The Emperor's New Clothes

A sail is not "like a wing".

The analogy that a sail is "like a wing" is implicitly or explicitly invoked in nearly every article describing the aerodynamic forces on a sail. This analogy invokes aeronautical terms like lift, drag, angle of attack, leading edge, aerofoil section, stalled and attached airflow, stagnation point etc., etc.
This article aims to explain how the use of these aeronautical terms is both confusing and unnecessary when used to describe the forces on a sail.

The author is fully aware that he is emulating the boy in the "The Emperor's New Clothes" and is aware of the risk of claiming Copernican wisdom when challenging this universally accepted truth.

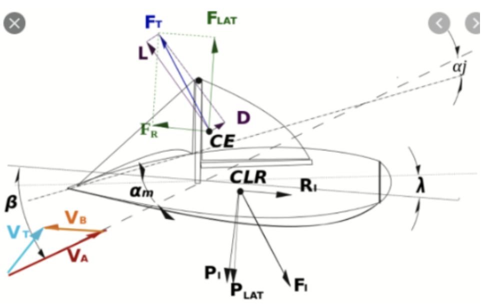
This article uses the Wikipedia article "Forces on Sails" as an example of where the wing analogy leads to confusing and unnecessary.

Confusing

The analogy is confusing because far from being clarifying the explanation, it confuses the issue in so many ways.

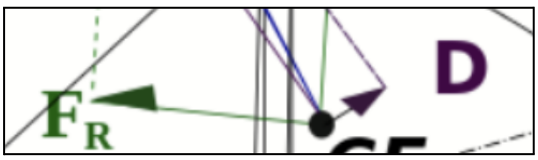
Confusing diagrams

The widely quoted diagram resolving Total Aerodynamic Force F_T into Lift and Drag also show it resolved into Thrust and F_{LAT}.



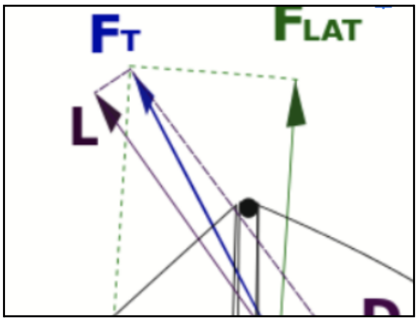
Explanations of the details require a confusing explanation about how a sail is different from a wing.

Parallel to the axis:



Q: "Is Thrust F_R fighting Drag D?"
A: " No, Drag is an aviation term."

Perpendicular to the axis:



Q: "If Lift is entirely useful, how come F_{LAT} , leeway/heel, is an adverse component?"
A: "Lift is useful on wings. Apart from downwind, it's adverse on a sail."

Confusing physics

Most readers have not studied physics recently enough to be familiar with the conventions of resolving a vector around an axis into its scalar components. For them the technical difference between the vector net aerodynamic force and its scalar resolution into either Lift and Drag or Thrust and Leeway/Heel are entirely foreign.

To them, the vector vs scalar difference between a force and its components is obscure at best. From their perspective Lift, Drag, Thrust and Leewy/Heel are as much forces as the aerodynamic force.

But since the discussion is about sail forces, it requires the use of this physics concept. It is already a bit confusing, so making it about five (5) forces instead of three (3) is unnecessarily complicating the matter.

Confusing maths

Having to explain the maths of how to convert one pair of aviation components into another pair for a sail is confusing.

To resolve the confusion of the force diagrams, the following formulae are presented:
$(1)\ F_R = L.sin(\alpha) - D.cos(\alpha)$

$(2)\ F_{LAT} = L.cos(\alpha) + D.sin(\alpha)$

This is confusing for four fundamental reasons

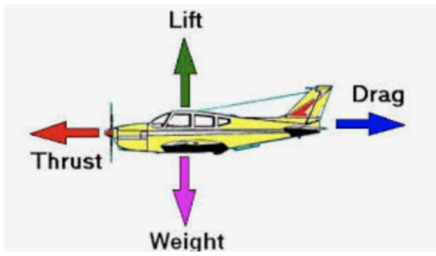
1. Most readers left their understanding of trig functions and algebra at high school, so find the formulae entirely incomprehensible.
2. αis the AoA which is a term difficult to apply to a sail. It's certainly not the AWA (*vis*. at AWA of say 160° the AoA would be around 75°).

3. For those readers who are familiar with trig functions and equations of rotation, the formulae imply that the equation can be solved with known values.
   With sails especially, there is no way of determining the values of L , D and α . So the reasons for presenting the formulae are confusing at best, self-serving at worst, to justify the very existence of L and D in the discussion.
4. The easily overlooked negative sign in (1) changes the sign of the component parallel to the axis of resolution from a negative Drag to a positive Thrust

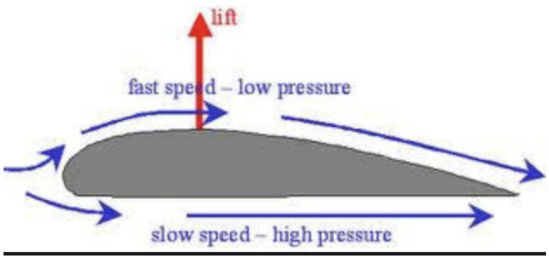
Confusing concepts

Once we establish that lift is one of the components of total aerodynamic force, the issue is that its definition differs depending on the application, Aviation, Aeronautical or Fluid Dynamics? They are subtly different on an aircraft but significantly different on a sail:

Aviation lift is the force opposing the weight of the aircraft, so is perpendicular to the horizontal and is not related to the "Angle of Attack"



Aeronautical lift is the component perpendicular to the *chord of the wing*, which is the line between the leading edge and the trailing edges of the wing.



Fluid dynamics lift is the component perpendicular to the oncoming fluid flow, i.e. the oncoming airstream.

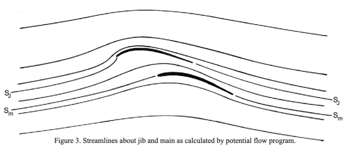


Figure 3. Streamlines about jib and main as calculated by potential flow program.

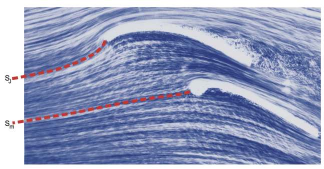
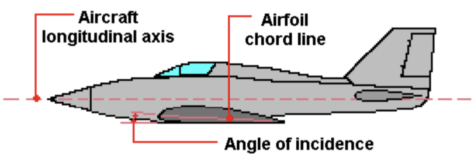


Figure 4. Water channel photograph of flow about jib and mainsail airfoils.

These three axes are fairly well aligned in an aircraft in normal cruising flight



- The centreline of the aircraft is horizontal (the drinks trolley doesn't roll down the aisle).

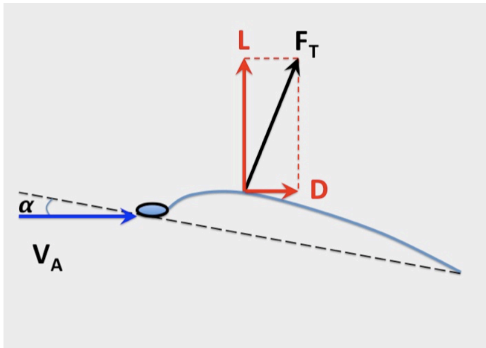
- The airflow is aligned with the centreline.
- The *chord* of the wing is slightly offset from the centreline by the "Angle of Incidence", which on an aeroplane is hardly obvious to the casual observer.

On a sailboat, these axes become far more separated:

- The **horizontal** axis is irrelevant (we're talking about forces around a vertical axis).
- The oncoming wind is at the AWA to the **centreline** of the boat, which is always considerably greater than an aeroplane wing (30° and 90°).
- The ***chord* of the sail** is the sheeting angle of the sail. There are two sails, and their chords are different but we will skim over that for the moment[1].

So, when we talk about lift in reference to a sail, it would seem that we are using it in the aeronautical (reference the *chord)*, not the aviation (reference horizontal), sense of the component.
The reason this rather lengthy exposition is relevant to explaining how this image has a confusing concept of Lift.

In this image, Lift is shown as perpendicular to V_A, the Apparent wind, which is shown at an angle α, the Apparent Wind Angle.



Lift, L, is shown as perpendicular to the **oncoming wind**, not the ***chord* of the sail**. That's Fluid Dynamics lift, not aeronautical lift.
To most readers, that distinction is confusing.

Another point that probably should fall under the heading of "Incorrect Diagrams" is that the angle α, AWA, is shown at an impossibly small angle of about 10°. This is well below the normal sailboat lower range of around 30°.

The wing analogy is therefore clearly confusing since it gives rise to so many confusing concepts.

Unnecessary

Since the forces can be clearly explained by omitting all references to lift and drag, the wing analogy is unnecessary .

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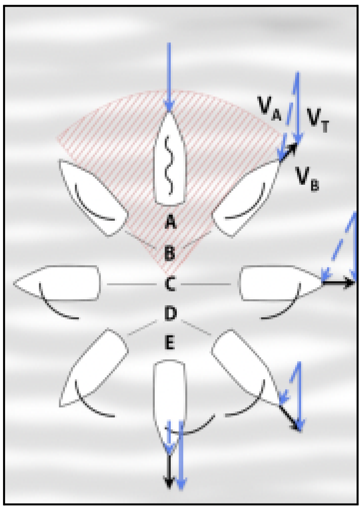
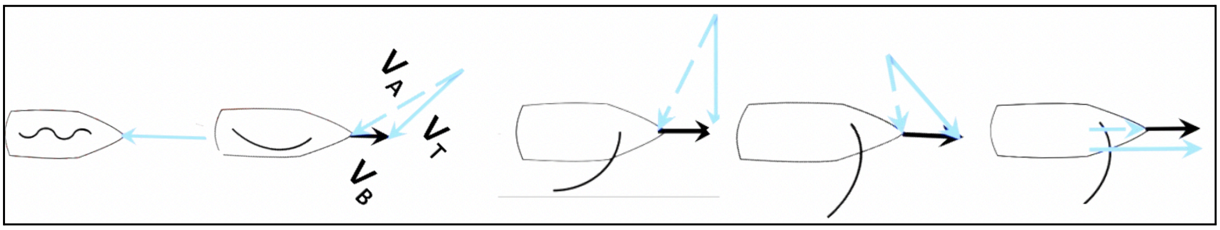
[1] A mainsail, when centred, is aligned with the centreline, and when fully eased is usually constrained from being fully square and fouling the shrouds
A jib with an *inhauler* can be sheeted to a small angle , but when fully eased would never exceed 45° (except when "poled out").

This can be demonstrated with following simple steps to show how the "standard explanation" could be re-worked quite easily without any reference to Lift or Drag.

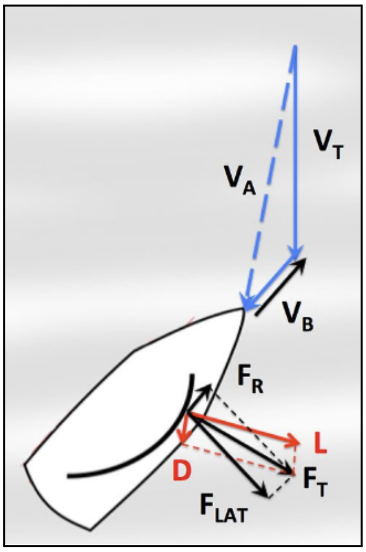
1) Open with the traditional diagram showing the points of sail relative to the wind.



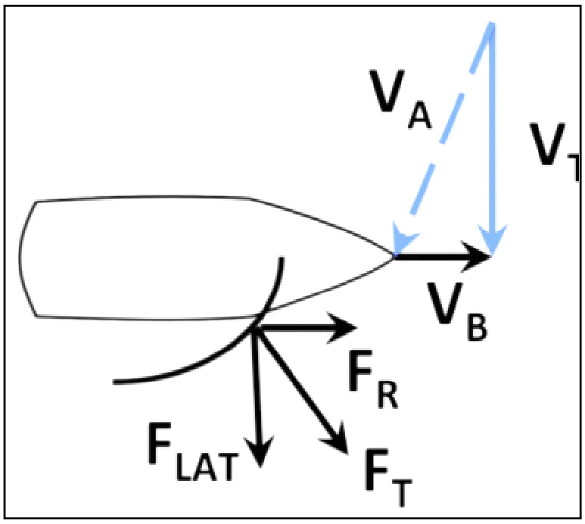
2) Decompose the diagram to its individual boat diagrams and rotate the diagrams to align the centrelines.



3) Follow the traditional drawing conventions.



But omit the LIFT and DRAG components



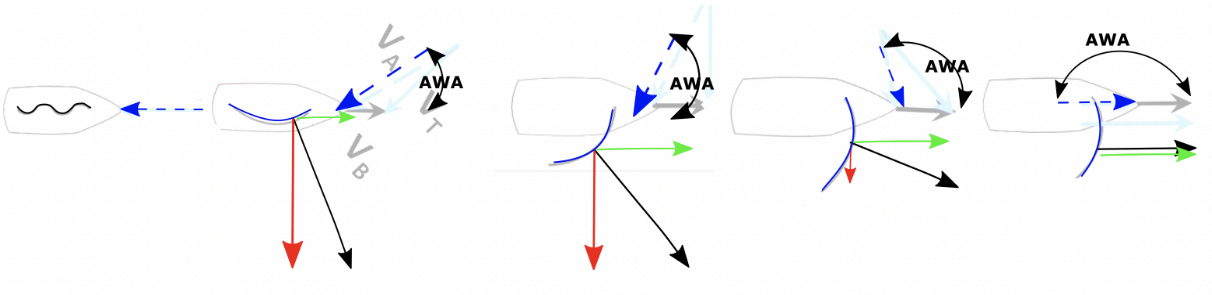
4) Follow the usual conventions for describing the force and its components.

Wind forces acting on a sailboat sail (**L** and **D**) and being transmitted to the boat (**F**$_R$—propelling the boat forward—and **F**$_{LAT}$—pushing the boat sideways), while close-hauled, are both components of total aerodynamic force (**F**$_T$).

But omit reference to LIFT AND DRAG:

"Wind forces acting on a sailboat sail and being transmitted to the boat (FR—propelling the boat forward—and FLAT—pushing the boat sideways), are components of total aerodynamic force (FT)."

5) Combine the force resolution (3) with the deconstructed POS diagrams (2):



6) Explain that the diagrams demonstrate that, as the AWA increases, the Aerodynamic force rotates forward and so Thrust increases and Leeway/Heel reduces.

The wing analogy is therefore clearly unnecessary since the forces can be explained without reference to the analogy.

Examples

By removing the confusing and unhelpful wing analogy, supporting material and examples can be explained with much simpler language.

One example of this is the great photo of boats on different Points Of Sail responding to different force components.

with its title:

> Aerodynamic force components for two points of sail.

and caption:

> *Left-hand boat*: Down wind with stalled airfow—predominant *drag* component propels the boat with little heeling moment.
> *Right-hand boat*: Up wind (close-hauled) with attached airflow—predominant *lift* component both propels the boat and contributes to heel.

Re-written without reference to **LIFT**, **DRAG** and **STALLED** and **ATTACHED AIRFLOW**, this caption more clearly supports the title of the picture by being rewritten as follows:

"*Left-hand boat*: Down wind with strong **THRUST** component and little **HEEL/LEEWAY**
Right-hand boat: Up wind (close-hauled) with strong **HEEL/LEEWAY** component and smaller **THRUST**"

Another example, which even to a reader versed in sailing, aeronautics, physics, maths and fluid dynamics, is nigh on incomprehensible:

"For apparent wind angles aligned with the entry point of the sail, the sail acts as an airfoil and lift is the predominant component of propulsion."

Conclusion

This article has analysed the use of the "like a wing" analogy from the perspective of confusion and necessity and presents the argument for removing all references to aviation and aeronautical terms and concepts from the otherwise excellent Wikipedia article "Forces on sails".

The challenge ahead is to emulate the boy in the "The Emperor's New Clothes" and risk the criticism of claiming Copernican wisdom to challenge this universally accepted analogy which is supported by the eminences of Fossati, Marchaj and Flay.