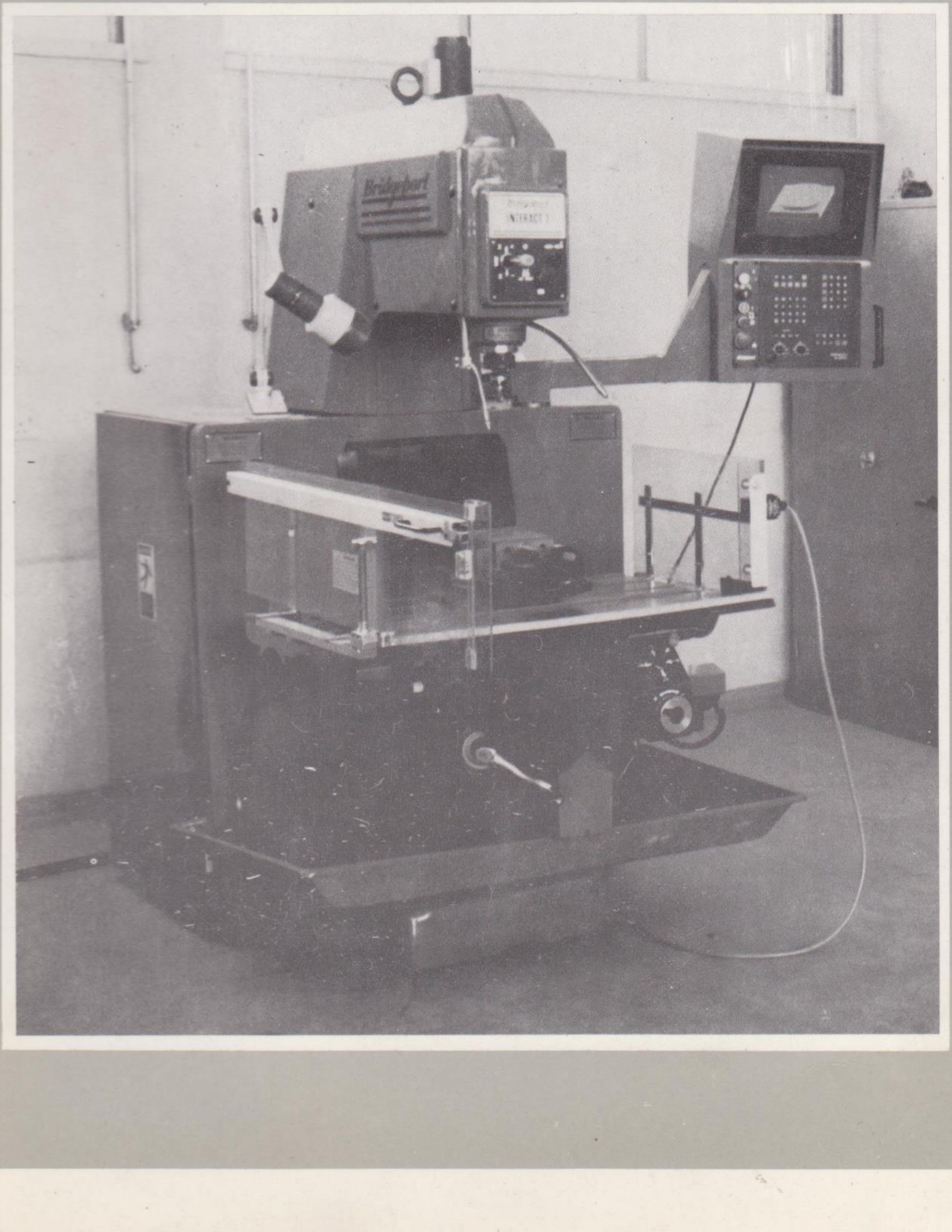
No. 19 June 1990 Nicosia Cyprus

Review

THE HIGHER TECHNICAL INSTITUTE



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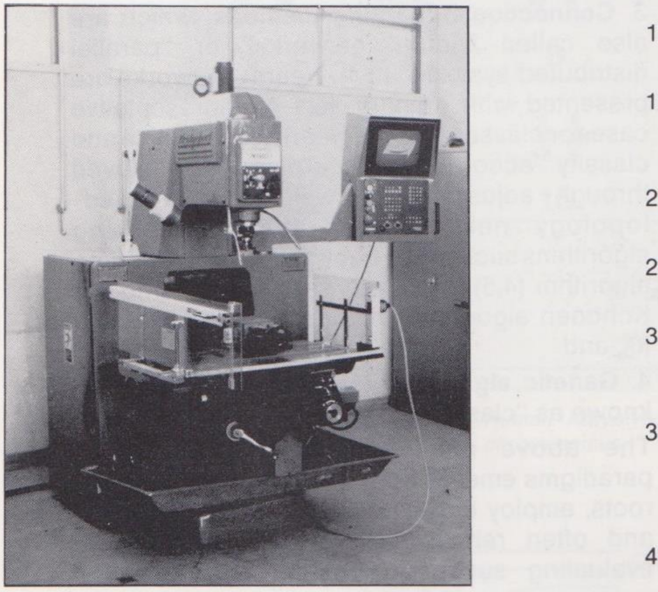

Computer Numerically Controlled Milling Machine

Cover Photograph by HTI

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Sail technology - the future

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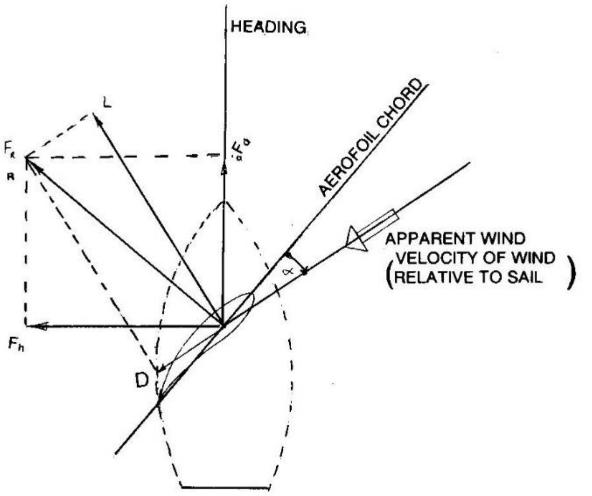
In this article the future of sail technology is reviewed and possible new sail designs are discussed at a generalised level. Some consideration is also given to the detailed engineering design of various concepts.

In contrast to the aeroplane wing, which began its development as a single sheet of fabric and developed in a matter of a few years to a rigid aerofoil construction, the concept of the fabric sail has changed little since ancient times. Even in the technological age of today the sail seems to be in a dominant position and well poised to sail into the 21st century. However there have been moves recently to "rock the boat" and the development of the automated rigid sail system seems a good contender for the "race of the sails".

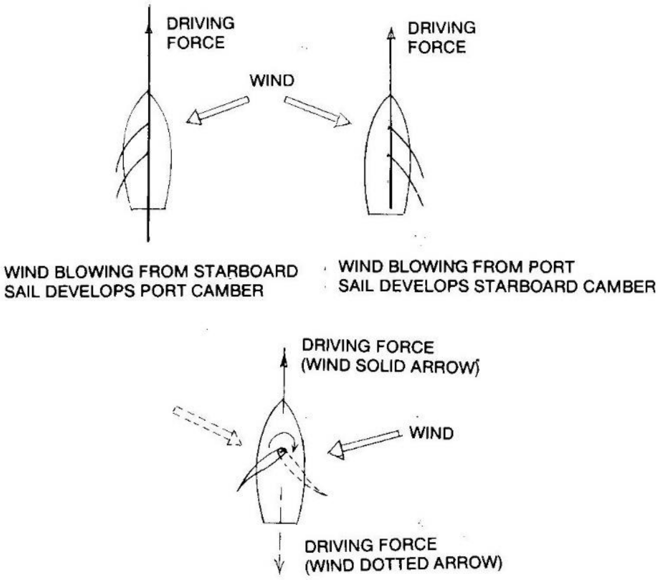
SAIL AERODYNAMICS

Fig. 1 shows the aerodynamic and geometrical terms used in the theory of the sail. Lift (L) and Drag (D) are the aerodynamic forces produced by the sail which are resolved into the Driving (Fd) and Heeling (Fh) forces which make the boat move on the water. The component of the force which produces forward motion is of course Fd. The Heeling force (Fh) produces no useful work but tends to overturn the boat and also produces sideways drift, the magnitute of which depends on the shape of the hull below the water line. One of the effects of the Heeling force is that it makes the boat follow a course which is different to its heading.



α = Angle of incidence
L & D = Aerodynamic Lift and Drag forces
F_R = Resultant force
F_d = Driving force component
F_h = Heeling force component

Fig. 1



VARIABLE GEOMETRY CANNOT BE ACHIEVED BY SIMPLY ROTATING THE RIGID SAIL ABOUT ITS AXIS

Fig. 2

Fig. 2 shows that flexibility is one of the strong merits of the fabric sail. When the wind changes direction so does the geometry of the sail. A rigid sail with "variable geometry" demands more advanced technology than that developed for the aeroplane wing. The rigid sail has to operate at the maximum possible efficiency when producing positive force (port force), as well as when producing negative force (starboard force). In contrast, the aeroplane wing needs to be efficient only when producing positive lift. Spoilers are used to destroy lift when it is not required, and gravity is utilised to bring the aeroplane down.

Theoretically, the force coefficients (lift and drag coefficients) produced by rigid aerofoils compare favourably with those produced by fabric sails. Fig. 3 shows typical Lift/Drag curves for the Bermudan sail rig, with superimposed curves for the Wortmann aerofoil section. Some aerofoil sections have been developed specially for low airspeeds and may be applicable for sail use. Examples are the aerofoil sections developed for man-powered flight. Fig. 4 shows the Wortmann section which was developed for this purpose by aerodynamicists at British Aerospace. The shape of these sections renders them difficult to use with variable geometry. High aerodynamic efficiency may have to be traded for the benefits of variable geometry. In Fig. 4(a) a variable geometry aerofoil is shown using a simple pivoting trailing edge flap. Other relevant aerofoil concepts are those with one or more slots (slotted aerofoils). If a new aerofoil section is designed then its performance characteristics must be established experimentally in a wind tunnel before it can be incorporated into the sail system.

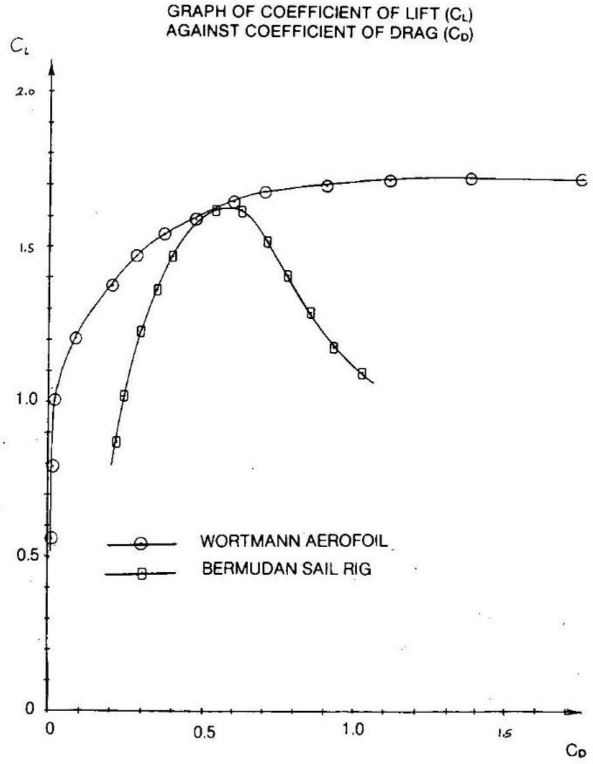


Fig. 3

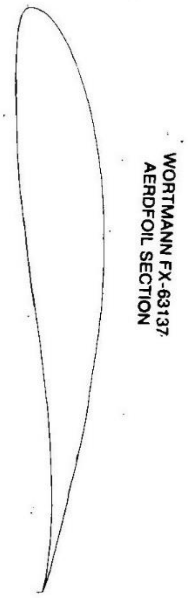


Fig. 4

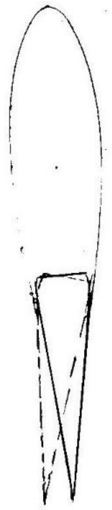


Fig. 4(a)

Rigid Sail Mechanics

The mechanics of the rigid sail system probably poses the greatest technical challenge for the designers. Apart from the fact that the system has to employ variable geometry, it also has to be made retractable. Fig. 5 shows various possible concepts.

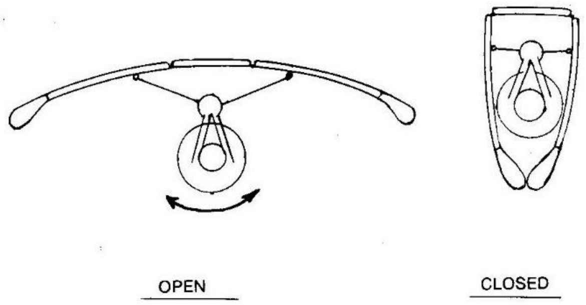


Fig. 5(a)

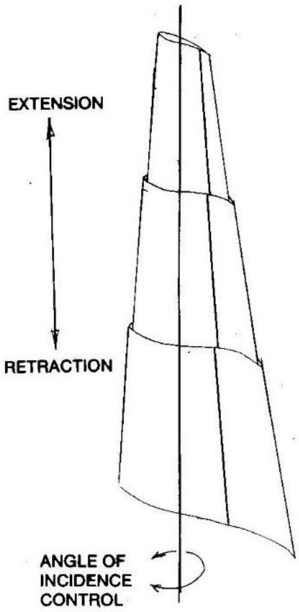
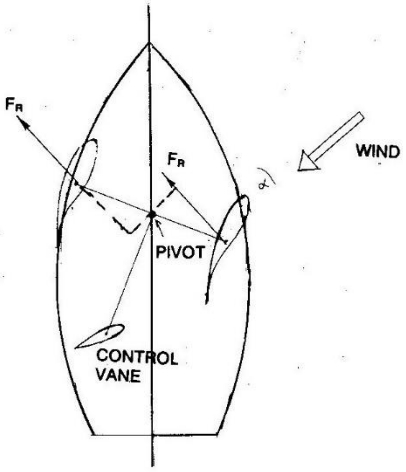
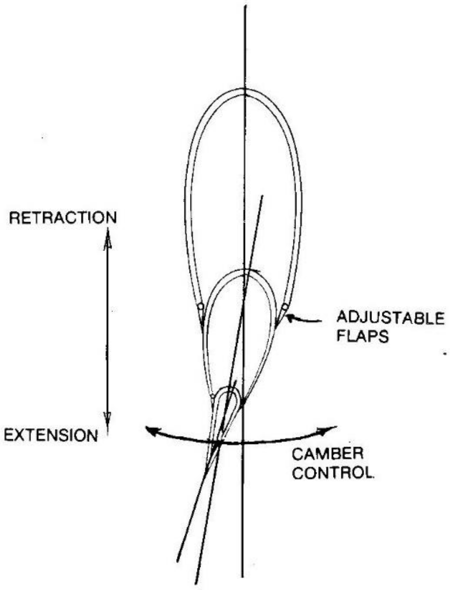


Fig. 5(b)



FREE FLYING RIGID SAIL SYSTEM

Fig. 5(c)



NESTED AEROFOIL SYSTEM

Fig. 5(d)

In Fig. 5 (a) the sail is made symmetrical about the longitutinal axis of the ship, therefore dispensing with the need to employ variable geometry. The sail retracts by folding around a central mast to reduce profile drag when it is not in operation. The operation of this system involves two actions, retraction/extension and rotation to set the correct angle of incidence for maximum driving force. It should be noted that this type of sail has been used on large ships as an auxilliary source of power to help reduce fuel consumption. For this reason high efficiency is not of primary importance.

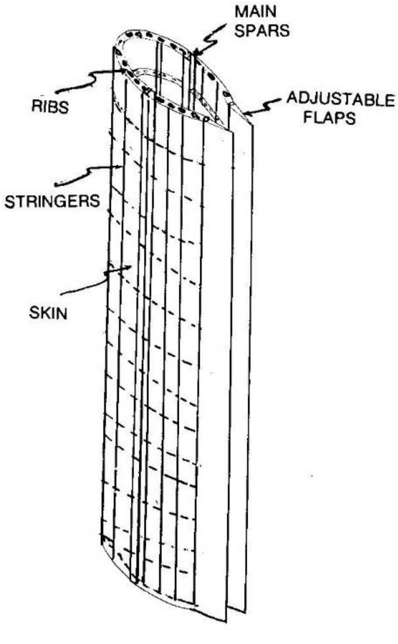
In Fig. 5(b) the sail extends and retracts vertically, and rotates about its axis for angle of incidence control. This system poses many technical difficulties and has the disadvantage that a large part of the cabin of the vessel will be taken up by the system structure and mechanics.

The free flying rigid sail shown in Fig. 5(c) has the advantage of simple mechanics and good structural integrity. In this system the rotation of the sail is controlled by a vertical tail vane (rudder). In this way the operation of the system is achieved aerodynamically rather than mechanically, therefore reducing the mechanical complexity. This particular system does not retract but is "feathered" when not in operation, rather like the blades of an aircraft propeller after an engine is switched off in flight. In this position the sail produces the minimum drag.

Fig. 5(d) shows a suggestion for a retractable variable geometry sail system. Its main advantage is the high aerodynamic efficiency that can be achieved if well designed, and a mechanical system which can combine the operations of extension/retraction with that of Variable Geometry. This "nested" aerofoil system could be used as part of a free flying (aerodynamically controlled) or mechanically controlled incidence system.

Structural Design

Structurally each of the systems described above presents unique problems for the designers. Generally a high mechanical complexity also means greater structural complexity. The rigid aerofoil system is structurally straightforward in design. However in some of the designs presented above, as is the case of the nested system, the open C-shaped section presents some structural weaknesses especially in torsion. In Fig. 6 the main structural elements of a rigid sail are shown.



RIGID SAIL STRUCTURAL ELEMENTS

Fig. 6

The materials to be used for the construction of rigid sails must be light and strong. Aluminium alloys similar to those used in the aircraft industry will be applicable.

AUTOMATIC CONTROL

A rigid sail system will not be worth employing if it is difficult to control. The multitute of parameters to be considered forces the designer to opt for computerised control. To facilitate the design of the computer software system, a logic diagram or flowchart can be drawn. Fig. 7 shows such a flowchart in a block diagram form.

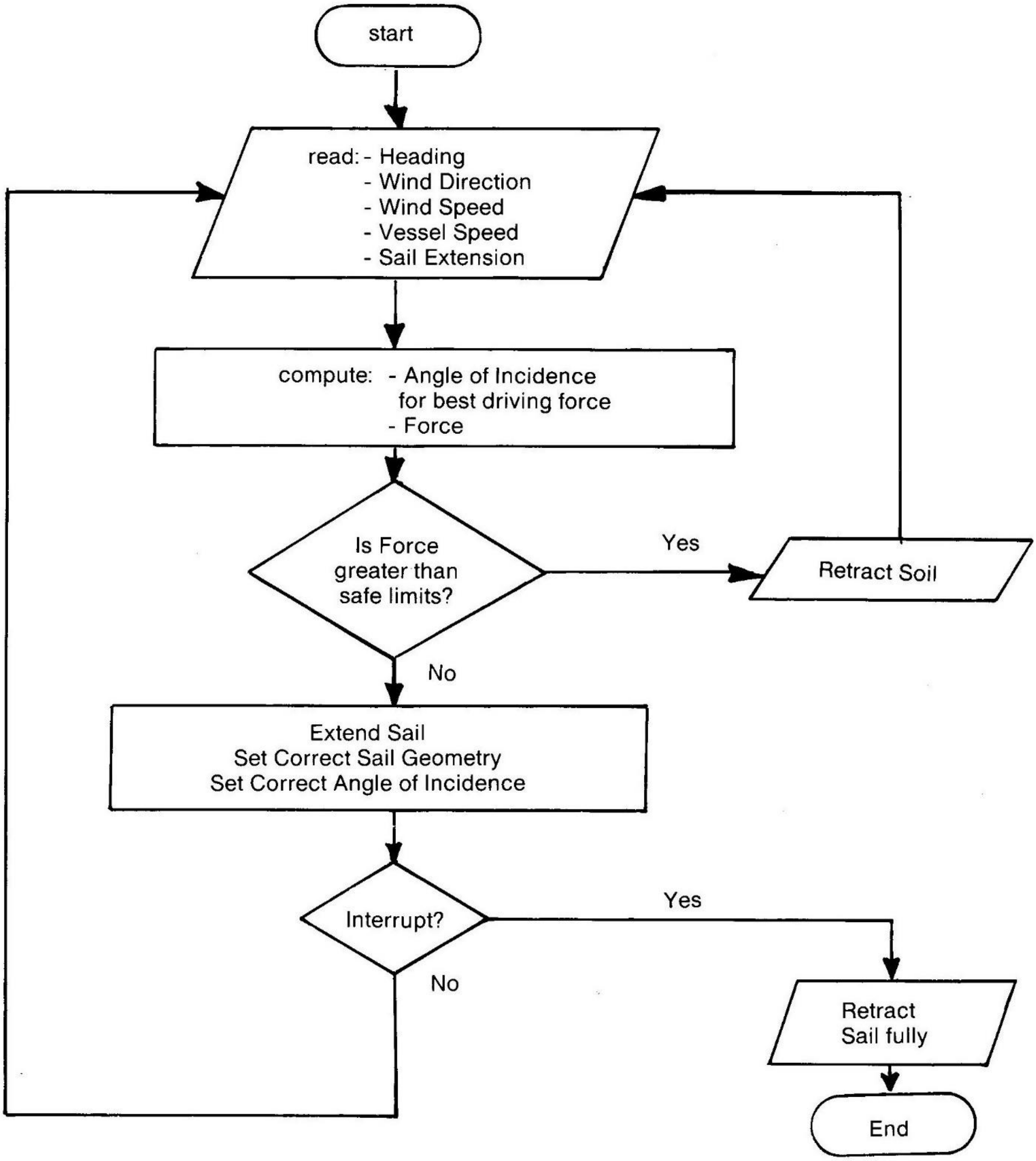


Fig. 7

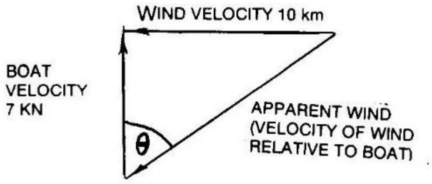
Automatic helm control is not shown in the above flowchart for simplicity, but it will have to be incorporated as part of an integrated control system.

Most of the blocks in the flowchart will have to be analysed further in more detail, as illustrated below for the computation of the angle of incidence, and the forces produced by the sail.

INPUT DATA: Heading = 0 degrees
Boat speed = 7 knots
Wind speed = 10 knots
Wind direction = 90 degrees

Step. 1 (Compute apparent wind velocity).

From velocity triangle obtain the apparent wind velocity (velocity of wind relative to boat or sail).

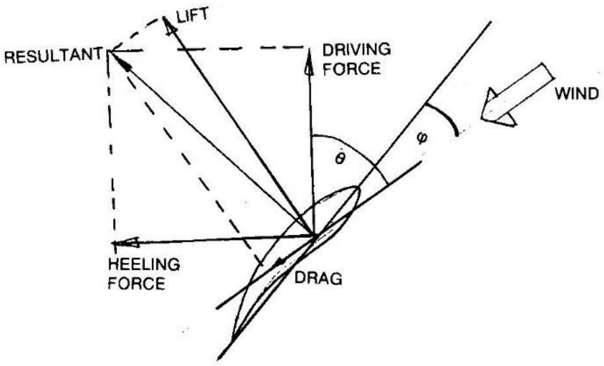


In practice the apparent wind velocity will be read directly from the on-board anemometer.

Step 2. (compute the angle of incidence)

The aerofoil will have to be positioned at an angle (θ - φ) at which the sail will produce the maximum driving force with the minimum heeling force.

To obtain the angle of incidence φ, the on-board computer will have to refer to the performance characteristics of the aerofoil section and perform calculations to maximise the driving force. Having calculated the angle φ and established the coefficients of Lift and Drag, the Driving and Heeling forces can be calculated. Using these values the computer will be able to give instructions for the correct setup of the aerofoil geometry, extension, and sail attitute. Unfortunately the calculations will not be the same for all the sailing modes. For example, when the boat is sailing on a run, it will be better to turn the sail so that the planform area is at right angles to the wind, and to utilise the Drag as the driving force instead of the Lift. It may be advantageous to analyse all the possible sailing conditions at the design stage and provide the on-board computer with a look-up table for reference. In this way the computing load on the on-board computer will be reduced, allowing it to be made smaller and cheaper.



The purpose of the present article is not to give ready made solutions to the exciting and challenging engineering problem of the rigid sail. On the contrary the discussion has been limited to the concept design phase of the Design process. The interested engineer may wish to study additional design solutions before embarking on further development and testing.