A Weathervane Turns into the Wind Not Because Its Tail Is Larger but Because Area Times Arm Wins

— even with a head larger in area than the tail, the vane turns into the wind if this difference is positive, and placing the axis near the tail makes it negative so the vane points the other way — the separator is whether the centre of pressure lies behind the axis — [Paper 653]

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September 2026

— *From thinking to syncing.* —

Abstract

A weathervane on a roof turns its head toward where the wind comes from. Because it has a small head and a large tail, it is often explained that "the tail, being larger in area, is pushed downwind".The moment that turns it back and the way its swing dies away are counted with quasi-steady aerodynamic forces.No new theorem or law is claimed. First, whether it turns is set not by area but by the difference in area times arm——if S_1, the tail's area times arm minus the head's, is positive, the vane turns into the wind. For the vane set here, $S_1 = 0.010000$ m^3. With a head of 0.050 m^2, larger than the tail's 0.040 m^2, but arms of 0.10 and 0.30, $S_1 = +0.007000$ and the vane still turned into the wind (Section 2). **Second, with the axis near the tail, the vane points the other way——with the tail's arm 0.05 and the head's 0.25, $S_1 = -0.000500$ and the tail turns into the wind. Head and tail then swap roles, S_1 becomes $+0.000500$, and the vane settles that way** (Section 2). **Third, and this is the core.The restoring stiffness grows as the square of the wind speed, but the way the swing dies away does not depend on wind speed——between 2 m/s and 20 m/s, the stiffness became 100.000000 times larger and the swinging 10.000000 times faster, but the damping ratio was 0.156525 at both. By numerical integration, too, the ratio of successive swing amplitudes was 0.369443 at both** (Sections 3 and 4). **Fourth, the separator is whether the centre of pressure lies behind the axis——this is the same as the sign of S_1. A strong wind shortens the time to settle (from 60 degrees to 2 degrees, 13.8824 seconds becomes 1.3882 seconds) but does not change how many swings it takes** (Section 5). **Keywords**: weathervane, directional stability, centre of pressure, damping ratio, quasi-steady aerodynamics.

Scope of this paper (scope note): No new theorem or law is claimed——that a vane turns back when its centre of pressure lies behind the axis of rotation (in aircraft called directional or weathercock stability), and damping by quasi-steady aerodynamic forces, are known in flight dynamics.This is a quasi-steady approximation——the normal force of each plate is taken proportional to its angle of attack (slope 2.0 per radian), and the change in angle of attack from the rate of turning is included as is. Nonlinearity at large swings, vortex shedding and gusts are not treated.This is an example——a tail of $0.040\ \mathrm{m}^2$ at an arm of 0.30 m, a head of $0.010\ \mathrm{m}^2$ at 0.20 m, a moment of inertia of $0.020\ \mathrm{kg\cdot m}^2$ and an air density of $1.225\ \mathrm{kg/m}^3$ are set as an example.Relation to earlier papers: Paper 454 showed that although the resultant water thrust grows as the square of depth and the overturning moment as the cube, the width of a dam need only grow in proportion to depth——here too, what counts is not the size of the force but the balance of its product with the arm.What is added is writing the condition for turning as a difference in area times arm, with an example that turns though its areas are reversed and one that points the other way because of where the axis is, confirming by closed form and numerical integration that the damping ratio does not depend on wind speed, and placing the separator on whether the centre of pressure is behind or ahead of the axis.

1. Notation and the Question

Setting: a weathervane turns about a vertical axis, with a tail of area A_r at arm l_r behind the axis and a head of area A_f at arm l_f ahead. When it swings through a small angle θ to a wind of speed V, each plate meets the wind at angle of attack θ and makes a normal force $\tfrac{1}{2}\rho V^2 A C_{N\alpha}\theta$. A rate of turning $\dot\theta$ changes the angle of attack of a plate at arm l by $l\dot\theta/V$.The motion about the axis is

$$I\ddot\theta + c\dot\theta + k\theta = 0, \qquad k = \tfrac{1}{2}\rho V^2 C_{N\alpha} S_1, \qquad c = \tfrac{1}{2}\rho V C_{N\alpha} S_2$$

with $S_1 = A_r l_r - A_f l_f$ (the difference in area times arm) and $S_2 = A_r l_r^2 + A_f l_f^2$ (the sum of area times arm squared).The premises are $\rho = 1.225\ \mathrm{kg/m}^3$, $C_{N\alpha} = 2.0$ per radian, $I = 0.020\ \mathrm{kg\cdot m}^2$, a tail of $0.040\ \mathrm{m}^2$ at 0.30 m and a head of $0.010\ \mathrm{m}^2$ at 0.20 m.

Question: what turns a weathervane into the wind, and what changes when the wind is strong?

2. The Condition for Turning

Computation 2.1: for the vane set here, $S_1 = 0.010000\ \mathrm{m}^3$ and $S_2 = 0.004000\ \mathrm{m}^4$. Since S_1 is positive, a swing produces a moment that turns the vane back.

Computation 2.2: the head was made larger than the tail (head $0.050\ \mathrm{m}^2$ at 0.10 m, tail $0.040\ \mathrm{m}^2$ at 0.30 m). $S_1 = +0.007000\ \mathrm{m}^3$, and the vane turned into the wind.The axis was placed near the tail (tail $0.040\ \mathrm{m}^2$ at 0.05 m,

head 0.010 m^2 at 0.25 m). $S_1 = -0.000500$ m^3, and the vane pointed the other way. Head and tail then swapped roles, and S_1 became $+0.000500$.

> **Observation 2.3**
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> whether a vane turns is set not by area but by the difference in area times arm.It is not that the side with more area is pushed downwind. The side with the longer arm makes the larger moment for the same area. And a vane with negative S_1 does not fail to point; it settles pointing the other way——a vane points neither way only when S_1 is exactly 0.

3. Wind Speed and Swinging

Computation 3.1: for the vane set here, the restoring stiffness, speed of swinging, damping ratio and time to settle were derived for each wind speed.

wind	restoring stiffness	period	damping ratio	from 60 to 2 degrees
2 m/s	0.049000 N·m/rad	4.0142 s	0.156525	13.8824 s
5 m/s	0.306250 N·m/rad	1.6057 s	0.156525	5.5530 s
10 m/s	1.225000 N·m/rad	0.8028 s	0.156525	2.7765 s
20 m/s	4.900000 N·m/rad	0.4014 s	0.156525	1.3882 s

Between 20 m/s and 2 m/s, the ratios were 100.000000 for stiffness, 10.000000 for the speed of swinging and 10.000000 for the time to settle.

4. The Damping Ratio Does Not Depend on Wind Speed

Computation 4.1: putting k and c above into the damping ratio $\zeta = c/(2\sqrt{kI})$, the wind speed cancels, leaving

$$\zeta = \frac{\sqrt{\tfrac{1}{2}\rho C_{N\alpha}}\, S_2}{2\sqrt{S_1 I}}$$

which is 0.156525 for the values set, agreeing with the four wind speeds within 10^{-12}.By numerical integration, the ratio of successive swing amplitudes was 0.369443 at both 2 m/s and 20 m/s, agreeing with the closed form 0.369447 within 10^{-4}.

Observation 4.2

this is the core: a strong wind makes the swinging faster but does not change how many swings it takes to settle.The restoring stiffness grows as the square of wind speed and the damping as its first power. The speed of swinging, the square root of stiffness, grows as the first power of wind speed, in exactly the same proportion as the damping——so each swing leaving 0.369443 of the last is the same in a breeze and in a gale; only the time each swing takes is different.

5. The Separator

Observation 5.1

the separator is whether the centre of pressure lies behind the axis.That the point at which the resultant normal force of the two plates acts (the centre of pressure) lies behind the axis is the same as S_1 being positive. A weathervane has a small head and a large tail not for the difference in area but to put the centre of pressure behind the axis——and how the swing dies away is set only by shape (S_1 and S_2) and inertia, not by the strength of the wind.

Observation 5.2

beside Paper 454.Paper 454 showed that although the resultant water thrust grows as the square of depth and the overturning moment as the cube, the width of a dam need only grow in proportion to depth——here too, what counts is not the size of the force but its product with the arm, and though wind strength acts as a square, it entered neither the condition for turning nor the way the swing dies away.

Observation 5.3

what is not said.Quasi-steady aerodynamic forces are assumed, and nonlinearity at large swings, vortex shedding and gusts are not treated. The dimensions are an example——what is shown is what sets the condition for turning and the way the swing dies away.

6. Roll Call and Closing

1. $S_1 = 0.010000\ \mathrm{m}^3$ (Computation 2.1): **positive difference in area times arm.**
2. $S_1 = +0.007000$ **with a larger head** (Computation 2.2): **turns into the wind.**
3. $S_1 = -0.000500$ **with the axis near the tail** (Computation 2.2): **settles the other way.**
4. **points neither way only at** $S_1 = 0$ (Observation 2.3): **not area.**
5. **stiffness ratio** 100.000000 (Computation 3.1): **square of wind speed.**
6. **swinging ratio** 10.000000 (Computation 3.1): **first power of wind speed.**
7. **damping ratio** 0.156525 (Computation 4.1): **the same at every wind speed.**
8. **amplitude ratio** 0.369443 (Computation 4.1): **the same by numerical integration.**
9. **wind does not change how many swings** (Observation 4.2): **the core.**
10. **centre of pressure behind the axis** (Observation 5.1): **the separator; Paper 454.**

Closing: **A weathervane turns into the wind not because its tail is larger in area.It turned when the difference in area times arm between tail and head was positive, turned even with a head larger than the tail, and settled pointing the other way when the axis was moved toward the tail.A stronger wind raised the restoring stiffness as its square and quickened the swinging, but the damping ratio stayed at 0.156525——a strong wind only makes the swings faster and does not change how many it takes to settle.The separator is whether the centre of pressure lies behind the axis.Placed among the earlier papers——as in Paper 454, what counts is not the size of the force but its product with the arm.To be honest——this is a quasi-steady approximation, and large swings and gusts are not included.**

References

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2. Yamagishi, Y. (2026). *The Water Load Grows as the Square, and the Dam Only as the First Power* [Paper 454]. Zenodo. 10.5281/zenodo.22732989

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