THE WEIGHT-FORCE FALLACY

Pressure as the Weight of the Atmosphere: Many reference sources define atmospheric pressure as the weight of the overlying atmosphere. Some, a bit more cautious, say only that atmospheric pressures represent the weight of the overlying atmosphere. Both statements are false.

The situation is made a bit muddier by the apparent belief that atmospheric pressure is somehow qualitatively different than air pressure in the free atmosphere, and that a barometer measures something different than a manometer.

The Nature of Gases: Up until the last half of the nineteenth century, gases—including the gases of the atmosphere—were viewed as continuous fluids. There were essentially two different ways of looking at these fluids. Those scientists who didn't believe in atoms and molecules simply viewed gases as infinitely divisible matter that had the property of being able to expand indefinitely. The German chemist, Wilhelm Ostwald, who won the Nobel Prize for Chemistry in 1909, allegedly went to his grave in 1932 without ever accepting the existence of either atoms or molecules.

Those scientists who were able to accept the existence of atoms and molecules viewed the molecules of gases as having fixed positions when the gas was still, repelling one another from impingement on their mutual "spheres of influence", and able to expand these "spheres of influence" indefinitely. They were held in position by the "ether", and were capable of transmitting impulses by their continuous physical molecule-to-molecule contact.

This continuous physical molecule-to-molecule contact (something like a jar full of marbles) was responsible for the transmission of the "weight-force" from overlying molecules to underlying ones, and—eventually—to the surface. Hence, the pressure at any elevation was equal to the mass of the overlying molecules times the gravitational constant. In other words, air pressure was equal to the weight of the overlying air.

This picture is false, of course, because we know now that air molecules are in only fleeting contact with one another, and have "influence" only within that space that constitutes their effective volumes. This space is only a very small fraction of the atmospheric space at temperatures and pressures normally encountered in the troposphere.

However, these earlier concepts of molecules lasted well into the twentieth century, and had an influence on both scientific and popular modes of looking at gases. If you were to say that, "a gas has the ability to completely fill any container into which it is released", a majority of the population—including some who should know better—would probably agree.

This statement is false, and reflects the "sphere of influence" view of gases described above. The spheres were seen as expanding and completely "filling" the available space.

On the other hand, if you were to say that, "the molecules of a gas have an equal probability of being found in any part of a container into which the gas is released", you would be correct. Once equilibrium is reached, the molecules (and hence the gas) are just as likely to be found in any one part of the container as in any other. However, they only ***occupy*** a very small percentage of it—less than a tenth of a percent at normal temperature and pressure; and less than that at higher elevations.

They do not "fill" the space, any more than water vapor is capable of "saturating" a volume of air in the normal sense of either word. Both words reflect the idea of infinitely-expanding molecular spheres.

The Hydrostatic Hypothesis: Gases were viewed very much as analogous to water and other liquids—only compressible. They are still viewed that way today, because that view has many convenient consequences. Since the pressure of water and other liquids was a function of the overlying mass and the acceleration of gravity, it was naturally assumed that the pressure of the atmosphere was similarly a function of the overlying mass of the atmosphere and the acceleration of gravity; i. e., the weight of the overlying atmosphere.

This belief was expressed mathematically by the hydrostatic equation:

$$\boldsymbol{p = \rho g z = \frac{Mg}{A}} \qquad \text{WFF01}$$

Here, $\boldsymbol{p}$ is the pressure per unit area of surface, $\boldsymbol{\rho}$ is the density of the overlying column of air in a column whose base had unit area, $\boldsymbol{g}$ is the acceleration of gravity, and $\boldsymbol{z}$ is the effective height of the column. In the second half of the equation, $\boldsymbol{M}$ is total mass and $\boldsymbol{A}$ is total area.

An interesting quibble may be found in the use of the mass in a ***column*** of overlying air. While acceptable to the members of the Flat Earth Society, this column must be replaced by a conic section (for circular surface areas) or a pyramidal section (for rectangular surface areas) for others of us. This egregious error makes only a small difference in the result, but is indicative of somewhat sloppy thinking.

Development of Gas Theory: In 1738, Daniel Bernoulli—a genius ahead of his time—developed a kinetic theory of gases. He suggested that the pressure of a gas was the force exerted by the impact of the moving molecules of the gas upon any exposed surface. His ideas were roundly ridiculed, and failed to gain acceptance in the scientific community.

Almost a century later, John Herapath, derived a relationship between gas pressure and molecular speeds. He submitted his findings in a paper to the Royal Society in the 1820’s. The president of the Society, Sir Humphrey Davy, rejected the paper because it implied the existence of an absolute zero temperature—a concept that Davy (like most physicists of his time) was unwilling to accept.

In the third quarter of the nineteenth century, Maxwell, Boltzmann, and Clausius each made substantial contributions to the kinetic theory of gases, contributions that established its validity for most (but not all, ***pace*** Ostwald) physical scientists. Gases were shown not to be continuous, but highly discontinuous. The empty space in between the molecules was many times the effective molecular volumes. And that space was truly empty—just as empty as any in interstellar space. “Ether” did not exist.

Molecules were in “contact” only briefly, and the impulses transferred in these collisions were random in direction, rather than simply down. There was nothing else there that could transmit a force. The intervening space was empty, and incapable of transmitting any physical force. In short, there was no way for a molecule at elevation z to make its presence felt at any lower elevation except through ordinary molecular collisions.

Propagation of Downward Force Through Molecular Impacts It may be argued that the impulses transferred in these collisions are conserved and directed downward. However, under conditions of equilibrium, the upward transfer of impulse is the same as the downward transfer of impulse. Hence, the net transfer of impulse is zero.

But, you argue, the atmosphere is not in a state of equilibrium. It is subject to the downward force of gravity, which imposes itself on all molecular movements of translation. Surely, this force may be transmitted through molecular collisions to underlying layers of air and eventually to the surface.

Unfortunately, forces exerted on the atmosphere are not conserved. Eventually, the energy involved in these forces ends up as increased atmospheric entropy.

As an example of what happens to the transmission of force through the atmosphere, let us take a violent thunderclap. The force produced by this event moves out radially from the source, and its intensity diminishes with the square of the distance from the source. Thus, any force exerted at elevation z would be diminished by the square of z by the time it reached the surface.

Thus, over time, entropy takes its toll, and the powerful sound of the thunderclap utterly disappears—utterly! It leaves behind only the entirely random motions of the molecules of the air. It is very rare for even the most violent thunderclap to be heard more than twenty kilometers from its source. Thus, any downward force of molecular impulses is diminished by the inverse-square law of radial transmission and by diminution and eventual conversion into entropy.

In any case, the average downward impulses of molecular movements are many times the weight-force, and can hardly be considered to be representative of it[1].

[1] See Table NGP02 in *The Nature of Gas Pressures*. The force per unit area of the mean atmospheric molecular impact at 25°C is some 186 times the mean atmospheric pressure at 1000 hectopascals.

Pressure and Winds On the macroscopic level, there are other problems that the weight-force hypothesis fails to address in any satisfactory fashion. The foremost of these is that atmospheric pressure is shown by both observation and experiment to be a function of wind velocity. For a full treatment of this concept, see ***Pressures in Moving Air***.

The Bernoulli Effect Daniel Bernoulli was the first to quantify the observation that a flow of a fluid across a surface creates a drop in pressure upon that surface. When the flow is laminar and parallel to the surface, the drop in pressure is proportional to the square of the wind velocity; i. e.:

$$\Delta \boldsymbol{p} \propto -\rho \boldsymbol{w}^2 \qquad \text{WFF02}$$

Where: $\Delta \boldsymbol{p}$ is the drop in pressure, ρ is the mass density of the fluid, and $\boldsymbol{w}$ is the fluid velocity parallel to the surface. This equation is still valid, even if the surface is an imaginary one.

This means that a parallel flow of air at any elevation in the atmosphere creates a drop in pressure on the underlying, the overlying air, and the surrounding air. Moreover, the pressure drop is cumulative; that is, a westward flow at one elevation does not cancel out an eastward flow at a different elevation. Instead, the two (or more) pressure drops are additive. If these winds persist for any appreciable length of time, differential rates of molecular diffusion will transmit the pressure change to other elevations, and—eventually—to the surface.

The effects of vertical movements of air on pressure are even more dramatic. Subsidence can create substantial increases in pressure, and updrafts can create substantial decreases in pressure. The conventional belief is that each is automatically compensated for by equivalent outflows and inflows aloft so that the number of molecules in the column of air still reflects the mass-weight of the pressure in some magical manner. Moreover, despite the Bernoulli Effect consequent on such outward and inward flows, the flows themselves are supposed to have no effect on the pressure at the surface.

Quite frankly, this whole “balance” concept strains credulity.

It has been argued that atmospheric pressures are only present when there is no wind blowing. Many meteorologists consider winds to be sources of "error". I find this concept to be incomprehensible. Atmospheric pressures are atmospheric pressures, whether the wind is blowing or it is still. From a global perspective, the winds are blowing at some elevation or another at virtually all times everywhere on earth.

Are we to assume that barometric readings taken in a building when strong winds are blowing outside the building ***do not*** measure the weight of the overlying atmosphere; whereas readings taken when the outside air is still ***do*** measure the weight of the overlying atmosphere?

Let us imagine a building with three rooms. One has a window facing the wind, the second has a window parallel to the wind, and the third has a window facing away from the wind. If barometers were placed in all three rooms, each barometer would show a different pressure. Which of these three represents the weight of the overlying atmosphere?

Atmospheric pressures are the forces exerted on an exposed surface by the impacts of air molecules with that surface. That's all that they are. This force ***is not*** the weight of the overlying atmosphere, nor does it relate in any mathematical or physical way to the "weight" of the overlying atmosphere. The idea that it does is rooted in outmoded scientific concepts.

Brownian Motions In 1905 Albert Einstein drove the last nail into the coffin of the hydrostatic concept of atmospheric pressures with his work on Brownian motion. The steady downward force of atmospheric weight turned out to be exceedingly unsteady on near-microscopic levels.

Reductio ad Absurdum Let us examine what happens when we gradually reduce both the scale of the pressure-sensing surface and the duration of the sensing process. Eventually we will reach some combination of surface area and time when no molecules at all are impacting upon the sensing surface. If pressure were in any way related to the mass of the overlying atmosphere, then that mass should equal zero during the specified time. However, simple free-path considerations tell us that this is not the case. The probability of N molecules being directly overhead is just as great for that period of time as for any other similar period of time.

The question then becomes, if pressure does indeed represent the weight of the overlying atmosphere, at what magical combination of sensing area and measurement time does this miraculous transformation occur?

It boggles the mind.

REFERENCES

INTERNAL REFERENCES: These are other papers in this collection that are cited or linked during the course of the discussion.

The Nature of Atmospheric Pressures – This paper defines gas pressures in terms of kinetic gas theory and statistical mechanics.

EXTERNAL REFERENCES: These are papers by other authors that contain specific statements or bits of data that are specifically incorporated in the above discussion. Specifically, these papers treat gaseous flows from the standpoints of kinetic gas theory and statistical mechanical theory.

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