Aircraft Cooling 102 for Tractor Installations of Air Cooled Engines
Or
"Cooling the Jabiru 3300 in the Europa XS"

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Introduction

This document is a compilation of information, techniques and comments specifically for the Europa owners and their cooling issues with the Jabiru 3300 engine. It is a series of fixes and or experiments I have found to rectify cooling issues in our Jabiru equipped Europa aircraft. The general description of the Jabiru is given below. Part 1 is a brief history of air cooled engine propulsion design issues. Part 2, is the Jabiru cooling requirements /cylinder fin and oil cooler sizing and a description of the Jabiru aircraft cowl cooling ducting as set by the manufacturer. Part 3 is a practical analysis of the Jabiru cowl problems of cooling the opposed 6 cylinder Jabiru engine using the stock or aftermarket cowls, and some acceptable modifications for successful cooling with these cowls. Part 4 is other cooling techniques which have proven to enhance cooling efficiency even further. This document will not address the uneven mixture problems solved or exacerbated by aftermarket add on intake manifold devices, however, I will touch on induction or carburetor intake fixes which we found greatly improved engine induction and improved engine operations and temperatures over a broader flight envelope. Propeller choice options for the Jabiru 3300 will also be touched on as we have found some concerns are unwarranted.

The Jabiru Engine General Description

The Jabiru 3300 six cylinder engine is a relatively inexpensive and attractive six cylinder engine which produces 120 HP, at 3300 RPM. The torque of the engine is nominally 205 ft. lb. at about 2400 to 2700 RPM but unfortunately, torque begins dropping off rapidly above 2900 RPM. The engine is made from billet aluminum, machined to close tolerances. It is an easy starting and smooth running engine. The engines history is checkered, as the Jabiru 3300 has been plaguing many, if not all, home builders as well as experimental aircraft kit, SLSA and ELSA aircraft manufacturers, due to its tendency to overheat on new installations. In general, during ground operations or when producing over 75% power, the engine has difficulty dissipating heat. We at Custom Flight Creations, Inc. used tried and true NACA and engineering propulsion practices to implement, verify and document proven solutions to the cooling problems of the Jabiru 3300 when installed in the Europa Kit Aircraft.

Our Experience

We have installed or worked on three Jabiru 3300s in the Europa XS with modest success. Our first two aircraft were monowheel aircraft. One was a mono wheel and used the original Jabiru stock cowl, the other was a mono wheel with an aftermarket cowl. Both aircraft only used our cowl modifications. Recently, another owner gave us full authority to fix all the problems and make his aircraft reliable and pilot friendly. The test aircraft was a Europa XS tri-gear with an aftermarket Jabiru cowl manufactured by a Canadian firm with round inlets which was initially distributed by a US dealer, Andy Sylvest. The problems the owner identified for us to correct were: ground overheating, overheating in the climb, shock cooling in descents, uneven cylinder cooling, and excessively high oil temperatures. This aircraft exhibited high EGT in cruise, and the engine would stop if the carb heat was pulled in-flight at pattern airspeeds and altitudes. The aircraft was terribly slow at about 107 KIAS at 2700 rpm cruise and 117KIAS at 3100 RPM at low altitude. Our client's preferences were to cure the above and achieve cruise speed increase through better air flow, ducting, and speed kits to achieve a 2750 RPM cruise of minimum of 120 Knots IAS at sea level and 130 Knots IAS at 2900 RPM.

We achieved the wishes of the owner with the following:
20 minutes of ground taxi time with RPMs from 800-1000 no wind.
Full power 90 KIAS cruise climb to optimum cruise altitude of 7500 MSL with cylinder head temps below 302 F (Original Jabiru solid lifter maximum continuous).
Cruise speed increase through reducing cooling drag via ducting, improved cowl flow, and a speed kit to achieve a 1000 MSL, 2750 RPM cruise of 126 Knots IAS at sea level and 136 Knots IAS at 2900 RPM and top speed of about 137 Knots flat out. Cross country performance has shown 125KTAS at 7500 to 9500 MSL at 2650 RPM at just under 6 US gallons per hour. Climbs to 9500 at 90KIAS yield max cylinder heads temps of less than 300F at full power, burning roughly 10 US GPH in the climb at 500 FPM average rate of climb.

Part 1.

First the issues affecting propulsion and cooling must be analyzed. The designer of an air cooled engine equipped aircraft looks at the following:

I. The requirements of a cooling system (in BTUs) must meet the following for successful light aircraft engine operations year round:
   A. Ground ops Taxi/idle
   B. Takeoff/Run-up
   C. Climb at Continuous Power
   D. Normal Cruise and Economical Cruise at Recommended Power Settings
   E. Rapid Descents/Throttle Transients
   F. Max Power / Max Speed

II. Transmission of Power
   A. The propeller power transmission or torque curves should be known and are assumed at 78%
   B. Ground operation cooling must count on propeller static thrust air movement and the existing wind conditions to provide normal ground operations.
   C. Propeller air movement around the cowl inlets must be known to determine the inflow rates for all ground conditions. Flight conditions are assumed to be free air stream speeds.

III. A/C Engine Cowl/Nose Shape.
   A. Normally the aircraft nose shape of an air cooled tractor power plant is determined by the designer. The designer may choose to put the cylinder heads out into the slip-stream, however for better efficiency he will cowl the cylinders. He then has some concern about cooling inlets and exit flows. The requirements of the cowl are normally for aerodynamics, inlets are sized to meet propeller spinner and a smooth engine enclosure as well as cooling inlet air for the engine cooling.

   B. Inlet shapes, areas and placement are designed based on the ideal cruise conditions and average inlet and exit areas proposed by the engine manufacturer. Then they are modified to suite ground operations, takeoff, climb and descent conditions.

Example abound in the history of aircraft development:
In the early history of air cooled engines the cylinder barrels were placed out in the free air stream for cooling. In 1927, an NACA team led by Fred Weick (Collier Trophy winner and designer of the Ercoupe) at Langley stood at square one with the following:

"*The goal that we had set for ourselves was a cowled engine that would be cooled as well as one with no cowling whatsoever. This program proceeded easily enough until the complete cowling, covering the entire engine, was first tried. At this point, some of the cylinder temperatures proved to be much too high. After several modifications to the cooling air inlet and exit forms, and the use of internal guide vanes or baffles, we finally obtained satisfactory cooling with a complete cowling.* In the 30's and 40's much research was accomplished at the Langley Research center and the NACA ring cowl showed great improvements in speed and cooling. The NACA cowl reduced drag of aircraft like the Lockheed Air Express and Vega by 2.6 times. Eventually the cowl was more carefully tested and later designed to be a pressure cowl, and by WWII radial engines were able to fly as fast as many inline designs despite huge flat faced cowls.

This is evident on the photo of the early Lockheed Vega below.

Figure 1a. Vega 1 prior to NACA cowl improvements above.

Figure 1b. Lockheed Vega with newly installed NACA cowl.

Later, radial engines gave way to the now popular horizontally opposed four and six cylinder engines. This same ducting technology was applied to the horizontally opposed air cool engines and great improvements in speed and economy prevailed. NACA Contractors Report 3405 is a superb reference for solutions.

Figure 2a.   J-3 Cub with over cylinder scoop.

Figure 2b. The later fully cowled Super Cub.

IV. Cooling Techniques used on Air Cooled Aircraft:

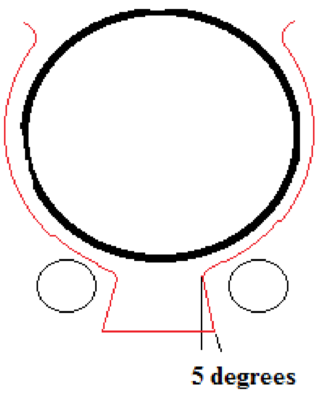
A. The cylinders of the air cooled engine are equipped with fins around the barrels, heads and in some cases the oil pan and cylinder block are finned. These finned areas need air flow commensurate with their BTU transfer requirements.

1. Each operating envelope must be gauged from I. above to insure the engine temperatures can be kept within limits.
2. Operational procedures must be devised to insure proper pilot technique, climb speeds, descent profiles and cowl flap configurations are maintained for all flight phases.
3. Basic good operating principles such as run up into the wind, hold into the wind when possible, limit high RPM when on the ground are assumed.

WWII saw the greatest research on cooling of air cooled engines to include how to baffle the irregular shape of a cylinder. NACA report 662 is adamant that the front or top of the cylinder be open to the turbulent cold air inlet, and the aft 50% be controlled via baffles or ducts to push the air through the fins of the cylinders. Although not routinely done due to maintenance concerns, the aft / bottom of the cylinders normally had a complete duct with smooth exit as shown in the picture 3and 4 below:

NACA Wartime Rpt 3H16

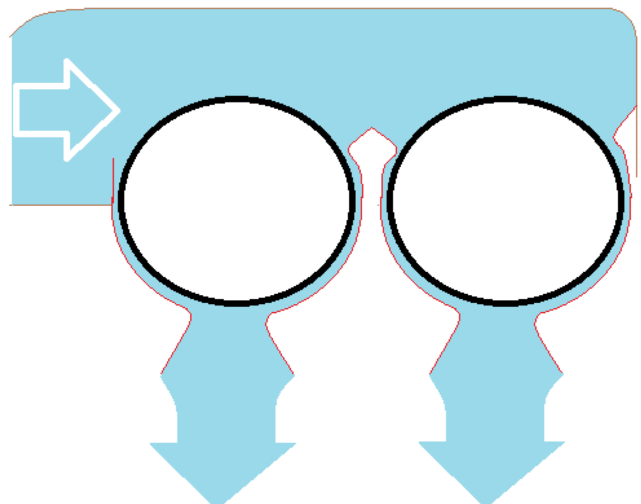
Improved Baffel Designs for Air Cooled Engine Cylinders



Note that this shape of the red baffel was done for a large R2800 style twin row radial but was adapted by many of the Lycoming and Continental engine experimenters to improve all around cylinder head cooling. Note that the face of the cylinder is basically open to the ram air and is ducted around the cylinder fins and push rods.

Figure 3

Air Deflectors and Baffels for Flow Control



**The horizontally opposed engine designer has an upper or lower intake mated to a plenum with the cylinders carefully ducted to allow flow of all plenum air through the cylinder fins and out the cowl exit.
Upper intake with lower cowl exit shown.**

Figure 4

B. Engine accessories and their air cooling must be anticipated.

1. Alternators and under cowl components such as regulators, ignition coils or gascolators must be cooled/vented or heat shielded for proper operation and longevity.
2. Fuel and oil lines must be protected when near exhaust or when trapped in hot air stagnation areas to prevent vapor lock (the vaporizing of the fuel due to high fuel line temperatures.

C. Engine compartment purge.

1. Mufflers are necessary for happy neighbors but the heat of the exhaust system must be purged from the engine compartment and from overheating fuel/oil lines or components especially during ground operations.
2. Cowl materials (fiberglass) must be protected from excessive heat to prevent structural and cosmetic problems.

V. Designs to meet all the above criteria are sent back to the aircraft designer from the propulsion engineers for incorporation into the nose cowl design.

A. Ducting and inlet size

1. Duct size and design is redrawn into the basic cowl design.
2. Oil and or carburetor inlets must be sized and positioned properly.

B. Cowl exit air design

1. The cowl exit must allow proper draw at low speeds and yet allow cowl air to be reintroduced into the slipstream near flight speed.
2. Provisions must be made for aerodynamic gimmicks such as cowl flaps and inlet scoops to improve cooling in other than cruise flight.

VI. Testing and validation. The final configuration must be exhaustively tested and fine-tuned before production can take place. Prototypes must be modified before production molding. It is easy to one off a component, but full production must include cost, time and materials. Kit manufacturers also must consider the capabilities of the average builder to install the fire wall forward components.

Part 2

Cooling requirements of the Jabiru given by the manufacturer are:
Free Air Cooling: 1.7 inches of water pressure must be maintained over the cylinders during takeoff, and a minimum of 2.4 inches of water pressure at cruise.
The older Jabiru 3300 with solid lifters has the most critical temperature range and will be discussed.
Max continuous cylinder head temp (F) 302
Max cylinder head temp (F) 348
Max oil temperature (F) 244, the delta P over the oil cooler should be at least 2.4 inches.

The fins on the Jabiru cylinders are thick and spaced at nearly 1/8 of an inch, so air flow passes through the fins quickly which provides barely adequate heat transfer. No paint is applied to the engine to absorb heat and promote transfer. The plenums are designed with many areas of large gaps around the heads and the pressure loss is excessive causing little or no cooling at low speeds. This is not the only problem with the plenums.

Original plenums were designed with all wires outside the plenum fiberglass but the plenum failed to allow proper airflow around the head. Most operators agree that these plenums are to be discarded. The plenums are molded as one piece, therefore servicing of the engine requires removal of plenums which stresses the rather taught wires. So, pulling the spark plugs and CHT probes for servicing, such as during normal compression checks or spark plug maintenance, requires complete removal of the CHT and Plug wires forced through the plenum grommet. The plenums are made of fiberglass and as a consequence even with the best craftsmen, the valve cover hold down screws, used to retain the plenum, tend to crush the fiberglass eventually breaks down the glass. As supplied, the plenums do not seal well and allow excessive air losses and fail to meet even the modest pressure differential requirements set forth by the manufacturer.

Old style Jab plenum is unacceptable.

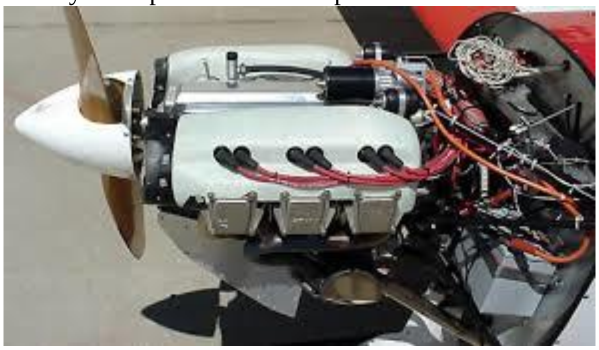


Figure 5. Original Plenum Supplied

Current Jabiru Plenum

Figure 6. New Factory Plenum

History of Jabiru cowl designs:
The Jabiru stock cowl designed for the Europa was developed from the Jabiru 400 and was pleasing in shape and fit the Europa and most other aircraft well. It is adequate for cylinder ram cooling at cruise flight speeds but needed more draft to help airflow through the engine cylinders. However, it was inadequate for cooling the oil, and the oil cooler was inadequate in size. A fixed duct exit failed to draw enough to pull cylinder exhausted air to allow more inlet plenum air inlet to continue to cool the cylinders. Plenums were just open fiberglass ducts without any flow control other than metal Vs which fit poorly between 2/4, 4/6, 1/3, 3/5 cylinders. The carburetor induction system provided carb heat and cool air induction but was not proper for Bing carburetor operations over the entire range. The cowl exit was a small ramp located about 4 inches forward of the mono firewall but only extended down into the airstream about 2 inches and just did not draw enough for operations on the ground, in climb or inflight.

Figure 7 Stock Jabiru Cowl

Figure 8 Later aftermarket Jab cowl.

On one early installation on the stock Jabiru cowl a cowl flap was installed to increase the draw but it was evident the lunch box style over cylinder engine plenums were leaking badly, inadequate in size and easy to install improperly. The client allowed us to install a movable cowl flap to improve cylinder cooling. With this change, if his start to takeoff was less than 10 minutes and he climbed at 2750 RPM at 90 KIAS he could step climb in increments, leveling off and allowing the cylinder temps to subside, then resuming the climb. Later a new aftermarket cowl was procured from a US dealer.

An aftermarket cowl arrives on the horizon:
This aftermarket cowl had a NACA like duct for the oil cooler, round 4 inch inlets and a large hole in the bottom of the cowl with a lip to improve the draft on the cowl air exit. Alas, the new cowl did not cool any better. The NACA type duct had very round edges negating the vortex to pull in air. The oil inlet was optimized for an automotive oil cooler and no ducting was planned for. The cowl exit and the slope of the lower cowl actually rammed air in from the exit during slow speed climbs. Unfortunately, this is common for most Jabiru installations (including the Jabiru kit aircraft). Owners/dealers blamed the propeller, installers, and type aircraft, however, as we stated in Cooling 101, if the engine cools with the cowl off and equipped with Piper Cub like air deflectors, then it is the cowl.

Both cowls house the engine well and fit the Europa fuselage and allow for 1.5 degree right offset. The spinner size is for a 7.8 to 8 inch spinner and wood Sensenich propeller.

The stock cowl and later cowl have the same basic elements except for the exit and oil cooler installations, so they will be discussed as one.

Each of the Jabiru cowls has an inlet area of approximately 16 square inches per side to fit their custom lunch box style plenums. This is an adequate inlet area as discussed above for cruise and cruise climb speeds of 90 KIAS. As far as positioning of the inlets, they work well for the speed range of the Europa aircraft. However, the wider spaced inlets on the aftermarket cowl tend to have higher popularity in the US market. This was thought to improve ground cooling and admit more airflow due to being closer to the cylinder head and propeller blade shape tends to begin forcing air down the inlet. The wider spaced inlets can take advantage of the air flow off the propeller (especially constant speed propellers) during ground operations and at very slow climb out speeds.

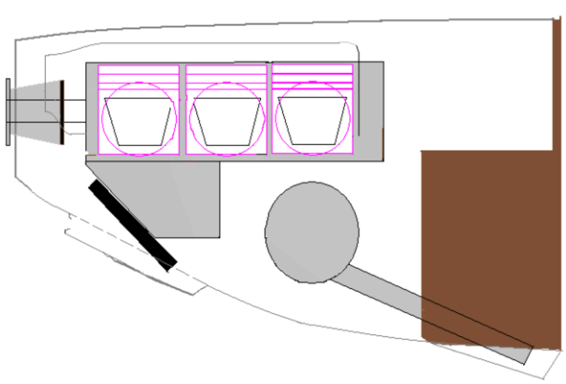


Figure 9. Original Jabiru Cowl Layout.

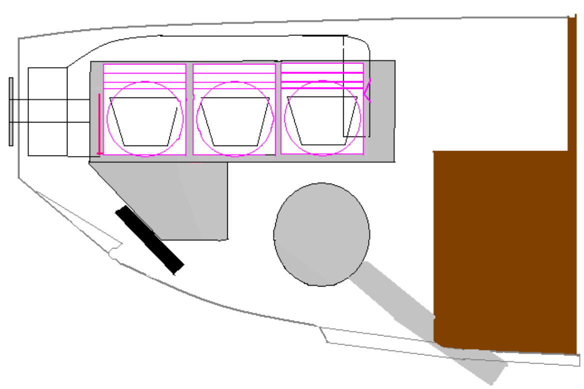


Figure 10. Later Jabiru Aftermarket Layout

Part 3.

Analysis of Europa with Jabiru engine cooling problems.

It is evident to most owners that the cooling of the Jabiru 3300 is unacceptable with ambient temperatures above standard day conditions. Full power operations normally cannot be conducted without overheating above 70F ambient temperature. Max angle of climb or even max rate of climb speeds do not provide for sufficient cooling at maximum continuous power settings. Since running the Jabiru 3300 on the ground without the cowl or plenums doesn't cause rapid engine overheating, this leads me to assume (ASS out of U and ME) the cowling has cooling efficiency problems.

The Europa Trigear aircraft seldom have the problems cooling that the mono wheel has with the original cowl, and the later cowl is barely acceptable for flight. Many trigear owners build a firewall aft of the nose gear trapezes as identified in Cooling 101. The movement of the firewall of the trigear aft, some 16 inches behind the nose gear springs, provides for 100 square inches of additional exit air from the cowl, aiding in the draft and providing additional airflow and better cooling during high power/cruise climb airspeed operations as well as ground operations. Cruise power settings in the trigear equipped with a stock or aftermarket cowl rarely encounter cylinder overheating even when outside temperatures exceed 95F. Therefore most of the discussion below will apply to the mono wheel and its peculiar problems. The techniques employed for mono wheel cooling would enhance trigear operations as well.

Cooling Analysis of the Current Europa XS with Jabiru Stock and Aftermarket Cowl:

Cowl shape.

The cowl shape is as close as is practical to the engine and allows for ease of assembly. Insufficient room is allowed for clearance from the front (1 and 2 cylinders) without a two inch prop shaft extension. The two inch prop extension is standard for the Europa. The inlet is of sufficient shape to meet Jabiru manufacturer inflight requirements of 16 inches each. The original cowl inlet leans heavily on AIAA79-1820R study of inlet positions and its air exit is fixed and like the XS Rotax and is a very low cowl ramp and a bit too close to the mono firewall limiting cowl air exit. The inlets of the aftermarket cowl are round and are nearly flush with the cowl face. They are nearly aligned with the center of the barrel/head combination. The later aftermarket cowls has a 13 inch wide 12 inch long cutout in the bottom with a small lip. The rounded shape of the lower cowl on the aftermarket cowl is a pleasing shape but at low speeds **tends to act as a cowl scoop** eliminating effective cooling air draw and proper pressure distribution over and under the cylinders.

Both cowls are made for an average sized spinner of 8 inches and accommodates most propellers of either fixed, ground adjustable or now the Airmaster constant speed AP420 or similar.

Oil cooler size and placement.

The oil cooler originally supplied for the Jabiru was totally inadequate. It was mounted up against the front of the oil sump face. The inlet of the stock cowl was not sufficient in size nor did it have sufficient inlet, ducting or exit control for proper cooling. On the aftermarket cowl, the oil cooler inlet is slightly larger. The original oil cooler was inadequate as it was a cheap auto aftermarket VW cooler. We highly recommend installing an aircraft approved type, such as the Aero Classic, and today this style cooler is now provided by Jabiru aircraft in their factory built aircraft. This cooler provides 120 square inches of plate area with a face area of 40 square inches and should be suitable.

The inlet and cowl shape is inadequate in size and shape for a proper oil cooler now recommended by Jabiru like the 7 or 8 bar oil coolers however, it will require cutting and fitting.

No provisions are made for sealing the oil inlet air intake to the oil cooler face or directing it out of the cowl by the manufacturer.

Over cylinder air ducts or plenums are provided for cylinder and head cooling. Normally, the engine is installed using these unmodified RAM AIR ducts provided with the engine. The ducts themselves are assembled loosely to the cylinders and flow control inside the cylinders is via aluminum V shaped vanes between the cylinder barrels and fiberglass triangle deflectors assembled to deflect air toward the head plugs as detailed in the installation manual. The fiberglass ram air ducts are screwed to the engine directly using the normal rocker cover screws. Unfortunately the duct is not fastened in such a way to the engine which would close off air leaks around the cylinders and heads. These leaks seriously reduce the pressure balance inside the plenum, allowing much needed air to be directed away from cooling fins and impede head cooling. It is a common thought that during ground or low speed operations the propeller was required to have significant pitch and blade area on the section immediately in front of the air inlets to provide all the cooling air. This thought continued to be the standard concern with the original cowl as it was felt the inlets at the hub of the propeller were at the least efficient part of the prop. The aftermarket cowl attempted to correct this with its round inlets some 4 inches from the spinner rim. However, experience has shown that much of the cooling of an air cooled engine is drawn into the inlet by the shape of the cowl exit and the draw at the back or bottom of the cylinder. At idle, it is common to have 35 knots of prop blast going around the cowl. If designed properly, the cowl exit will actually draw air out of the cowl and into the inlets and plenums.

Another problem was cooling of the coils. Jabiru required a ½ inch tube from the plenum to be manufactured to blow air on the coils, later they added a requirement to make a one inch hole in each plenum to blow air across the crankcase. This cools the coils with ram air but robs air from the plenum and reduces pressure in the plenum greatly. At low speeds, the tubes actually suck air from the coils through the lower cowl allowing the coils to heat up during ground operations.

Through my initial testing with the US dealer and owners we found we needed a pressure differential between the top of the cylinders and the cowl of about 4 to 6 inches of water pressure to get effective head cooling. These extra holes made getting that kind of pressure impossible.

To better flow air from the plenum through the cylinders, Jabiru used "V" shaped "Gull Wing" baffles to control flow and losses of air between each cylinder barrel fins. The fit of the Vs are poor against the fiberglass plenum. Nothing is done to improve air flow immediately under the cylinder barrels. Early on, Jabiru contended that the gull wings should be dropped "as a significantly larger volume of air must be sucked between the cylinders to improve cooling. This often requires a larger cowl outlet or a larger lip on the existing outlet". They were wrong.

The cooling plenums (ducts) provided are a starting point in establishing effective engine cooling, however we found the ducts needed heavy modification for cooling and maintenance considerations. Specifics of each cowl is amplified below:

The Original or Supplied Jabiru Factory Cowl:
The stock cowl is adequate for inlet size but the exit air space and mechanical draw is a bit small at only about 65 square inches. The original cowl has another handicap in that the lower cowl angle is at an angle where in climb and cruise the lower cowl duct exit is at too low an angle and tends to negate its effectiveness. Jabiru advocated adding a larger inlet lip, but it ends up being a very effective airbrake before it adds enough cooling suction. Hence it became obvious there was a need for a cowl flap for ground operations, low speed climb and even at economical cruise speeds to achieve proper draw through the cylinders.

The cowl air inlets for the baffles were not modified. The oil cooler inlet was significantly enlarged and the oil cooler was repositioned to allow a bit more flow inlet. The vertical oil cooler was ducted around the top and sides and cowl seal material used to seal the duct to the bottom of the cowl. The exit was enlarged and a small adjustable metal cowl flap was made to increase cooling flow.

Cooling flow in the original Jabiru Cowl

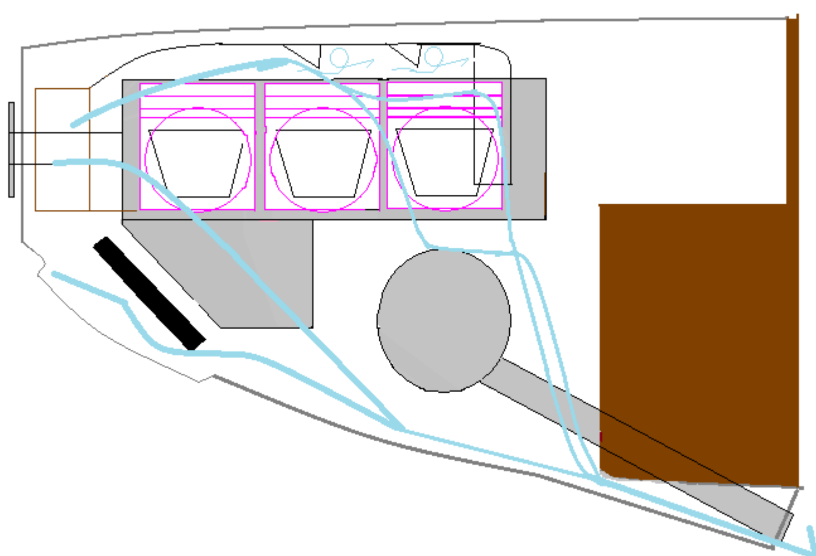


Figure 12.

Oil cooling was now adequate with the VW style oil cooler and cowl draw sufficient but extensive work was needed on the plenums. The owner chose to change cowls.

The Aftermarket Jabiru Round Inlet Cowl:

This cowl tries to use the excellent ram air inlet pressure recovery design identified by NASA, used by Lopresti on civil aircraft and now so effectively used on the Lancair Aircraft. However, this cowl has smaller inlets than desired, oil cooling inlet deficiencies and cowl exit area problems prevent proper cooling. The oil inlet is a NACA type duct with an inlet lip that is rounded and the duct edges rounded as well. This greatly reduced the effectiveness of this oil inlet. The oil cooler was not set fully square to the inlet face nor was there any ducting for air exit. The exit hole was discussed above and found totally inadequate for cooling draw. Luckily the corrections are easy for the average builder.

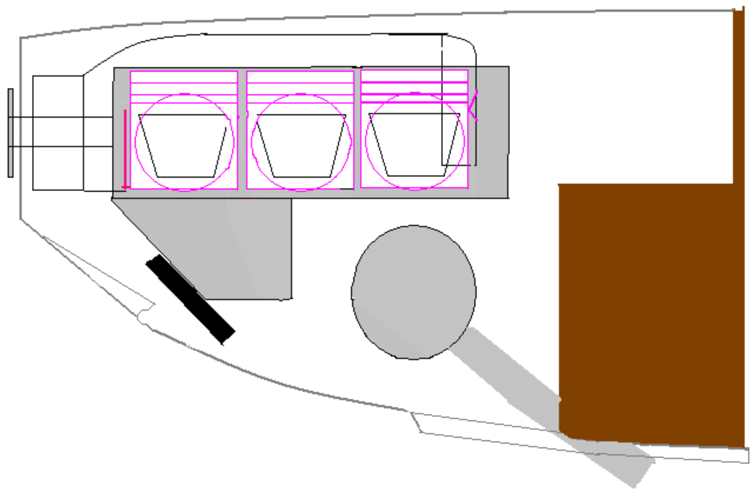


Figure 13. The typical installation of the aftermarket cowl is shown above.

The 4 inch round inlets were left unchanged in our cowl modification. The newer round inlet aftermarket cowl needs a slightly larger inlet (5 inch diameter) for ground cooling and low speed operations, but the 4 inch can work. Many aircraft manufacturers are now transitioning to much larger inlets and plenums to achieve acceptable operation.

The cowl exit air hole has a Cessna 150 type ¾ inch lip to create a draw out of the cowl. As I stated before, the cowl is angled down and aft, for a pleasing shape, however, at low speeds the exit hole acts as an inlet, trapping air in the cowl. It was obvious that on inspection on the ground, with the tail at level flight attitude, we could clearly see the mono firewall. This accounts for the poor cowl performance and prevents a proper pressure differential required over the cylinders. Initially an extension to the cowl lip was manufactured to improve the draw of the cowl. It had no effect. Jabiru Australia suggested we add a three inch slopped 70 degree flange to improve our draw problem. Not wanting to add more of a speed brake, it was evident, the exit of the cowl must be removed and a fixed ramp (cowl flap) manufactured of fiberglass to draw cooling air. The owner requested the ramp to be fixed. During testing the ramp was adjusted to achieve an average setting which would allow for ease of pilot workload and still give all around engine cooling and ease of cowl maintenance. We found a ramp of three inch deep and full length and width of the existing opening allowed sufficient draw for normal operations. More on that later.

The NACA style oil cooler inlet is poorly executed and instead of having a sharp edge with a straight inlet lip, it has rounded edges and the lip is rounded which decreases the efficiency of the inlet reducing the oil inlet air flow. The NACA duct inlet lip curl was removed leaving only a sliver of glass however the sloped sides were left alone. The oil cooler was then set fully square to the inlet face. The oil cooler inlet from the cowl to face of the cooler was sealed by a metal duct, cowl seal and the hot exit air was ducted aft, under the muffler to the air exit.

At Custom Flight Creations I rarely look only to the analytical answers to cooling issues, I do rely on the principles of experimentation used by the early NACA pioneers. We use the analytical and theoretical approaches, but rely heavily on testing to validate the effectiveness of the theory execution. In the case of the Jabiru 3300, we felt the Jabiru factory was on the right approach but their execution is typical for a manufacturer. If it requires new moldings, they are not prone to make changes, just add ons.

Figure 14 and 15. As can be seen in the above photos, the metal duct is sealed tightly, and the photo on the left shows how the lip of the oil inlet and the cowl exit ramp were included in the cowl to still leave the cowl pleasing in shape. However, all was not well initially.

The next major issue was the plenums:
Initially clients wanted to stick to Jabiru approved (or internet chat room solutions) and not deal with the plenums. Since no factory, aftermarket or internet chat room solution proved to viable we fell back on sound tried and true practices.

The lunch box plenums were extensively modified. A fixed sheet metal plate was added to the valve lifter faces to improve the fiberglass plenum attachment and help control flow as originally done by John Lawton. To facilitate maintenance (access to plugs and wiring) the lunch box was cut off at the rear, and a lip manufactured for a tight fit. Nut plates were added, which allowed easy access for cooling fin adjustments and duct and cylinder maintenance. A full fiberglass plate was placed against the front cylinders so as to direct air over the front cylinders, and minimize front cylinder shock cooling on throttle reduction.

More metal and or fiberglass seals were added to the ducting to keep air flow through the cylinders rather than out the rear as detailed below:

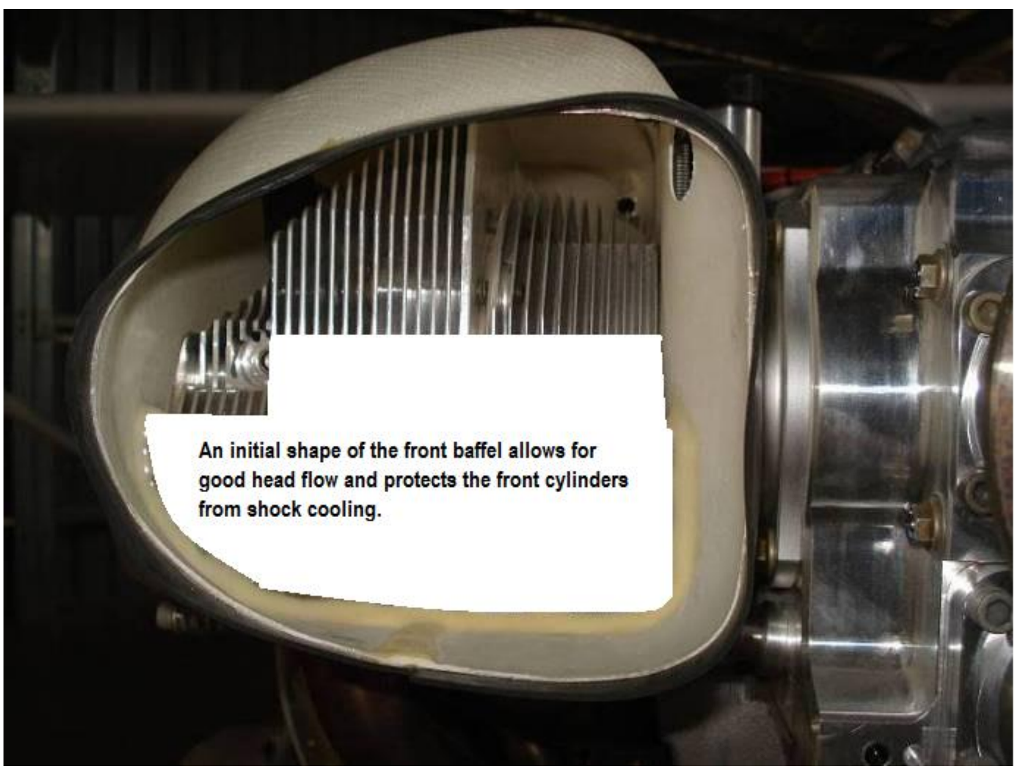


Figure 16. Fashion the front air dam from four layers of glass and lay release tape on the cylinder to allow the glass to be as tight to the cylinder as possible.

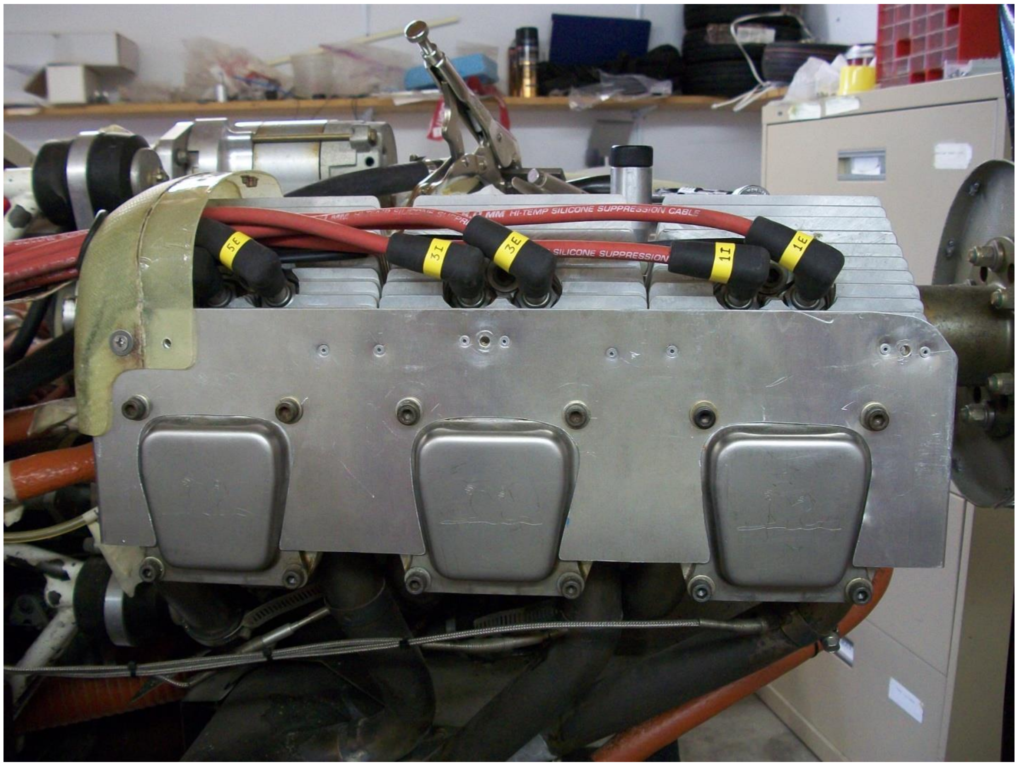


Figure 17. First a metal side skirt was fabricated to attach the lunch boxes to the cylinders. The metal side skirt allowed the attaching screws through metal solidly to the cylinder heads. The sheet metal work is extended a bit lower on the cylinders to deflect more of the air down through the head fins in an attempt to improve flow and dissipate more heat. The fiberglass lunch box plenum is attached to the side skirt via nutplates, screws and sealant. Note no beneath the cylinder ducting is provided.

Figure 18. The new fiberglass plenum is installed using 5 screws and one spring on the inboard side. The aft section is held on with one screw. This makes for very easy access and a good foundation for cooling deflectors and seals.

Figure 19. Small air dams were placed between the cylinder heads where the oil galleys connect to the heads so as to block any air exit about these 1 inch sized holes. All air goes through the cylinder fins. The metal sheet makes it very easy to attach and adjust these vanes and gap seals.

Also included were .016 inch thin metal air deflectors between the middle and rear cylinder to direct the moving air between the cylinders. These easy to adjust plates are key to adjusting the air which passes quickly over the the wide gaps between fins of the cylinders and rout it down through the fins as seen below.

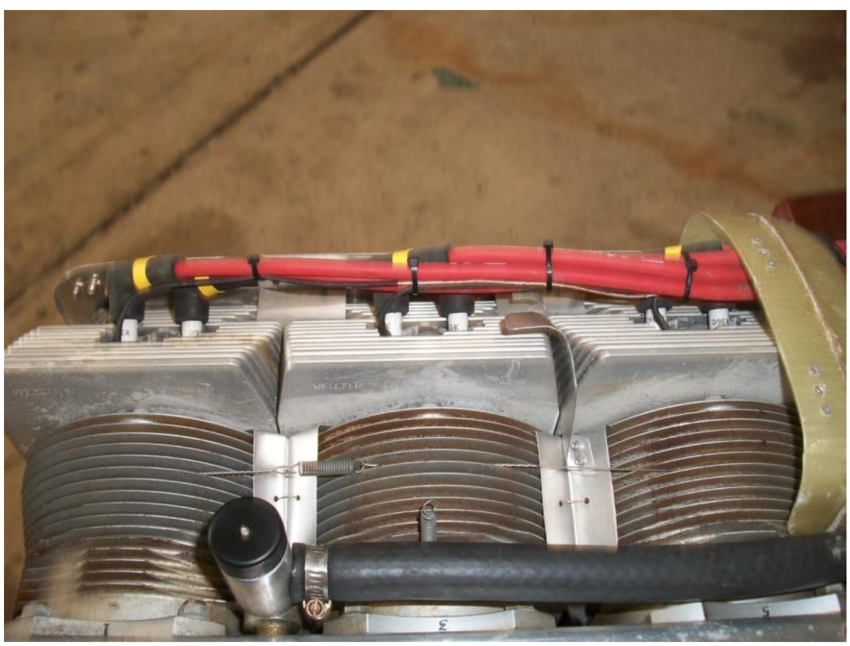


Figure 20. Air flowing through the plenums also has difficulty making the square corner around the heads so these thin sheets between the heads were are added then bent to help induce the air around the square corner and down through the fins. These inner thin deflectors are adjusted between flights to correct the pressure distribution. Note that smaller sized "V" metal air deflectors were added to the barrel gap to prevent plenum air pressure loss, improve between cylinder flow, and fit tightly to the head and fiberglass plenum. Most notablyto the Jabiru owner is the V air deflectors were made smaller and cut to fit tight on the ends rather than using the supplied stock.

The manufacturer adds fiberglass dams to the top of the lunch box plenums to try to deflect and correct the air flow problems, but this seems to block air from going aft to the back cylinders, reduces the effective volume of air and adds turbulence to the air flow to the rear cylinder. That said, they do help at cruise speed to force air onto the CHT probe and lower inflight CHT readings. But it does not improve the delta P between the upper cylinder and lower exit.

Figure 21. In the picture above, even the aft end of the duct was tightly sealed to assure all the air exited the plenum between the cylinder fins only.

These simple detailed changes, allow more even cylinder cooling and a better chance at high power operations at low speeds. It should be noted that the slightest miss alignment causing a gap in these ducts after the work above, increases cylinder temps on the offending side by a significant amount (20-30 degrees F).

The next problem was to increase the draw of the cowl and reduce the oil temperatures.

The oil cooler supplied originally was a cheap metal tube type. It proved totally inadequate. The owner had a 7 bar steel inexpensive automotive cooler which was about the size of the cowl inlet hole. We installed it to find out its effectiveness. The oil cooler was attached to a bracket on the engine which fit the oil cooler directly in front of the NACA type cowl inlet. The cooler was angled to be as nearly parallel to the airflow coming into the inlet as possible. A metal duct was fabricated to fully seal the oil cooler on the top and sides along with cowl seal so that no air could escape under or around the oil cooler. The exit air off the oil cooler was ducted and sealed to keep the high pressure air from entering the lower cowl. This exit air was directed to the cowl exit hole. The oil temps improved, but were at the limit on climb out speeds below 90KIAS.

It became evident that the rounded lip on the bottom of the NACA oil inlet needed to cut off to increase the area of the inlet. This was nearly a 20 degree temperature help. One should review NACA Report 645 documentation on flush inlets as the design of this inlet is inadequate due to its rounded edges on the NACA, however cutting off the lip left the cowl paint in great shape. The inlet edge lip must be shaped correctly to be effective which is covered in NACA documentation on buried inlets. Also a proper aircraft oil cooler, as stated before, is essential for the Jabiru series engines. I'd much rather overcool the oil and have to put a baffle in or change the ducting via a flap during cruise or cooler weather so on the hottest of days proper cooling can be achieved.

Figure 22. Oil cooler ducting was angled down and aft slightly and sealed completely with metal and cowl seal and sealant to the duct and cowl floor.

The final area of concern was the cowl exit ducting. As stated before, the cowl exit hole is a ram air inlet most of the time at low speed, so a ramp style air exit similar to the XS Rotax cowl, was fabricated to increase the suction draw. The ramp is only about 3 inches deep and extends from the front of the hole to just aft of the foot wells and almost touching the nose gear leg of the trigear when compressed. It is also positioned to be as close to the exhaust stack ends as possible, so any draw of the exhaust pressure pulse may assist in draw. However, there was insufficient space and money to fabricate a pure exhaust augmenter.

Figure 23. Note that the first attempt at a cowl exit ends about the same point as the exhaust stacks.

A movable exit ramp was considered but the proximity of the exhaust stacks and the nose gear leg made installation of a movable cowl flap or augmenter somewhat time consuming. The client preferred a fixed ramp so the ramp was extended another two inches parallel to the exhaust tubes making about a three inch ramp. This would not be a problem on the mono wheel and is highly recommended.

After these modifications, ground running with a fixed pitch cruise prop allowed 20 minutes of taxiing before the heads reached 250 F. This is the temperature which I consider the max permissible temperature before full power is applied for takeoff. The operational limit of 250F allows full power acceleration to takeoff and acceleration to climb speed before 302F. It should be noted that in tests, the hottest CHT for takeoff attempted was 304F and the hottest cylinder did not exceed 340F during takeoff, acceleration to climb or climb out, but the aircraft was throttled back at a safe altitude and cruised at 2750RPM until cylinder temp on the hottest cylinder went below 300F. Climb was then resumed. Flight testing indicated the draw was adequate for full power operations but not below 90 KIAS due to the fixed cowl exit ramp. (Note that Jabiru Ltd. has raised their max continuous and maximum cylinder temps in their new manuals. However we still use the old temperatures as it prolongs engine life.)

The current cowl modifications allow a takeoff at 95 degrees F at a climb of 90 KIAS which draws approximately 5 inches of water which allowed continuous climb to at least 7500 AGL with the highest cylinder temp on cylinder 4 or 6 of about 300F. It was clear a slightly larger draw was needed, however the client was happy so it was left fixed at this point.

Cruise speeds were nominally 127KIAS at 2750 RPM and cylinder head temperatures of 260-280F at outside temperatures of 95F at sea level. At cruise altitudes of 6500 and higherMSL the cylinders were 10-20 degrees lower due to lower outside temperatures as well as a superior ram pressure through the cylinders. A flight test was videotaped and is available at U-tube or at www.customflightcreations.com.

Note: After maintenance, we slightly miss-positioned one of the plenums by one fin. The result was the number 4 and 6 cylinders were nearly 30 degrees hotter than the right. After correctly repositioning of the plenum, all was well again. This confirmed our sealing was doing its job.

Overall, the modifications were successful and allowed the Jabiru equipped Europa to give acceptable service, however, the pilot must take care in always observing his temperatures and temperature spreads. Descents at low power settings were particularly annoying as cylinder temperatures dropped very quickly when using the fixed duct at high speed. However, slowing down to descend at 75-90 KIAS at 500 fpm rate of descent prevented shock cooling. Unfortunately, we were still plagued by EGT differences between left and right bank cylinders.

Engine induction problems:
In testing it was very disappointing trying to get consistent test runs. The Jabiru has intake manifold leak issues between the metal spider and at the tube rubber hose junction causing EGT spikes. A great deal of care was taken to seal all leaks in the intake manifold to assure a sound engine performance. With this accomplished, the left and right side EGTs finally stabilized, but EGT increased with airspeed increase. The Jabiru USA dealer was instrumental in leading us to a fix.

In our experience, we know that the Bing carburetor is not designed to take any inlet pressure. In fact, for proper fuel metering, the carburetor inlet must allow a suction flow. As the manifold suction increases, the piston in the Bing is elevated and the needle attached is pulled up and allows a richer mixture at high power. This bathes the cylinders in extra fuel if jetted properly. Any inlet pressure from the cowl intake through the filter will cause the vacuum at the piston needle to lower and cause leaning of the engine. This was evident when the speed kit was installed further increasing the speed of the aircraft and subsequently the ram air pressure coming in from the cowl NACA inlet caused an EGT and CHT rise with no throttle or altitude change. Even though the air filter plenum is vented to the cowl, the air flow in the inlet at cruise was just high enough to pressurize the Bing. By blocking off the NACA carb inlet duct with tape and simply making a 4 square inch hole in the tape as suggested by Jabiru USA, we achieved improved engine EGT and CHT evenness at all speeds. It was also found that those cobra necks and smooth tubes were not a factor in our tests and were removed. We found proper cowl inlet, engine intake manifold sealing, carb tune and jetting were the only factors in EGT evenness. No attempt was made to install leaning or economy jets as the engine cylinder temps will rise with a leaner mixture and increase cylinder temps. This is especially true at altitudes above 6500 MSL and low cruise RPMs. With the speed kit and higher cruising speeds, it was noticeable that only ¾ throttle was needed to achieve 2650 RPM and it became obvious at this economical setting that EGTs would climb higher than we would like (about 1350F on the rear cylinders) yet at wide open throttle, EGTs decreased 50 degrees and stay in the 1250-1300F range. We avoided cruise at RPMs below 2600 (about 2/3 throttle). No manifold pressure gauge was provided.

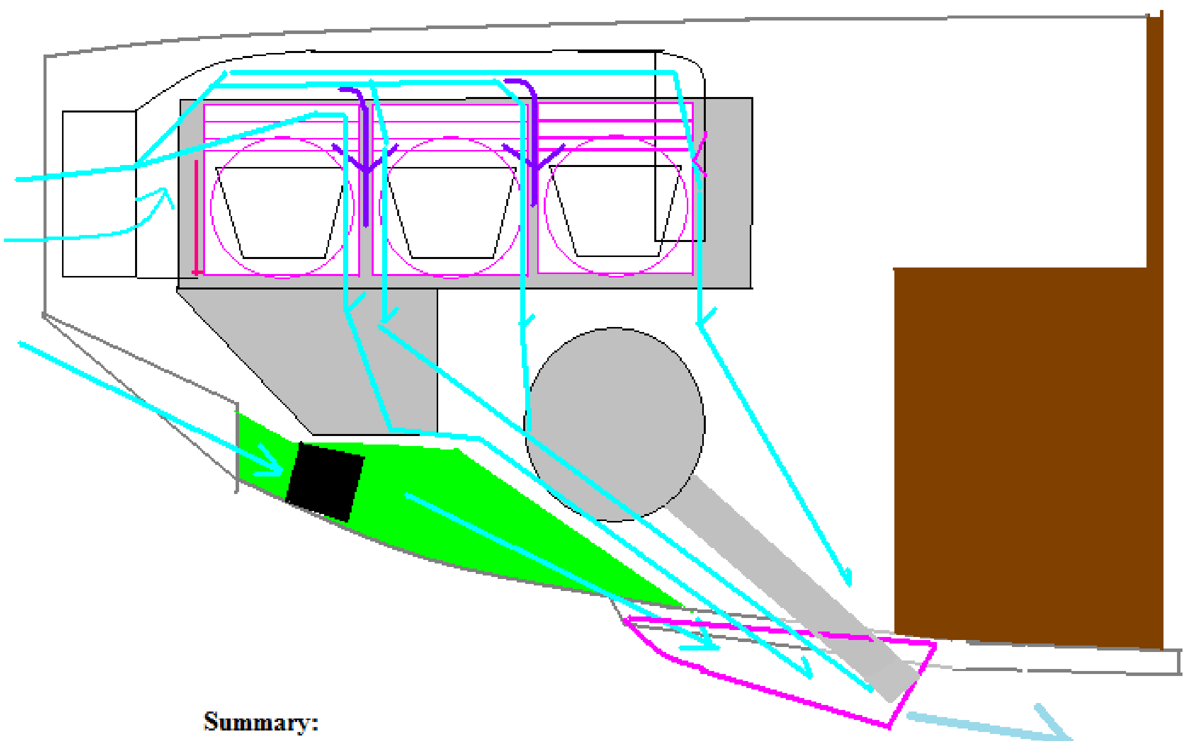
Propeller concerns:
The propeller selection is not an issue normally and we found the fixed pitch all wood Sensenich W64ZK worked well. This prop is very light and absorbs the torque of the Jabiru very well. Another excellent point to this prop is in the event of a ground loop prop strike, less stress is placed on the crank shaft. The Sensenich R64Z ground adjustable carbon fiber prop seems to work well also. The prop should be pitched to achieve a static RPM at full power of 2650 at sea level for reasonable cruise and acceptable climb. Takeoff and climb performance are reduced somewhat. At sea level we see takeoffs at full gross of 800-1000 feet and climb rates of 750 FPM

at sea level dropping to 250 by 10,000 at cruise climb. Heavier props of higher rotational inertial such as the Warp Drive have been used with success but we cannot confirm it from our testing. The Jabiru dealer insists that Constant Speed (CS) propellers cannot work on the Jabiru. We have found success has been achieved with the two blade Airmaster AP420 using the Sensenich 64 inch ZN blades specifically designed for the Jabiru 3300. Ground cooling was enhanced by taxiing with the constant speed prop in manual control using coarse settings for additional ground idle/taxi airflow. Noticeable increases in the airflow with this setting allowed longer taxi times before exceeding our operational limit of 250F on the cylinder head temperatures. Improved takeoff performance was noticed as one would expect with the propeller set at 3150 RPM for takeoff. These techniques also work with the Airmaster AP332, 64 inch. Cruise speeds were slightly improved over the fixed cruise prop, however the failure of Jabiru to produce manifold and propeller curves (to prevent lugging or detonation) requires owners to do extensive cruise and power testing to achieve optimal aircraft cruise performance, engine cylinder head, EGT, Oil Temp and fuel economy. The torque drop off after 2700 prevents optimum performance with the CS prop blades when trying to achieve maximum speed. However if cruise is planned at 2750 RPM, performance with the CS is improved over the fixed pitch prop of average climb/cruise pitch and as altitude is increased full throttle can be maintained keeping the metering piston higher and cylinder head temps well in control.

In Summary:

The Jabiru installation in the Europa XS is a viable option, but it is not a plug and play installation. Much extra work is needed on the cowl inlets and exits to allow proper intake, draw, and exit. That is not where the work ends. To allow easy spark plug axis and CHT probe maintenance we feel it is essential to make a two or three part plenum (metal side as an option, 2 part fiberglass lunch box). Proper sealing of the intake plenums and extreme attention to any air leaking between cylinders or plenum is essential. The changes we employed allow even the most miserably overheating Jabiru to be tamed into a usable engine for the experimental Europa builder.

The drawing below summarizes the changes made which allow acceptable operation:



Summary:
Between cylinder V inserts were made smaller. We installed vertical baffels between the heads to direct air down between the head fins. Metal plenum sides allowed easy install of between head gap filling metal tangs and a way to attach baffels. We did not use the triangle type fiberglass baffels recommended by Jabiru as they starve the rear cylinder of air pressure and only increase the volume of the air to the CHT probe area. The oil cooler is tightly sealed and the exhaust of the oil cooler is directed out the bottom of the cowl flap. The bottom exit hole of the cowl needs more draw so a ramp of a minimum of three inches or more is needed. These changes made cooling acceptable.