New Explanation of Aerodynamic Lift Leads to Innovation Windfall

Introduction

For over half a century, known flaws in explanations of how air flow generates aerodynamic lift have evolved into different "schools of thought" rather than a core science; all of which are flawed in many ways. A nice summary of this dilemma was provided in the Scientific American article "No One Can Explain Why Planes Stay in the Air" (Regis, 2020).

Flawed fundamental understandings of phenomena ultimately lead to the inability to accurately extrapolate observations into new innovations. The result has been the stifling of innovation; the extent of that innovation stifling is unknown.

A new "Airfoil Science including causality" has a foundation in basic physics and has led to a windfall of innovation ranging from **solar-powered trucks** to **aircraft at 3X the efficiency of today's best airliners** to a two-year timeline to the **commercialization of hyperloop** (Suppes, Adam et al., 2024).

The goal of the science is to understand how air flow creates pressures on surfaces. Higher pressures on lower surfaces and lower pressures on upper surfaces are the primary sources of aerodynamic lift. Other applications include understanding aerodynamic drag, creating secondary air flows such as wind creating air flow up a chimney, and understanding common phenomena such as why a pipe's air flow follows the curvature of an elbow in the pipe.

The Fluid Flow Science

The way air flow follows the curvature of a wing's surface or the curve of a pipe's elbow is such a common phenomenon that it has been given a name: the Coanda Effect. However, an important distinction between a common phenomenon observation and a fundamental principle is that fundamental principles accurately extrapolate to innovative unexpected improvements.

Figure 1 summarizes the pressures that form from flow through elbows of a pipe as calculated with computational fluid dynamics, which is widely accepted as being accurate. The flow is described by three basic principles:

1. Impacting air creates higher pressures such as by the outer radii surfaces of the elbows.
2. Diverging air creates lower pressures such as by the inner radii surfaces of the elbows.
3. Air expands from higher to lower pressure at the speed of sound such as the higher pressures in pipes preceding the elbows and the way lower pressures are expressed forward of the elbow curvature.

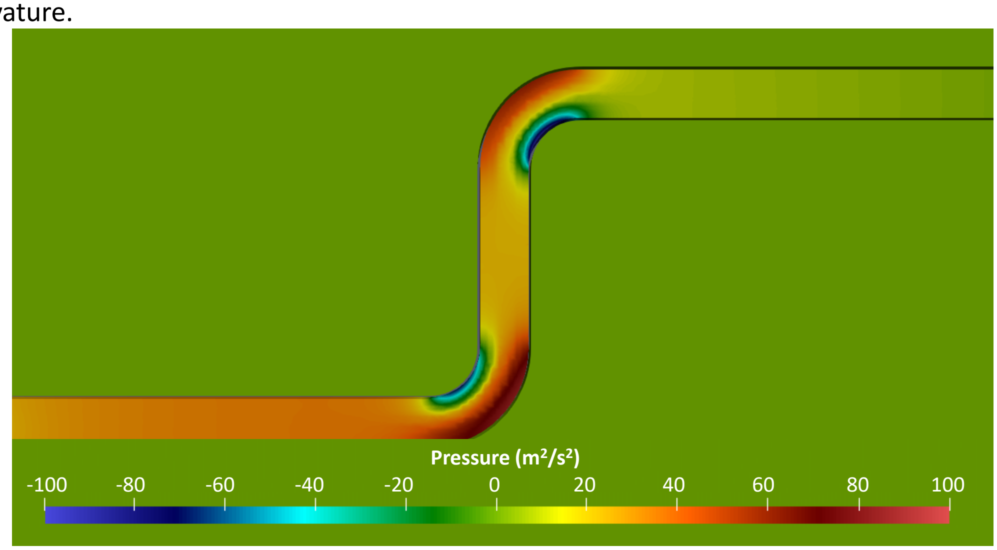


Figure 1. Pressure profile of flow around a pipe. Air flows from left to right at average speed of 10 m/s.

The pressure profiles of the airfoils of Figure 2 illustrate the same phenomena. The airfoils are flat plates with rounded leading edges. The upper airfoil has a vertically symmetric taper while the lower airfoil has a taper extending from the upper surface to a trailing edge on the lower surface. The pressure profiles are explained by the same three basic physical phenomena:

1. Impacting air creates higher pressures which are illustrated by the higher pressures at leading and trailing edges.
2. Diverging air creates lower pressures which is the case for the four (a) or three (b) blue areas.
3. Air expands from higher to lower pressure at the speed of sound which is why a change in the airfoil's trailing taper impacts the pressure throughout the airfoil.

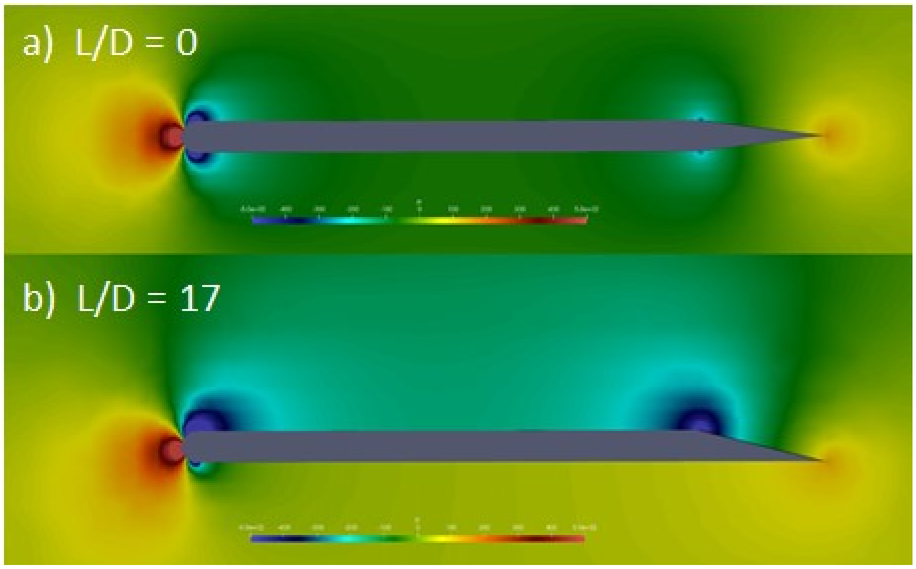


Figure 2. Illustrative example of how a change in shape at a trailing edge impacts the 2D pressure profile throughout an object due to pressure propagation at the speed of sound. Red is higher pressure and blue is lower pressure; both are pressures relative to the surroundings. Air flows from left to right at average speed of 40 m/s.

Air flow may impact with a surface, a higher-pressure field, or air flowing in a different direction (e.g., trailing-edge) to create higher pressures. It is a philosophical argument as to whether the leading-edge higher-pressure region is due to air flow impacting the leading edge or due to air flow impacting the higher-pressure field at the leading edge, similar to the anecdotal question of "Which came first, the chicken or the egg?" The answer is that temporal phenomena are at play where initial flow clearly impacted the surface, but as the pressure field formed, the flow of the air transforms into pressure before impacting the surface and develops a boundary layer.

Per the formation of lower pressures, when a surface curves away from the direction of air flow next to that surface, a void of molecules is immediately present in the flow's "shadow" (with analogy to an objects shadow to light). What starts out as a perfect vacuum is immediately filled with gas molecules expanding into that space (at the speed of sound). To a first approximation, the greater the curvature, the lower the pressure that ultimately develops. If the surface curves away too fast, turbulence can occur which leads to "boundary layer separation" and stall.

Further reading is available on how these three principles can be extended as part of the design process and how these principles differ from past philosophies.

The Coanda Effect assumes that air flow next to the surface sticks to the surface and acts as a force to cause the flow to turn. An erroneous explanation is made that pressures are generated as an equal and opposite momentum in response to the turning of the air. The Coanda Effect erroneously identifies that turning of air generates higher and lower pressures which confuses cause with effect. Principles 1-3 generate higher and lower pressures which can then accurately be interpreted as turning air.

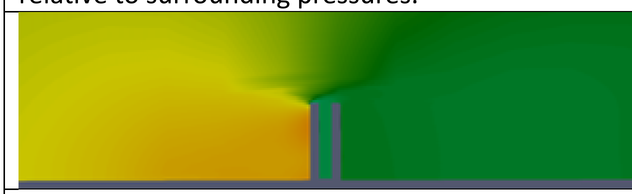
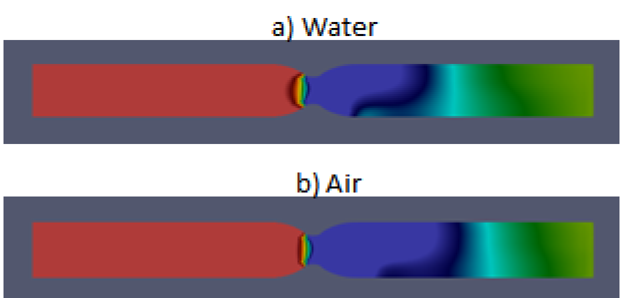
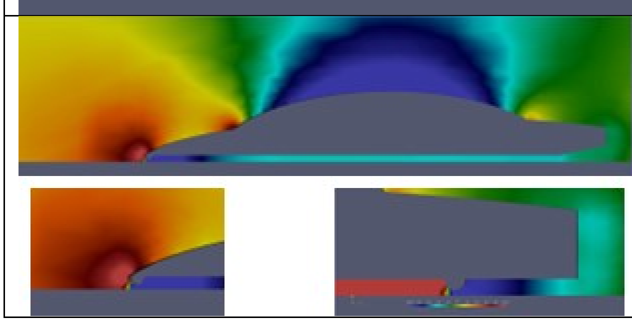
The other common explanation for aerodynamic lift is Bernoulli's Theory of Lift which attributes a geometry as causing higher velocities, erroneously assuming that air takes the same amount of time to traverse a longer upper surface than the lower surface. Then this theory taps into the Bernoulli Equation to suggest that higher velocities lead to lower pressures. As with the Coanda Effect, Bernoulli's Theory of Lift has confused cause with effect.

Most of the aerospace engineering profession has segregated into schools of thought related to one of these theories. In the absence of an accurate science, most of today's aircraft pilots have been educated in one of these erroneous schools of thought.

Fortunately, flight safety has had many safeguards between the observation that "No One Can Explain Why Planes Stay in the Air" and safe air transit. The victim and opportunity remains continued innovation.

Common Examples – Table 1 summarizes three examples of how the Three Principles explain devices in widespread use. Chimneys are often erroneously described as having upward air flow due to the Venturi Effect when they are example of diverging air flow above the duct that creates a lower pressure that pulls air up through the chimney.

Table 1. Examples of common devices with expression of the Three Principles in the pressure profiles. All pressure profiles are symmetric in scale of red (high), lime-green (zero), and blue (low) pressures relative to surrounding pressures.

	**a) Chimney** - A generation of higher pressure on the windy side of the chimney causes diverging air flow above the duct exit. Diverging air creates lower pressure suction.
	**b) Venturi Meter** – Classic explanations of the Venturi meter consist of the restriction causing higher velocity and the higher velocity creating lower pressure in the restriction. If that explanation were correct, the pressure of fluid after the restriction would be similar to the pressure before the restriction. The three principles accurately describe the pressures.
	**c) Sportscar Racecar** – Race cars use a front (lower) spoiler to create suction under the car to increase traction for steering and acceleration. The spoiler works like the upper half of the Venturi tube, not to be confused with the "Venturi Effect" which is erroneous. Moving the spoiler (bump) rearward causes higher pressures under the underbody.

The Venturi meter is a topic of course content and experiments throughout engineering and the sciences; it is so widely recognized that the observed generation of lower pressure is referred to as the Venturi Effect. While the meter consistently generates a lower pressure at the restriction, the common explanation of how higher velocities create lower pressures in the restriction is in error. Diverging air flow at the restriction is the cause of lower pressures. If the meter were substantially a tradeoff between energy stored as velocity versus pressure, the pressure before and after the restriction would be similar and there would be a steady decrease in pressure as the diameter reduced on approach to the constriction. Impacting air related to the decreasing diameter creates higher pressures which caused diverging air and lower pressures in the restriction.

When air enters at an opening to the surroundings, such as a front spoiler, the higher pressures reach the opening (at the speed of sound) and partially divert air flow from entering device. This restriction of air flow is the primary cause of lower pressures behind the restriction/spoiler which pulls down on a racecar to create improved traction. If the restriction is moved rearward on a car, higher pressures generate aerodynamic lift on the car.

Two Strategic Inventions – Figures 3 and 4 are two high-impact inventions that resulted from thought processes initiated by the Three Principles. A key concept of Principle 1 is dynamic pressure. Dynamic pressure is the amount of pressure that a fluids velocity can be converted to serve useful purposes such as generating aerodynamic lift or providing fluid flow to augment processes.

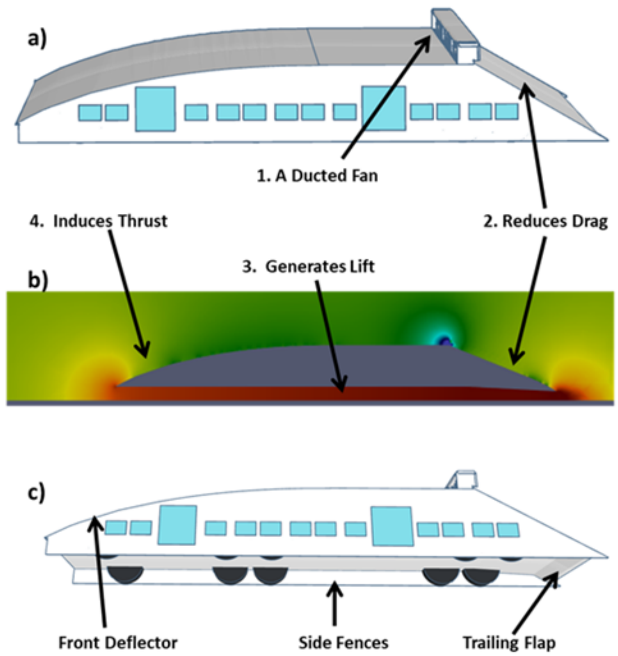


Figure 3. The ground-effect flight transit (GEFT) platform.

Figure 3 is a ground-effect flight transit (GEFT) vehicle platform. It is referred to as a platform because it can be used for railcars, trucks, cars, and even flying ships (Suppes, Adam & Suppes, 2024). To a first approximation, it is similar to a hovercraft with a lower cavity defined by fences (aka skirts) on the sides and a trailing flap. Unlike a hovercraft which has blowers to push air into the lower cavity, the dynamic pressure of oncoming air generates the GEFT's lower pressure. Three-dimensional CFD simulations confirm that optimized GEFT are more energy efficient than today's best airliners, road vehicles, and trains.

The trailing flap initiates pressure generation at the rear of the cavity, and that pressure expands forward with the side fences blocking sideways dissipation of the pressure. Clearance as high as three inches is enough to block losses to generate good lift forces at 90 mph. As a point of reference, many race cars use lower-cavity fences to block the loss of lower pressures for increased traction. Those fences typically have a clearance of 3-3.5 cm with the ground. It is anticipated that fence clearances as low as 1 cm are viable above smooth and even railway track surfaces. The fence clearance may be coupled to wheels or controlled with actuators to accommodate uneven surfaces.

Figure 4 illustrates “Bernoulli Loops” between adjacent opposite-direction tunnels at their respective entrance and exit. With air flowing in the direction of the arrows, the tubes connecting the adjacent tunnel sections convert air’s velocity from the entry section to higher pressures similar to the pipe elbows of Figure 1. At the exit tunnel section of the Bernoulli Loops, air’s velocity acts to create lower pressures. Thus, air’s flow from higher to lower pressure takes air from the entry tunnel to the exit tunnel. The extent to which pressure decreases in the main transit tunnel sections depends on the number of Bernoulli Loops and the velocity of the air flow within the tunnel sections.

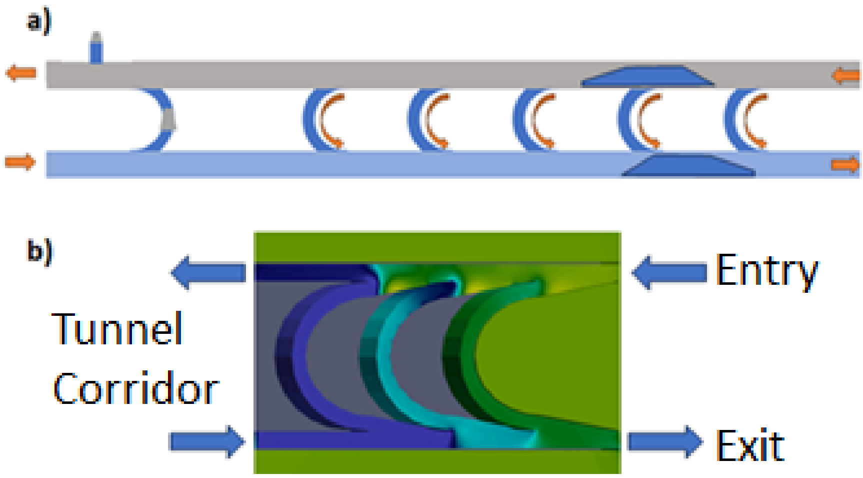


Figure 4. Bernoulli Loops for open-entry hyperloop tunnels.

The multiple advantages of the Bernoulli Loop configuration of Figure 4 include (Suppes, A. & Suppes, January, 2024; Suppes, Adam & Suppes, 2025a):

- **a)** Vehicles may freely travel to and from the low-pressure corridors, ultimately allowing seamless non-stop transit to hyperloop corridors from local rail and subway networks, eliminating the time and cost of hyperloop corridors being disconnected from exiting transit systems.
- **b)** As an incremental improvement for existing corridors, tunnel sections as short as a few miles, including existing tunnels, may be converted to hyperloop corridors in short order and infrastructure expansion may be incremental without the huge startup costs of long dedicated tunnel sections.
- **c)** A perpetual tailwind in the corridors increases efficiency and travel speeds.
- **d)** Operation at modest pressures can tap into the safety and cabin-control features used by airliners to provide passenger safety and comfort; common operating pressures for airliners are 0.2 atmospheres of pressure.
- **e)** The momentum of air flow in the tunnels creates a robustness against otherwise catastrophic leaks (i.e. a bullet hole) in tunnel sections.

Bernoulli Loop technology would allow existing tunnel sections to be converted into hyperloop corridors in a matter of months rather than years; and the technology could go directly from digital prototypes to commercial use with minimal risk due to ability to incrementally implement the extent of pressure reduction and speed limits.

Higher Levels of GEFT Innovation – An immediate inspection of GEFT identifies that flight can be attained on railways and highways without the need for new transit systems like maglev train tracks.

This is one of many advantages the Three Principles point towards in optimization.

An upper-surface ducted fan as illustrated by Figure 3 has the additional advantage of creating lower pressures on the upper surface with respective increases in lift. In addition, the ducted fan pushes air over a trailing taper where a number of benefits manifest:

- **a)** Air from the duct allows a steeper trailing taper truncates than the length needed for more-gradual tapers consistent with design of wings; this reduces vehicle costs and footprints.
- **b)** When the higher pressure in the lower cavity reaches the leading edge, it effectively pushes oncoming air more-upward over the deflector forward surface; this leads to an increase in the lower pressures on the frontal surface with induces thrust which decreases drag.
- **c)** The higher pressures of the ducted fan reduce the extent of lower pressures on the trailing taper; this decreases drag and creates a flow parallel to the surface of the trailing taper which eventually impacts with the pressure field next to the ground at the trailing edge of the lower cavity; this creates higher pressures in the lower cavity with further increases lift.

A series of additional advantages result from using aerodynamic lift to replace about 95% of the wheel suspension by eliminating 95% of the mechanical losses (National Research Council, 2018; Suppes, Adam et al., 2025). For streamlined vehicles, mechanical losses can exceed aerodynamic losses and the elimination of most of the mechanical losses results in higher efficiencies not otherwise attainable for cars, trucks, and railcars.

The efficiency is so high that direct solar power can fully replace fuel consumption at locations of high solar irradiance for cars and trucks, and solar power can systematically displace battery costs and weights. As photovoltaic cell productivity increases, this performance advantage increases.

Replacing steel wheels with tires is not viable with trains since tires have increased rolling losses which can add to a significant load when dozens of railcars connect to form a train. A disadvantage of train railcars is the heavy metal construction of the bogies which is necessary since each railcar must transfer hundreds of tons of push and pull. A highspeed train translates to four hundred tons of train traveling at 200 mph and expensive railway tracks to handle these forces. A GEFT operating as a single railcar with tires and aerodynamic navigation would be able to travel faster than the world's best high speed train on rail infrastructure unsafe for high speed train operation.

Further Levels of Innovation – Thermodynamics and fluid dynamics are engineering sciences that form the foundation of engineering disciplines such as chemical, mechanical, and aerospace engineering. However, thermodynamics has been founded in solid fundamentals for over a century, allowing more-sophisticated engineering analysis methods such a lost work analysis. In thermodynamics, best-case ideal engine performances are understood and used as reference points against which actual engines can be compared. That referencing allows the fate of lost work to be associated with design features.

The Three Principles enable a similar lost work analysis to be applied to vehicle aerodynamics. Common forms of lost work for aircraft are: a) viscous drag which rapidly dissipates to thermal energy waste, b) turbulence such as boundary layer separation above lift-generating surfaces, c) jet wash which are streams of high-velocity air flow behind an aircraft, and d) the vertical and lateral dissipation of lift pressures.

Ground-effect flight is able to achieve higher energy efficiencies than free flight because the ground blocks downward dissipation of lift pressures. Flight in tunnels can achieve even higher flight efficiencies by blocking both vertical and downward dissipation of lift pressures. Table 2, Figure 5, and Figure 6 summarize 2D simulations of GEFT in ground effect and in tunnels. Tunnels enable higher lift coefficients due to the blocking of both upward and downward lift pressure dissipation.

Parallel 3-dimensional simulations result in lower lift-drag ratios (L/D), which are a key measure of aircraft efficiency; but the efficiencies are better than today's best airliners or road vehicles. While the upper surface of the tunnel increases lift, it also interferes with air flow patterns to better-diffuse the jet wash that forms behind the vehicle. This is a work in progress where the lost work analysis identifies the problem and points toward improved designs.

TABLE 2.

SUMMARY OF 2D SIMULATIONS P-S. $C_{D,V}$ IS THE PERCENT OF TOTAL DRAG WHICH IS VISCOUS DRAG.

	S(m⁴/s²)	L/D	Cl	Cd	Cd,v
P	1, 3	28.3	2.19	0.0776	12%
Q	6.1	36.3	2.48	0.0685	12%
R	0	46.7	1.23	0.0263	16%
S	5	83.0	1.57	0.0190	35%

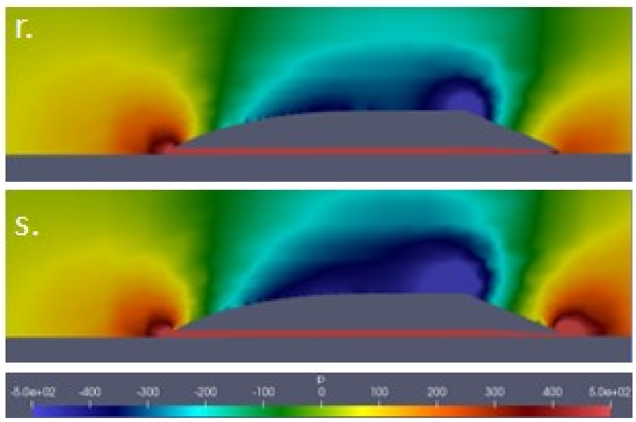


Figure 5. Pressure profiles of 2D digital prototype in ground effect outside tunnel. Pressure is in m^2/s^2.

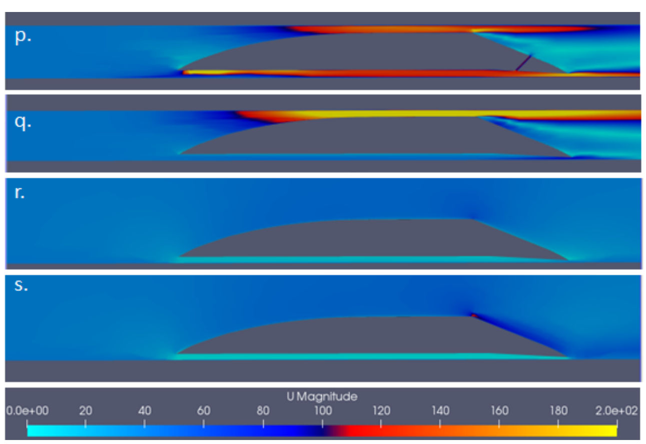


Figure 6. Velocity profiles of models p-s. Velocity is in m/s. Velocity is relative to the vehicle which is the x-coordinate with positive to the right (not the ground).

An additional benefit of more streamlined air flow due to ground effect is the ability for individual vehicles to travel in close proximity with reduced interference which can decrease lift and increase drag. It is possible for moving vehicles on a railway track to join and separate with minimal turbulence as illustrated by the velocity profile of Figure 6s where pressures are near atmospheric before and after the vehicle. This ability enables railcars to leave a station ahead of a train to take the position at the lead of the train once it is up to speed, and it allows the trailing cars of a train to slow down and stop at stations. This mode of operation allows for a scheduling method with regular-interval nonstop service between multiple stations along a single railway track which can be used for both commuter and intercity transit (Suppes, Adam & Suppes, 2025b). This approach can cut transit times and costs by 50% to 80% using existing single-track lines. Multiple tracks and the ability to leave tracks at stations provide further capabilities and performance increases.

When considering the time value of money and 50%-80% reductions in commuter and intercity times and costs, the combination of GEFT and novel scheduling technologies has a value of trillions of dollars per year. Ground effect flight can be readily extended to transit over calmer waters such as rivers, bays, and protected coastlines. The service would have lower total transit times than the best air taxi concepts and would be widely available for every-day use.

Memorizing Verus Global Understanding – When designs are founded on memorizing analogies like the Coanda Effect, Venturi Effect, and Bernoulli's Theory of Lift; a proper understanding of fundamentals is not achieved. The Three Principles are substantiated in molecular mechanics, continuum mechanics, and an accurate extrapolation toward innovation. The understanding of a subject from fundamentals to the ability to accurately extrapolate results to new applications is known as a global understanding.

As previously stated, "the extent of that innovation stifling is unknown" because many paths of innovation have not been pursued without a more fundamental understanding of the science. One path of innovation resulting from the global understanding are GEFT vehicles with the prospect to reduce transit times and costs by 50% to 80%. Another path of innovation is an improved hyperloop approach with: open access to existing rail infrastructure, use of common railway lines rather than maglev tracks, and approaches for incremental implementation that could start within a couple of years.

The dollar value of these technologies is high. The value to society is higher than the monetary value because the technologies provide renewable and lower cost alternatives to diesel trucks and jet aircraft. The technologies provide a path to substantially eliminate the use of petroleum-based fuels with significant benefits toward reducing global warming and reducing cash flow to nations relying on petroleum-based cash flow to power war machines.

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