Revolutionizing Aviation: Pressure Assisted Electromagnetic Braking System (PAEBS) for Sustainable Air Travel

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Abstract:
Air transportation is integral to modern society, facilitating global connectivity and access to remote regions. Nevertheless, challenges such as runway length requirements, landing/take-off accidents, airport congestion, and fuel inefficiencies necessitate innovative solutions. This research paper introduces the Pressure Assisted Electromagnetic Braking System (PAEBS), a self-sustained braking and accelerating system designed to address these challenges and enhance air travel safety, accessibility, and sustainability. The integration of the PAEBS is a seamless process, necessitating no significant alterations to the existing hardware of commercial aircraft, as its operation occurs beneath the runway surface. This innovation has the remarkable capacity to reduce the required runway length for aircraft landing and take-off by up to half. Traditionally, a runway extends to approximately 3000 meters, but with the implementation of PAEBS, this length can be halved to a mere 1500 meters.
Preliminary calculations indicate the potential for substantial fuel consumption reductions, ranging from 3% to 4.5% (Rowland, n.d.) [1], contingent upon the size of the airliner. The adoption of this system holds the promise of reducing worldwide commercial jet fuel consumption by a significant 9 billion litres annually (stat, n.d.) [2], which would result in substantial cost savings for airliners, estimated at approximately $4.2 billion per year.

Keywords: PAEBS, ILS

Pressure Assisted Electromagnetic Braking System (PAEBS): This innovative model, as presented in this paper, offers a pragmatic alternative for aircraft braking and acceleration.

Instrument Landing System (ILS): ILS, an existing technology, plays a crucial role in aligning aircraft with runways during the landing phase.

NOTE: Full forms wherever possible have been used instead of the abbreviations.

Introduction:

Challenge 1: The Need for Expansive Runways

Traditionally, the operation of aircraft has demanded extensive, featureless runways for safe take-off and landing. These runways, often measuring thousands of meters in length, occupy significant

tracts of land. This requirement poses a substantial hurdle, particularly in regions with limited available land for airport expansion.
In the Maldives, an archipelago of islands in the Indian Ocean, the construction of lengthy runways on narrow islands has been environmentally destructive and financially burdensome. The project often involves land reclamation and ecosystem disruption.

Challenge 2: Airport Congestion and Traffic

Airports, especially major international hubs, grapple with congestion and heavy traffic daily. This not only causes frustrating delays for passengers but also results in significant fuel wastage as planes circle, wait on taxiways, or remain on the tarmac for extended periods.
Heathrow Airport in London frequently experiences congestion, leading to delayed departures and increased fuel consumption. Inefficiencies like these have ripple effects throughout the aviation industry.

Challenge 3: Landing and take-off Accidents

Aviation incidents related to runway issues, such as failed take-offs or planes overshooting runways due to factors like human error, inadequate braking systems, short runway length, or skidding, have been documented worldwide. These accidents can lead to catastrophic consequences in terms of human lives and property damage.
The 2005 incident at the Chicago Midway International Airport, where a plane skidded off a snowy runway and into a city street, highlights the dangers of runway-related accidents (cbs news, n.d.) [3].

Challenge 4: Environmental Impact

The environmental impact of air travel extends beyond emissions during flight. Aircraft emissions, primarily carbon dioxide (CO2), contribute significantly to greenhouse gas levels. The aviation industry is responsible for over 1 billion tons of CO2 emissions annually, ranking it as one of the top emitters worldwide.
“If aviation were a country, it would be the world’s sixth-biggest emitter, falling after China, the US, India, Russia, and Japan .” (Klöwer) [4].
By tackling the need for extensive runways, mitigating airport congestion, preventing landing accidents, and reducing aircraft emissions, the project's comprehensive approach offers a promising solution to the contemporary challenges facing the aviation industry.

Proposed Solution: The Pressure Assisted Electromagnetic Braking System

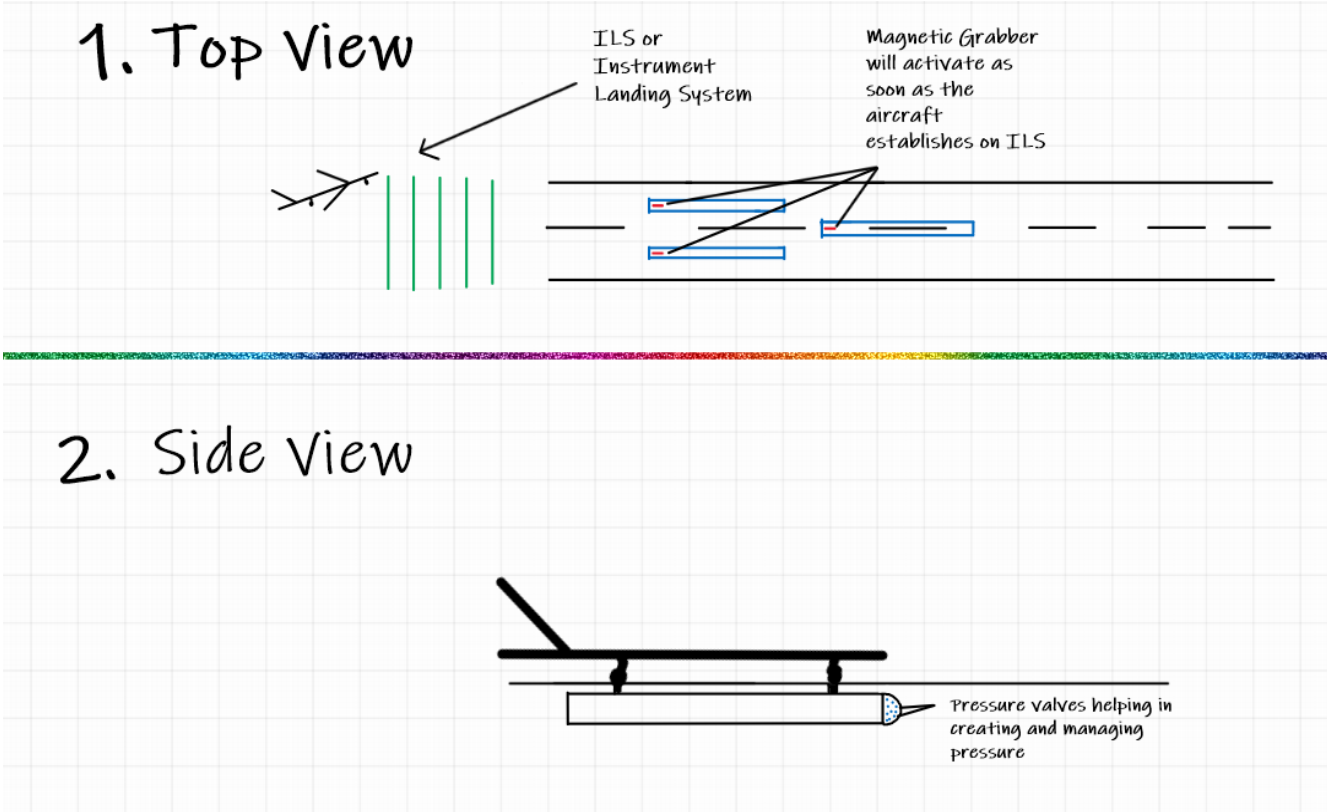

Fig. 1 First look at the Pressure Assisted Electromagnetic Braking System

The Pressure Assisted Electromagnetic Braking System (PAEBS) embodies a pragmatic approach to augment aircraft braking and acceleration, seamlessly assimilating with runway infrastructure. By addressing both acceleration and deceleration, it guarantees the adequacy of a single runway for both take-off and landing operations.

PAEBS introduces a series of up to six electromagnetic grabbers, strategically arranged in rows within specially designed indented channels along the runway's surface. These channels are crafted from conductive materials, ensuring a consistent flow of electricity and preserving the essential magnetic properties for optimal functionality.

Each electromagnetic grabber is connected to a sturdy metallic block, which in turn links to a cylindrical piston positioned beneath the runway. This piston is encased within a generously sized, pressurized cylinder that spans the entire length of the runway. Within this cylinder resides helium gas, and its pressure can be finely tuned using precision valves located at the cylinder's head, adapting to the unique requirements of each aircraft.

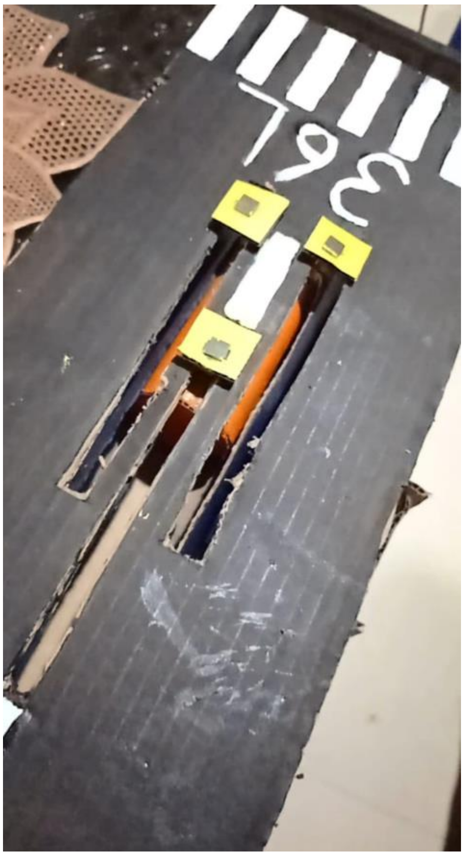

Fig. 2 *Fig. 3*

Fig. 2 & 3 Electromagnetic Grabbers (yellow) are attached to the piston inside the pressure cylinder.

The electromagnetic grabbers serve a dual purpose, exhibiting an ingenious design. They feature an additional electromagnetic coil designed to capture and harness the energy dissipated during braking. As the aircraft's landing gear gracefully moves over them, these coils efficiently generate electric currents through electromagnetic induction, capturing the kinetic energy of the landing aircraft. This generated electricity can be routed to the airport's power grid or used locally, ensuring that no energy goes to waste.

The electromagnetic grabbers come with meticulously designed precision motors and advanced ultrasound sensors, ensuring a flawless alignment with the aircraft's wheels during both landing and take-off procedure. Additionally, the only alteration made to the aircraft itself involves the installation of electromagnets within the landing gear, leaving the aircraft's original design unaffected.

Retaining the original tires on the landing gear serves as a fail-safe mechanism during strong crosswinds. They provide stability until the electromagnetic grabbers catch up with the aircraft and facilitate a timely stop.

This design and integration have culminated in the PAEBS. The entire system is connected to a direct current (DC) circuit, delivering a stable voltage, with the wiring discreetly concealed beneath the runway's surface.


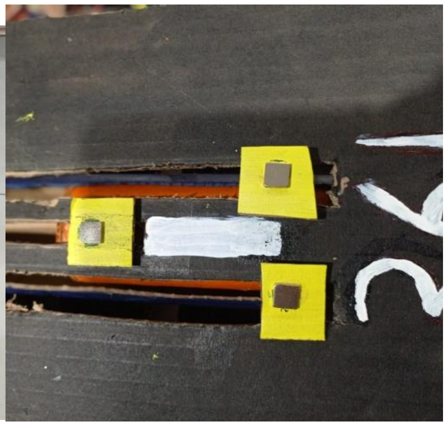

Fig. 4 *Fig.5*

Fig. 4 & 5 Showcasing the prototype pressurized cylinder(blue) that envelops the piston(orange). Notice the EM grabbers extending outward from its surface. To uphold the necessary pressure, the prototype cylinder features a system of flaps that effectively seal the gaps along its surface.

Mechanism:

The Pressure Assisted Electromagnetic Braking System (PAEBS) operates automatically as an aircraft approaches the runway, showcasing its intricate coordination with Air Traffic Control (ATC) to ensure safe landings and robust takeoffs.

PAEBS comes into action as the aircraft nears the runway, collecting vital data from multiple sources, including ATC. This data, encompassing crucial parameters like aircraft weight, landing or takeoff velocity, and wheel positions, wind speed and even weather conditions forms the basis for precise alignment with the runway, facilitated by the Instrument Landing System (ILS), which is still commonly employed in aircraft landings and takeoffs.

Once the pilot aligns the aircraft with the ILS trajectory, a pivotal aspect of the system activates. Subsequently, the aircraft engages with strategically positioned electromagnetic grabbers on the runway, establishing a secure connection with the landing gear. This connection ensures a steadfast grip on the aircraft's wheels, effectively preventing any slippage or skidding during both landing and takeoff phases. Notably, PAEBS can achieve maximum safe acceleration within the range of 10-15 m/s^2.

A central component of PAEBS is the pressurized chamber, linked to these grabbers. The chamber's pressure dynamically adjusts based on real-time ATC data. This adaptive pressure control plays a crucial role in assisting the aircraft's deceleration during landings and acceleration during takeoffs. It enables the system to apply precisely the right amount of force through the electromagnetic grabbers, facilitating either smooth landing or swift takeoff.

What distinguishes PAEBS is its ability to synchronize the movement of the piston in the pressurized chamber with the electromagnetic grabbers, ensuring a seamless operation. As the grabbers maintain a secure hold on the wheels, the pressurized helium inside the chamber collaborates with them, generating the requisite force to gradually decelerate or accelerate the aircraft. This synchronized action minimizes the risk of wheel slippage or overshooting the runway, even in adverse weather conditions, substantially enhancing both safety and operational efficiency.

Calculating Force, Energy Dissipation, Current Supplied to PAEBS, and Cylinder Pressure in a Dynamic Manner:

```
val = {'A380': 386000, 'B747': 320000, 'A320': 64500, 'A350': 207000, 'B787': 172000, 'B737': 40687}

def ComputeForce(m, u, s, is_takeoff=False):
    if m in val:
        m = val.get(m)
    else:
        m = int(m)

    u = int(u)
    s = int(s)

    # Calculate stopping force
    if is_takeoff:
        Force = (m * (u**2)) / (2 * s)  # Takeoff force
    else:
        Force = (m * (u**2)) / (2 * s)  # Landing force

    # Calculate energy loss due to braking (assuming 20% energy loss)
    EnergyLoss = 0.2 * Force * s

    # Calculate current required (assuming 90% efficiency)
    Efficiency = 0.9  # 90% efficiency
    Current = EnergyLoss / (Efficiency * 12)  # Assuming 12V electrical system

    # Calculate required pressure of air (assuming ideal gas law and constant temperature)
    Pressure = (Current * 12) / (0.0821 * 300)  # Assuming constant temperature of 300K

    return Force, EnergyLoss, Current, Pressure

operation = input('Enter operation (landing or takeoff): ').lower()
m = input('Enter mass [Kg]: ')
u = input('Enter velocity [m/s]: ')
s = input('Enter length of runway [m]: ')

if operation == 'takeoff':
    Force, EnergyLoss, Current, Pressure = ComputeForce(m, u, s, is_takeoff=True)
    print('The takeoff force required is', Force, 'newtons.')
else:
    Force, EnergyLoss, Current, Pressure = ComputeForce(m, u, s)
    print('The landing force required is', Force, 'newtons.')

print('The energy loss due to braking is', EnergyLoss, 'Joules.')
print('The current required to produce braking force is', Current, 'Amps.')
print('The required pressure of air is', Pressure, 'Pascals.')
```

Fig. 5

1. **Dictionary for Aircraft Masses (val)**:
   - This dictionary (**val**) holds the masses (in kilograms) of various aircraft models as key-value pairs. It's used to look up the mass of an aircraft based on its model name.

2. **ComputeForce Function**:
   - This function calculates several parameters related to the forces involved in landing or takeoff, including braking forces. It takes four arguments:
     - **m**: Mass of the aircraft (can be either a numeric value or a known model name from the **val** dictionary).
     - **u**: Velocity of the aircraft (in meters per second).
     - **s**: Length of the runway (in meters).

- **is_takeoff**: An optional boolean parameter (default is **False**) that indicates whether the calculation is for takeoff (if **True**) or landing (if **False**).

Inside the function, it performs the following calculations:

- Calculates the stopping (braking) force for landing or takeoff, depending on the **is_takeoff** parameter.
- Computes the energy loss due to braking, assuming a 20% energy loss.
- Determines the current required for braking force, assuming a 90% efficiency and a 12V electrical system.
- Calculates the required pressure of air, assuming the ideal gas law and a constant temperature of 300K.

3. **User Input**:
- The code prompts the user for the following input:
  - Operation ("landing" or "takeoff"): The user specifies whether they want to calculate landing forces or takeoff forces.
  - Mass of the aircraft (in kilograms).
  - Velocity of the aircraft (in meters per second).
  - Length of the runway (in meters).

4. **Calculation and Output**:
- Depending on the specified operation (landing or takeoff), the code calls the **ComputeForce** function with the appropriate parameters.
- It then prints out the calculated forces and related parameters, such as landing force (for landing) or takeoff force (for takeoff), energy loss, current required, and the required pressure of air.

5. **Usage**:
- The code provides a versatile tool for estimating the forces involved in aircraft landing and takeoff, which can be useful for aviation engineers, researchers, or anyone interested in aviation physics.

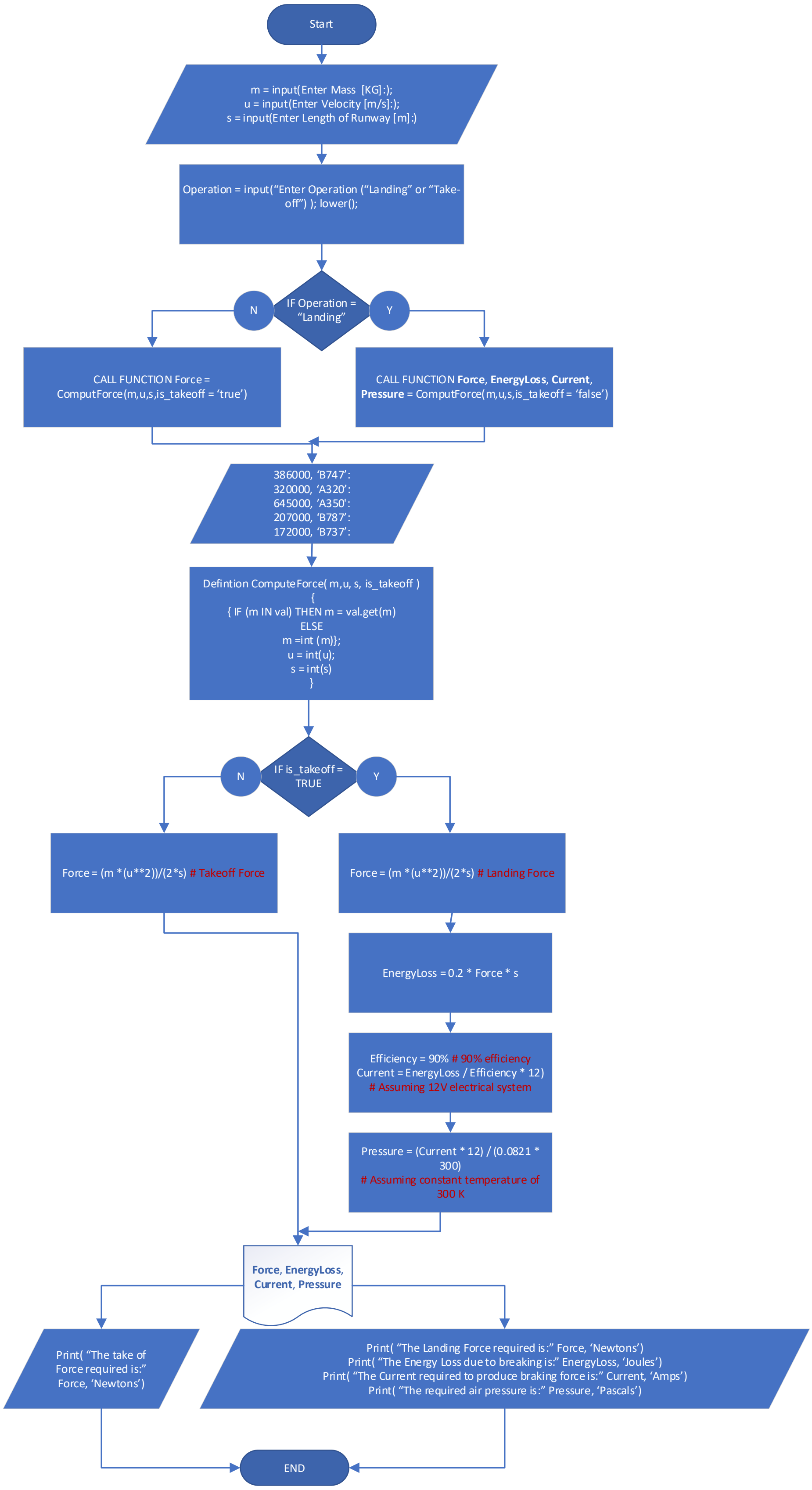

Fig. 6

Fig. 5 & 6 The provided Python code calculates the stopping force required for an aircraft based on its mass (m), velocity (u), and the length of the runway (s). It first retrieves the mass from a predefined *dictionary if it matches a known aircraft type; otherwise, it accepts it as input. The code then calculates the stopping force using the formula (mass * velocity^2) / (2 * length of runway).*

To modify the code for the Pressure Assisted Electromagnetic Braking System to calculate air pressure, energy loss due to braking, and current required for braking force, substantial changes need to be made. This would involve incorporating additional physical parameters, equations, and logic related to the PAEBS system's operation, energy capture, and braking mechanism. The modified code would be considerably more complex than the original code provided.

A Leap Toward Sustainable Aviation:

The proposed model offers several avenues for promoting sustainability within the aviation industry.
Here's an overview of how it contributes to a more sustainable future:

1. j the burden on aircraft engines, this model effectively reduces fuel consumption during the landing and the take- off phase. Typically, when aircraft engines transition from idle to 75% of maximum thrust during touchdown, fuel consumption surges. This innovation can lead to an approximate 90% reduction in fuel consumption during landing, equating to a 4.5% overall decrease in total fuel consumption (Rowland, n.d.) [1] . To put this into perspective, for a Boeing 747 with a fuel tank capacity of 240,000 litres (Boeing 747.com, n.d.) [5], this translates to savings of approximately 12,000 litres of fuel, amounting to USD 19,200 in cost savings (at a rate of USD 1.6 per gallon, as per iata.org).
2. Environmental Impact Reduction: Overcrowded airports often result in extended waiting times for aircraft, contributing to increased greenhouse gas emissions. By implementing this model and reducing congestion, air travel efficiency improves, resulting in fewer delays and less time spent with engines idling on the ground. This reduction in aircraft idle time not only lowers emissions but also helps minimize the overall environmental impact of air transportation. For instance, a 5% reduction in fuel consumption per aircraft, resulting in savings of 9 billion litres of fuel annually, could make a substantial contribution to slowing global warming and extending the lifespan of finite fossil fuel resources.
3. Land Conservation: The model's capacity to reduce traditional runway length requirements, from the typical 3000 meters to a mere 1500 meters, offers a remarkable opportunity for air travel in rugged landscapes or areas with limited flat land availability. Instead of necessitating extensive flat land for lengthy runways, airports can now be designed with shorter runways, considerably reducing the need for large-scale land development. This focus on land conservation aligns closely with sustainable practices by minimizing the ecological footprint of airport infrastructure. As a rough estimate, this reduction in runway length could lead to a 16% to 33% decrease in the land area required for major international airports (Britannica, n.d.)[6].
4. Cost Savings: The model's ability to provide ample braking force translates to efficient deceleration and stopping of aircraft, resulting in lower maintenance costs for brake systems and reduced wear and tear on runway surfaces. By optimizing braking mechanisms, airlines can anticipate significant cost savings through reduced maintenance requirements and extended component lifespans. In essence, airlines stand to save approximately USD 4.2 billion per year on fuel expenditures, in addition to saving approximately USD 170 million on the transportation costs associated with this fuel (Forbes, n.d.) [7].

5. Enhanced Accessibility: By reducing runway length requirements, the model facilitates improved access to remote areas that may have limited space for conventional long runways. These areas include isolated islands in the Pacific and Indian Oceans, mountainous regions like the Himalayas and Andes, Arctic and polar regions, desert areas, northern and remote Canada, African savannas, the Amazon rainforest, remote mining and resource sites, and indigenous communities. This increased accessibility fosters economic development and connectivity, empowering regions that were previously challenging to reach to benefit from air travel. Additionally, heightened efficiency stemming from reduced congestion and shorter runway lengths results in more streamlined air transportation operations, benefiting both passengers and airlines.

Conclusion: A Sustainable Flight Path Ahead

In the Pressure Assisted Electromagnetic Braking System (PAEBS), we see the promise of transforming aviation into a more sustainable and efficient industry. By addressing runway length challenges, reducing congestion, enhancing safety, and curbing emissions, the PAEBS charts a course toward a greener and more accessible future for air travel. As we embrace this innovation, we take a significant step closer to a world where aviation is not only faster but also kinder to our planet and more inclusive for all. The runway to sustainable aviation is open, and with the PAEBS, we are on a clear and promising flight path forward.

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