Mysterious Properties of the Air

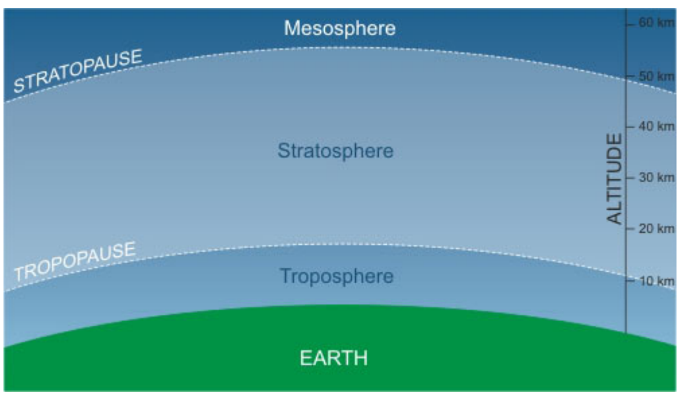
by amateur astronomer John Newell, edited by Diana Jemson

Why does what happens 'out of this world' affect what happens near the ground?

The air may yield to the swish of your hand as if it is barely there but it is substantial, weighing almost one and a quarter kilograms per cubic meter at sea level and carrying a few percent of water vapour. It wraps about the earth as a protective blanket, one hundred kilometres thick and weighing about six million billion tonnes. We fly through it and much of what we see results from its motion or from the dust, gas and vapour it contains. Do we understand its behaviour?

If you live in a city then sulphates and long chain carbon molecules add to the natural components of the air, scattering the light from streetlights, houselights, cars and billboards. When you climb to ten thousand feet the air is clear and thin and you can see ten times as many stars.

Some basic theory. The atmosphere consists of the troposphere, the stratosphere and the outer mesosphere which is surrounded out in space by the ionosphere. The troposphere is the layer closest to the earth 's surface and this is where most of our weather occurs.



In the troposphere there are planet wide circulations which form six separate latitudes of weather; stormy polar zones, temperate zones where the air is dry and warm and tropical zones where it is hot and humid.

The heat of the sun causes wet air to rise from the equator and fall again at the edge of the temperate zone where we live. This drives the circulation of all the zones, forcing the wind into eddies of high and low pressure along the boundaries. In the summer those eddies pass south of us in the southern ocean but in the winter they cross the southern half of the continent bringing cloud, rain and the occasional storm. Our weather is a consequence of these motions, water evaporated from the sea is moved onto the land.

Moist air rises because it is lighter than dry air, the molecular mass of water being much less than that of Nitrogen or Oxygen. *Avogadro* explained that equal volumes at equal pressures have equal numbers of molecules, so humid air is lighter than dry air because water molecules are lighter than nitrogen molecules. Cloud forms as the air rises because pressure falls with a rise in altitude. This cools the air and allows the moisture to condense into visible droplets (clouds).

The tropopause is the upper layer of the troposphere and occurs around 35-36,000 feet in temperate zones and at more than 50,000 feet in the tropics. This 'caps' the vertical development of thunderstorms and causes cumulonimbus clouds to display the classic

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anvil shapes when their tops reach into the tropopause and are blown along by upper level winds.

The top of this troposphere can also be seen as a surface when waves caused by turbulence form clouds which resemble waves on the surface of the ocean, moisture in the air condensing and evaporating in shifting rhythms. On a still night it can be seen as wide rings about the moon as the moisture there forms minute ice crystals.

Above the tropopause, the stratosphere exists; a cold thin uniform layer of air where there is virtually no cloud or weather and the temperature drops far below freezing. The air is less than half the density of air at ground level. Passenger jets fly at this height because there is less resistance to their motion and the air is more stable. They must of course fly at a higher velocity to maintain lift when the air is less dense.

Above eleven kilometres, the air is too thin to breathe and the sun shines all day, so bright that watching the clouds below will cause the sight to grey and the eyelids to force themselves shut. The conditions of the stratosphere continue with height, colder and clearer, the temperature dropping to minus fifty degrees centigrade. At about twenty kilometres from the earth's surface, aerodynamic flight can no longer be sustained. Here the Ozone fraction increases, absorbing the ultraviolet from the sun.

Between fifty and one hundred kilometres, the mesosphere allows ionising radiation to penetrate as the gas thins to almost nothing. The outer surface of the atmosphere is warm but not still, it is driven by the pressure changes of the weather below and by the highly variable solar wind so it has waves like an exaggerated version of the swell on a calm ocean.

These waves act as a flexing lens to distort our line of sight to the stars, disturbing the clarity of observation. To the naked eye the stars twinkle gently but through a telescope the more distant stars move and shimmer and vanish into haze.

The famous nineteenth century physicist *Ludwig Boltzmann* described the behaviour of gas molecules as being similar to that of molecules within a solid, they vibrate, but usually maintain their place within the lattice of their neighbours, changing their location only when their energy overwhelms the forces of repulsion which would keep them in place.

What then is wind? The molecules of the whole atmosphere are in motion. They have a velocity relative to each-other, rotations and vibrations about their own centre of mass and then they have shear, which is the slip between layers present in wind. The wind shear we encounter at surface levels when endeavouring to land is an extreme form of this.

Temperature causes gas molecules to move, each one moving faster than the speed of sound, but wind, even in extreme shear, moves the neighbouring planes of molecules at tiny velocities relative to each-other. The interactions of individual gas molecules are elastic, they exchange energy without loss

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so they are not responsible for the drag caused by wind.

Heat is generated by turbulence and the dislocation of an entire plane of molecules requires a change in pressure or volume at the molecular scale, which results in a temperature increase. The equations of aerodynamics describe the energy required to move through the air but do not reveal the fine detail of the flow. The formation of surface vortices causing turbulence in the boundary layer of a flow, is still a mystery.

For an object to pass through the air, energy must be continuously supplied to initiate shear, the motion of molecules relative to their neighbours. This energy is then contained in the state of the mass of the flow not in the energy of the flow itself. It will dissipate as heat when the shear diminishes in the wake of the disturbance. Evidence of this can be seen in the persistence of vortices like those visible at the wingtip on a humid day, the energy they contain is proportional to their size.

Complete mathematical solutions have not yet been found for the equations of *Navier and Stokes* which are used in aerodynamics.

There are far more questions than answers for the mysteries of the atmosphere, even its warming can be better understood by simplifying our logic. Multiply the average carbon footprint by the number of humans, then compare the result to the mass of the atmosphere, to see for yourself how its chemistry might change.

$$\text{Lift} = \tfrac{1}{2}\rho\, V^2\, C_L\, S$$

Lift is proportional to the square of the velocity multiplied by the plan area of the wings and the co-efficient of lift which depends on the wing shape. There are many factors which affect lift, some we can change like velocity and angle of attack, others we cannot. Hopefully this article gives us a little insight into how atmospheric conditions and air density impact on the flight performance of our aircraft.

Editors Note: Some additions made using *Aviation Theory Centre Basic Aeronautical Knowledge (BAK) manual* as a reference.

Atmosphere Layers image from www.skepticalscience.com