An Integrated System of Control For Hovercraft Using Differentially Acting "Elevons"

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Introduction

THE design of the "River Rover" light Utility hovercraft posed a number of stringent demands. The most exacting was without doubt the requirement that the craft should possess the ability to negotiate sharp bends in rivers with the least possible sideways skidding.

Hitherto, most light hovercraft have relied on vertically hinged rudders or vanes to achieve directional control. The undesirable "side effects" of such systems will be explained later in this paper. Suffice it to say here that, as a result, lack of really positive control is a feature which has to a large extent become accepted as inevitable.

On larger commercial craft where more precise control is a requirement, this is only achieved at considerable expense and complication. Various systems, such as skirt shift or skirt lift, "puff-ports", and pivoting Propeller pylons are employed. Sometimes a combination of all three systems may be found on one craft.

The "elevon" system of control described in this paper not only combines the functions of these systems in one extremely simple system, but with little extra complication it can also provide longitudinal pitch control, and thrust control over a full range from full forward thrust, through zero, to full reverse thrust. This feature makes the elevon system readily adaptable to hovercraft using the simplest of integrated lift and propulsion systems (ie, one where the engine is permanently engaged to both lift and propulsion fans). The "River Rover" embodies such an integrated System and, together with its elevon controls, results in a hovercraft which is of extremely simple construction, but which is easy to drive and very manoeuvrable.

The purpose of this paper is to describe, in general terms, a typical elevon control system, and to analyse its method of Operation, comparing it at the same time with the Operation of a conventional vertically-hinged rudder. Finally, it will be demonstrated how, for full control under all possible conditions, the horizontally-hinged elevon and the vertically-hinged rudder are complementary to each other.

The Effect of the Elevon System on Directional Control

In its simplest form, an elevon tan be considered as a pressure-balanced butterfiy valve hinged horizontaliy across the efflux of a propulsion fan duct. These ducts are mounted in pairs, each one being positioned either side of the craft centre line, as far outboard as practicable. A single engine drives both fans via belts and pulleys. The elevons are rigged so that, in the neutral Position, both lie horizontal, thus presenting the least possible resistance to rearward thrust.

A joystick-type control column in the cabin is used to effect differential movement of the elevons. Lateral displacement of the control column causes the trailing edge of one elevon to move downwards through a relatively small angle (up to 13° on the River Rover). The trailing edge of the other elevon can be moved upwards through a greater angle, until the vertical position is reached. In this position it shuts off all rearward flow from the duct. The combined action of the two elevons is therefore as follows:

Small sideways movements of the control column impart small positive incidence angles to one elevon, and small negative angles to the other. This action is analogous to the Operation of ailerons on an aircraft, causing the craft to bank into the desired direction of turn.

Further, coarser, sideways movement of the control column progressively increases the negative incidence of the upgoing elevon, thus increasingly restricting the rearward efflux from the fan on that side. On the other side, the elevon retains its small positive incidence angle, with little reduction in thrust. The resultant differential thrust combines with the bank into the turn to cause the craft to yaw in the desired direction.

These effects of control are now illustrated in detail. Also included is an analysis of the effects of a conventional vertically-mounted rudder, in order to afford a means of direct comparison between the two systems.

It will be seen from Fig 1 below that, without exception. all forces and the moments induced by them act in a productive manner. The chain of events producing this favourable condition can be explained as follows:—

1. Driver moves control column to right (as if banking an aircraft) to initiate a turn to starboard.
2. Port elevon goes down a small amount. Starboard elevon goes up a greater amount. producing:
   (a) A rolling moment (Mr) into the turn, due to Fp up, and Fs down.
   (b) Differential thrust, because upgoing elevon reduces thrust on starboard side more than does the downgoing elevon on the port side. This in turn produces a turning moment Mr to starboard.
3. Mr causes:
   (a) The skirt hem on the port side to rise, allowing lift air to escape. The resultant side thrust Fst opposes side-slip away from the centre of the turn.
   (b) The skirt hem on the starboard side is forced into the water, producing a rearward drag force Fd, acting along the line of contact. This asymmetric drag induces a turning moment Md in the desired direction of turn.

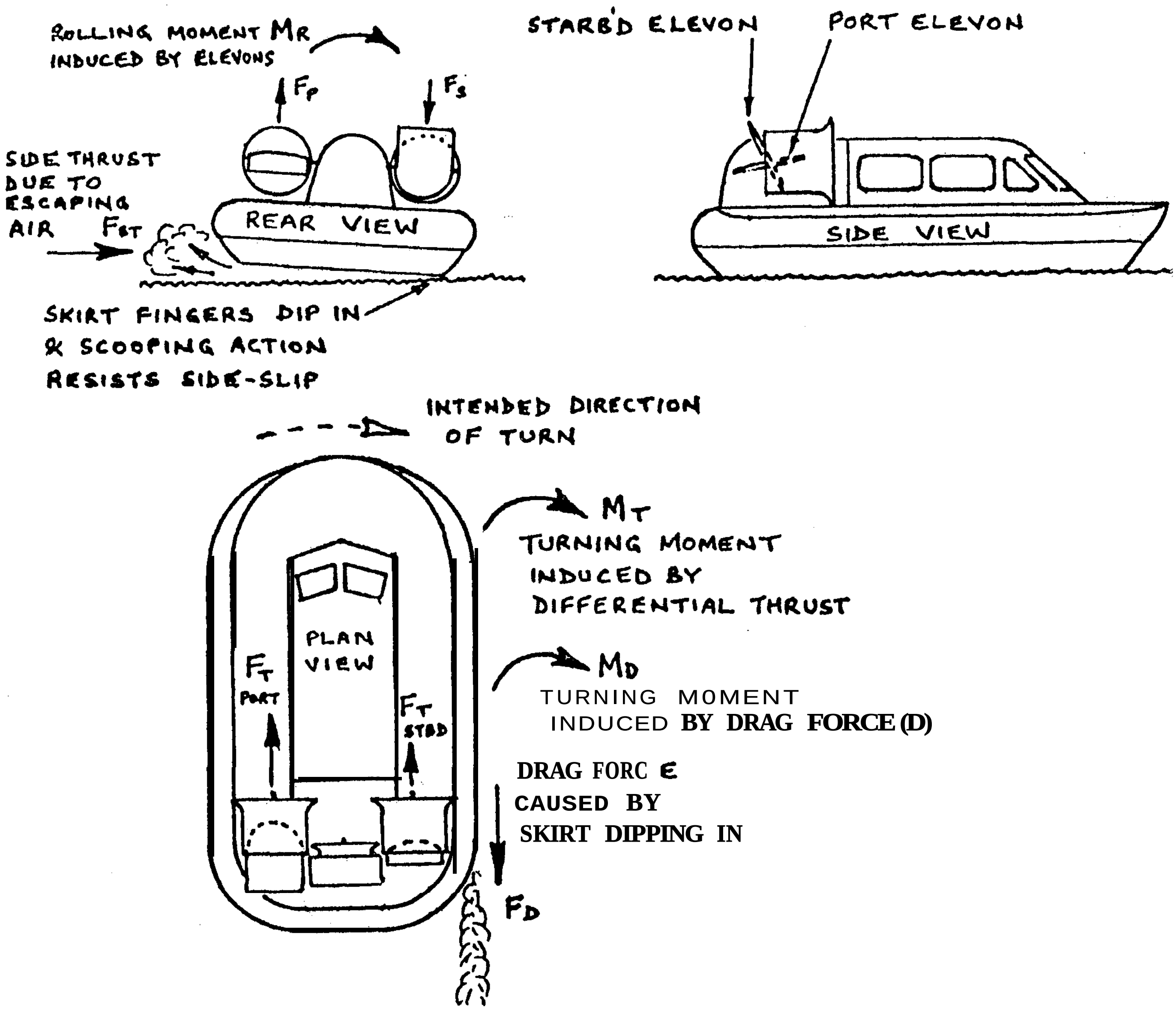

Fig 1 Still air conditions : Effect of controls on a hovercraft fitted with horizontally-hinged differential "elevons"

It will be seen from Fig 2 facing that, with the sole exception of the Turning Moment (Mt) induced by the rudder, all other forces, and the moments induced by them act in a counter-productive manner. The chain of events which produces this unfavourable condition can be explained as follows :

1. Driver applies right rudder to initiate a turn to starboard.
2. Rudder produces a horizontal force Fsr to port, acting through the centre of pressure of the rudder.
3. Fsr induces two moments:
   (a) A tuming moment Mt in the desired direction of turn.
   (b) A rolling moment Mr out of the turn.
4. Fsr also produces a side-slip away from the centre of the turn. The skirt offers little resistance to this side-slip, because only the outside (planing) face makes contact with the water.
5. Rolling moment Mr causes:
   (a) Skirt hem on the starboard side to rise, allowing lift air to escape. The resultant side thrust Fst Supplements Fsr in producing side-slip away from the centre of the turn.
   (b) The skirt hem on the port side to be forced into the water, producing a rearward drag force Fd acting along the line of contact. This asymmetric drag induces a turning moment Md opposite to the desired direction of turn.

lt will be seen from Fig. 3 later that, in contrast to the effect of controls under still air conditions, there is a complete reversal of the functions of elevons and vertical rudders when crosswind conditions are encountered. Under such crosswind conditions, a vertical rudder has a productive effect on the craft, whereas elevons have a counter-productive effect.

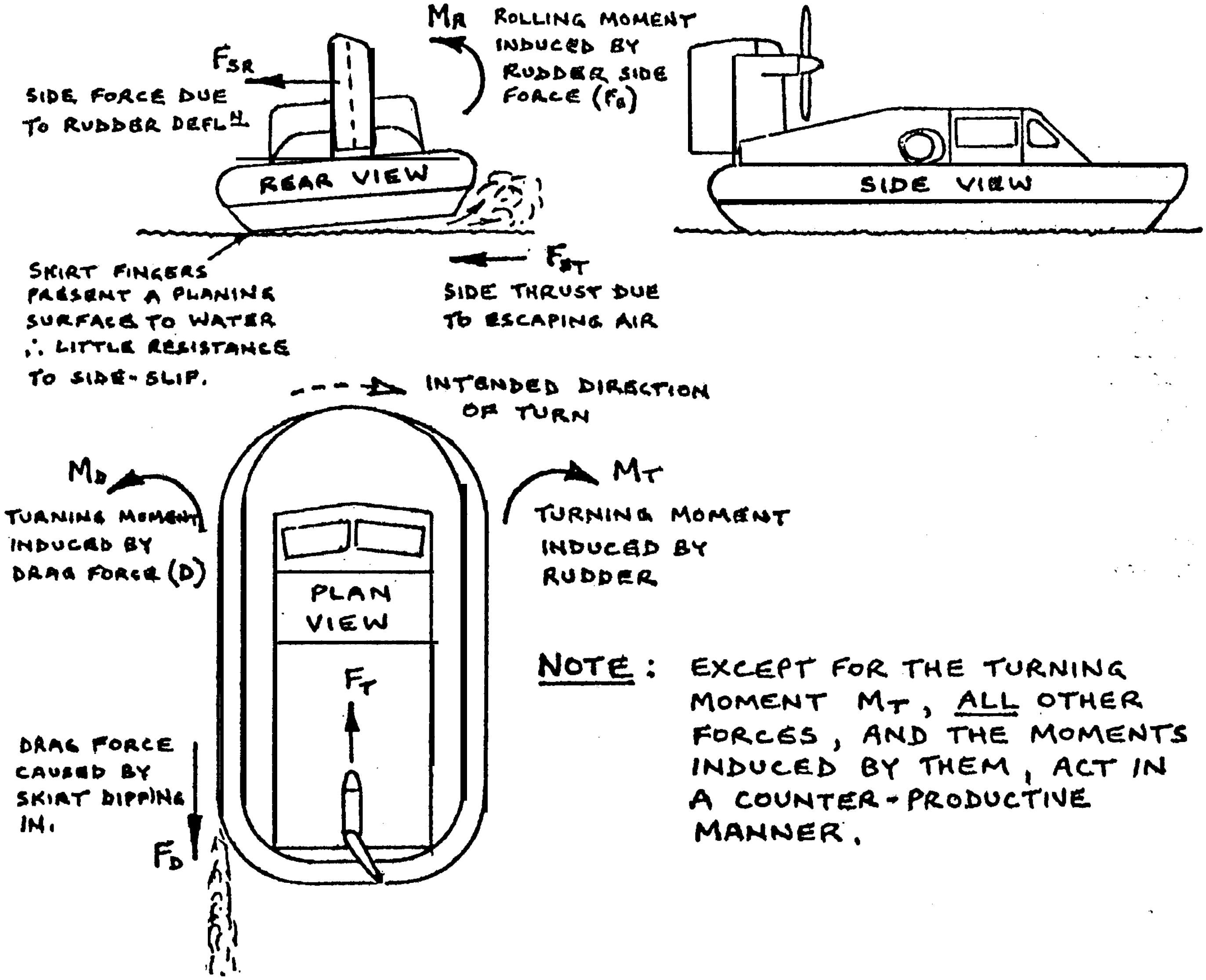

Fig 2 Still air conditions: Effect of controls on a hovercraft fitted with a conventional vertically-hinged rudder

The Application of the Elevon System to an Integrated System of Lift and Propulsion

An integrated system, in which both lift and propulsion are driven by a single engine, presents the problem of how to Proportion the power between lift and propulsion. Ideally it should be possible for lift power to remain constant whilst propulsive power is infinitely variable from full forward thrust, down through zero, to full reverse thrust. The elevon system of control lends itself admirably to meeting these requirements.

So far, only the effects of elevons on roll and yaw have been considered. These effects are the result of differential movement of the elevons. The effects of moving both elevons simultaneously in the same direction will now be discussed. This action is analogous to the Operation of the elevators on an aircraft and, like an aircraft, it is effected by means of fore-and-aft displacement of the control column.

The significance of the word "elevon" may now be appreciated, because it combines in the one control the functions of both elevators and ailerons. Elevons are, of course, the primary means of control on tail-less aircraft, of which Concorde is the best-known example. We have, however, already suggested that elevons applied to hovercraft can be made to fulfil yet another function, namely that of thrust control.

The "elevator" action of the elevons will now be considered. Small simultaneous movements of the elevons have the effect of changing the longitudinal, trim of the craft. They have a useful application in countering small variations in centre of gravity position due to load distribution, or to vary the bows-up or bows-down attitude of the craft, depending on whether it is heading down wind or into wind.

Further simultaneous movement of the elevon has the effect of progressively restricting the rearward efflux from

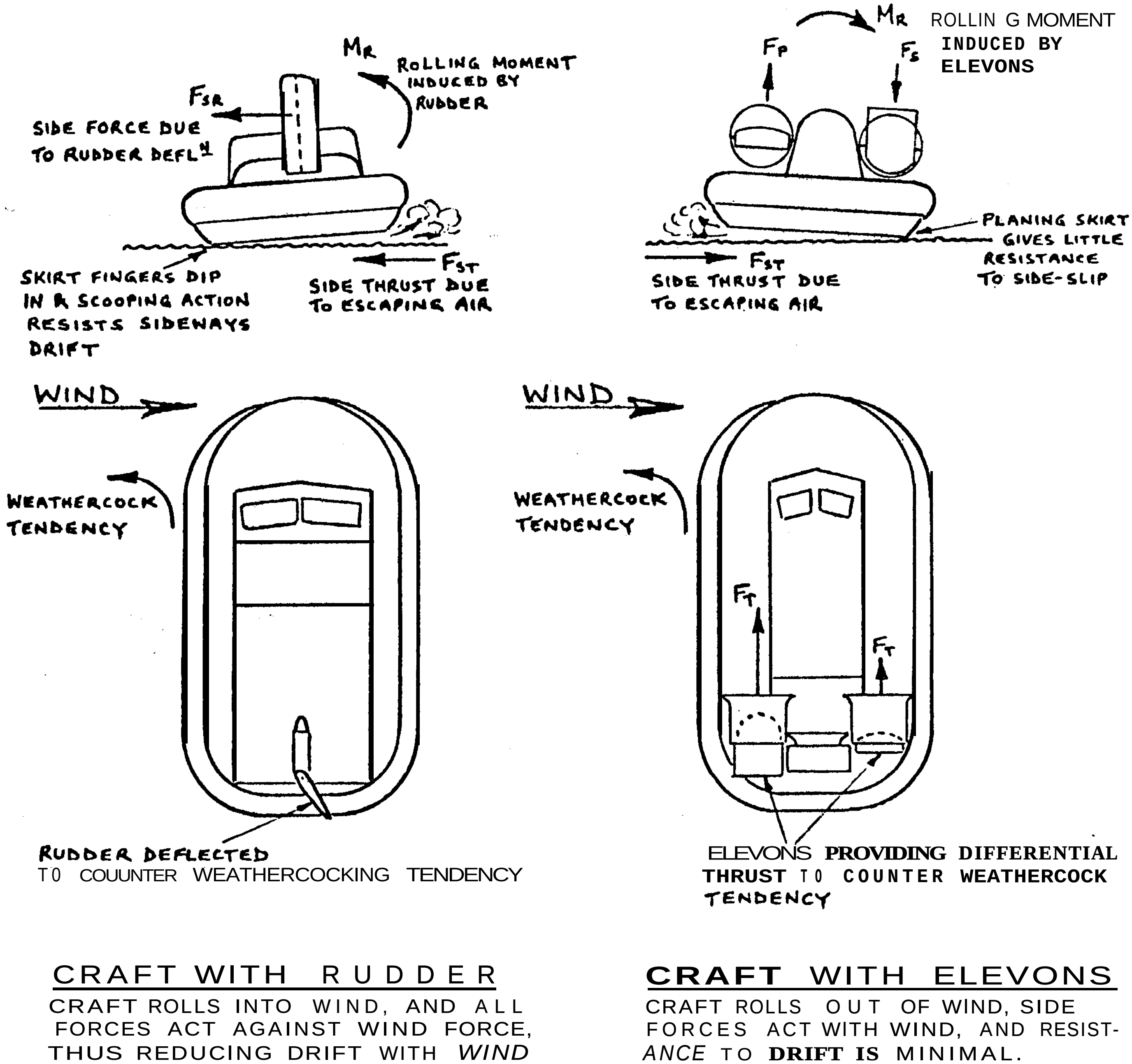

Fig 3 Cross-wind conditions : Effect of controls in resisting weathercock tendency

the propulsion fans until both ducts are completely closed, resulting in no forward thrust. The further addition of reverse-thrust "cowl" around the aft end of the propulsion ducts allows the propulsion airflow to be deflected forward, thus providing a certain amount of reverse thrust capability. It should be pointed out that, at all times, the simultaneous Operation of the ailerons is fully harmonised with their differential action, right up to the extreme case where the duct on one side is producing full forward thrust, while at the ame time the duct on the other side is producing full reverse thrust. A typical fan duct assembly incorporating an elevon and reverse-thrust cowl is shown in Figure 4.

Finally, the addition of vertically-hinged rudders completes the control System, thus providing a fully harmonised means of control which, when correctly used, will ensure the right response from the craft under all conditions, with a minimum of sideways skidding.

The **Rudder Control System**

It will be noticed that, in addition to the elevon system, the "River Rover" hovercraft is also fitted with conventional vertically-hinged rudders. These rudders are necessary to counteract the effect of crosswinds. Reference to Figure 3 will explain how this is achieved.

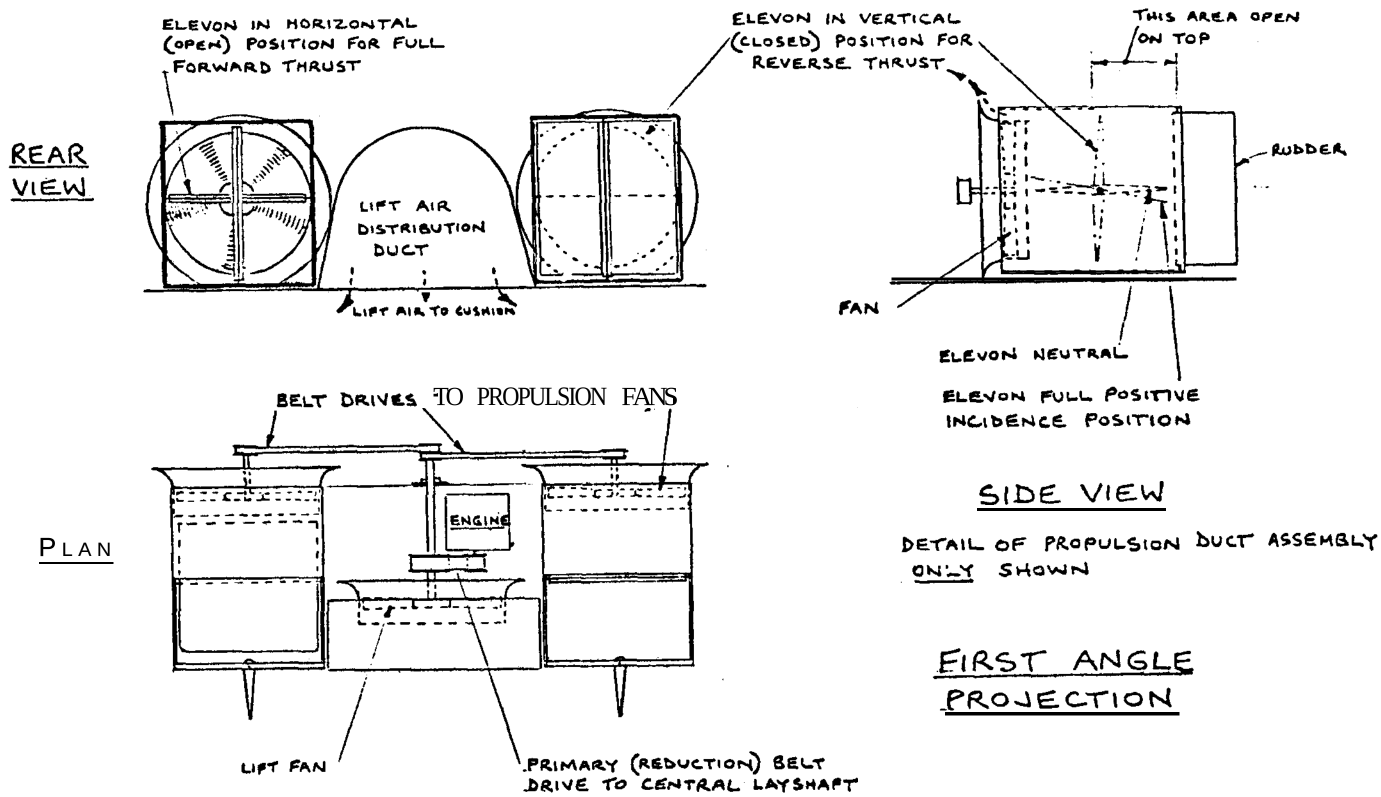

Fig 4 An integrated system of lift and propulsion using elevon and rudder controls.

Tbe Combined Effect of Elevon and Rudder Controls

Briefly stated, the prime object of any hovercraft control system is to obtain the greatest possible turning effect with the minimum of sideways skidding. Such a condition is desirable under all normal conditions of Operation and at all Speeds.

The foregoing analysis of the effects of both elevon and conventional rudder systems demonstrates that no one system can fully cater for all conditions of Operation. Our experience of actual Operation of the “River Rover” craft has confirmed these theoretical predictions, and both elevons and rudders are fitted. Under normal conditions, either control system used independently of the other will achieve satisfactory control. The driver will, however, soon learn how to harmonise both systems together, to obtain the maximum effect. One striking example of the combined effect of elevons and rudders is worth mentioning here: that of operating in a crosswind. Under this condition much of the sideways skidding, or “crabbing” normally experienced by a hovercraft operating in a crosswind can be eliminated. The elevons are used to bank the craft towards the windward side, and the tendency for the craft to ***veer*** into wind is resisted by the application of opposite rudder. This technique is weh-known to aircraft pilots, who use it to keep Iined up on a runway while on the approach for a crosswind landing.

So far, only the combined use of elevons and rudders has been considered. The separate functions of elevons in achieving longitudinal pitch control and, on an integrated lift and propulsion craft, in achieving thrust control should not be overlooked.

Conclusion

The integrated system of control used on the “River River” light hovercraft has demonstrated the effectiveness of elevons in improving directional control whilst at the same time providing pitch and thrust control.

Such a system could be applied with considerable advantage to almost any hovercraft. irrespective of size. On ***larger*** hovercraft, the only added complication might be the need for hydraulic actuation of the elevons, in order to keep control within acceptable limits.