

# Air density: advantage Colorado?

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It has been known for several years among baseball experts that Coors Field in Denver, Colorado, is the hitter-friendliest ballpark in the MLB. Being the highest-altitude ballpark in the majors, the ball tends to travel the farthest, and not necessarily because gravity is weaker. A 400-foot drive at a sea-level ballpark, New York for example, translates into 420-foot hit in Denver, the “mile-high city”<sup>1</sup>.

The kinds of altitudes we’re talking about mostly affect air density. The reason why alpinists need oxygen masks when climbing tall mountains is precisely because the air is so thin. In sports, air density plays a central in slowing things down because the drag force goes like

$$f_{air} = \frac{1}{2}CA\rho v^2 \quad (1)$$

where  $C$ ,  $A$ ,  $\rho$ ,  $v$  relate, respectively, the object’s aerodynamics and cross section area, the density of air and the velocity of the object.

Dry air density  $\rho$  at sea-level is 1.2 kg per meter-cube (humid air is lighter<sup>2</sup>), but how does it change with altitude? The derivation of an accurate equation goes beyond the level of this paper, but it can be found in any standard atmospheric physics textbooks<sup>3</sup>. The relation is based on two important physics principle: the ideal gas law (Eq. 2) and the principle of hydrostatic equilibrium (Eq.3).

$$PV = nRT \Rightarrow \rho = \frac{MP}{RT} \quad (2)$$

$$dP = -\rho g dz \quad (3)$$

Eq. 2 says density increases with pressure while Eq. 3 is simply Newton’s law. Combining the two yields the formula of  $\rho$  versus elevation  $z$  (not pretty enough to be typed here, but useful for what follows).

Now we turn our attention the effect of air density on hockey. All 30 NHL teams were classified in 8 groups according to their range of altitude<sup>4</sup>. These elevations give a general idea and can vary from the actual elevation of the ice rink. The

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<sup>1</sup> A good discussion can be found in: “The Physics of Baseball”, R.K. Adair. Perennial, 3rd edition (2002)

<sup>2</sup> While water is certainly heavier than air, water molecules H<sub>2</sub>O in vapor are lighter than the most common molecules in air, namely O<sub>2</sub> and N<sub>2</sub>. Humidity “displaces” those heavier molecules and contributes to reducing the overall density.

<sup>3</sup> Useful reference: “Fundamentals of Atmospheric Physics”, M.L. Salby. Academic Press. (1996)

<sup>4</sup> The weather underground : <http://www.wunderground.com>

elevations are shown in table 1 along with a calculation of the respective air density.

**Table 1: Distribution of the elevation of all the NHL teams with their respective air density.**

	<b>Elevation group</b>	<b>Air density (kg/m<sup>3</sup>) (at average elevation group)</b>
Boston, East Rutherford (NJD), Sunrise (FLA), Tampa Bay, Vancouver, Washington	0 m (Sea level)	1.2250
Anaheim, Montreal, New York, Philadelphia, San Jose, Uniondale (NYI)	0-50 m	1.2221
Dallas, Los Angeles, Ottawa, Raleigh (CAR), St-Louis, Toronto	50-150 m	1.2162
Buffalo, Chicago, Detroit, Nashville, Saint-Paul (MIN)	150-275 m	1.2002
Atlanta, Columbus, Phoenix, Pittsburgh	275-400 m	1.1858
Edmonton	668 m	1.1483
Calgary	1048 m	1.1064
Denver (COL)	1609 m	1.0467
Mount Everest	8848 m	0.4749

As expected, air density drops at higher elevations. There is, for example, a difference of about 15% for the air density between Tampa Bay and Denver. When the Colorado Avalanche practice at home, they experience 15% less air drag than when they play in Tampa. Considering that a large fraction of energy expenditure comes from air drag, this is a significant change. Moreover, thinner air does require the body to make physiological adjustments for the lesser amount of oxygen. From that point of view, while both teams playing in Denver receive the same reduction in air drag, the Avalanche may have a slight edge in being better acclimated.

To show how air density affects the puck's motion, let's look at Eq. 1. We have plotted the drag force in Figure 1 for different elevations. This is done for a horizontal puck traveling at 100 mph. The higher the elevation, the less the air drag force acts on the puck. Again, a puck shot in Tampa Bay experiences 15% more drag than in Denver.

Not shown in the figure is the air drag force that would occur if there was a rink on top of Mount Everest (not in the NHL's expansion plan, yet). Air drag would be 0.41 N, or half of that at sea level. Playing at such impossible altitude would make the puck lose a lot less speed by the time it reaches the goalie.

Figure 1: Air drag force of a puck moving at 100 mph for different elevation

