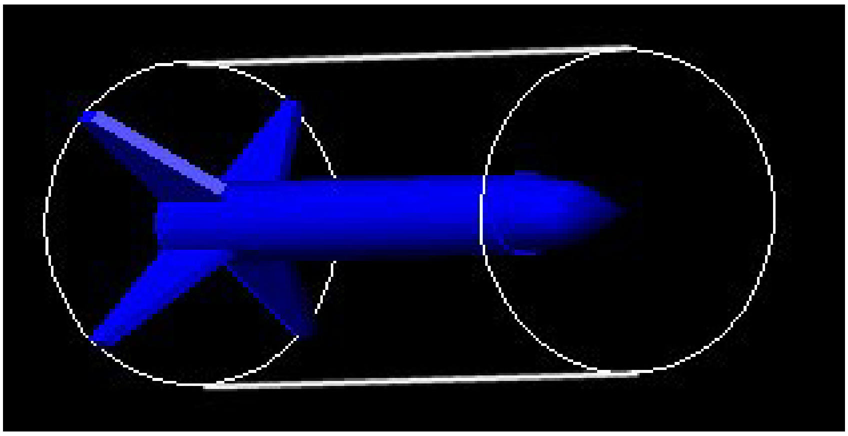
Lowering rocket drag

Rocketeers launching from Sea-level live at the bottom of a dense sea of air. This trite statement has serious consequences for rocketry however: Aerodynamic drag is the major force that small (HPR) rockets experience, gravity is almost secondary. To prove this to oneself, simply perform any rocket trajectory simulation, but switch off the atmosphere: in the absence of drag, most HPR rockets reach an apogee over nine times higher, sometimes ten times. That a little ESTES rocket could reach 30,000 feet rather than 3000 were it not for the atmosphere shows where all the propellant goes.

Any trick or modification that can reduce the drag therefore, is definitely worth doing.
Such a trick is the famous Area rule first discovered in Germany during the 2nd world war, but then independently discovered by Richard Whitcomb at NACA in the '50's, after whom the rule is sometimes named.

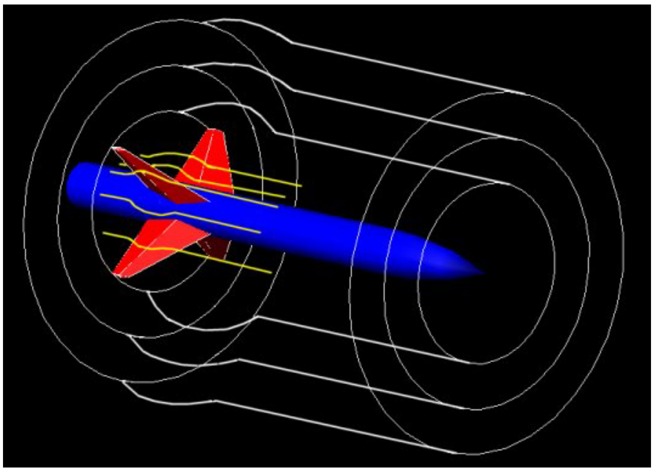
Imagine a tube of air flowing past the rocket; the diameter of the tube is the same as the tips of the fins.
Assuming nice, streamlined tangent-ogive nosecone and boat-tail, then the major obstruction that the air encounters are the fins.



When the air flows through the gap between each fin, the cross-sectional area available to the air between the fuselage and the edge of our tube is reduced by the bulk of the fins.
At subsonic speeds, the air simply speeds up temporarily as it flows through this restriction in accordance with Bernoulli's principle.
At supersonic speeds the reverse happens, the air slows down with a reduction in area.

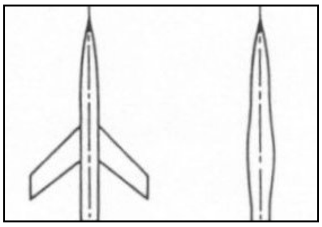
We see these two effects with a rocket nozzle; at the entrant section of the nozzle, the air speeds up with a reduction in nozzle cross-sectional area, whereas after the throat the reverse happens because the flow is then supersonic.
But *at* the nozzle throat, the flow is at Mach 1, neither sub- nor super-sonic, but known as trans-sonic, and the cross-sectional area is temporarily constant: transonic flow cannot respond to changes in area by either slowing down or speeding up.

Sure enough, at Mach 1, the air flowing down our imaginary tube cannot alter its speed to get past the fins smoothly. Instead it bulges radially outward, the diameter of our tube temporarily increases around the fins.
Rockets affect the air around them to quite some distance; another tube of air flowing down the outside of our imaginary tube will be affected by the bulge and will itself bulge, and so on out to quite a distance.



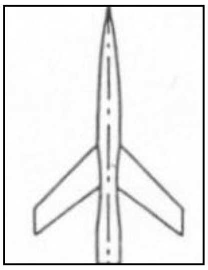
All this disturbed air soaks up energy as Wave drag; a big drag increase at Mach 1. The drag of the whole rocket might increase from around 0.5 to 0.7 (based on the fuselage cross-sectional area) at Mach 1.

Mach 1 is at the high end of the speed range that HPR rockets experience, and so multiplying this drag coefficient by the square of the rocket's airspeed gives a huge drag spike at Mach 1, it's quite likely that the rocket will hit this drag 'wall' and be unable to get past it; it'll just stay below Mach 1 wasting propellant combating this drag.



This sketch shows two rockets with the same transonic drag: as noted above, the fins have the same effect as a radial bulge.

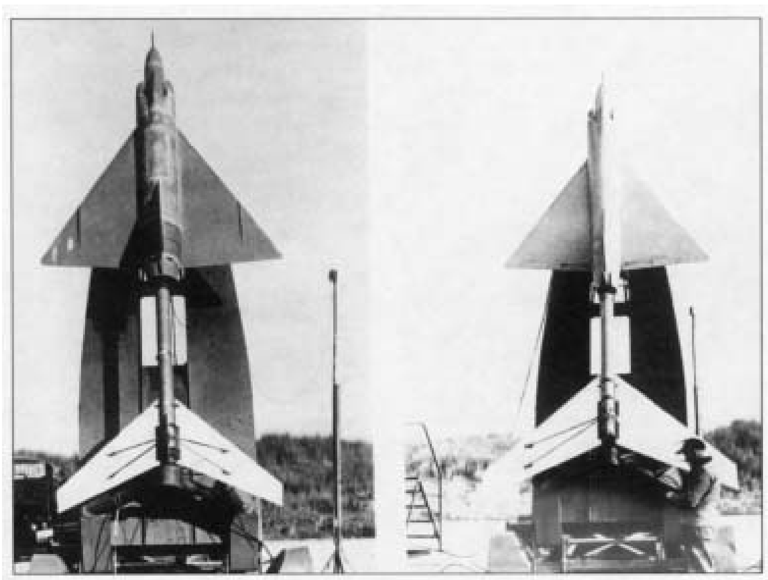
Whitcombe realised that a simple 'rule' to combat the problem was simply to reduce the cross-sectional area of the fuselage around the fins to give extra cross-sectional area for the airflow past the fins: the flow can now flow radially inward instead of radially outward.



The reduction in drag is dramatic; some jet aircraft that couldn't get even to Mach 1 were able to fly supersonically once their fuselages were modified this way.

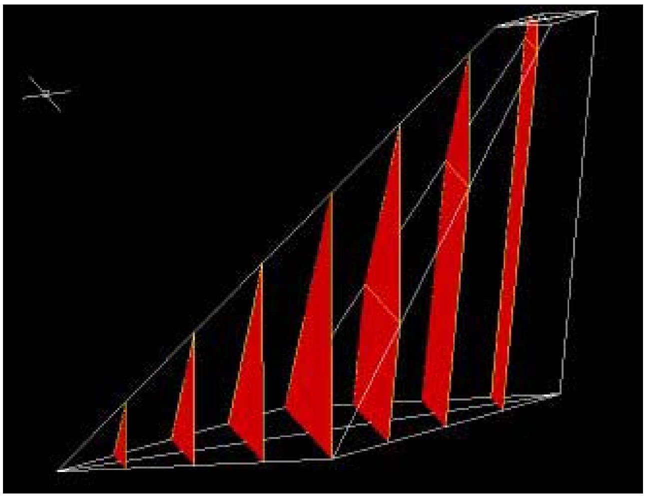
You may see rocketry fin-cans on sale where the fuselage bulges outward instead of inward. Buyer beware! These fin-cans will never let your rocket go supersonic.

Here are two rocket-boosted test models of an early 50's jet; the one on the right with the area-ruled fuselage was the one that could get past Mach 1 by reducing its fuselage cross-sectional area around its wings.



Applying the area rule to your rockets is an exercise in geometry. Select several positions down the fuselage and plot the cross-sectional area of the fuselage and fins at each point on a graph. (Don't forget the fin fillets).

This sketch shows the cross-sectional area of a standard supersonic double-wedge fin at several positions:
Calculating these areas is best handled by a CAD package such as Autocad, whereas a simple fin using flat G10 laminate can be analysed on a spreadsheet.



For example, if 4 fins plus fillets came to 100 square millimetres at some position, then the fuselage must be locally reduced so that the new fuselage circular cross section at that position is 100 square millimetres less than the original fuselage cross section.

A mathematical upshot of the area rule is that if it isn't possible to keep the cross sectional area constant right down the fuselage, then any changes in area must occur as slowly as possible with distance down the fuselage (rate of change of area with fuselage distance.) Consequently, it's important to bevel the trailing edges of straight deltawing fins otherwise there's a sudden decrease in cross-sectional area at the trailing edge.

Area ruling your rocket is rather time consuming, but it will make a big difference to your rocket's apogee.

References:

University aerodynamics notes.
Area rule webpages.