Engine Cooling System Design Guide Basics

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General Cooling System Information

In terms of the total fuel energy supplied, the heat flow to the coolant is nearly constant at 28percent of the supplied energy, with a slight fall with rich mixtures to 25percent at an equivalence ratio of 1.2 (AFR = 12.2).' "Intro. To Internal Combustion Engines by Richard Stone 3rd ed. Pg 478"

Rule of thumb: Of 100% fuel energy the distribution is 1/3 exhaust heat, 1/3 cooling, 1/3 crank output.
Cooling implies convection, radiation, and conduction of the engine block, oil, and coolant.
Of the 100% fuel energy, use between 9-12% for the engine coolant radiator sizing.

Figure 1 shows a typical energy balance for automotive engines.

Energy balance for automotive engines at maximum power

	P_b	$\dot{Q}_{cool}$	$\dot{Q}_{misc}$	$\dot{H}_{e,ic}$	$\dot{m}h_{e,s}$
	(percentage of fuel heating value)				
SI engine	25–28	17–26	3–10	2–5	34–45
Diesel	34–38	16–35	2–6	1–2	22–35

Figure 1: Energy Balance For Automotive Engines At Max Power: Heywood "Internal Combustion Engine Fundamentals"

The max brake thermal efficiency for a gasoline engine is about 35% and for a diesel engine about 45%. The losses are attributed to heat transfer losses, mechanical friction losses, and energy lost in the exhaust gases (Oxford Brookes University. Class Paper 2007)
Combustion efficiency is around 95-98%, which implies near complete combustion.

Total energy available for an engine comes from the fuel and can be found using the equation;

W = m Qhv

W = total energy coming in.
m = mass flow rate of fuel
Qhv = heating value of the fuel or specific heat

Common air to fluid radiator coolant temperature differential is 5-10C at max power.

Degassing or deaeration bottles continuously remove air from the coolant. These are the best. Coolant constantly creates air bubbles as it flows through bends, boils, or in the water pump. Air entrained fluid will reduce the effectiveness of the heat transfer.

Radiator ducting system needs to be water tight or it will not work properly. As air is diffused in the inlet duct the velocity slows down and the pressure rises. As air goes thru the radiator it will heat up which increases the pressure. In the exit duct nozzle the higher pressure accelerates the air to higher velocity. If done right, the aero drag can be reduced to near zero. In aircraft, positive thrust has been seen.

The inlet side of the radiator duct should be adjustable. Reverse air flow can happen in the inlet side if the car average speed is too low. This needs to be determined. Reverse flow creates high drag (undesirable). Some alternatives have been to add removable vents on the nozzle side.

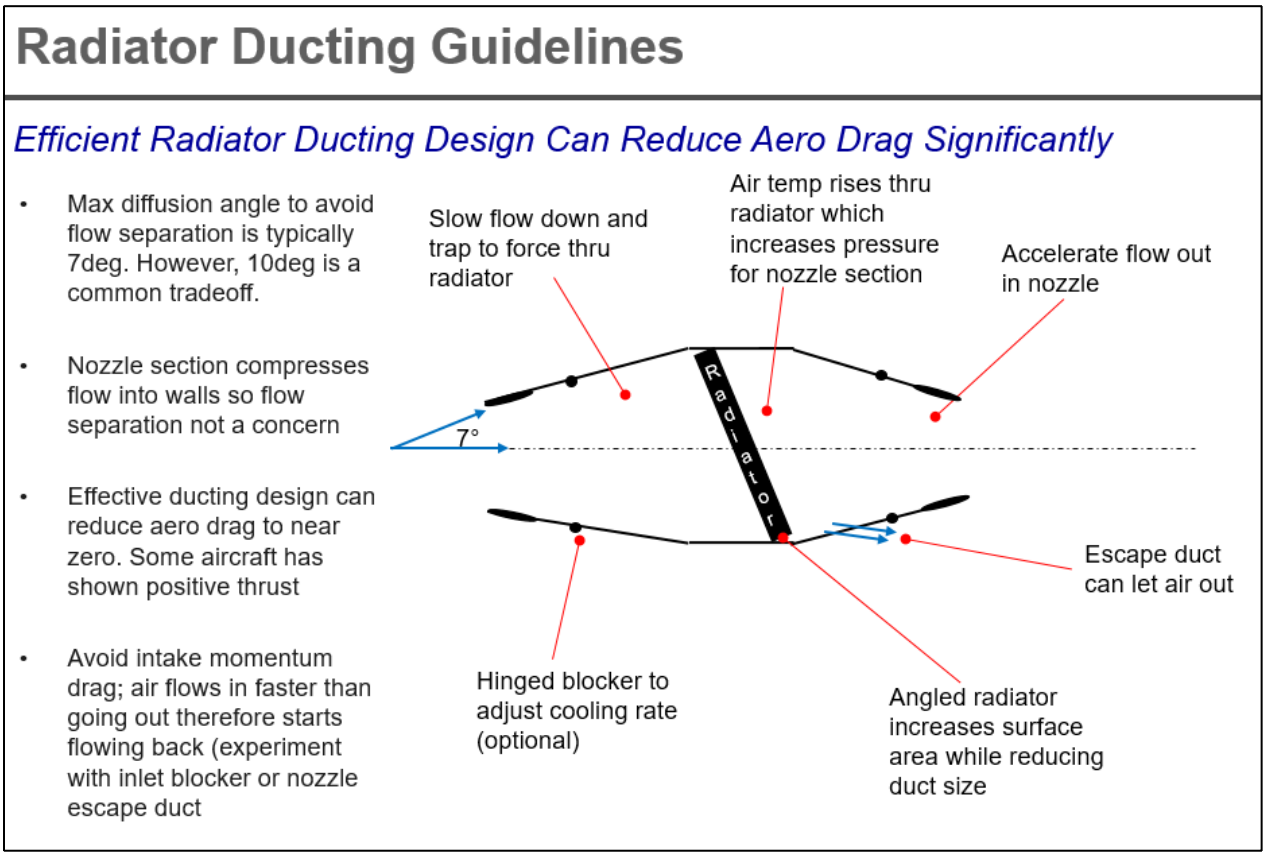

Figure 2: Radiator Ducting Guidelines

In water only systems, add a corrosion inhibitor. Fouling in the engine can drastically reduce cooling performance.

Increase volumetric efficiency of radiator by having large expansion fittings at inlets and outlets of the radiator. For example, see figure 3.

Figure 3: Examples Of Inlet/Outlet To Increase Radiator Efficiency By Distributing Flow

Design Starting Points

A new cleansheet design can begin with these principles. These can be optimized during the design process.

Volumetric flow rate: 1gpm per every 10hp. E.g. a 300hp engine requires 30gpm water pump.

Supply line velocities: 3-5m/s (Use this for line sizing)
Pump suction velocities: 1-3m/s (Use this for line sizing)
Pump suction pressure: 0 to -4psi. (Cavitation must be avoided. -5psi may onset cavitation)

185F is the target cooling temp for aluminum engines. (At 302F [150C] aluminum starts to anneal. i.e. loses strength)

Coolant system pressure: 10-15psi for road cars, 15-21psi for road cars with degassing bottles, up to 40psi for race cars (Nascar). Boiling point changes with higher pressure. Higher pressure prevents boiling during unforseen events such as radiator damage/blocking due to debris. A pressure increase of 15psi (101kPa) will increase the boiling point of water by 20C.