetic oil for my airplane and my cars. However, full-synthetic oils (which I have used) do not handle the lead in leaded fuels very well at all. I burn 100 LL (low lead) fuel in my aircraft. After using a full synthetic oil in my aircraft engine for 250 hours, the interior of the engine was coated very heavily with a gray, sludgy deposit commonly called "gray paint". I do like the better lubricating qualities and the thermal protection of synthetic oil, though. So now I am using a multi-weight, semi-synthetic oil in my aircraft and believe that I am enjoying the best of what both petroleum based and synthetic lubricants have to offer. However, I do use full-synthetic lubricants in my cars, since the cars burn non-leaded fuel.
- I am very religious about keeping clean oil in my aircraft engine. I change the oil and oil filter every 50 hours. $4.00 per quart of oil is very cheap insurance, especially when compared to $8,000 for an major engine overhaul.
- When checking the oil level in

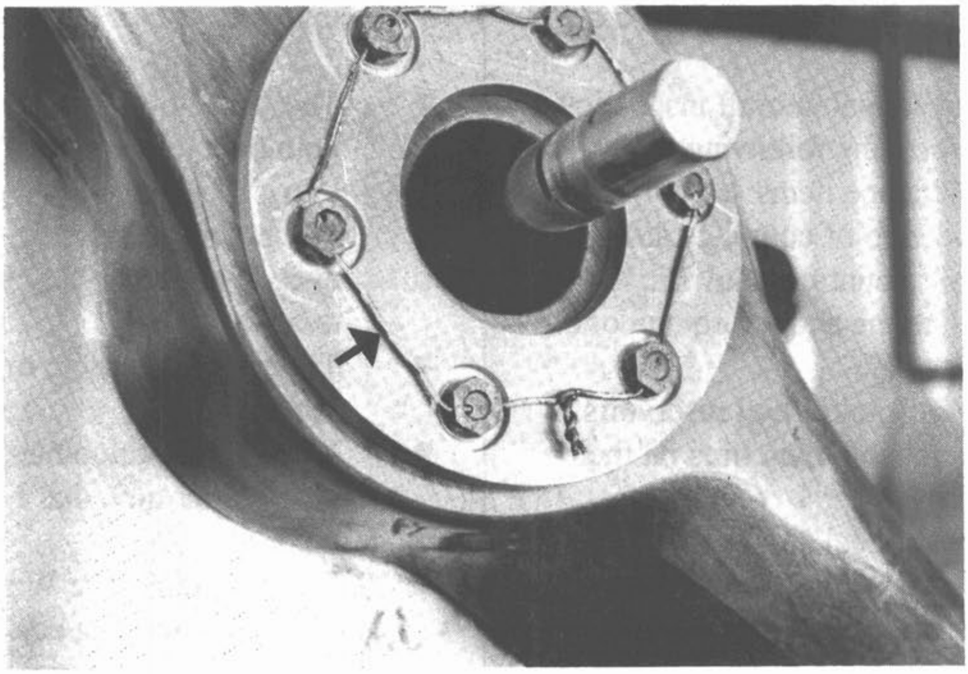
the engine, it seems that it takes 24 hours of inactivity for all of the oil to return to the sump after engine shut down. I have seen as much as 1/3 quart difference in dip stick reading between readings taken right after engine shut down versus a day later.

- I have a quick-drain fitting on my oil sump which makes it very easy to drain the oil without removing the lower cowl half. I always fly the airplane to bring the engine temperatures up to operating levels before draining the oil. When draining the oil, I level the engine by raising the aircraft's tail. Then, I leave the oil quick-drain open for 24 hours, to make sure that all of the used oil is removed from the engine.
- My engine has a spin-on oil filter, which makes it quite easy to replace the filter. However, even with a spin-on filter, the residual oil in the filter can still make a considerable mess in the engine compartment, when being changed. To reduce the mess, I cut a ½ gallon milk carton in half, vertically. Each half of the milk carton makes a small, easy to handle drip pan to put under the filter as I am unscrewing it. Incidentally, I change the filter after all the oil had drained out of the engine and the engine is cooled down (after the 24 hour wait period).
- At the 25-operating hour intervals, I retorque the propellor bolts (18-20 ft.lbs.). So I don't have to remove the spinner to do this retorquing, I have captured the propellor bolt heads by drilling the bolt heads and using light-coat-hanger wire to wire all the bolt heads together. This

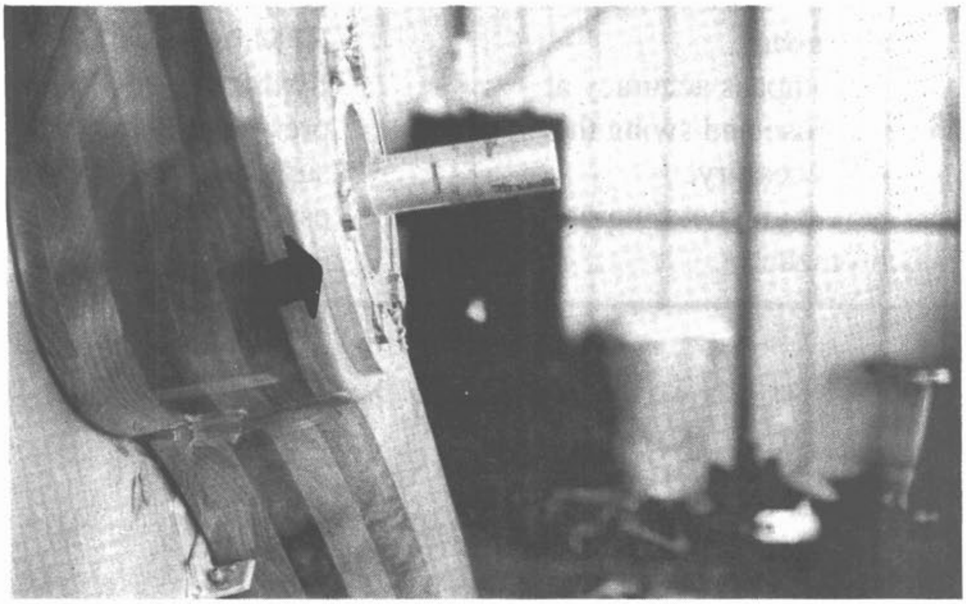


A ½ gallon milk carton, split vertically, makes a small, easy-to-use drip pan when changing the oil filter.

regular retorquing of wood propellor attachment bolts is extremely critical. There have been numerous instances of propellor bolts coming loose, being sheared off and aircraft losing propellors in flight, all due to ignoring the need to regularly retorque the bolts. In order to obtain and hold the aforementioned torque values, it is absolutely mandatory to install



Wiring the propellor bolt heads together allows me to retorque the propellor nuts without removing the spinner shell.



The propellor anti-crush plate allows a higher torque to be held on the propellor attachment hardware.

a 5/16" thick aluminum anti-crush plate under the bolt heads.

- While I have the top of the cowling removed to retorque the propellor bolts, I also service the battery which is mounted on the firewall.
- At the annual aircraft inspection, I perform the following maintenance items:
  -Inspection of complete airframe and all mountings and installations and retorquing of all fasteners.
  -Top off brake fluid reservoirs.
  -Reverse the main tires on their rims.
  -Check wheel alignment (geometry).
  -Oil/grease all hinges and slip-joints.
  -Clean, gap and rotate the spark plugs using anti-seize compound on the plug threads.
  -Check the compass accuracy at the compass rose and swing the compass, if necessary.
  -Check/correct magneto timing and synchronization.
  -Touch up all paint.
  -Replace all joint sealing tape.
  -Vacuum cockpit area.
  -Clean engine compartment and aircraft belly.
  -Clean and polish aircraft exterior.

- The wheel bearings are repacked with high temperature grease every 2 years.
- The brake pads are replaced every 3 years, or sooner, as wear dictates.
- The main tires seem to last about 300 tach hours.
- I replace the tire inner tubes every other time that I replace the tires.
- Since I had Bernie Warnke put the plastic leading edges on my wood propellors, propellor maintenance has been minimal. However, I still pull the engine RPM back to 1800 whenever I fly through any rain. This prevents rain erosion of the surface finish of the propellor, especially the leading edges.

ACRONYMS AND ABBREVIATIONS

AGL = Above ground level
AIAA = American Institute of Aeronautics and Astronautics
ALCLAD = Aluminum clading
ALT = Altitude
BTDC = Before top dead center
Carb = Carburetor
CAS = Calibrated airspeed
C.G. = Center of gravity
CHT = Cylinder head temperature
Coax = Coaxial cable
Comm = Communication
Cowl = Engine cowling
CT = Cylinder head temperature
DC = Direct current
Dia = Diameter
DOT = Department of Transportation
EAA = Experimental Aircraft Association
EGT = Exhaust gas temperature
ET = Exhaust gas temperature
FAA = Federal Aviation Administration
Flex = Flexible
FMEA = Failure mode and effects analysis
FPM = Feet per minute
FT. = Feet
GPH = Gallons per hour
Hi-temp = High temperature
IAS =Indicated airspeed
Lbs. = Pounds
LL = Low lead
Mhz = Megahertz
Moly = Molybdenum
MP = Manifold pressure
MPG = Miles per gallon

MPH = Miles per hour
NACA = National Advisory Committee for Aeronautics
NASA = National Aeronautics and Space Administration
NAV = Navigation
OAT = Outside air temperature
OT = Oil temperature
Oz. = Ounces
Prop = Propellor
PSI = Pounds per square inch
PTFE = Polytetraflourethylene (Teflon)
RF = Radio frequency
RPM = Revolutions per minute
Tach = Tachometer
TAS = True air speed
TCA = Terminal control area
Temp = Temperature
TV = Television
VOR = Very high frequency omni-directional ranging

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