

A Research on Electromagnetic Aircraft Launch

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Abstract—The design and development of an Electromagnetic Aircraft Launch System (EMALS), a cutting-edge and effective substitute for conventional steam catapult systems, is presented in this study. During launch, conventional steam catapults put a lot of mechanical strain on aircraft and are heavy and energy-intensive. EMALS, on the other hand, uses linear electromagnetic propulsion to provide more energy-efficient, smooth, and precisely controlled acceleration. Neodymium magnets, aluminium structural frames, ABS holders, and Li-Po batteries are used in the study's mathematical modelling, simulation analysis, and prototype construction. Both manned aircraft and unmanned aerial vehicle (UAV) applications can benefit from the proposed system's increased operational flexibility, reduced maintenance needs, and improved efficiency. All things considered; this work advances next-generation aeroplane launch technologies.

Index Terms—Electromagnetic Aircraft Launch, EMALS, Linear Motor, Simulations, Energy Storage, Prototype.

I. INTRODUCTION

Aircraft carriers play a crucial role in modern naval operations, enabling rapid deployment of aircraft for defence, surveillance, and combat missions. Traditionally, aircraft have been launched using steam catapults, which rely on pressurized steam to accelerate aircraft to take-off speeds. While effective, steam catapults are bulky, energy-inefficient, require extensive maintenance, and impose high mechanical

stress on aircraft structures. These drawbacks have led to the exploration of advanced launch technologies that are more efficient, reliable, and adaptable to a wide variety of aircraft.

A potential remedy for the drawbacks of traditional aeroplane launch methods is the Electromagnetic aeroplane Launch System (EMALS). By creating a travelling magnetic field that accelerates a shuttle attached to the aircraft, EMALS generates thrust using the linear electromagnetic propulsion method. This method greatly lessens structural stress on the airframe and increases overall energy efficiency by enabling smoother and more accurately regulated acceleration. EMALS can effectively launch both large combat aircraft and lightweight unmanned aerial vehicles (UAVs) because to its modular architecture, reduced deck space requirements, and increased flexibility.

Its considerable potential as a cutting-edge aircraft launch system has been shown by research studies and practical applications, such as the deployment of EMALS on the USS Gerald R. Ford. Energy optimisation, coil heating, and the creation of affordable designs for smaller-scale systems are some of the issues that still need to be resolved. In order to assess its performance, verify theoretical predictions, and explore its adaptability for future defence platforms and UAV launch applications, this research focusses on the design, simulation, and prototype construction of an EMALS model.

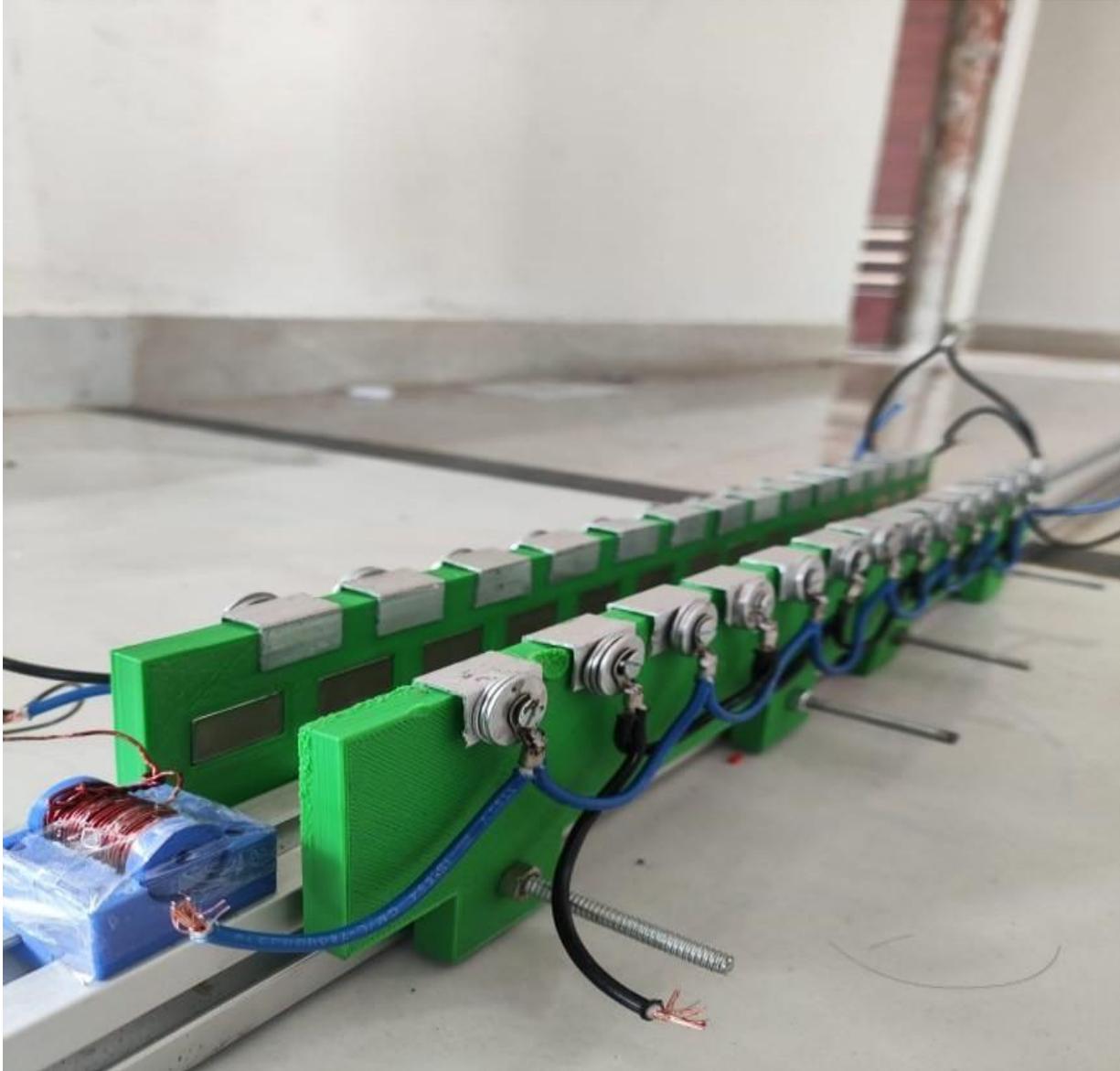


FIGURE.NO.01 ELECTROMAGNETIC AIRCRAFT LAUNCH

OBJECTIVES

1. To study the concept of electromagnetic force application in aircraft launching systems and its advantages over traditional steam catapults.
2. To design and develop a small-scale model of an Electromagnetic Aircraft Launch System (EMALS) using linear induction principles.
3. To analyze the performance of EMALS in terms of acceleration, force generation, and power consumption.
4. To compare the efficiency, maintenance, and control characteristics of EMALS with conventional steam-based systems.
5. To demonstrate the working of an electromagnetic launch system capable of propelling a model aircraft to take-off speed.

II. REVIEW OF LITERATURE / RELATED WORK

Sr. No.	Hybrid Robot / System	Key Features / Contribution	Reference
1.	Electromagnetic Aircraft Launch System (EMALS)	Feasibility study for India's INS Vishal; notes steam limits with modern aircraft weights.	A BRIEF REVIEW ON ELECTROMAGNETIC AIRCRAFT LAUNCH SYSTEM (2-382-150408975258-67.pdf)
2.	EMALS (U.S. Navy Design)	High controllability, reliability, and efficiency; reduces airframe stress vs. steam; enabled by pulsed power advances.	Electromagnetic Aircraft Launch System - EMALS (Catapult (3).pdf)
3.	Coil-Gun EML Structures	Review of EML types (Rail/Coil-Gun); finds multi-pole fields and air-cored systems increase velocity/force.	ELECTROMAGNETIC LAUNCHER: Review of Various Structures (electromagnetic-launcher-review-of-various-structures-IJERTV9IS090223.pdf)
4.	Permanent-Magnet EMALS	Design/simulation of a Permanent-Magnet concept to reduce losses and improve efficiency in "all-electric ship" context.	Design and Simulation of a Permanent-Magnet Electromagnetic Air cr (1).pdf
5.	EMALS Design Simulation	Uses Virtual Test Bed (VTB) for simulation-based optimization across total mass, volume, and thermal management.	Design_and_simulation_of_an_electromagnetic_aircraft.pdf
6.	EMALS Technology Overview	Provides a comprehensive analysis of EMALS components (LIM, Energy Storage) as a more efficient and reliable replacement for steam.	ELECTROMAGNETIC AIRCRAFT LAUNCHING SYSTEM (fin_irjmets1684748835.pdf)
7.	EMALS (General)	Discusses EMALS feasibility; notes the trade-off of high power with the potential for Electromagnetic Interference (EMI).	ELECTROMAGNETIC AIRCRAFT LAUNCHING SYSTEM (EMALS) (JETIR2405515.pdf)

LITERATURE GAP

Although many studies have explored electromagnetic aircraft launching systems, some key gaps remain:

- Most research is simulation-based, with limited small-scale experimental validation.
- Power supply and energy storage designs are still costly and complex.
- Thermal and electromagnetic interference (EMI) issues are not well addressed.
- Integration of EMALS with Indian naval platforms is still underexplored.
- Comparative cost, efficiency, and control system studies are limited.

III. EMALS VS. STEAM CATAPULT

Steam catapults, although proven, depend on large quantities of pressurized steam. A single launch typically uses high steam and requires complex mechanical, pneumatic, and hydraulic systems.

EMALS, on the other hand, completely eliminates the need for steam, making it ideal for modern ships powered by electric, gas-turbine, or nuclear systems.

LIMITATIONS:

- EMALS requires a large amount of electrical energy, equivalent to the power consumed by a small Indian town in the same duration.
- For this reason, it cannot be installed on existing carriers like the Nimitz-class ships. Instead, new Ford-class carriers are designed with advanced energy storage subsystems that draw power from the ship's generator, store it in high-speed rotors, and release it during launch (within 2–3 seconds).
- Additionally, high electromagnetic radiation can cause electromagnetic interference (EMI), which must be controlled using proper shielding and EMC measures.

IV. METHODOLOGY

Developing the Electromagnetic Aircraft Launch System involves several steps:

1. DESIGN:

A 3D model of the EMALS is created using Computer-Aided Design (CAD) software. This includes components such as linear induction motors, electromagnets, power modules, and control circuits.

2. CONSTRUCTION AND TESTING:

The designed components are fabricated and assembled according to specifications. Testing is conducted using simulated aircraft models to ensure performance matches the design parameters. System output and energy efficiency are recorded and compared to verify reliability.

3. FORCE CALCULATION:

The required launch force is calculated using the equation $F = m \times a$.

Following this process ensures that the EMALS achieves high precision, reliability, and reduced operational costs compared to conventional systems.

V. EMALS SYSTEM COMPONENTS

1. **Power Supply:** Provides electrical energy needed to generate the magnetic field. It uses large capacitors capable of delivering high current in a short burst during launch.
2. **Energy Storage:** Stores the electrical energy produced by the power supply. Common types: Li-Po batteries.
3. **Copper Coils (Linear Motor):** Arranged along the launch track, these coils create a moving magnetic field that interacts with magnets attached to the aircraft, propelling it forward.
4. **Support Structure / Rail Frame:** Mechanical framework (often aluminium) that supports the coils, sensors, and shuttle track.

COMPONENTS

Component	Specifications / Details	Purpose / Function
Battery (Energy Source)	Li-Po Battery, 14.8V, 2200 mAh, 40C discharge rate	Stores and supplies high-current power for launching operations.
Support Frame / Rail Structure	Aluminium extrusion frame (30×30 mm)	Provides mechanical support for the track, coils, and shuttle.
Magnets / Coils	Neodymium (NdFeB) magnets, copper wire windings	Produce strong magnetic fields for thrust generation.
Shuttle / Launch Carriage	Aluminium or ABS body connected to aircraft hook	Transfers electromagnetic thrust to the aircraft and releases it after take-off.
Linear Motor (Launcher Track)	Rectangular electromagnets or copper coils arranged linearly	Converts electrical energy into linear motion (Lorentz force) to accelerate the shuttle.
3D-Printed Parts (ABS)	Magnet holders and coil supports	Secure magnets and components, maintain correct alignment, and reduce weight.



FIG. ALUMINIUM EXTRUSION PROFILE



FIG. LITHIUM POLYMER BATTERY



FIG. 3D-PRINTED PARTS (ABS)



FIG. BLOCK MAGNET



FIG. HIGH QUALITY ULTRA FLEXIBLE WIRE

***ADVANTAGES OF EMALS**

1. HIGHER LAUNCH SPEED:

EMALS can launch aircraft up to high, compared to for steam catapults.

2. REDUCED MAINTENANCE:

With fewer moving parts, EMALS minimizes maintenance and increases overall reliability.

3. PRECISE CONTROL:

It can adjust acceleration and launch speed based on aircraft weight, offering smooth operation.

4. ENHANCED SAFETY:

Reduced mechanical stress during take-off increases the lifespan of both aircraft and carrier systems.

***DISADVANTAGES OF EMALS**

1. HIGH INITIAL INVESTMENT:

The installation cost of EMALS is higher than that of traditional systems.

2. HIGH POWER REQUIREMENT:

It requires massive electric power for each launch, demanding additional onboard power generation.

3. TECHNICAL COMPLEXITY:

The system needs highly trained engineers and operators for installation, control, and maintenance.

4. CYBERSECURITY RISK:

As EMALS is computer-controlled, it may be vulnerable to digital threats, requiring robust cyber protection mechanisms.

VI. CALCULATION & ANALYSIS

- Aircraft mass $m = 100 \text{ g} = 0.1 \text{ kg}$
- Required speed $v = 12 \text{ m/s}$
- Battery: Li-Po, $V = 14.8 \text{ V}$, $2200 \text{ mAh} = 2.2 \text{ Ah}$, $C = 40$
- Max continuous current (theoretical) $I_{max} = C \cdot \text{Ah} = 40 \cdot 2.2 = 88 \text{ A}$
- Theoretical max instantaneous electrical power $P_{max} = V \cdot I_{max} = 14.8 \cdot 88 = 1,302.4 \text{ W}$
- We use here 2 battery so required power is 2604.8 W
- Required time is 0.05 sec (approx) to covered track
- Required acceleration is 240 m/s^2

Required kinetic energy

$$E_K = \frac{1}{2} mv^2 = 0.5 \times 0.1 \times 12^2 = 7.2 \text{ J.}$$

That is the *mechanical* energy the aircraft must have at launch.

Heat energy generation

Energy lost after travelling distance L is

$$E_{\text{lost}}(s) = \frac{1}{2}mv_0^2(1 - e^{-2kL/m}).$$

$$E_{\text{lost}}(s) = 7.2(1 - e^{-2*0.1465*0.6/0.1})$$

$$E_{\text{lost}} = 3.112 \text{ J}$$

Efficiency

$$\eta = \frac{E_K - E_{\text{lost}}}{E_K}$$

$$\eta = \frac{7.2 - 3.112}{7.2}$$

$$\eta = 56.78\%$$

Minimal track length

If we accelerate over a track length L with constant acceleration a ,

$$v^2 = 2aL \Rightarrow L = \frac{v^2}{2a}$$

$$L = \frac{12^2}{2*240}$$

$$L = 0.3 \text{ m}$$

Required net force to produce that acceleration (mass×accel)

$$F_{\text{accel}} = ma = 0.1 \times 240 = 24 \text{ N.}$$

Lorentz / inductive force (using inductance per meter)

For a launcher where force arises from inductance gradient, the standard formula when $L'(dL/dx)$ is approximately constant is:

$$F = \frac{1}{2} L' I^2$$

With $I = 100 \text{ A}$ and $L' = 0.4 \times 10^{-6} \text{ H/m}$: (For the typical values of an armature current of 100 A and an inductance of 0.4 uH/m)

$$F_{\text{Lorentz}} = 0.5 \times (100)^2 \times 0.4 \times 10^{-6} = 0.0020 \text{ N}$$

DRAG FORCE

$$\text{Density } (\rho) = 1.225 \text{ kg/m}^3$$

$$\text{Coefficient of drag } (C_d) = 0.04 \text{ (streamline body)}$$

$$\text{Velocity} = 12 \text{ m/s}$$

$$\text{Area} = 0.02 * 0.02 \text{ m}^2$$

$$F_D = \frac{1}{2} \rho C_d A v^2$$

$$F_D = \frac{1}{2} * 1.225 * 0.04 * 0.01 * 12^2$$

$$F_D = 0.1465 \text{ N}$$

FRICITION FORCE

Coefficient of friction (μ) = 0.02

Mass (m) = 0.1 kg

Acceleration due to gravity (g) = 9.81 m/s²

$$F_f = \mu \times m \times g$$

$$F_f = 0.02 \times 0.1 \times 9.81$$

$$F_f = 0.01962 \text{ N}$$

NUMBER OF TURNS

For a simple electromagnet/coil attracting a ferromagnetic slug across an air gap g , a common approximation for the peak axial force is:

$$F \approx \frac{\mu_0 N^2 A I^2}{2 g^2}$$

Where,

- $\mu_0 = 4\pi \times 10^{-7}$ H/m (vacuum permeability)
- N = number of turns of the coil
- A = effective cross-sectional area of magnetic path / projectile (m²) = $\pi \times 0.005^2$ m²
- I = coil current (A) = 88
- g = effective air gap between coil and projectile (m) = 0.002

This is a crude but useful engineering approximation. Rearranged to solve for N :

$$N \approx \sqrt{\frac{2 F g^2}{\mu_0 A I^2}}$$

$$N \approx \sqrt{\frac{2 * 24 * 0.002^2}{4\pi \times 10^{-7} * \pi * 0.005^2 * 88^2}}$$

turns $N = 50.12 \approx 51$

VII. CONCLUSION

The Electromagnetic Aircraft Launch System (EMALS) represents a revolutionary step in naval aviation. By permitting quicker, safer, and more energy-efficient aircraft launches than traditional steam catapults, the Electromagnetic Aircraft Launch System (EMALS) represents a major leap in naval aviation. The system offers significant long-term benefits through lower maintenance requirements, better energy utilisation, and flexibility to accommodate future aircraft designs, despite its greater initial costs and technological complexity. All

things considered, EMALS shows great promise for satisfying the rigorous energy and performance requirements of the Indian defence industry's next-generation aircraft carriers.

RESULT

The prototype Electromagnetic Aircraft Launch System successfully demonstrated its capability to lift and launch a model aircraft, validating its potential for practical application in future naval platforms.

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