ASA 106: Theory

WARNING: This essay is by a newbie sailor attempting to report the remarks of very experienced sailors Skipper Steve Summers and Mate Doug Lombard. Take with appropriate grain of salt.

Abstract: During an ASA 106 cruise we were docked in Kingston marina, listening to Coast Guard reports of vessels in distress and offering assistance where we could. While there, Doug and Steve did a chalk-talk on sailing theory.

This detoured to Steve's remarks on sailing fundamentals.

Table of Contents

1 The Premise

How to learn sailing theory? 3 approaches:

a) Understand the fundamental physics and then deduce the needed sail handling. This is necessary for highly experienced racers but bewildering for most folks.

https://www.northsails.com/sailing/en/2016/09/how-sails-work.

b) Most sailing texts give lip service to fundamentals, but then list special rules-of-thumb. Do this on a tack, and this other thing on a jibe, and yet another when picking up a buoy. The moment for action has passed before a newbie determines which rule applies.

c) Develop a mental model of simplified fundamentals. Then the correct response to any change in wind or sea will be obvious and can be quickly applied. You don't need to learn and sort through a dozen special rules. Adjust for nuances based on feedback observed after trimming to more or less the right condition.

This essay follows "c".

2 Wind

2.1 True Wind and Vertical Gradient

For background on why there are winds at all, and mechanisms of wind change (veering, backing, puffs, lulls, etc.) see:

https://www.weather.gov/jetstream/global_intro

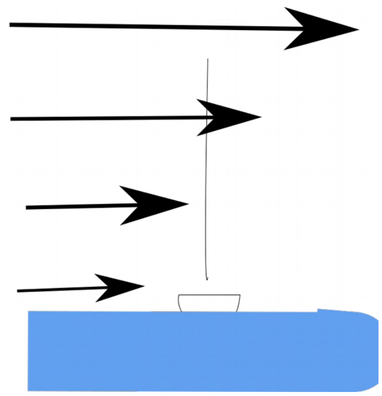
David Burch "Modern Marine Weather"

Here, we focus on the wind right at the boat, right now. We care about its direction (TWD) and speed (TWS), giving a velocity vector. For most of this analysis, true wind at 10m (33 ft) is assumed to be at a constant direction, and a constant speed.

Wind is moving air - a mixture of gasses. The movement is a form of kinetic energy, which is proportional to the square of the speed or velocity (K=1/2 mv^2). That square-of-velocity factor is key to trimming hulls and sails.

As moving air molecules hit relatively stationary water molecules at the surface of the sea, their kinetic energy is partially transferred to the water. The effect is to accelerate the water and decelerate the air. The water forms ripples, then wavelets, and then fully developed waves. The air at the surface slows down, and gets turbulent as it bounces off waves.

Next, the air just above the slowed surface air hits the lower air molecules, energy is transferred, and the upper air slows down, but not as slow as the lower air. This relative slowing continues up, far above the top of the mast. For practical purposes, we can assume a velocity gradient from sea level to top of mast.



2.2 Apparent Wind and Twist

Apparent Wind is the wind as experienced from the boat, resulting from vector addition of True Wind and Boat Speed. This gives apparent wind velocity, reported as Apparent Wind Direction (AWD) and Apparent Wind Speed (AWS).

See:

> a) **Analysis:** https://www.northsails.com/sailing/en/2016/09/how-sails-work
>
> b) **Discussion:** Chapman "Piloting and Seamanship", 65th ed. pp 280-281. Uses iceboats and Spanish galleons to explain the effects. Figure 8-05 illustrates vector addition. Concludes with 3 rules:
>
> > 1. Except when sailing directly downwind, apparent wind will always come from "farther ahead" than the true wind does.
> >
> > 2. Sailing at any angle from perpendicular to quite close to the wind, apparent wind will be greater than true wind.
> >
> > 3. As wind strength increases, the angle of the apparent wind move forward.

At any one time all parts of the boat have the same velocity: Boat Velocity (Speed and Direction). But the True Wind gets faster as you go up the mast. Therefore AWS increases up the mast, and AWD shifts forward up the mast.   This is true upwind and downwind, though the vector-addition means Athat for given TWS, WS is dramatically lower downwind than upwind.

2.3 Detecting air flow

a) True Wind Direction/Speed:

TWD: Flags and trees ashore.   Direction of the small ripples on top (not the fully formed waves).

TWS: Primarily by sea conditions.   Burch's "personal" Beaufort scale:

Knots	**Observed**
1-2	See smoke drifting but can't feel it
4	Feel wind on face or neck
10	See isolated whitecaps. maybe 8 kts if wind against current and 12 if wind with current.
15	Halfway between 10 and 20
20	Surface is a bedspread of whitecaps

n a fully instrumented boat, system can back-calculate TWD/TWS from AWD/AWS and boat direction and speed.

b) Apparent Wind Direction/Speed: Telltales in the shrouds and backstays (away from sails), and the feeling on your face and neck.   Windex at masthead -- if you can see it.   AWD/AWS instrument indicator.

3 Trim the Hull

The basic rule: Keep the hull on its water line, heeled about 10%, with 1-3 degree weather helm.

The designer worked hard to design a hull which would accelerate given power from the sails.   He/she knew the sails would force *some* heeling, so designed for clean underwater shape for 0-10% heel.   Beyond that the underwater shape is a horrible drag-inducing mess. [Boats designed to trick race rating rules may be designed to work best at 20%, but cruisers don't use those boats.]

The crew worked hard to trim the sails to provide that power.

So it is up to the skipper: Don't screw up that work with excessive bow up or down, or excessive heel, or excessive weather helm -- any of which leaves a horribly drag-inducing shape in the water.

a) **Balance fore-and-aft.** Shift ballast (people and/or gear) until the boat is sailing along its waterline.

b) **Balance heel.**

1. In light air, shift ballast to leeward so the sails can sag to an airfoil shape
2. In moderate wind, shift ballast to windward so hull heels no more than 10%
3. In heavy wind, de-power so hull heels no more than 10%.

c) **Balance helm**. Best determined by feeling modest weather helm. Too much weather helm, then de-power the main relative to the jib. Too little weather helm, then de-power jib relative to main.

4 Trim the Sails

The basic rule: Trim to optimize driving power for the given course and wind.

Polar charts from the sailmaker tell you what is possible. Your job is to approach that as best you can given weather, boat condition, and crew.

Usually "optimize" means extract maximum available power; sometimes it means de-power.

Each sailing text for the past century has explained the physics of sails, and has then been debunked by the next text or research paper. For a modern summary see:

https://en.wikipedia.org/wiki/Forces_on_sails

Obviously, this is too complex to be used in actual sailing. The better approach is to build up a mental model of the basics so you can make competent adjustments in real-time, and then deal nuances from there.

4.1 Mainsail, no vertical gradient

[For fabric sails, not metal airfoils]

1. **Full vs Flat:** Sails can only take 2 useful shapes:

a) "Full". E.g., a square sail, a spinnaker, or a main-and-jib set as wing-and-wing. Wind blows on the front surface and eventually billows over the sides (top, bottom, left, right). Useful for going downwind.

b) "Flat". E.g., main or jib on any point of sail besides run. Air hits the luff, flows along the remainder of the sail to exit past the leech. Sail is at an angle forming an airfoil. Useful (if done right) for going any direction besides directly downwind.

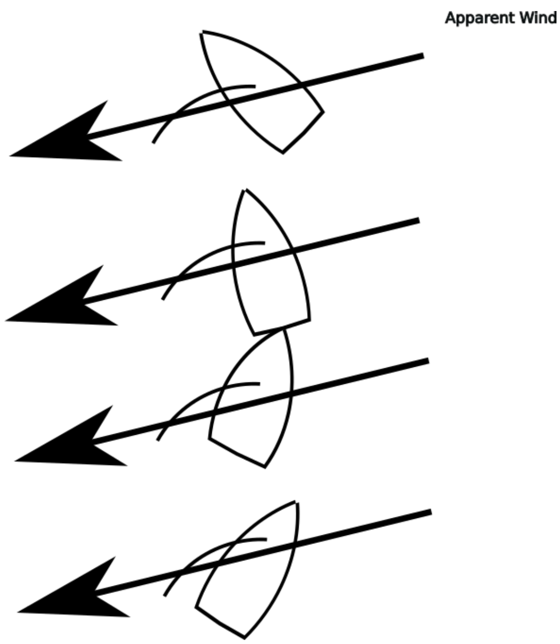
Most of the rest of this story is about flat sails.

2. **Laminar flow:** On a properly trimmed flat sail, the air flows along the fabric from luff to leech -- smoothly, without turbulence. To detect this condition, check the telltales.

a) Laminar flow on jib: Telltales near jib luff. Dancing on windward side means angle of attack too far into wind. Dancing on leeward side means angle too far off the wind. Both sides dancing means there is just turbulence -- hopefully only during a tack.

b) Laminar flow on main: Telltales near leech. Dancing on windward side means leech is curled in too tight -- need to straighten the leech or turn angle of attack away from wind or both. Dancing on leeward means the slot isn't working -- trim to line up with jib's windward flow.

3. **Constant angle of attack:** Aim the flattened sail at an angle to the apparent wind, so that the luff and the first foot or so form an airfoil. Since we always need a good airfoil, we use the same angle no matter what point-of-sail. The boat may rotate under the sail, but the sail's orientation to the apparent wind is constant.



4. **Shape for power:** The basic rule is always trim for power. You need power to punch through waves, to accelerate after a tack, and to handle gusty winds.

Like an airplane wing, more flat is good for high-speed (fighter jet), less flat is good for power and acceleration (crop duster) Less flat provided by:

a) Ease luff tension (halyard and cunningham or downhaul),

b) Ease foot tension (outhaul or reefing lines)

c) Ease leech tension (mainsheet when close hauled, or vang).

With enough easing the sail becomes too baggy and the wind loses laminar flow over the sail (telltales dance or lift). Trim in just enough to restore laminar flow. As boat speed picks up and thus apparent wind shifts forward, you must re-trim angle of attack to maintain laminar flow.

NOTE: This is the basis for "*When in doubt let it out"*. But instead of being a rote rule, it is a natural outcome of optimizing power.

5. Shape for de-power: As heel becomes excessive, de-power in this order:

a) Temporary: When close hauled where you were depending on traveler to maintain angle of attack. Ease traveler so angle points too high and airfoil is spoiled.

b) Temporary: When on beam/broad reach where you were depending on vang to keep boom down. Ease vang to allow more twist, thus spilling wind aloft.

c) Temporary: When close-hauled where you were depending on mainsheet to maintain angle and to keep boom down. Ease mainsheet a couple of inches to allow more twist, thus spilling wind aloft.

d) Long-term: Reef main. Protect the sail from tearing out by snugging a sail-tie through the reefing cringle and around the boom, so that the tension on the reefing line is directed fore-and-aft, not upward. After reef is in, reef (furl) jib enough to restore light weather helm.

4.2 Mainsail, vertical gradient

Because the apparent wind direction (AWD) shifts forward as we go up the mast, we have shift the angle of attack forward as we go up. This is called "sail twist".

Notice that as a mainsail leaves the boom, the leech immediately falls off downwind, and then gradually comes back parallel to the boom near the masthead. This is true of the whole draft of the sail -- there is no one angle of attack.

However, we can trim the angle of attack (mainsheet and traveler) so the bottom 1/3 of the sail is properly powered. After that it is a matter of trimming for twist further up.

a) If the sail is trimmed "full", the top leech remains away from the boom, thus no twist and the wind above is wasted.

b) If the sail is trimmed "flat" the leech comes back to the boom, the angle-of-attack is aligned with the faster wind, and we get power from the wind aloft.

So, how do you use this knowledge?

a) **Need more power?** If leech telltales are streaming down below but dancing up above, we need to pull the top closer toward the boom. That will let the faster (and further forward) winds at the masthead work effectively on the sail.

NOTE: This is the origin of the rule: Trim until the top batten is parallel with the boom.

b) **Need less power?** If the whole sail is overpowered, we need to spill some of the power -- and specifically want to do so up above to reduce heeling effects. So need to reduce twist by letting the boom lift (ease vang). This makes leech bulge downwind, and ruins the angle-of-attack for the top of the sail. Wind aloft just flows by harmlessly.

NOTE: This is the origin of the rule: To spill power, ease the vang.

4.3 Jib

Angle of Attack: Just like the main, the jib needs the proper angle of attack, constant across all non-downwind points of sail. If the lower telltales are streaming, the angle of attack is about right. For broad through close reach, angle is controlled by jibsheet tension. When the jib is fully tensioned (close-hauled), then the angle of attack is controlled by the boat heading.

Twist: Just like the main, the jib needs to deal with higher AWS up above, thus needs to control twist. We don't have a traveler to do that, but we do have jib cars. By moving the jib car aft (back), we get a shallower angle to the jib and thus tension more along the foot and less along the leech. That lets the leech open up for more twist.

a) **Increase power:** Just like the main, in moderate winds we adjust the cars until the bottom and top telltales are streaming at the same time -- indicating proper twist. If the bottom telltales break first, that means the bottom of the jib is curled in too tightly. We need to uncurl it but keep the same overall tension so the top stays right. Do this by moving the cars back, giving a flatter foot.

NOTE: This is the origin of the rule "*If bottom breaks first, move back*". But by understanding the effects, it is the obvious way to optimize power, instead of a rote rule.

b) **Decrease power:** Just like the main, in heavy winds we adjust cars aft to de-power by spilling wind aloft.

4.4 Slot

The slot between the jib and mainsail is aerodynamically complex. Ignore the physics models (which are questionable at best and useless at sea anyway). Instead:

a) **Trim jib first.** It is in "clean air" and can be controlled independent of other activities.

b) **Trim the main for streaming leech telltales**. What we really want is the back half of the main in nice laminar flow from the slot. Don't worry if the main's luff is backwinded by the jib -- the added power from the fast air in the slot more than makes up for it.

4.5 Trim for a Puff

4.5.1 Wrong way

a) Puff hits (same TWD, higher TWS). AWD shifts forward.

b) Helm turns boat to align with new AWD. Boat accelerates. AWD shifts further forward. Helm turns yet further toward AWD.

c) Crew does nothing.

d) Puff dies. TWS drops. AWS drops. AWD falls back to or even below where it was originally.

e) Boat direction and momentum pointed hopelessly into irons. Boat speed drops. AWS drops. AWD falls back to near TWD.

f) Net effect is that boat came to a near halt. Must fall off and restart the boat.

4.5.2 Right way

a) Puff hits (same TWD, higher TWS). AWD shifts forward.

b) Helm recognizes it is a puff (vs a shifting wind), so stays steady on course.

c) Crew recognizes it is a puff, with AWD shifted forward temporarily. Moves traveler to windward so the angle of attack better matches the temporary AWD.

d) Puff dies. TWS drops. AWS drops. AWD falls back to or even below where it was originally.

e) Boat direction and momentum still pointed right direction for prevailing wind. Helm stays on course. Crew eases traveler to re-align angle of attack with new AWD.

f) Net effect is that the boat stayed on course but picked up a burst of power.

5 Trim the Rudder (steer)

The basic rule: Determine an on-the-boat sighting line. Aim that at the target. Steer to keep within a few degrees of target, averaging on-target.

5.1 Normal

a) **Start with your eyes**, obviously near the helm, but possibly off to port or starboard.

b) **Find a front sight** -- e.g., a stanchion in the bow pulpit, or a shroud. At first this sighting line (eye to front sight) can be exactly parallel to the boat center-line, but if the boat is crabbing, then adjust the sight-line to be parallel to the actual track.

c) **Steer to target.** Using the sight-line, steer to the target. Do not over-correct -- every rudder action slows the boat. Allow the boat to wander +/- 10 degrees as waves and gusts come and go, but average on-target.

5.2 To a spot

E.g., MOB, mooring buoy, dock cleat

a) **Move eyes to target's side**, e.g., move over to starboard with hand still on the wheel or tiller. Get far enough over that sight-line eyes-to-V-of-shrouds is parallel to center-line.

b) **Sight through the V** of the upper/lower shrouds to the target.

c) **Align boat's momentum with sight-line.** This takes about 3 boat lengths.

d) **Maintain steerageway.** Each boat, with given wind and current, will need different boat-speed to do this.

e) **Steer more precisely.** Wander just a few degrees either way and immediately get back on line. Gently does it -- don't over-correct.

f) **Come to a stop.** Coast to a stop due to normal drag. If coming in hot (e.g., for steerageway) then kill speed by wagging the rudder, or backing a sail, or reversing the engine.

6 Appendix

6.1 Template Revisions

Rev	Author	Date	Notes

6.2 Document Revisions

Rev	Author	Date	Notes
New_rc01	Harry George	2019-10-23	First draft
New_rc02	Harry George	2019-11-05	Rework treatment of twist.

6.3 Glossary

Term	Definition