Pneumatic Variable-Flow-Splitter Control for Hovercraft Responsive to Cushion Pressure

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Purpose:

An object of my invention is to provide a force or torque proportional to an applied, low, pneumatic pressure. This force in turn causes a change in the position of a device (hereinafter "splitter") tending to increase or reduce the pressure to the desired level.

Another object is to provide a damping force or torque to limit overshoot and prevent oscillation.

A further object is to provide all of the above in a device that is easily constructed and maintained, light and inexpensive, having only one rigid moving part.

A final object is to provide the above features in a device that can be made an integral part of the plenum chamber whose operating gage pressure it controls.

Background:

In the course of the inventor’s work on integral lift/propulsion systems for static air cushion vehicles (hovercraft) and on liftoff aids for wing-in-ground effect vehicles (WIG), a recurring problem has been to maintain a constant pressure in a plenum chamber feeding a static ground cushion, while engine power and fan rotation speed varied in response to propulsion requirements.

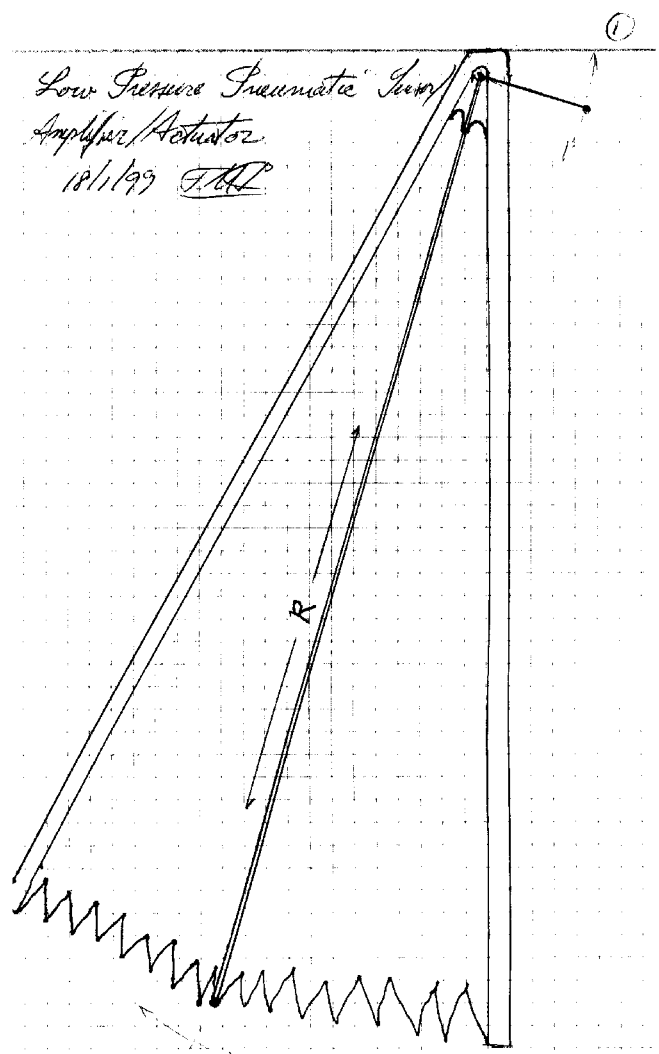
Problem:

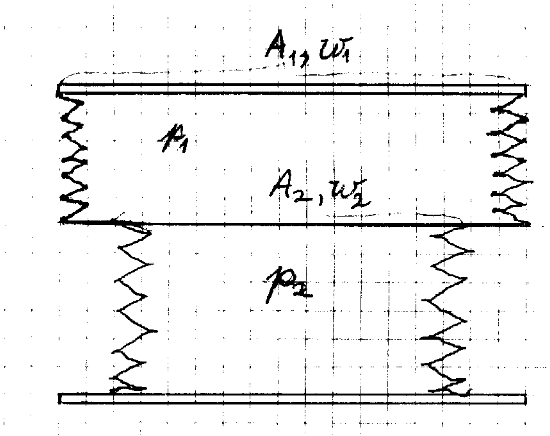
In small hovercraft at least, constant cushion pressure is usually sacrificed to simplicity of construction, and the solution adopted is a fixed flow splitter downstream of the lift/propulsion fan, which of course furnishes a cushion flow that varies with propulsion power setting. As a result, the necessity of maintaining a minimum skirt flow and pressure at minimum power setting ensures that excess flow occurs at higher settings, wasting propulsion power and causing handling problems. In the course of developing an automatic regulating mechanism for maintaining constant cushion pressure, it became evident that a sensor/amplifier/actuator (hereinafter actuator) was needed that was capable of producing large forces from small pneumatic pressures (in the ones to tens of pounds per square foot), and reliable damping responsive to changes in those pressures and to displacements of the actuator itself. As this need arises particularly in the case of small, amateur-built craft, the device had to be easy and cheap to build and to operate reliably without driver intervention.

Description:

The actuator consists of three plates—two fixed, one mobile. The two fixed plates are attached to one another (they may be a single unit) at one end, forming a triangular prism with one open side. The mobile plate lies between the two fixed ones, and is pivotably attached to them where they meet. Two radially-tapered bellows bridge the spaces between the fixed plates and the mobile one, defining two air chambers, one on either side of the mobile plate.

In the preferred hovercraft embodiment one of the two air chambers, labeled A_1, has a larger area (R x w) than the other, achieved by making its width w_1 greater than that of chamber A_2. Thus when the same pressure exists in both chambers, a force is engendered, equal to the gage pressure multiplied by the difference in areas $p\,(A_1 - A_2)$, tending to move the movable plate toward the smaller chamber. With the actuator connected to the variable splitter, this force tends to move the splitter from the open toward the closed position. This force in turn is opposed by another—perhaps from a linear spring, perhaps from a nonlinear spring or spring/cam arrangement—tending to keep the splitter wide open. The desired effect is that whenever the plenum pressure deviates from that desired, the splitter is displaced





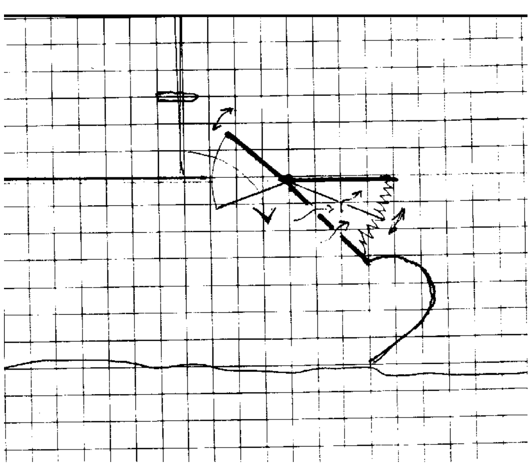
in such a way as to correct the deviation, in accordance with the well-known principle of closed-loop or feedback control. Because this effect is proportional only (no integral effect), the error is not brought to zero except at one ("design" or "ideal") power setting, but skirt flow in confined to a narrower band than when a fixed splitter is used.

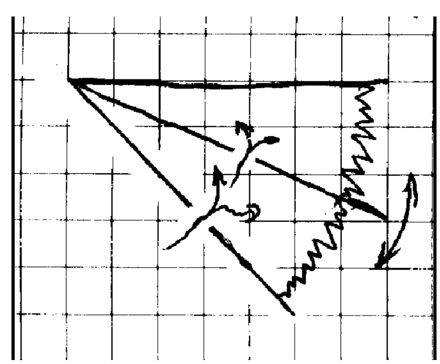
In the preferred embodiment, the actuator is fed from the plenum chamber directly into chamber A_1 (the larger one), preferably through holes in a common partition rather than through external plumbing. The movable plate is perforated with one or more orifices to allow pressure in chamber A_2 to become equal to that in chamber A_1. Because the purpose of a two-chamber arrangement is to allow damping and other desirable time-varying effects, the orifices in the movable plate are designed to restrict flow such that there is a time lag between a change in pressure in A_1 and equalization of pressure. These connecting orifices may be designed so as to provide equal restriction to flow in either direction, or greater restriction to flow in one direction.

Operation:

The operation of the preferred embodiment of my invention is best illustrated by tracing in qualitative terms its response to a stepwise increase or decrease in plenum pressure. The forces on the mobile plate resulting from pressure changes are the following:

Filling force: caused by the momentary difference in pressure resulting from the fact that the chamber communicating with the





plenum is the first to respond to the pressure change, owing to the flow restriction between the two chambers.

Damping force: Once the movable plate begins moving, one chamber decreases in volume while the other increases, requiring air to be transferred from the shrinking chamber to the expanding one. The flow restriction between the two chambers causes a pressure difference, giving rise to a force opposite to the direction of motion of the plate.

Static force: This is the force exerted by the plate on the rest of the control system when a steady state is established—no pressure excursions, movable plate at rest.

Static force change (ΔF): the difference between the static forces before and after a pressure change (Δp).

Pressure Increase:

Imagine that plenum pressure has suddenly increased (say, as a result of a rapid increase in engine output).

The filling force is in the same sense as the final static force change, tending to move the movable plate so as to compress the smaller chamber A2. This produces an early force peak higher than the final static force, accelerating the splitter quickly in the desired direction.

As the movable plate begins moving and air passes from the larger to the smaller chamber, the force peak decays as pressures begin to equalize.

As the movement of the plate continues, the flow of air through the orifices in the movable plate reverses as the smaller chamber continues to shrink. This reverse flow creates a momentary damping force (opposite to the static force) that tends to brake the movable plate as it approaches its new force-equilibrium point; this damping also inhibits any tendency to overshoot caused by the inertia of the splitter. The result is a smooth, but rapid response.

Pressure Decrease:

Here again the filling force is in the same sense as the final static force change, producing a force peak tending to accelerate the splitter toward the open position. Damping force is mostly absent because of unrestricted communication between the larger chamber and the plenum. The result is very rapid opening of the splitter, which is needed to prevent the craft from coming off-cushion if the throttle is chopped during a high-speed run.