The merit of sharp edges

Introduction

It's well known that at **subsonic** airspeeds, rounded nosetips and fin **leading edges** create considerably less **drag** than sharp ones. Furthermore, rounded fin leading edges create considerably more subsonic **lift**.

At **transonic** and **supersonic** airspeeds however, much of the missile design literature attests to the efficacy of lethally sharp front edges. But the literature is not always correct.

We need to separate the sharpness requirements of aerodynamic design into design for best lift, design for lowest drag, and at higher supersonic airspeeds: design for survivable aerodynamic heating. Safety of personnel is also an issue.

These differing requirements may not point the same way: sharpness at supersonic airspeeds may be good or bad depending on what you're designing for.

This paper focusses on swept fins and **tangent ogive nosecones**, but the trends should be applicable to similarly-shaped nosecones.

See our paper 'Rocketry aerodynamics' for more aerodynamic definitions, including discussion of static stability.

Items in **bold** appear in the glossary at the end of this paper.

How sharp is sharp?

First, we have to define 'sharp'.

As far as the aerodynamics are concerned, a sharp edge could be defined as one that has an edge radius less than one percent of the length of the nosecone or wing/fin chord. At this level of sharpness, the effect of the aerodynamics in the region of the rounded edge are swamped by the aerodynamics of the rest of the body so can be considered negligible.

A *physically* sharp edge would be sharp to the atomic level, but this is neither required nor attainable.

Supersonic lift

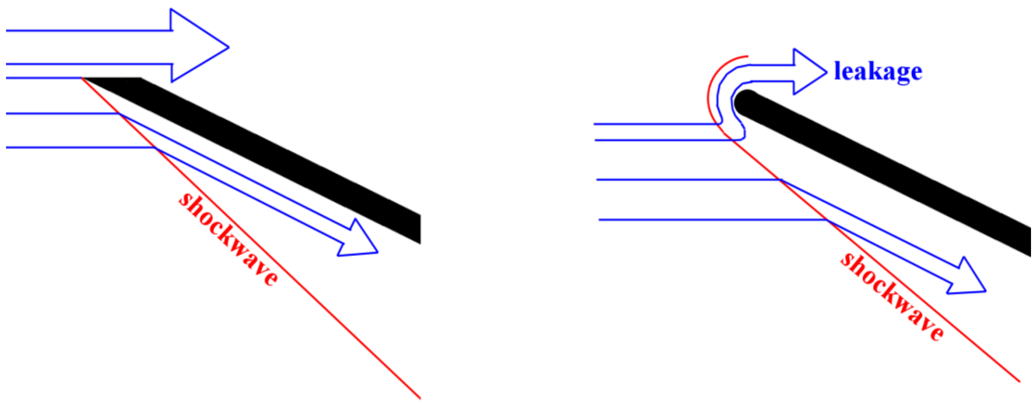
Nose

In rocketry, the **lift** of the nosecone is destabilising - in terms of static stability - so there's nothing to gain by increasing the lift of the nose. A blunter nosetip probably causes less lift, so is preferable for that reason, and for reasons we'll discuss below.

Fins

The lift of wings/fins increases markedly as the edge is sharpened because the **shockwave** caused by the leading edge 'attaches' to the edge rather than standing ahead of it.

The rounded shock that stands some distance ahead of a rounded edge allows spillage of underwing compressed air - which is the basis of most of the lift of a supersonic wing/fin - round the gap between edge and shock. ¼ of the lift can be lost by this spillage, particularly if the leading edge is **swept back**.



Sharp and blunt edge flow at angle of attack

See our paper 'Supersonics and Waveriding' for more discussion of wings with sharp edges at supersonic airspeeds.

For typically-sized rocketry fins, the area of the fins is relatively small compared to the length of the vehicle. Sharpening the leading edge to improve fin lift therefore only gives a slight improvement in static stability; it would be easier just to increase the fin area slightly. This minor increase in fin size needn't increase fin drag as we'll see below.

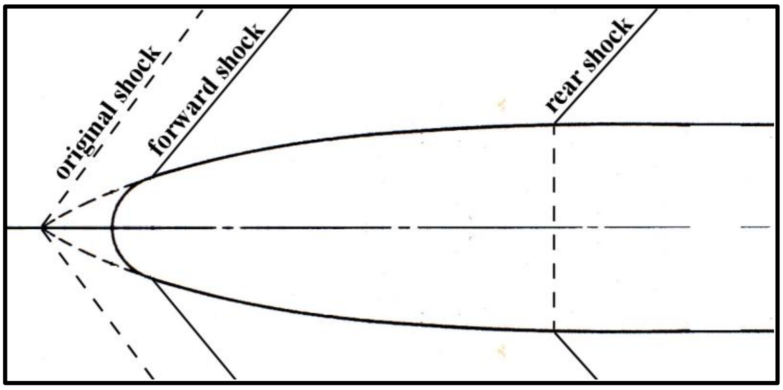
Supersonic drag

Basic aerodynamic theory says that sharp edges cause the least **wave drag** at supersonic airspeeds.

However, it is a little known fact - because the research was restricted to military circles - that minor blunting of the edge causes *less* wave drag at low supersonic Mach numbers.

Whilst the wave drag immediately at the blunter tip does cause more drag, experiments show that an expansion occurs immediately behind it that causes forces (a suction) in the opposite direction to the drag (so is a thrust). So the overall force in the drag direction is less than for a sharp edge.

For sharp nosecones (including **tangent ogives**) a shockwave occurs at the junction between the nosecone and the cylindrical mid-body. For blunted nosecones, another shock occurs at the junction between the spherical nosetip and the rest of the nosecone.



This forward shock as it were 'pulls the teeth' of the rearward shock, resulting in two shocks that are weaker than the original single shock. Weaker shocks give less wave drag.

Blunting can be geometrically defined by the blunting ratio *b*: the ratio of the spherical nosetip diameter *d* divided by the diameter of the base of the nosecone *D*:

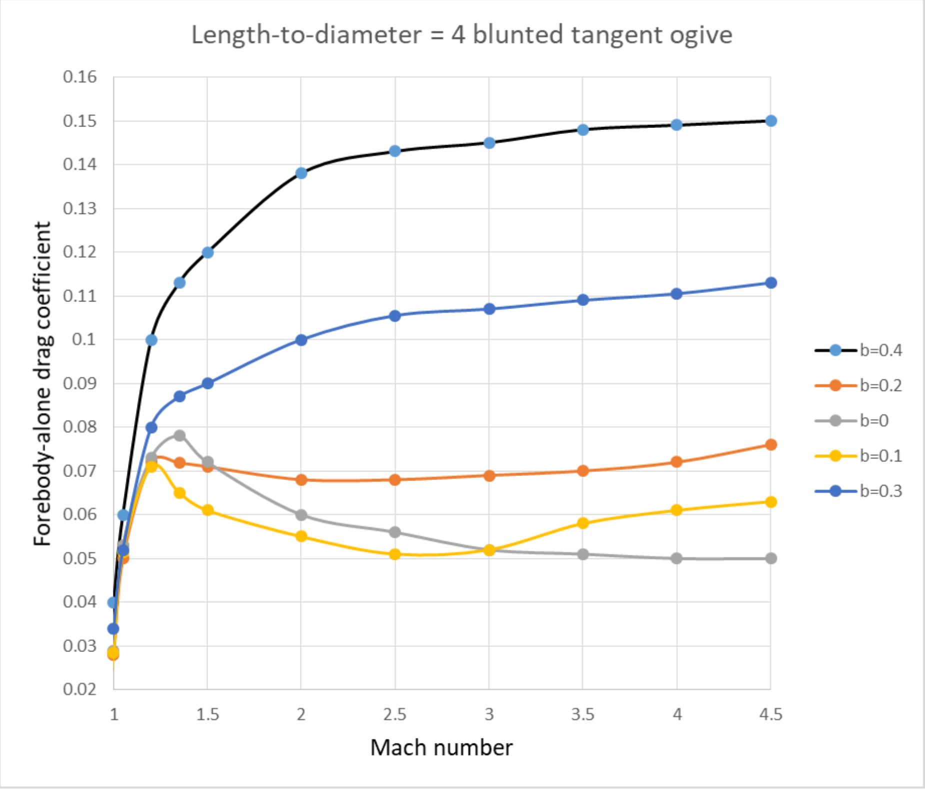
$$b = \frac{d}{D}$$

Several EDSU papers on the subject are fixated on tangent-ogive nosecones with **fineness ratios** of two, as these form the basis of military jet nose design. However, we can assume that the trends are applicable to rocketry nosecones of higher fineness ratios.

For a tangent-ogive of fineness ratio two, Ref. 1 says that the optimum blunting ratio to give minimum pressure-wave drag is about 0.3 at Mach = 0.9, rising rapidly to 0.4 at Mach = 0.97. Then decreasing linearly to 0.3 at Mach = 1.4. Angle of attack has a minor influence on these values, reducing the blunting ratio at Mach = 0.97 by about 0.1.

Ref. 2 shows the effect of increasing fineness ratio, and increasing Mach number up to 4.5. As fineness ratio is increased from 2 to 4, the optimum blunting ratio in the subsonic and transonic region (up to about Mach = 1.3) drops down to around 0.2, then steadily drops to 0.1 at around Mach = 3. Above Mach = 3, zero blunting gives lowest drag.

The following chart is plotted from Ref. 2 for a fineness ratio of 4 tangent ogive, for different bluntness ratios *b* including *b*=0 (sharp).



Note that these data are for the wave drag (pressure drag) of the **forebody** *alone*, assuming a perfectly aerodynamic afterbody and no viscous/boundary layer effects. Below about Mach 0.7 there are no shockwaves, therefore these curves drop to zero at Mach = 0.7

Based on these data, I would recommend a blunting ratio of between 0.1 and 0.2 for HPR tangent-ogive rocket nosecones.

For straight conical nosecones (Ref. 3), similar blunting ratios are best.

Aerodynamic heating

Since the 1950's it has been known that sharp edges tend to melt off if launched from ground level to airspeeds exceeding Mach 3.

It was found both mathematically and experimentally that the heating q experienced by a nosetip or leading edge depended inversely upon the nose radius r of the edge:

$q \propto \sqrt{\frac{\rho}{r}}$ where ρ is air density.

Consequently, most vehicles flying above Mach 5, such as the Space Shuttle, had profoundly rounded noses and wing-edges; seriously blunt.

Many **hypersonic** vehicles have insulating heat-shields. What little heat does flow through the heatshield accumulates with time, therefore the vehicle has only a finite time it can spend hypersonically before its internal fuselage overheats.

There is another approach however: if the higher heating commensurate with a sharp edge can be 'drained away' at the same rate, then the edge can remain at a survivable temperature for an indefinite time.

To allow this, the edge has to be made of a conductive material, able to conduct the heat away to cooler regions of the airflow such as the lee of the wings. This also relieves the thermally-induced stresses at the edge.

On a Mach 3 HPR rocket, this would entail having the forward centimetre or so of nosetip and fin leading edges manufactured from solid metal such as aluminium or copper.

Safety issues

High speed impact

If we ignore the potential for injury during handling, it is a fallacy that sharp edges would cause more damage to persons or property due to a high speed impact even though at first sight they look 'more lethal'.

Googling the shape of commercial bullets reveals just as many sharp as blunt ones.

If the rocket vehicle goes off course during ascent, or if the parachute fails, a robust blunt edge will cause 'blunt trauma'; just as big a hole as a sharp edge.

In practice this means that a plastic nosecone with a hollow tip filled with lead shot will cause just as much damage as a sharp metal nosetip of similar mass.

Having said that, a fully metal nosecone on a **model rocket** represents a point mass of high density far and above that needed for static stability. This should be avoided for safety, as it's effectively a small cannon-ball.

Low speed impact

Low speed impacts are a different story: a sharp edge descending swiftly under a small parachute will cause a puncture, whereas a rounded edge will not. For this reason, many model aircraft organisations recommend rounded edges.

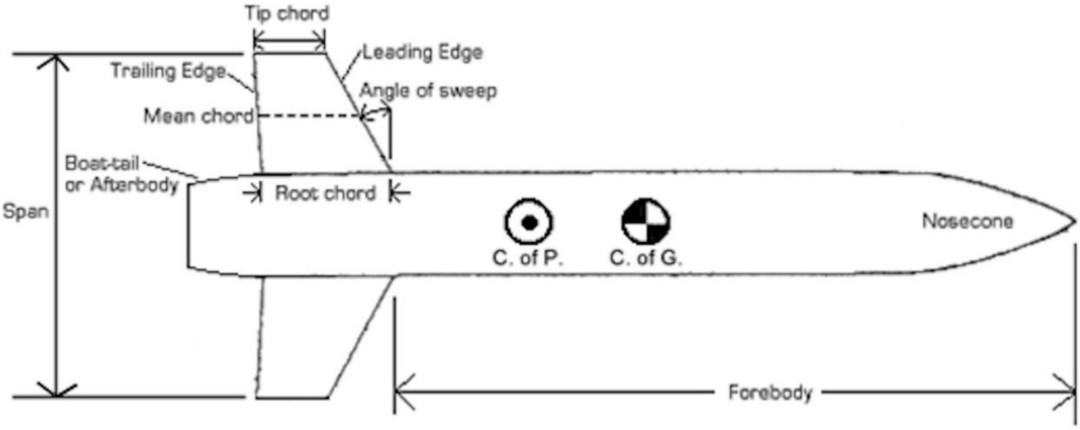
Ground handling

Fully metal fins on model rockets would be made of very thin sheet metal due to the small scale involved, which would result in very sharp edges which are a handling hazard.

Sharp edges at any scale represent the potential for handling injury during manufacture, ground handling, and ground recovery. Precautions must be taken to protect personnel.

Glossary

Geometric definitions:



(Strictly, the forebody is everything upstream of the boat-tail when there are no fins present.)

Angle of attack: α (or Angle of Incidence)
This is usually referred to as 'alpha', and corresponds to the angle between the incoming airflow direction (usually the **Freestream** direction) and some vehicle or fin datum.

Drag (equation):
Drag, or 'air resistance', is the retarding force experienced by bodies travelling through a fliud (gas or liquid).
The equation used to calculate drag is simply the *drag coefficient, Cd*, times **dynamic pressure**, times some reference area '*S*'.
For the rocket vehicle, this reference area 'S' is the maximum cross-sectional area of the fuselage (ignoring the fins or small, local structures), whereas for aircraft, it's the total wing area.

Dynamic pressure: (q)
All aerodynamic forces scale directly with the kinetic energy term: $\frac{1}{2}\rho V^2$
ρ being volume-specific mass or air density, and V = flow velocity.
This kinetic energy term is called Dynamic Pressure (q), to distinguish it from its Potential energy counterpart of static pressure (P).

Fineness ratio:
The length L of the nosecone divided by the diameter of its base D.

Forebody:
The nosecone and forward fuselage.

Freestream (flowfield): ∞
The undisturbed airflow at a large ('infinite') upstream distance ahead of the **vehicle,** i.e. not **local.** For example, freestream **Mach number** is Mach number for the whole vehicle as we'd usually understand it, and not the **local** Mach number around the nosecone or fins.
Freestream properties have the subscript ∞, and are those of the atmosphere.

HPR: 'High-powered rocket' a model/amateur rocketry designation denoting a rocket powered by H to O class engines.

Hypersonic:
Higher **supersonic** airspeeds where chemical effects caused by the air molecules breaking down as they traverse shockwaves begin to manifest themselves. The exact boundary of hypersonics depends on the criteria being studied, but is generally assumed to mean airspeeds above **Mach** 5.

Lift (equation):
Lift is the normal force experienced by bodies travelling through a fliud (gas or liquid) at **angle of attack**.
The equation used to calculate lift is simply the *lift coefficient, C_L*, times **dynamic pressure**, times some reference area '*S*', i.e: (ρ = atmospheric density.)
For the rocket vehicle, this reference area 'S' is the maximum cross-sectional area of the fuselage (ignoring the fins or small, local structures), whereas for aircraft, it's the total wing area.
Lift coefficient C_L varies with angle of attack.

Local (flowfield):
The airflow properties in the immediate vicinity of the vehicle i.e. not **Freestream.**

Mach number:
The vehicle's airspeed V (or the **local** airspeed around a nose or fin) compared to the speed of sound 'a':

$$M = \frac{V}{a}$$

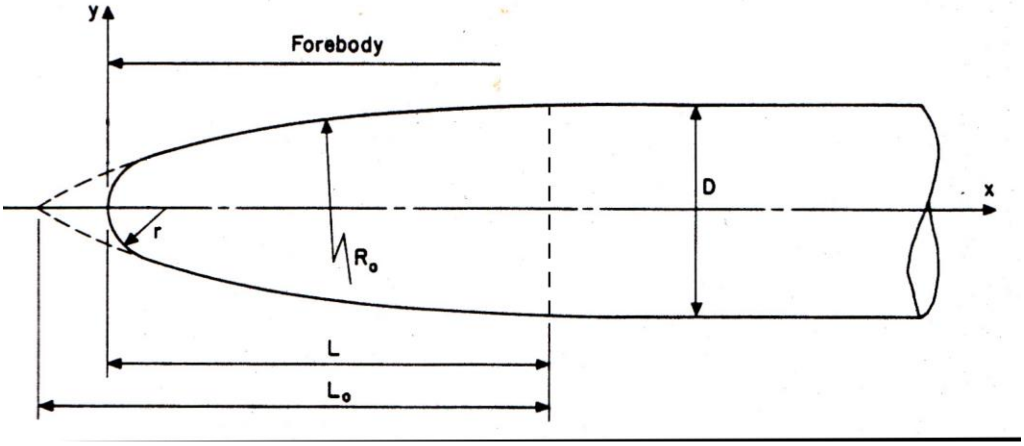
Model rocket:
A rocket vehicle utilising motors of G-class and below.

Shockwave:
A thin region where **flowfield** properties (temperature/pressure/density) suddenly jump in value.

Subsonic:
Vehicle airspeed is below Mach 1 (see **Mach number**).

Supersonic:
Vehicle airspeed is above Mach 1 (see **Mach number**).

Tangent ogive nosecone:



A nose cone formed by revolving a circular arc of radius R_0 about the central x axis. The arc is tangent to the cylindrical fuselage at the nosecone base. Note that in this paper, the **fineness ratio** (length to diameter ratio) of the nosecone is based on L rather than the unblunted L_0. The majority of HPR nosecones are tangent ogives as they give adequate low drag performance and are easy to design.

Transonic:
Above a **freestream Mach number** of about 0.7, certain parts of the **local** flow around the nose and fins will hit a local Mach of above 1.0, **supersonic**.
Similarly, up to a freestream Mach number of about 1.4, certain parts of the local flow around the nose and boat-tail are still **subsonic**.
The transonic zone is this **freestream Mach number** region where there is a mix of subsonic and supersonic flow. This mixture makes predicting the aerodynamics of the zone difficult and inexact.

Viscous (drag):
Drag caused by the viscosity of the air.

Wave drag: (see **drag**)
As parts of the **local flowfield** go **supersonic**, **shockwaves** will be formed. Shockwaves are a dissipative process: energy is wasted. Wave drag is a manifestation of this loss of energy. Wave drag is a pressure drag.
The higher the nosecone fineness ratio, the lower the wavedrag, though excessively long nosecones have structural/weight issues, and suffer large **viscous drag**.

References

1. ESDU paper 89033, “Pressure drag and lift contributions for blunted forebodies of fineness ratio 2.0 in transonic flow”

2. ESDU paper 80021, “Pressure drag of blunt forebodies at zero incidence for Mach numbers up to 4”

3. ESDU paper 68021, “Foredrag of spherically blunted cones in supersonic flow”

4. “The design of the aeroplane”, Darrol Stinton, Blackwell science, 1995

5. “Hypersonic and high temperature gas dynamics”, John D. Anderson Jnr, McGraw Hill, 1989

6. “Aerodynamics for engineering students – third edition”, Houghton and Carruthers, Arnold publishing, 1988