Sizing a Parachute for a Model Rocket

Choosing a descent speed from a simple landing model

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Most parachute calculations start with the rocket's mass and a desired descent speed. Mass is easy enough to measure. But why do we choose 5 m/s, or 6 m/s? How fast can the rocket land before a fin breaks?

A smaller parachute gets the rocket down sooner and usually reduces wind drift. A larger one reduces landing speed and impact energy. To choose between them, we need an estimate of the landing load the rocket can tolerate. This post develops a deliberately simple method: estimate a fin's bending-load limit, assume an effective stopping distance, work backward to a candidate landing speed, and use that speed to size the parachute.

The result is conditional on a few assumptions we make to simplify the problem otherwise it's a long rabbit hole of complexity. That still makes it useful: we can see what supports a speed choice, how sensitive it is, and which measurements would improve it.

1. Estimate the load a fin can carry

A study of Papua New Guinea balsa reports a mean *modulus of rupture* of 16.6 MPa for its medium-density group.[1] This is a bending-strength estimate expressed as a stress:

$$\sigma_b = 16.6\,\mathrm{MPa} = 16.6\,\mathrm{N/mm}^2.$$

Given this value for balsa wood stress threshold we want to determine how much force loading it equates to. We need the fin dimensions to turn it into a load estimate.

Imagine holding the fin along its root and pushing at its tip, perpendicular to its broad face. Approximate it as a cantilever, fixed at the body and free at the outer end. Let

- b be the root chord, the length attached to the rocket body;
- s be the span, measured outward from the body;
- h be the balsa-sheet thickness.

Assume properly constructed fins made from sound, uniform balsa of 3 mm thickness, with a secure root attachment and grain running from root toward tip, favorably aligned for the bending direction considered. We model the fin as a cantilever beam undergoing small deflections without twisting, with the load shared across the full root width. Applying the force perpendicular to the fin at its tip gives the largest root bending moment for a given force within this model. These simplifying assumptions illustrate an unfavorable bending load, but do not establish a worst-case impact: a corner strike may introduce twisting or concentrated loading that causes failure at a lower force.

[1] N. J. Kotlarewski, B. Belleville, B. K. Gusamo, and B. Ozarska, *Mechanical properties of Papua New Guinea balsa wood*, European Journal of Wood and Wood Products **74**, 83–89 (2016). doi:10.1007/s00107-015-0983-0.

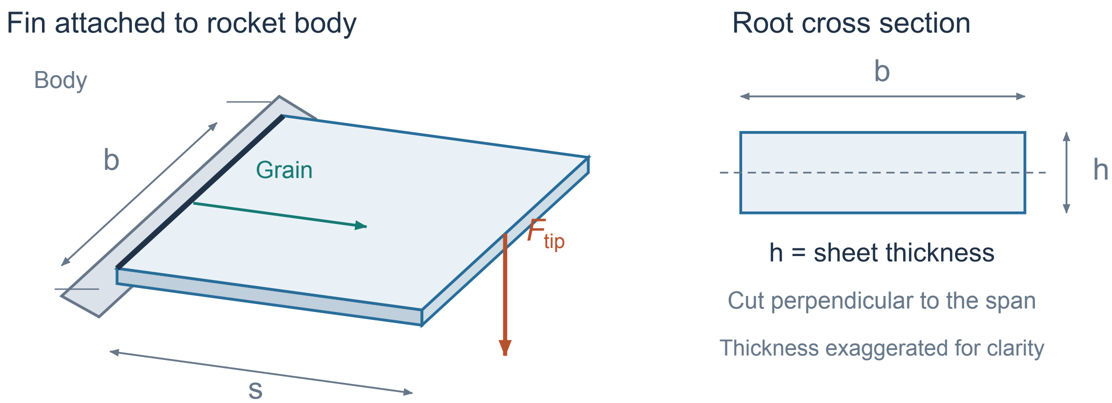

Figure 1: The fin as a thin cantilever. The root chord b lies along the body; span s runs outward; thickness h is perpendicular to the broad face. The tip force bends the fin through its thickness.

From bending moment to bending stress

The following steps follow the flexure and beam-design treatment in *Mechanics of Materials*.[2]

First, find the bending moment. A force produces a moment equal to its magnitude times the perpendicular lever arm. At the root, the tip force F_{tip} has lever arm s, so

$$M_{\text{root}} = F_{\text{tip}} s.$$

The moment is greatest at the root for this tip-loaded beam. At a section x from the root, its magnitude is $F_{\text{tip}}(s - x)$.

Next, identify the bending section. Cut across the fin perpendicular to the span. The cut is a rectangle of width b and thickness h. Its centroidal *second moment of area* is

$$I = \int_A y^2 \, dA = b \int_{-h/2}^{h/2} y^2 \, dy = \boxed{\frac{bh^3}{12}}.$$

This geometric quantity has units of length to the fourth power; it is not mass moment of inertia. Material farther from the neutral axis contributes more strongly because of the y^2 weighting.

Then locate the most highly stressed fibers. As the fin bends, fibers on one side lengthen and those on the other shorten. The neutral axis runs through the middle of the thickness in this symmetric model. Under the usual elastic beam assumptions, strain and normal stress vary linearly with distance y from that axis. The flexure formula gives the stress magnitude as

$$|\sigma(y)| = \frac{|M|\,|y|}{I}.$$

Here y is a distance *through the thickness*, not the span. At the outermost fibers, $|y| = h/2$. The span has already entered through $M = F_{\text{tip}} s$. Thus the maximum root-stress magnitude is

$$\sigma_{\text{root,max}} = \frac{M_{\text{root}}(h/2)}{I} = \frac{F_{\text{tip}} s(h/2)}{bh^3/12} = \boxed{\frac{6F_{\text{tip}} s}{bh^2}}.$$

[2] J. M. Gere and S. P. Timoshenko, *Mechanics of Materials*, 3rd ed., PWS-Kent, 1990, Sections 5.3, "Normal Stresses in Beams," and 5.4, "Design of Beams."

The normal stress acts along the span even though the applied tip force is perpendicular to the fin face. Reversing the force swaps the tension and compression faces; the maximum stress magnitude is unchanged.

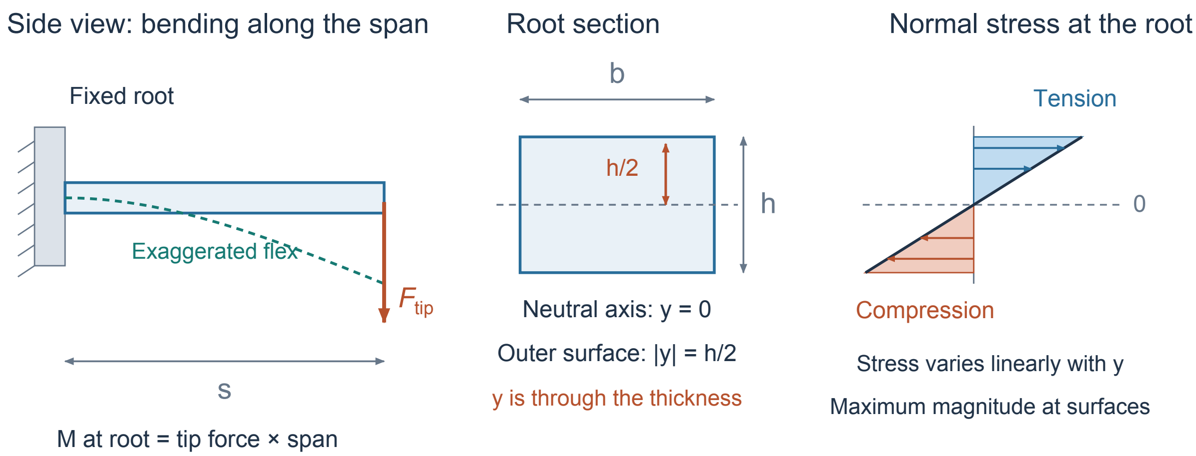

Figure 2: The two distances in the flexure calculation: s is the lever arm along the beam, while y is measured from the neutral axis through the thickness. At the root of the downward-loaded cantilever shown, the upper face is in tension and the lower face is in compression.

The section-modulus shortcut

The *section modulus* collects the section geometry into one quantity:

$$S = \frac{I}{h/2} = \boxed{\frac{bh^2}{6}}, \qquad \sigma_{\text{max}} = \frac{M_{\text{max}}}{S}.$$

Use capital S for section modulus and lowercase s for span. Section modulus has units of length cubed. In the textbook's design form,

$$S_{\text{required}} = \frac{M_{\text{max}}}{\sigma_{\text{allow}}}.$$

Equivalently, a chosen allowable normal stress gives a corresponding tip load:

$$F_{\text{allow}}\, s = \sigma_{\text{allow}} S, \qquad F_{\text{allow}} = \frac{\sigma_{\text{allow}} bh^2}{6s}.$$

The balsa study supplies an estimated bending strength σ_b, rather than a ready-made allowable stress for our fin. Substituting that strength first gives an estimated static bending limit,

$$\boxed{F_{\text{bend}} \approx \frac{\sigma_b\, bh^2}{6s}}.$$

An illustrative fin

For example, use a 6 cm root, 6 cm span, and 3 mm thickness. Figure 3 shows those dimensions in the two views needed for the calculation.

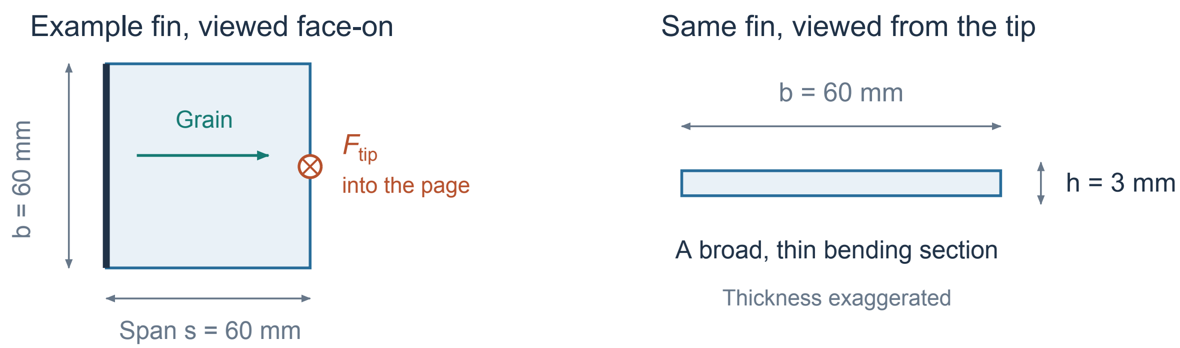

Figure 3: Worked-example dimensions: $b = 60$ mm, $s = 60$ mm, and $h = 3$ mm. The circled cross denotes a force into the page. The edge view makes clear that h, not s, is the bending-section thickness.

With millimetres throughout,

$$I = \frac{60(3^3)}{12} = 135\,\mathrm{mm}^4, \qquad S = \frac{60(3^2)}{6} = 90\,\mathrm{mm}^3.$$

The root moment at the assumed bending strength is

$$M_{\text{limit}} = \sigma_b S = (16.6)(90) = 1494\,\mathrm{N\,mm}.$$

Dividing by the 60 mm lever arm gives

$$F_{\text{bend}} \approx \frac{1494}{60} = 24.9\,\mathrm{N}.$$

Doubling span halves this load estimate, doubling root chord doubles it, and doubling thickness multiplies it by four. If the force acts closer to the root, replace s by its actual distance from the attachment. The same force produces more bending when it acts farther out.

2. Assume a stopping distance

Take the recovery mass to be $m = 0.195\,\mathrm{kg}$, or 195 g, including the spent motor and recovery equipment. As a working lawn-landing scenario, assume an *effective stopping distance* of

$$d = 0.05\,\mathrm{m} \quad \text{(about 2 inches)}.$$

This is the distance over which the moving rocket is brought to rest. It is an explicit modeling assumption inspired by a yielding landing surface, not a claim that 2-inch grass always provides 2 inches of effective cushioning.

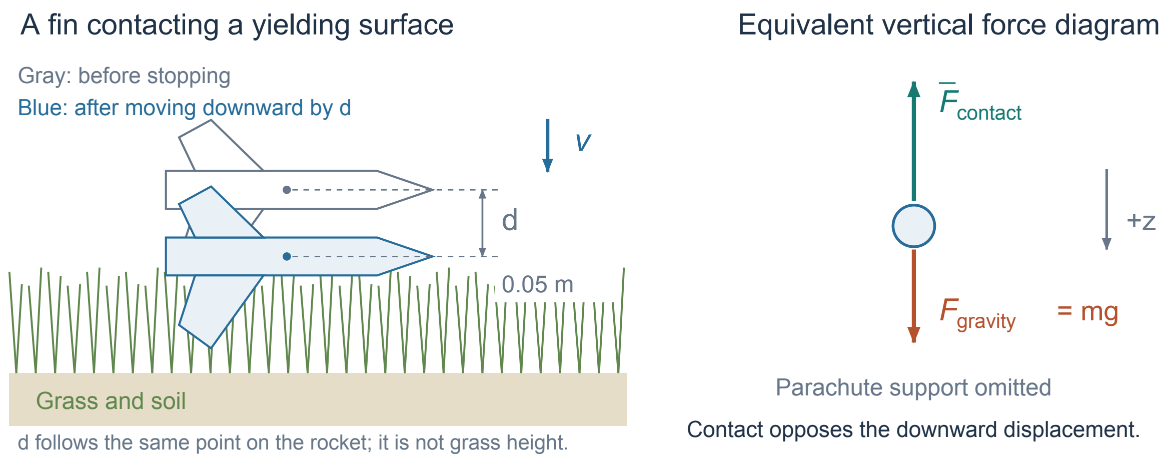

Figure 4: An illustrative fin-first landing and the equivalent vertical force model. Distance d follows a fixed point on the rocket during stopping; it is not a measurement of grass height. The right-hand diagram omits parachute support and uses downward-positive displacement.

Work done while the rocket stops

The work–energy theorem states that net work equals the change in kinetic energy:[3]

$$W_{\text{net}} = KE_f - KE_i.$$

For a vertical landing without rebound, $KE_f = 0$ and $KE_i = \frac{1}{2}mv^2$, so

$$W_{\text{net}} = -\frac{1}{2}mv^2.$$

Take the stopping displacement as downward-positive. The net retarding force points upward, opposite that displacement, and does negative work. Writing its average magnitude as $\overline{F}_{\text{net}}$ gives

$$-\overline{F}_{\text{net}}d = -\frac{1}{2}mv^2, \qquad \boxed{\overline{F}_{\text{net}} = \frac{mv^2}{2d}}.$$

Bars denote averages over the stopping distance. The minus sign in the work equation is what makes the final force *magnitude* positive.

Separate contact force from net force

The ground must both oppose the downward motion and overcome weight. Label the weight $F_{\text{gravity}} = mg$, with $g = 9.81\,\text{m/s}^2$. Neglecting any remaining upward parachute support,

$$\overline{F}_{\text{net}} = \overline{F}_{\text{contact}} - F_{\text{gravity}}.$$

Equivalently, gravity does positive work and contact does negative work:

$$mgd - \overline{F}_{\text{contact}}d = -\frac{1}{2}mv^2.$$

[3] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 15th ed., Pearson, 2020, Section 6.2, "Kinetic Energy and the Work–Energy Theorem."

Rearranging gives

$$\boxed{\overline{F}_{\text{contact}} = mg + \frac{mv^2}{2d}}.$$

Crediting upward parachute support would reduce this contact-force estimate in the vertical model. At our example mass and stopping distance, the loads are:

Speed	Kinetic energy	Average net force	Average contact force
5.0 m/s	2.44 J	48.8 N	50.7 N
6.0 m/s	3.51 J	70.2 N	72.1 N

This explains why 5 or 6 m/s cannot be justified by quoting kinetic energy alone. Whether those speeds are tolerable depends on how the energy is dissipated and where the resulting contact force acts.

3. Connect the landing load to the fin limit

For a simple adverse loading scenario, assign the entire ground-contact force to one fin as a perpendicular tip load. We give no credit for other fins sharing the load. This connects the vertical stopping model to the sideways fin-bending model through an equivalent-load assumption; it does not simulate the rocket's orientation and rotation during impact.

Substituting the contact-force estimate and solving for speed gives

$$\left(mg + \frac{mv^2}{2d}\right) \le F_{\text{bend}},$$

$$\boxed{v_* = \sqrt{\frac{2d}{m}\left(F_{\text{bend}} - mg\right)}}$$

The calculated v_* is a candidate upper landing speed *for this assumed scenario*. Choose a target at or below it. If $F_{\text{bend}} \le mg$, no positive landing speed satisfies this assumed one-fin tip-loading scenario. Revisit the fin dimensions, strength, mass, or assumed load path; this does not mean that every way of supporting the rocket is physically impossible.

Expressing the same limit as an energy budget

The corresponding kinetic-energy budget is

$$\boxed{KE_* = \left(F_{\text{bend}} - mg\right) d}.$$

If weight is small compared with the assumed allowable contact force, the leading approximation is especially simple:

$$KE_* \approx F_{\text{bend}}\, d, \qquad v_* \approx \sqrt{\frac{2F_{\text{bend}}\, d}{m}}.$$

This is an energy budget for the *whole stopping scenario*, based on an assumed force limit. It does not say that the fin itself can absorb that many joules before breaking. The ground, grass, and rocket deformation may absorb energy while the fin transmits the contact load.

What the example predicts

For $F_{\text{bend}} = 24.9\,\text{N}$, $m = 0.195\,\text{kg}$, and $d = 0.05\,\text{m}$, the candidate speed is

$$v_* = \sqrt{\frac{2(0.05)}{0.195}\left[24.9 - (0.195)(9.81)\right]} \approx 3.43\,\text{m/s}.$$

Its energy budget is about 1.15 J.

Our original trial target of 5 m/s exceeds this particular model's estimate. If the rocket lands faster and one fin carries the entire equivalent tip load, the estimated bending limit is exceeded.

4. Turn the chosen speed into a parachute size

Once a parachute is fully inflated, a descending rocket can approach a nearly constant terminal velocity. Write the forces as

$$F_{\text{drag}} = \tfrac{1}{2}\rho C_D A v^2, \qquad F_{\text{gravity}} = mg.$$

Equating parachute drag to weight gives

$$\frac{1}{2}\rho C_D A v^2 = mg, \qquad \boxed{A = \frac{2mg}{\rho C_D v^2}}.$$

This is the force balance used in NASA Glenn's explanation of parachute recovery.[4] Here ρ is air density, C_D is the drag coefficient, and A is the reference area associated with that coefficient. We neglect drag on the rocket body and use still-air descent speed as the vertical landing speed.

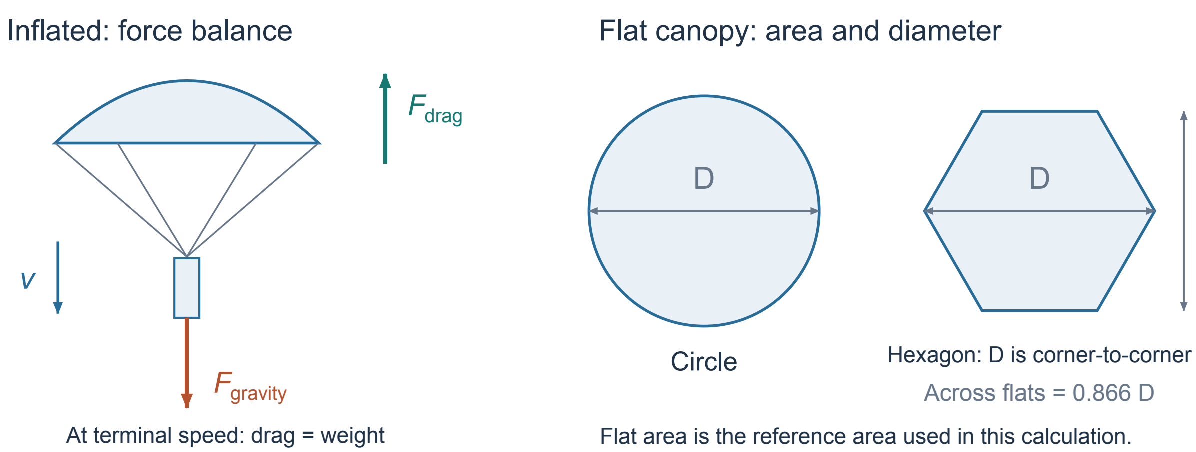

Figure 5: At terminal descent, $F_{\text{drag}} = F_{\text{gravity}}$. The inflated canopy on the left produces the drag, while the sizing calculation uses the flat reference areas shown on the right.

For a circular flat canopy of diameter D,

$$A = \frac{\pi D^2}{4}, \qquad \boxed{D = \sqrt{\frac{8mg}{\pi \rho C_D v^2}}}.$$

[4] NASA Glenn Research Center, *Velocity During Recovery*. This reference supports the force balance. Its quoted parachute drag coefficient differs from the assumption used here.

Use the canopy's flat area with a coefficient defined on that basis. The inflated projected area is different and cannot be substituted without changing the coefficient. Near sea level, take $\rho = 1.225\,\mathrm{kg/m^3}$ and, as a starting assumption for a simple flat circular parachute, $C_D = 0.75$.[5]

For the example mass, a selected speed of $5.0\,\mathrm{m/s}$ gives $D \approx 18.1\,\mathrm{in}$. That answers the sizing question *if* we accept $5.0\,\mathrm{m/s}$; it does not establish that the speed is appropriate. Using the fin-and-landing model instead gives:

Assumed d	Candidate speed v_*	Circular diameter
$0.01\,\mathrm{m}$	$1.54\,\mathrm{m/s}$	$59.0\,\mathrm{in}$
$0.05\,\mathrm{m}$	$3.43\,\mathrm{m/s}$	$26.4\,\mathrm{in}$
$0.10\,\mathrm{m}$	$4.86\,\mathrm{m/s}$	$18.7\,\mathrm{in}$

All rows use the same 195 g mass and illustrative 24.9 N fin limit. These are sensitivity cases to show how strongly the assumed stopping distance affects the result.

Circle or hexagon

For a regular hexagonal canopy, define D as the distance between opposite corners. Its flat area is

$$A = \frac{3\sqrt{3}}{8} D^2.$$

At the same required area and assumed C_D, the hexagon's corner-to-corner diameter is about 10% larger than the circle's diameter. Its distance across opposite flat sides is $\sqrt{3}D/2$. Using the same coefficient for the two outlines is a first approximation. Use the appropriate area formula when converting the required area to a canopy dimension.

5. The competing requirement: less time drifting

In steady horizontal wind of speed u, assume the rocket drifts with the air while descending vertically at constant speed v. Over a remaining height H, the approximate time and horizontal displacement are

$$T \approx \frac{H}{v}, \qquad \Delta x \approx \frac{uH}{v}.$$

With $u = 3\,\mathrm{m/s}$, each 100 m of descent produces approximately the following values. The 2.32 m/s case is a slower comparison target, not a second prediction for the same stopping distance:

Descent speed	Time per 100 m	Horizontal drift per 100 m
$5.00\,\mathrm{m/s}$	$20\,\mathrm{s}$	$60\,\mathrm{m}$
$3.43\,\mathrm{m/s}$	$29\,\mathrm{s}$	$87\,\mathrm{m}$
$2.32\,\mathrm{m/s}$	$43\,\mathrm{s}$	$129\,\mathrm{m}$

[5] Apogee Components, *Technical Publication 3*, Figure 2, lists $C_D = 0.75$ for a solid flat circular canopy. Actual performance varies with canopy design and operating conditions.

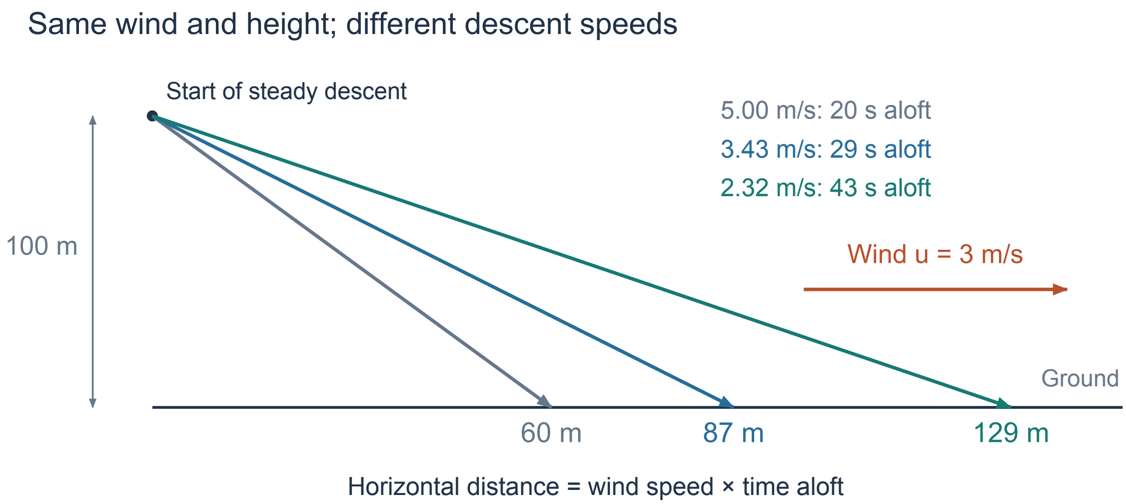

Figure 6: In the same steady wind, a slower vertical descent takes longer and carries the rocket farther horizontally. The trajectories share the same starting height; the horizontal and vertical drawing scales differ.

This is the tradeoff we were looking for. A lower target speed reduces the modeled landing load, but increases time aloft and drift. Within the chosen model, the fastest acceptable target gives the least drift. A smaller parachute reduces time aloft and drift, but can bring the rocket down too fast for the assumed fin-load limit. To accept that smaller parachute, we would need stronger fins or a less severe landing load; otherwise, increase the parachute area.

The wind calculation estimates steady drift only. It does not include motion before steady parachute descent, changing winds with height, or swinging. Horizontal ground speed also adds kinetic energy; the fin-load calculation above covers a vertical stopping scenario and does not model lateral snagging or sliding.

6. Worked example: from rocket measurements to parachute size

For practical use, the process has three steps. Here we apply them to the 195 g rocket used throughout this paper.

Step 1. Collect the data

Measure the rocket's recovery mass and fin dimensions, estimate the stopping distance from the landing field, and choose a circular or hexagonal canopy. For this example, use:

Input	Example value
Recovery mass, including spent motor	$m = 195$ g $= 0.195$ kg
Fin root chord and span	$b = 60$ mm, $s = 60$ mm
Fin thickness	$h = 3$ mm
Balsa bending strength (published mean)	$\sigma_b = 16.6$ MPa
Estimated stopping distance	$d = 50$ mm $= 0.05$ m
Parachute type	Circular flat canopy
Air density and drag coefficient	$\rho = 1.225$ kg/m^3, $C_D = 0.75$

Consider whether the field has tall grass, short grass, or bare dirt when estimating d. Here we assume 50 mm for a yielding lawn. Grass height is not itself the stopping distance; firm ground generally calls for a smaller estimate. Use $\sigma_b = 16.6$ MPa from the cited balsa study.

Step 2. Calculate the model's maximum landing speed

First use the fin measurements to obtain the bending-load estimate:

$$F_{\text{bend}} = \frac{\sigma_b b h^2}{6s} = \frac{16.6(60)(3^2)}{6(60)} = 24.9 \text{ N.}$$

Then substitute the load, mass, and stopping distance into

$$\boxed{v_* = \sqrt{\frac{2d}{m}\left(F_{\text{bend}} - mg\right)}} = \sqrt{\frac{2(0.05)}{0.195}\left[24.9 - (0.195)(9.81)\right]} \approx 3.43 \text{ m/s.}$$

This is the maximum speed under the model's assumptions.

Step 3. Calculate the estimated parachute diameter

Use $v = v_*$ in the circular-canopy equation:

$$\boxed{D = \sqrt{\frac{8mg}{\pi \rho C_D v^2}}} = \sqrt{\frac{8(0.195)(9.81)}{\pi(1.225)(0.75)(3.43)^2}} \approx 0.672 \text{ m} = 26.4 \text{ in.}$$

For this example, the estimated circular flat-canopy diameter is therefore **about 26.4 inches**. If a regular hexagon was selected instead, multiply the circular diameter by $\sqrt{2\pi/(3\sqrt{3})} \approx 1.10$: the required corner-to-corner size is about **29.1 inches**, assuming the same C_D.