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Aerodynamics: a different perspective with profound implications

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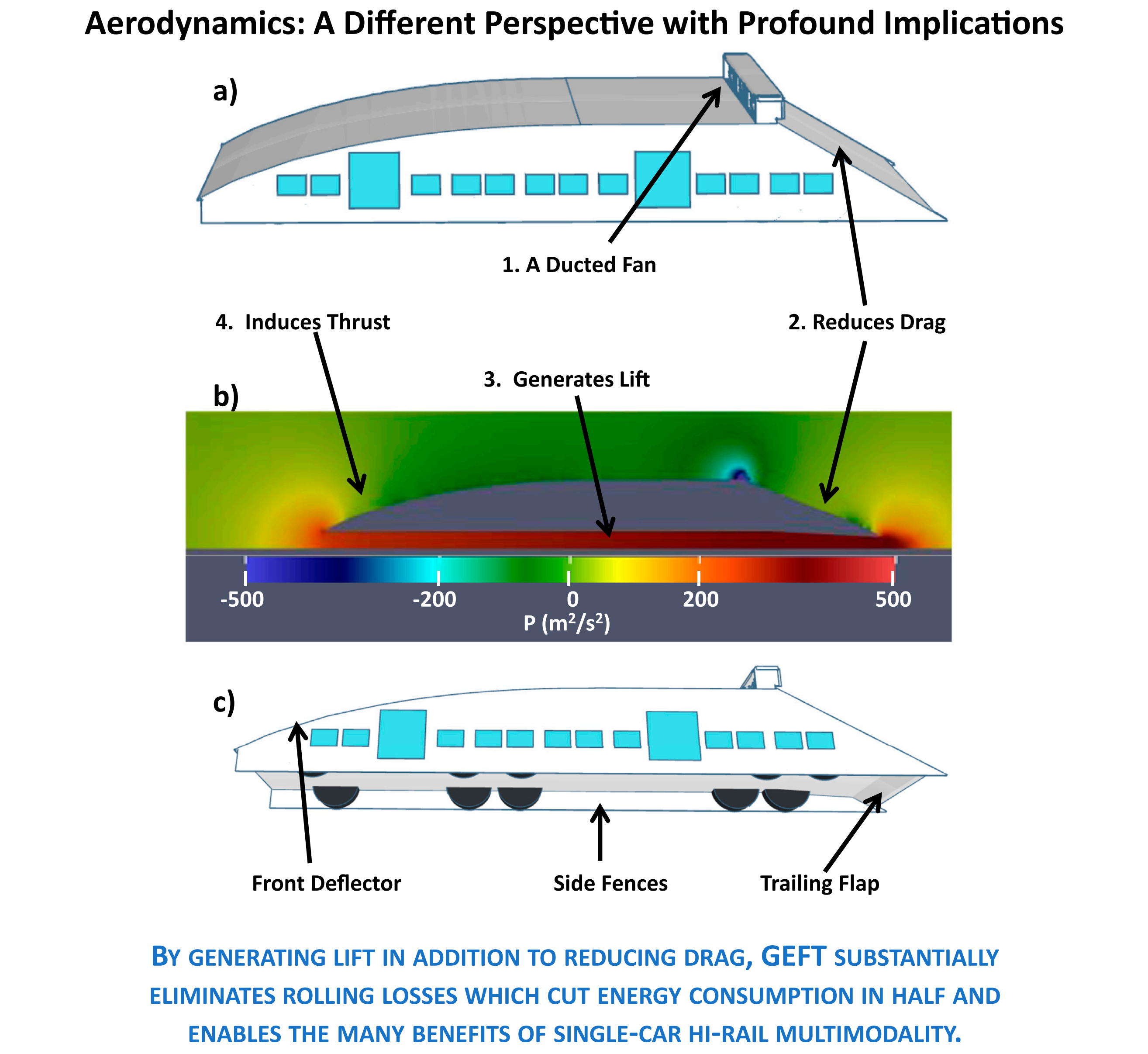
An increased rigor in the fundamental mechanisms of how air flow generates lift teaches toward a new type of ground effect aircraft referred to as ground effect flight transit (GEFT). While GEFT have lower underbody cavities similar to hovercraft, the pressure field is generated by oncoming air flow with the result of improved energy efficiency in both lift generation and drag reduction as based on computational fluid dynamics studies. The result is a new intermodal transportation with the prospect of higher speeds and efficiency than trucks and trains. The technology will utilize existing railway and highway infrastructure. The prospect includes a significant expansion of capabilities for electric vehicles with advantageous environmental impact and reduced reliance on petroleum-based fuels.

KEYWORDS
lift, theory of flight, ground effect, computational fluid dynamics, aerodynamics

Introduction

For over half a century, known flaws in explanations of how air flow generates aerodynamic lift have evolved into different "schools of thought;" all of which are flawed. A summary of this dilemma was provided in the Scientific American article "No One Can Explain Why Planes Stay in the Air" (Regis, 2020). A reliance on these explanation leads to inaccurate insights which stifles innovation *in lieu* of incremental modifications to decades-old designs. This perspective is based on a new insight applied to ground effect flight which leads to novel paths of evolution and innovation within transportation (Suppes and Suppes, 2024a). The state of the art for ground-effect flight prioritizes research on how wings interact with ground effect forces for improved efficiency (Lee and Lin, 2022). The gaps in the state of the art provide an opportunity for novelty and innovation within the field of ground effect lifting bodies.

A primary result of this work is a new ground-effect flight transit vehicle (GEFT) which reduces drag and may substantially eliminate rolling losses on vehicles capable of navigating highways, railways, and waterways at high efficiency in seamless intermodal transit. High speeds are enabled due to aerodynamic lift and navigation. Transport on current infrastructure is enabled by low aspect ratios. This perspective summarizes the GEFT design features and identifies the environmental and social advantages of this new path of technological evolution.



GRAPHICAL ABSTRACT

Schools of thought versus science

Example schools of thought on flight include the Coanda Effect, Turning Air Theory, Momentum Theory of Lift, and Bernoulli's Theory of Lift (Hurt, 1965; The Free Encyclopedia, 2023; Liu, 2021). Each of these schools of thought are correlations between changes in pressure and indicated changes in other properties, such as air's velocity. They are generally empirical correlations that allow the user to believe they understand how air flow generates aerodynamic lift.

The authors' perspective on the potential of GEFT is based on three phenomena of basic physics as presented by the computational fluid dynamic (CFD) pressure contours of Figures 1, 2 and expanded on in related research (Suppes et al., 2025a; Suppes and Suppes, 2024b; Suppes et al., 2025b). 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 contours are explained by Three Principles of basic physics:

1. Impacting air creates higher pressures which are illustrated by the higher pressures (i.e., stagnation points) at leading and trailing edges; the air flow creates pressure when impacting surfaces, regions of high pressure (e.g., leading stagnation point), and air flow at different velocity vectors (e.g., trailing stagnation point).
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.

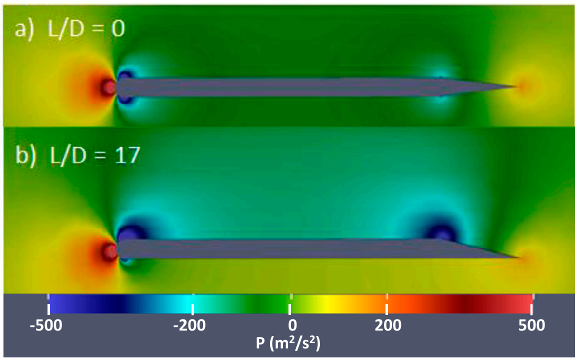


FIGURE 1
Illustrative example of how a change in shape at the trailing edge impacts the 2D pressure contour throughout an object traveling at 40 m/s due to pressure propagation at the speed of sound. **(a)** is a vertically symmetric flat plate, while **(b)** is a flat plate with an assymetric tail. Pressure is computed as kinematic pressure, the pressure divided by air's density. Red is higher pressure and blue is lower pressure; both pressures are relative to the surroundings. Air flows from left to right at an average speed of 40 m/s.

The "Three Principles" are consistent in: a) molecular mechanics, b) continuum mechanics, and c) accurate extrapolation; substantiating the perspective that they are an airfoil science (Suppes et al., 2025b). Changes in pressures propagate at the speed of sound, significantly faster than the travel speed of the vehicle. As the lift is generated through the application of pressures on the airfoil, features which create or reduce pressures at the trailing end of the airfoil still impact lift throughout the entire airfoil.

Insite leading to GEFT innovations

GEFT (see Figure 2) vehicles are the result of three innovations resulting from the insight of the Three Principles:

1. An upper surface ducted fan creates areas of lower and higher pressure to enhance lift and reduce drag respectively; this supplements surface shape as per Principles 1 and 2.
2. The ducted-fan-enhanced air flow along the trailing taper leads to a more-robust trailing edge stagnation point per Principle 1, and the higher pressures of that trailing-edge stagnation point extend under the underbody per Principle 3; fences on the sides of the lower cavity reduce lateral dissipation of the higher pressures.
3. When the higher pressures reach a lower surface edge on a front deflector, the pressure deflects oncoming air's velocity vectors upward, leading to increased divergence of air along the front surface, transforming pressure drag into induced thrust on the front surface as per Principle 2.

The pressure contours of Figures 1, 2 were generated using computational fluid dynamics (CFD) and imaged in Paraview. The computational fluid dynamics were performed with SimFlow software's incompressible SimpleFOAM solver with RANS k-ω SST turbulence modelling. The boundary conditions are set from free stream air flow of 40 m/s and in Figure 2 the ground is modelled as a moving wall boundary.

A ducted fan impacts the lift and drag of the vehicle surfaces to which it is attached; and likewise, surrounding vehicle surfaces impact the efficiency of a ducted fan (Abdolahipour, 2023; Abdolahipour, 2024). When accounting for reduced drag, a result of an effective placement of a ducted fan is beneficial drag reduction which can leverage thrust several fold (Suppes et al., 2025a). Especially when boundary layer separation occurs with onset of turbulence behind the vehicle, the ducted fan is able to preserve laminar flow with respective reduction in drag and lost work.

The extent of leverage depends on the engine power and the surface morphology. The optimal surface morphology is a function of power setting. A conclusion of these preliminary studies on this topic was that lift-to-drag ratio (L/D) efficiencies exceeding 20 were beyond any reduced thrust and lost work (Suppes and Suppes, 2023). A lost work analysis of air surrounding the vehicle was the best metric to identify if optimal conditions were achieved. Furthermore, in tunnels the vehicle's upper surface, upper fences, and the upper surface of the tunnel serve as a lift and thrust generating duct to the fan and should be optimized in this capacity.

For transit over railway tracks, the tracks augment blocking the lateral dispersion of desirable lift pressures under the vehicle. The smooth and uniform upper surface of the tracks enable the use of low clearances (e.g., 1 cm) between the fence and the track. Routine operation at low ground clearances (3–3.5 cm) by sportscar racecars provide decades of experience toward advanced vehicles designed to operate at low ground clearances (Suppes and Suppes, 2025a; Hassaan et al., 2023; Iftekhar, 2024; Roslan et al., 2023; Ma et al., 2024; Porcar Galán, 2020).

The value of aerodynamic lift on ground vehicles

The majority of the current research into utilizing ground effect focuses on the interaction of wings at moderate height, 1–5 m from the ground, and implementations for improving airplane take-off and landing or flight over water (Qu et al., 2015a; Qu et al., 2015b; Wang et al., 2023; Halloran and O'Meara, 1999). This research has identified that horizontal stabilizers have improved effectiveness in ground effect, including delta designs, and that the aerodynamic center moves rearward in ground effect, with an emphasis on data between 10- and 30-degrees angle of attack (Taleghani and Ghajar, 2024; Taleghani et al., 2020). Flight over water has a research focus on wing shape design for stability at greater clearance from the water, which has less inherent stability improvements and reduced overall improved efficiency from the higher clearance distance (Lee, 2018; Lee and Lee, 2012; Hu et al., 2022; Lee and Lee, 2013). Additional research for ground effect applications includes boundary layer choking and trailing shockwave development, particularly within tunnels for Hyperloop technologies (Deviparameswari et al., 2021; Veerasamy et al., 2021; Huang et al., 2020). Consistent advantages of ground effect studies highlight the improved lift and decreased drag.

Effective use of ground effect in these situations provides marginal improvements in efficiency due to the inherent higher clearance between the ground and lifting body rather than GEFT designs. This prevents rapid and efficient implementation of technologies that utilized ground effect augmentation of lift forces. It is the perspective of the authors that a focus on ground

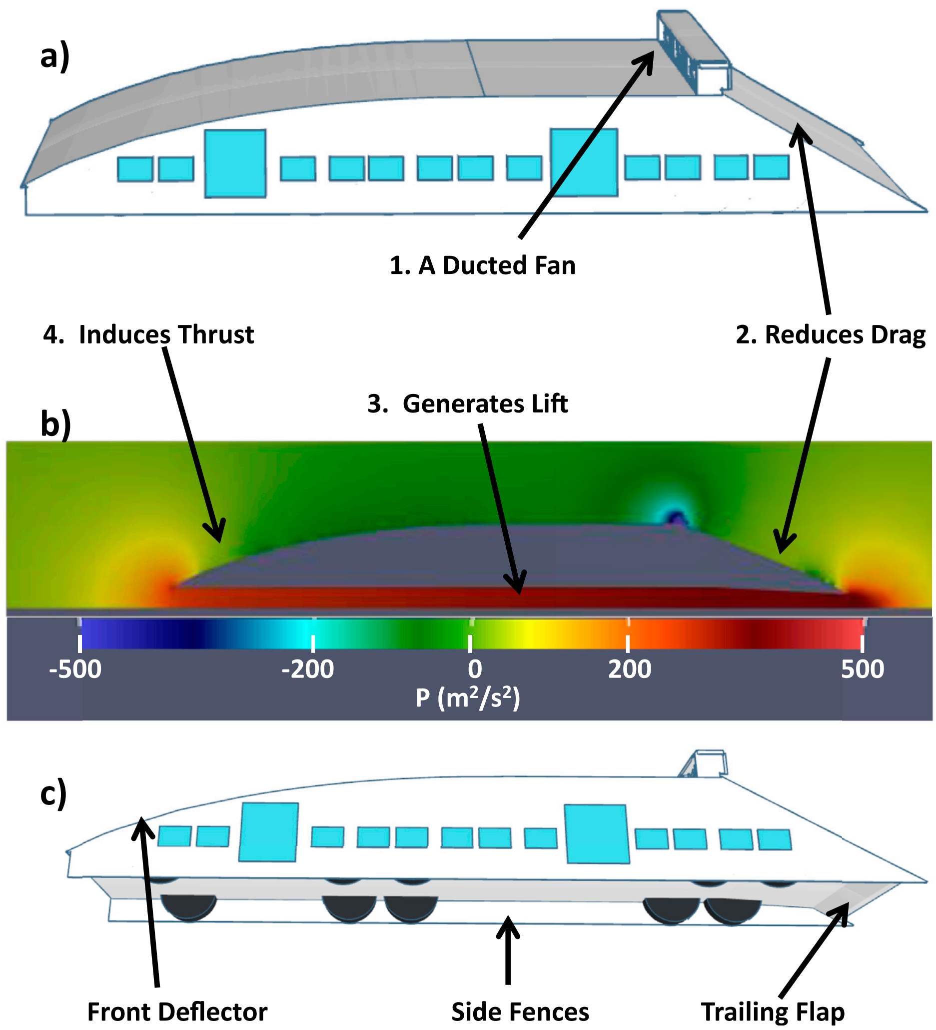


FIGURE 2
The ground-effect flight transit (GEFT) platform design. **(a)** lifting body with ducted fan. **(b)** Pressure contour of the GEFT lifting body with the scale in kinematic pressure. **(c)** Illustrative example of GEFT undercarriage highlighting wheel, fence, and trailing flap placements.

effect flight through use of cavities in conjunction with surfaces that safely support low clearances provides a more effective route to utilize the knowledge and technologies related to ground effect. The use of cavity pressure developed by oncoming air's dynamic pressure allows for control mechanisms beyond horizontal stabilizers such as a mid-chord flap within the cavity which allows for the redistribution of pressure forward or aft to enhance stability as well as actuated fences which may alleviate pressure asymmetrically within the cavity without adding drag to the vehicle's profile.

Multiple characteristics result from the GEFT design for transit over railways and highways:

1. The design enables high lift on low aspect ratio lifting body designs which allows ground-effect flight over roadways and railways.
2. Without removing wheels, yet replacing about 95% of wheel suspension with aerodynamic suspension reduces rolling losses which are often as significant as aerodynamic losses (National Research Council, 2018). Ground transport lacks low rolling loss alternatives. Alternatives like hovercraft have low rolling losses, but lack efficiency; the result of GEFT is significantly reduced energy consumption versus alternatives.
3. Substantial elimination of rolling losses enables displacing steel railcar wheels with tires; this enables quieter operation and routine railway-highway multimodality.
4. By overcoming rolling losses, single-vehicle operation is viable on railway tracks with new approaches to scheduling which can provide nonstop service to neighborhood stations as a new standard for both commuter and intercity service (Suppes and Suppes, 2025b).
5. Suspension that is primarily aerodynamic with wheels purposed as guides enables high speeds; with the perspective that the speed will eventually be faster than highspeed trains or maglev.
6. Aerodynamic navigation enables tighter corners and existing track infrastructure to be negotiated at higher speeds without expensive modification; by example, GEFT's stress on tracks would be about 400 kg versus 400 tons for a high-speed train as chassis weight will be reduced and vehicles will travel

independently. An aircraft basis in design allows for navigation and turning to be operated through control surfaces rather than rail traction, allowing for a vast reduction of weight supported by wheels.

The Figure 2 GEFT is projected to have less than half the cruising energy consumption of today's semi-trucks and have an effective upper surface for solar panels (Suppes et al., 2025a). These features enable electric trucks and substantial solar augmentation of batteries at locations of high solar irradiance.

Alternative ground effect vehicles

Most commercial activity in today's ground-effect flight sector are wing in ground ("WIG") aircraft (Blain, 2024). WIG aircraft are not able to operate on railways and highways; therefore, WIG are not able to provide the extensive multimodal connectivity possible with GEFT. WIG aircraft end up as less efficient. Also, WIG aircraft tend to have efficiencies about 25% greater than passenger aircraft in the same weight category versus GEFT which are capable of more than 100% increase in efficiency. The differences in efficiency of WIG versus GEFT are fundamental where the WIG tail sections and abundance of wing surfaces with surfaces pitches greater than 4% which leads to lower L/D efficiencies in ground effect regimes.

Ground effect machines ("GEM") is another classification of ground-effect vehicles that include hovercraft and a GEM by Smith (Anonymous, 1974). Smith's design is consistent with other findings that identify the efficiency of GEM to correlate with the ratio of ground clearance to vehicle length. The trailing taper of the Figure 2 GEFT design in combination with the ducted fan are able to overcome boundary-layer separation to decrease the length to improve efficiency. The results are reduced vehicle costs, more useful higher-ceiling cabin space, and reduced loss of cavity lift pressures when expanding from the trailing edge to the leading edge.

A critical analysis of the thought process behind the GEFT design versus the Smith GEM identifies the underlying simple explanations of aerodynamic lift that the mind uses in innovation processes (Suppes et al., 2025a; Suppes and Suppes, 2024c).

Taleghani and Torabi have identified recent developmental pathways in aerodynamics. GEFT technology uses advances in computational aerodynamics software and methods to branch design, optimization, and analysis into an additional emerging technology targeting the use of existing railway and highway infrastructure at higher efficiency and speeds (Shams Taleghani and Torabi, 2025). In view of the large sums of money spent on experimental approaches to concepts like Hyperloop, GEFT identifies the importance of computational aerodynamics to both expedite and reduce the costs of research and development. Future advances and research in GEFT technology will benefit from the incorporation of machine learning to further refine and apply the applied principles for application.

Geopolitical ramifications

China has emerged as a world leader in both highspeed trains and large infrastructure projects. For countries with older railway infrastructure, like the United States and Switzerland, the prospect of upgrading to highspeed rail is expensive and humiliating from the perspective that the final result would likely lag behind China which has become efficient at building the infrastructure and expanding the capabilities of highspeed trains.

GEFT technology has the potential to surpass highspeed rail capabilities using existing infrastructure. Non-stop service and higher speeds can cut transit times and costs in half versus highspeed train and commuter alternatives.

Intercity nonstop service between neighborhood stations is able to overcome the first-mile, last-mile, and security money value of time costs of air transit. As a result, GEFT rail service would be faster than most airliner services or proposed air taxi services.

From a carbon footprint perspective, the replacement of aviation and diesel truck fuels with green alternatives is a formidable challenge. GEFT technology provides an exception. GEFT can provide a fast track to zero-carbon footprint society and substantial reductions in petroleum fuel consumption.

The devaluation of highspeed train technology, massive infrastructure expansion, and petroleum fuel with the simultaneous low-cost upgrades of existing railway and highway infrastructure has significant geopolitical ramifications. Those ramifications advance causes towards ending wars and global warming.

Discussion

GEFT technology is disruptive at multiple levels, ranging from how aerospace engineers were taught to think about how airplanes achieve flight to major economic sectors such as petroleum fuel, air transit, and automobiles. The above perspective on capabilities challenges the standards of what has been thought of as possible.

A worldwide research interest is Hyperloop, which proposes speeds in excess of 600 mph. GEFT is compatible with transit in low-pressure tunnels at high efficiency where substantial elimination of the dissipation of lift pressures is possible in upward, downward, and lateral directions. At low pressures, engineered tailwinds in tunnels are able to increase speed and efficiency. Of even higher impact is the ability to operate low-pressure tunnel corridors with open entrances and exits providing seamless connectivity to existing rail and highway infrastructure.

Open entrances and exits to lower-pressure tunnel corridors are possible with loops which use air's dynamic pressure to pump air from tunnel exit sections to adjacent tunnel entrance sections (Suppes and Suppes, 2025c). The aerodynamics establish engineered tailwinds where static pressure is transformed to dynamic pressure resulting in both decreased tunnel pressure and tunnel tailwinds. The technology may be used to gain advantage on existing tunnel infrastructure starting with tunnel sections only a few miles long. This technology allows the incremental evolution of transit infrastructure to include transit in lower-pressure tunnels without the delays, costs, and inefficiencies of isolated tunnel systems (Shams Taleghani and Torabi, 2025).

Since GEFT can operate with up to 100% aerodynamic lift, it is possible to expand current infrastructure to be more in harmony with nature. For example, GEFT can achieve ground effect flight over rivers and bays, eliminating the need for bridges. Furthermore, lacking the heavy bogies of railcars, light-weight vehicles can operate on elevated tracks for a lower environmental footprint. Passenger-specific weights would be much less than railcars, even less than aircraft, due to low stresses on wheel suspension which would have significant weight loads only at low speeds acceleration and deceleration and do not need to be retractable.

Concluding perspective

Today, vast amounts of money are proposed for projects such as manned missions to Mars, a $20 trillion hyperloop corridor between the United States and England, and $20 billion dollar highspeed rail in the United States (Ohanian, 2025; Jones, 2016; O'Hare, 2024). For less than 1% of the cost of the least expensive of these projects, GEFT technology can be demonstrated and placed on a fast track towards world-wide implementation. The same technology would improve quality of life and place society on a fast track to zero carbon emissions due to displaced fossil fuels.

It is suggested that the primary barrier is not technology, but rather, that old paradigms trump science for today's engineers.

Future research

The GEFT design jointly optimizes the ducted fan and vehicle's surfaces toward high L/D efficiency where an upper-surface ducted fan creates a beneficial pressure contour over the entire vehicle. Toward the creation of optimal pressure contours, vehicle surfaces in front of the fan function as nacelle surfaces and surfaces aft the fan replace nozzle functions to create higher pressures. A next step is the computationally intensive optimization of additional ducted fans to reduce the lateral dissipation of pressures that occurs with 3D systems.

Applications and designs will evolve both in capabilities with several potential entry points for initial applications using existing infrastructure. An additional next step is physical prototype R&D for one or more application on highways and railways. Safety and navigation features will evolve with the prototypes; today's vehicular safety standards are the results of decades of evolution. Work performed with modern sophisticated CFD capabilities can expedite the development of both safety and navigation features.

This work represents an advance over past CFD digital prototype R&D due to a foundation in proposed "fundamentally-correct" explanations of how air flow creates pressure contours, lift, and pressure drag. The future of this and other R&D includes increasing the reliability of both digital prototypes and digital twins with physical prototypes and extrapolating designs toward innovation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AS: Methodology, Validation, Formal Analysis, Investigation, Writing – review and editing, Conceptualization, Software. GS: Validation, Investigation, Methodology, Conceptualization, Writing – original draft.

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Conflict of interest

Authors AS and GS were employed by HS-Drone, LLC.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

References

Abdolahipour, S. (2023). Effects of low and high frequency actuation on aerodynamic performance of a supercritical airfoil. *Front. Mech. Eng.* 9. doi:10.3389/fmech.2023.1290074

Abdolahipour, S. (2024). Review on flow separation control: effects of excitation frequency and momentum coefficient. *Front. Mech. Eng. Fluid Mech.* 10. doi:10.3389/fmech.2024.1380675

Anonymous (1974). Ground effect machine. Available online at: https://patents.google.com/patent/GB1347352A/en?oq=London+1347352.

Blain, L. (2024). Regent to debut its hydrofoiling ground-effect seagliders in hawai'i. Available online at: https://newatlas.com/aircraft/hawaii-seaglider/.

Deviparameswari, K., Meenakshi, S., Akshay Kumar, N., Vigneshwaran, R., Rohini Janaki, B., Vinsiya Maria, A., et al. (2021). The effects of ground clearance and boundary layer blockage factor on the aerodynamics performance of the hyperloop pod and transonic ground-effect aircraft. *AIAA Aviat. Forum*. doi:10.2514/6.2021-2586

Halloran, M., and O'Meara, S. (1999). Wing in ground effect craft review. *Aeronautical Marit. Res. Laboratory, Melb. Vic. 3001 Aust.* Available online at: https://apps.dtic.mil/sti/pdfs/ADA361836.pdf.

Hassaan, M., Dewivedi, S., and Khurshid, H. (2023). *Computational study on the diffuser of formula racing car*. Singapore: Springer Nature, 481–496. doi:10.1007/978-981-99-1894-2_41

Hu, H., Zhang, G., Li, D., Zhang, Z., Sun, T., and Zong, Z. (2022). Shape optimization of airfoil in ground effect based on free-form deformation utilizing sensitivity analysis and surrogate model of artificial neural network. *Ocean. Eng.* 257, 111514. doi:10.1016/j.oceaneng.2022.111514

Huang, W., Wu, H., Yang, Y., Yan, L., and Li, S. (2020). Recent advances in the shock wave/boundary layer interaction and its control in internal and external flows. *Acta Astronaut.* 174, 103–122. doi:10.1016/j.actaastro.2020.05.001

Hurt, H. H. J. (1965). *Aerodynamics for naval aviators*. Washington, DC: USAF.

Iftekhar, A. K. (2024). Racing through the wind: deciphering the aerodynamic impact of spoiler shape and setting angles on car performance. *Int. J. Adv. Sci. Res.* 4 (01), 1. doi:10.37547/ijasr-04-01-01

Jones, H. W. (2016). "Humans to Mars will cost about "Half a Trillion Dollars" and life support roughly two billion dollars," in 46th International Conference on Environmental Systems.

Lee, J. (2018). Computational analysis of static height stability and aerodynamics of vehicles with a fuselage, wing and tail in ground effect. *Ocean. Eng.* 168, 12–22. doi:10.1016/j.oceaneng.2018.08.051

Lee, S., and Lee, J. (2012). Optimization of three-dimensional wings in ground effect using multiobjective genetic algorithm. *J. Aircr.* 48 (5), 1633–1645. doi:10.2514/1.C031328

Lee, S., and Lee, J. (2013). Aerodynamic analysis and multi-objective optimization of wings in ground effect. *Ocean. Eng.* 68, 1–13. doi:10.1016/j.oceaneng.2013.04.018

Lee, T., and Lin, G. (2022). Review of experimental investigations of wings in ground effect at low reynolds numbers. *Front. Aerosp. Eng.* 1. doi:10.3389/fpace.2022.975158

Liu, T. (2021). Evolutionary understanding of airfoil lift. *Adv. Aerodynamics* 3 (37), 37. doi:10.1186/s42774-021-00089-4

Ma, X., Li, J., Zhao, J., and Chen, J. (2024). Aerodynamic characteristics of the race car in pitch and roll attitude. *Int. J. Numer. Methods Heat and Fluid Flow* 35, 330–357. doi:10.1108/HFF-05-2024-0375

National Research Council (2018). "*Review of aerodynamic drag reduction devices for heavy trucks and buses*,". Ottawa, ON: Government of Canada Website. Available online at: https://tc.canada.ca/en/programs/non-funding-programs/ecotechnology-vehicles-program/review-aerodynamic-drag-reduction-devices-heavy-trucks-buses.

Ohanian, L. (2025). California's bullet-train fiasco continues: $20 billion for 120 miles?. Available online at: https://www.hoover.org/research/californias-bullet-train-fiasco-continues-20-billion-120-miles (Accessed April 22, 2025).

O'Hare, M. (2024). A $20 trillion tunnel that could link New York and London in an hour? don't cancel your flight just yet. Available online at: https://www.cnn.com/2024/12/14/travel/travel-news-transatlantic-tunnel-new-york-london/index.html.

Porcar Galán, L. (2020). Study of the functioning and importance of diffusers in formula 1 cars. Available online at: https://upcommons.upc.edu/handle/2117/331430.

Qu, Q., Wang, W., Liu, P., and Agarwal, R. K. (2015b). Airfoil aerodynamics in ground effect for wide range of angles of attack. *AIAA J.* 53 (4), 1048–1061. doi:10.2514/1.J053366

Qu, Q., Zuo, P., Wang, W., Liu, P., and Agarwal, R. K. (2015a). Numerical investigation of the aerodynamics of an airfoil in mutational ground effect. *AIAA Jouranl* 53, 3144–3154. doi:10.2514/1.J054155

Regis, E. (2020). No one can explain why Planes stay in the air. *Sci. Am.* 322, 44. doi:10.1038/scientificamerican0220-44

Roslan, M. H., Hasbullah, H. H., Ramesh, T., Didane, D. H., Manshoor, B., and Kabrein, H. A. (2023). Effect of a spoiler on the aerodynamic performance of a race car on track using two different turbulence models. *J. Des. Sustain. Environ.* 5 (2), 28–37.

Shams Taleghani, A., and Torabi, F. (2025). Editorial: recent developments in aerodynamics. *Front. Mech. Eng.* 10. doi:10.3389/fmech.2024.1537383

Suppes, A., and Suppes, G. (2023). Thermodynamic analysis of distributed propulsion. *Res. Square*, 1–26. doi:10.21203/rs.3.rs-4670270/v1

Suppes, A., and Suppes, G. (2024a). *Ground effect machine system*.

Suppes, A., and Suppes, G. (2024b). "Highly-efficient Low-AR aerial vehicles in urban transit," in Proceedings of the 2024 Transportation Research Board Annual Meeting.

Suppes, A., and Suppes, G. (2025a). Extended implications of racecar ground-effect machines. *Camb. Engage Pre-Prints*. doi:10.33774/coe-2025-9xnch

Suppes, A., and Suppes, G. (2025b). GEFT scheduling to maximize value of current infrastructure and upside potential. *Camb. Open Engage [Pre-Print]*. doi:10.33774/coe-2025-x07tg

Suppes, A., and Suppes, G. (2025c). Extreme multimodality and seamless transit. *TechRxiv Prepr.* doi:10.36227/techrxiv.173932968.82108672/v1

Suppes, A., Suppes, G., and Al-Moameri, H. (2025a). Overcoming boundary-layer separation with distributed propulsion. *Sustain. Eng. Technol. Sci.* 1 (01), 71–89. doi:10.70516/7a9e2y30

Suppes, A., Suppes, G., Lubguban, A., and Al-Maomeri, H. (2025b). An airfoil science including causality. *Sustain. Eng. Technol. Sci.* 1 (2), 12–31. doi:10.70516/j215nh63

Suppes, G., and Suppes, A. (2024c). *Critical data and thinking in ground effect vehicle design*. Cambridge Open Engage: Cambridge University Press. doi:10.33774/coe-2024-76mzx

Taleghani, A. S., and Ghajar, A. (2024). Aerodynamic characteristics of a Delta wing aircraft under ground effect. *Front. Mech. Eng.* 10. doi:10.3389/fmech.2024.1355711

Taleghani, A. S., Ghajar, A., and Masdari, M. (2020). Experimental study of ground effect on horizontal tail effectiveness of a conceptual advanced jet trainer. *J. Aerosp. Eng.* 33 (4). doi:10.1061/(asce)as.1943-5525.0001140

The Free Encyclopedia (2023). Anonymous Lifting-line theory. Available online at: https://en.wikipedia.org/w/index.php?title=Lifting-line_theory&oldid=1157579627.

Veerasamy, D., Atkin, C. J., and Ponnusami, S. A. (2021). Aerofoil wake-induced transition characteristics on a flat-plate boundary layer. *J. Fluid Mech.* 920, A29. doi:10.1017/jfm.2021.452

Wang, J., Chen, R., Yu, Z., and Lu, J. (2023). Ground test and numerical investigation on aerodynamic performance of a quad tilt-rotor aircraft in ground and water effects. *Ocean. Eng.* 289 (2), 116169. doi:10.1016/j.oceaneng.2023.116169