Dec. 17, 1968 J. E. NICHOLSON ETAL 3,416,758

SELF-BALANCING SPIKE CONTROL

Filed Oct. 4. 1967 3 Sheets-Sheet 1

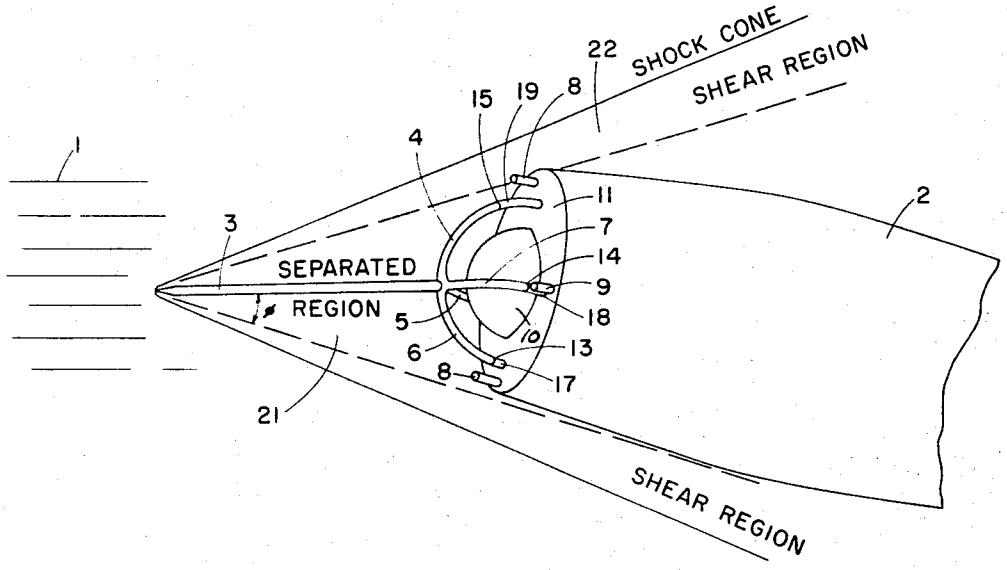


Fig. 1

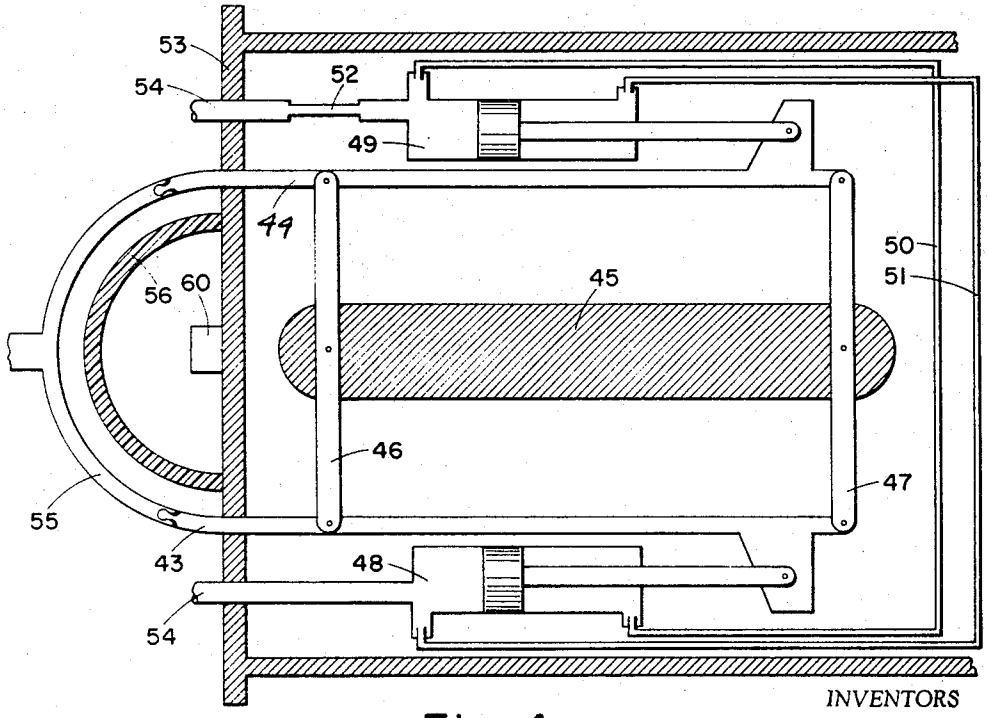


Fig. 4

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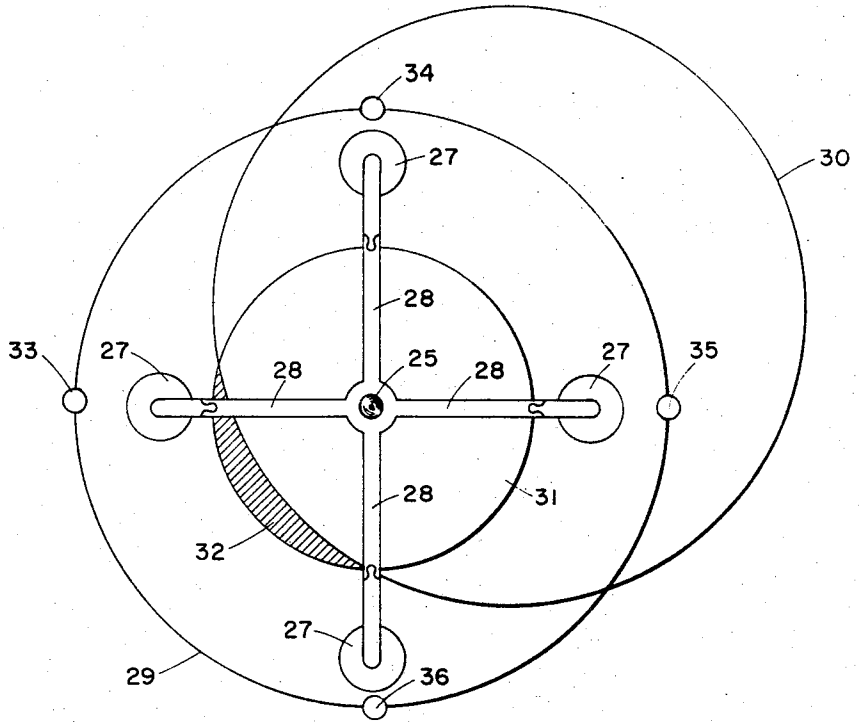


Fig. 2

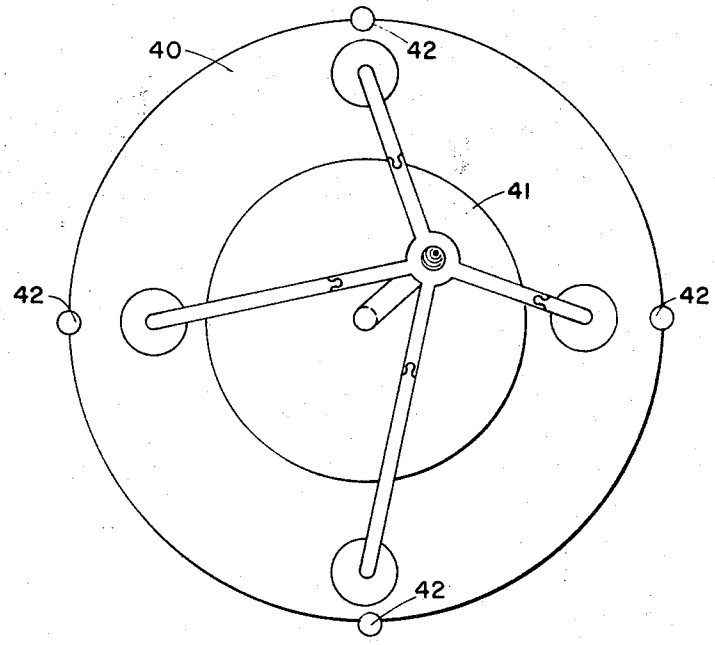


Fig. 3

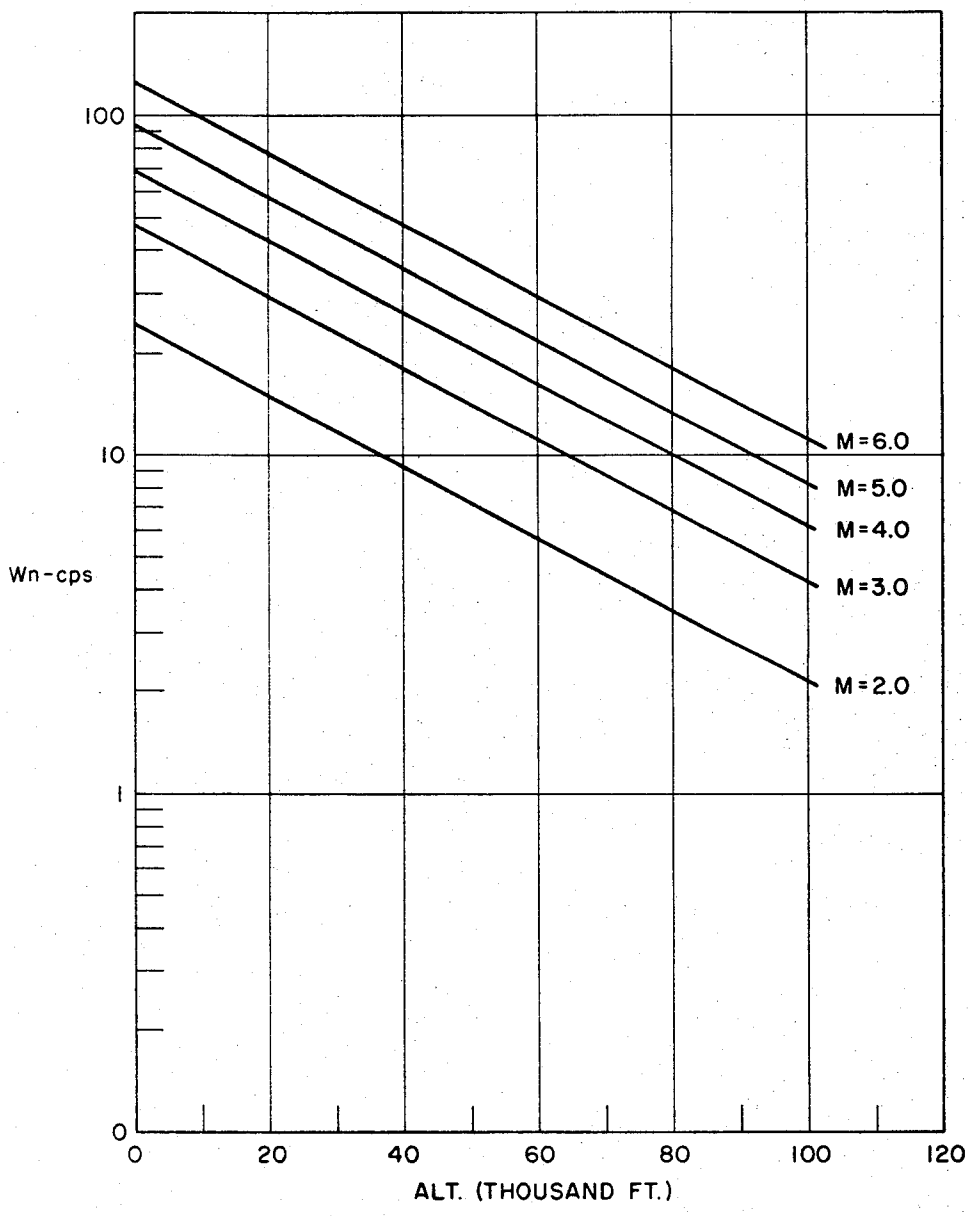

100
10
1
0
Wn-cps
M=6.0
M=5.0
M=4.0
M=3.0
M=2.0
0
20
40
60
80
100
120
ALT. (THOUSAND FT.)

Fig. 5

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SELF-BALANCING SPIKE CONTROL

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8 Claims. (Cl. 244—130)

ABSTRACT OF THE DISCLOSURE

A self-aligning spike control system has been devised to automatically maintain the spike in alignment with a supersonic airstream to provide a separated region of protection at or adjacent to the nose or leading edge of an aerodynamic structure such as an IR radome, whereby rain erosion, heat damage, drag and structural loading are minimized in the separated region. The alignment of the spike is responsive to the pressure differential between the shock wave and/or shear layer and the separation region, the control system utilizing the pressure differential both for control purposes and power means.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to supersonic vehicles and is concerned more particularly with means for protecting the nose or leading edge portions of such vehicles, thus minimizing the drag, temperature rise and erosion. The effectiveness of a physical spike mounted on a blunt nose radome or IR dome configuration for supersonic missiles is well known to provide such protection. It has been demonstrated that the spike protected radome concept in addition to protecting guided missiles from rain erosion, also reduces aerodynamic heating and structural loading.

It is desirable however that the spike be aligned with the oncoming flow such that a uniform flow separation region may be maintained over the dome or protected area.

In supersonic vehicles (Mach number greater than one) it is customary to have an extended rod or spike to create a shock wave. The shock wave thus produced will be essentially conical having a shock region, a shear region and a region interior to both, called the separated region. The purpose of propagating this shock wave is to reduce drag on the vehicle by directing the airstream away from the vehicle body and thereby creating a region of protection interior to the cone. The formation of the shock cone creates the separated region, interior to the cone, which region is lower in temperature and more uniform in composition. This condition allows the placement of either an active or passive sensor within the separated region and protects the sensor from both heat and erosion due to rain or particulate matter. The sensor may be housed in a hemispherical "window," which is transparent to the radiation to be measured. Heat generated at supersonic speeds causes the window to become opaque while rain may erode the window to such an extent that it no longer serves its protective function. It is known that the positioning of a spike or rod upstream of the window or sensor causes the airstream to be diverted, thus protecting the window from undue heating and resultant opacity as well as erosion.

When a fixed spike or rod is not in alignment with the airstream, the shock cone is off-centered, causing damage to the portion of the sensor then exposed to the airstream. The self-aligning spike is designed to align itself with the airstream when the vehicle becomes misaligned. When

such a misalignment occurs, one portion of the vehicle is submerged in the shear or shock region while an area diametrically opposite is submerged in the separated region of lower pressure. The pressure differential occurring between these diametrically opposite points is then used to reposition the spike or rod. Two pairs of pitot tubes located on the shoulder of the vehicle sense the unequal pressure resulting when the vehicle is misaligned to the airstream in either pitch or yaw or a combination of both motions. These actuating pressures are fed to pistons in pneumatic cylinders which drive the spike in a direction so as to reduce the pressure differential. When the spike is aligned with the airstream, no pressure differential exists.

It is therefore the object of this invention to provide a system for orienting the spike or rod with respect to the airstream such that the shock cone is positioned so as to completely protect the nose or leading edge of a supersonic vehicle.

It is a further object of this invention that the orientation of the spike or rod be dependent on a pressure differential created by a misalignment of the vehicle with the airstream.

It is a further object of this invention to provide power for the system from the air pressures developed in the shear and shock regions.

It is a further object of this invention to provide for damping by providing capillary tubes in the flow path of either or both of the diametrically opposed pressure responsive flow paths.

In particular the invention involves the provision of diametrically opposed pitot tubes to sense a difference in air pressure; the provision of capillary restrictions in one or both of the lines coming from the pitot tubes; the provision of pistons which positions are responsive to an external change in pressure; and which drive, in turn, a linkage, a movable spike support system, and a spike, to orient the spike or rod with the airstream.

While the invention has so far been indicated as being particularly applicable to vehicles wherein a radiation window is to be employed, and will be so described in relation thereto for purposes of illustrating the resultant advantages, it is to be understood that the invention is not so limited as the spike may be embodied in a variety of configurations and structures apart from the use of a "window," to protect the forwardmost member of a supersonic vehicle.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description thereof when considered in conjunction with the accompanying drawings in which like numerals represent like parts throughout and wherein:

FIG. 1 is a diagrammatic view of a vehicle at a 10° angle of attack having a spike aligned with the airstream;

FIG. 2 is a top view of the support structure showing the areas of protection afforded by a fixed spike when the vehicle is aligned and misaligned with the airstream;

FIG. 3 is a top view of the support structure with the spike displaced in both lateral and vertical directions;

FIG. 4 is an enlarged detailed schematic view of the control system; and

FIG. 5 is a graph displaying natural frequency of the self-aligning spike system as a function of altitude and Mach number.

Referring to FIG. 1, a blunt nosed supersonic vehicle 2 is shown misaligned with the airstream generally represented by lines 1. If spike 3 were not angled downwardly as shown, the protective cone would not completely enclose the region to be protected. Means for aligning the spike in automatic response to a pressure differential caused by the misalignment of the vehicle 2 with the airstream 1 is shown by a spike 3 mounted for

displacement from a null or center position, having a virtual pivot point at the center of plate **11**. The spike is supported by four arcuate legs **4**, **5**, **6** and **7**. The free ends are connected by means of ball and sockets **13** through **15** to reciprocating linkage arms **17** through **19**. Beneath the arcuate arms **4** through **7** is centered a window **10** in which is housed an active or passive sensor (not shown). Two sets of pitot tubes **8** and **9** (one not shown) pass through plate **11** adjacent their respective legs. The tubes and legs are spaced from each other by 90° to facilitate sensing and movement in the yaw and pitch directions although there is no reason why the elements could not be located at other angular positions with respect to each other. However, diametrically opposed elements give both structural strength to the support structure while at the same time providing for an orthogonal balancing system.

The spike **3** forms a uniform region **21**. This uniform region is characterized by a uniform nonturbulent flow pattern generally cooler than the shear and shock regions. The formation of this region prevents turbulent hot spots from occurring at or near the surface of window **10**. Immediately adjacent the uniform region is a shear layer contiguous with the cone and characterized by an increase in viscosity. When the spike **3** is in the null position, all four pitot tubes will be emersed in the shear layer **22**. The maximum pressure differential is obtained when one of two diametrically opposed pitot tubes is completely submerged in the separated region **21** while the other is completely outside of the shear layer **22**, sensing the pressure behind a normal shock wave. This corresponds to the misalignment of the vehicle with the airstream.

FIG. 2 shows how the yaw and pitch systems are cross-linked to provide two-dimensional movement of the top of the spike **25**. This figure also shows the orthogonal arrangement of the pitot tubes **33** through **36** with respect to pistons **27** and linkage arms **28**. FIG. 2 shows further the areas that would be protected if the spike were fixed in the null position. In a rigid spike system, off-centering of the protective cone is due to a misalignment of the vehicle with the airstream. The protective cone is shown centered, **29**, and off-centered, **30**, from the radome or window **31**. The area of radome covered by circle **30** is protected when the cone if off-centered while area **32** is not in the case of a fixed spike. When cone **30** is off-centered, pitot tubes **33** and **36** have less pressure at their apertures than do tubes **34** and **35**. This pressure differential causes the support system to shift the spike as shown in FIG. 3. The spike shift causes the protective cone **40** to recenter, both protecting window **41** and immersing all pitot tubes **42** in the shear layer. A rebalance is thereby effected. The spike will stay in alignment with the airstream so long as the relative position of the vehicle body and the airstream remain the same.

In the preferred embodiment a spike is mounted for movement in the pitch and yaw planes. FIG. 4 is a diagrammatic representation of control in one of these planes. The spike is attached to an arcuate support **55** which overlies window **56** and sensor **60**. Support **55** is joined at its diametrically opposite extremities by linkage arms **43** and **44**. Arms **43** and **44** are made to reciprocate with respect to a central support **45** by crossmembers **46** and **47**; pivotably anchored at their extremities to legs **43** and **44**. Crossmembers **46** and **47** are pivotably mounted at their centers to support **45**. This forms a pivoted parallelogram linkage system. A difference in pressure will distort the parallelogram and thus move the spike. Arms **43** and **44** reciprocate through a face plate **53** in response to a pressure differential in pistons **48** and **49**. The pressure differential is caused by a difference in pressure at the pitot tubes **54** which feed the piston chambers. Feedback loops are provided by flow paths **50** and **51** to rebalance the imbalance of pressure sensed by the pitot tubes to maintain the spike at a given angle dictated by the pressure differential. A capillary tube **52** is provided in one arm of the system to damp any oscillations that may occur although capillary tubes on both arms may be used. The length of the capillary depends primarily on the pitot tube lengths and varies for different parameters. These parameters are governed by the following differential equation, which describes the ideal (linear and 2nd order) system:

$$\ddot{\theta}+K_1\dot{\theta}+K_2\theta=0 \tag{1}$$

where

$$K_1=2\delta\omega_n=\frac{8\mu}{\pi}\frac{l}{r}\frac{(A_p b)^2}{I} \tag{2}$$

and

$$K_2=\omega_n^2=\frac{d(\Delta C_p)}{d\theta}\frac{q\infty Apb}{I} \tag{3}$$

μ=viscosity of the air in the capillary tubes
l=length of the capillary tube
r=radius of the capillary tube
Ap=area of the piston
b=distance between the pistons
I=system moment of inertia
q=free stream dynamic pressure

$\frac{d(\Delta Cp)}{d\theta}$=differential pressure coefficient slope for a given pitot tube position

Preliminary runs in a wind tunnel established a pitot tube length of 0.135 body diameters as the optimum length. It should be noted that in the above formula

$$\frac{d(\Delta Cp)}{d\theta}$$

is linear only up to $\theta=2°$. A non-linear response has been noted up to angles of $\theta=20°$. The ability of the self-aligning spike to align itself with the airstream has been confirmed up to a misalignment angle or angle of attack of 20° with an error in alignment of ±3°.

Preliminary runs also established an adequate response time of the system to changes in angles of attack. The response of the system is defined by Equation 3 in which we find:

$$\omega n\sim\left(\frac{d(\Delta Cp)}{d\theta}\right)^{1/2}(q\infty)^{1/2}\left(\frac{Ap}{W}\right)^{1/2}\left(\frac{b}{R^2}\right)^{1/2} \tag{4}$$

where W is the mechanism weight and R is the radius of gyration.

The lengths b and R are fixed by the size of the missile and are roughly proportional to the radome diameter, D, such that

$$\omega_n\sim\left(\frac{d(\Delta Cp)}{d\theta}\right)^{1/2}(q\infty)^{1/2}\left(\frac{Ap}{W}\right)^{1/2}\left(\frac{1}{D}\right)^{1/2} \tag{5}$$

In a missile having a 9 inch radome and a piston area of 1.3 inches (triple the dimensions of the test model), the ω_n will be approximately 5 c.p.s. at q^∞. Such a design is quite feasible since system weight in the flight missile would be held at a minimum.

Flight ω_n vs altitude may be plotted as in FIG. 5.

The Mach number scaling shown in FIG. **5** was accomplished by considering the first two terms in Equation 5.

$$\omega_n\sim\left(\frac{d(\Delta Cp)}{d\theta}\right)^{1/2}(q\infty)^{1/2}$$

which may be reduced to

$$\omega_n\sim\left(\frac{dP}{d\theta}\right)^{1/2}$$

Since $dP/d\theta$ is linear over only 2°, the maximum P obtainable is considered to be the governing parameter for the natural frequency. That is

$$\omega_n\sim(\Delta P_{max})^{1/2}=(P_{c_{t_2}}-P_c)^{1/2}$$

which for a given altitude and a given conicalseparation is a function of Mach number. This Mach number scaling

has been applied to the data and is presented in FIG. 5 from M=2.0 to M=6.0. The natural frequency range shown is considered quite acceptable for an operational system. Note that since the missile natural frequency is also dependent upon dynamic pressure, it would show similar trends with altitude and Mach number. This is one of the most advantageous features of a self-aligning spike system which is self-powered by pitot pressures.

What is claimed is:

1. In a vehicle operating at supersonic velocity with respect to an airstream, a system comprising:
- means for producing a conical shock wave in advance of said vehicle,
  - said shock wave having an interior separated region which covers an area of said vehicle; and
- means mounted on said vehicle, for aligning said shock wave producing means with said airstream whereby said separated region is maintained over said area,
  - said aligning means being actuated by a pressure differential occuring at two spaced points on said vehicle, one of said points being located within said separated region and the other of said points being located outside of said separated region when said vehicle is misaligned with said airstream.

2. The system as recited in claim 1, wherein said aligning means comprises:
- means mounted on said vehicle to sense said pressure differential;
- pressure responsive actuating means coupled to said sensing means and operated by said pressure differential to move said shock wave producing means into alignment with said airstream; and
- damping means coupled to said actuating means to eliminate oscillations in said pressure caused by the movment of said actuating means.

3. The system as recited in claim 2 wherein the shock wave producing means is a spike, mounted on said vehicle and projecting forwardly thereof.

4. The system as recited in claim 1, wherein said aligning means comprises:
- a pair of Pitot tubes mounted on said vehicle to sense said pressure differential;
- damping means, coupled to said Pitot tubes to eliminate oscillations in said air pressure;
- a pair of piston chambers having input lines coupled to said damping means, each of said chambers having an output line coupled to the input line of the other;
- pistons accommodated in said chambers adapted to be positioned in said chambers by said pressure differential;
- linkage means coupled to said pistons;
- support means coupled to said linkage means adapted to move therewith; and
- shock wave producing means coupled to said support means, whereby said shock wave producing means is moved into alignment with said airstream as a result of said pressure differential occurring at the input ends of said Pitot tubes.

5. The system as recited in claim 4 wherein two pairs of Pitot tubes are mounted in an orthogonal configuration with respect to said vehicle.

6. The system as recited in claim 4 wherein said damping means comprise a length of capillary tubing between said Pitot tubes and said piston chambers.

7. The system as recited in claim 4 wherein said linkage means comprise a deformable parallelogram.

8. The system as recited in claim 7 wherein said support means comprise an arcuate leg coupled at each end to parallel legs of said parallelogram.

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