# How Sails Work

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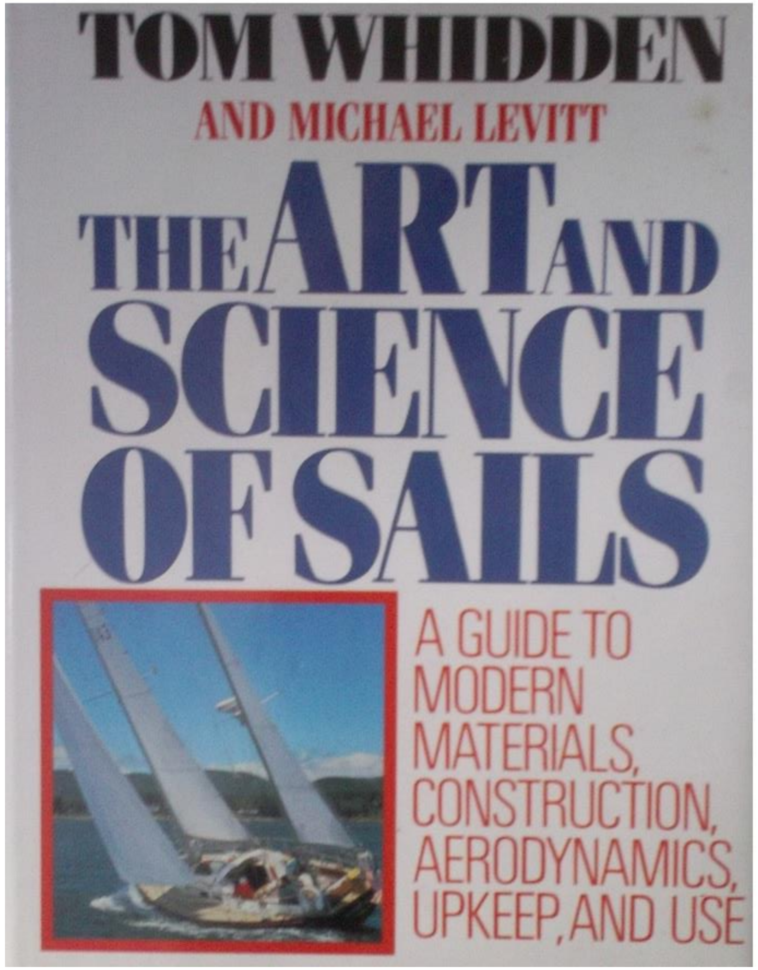
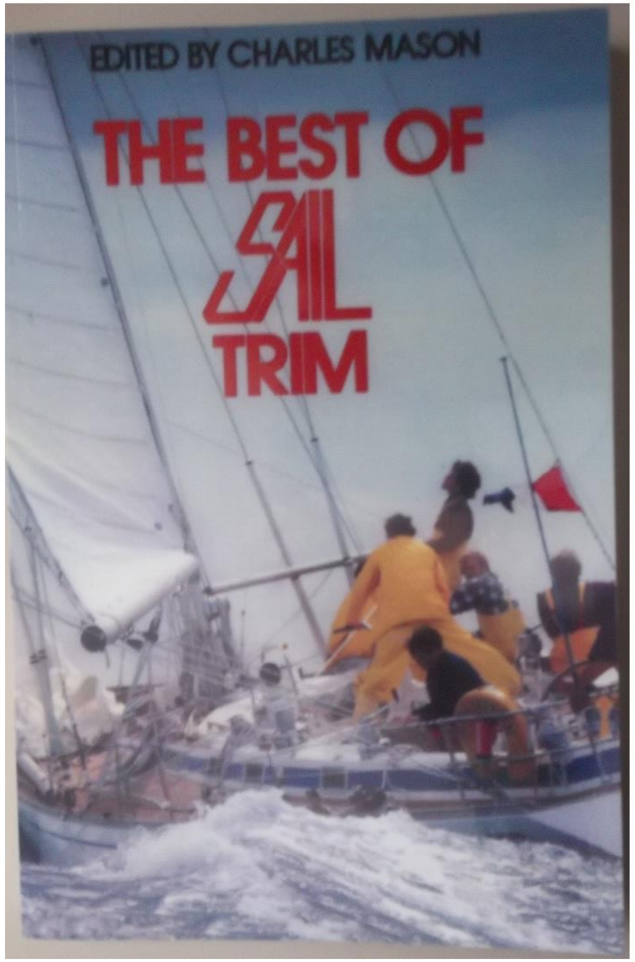
Seminar #2 – March 5, 2019

Tonight, I would like to:

1. Explain the latest thinking on aerodynamics of sail(s)
2. Describe how to trim sails to go FAST

# Good Reference Books

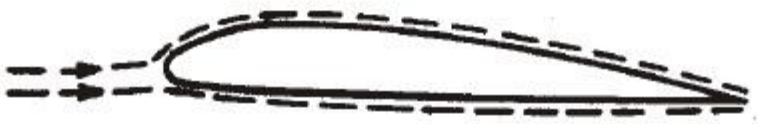


# Aerodynamics of Sails

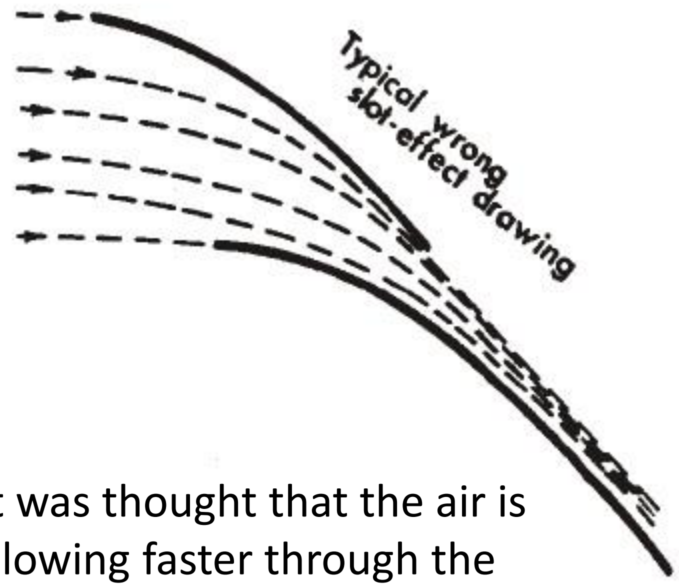
Section 1

**Many books written for sailboat racing by well known, successful racers incorrectly show how wind and sails work.**

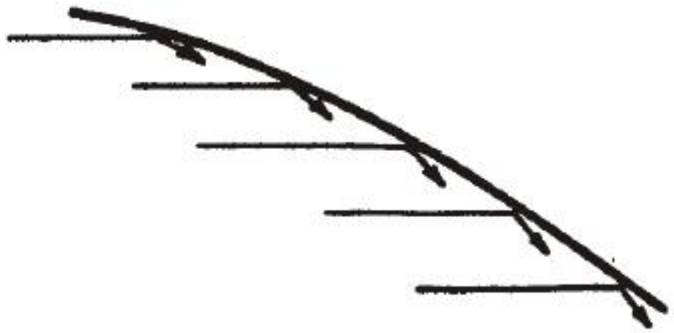


Theory – Air has to go faster around a wing where one side is longer than the other.

Problem – Sails do not have much thickness and they work.




It was thought that the air is blowing faster through the slot, causing a rush of air at the back of the main.



Theory – Air particles hit the sail like grains of sand to product force.

Problem – Predicted force is much smaller that observed.

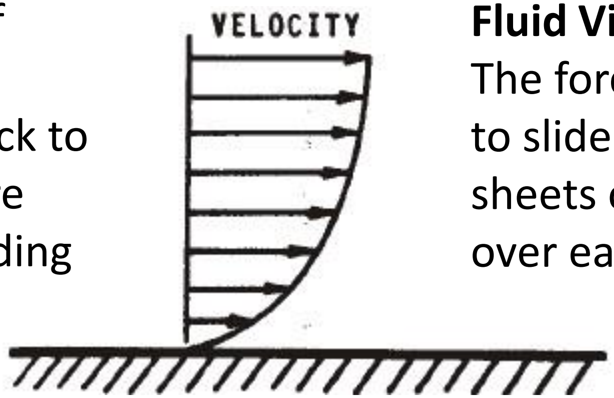
**Avril Gentry, an aerodynamicist working in the aircraft industry and an avid racing sailor, researched how sails worked and published articles in Sail Magazine with his findings in the early 1970's.**

**Bernoulli's Equation:**

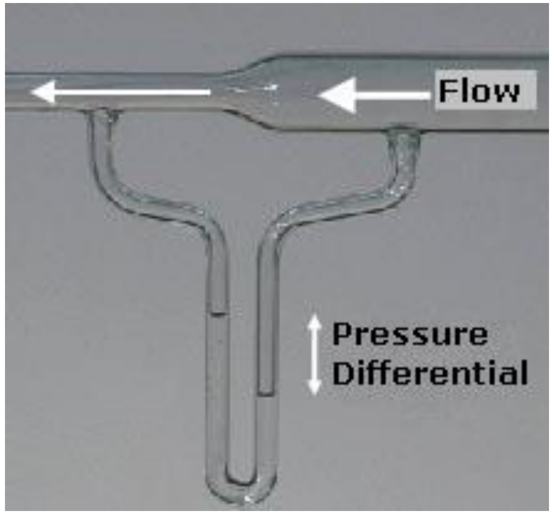
As airflow increases in speed,

pressure decreases.

**Airflow on Surface:**
Imagine sheets of paper, with the bottom sheet stuck to the surface, where the sheets are sliding past one another.

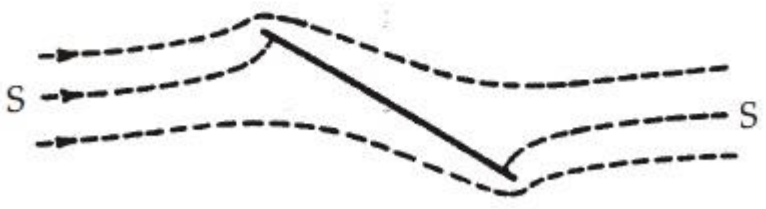



**Fluid Viscosity:**
The force needed to slide the sheets of paper over each other.

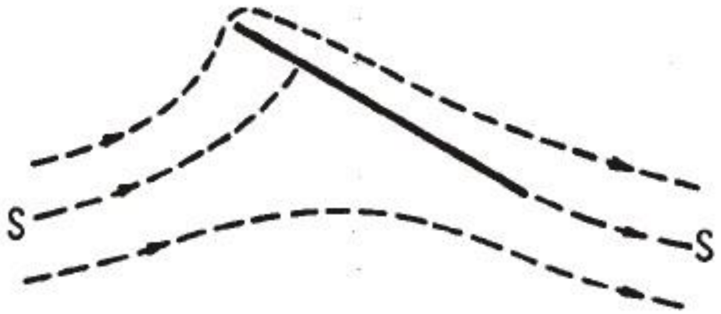



Venturi Tube:
Air picks up speed through the narrow tube.

Angle of board to wind is called “Angle of Attack”

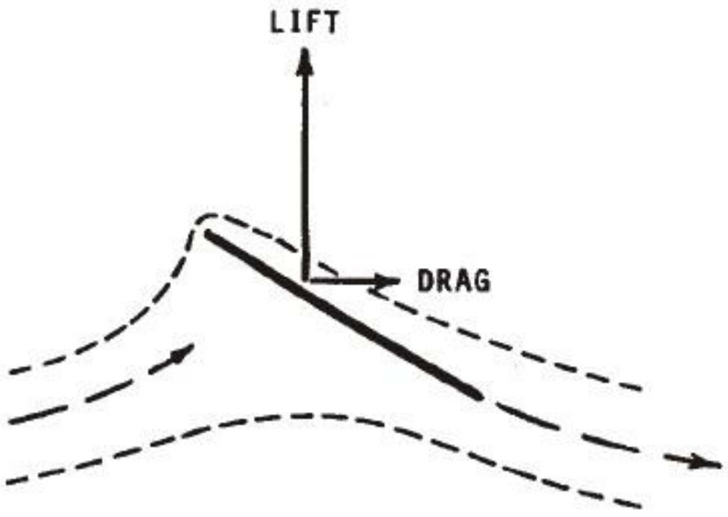



**Flat Board, no viscosity:**
-Flow of air divides at line labeled S, so air on one side flows over the board and air on the other side flows under the board.
-Flow patterns are symmetrical on both sides of the board, therefore no force generated.
- This case is ideal and doesn’t happen in real life.  Used in the development of the computer models.



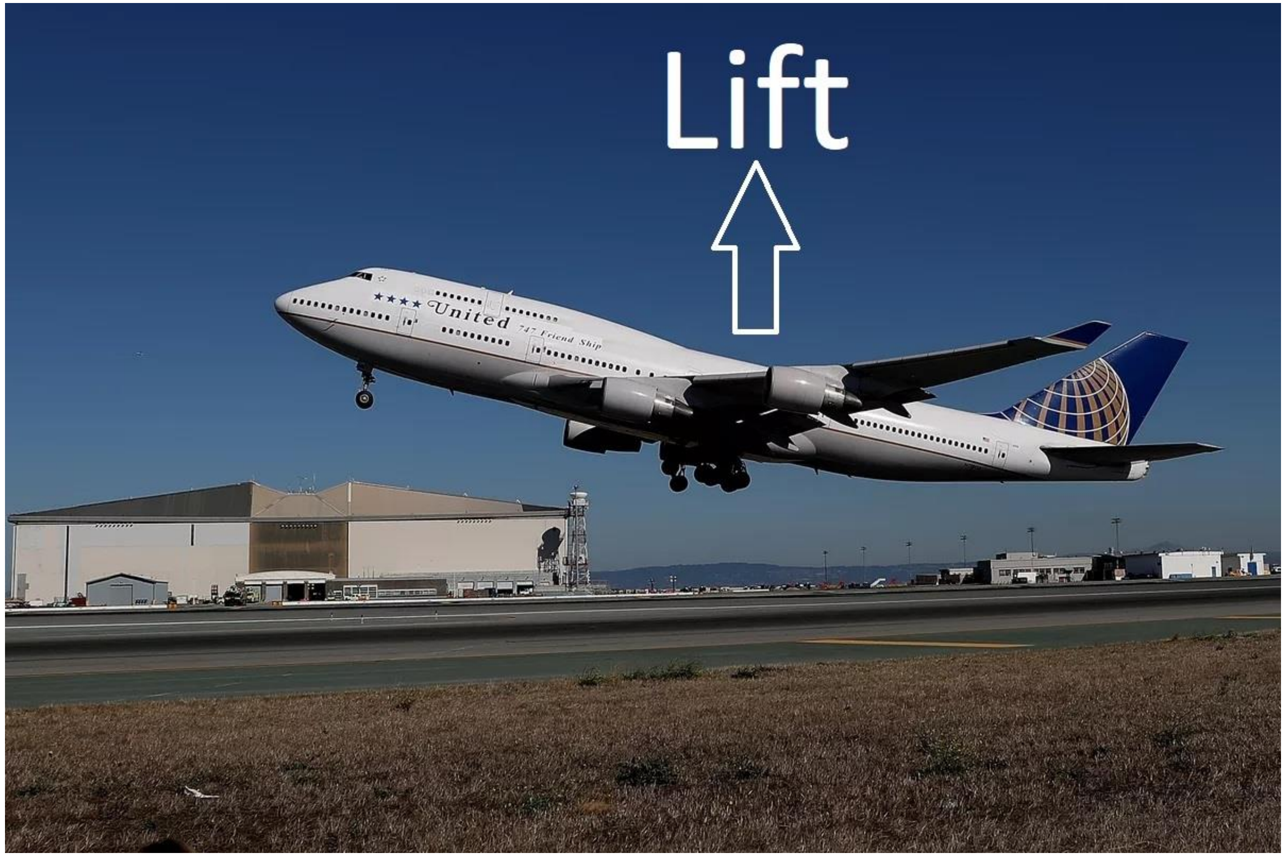

**Flat Board, with viscosity:**

- Front line labeled “S” moves behind the front edge of the board, causing a larger air volume to flow over the top side of the board.
- Higher air flow over the top of the board results in lower pressure than the slower airflow over the bottom of the board.  (larger space between flow lines means slower air flow)

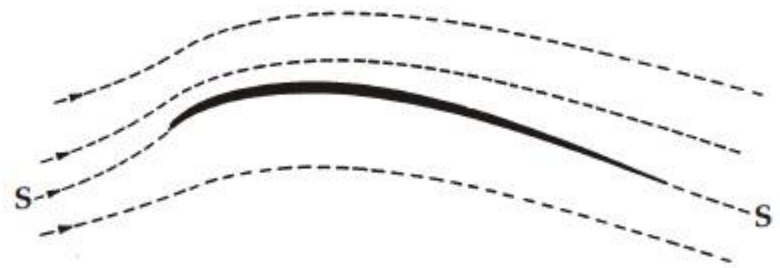



Force diagram shows that a force called ‘lift’ that is perpendicular in direction to the air flow is generated due to the pressure difference from air flow over the board.

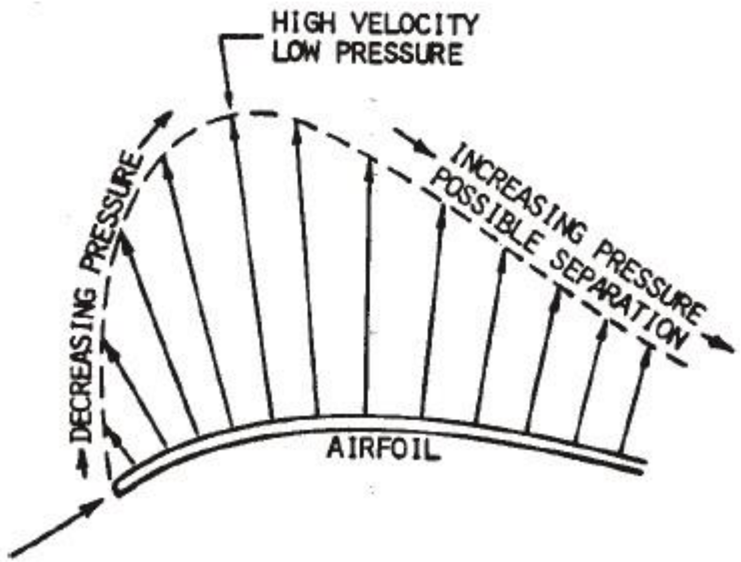
There is also a force component called ‘drag’ in the direction of the air flow due to friction of the air over the surface.




The side force got the name ‘Lift’ because the first aerodynamic studies were done for aircraft, and the name was used to describe the force needed to lift the aircraft off the ground and keep it airborne.

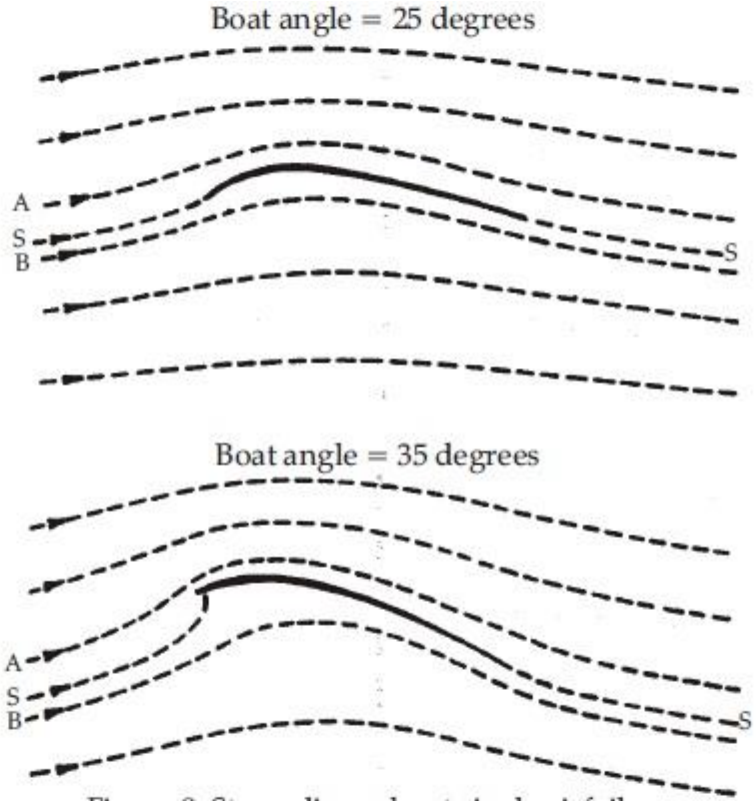


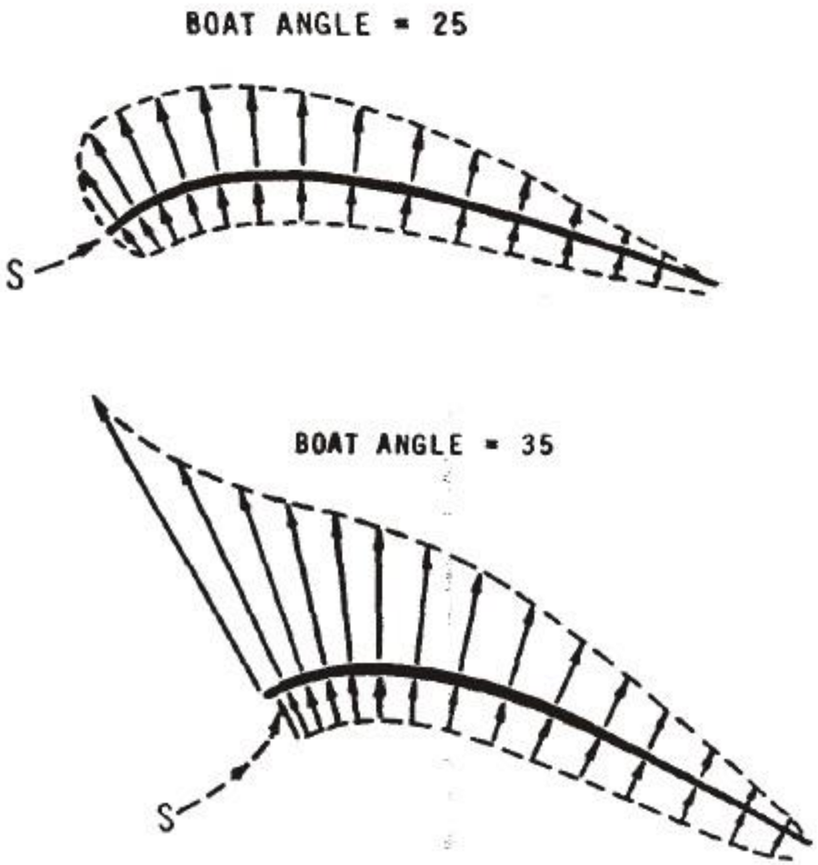

Airfoil Shape - Force generation is same as board except with a curved shape for better efficiency in producing driving force from airflow.




Force diagram on leeward side of a sail.
Force is higher when air is faster.

# Changes in Angle of Attack

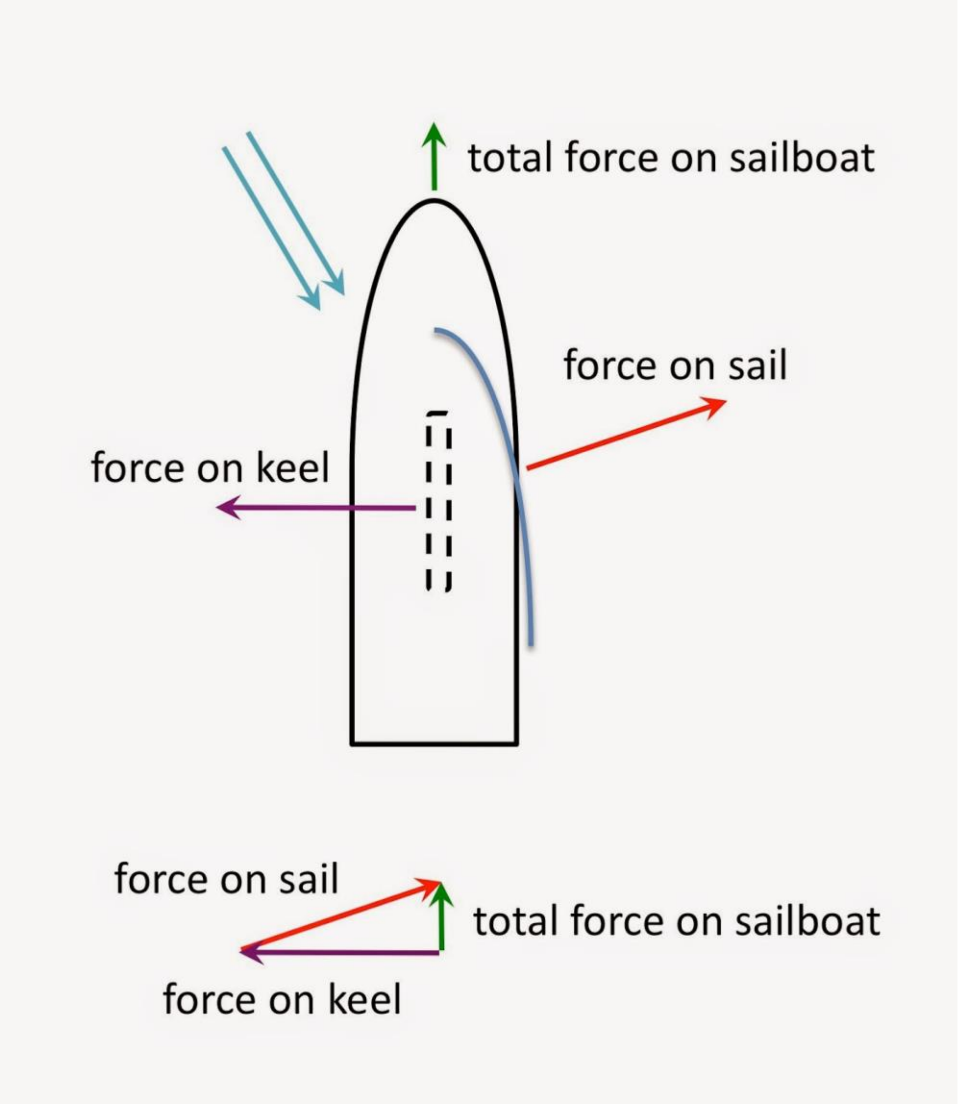



Greater chance of separation from the sail at a higher angle of attack due to deceleration of airflow.

At 35° Angle, airflow around the leading edge is high. S line is back from the leading edge, and greater volume of air flows to the leeward side of the sail

# Translation of Sail Forces to the Boat

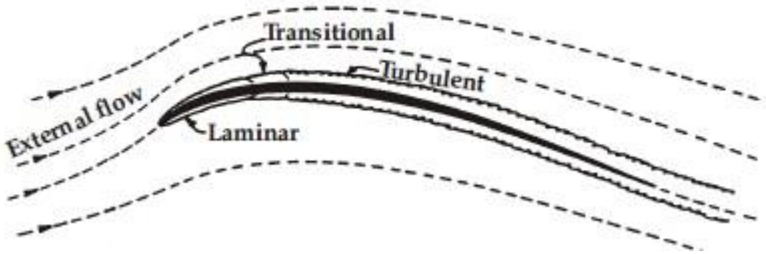


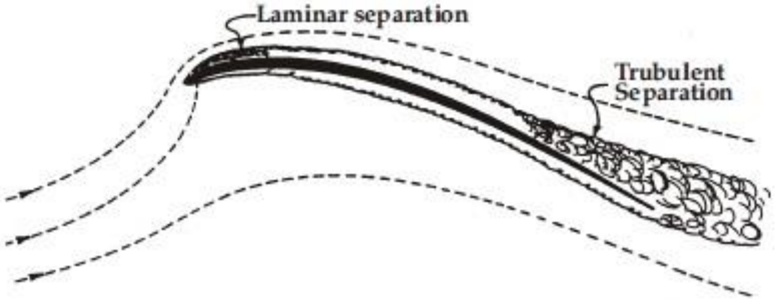

Force from the sail has two effects on the boat

1. Forward Force (labeled “total force on sailboat” in the diagram.)
2. Side Force (labeled “force on keel” in diagram.)

Sailing upwind (beating, close hauled)- has a high side force compared to the forward force → limited boatspeed. Hiking may be required. Effectiveness of centerboard or keel is important.

Reaching - Force on sail points further forward than when sailing upwind, so forward force increases and side force decreases. → Good boatspeed. Hiking may be required but less than for upwind.



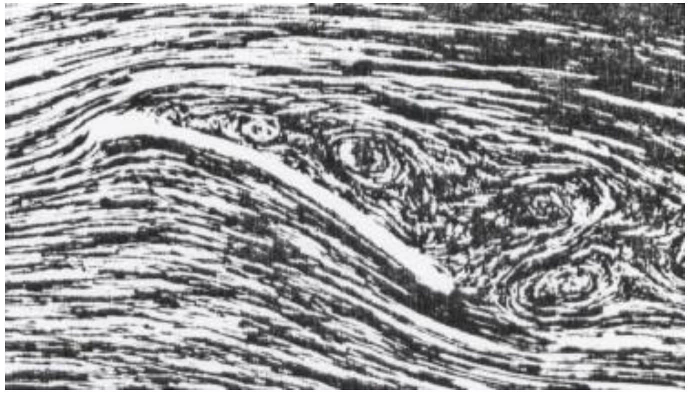

The sail has:

Laminar flow – undisrupted airflow. Described by the sheets of paper example.

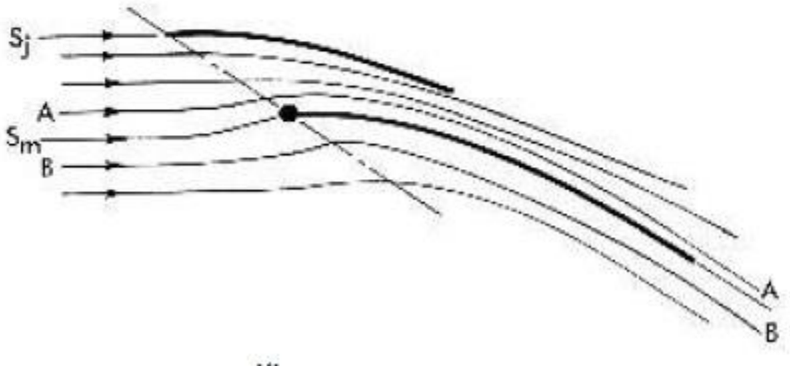
Turbulent flow – some disruption of flow.

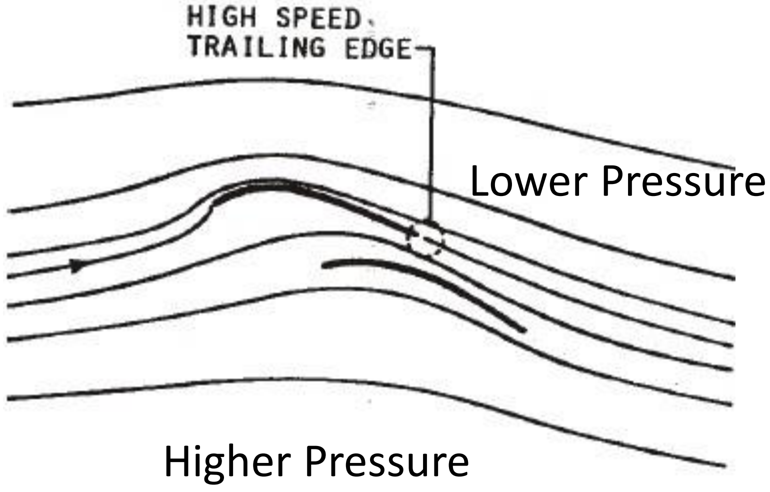
**Separation**- When the increase in pressure due to air slowing down is too great, the airflow separates from the surface of the sail. This may be caused by overtrimming the sail, hooking the leech, or having too much camber in the sail.

Lift force goes down and drag force goes up.



# Interaction of Main and Jib



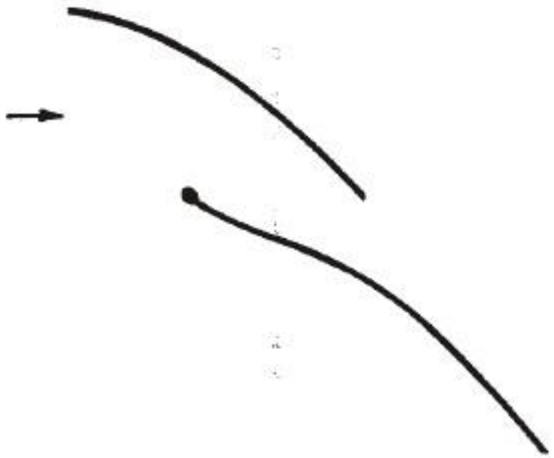




Incorrect Drawing-

- Many books written by reputable sailors show a diagram like this.
- Lines are closer together between the sails (slot), indicating that the air is speeding up.

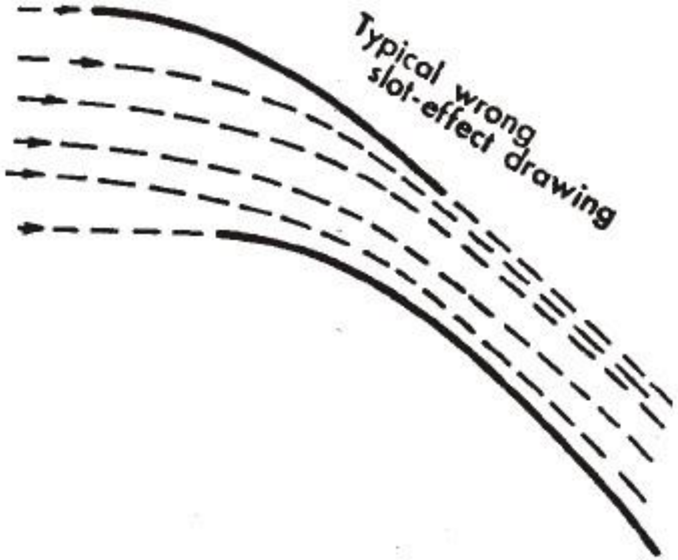
Avril Gentry's Revised diagram-

- Wind bends ahead of the jib due to the effect of the airfoil
- Lesser volume of air  goes over the windward side of the sail, causing the air to slow down.
- Air is slow through the slot.
- Air flows fast around the lee side of the jib and transfers to the lee side of the main



Billowing of main at luff- "Backwinding" of the main by the jib.

Caused by higher pressure between the main and jib
→ Air must be slower between main and jib when "backwinding" the main




If this were the case, instead of the main billowing out when "backwinding", the higher speed of airflow through the slot would create low pressure in the slot and cause the luff of the main and jib to be pulled towards each other.

Backwinding is an incorrectly used term, started when it was thought that air was being blown against the main. However it is still used.

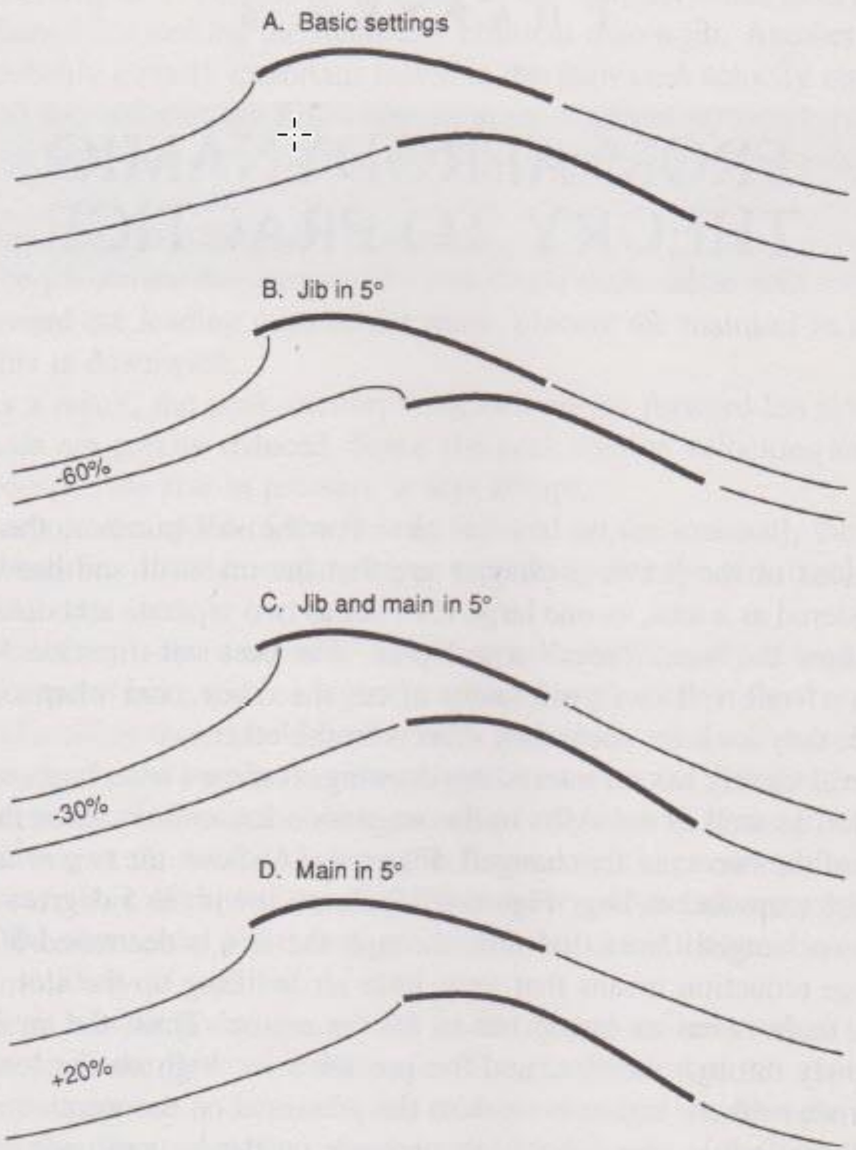



**Figure 6.1** Effect of jib and main sheeting angles on slot flow and stagnation streamlines

Figure A – Sails properly trimmed for upwind sailing.

Figure B - Decreased flow through the slot by 60%, and air spreading to windward and leeward side of sailplan. →Higher pressure in the slot between the main and jib and decreased pressure on windward side of main from faster moving air, causing "backwinding".

Figure C –Increased angle of attack. Wind has to take a sharper turn around the jib leading edge, and airflow through the slot decreases by 30%.
The jib could stall unless the boat is pointed higher or jib is let out.

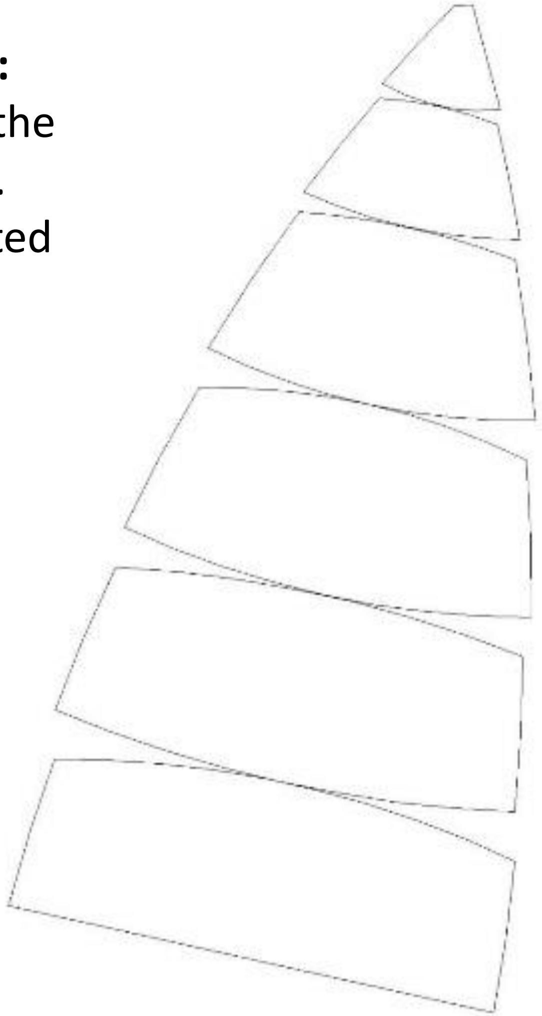
Figure D – More airflow through the slot, increasing airflow speed. Trailing edge of the mainsail is directed more to windward so air has to make a sharper turn and therefore is more likely to separate

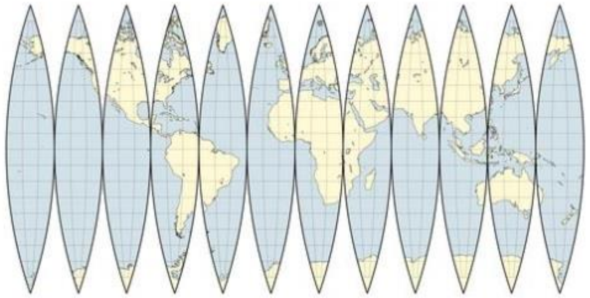
.

# What gives a sail its shape?

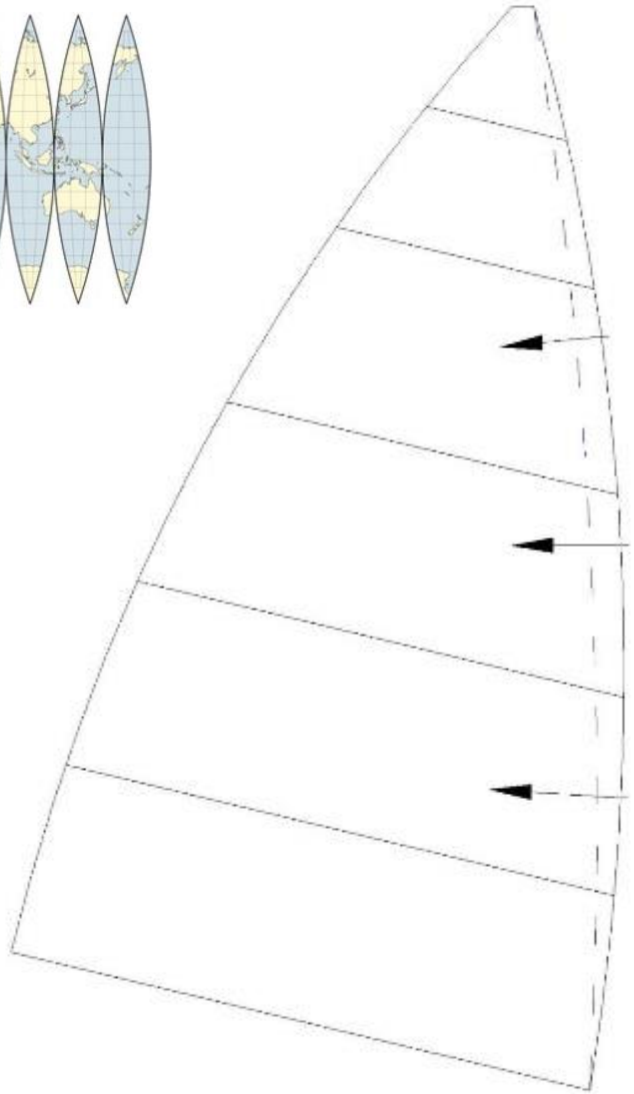
**Broadseaming:**
Designed into the sail – locked in. Can't be adjusted by sail trim.

## Seams





## Luff Curve



Bend of the mast will adjust shape:

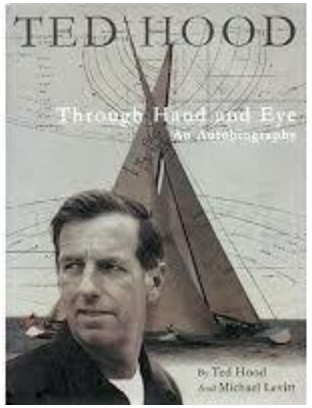
| Mast | Sail |
|---|---|
| Straight- | Full |
| Bent- | Flatter |

Bending mast is limited in a Townie, due to a relatively stiff mast and no backstay. Mainsheet tension is only control.

# Artist and a Scientist

- Interim Subject:  History of Modern Sailmaking -

# Ted Hood




Intuitive Designer - Knew what a good sail should look like.

Combined his knowledge of sails with use of in-house sail cloth that was better than any other.

Building sails involved actual use testing followed by recutting to get correct shape.

Performance of sail can vary from sail to sail.

Success of sails built by Hood sail were heavily reliant on Ted Hood's knowledge.

Hood ceased making sails once Ted Hood decided to leave the sailmaking business.

# Lowell North

Engineer by training,  worked by the numbers.  Sail design  to him was not as intuitive as for Ted Hood.

Wanted to be able to build a fast sail then easily duplicate the design.

Came up with his own sailcloth, helped by testing  of its properties

Worked with a German professor of fluid dynamics on a computer based analysis to optimize sail design.

Also used computers to cut sail panels to correct dimensions.

Resulted in fast sails that can be made repeat ably with little variation between sails.

North could pass the business on to others who helped him develop the sail making technology and continue to grow the business.

# Sail Trim

Section 2

# How do you know if you have properly trimmed your sails?

Depends on:

- Windspeed
- Sea condition
- Design of sail

Things to look at:

- Fullness or Flatness of sails
- Position at deepest draft
- Sail twist
- Telltales

Sail Power:

<u>Draft Depth</u> - Fuller sail is more powerful than flatter sail, but also has higher drag force.

<u>Twist</u> - Sail with straight leech has more power than with a twisted leech.

Increasing <u>angle of attack</u> increases sail power.

Mainsail Controls:

Luff Tension – Increasing moves the draft position forward. Can be done by halyard tension, adjusting the boom up or down, or by the Cunningham.

Outhaul – Controls Flatness the bottom 1/3 of the sail

Mainsheet – Tensions leech; adds or removes twist. Bends mast to flatten sail.

Vang – controls twist, particularly downwind

Traveler – Side to side position of boom.

Backstay (N/A for Townie) – Bends mast to flatten sail.

Hook on block system hooks into grommet on main

Cunningham on Aufblitzen.- used to adjust luff tension

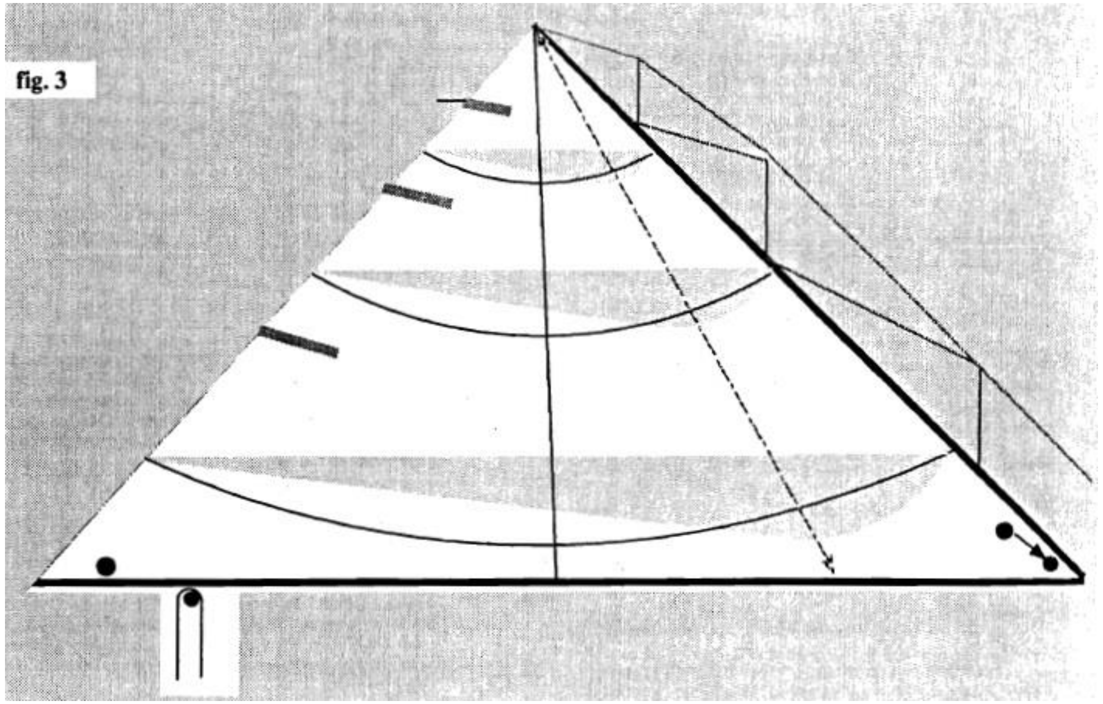
Jib Controls:

- Forestay Tension – Fullness of jib.
  - Slack – Increased fullness, good for choppy seas
  - Tight – Flatter entry, good for flat seas
- Luff Tension – Increasing moves the draft position forward.
- Jib Leads – controls twist. Forward – less twist, Back-more twist

Typical Procedure to set up jib lead position:

- Trim sails normally and sail upwind
- Skipper head slightly above upwind course
- Crew observes telltales on the jib (3 telltales)
  - If:
    - telltales all 'break' evenly, jib lead is set properly.
    - lower telltale breaks first, jib lead need to move aft
    - upper telltale breaks first, jib lead need to move forward.

# Draft Position




Steering Angle – The ability to deviate from the course sailed and still have the sails working properly and not stalling.

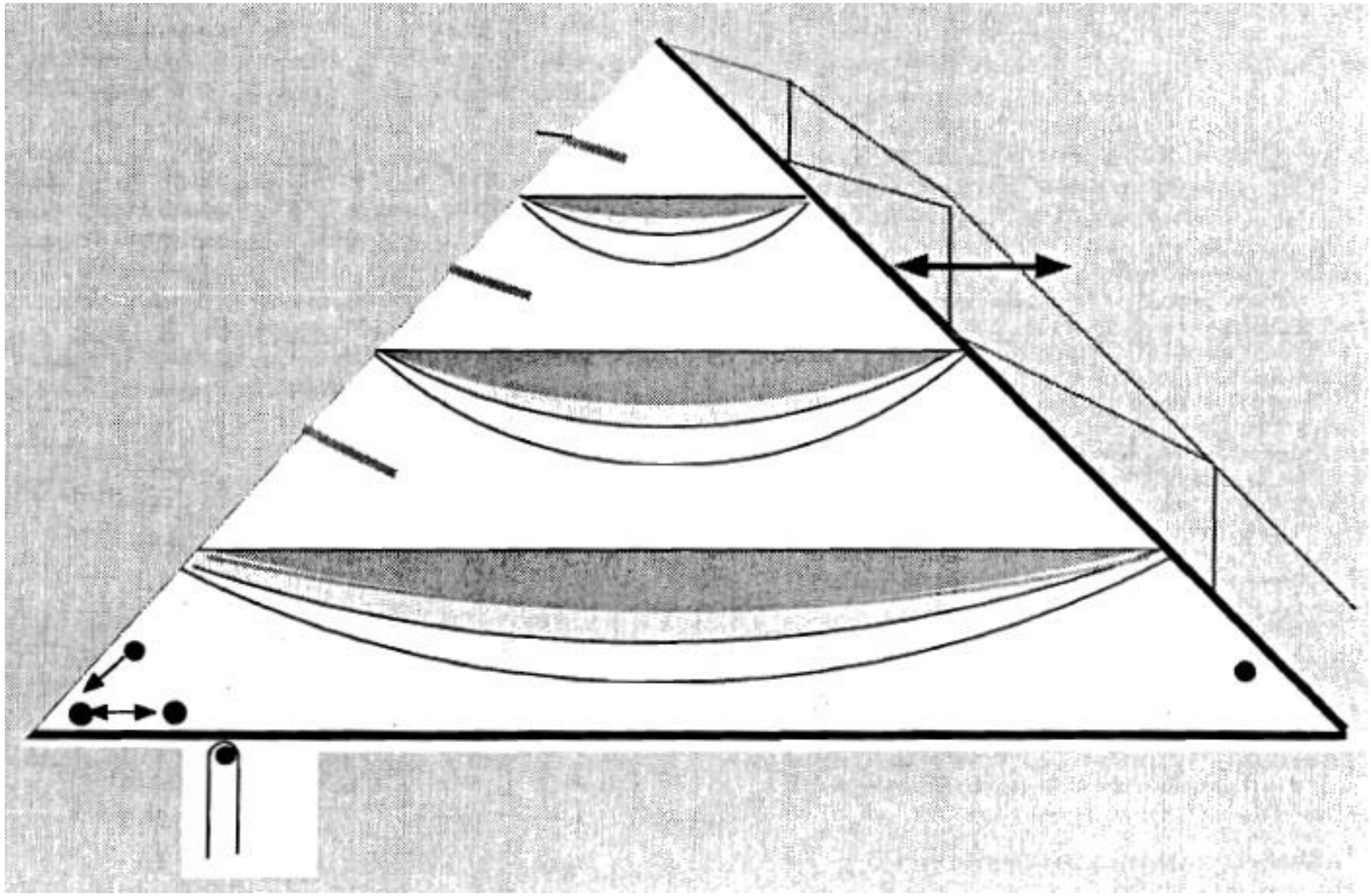
The position where the draft is deepest should be at 45%-50% aft of the mast to give the best sail performance.

Tightening the luff tension moves the draft forward. Loosening the luff tension moves the draft back.

As winds increase, the draft of the sail will move aft, requiring luff tension to move back to the correct position.

Forward draft position give a wider steering angle.

# Draft Depth



Deeper draft has more power, but also more drag.

- Use when seas are significantly slowing down the boat.

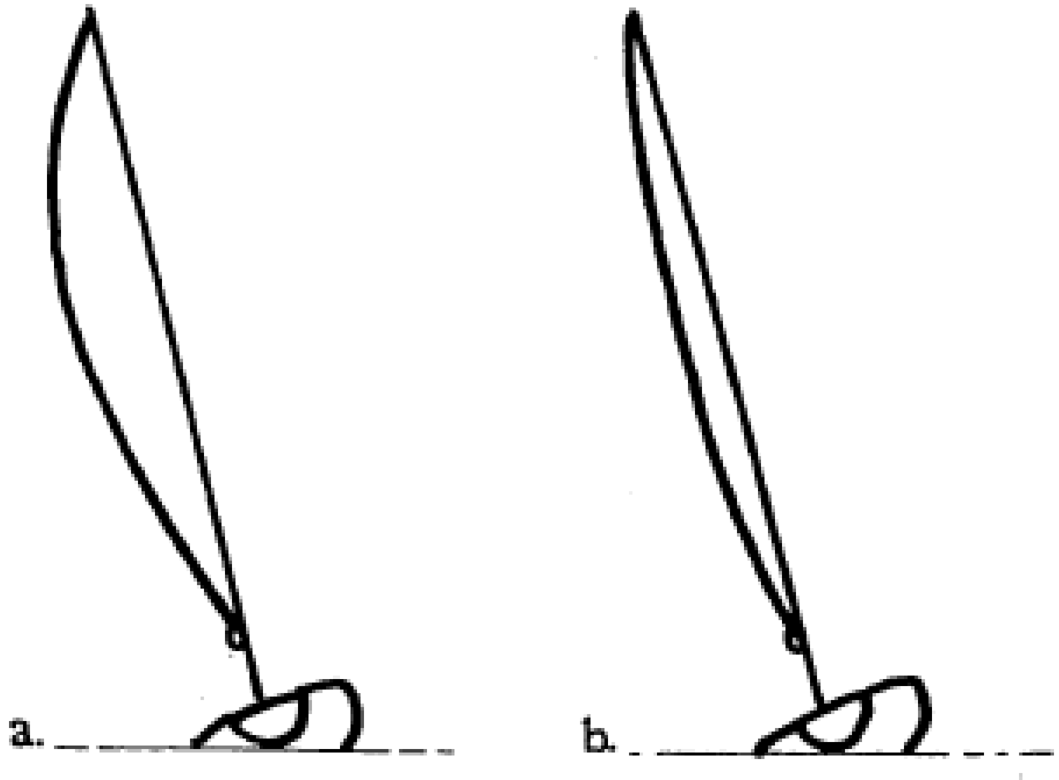
Less draft has less power, but also less drag.

- Faster in flat seas.

Flatten the bottom of the sail using the outhaul.

Trimming the mainsheet will flatten the sail.

# Twist




Twist depowers the sail

Twist is needed in light winds to prevent the sail from stalling

Twist gives a wider steering angle. Use twist in lumpy seas so part of the sail is always working.

Twist may be necessary if the wind speed is greater at the top of the sail.

Letting off the sheet tension increases twist.

An adjustable traveler is helpful to properly trim the mainsail for the wind conditions while varying the twist of the sail.

# Light Air Settings

| | |
|---|---|
| Outhaul – | Loose |
| Luff Tension - | Loose |
| Vang - | Off |
| Traveler - | Towards windward |
| Mainsheet-Trim | Top batten parallel to the boom. |

In light air you want maximum sail power with some twist in the leech to prevent the sails from stalling.

The traveler trimmed towards the windward side of the boat give the main a good angle of attack.

# Moderate Air Settings

| | |
|---|---|
| Outhaul – | Tight |
| Luff Tension - | Loose |
| Vang - | Take up slack |
| Traveler - | Near Middle |
| Mainsheet-Trim | Top batten parallel to or slightly outside of the boom. |

In moderate air the trim may depend of the wave and sea condition.

- Lumpy seas – more power needed→ Deeper draft.  [low gear].  Higher steering angle needed→ Twist in leech, slack forestay.
- Flat seas – speed desired → shallower draft [high gear], less twist in leech and tighter forestay for more power, tradeoff with smaller steering angle.

# Additional Notes for Light and Medium Air Sailing

Mainsail Trim Upwind-

Try to have the leech telltales flowing backward with the upper telltale trying to hook around the back of the main.

Jib Trim Upwind-

Telltale on leech should always be flowing backwards.

Gear Analogy

| Gear Name | Bicycle | Sailboat |
| --- | --- | --- |
| 1st Gear | Low gear ratio:<br>Easy to pedal uphill.<br>Can only go so fast on straightaway. | Deep draft in the sail (full sail):<br>Most power from the sail which gets the boat through waves.<br>In flat water, top speed is limited due to drag force on sail. |
| 2nd thru 4th | In-between 1 and 5 | In-between 1 and 5 |
| 5th Gear | High gear ratio:<br>Can go fast on straightaway.<br>Hard to pedal uphill. | Draft is shallow (flat sail):<br>Less power from the sail, but the drag force is proportionally less, giving the best boatspeed in flat water.<br>Will be slower if seas get rough. |

# Heavy Air Settings

| | |
|---|---|
| Outhaul – | As Tight as possible |
| Luff Tension - | Enough to remove wrinkles |
| Vang - | Snug with no slack |
| Traveler - | Down to leeward |
| Mainsheet- | Top batten<br>5-10 degrees outside of the boom. |

In heavy air you want reduce power in the sail because you usually have more power than you need.

In a Townie, where there in no backstay, the mainsheet may have to be in tight to flatten sail.  Sailing the boat slightly above close hauled will reduce the angle of attack.

Tightening the mainsail luff and moving the draft forward will depower the main and open the leech.  Steering will be more forgiving (wider steering angle).

2010 Mainsail – Cressy Template Design

2016 Mainsail – First Doyle Redesign

# That’s it!!!


# Any more questions??????