13 Cooling Systems

13.1 General Principles

- An ideal cooling system:
  - i. Controls engine temperatures through speeds ranging from taxiing on the ground through to V_{NE}.
  - ii. Controls the engine temperatures through a wide range of angles of attack.
  - iii. Is simple to build, install and maintain
  - iv. Produces minimum drag
  - v. Requires no pilot attention
  - vi. Is not affected by rain, dirt or insects sticking to it.
  - vii. And weighs next to nothing
- For the sake of the following discussion, a "gap" is considered an opening roughly large enough to slide two fingers into – around 13mm by 32mm (0.5" by 1 ¼ ").
- The total area of the air intakes (combined cylinder head and oil cooling openings) should generally be no more than one third the total area of the cowl outlet (the outlet area must be a minimum of about 3 times as large as the total area of the inlets). This assumes that the outlet area is oriented effectively (see Figure 58).
- Each cowl cylinder head Inlet of a Jabiru Aircraft has an area of approximately 10,500mm^2 (16.25 in^2). Oil cooler inlets have an area of approximately 12,500mm^2 (19.4 in^2). This gives a required total outlet area of approximately 100,500mm^2 (155 in^2). These sizes are based on a Jabiru Aircraft. Inlet and outlet sizes required will vary depending on the aircraft's speed, drag and the positions of the inlets and outlets – the areas given should be used as a guide and starting point only.
- A generalised picture of the airflow and air temperature is shown in Figure 47.
- Most of the time, air leaking through gaps instead of flowing though a cylinder head, oil cooler or similar is waste air – it does not transfer heat and does not cool the engine. Sometimes air leaking through controlled gaps – such as the holes in the front of the ram air ducts (Figure 50) or the gaps between cylinders – can have beneficial effects. However, it is recommended that gaps around the engine and oil cooler be closed as a starting point.
- The propeller & rush of air from the aircraft's speed make it easier to get air into the cowl than to get it out.
- Too much air flowing through the oil cooler can restrict airflow through the cylinder heads, & vice versa.
- The pressure difference between the low pressure outlet area of the cowls and the high pressure inlet areas controls the amount of air flowing through the engine. The pressure differential testing described in Section 13.5 gives target pressures.
- During developmental work it is strongly recommended that each cylinder head has it's own temperature sensor. Modifications to cowls etc can have unpredictable effects and normally a change will affect each cylinder head differently – i.e. head #4 may cool down while head #3 heats up.
- Testing of an installation in a Jabiru Aircraft showed that the heat radiating from the engine exhaust system normally has a minimal effect. Wrapping the exhaust in insulation etc does not produce a measurable temperature reduction during taxi or in the air.

WARNING

The limits in the Specification Sheet, contained in Appendix B, must be strictly adhered to. Warranty will not be paid on engine damage attributed to overheating of cylinders or oil.

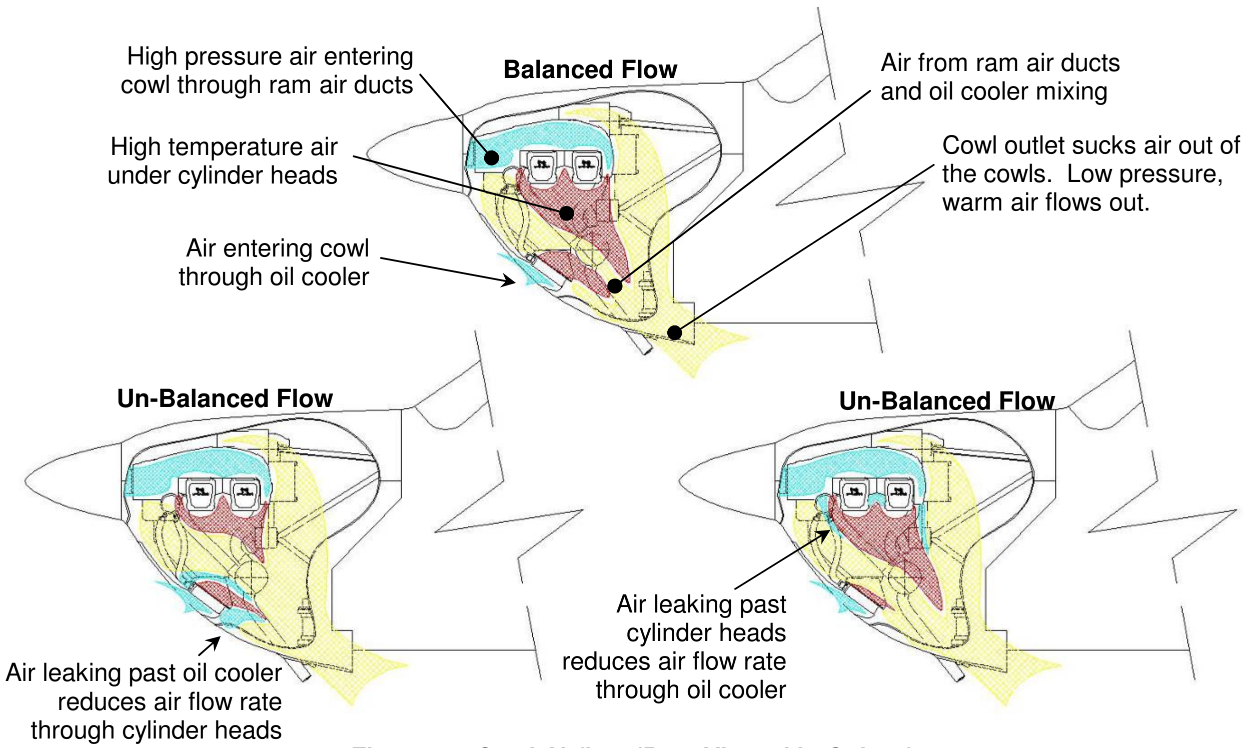


Figure 47. Cowl Airflow (Best Viewed in Colour)

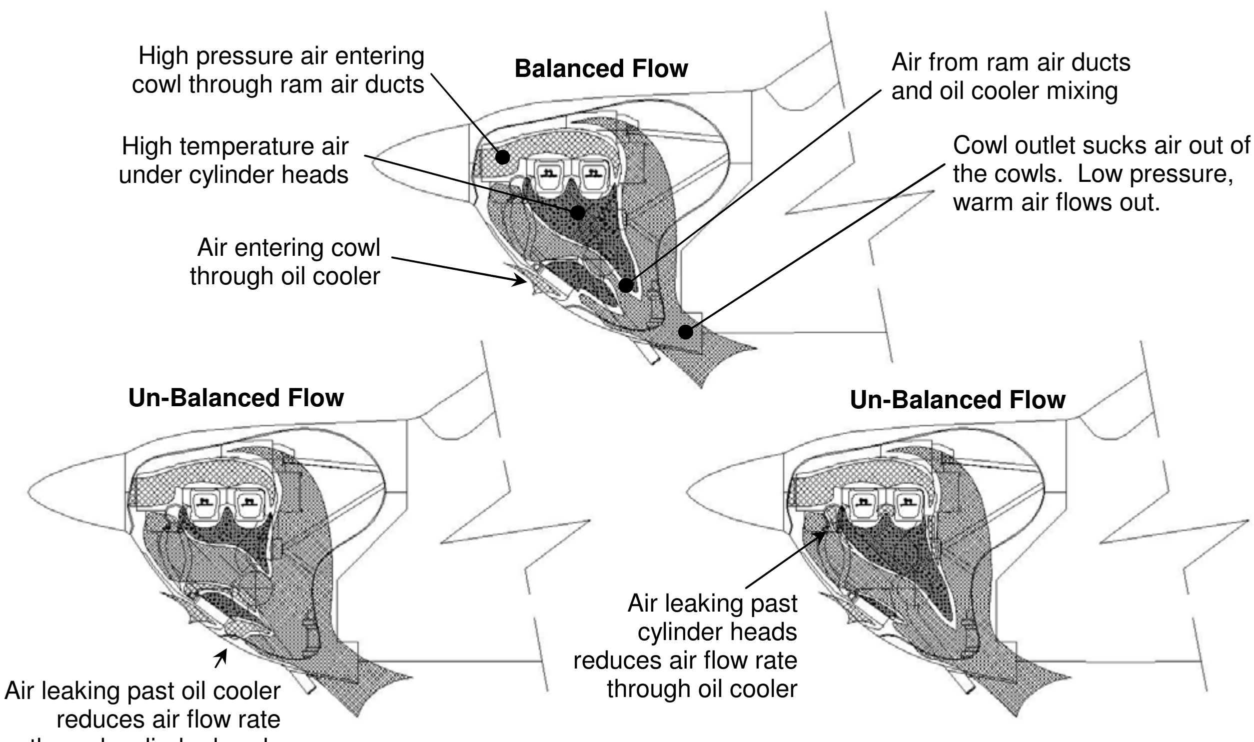
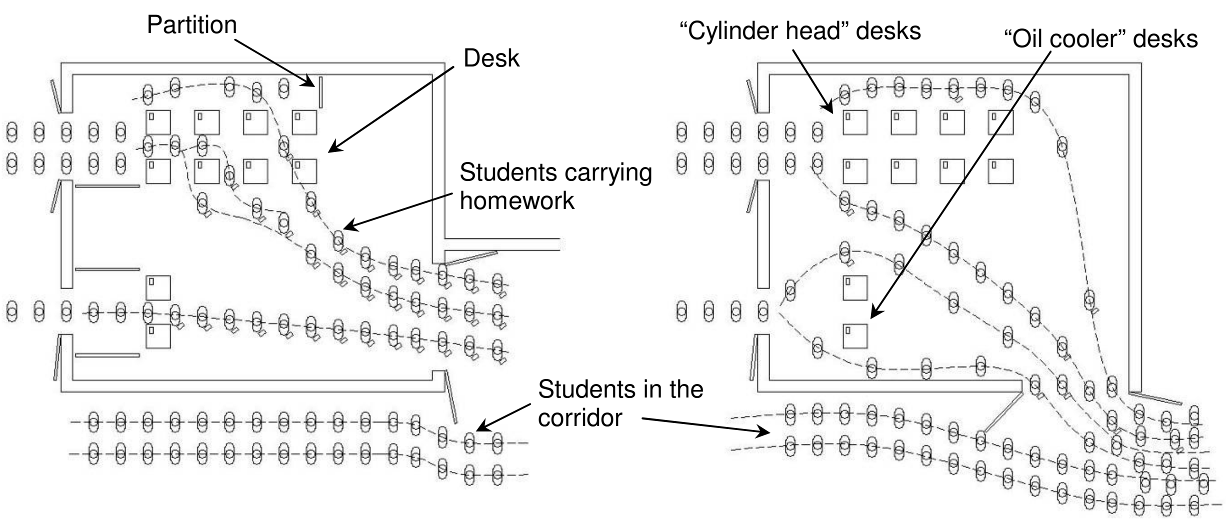


Figure 48. Cowl Airflow (Black & White Version)

13.2 Flow Visualisation

- In designing the cooling system the designer must have a basic understanding of how air flows and behaves inside the cowl. The pictures below are intended to explain it in simple terms.
- Figure 49 shows two schoolrooms, drawn as if seen from above. Each room represents an engine and oil cooler inside a cowling.
  - i. There are two doors in the inlet side of the room and one on the outlet side.
  - ii. Several desks are placed in the room, representing the engine cylinders and the oil cooler.
  - iii. Students walk through from left to right, representing the air flow through the cowls.
  - iv. On each desk is a pile of homework papers, representing heat generated by the engine.
- Air always takes the path of least resistance. It tries to escape quickly to the playground without taking the homework.
- The desks and doorways form restrictions. If the desks are too close, not enough students can pass through. If the desks are too far apart some students will not pick up their homework. If the inlet doorways are too large then there will be a traffic jam trying to get out of the outlet door.
- Gaps can leave room for students to pass without picking up homework.
- Given a group of desks as shown, students can follow many paths through them – from front to rear, from top to bottom or any combination.
- Slowing down the students as they pass through the desks means they will pick up their homework, but if they are slowed down anywhere else it only reduces the amount of students that can get through the room.
- If the exit becomes jammed with people, installing bigger inlet doors will not increase the number of students passing through the room. Exits should be as clear and free of obstructions as possible to let people out.
- Students will often have a preferred desk to take their homework from, meaning that some cylinder heads will have more heat removed than others – temperatures will wary between different heads.



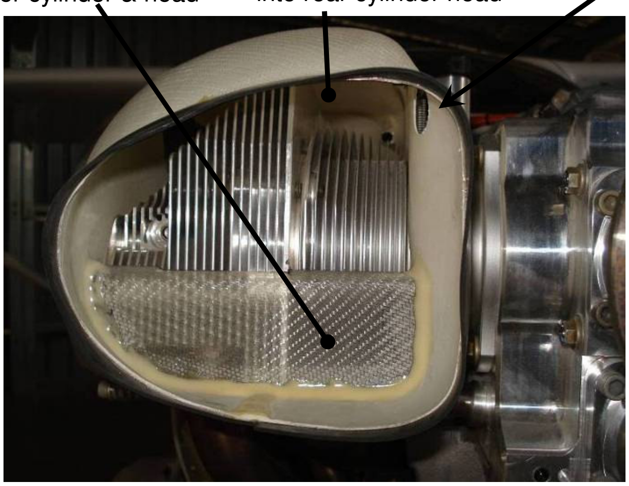
- Partitions are used to force the students to walk through the desks.
- Each student picks up the homework.
- Outlet door is 90° to the flow of students in the corridor; there is no restriction & jostling at the exit

- No partitions are used, so students walk around the desks instead of through them.
- Most students don't come close enough to a desk to pick up the homework
- Outlet door is parallel to the flow of students in the corridor, causing restriction & jostling at the exit

Figure 49. Flow Visualisation

13.3 Air Inlet & Ram Air Ducts

- The engine should be installed using RAM AIR ducts provided with the engine. The ducts themselves are to be assembled as detailed in Section 13.3.1.
- The ram air ducts are screwed to the engine using the normal rocker cover screws. Note that if the duct is not fastened to the engine then air pressure at high speed can lift the ducts off the engine. This will upset the pressure balance inside the cowl and impede cooling. More importantly, with some types of ducts, the duct lifting will dislodge the spark plug high tension leads, causing the engine to run roughly or stop.
- For best cooling on the ground, during climb and low speed flight the propeller used must have significant pitch and blade area on the section immediately in front of the air inlets. At low speeds the airflow does not have much energy, and the acceleration and pressure provided by the propeller greatly assists in getting air into the ram air ducts.
- Each duct must have a 25mm hole at the inside top front to bleed air over the crankcase.
- The pressure differential between the inside the cooling ducts and the cowl outlet must not be lower than 60mm (2.4”) water gauge at when the aircraft’s speed is 1.3 times the stall speed (1.3 x V_S).
- The cooling ducts provided are a starting point in establishing effective engine cooling. The ducts may require to be increased in size and additional baffles provided for best cooling.
- Tubes of approximately 12mm diameter are required to provide cooling air to the ignition coils - Figure 51.
- For an air cooled engine it is entirely normal for there to be significant differences in the temperature of each cylinder head. Often the head which is hottest in the climb will not be the hottest during cruise & descent. This is only a problem if the hotter heads exceed the engine’s set limits.
- “Gull Wing” baffles can be used to fine-tune the restriction to airflow caused by the engine, and this in turn affects the volume of air flowing through the engine and into the cowls. Fitting the baffles will give a higher restriction as it forces air to flow through the small gaps between fins. Leaving the baffles out provides larger gaps – and a higher volume of relatively cool air blows through these gaps into the “Hot” zone immediately under the cylinder heads. Wherever possible it is recommended to leave the baffles out. However, compared to an installation with the Gull Wings fitted, a significantly larger volume of air must be sucked out of the cowl outlet. This often requires a larger cowl outlet or a larger lip on the existing outlet. Pressure differentials must be maintained.
- Check for contact of engine, cooler or ducts on cowl. Any contact will cause excessive vibration & if the oil cooler is rubbing it will eventually fail & leak.



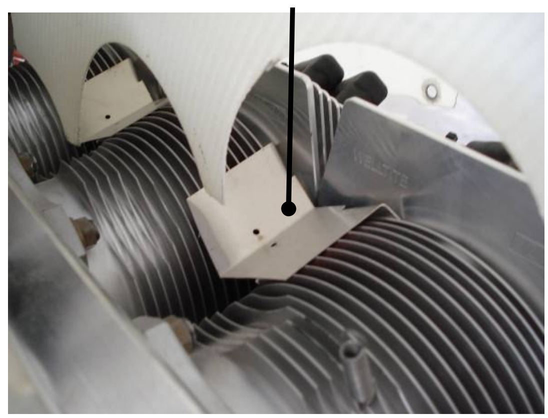


Figure 50. Front-On View Into Ram Air Duct

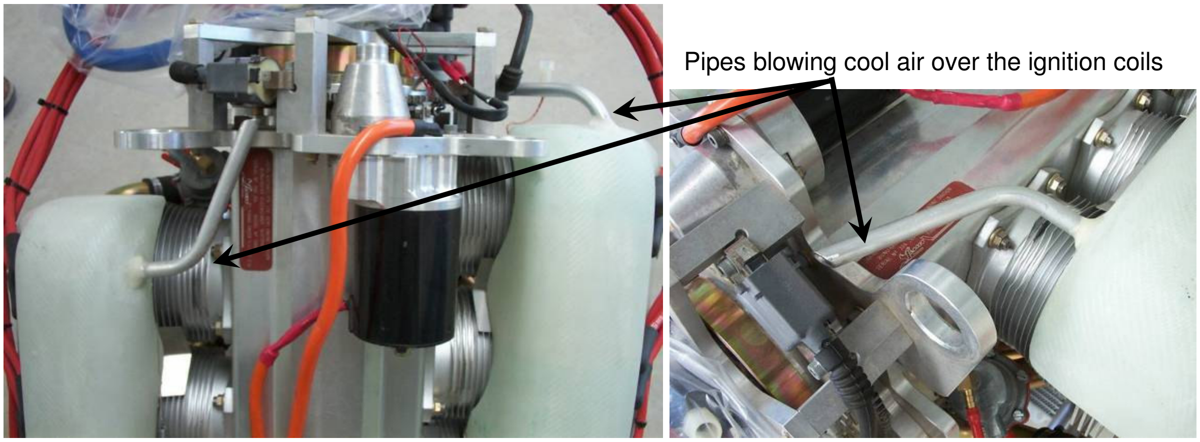


Figure 51. Coil Cooling Detail

13.3.1 Ram Air Duct Assembly & Installation

- As supplied, the seam at the front of the ram air duct is not joined. This joint must be bonded using 5-minute epoxy & flock. Use a length of masking tape on the join line at the bottom of each duct inlet to hold the join firm and prevent Epoxy/flock from leaking through.

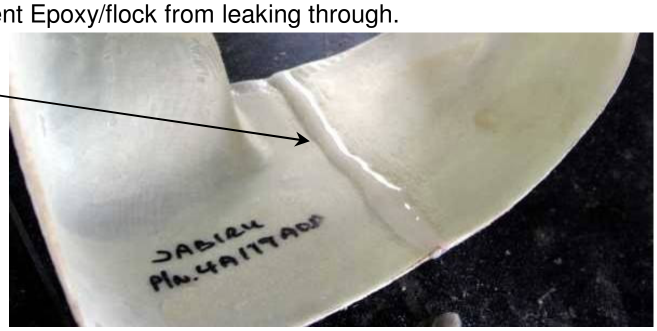


Figure 52. Ram Air Duct Front Seam

- Before installation the front air dams need to be cut to size. Take the length of glass fibre sheet with the curved edge, hold it against the rear of the duct inlet with the curve towards the top rear of the duct and mark around the bottom of the duct then cut to shape. Figure 53 refers.
- Tape the air dam into place. Mix a small batch of 5-minute Epoxy and flock and use it to fix the air dam into place. Leave to cure, then sand away any rough edges.
- Remove the masking tape and roughen the underside of the duct and the back of the air dam.
- Mix a small batch of epoxy resin (structural resin – not 5-minute epoxy) and brush 2 layers of AF303 glass fibre cloth to the underside of each duct, covering the join line and wrapping up around the back edge of the air dam. Leave overnight to cure.
- The completed baffle is shown in Figure 50.

Figure 53. Air Dam Installation

13.4 Oil Cooling

- The dipstick cap must be screwed fully in before removal for reading oil level.
- An oil cooler adapter is supplied with the engine & fits under the oil filter. The cooler can be plumbed either way to the adaptor – flow direction is not important. Oil coolers are available from Jabiru Aircraft.
- Unless consistently operating in low temperatures, oil coolers are mandatory. Note: if you fly in cold weather and don’t have an oil cooler you can’t fly if it warms up. You can always block the oil air off in cold conditions.
- In continuous operation oil temperatures between 80℃ and 90℃ (176℉ – 194℉) are desirable. 70℃ (158℉) is the minimum allowable temperature for continuous running and 100℃ (212℉) is the maximum allowable temperature for continuous running.
- Over filling with oil is not desirable. It can cause elevated temperatures & excessive oil use & loss.
- Hoses should be nominally 10mm (3/8”) bore.
- Hoses must be changed every 2 years or if visible degradation (cracking, hardening) is visible at inspection.
- A pressure drop of at least 60mm (2.4”) water pressure between the air flowing into the cooler and the air flowing out of the cowls should provide sufficient oil cooling if using a standard Jabiru oil cooler.
- Section 13.1 noted that air leaking through gaps in the cooling system ducts is generally waste air, not contributing to cooling – though it noted that there were exceptions to this rule. Oil cooling is the feature of engine installations that is most often improved by “leaks” like this. A controlled amount of free air blowing over the sump, crankcase and underside of the engine can significantly improve oil temperatures (Figure 54 shows a duct of this type fitted to a Jabiru 6-cylinder engine). However, for this to work the cowl installation must be able to cope with the extra volume of air flowing into the cowl space – the outlet area or outlet lip size may need to be increased to suck out the extra volume.
- Figure 55 shows an oil cooler installation of a Jabiru 3300. Note Detail C in the lower corner of the drawing, which shows the cooler being fitted using rubber mounts. This is very important as it insulates the cooler from engine vibrations – coolers installed with a soft mount like this are much less likely to fail in service.

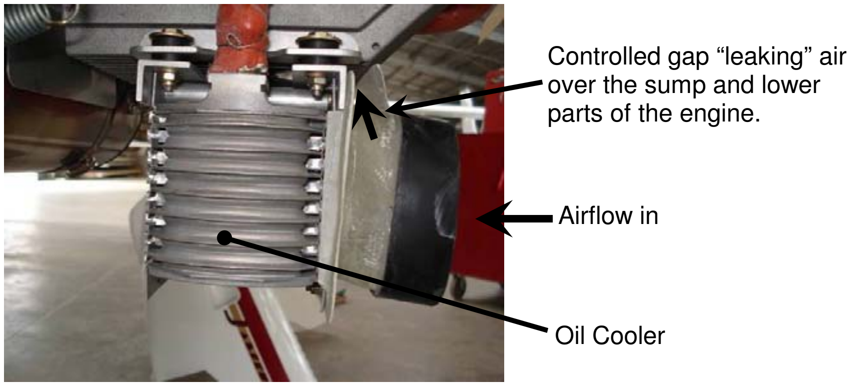


Figure 54. Oil Cooler Duct Design

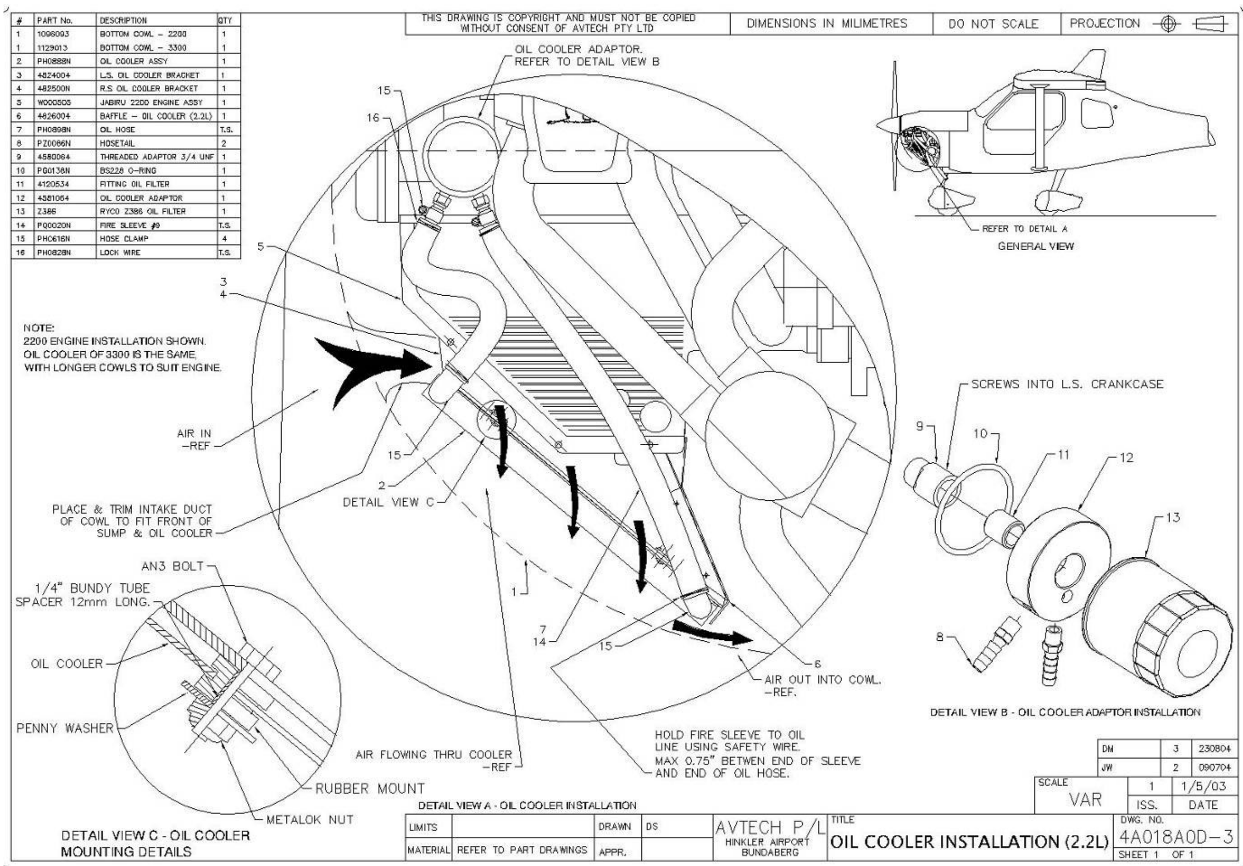


Figure 55. Oil Cooler Installation

13.5 Air Outlet

- As the sections above describe, getting air out of the cowling is often the factor limiting how much air can be pushed through the engine and how well it is cooled.
- The shape of the outlet of the cowls controls how effectively air is sucked out of the cowling and is arguably the single most important aspect of cowling design.
- As noted above, as a rule of thumb the cowl outlet area should be at least 3 times the combined area of all the cowl inlets.
- Figure 56 shows a small lip added to the rear of the cowls of a Jabiru Aircraft. This lip gives a large improvement to pressure differentials and engine cooling.

- Figure 57 shows an aircraft at varied angles of attack to the surrounding air. The cowl inlets and outlets must both be designed to work effectively at all angles which the aircraft will normally experience.
- Figure 58 shows two different cowl outlets – one is basically an opening in the flat bottom of the cowl, while for the other the opening is oriented at 90° to the airflow direction. Vertical orientations (Deep Outlet) give better pressure differentials and are less affected by aircraft angle of attack than horizontal (Long Outlet).
- Figure 58 also shows the lower firewall section of a Jabiru Aircraft. The lower part of the fuselage has two large ramps moulded in which increase the depth and area of the cowl outlet (and also provides mounting points for the rudder pedals). This type of feature is not mandatory for good engine cooling but it does help. An alternative is to make the bottom corner of the firewall as smooth and rounded as possible to help airflow and minimise the outlet restriction.
- Some aircraft types have a flange running around the firewall. Particularly on metal types, this flange is a useful way of mounting the cowls. However, if the flange runs across the edge of the firewall where the cowl outlet is located then it causes a significant flow restriction. Figure 59 shows a drawing of the lower section of a firewall with a flange of this type. Wherever possible flanges across the cowl outlet should be avoided. Alternatively a fairing can be built inside the cowl to smooth airflow over the lip & reduce flow restriction.

Figure 56: Lip to aid cooling as installed on a Jabiru.

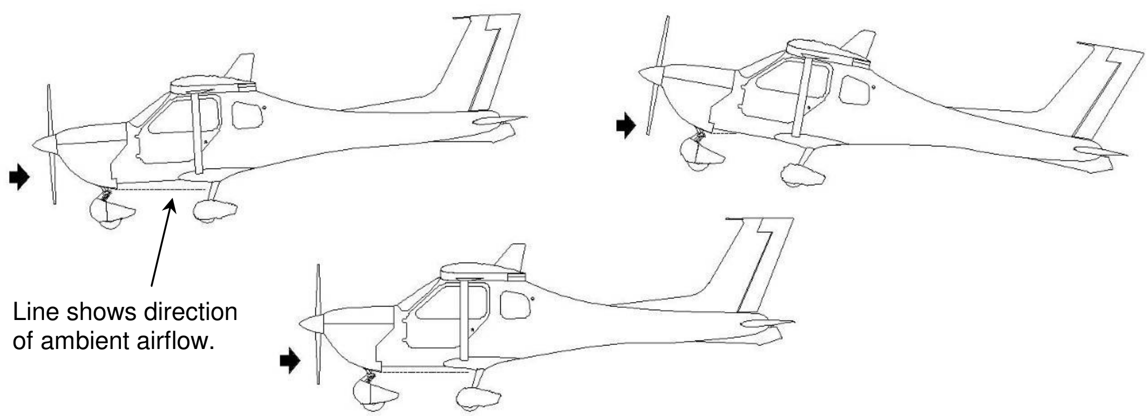
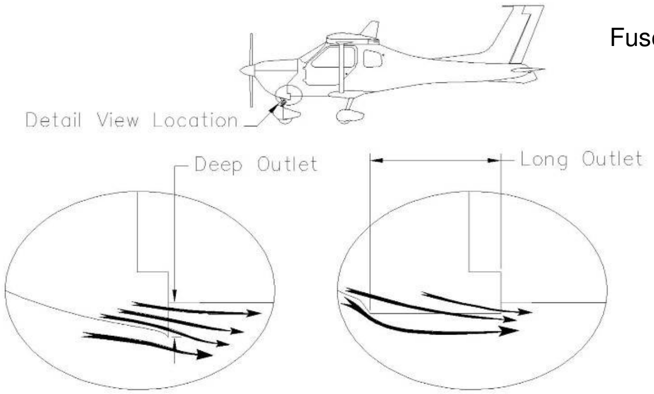


Figure 57. Affect of Angle of Attack on Cowl Outlets



Fuselage cut away to give deeper & larger cowl outlet

Figure 58. Cowl Outlet Geometry

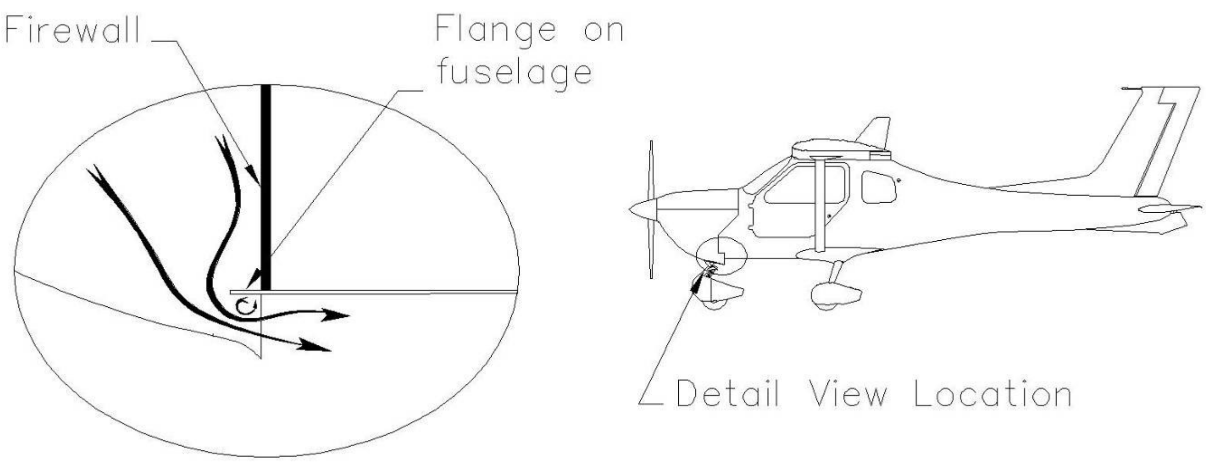


Figure 59. Outlet Restriction Caused By Flange On Lower Firewall

13.6 Cooling System Testing & Evaluation

- For new installations (new designs rather than new aircraft of a known type) the pressure drop across both Ram air ducts must be checked.
- The following is a guide to evaluating an engine installation to see if it meets minimum cooling requirements.
- The easiest way to measure the air pressure drop across the engine and oil cooler is using a U tube manometer using water. It is basically a piece of clear tube bent into a "U" and half filled with water (if the water is hard to see add a bit of food colouring).
- For ram-air duct pressure, connect one side of U to a static port inside the ram air duct and the other to a static probe inside the cowl near the outlet. For the pressure drop across the oil cooler plumb a static probe against the front of the cooler and a static probe inside the cowl near the outlet. The further the probe is in front of the cooler the less the static pressure that will be measured, so place the probe no more than 5mm in front of the cooler and parallel to it.
- Using multiple U-tubes several measurements can be taken in one flight.
- Details of a typical static probe are shown in Figure 60.
- Note that probes must be fitted in the same place each time to ensure you get consistent measurements.

Some hints.

- Usually the most critical situation for cooling is climb however this is not always true, so check all situations.
- The change in air temperature is approximately the same as the change in engine temp. For example if you did all your testing in 15°C and you want to flying in up to 35°C weather, in 35°C all your engine temps will be approximately 20°C higher. Check you have sufficient margin for all conditions you plan to fly in.
- If the engine gets too hot during testing don't push it. Something needs to be changed.
- For low speed cooling a lip on the front edge cowl outlet can add up to 20mm of pressure drop at 65kts (a lip 25mm deep at 60° to the airflow – shown in Figure 56).
- Refer to Figure 22. CHT terminals must be placed correctly or inaccurate (too high) readings can result.

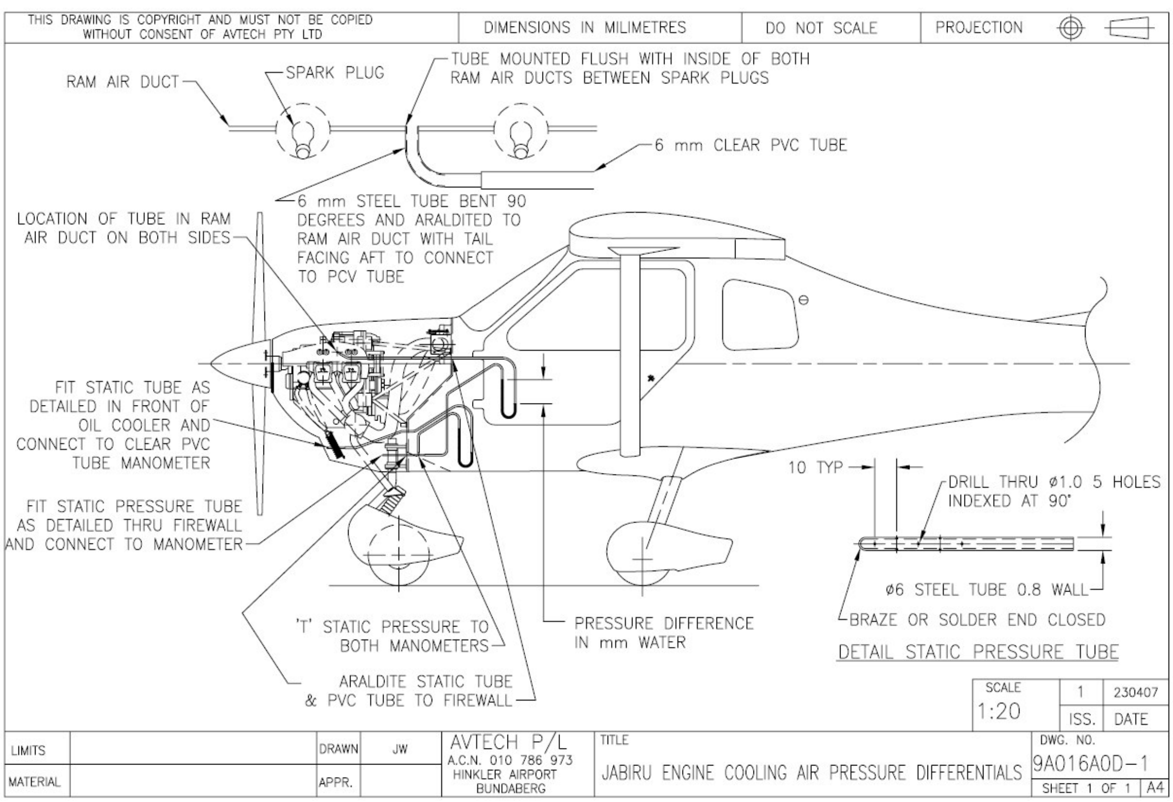


Figure 60: Cooling pressure measurement.

Figure 61: Ram Air duct pressure tapping.

13.7 Pusher Installations

- For pusher installations the details given above hold, though some changes are necessary for the different configuration.
- Versions of Jabiru ram air ducts are available for high speed and low speed pusher installations.
- The propeller can be used to suck air out of the cowls, using the following as a guide:
  - i. Wherever possible the cowl outlets should be vertical openings with lips that come close to the propeller – as close a possible without the blades hitting the cowls.
  - ii. The propeller blade must have significant pitch and chord in the section which passes over the outlets.
  - iii. The cowl openings should each be reasonably small. As each blade passes the opening it will create a suction in the cowl behind it, but if the cowl opening is large this effect will be dissipated. Alternatively, larger openings can be divided up by fitting louvers or vanes.
- Augmentor type exhausts (Figure 62) can also be used to suck air out of the cowlings.
- In pusher installations the inlets into the cowl are harder to get right than in a tractor installation. Intake ducts should be as straight as possible with no sharp corners or other restrictions to the flow.
- The position of the cowl air inlets is critical – inlets on the upper surface of the aircraft are generally in low pressure zones while those on the underside are normally in high pressure zones. Depending where the inlet is located, the area ratio between inlet and outlets may need to be modified.

13.8 Amphibian or Seaplane Installations

- Water taxiing requires relatively high power settings for long periods and this is often the most critical condition for cooling systems in these aircraft.
- Increased duct size (scooping more air through the engine) may be necessary.
- For amphibian or seaplane aircraft using a pusher engine installation the methods outlined above can use the propeller to suck air out of the cowls, but ultimately the effect is limited and can conflict with cooling requirements in other modes of flight. For these installations some form of active venting for the cowls – such as flaps, fans or an augmentor-type exhaust system (See Figure 62) may be required.

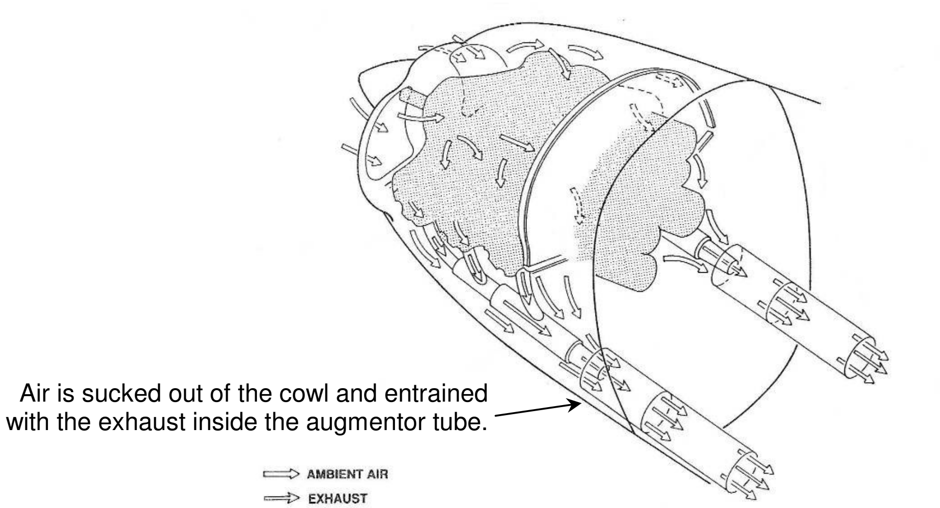


Figure 62. Augmentor Exhaust System

13.9 Slow Speed Installations

- Installations where the cruise speed is below around 70 – 80 knots are considered slow speed installations.
- Jabiru ram air ducts are available for slow speed installations. These are larger than the ducts used for faster aircraft.
- Increased duct size (scooping more air through the engine) may be necessary for slow speed installations.
- Increased outlet size and more aggressive outlet lips may be required.
- In some of these installations where the airframe has a lot of drag it is preferable to do away with cowls altogether and run an open installation. Aircraft such as the Thruster (Vision), Drifter, X-Air and some RANS models are examples of this. In these cases large ram air ducts are used, and the rest of the engine is exposed to the propeller wash for cooling.