A BRIEF REVIEW ON ELECTROMAGNETIC AIRCRAFT LAUNCH SYSTEM

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Abstract - This paper describes the basic design, advantages and disadvantages of an Electromagnetic Aircraft Launch System (EMALS) for aircraft carriers of the future along with a brief comparison with traditional launch mechanisms. The purpose of the paper is to analyze the feasibility of EMALS for the next generation indigenous aircraft carrier INS Vishal.

I. INTRODUCTION

India has a central and strategic location in the Indian Ocean. It shares the longest coastline of 7500 kilometers amongst other nations sharing the Indian Ocean. India's 80% trade is via sea routes passing through the Indian Ocean and 85% of its oil and gas are imported through sea routes. Indian Ocean also serves as the locus of important international Sea Lines Of Communication (SLOCs) . Development of India’s political structure, industrial and commercial growth has no meaning until its shores are protected. Therefore to achieve sustainable national development, India needs a secure maritime environment. Since the end of the cold war most of the conflicts have taken place in and around the Indian Ocean. Indian Navy plays the most important role to keep the Indian Ocean as a zone of peace. To address the maritime challenges in the Indian Ocean, India will have to build its naval strength and rapidly modernize it.

Such modernization and strength enables the Indian Navy to fulfill its strategic purpose of blue water power projection.

Blue Water navy not only protects India's own territory but also serves the purpose of establishing strategic dominance beyond it. Aircraft Carriers have always been the primary and effective method of power projection beyond a country's land limit. Hence aircraft carriers play a very important role in India's strategic importance in future. As noted by India's former Prime Minister, Jawaharlal Nehru "To be safe on land, we must be supreme at sea".

Since India is continuously adding new aircrafts to its air power, a regular check and update of the interrelated technologies is very necessary at specific time intervals. Indian Naval Aviation being directly affected should be equipped to handle these continuously occurring changes, such as developing more advanced aircraft carriers which can support advanced aircraft that India may introduce in near future.

Every aircraft is required to achieve its takeoff speed by the end of the runway length. This is the reason why maximum thrust is required during takeoff and maneuvering. Depending on the thrust produced by the engines and weight of aircraft the length of the runway varies widely for different aircraft. Normal runways are designed so as to accommodate the launch for such deviation in takeoff lengths, but the scenario is different when it comes to aircraft carriers. Launch of an aircraft from a mobile platform always requires additional systems and methods to assist the launch because the runway has to be scaled down, which is only about 300 feet as compared to 5,000-6,000 feet required for normal aircraft to takeoff from a runway. This requires the aircraft to accelerate more quickly to gain lift in the shorter distance. Engineers have modified runways and created systems that are capable of enabling the aircraft to accelerate from 0 to 150 knots in just 2 seconds.

Aircraft launch system is the mechanism which is primarily affected due to a wide diversity in the aircraft family itself with respect to their weight, capabilities and other such parameters. Electromagnetic Aircraft Launch System is one such path breaking technology that claims to adapt to these continuously occurring changes without any major effect on the carrier structure, following its installation. India may have access to this technology, with the United States offering to share the Electromagnetic Aircraft Launch System (EMALS) which could be used in future aircraft carriers.

II. TECHNIQUES TO LAUNCH AIRCRAFT FROM AIRCRAFT CARRIERS

There are two main aircraft launch techniques to manage constraints of the deck length:

1. Using integral thrust: Using aircraft’s own thrust to provide rapid acceleration, which can be used in conjunction with a ski-jump and thrust vectoring . These systems do not use any mechanical assistance for launch and therefore solely depend on the thrust generated by the engines. Short Take Off But Arrested Recovery (STOBAR), Short Take Off and Vertical Landing (STOVL) and Vertical Take Off and Landing (VTOL) are the methods, which fall under this technique.

2. Assisted takeoff: Adding thrust to the aircraft using external sources which can generate sufficient thrust to achieve take off speed. Thrust is generally transferred to the aircraft by employing a catapult system. Compressed air, hydraulic and steam catapults are examples of this technique.

There are two important launch mechanisms, which are widely being used by different countries around the world in their aircraft carriers, and they are Short Take Off But Arrested Recovery (STOBAR) and Catapult Assisted Take Off But Arrested Recovery (CATOBAR). A descriptive analysis of these mechanisms is covered in succeeding parts.

III. SHORT TAKE OFF BUT ARRESTED RECOVERY (STOBAR)

Short Take Off But Arrested Recovery (STOBAR) is a system used for the launch and recovery of aircraft on carrier platforms. Aircraft launch with itsown power using a ski-jump at the end of the runway to assist take off rather than any mechanical assistance such as catapult. As of 2015 only Indian, Russian and Chinese aircraft carriers are using this system regularly . Both INS Viraat and INS Vikramaditya are STOBAR equipped carriers, with Mikoyan MIG-29K and the naval variant of Mikoyan MIG-29M being the primary aircraft having ski-jump launch capabilities. Comparatively STOBAR is less expensive to maintain, develop and easier to operate due to lack of any moving parts and therefore less number of operators required for accomplishing a successful launch. Moreover, STOBAR does not require any additional power system to generate force for commencing launch and therefore does not require any high power generating equipment like a nuclear reactor to support the launch mechanism, which may be necessary for CATOBAR configurations.
The launch run starts with ordinary acceleration of the aircraft over the flat deck and the ramp, followed by reaching optimal angle of attack towards the end of the ramp. When the aircraft leaves the carrier from the ramp, it still does not have enough speed to sustain level flight, but it has a positive climb rate provided by the ski-jump. The aircraft continues to gradually accelerate losing its climb rate but gaining more airspeed and thus increasing the lift efficiently, virtually increasing its runway length significantly .

3.1 Limitations and Disadvantages of STOBAR

1. One major limitation of STOBAR configuration is it works only with aircraft having high thrust to weight ratio.
Therefore the weight of the land-based aircraft has to be significantly reduced, which may require minimizing the weaponry, which in turn can affect their combat performance. Therefore, numerous modifications, essential or convenient are needed to be introduced for converting the ground based combat airplanes to make them STOBAR compatible. Such analysis starts with a description of the takeoff maneuvers performed on deck with the ski jump at the end of the runway including wind effects on the deck and semi ballistic flight path immediately after5.

2. Short take off induces more stress on the airframes of the aircraft leading to reduction in service life of carrier-based aircraft with time.

3. Semi Ballistic Flight Path: When an aircraft leaves the ski-jump it suddenly jumps into free air. This poses a challenge to the pilot too, who until this moment has not interfered in the aircraft's maneuver. The objective is to reach suitable angle of attack and speed at the end of the runway, without actually establishing a lift to weight equilibrium. For sustained flight, it is required that the aircraft should attain a minimum value of flight speed after leaving the curved deck, before its altitude drops beyond a certain limit .

4. Wind on Deck Effects: In naval operations it is always necessary to consider the effect of wind that is either natural or due to carrier propulsion for safe operation . If the flow of air is along the direction of launch run for the aircraft, then it can significantly improve certain flight parameters such as lift and velocity, which help in achieving take off speed.
The wind on deck will result in an increase in aerodynamic force, F. Increase in wind speed results in an increase in angle of attack ($\Delta\alpha$) and speed, which consequently results in significant increase in aircraft lift. Hence, wind on deck plays a crucial role in STOBAR configuration (both during flat and curved deck run) and generates additional lift. Absence of wind (both due to carrier propulsion and natural) may lead to unsafe take off maneuvers because of virtually increased requirement for runway length. This forms one of the limitations of the vessel, that it cannot commence the launch of aircraft while being stationary.

Following example of Russian carrier Admiral Kuznetsov shows the importance of wind on deck in STOBAR enabled vessels. The primary aircraft being used for the analysis is the conventional Su-33.The main data used for this analysis are:

Thrust to weight ratio of the aircraft (T/W) =0.89,
Radius of curvature of the curved flight deck(R m) = 180m; which results in:
Velocity of the aircraft towards the end of the curved deck; VII= 55.5 m/s;
Increase in angle of attack due to wind on deck effects;$\Delta\alpha$=2.3o

The increase in aerodynamic force due to wind effects during flat deck run; ($\Delta F/F$) = 66.3%

Hence, it can be inferred from the above example that wind on deck plays an important role for STOBAR configured vessels. Moreover, as discussed earlier ski-jump is preferred only for those aircraft having high thrust to weight ratio, to enable take-off solely through engine thrust. These constraints pose limitations to those aircraft having a low value of thrust to weight ratio.

IV. CATAPULT ASSISTED TAKE OFF BUT ARRESTED RECOVERY (CATOBAR)

Catapult assisted takeoff is another very efficient method of launching aircraft under short deck length. The use of catapults is not new as they were in practice since early in history. Octave Chanute used a primitive form of catapult to launch his gliders in 1896 . Catapults of various designs have been used since Wright brothers for their aircraft equipped with 15 horse-power engine way back in 1903. There are various other methods to perform catapult assisted take off as discussed in further sections.

Under this technique the takeoff is assisted by pulling the aircraft under the influence of a high speed shuttle. The catapults are built into the surface of the carrier's flight deck which is in turn propelled by using the vessel's power system which may be nuclear reactors or steam boilers. Currently there are three countries having operational CATOBAR configurations, i.e. Nimitz class of the United States of America, Charles de Gaulle for the French Navy and the Clemenceau class which is in active service for the Brazilian Navy (previously operated by the French Navy). According to reports on design layouts of INS Vishal (indigenous) of the Indian Navy,it is believed that the vessel will be configured with CATOBAR system.

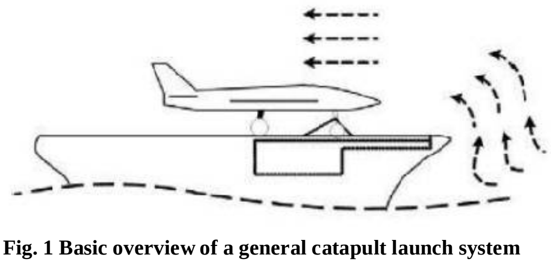


Fig. 1 Basic overview of a general catapult launch system

4.1 Types of Catapult Assisted Takeoff systems

1. Compressed Air Catapult: The compressed air catapult is similar to Wright brothers gravity catapult with the weight being replaced by compressed air. In compressed air catapult the piston used had a stroke of 40 inches and was designed to bring the aircraft to launch speed gradually. The aircraft was attached to the compressed air rig through cables passing over series of pulleys, fixed to the shuttle at one end and the piston at the other .

Theses catapults started to prove inefficient and were soon decommissioned due to certain reasons such as inevitable leaks in airlines and moreover the air flasks were needed to be refilled quickly between successive launches.

2. Flush Deck Catapults: Flush deck catapult was a type of compressed air catapult with one major modification. A metal cable called bridle was attached to the aircraft in place of retractable metal fitting that secured the plane with the launch system along the flight deck .

These systems were used during the World War II, but a need for more powerful system was soon recognized with the introduction of jet-powered aircraft.

3. Hydraulically Powered Catapults: Hydraulic catapults use pressurized fluid to release energy to launch the aircraft attached to the tow bar . This system was soon decommissioned due to its unreliability, being less adaptable and even dangerous (in May 1954 an explosion of hydraulic catapult aboard USS Bennington killed near 100 crew men). Hence the use of hydraulic catapults were discontinued due to technical challenges and risk associated with its use.

4. Steam Catapult: Steam catapults were developed by Britain's Royal Navy in 1952. These catapults acquire power in the form of pressurized steam from the heat of carrier's engines. The shuttle to which the aircraft is connected by its towing bridle is propelled along the track by two pistons directly attached to it. These catapults are able to launch jet powered aircraft and other heavier planes in the fleet. It has the maximum capacity as compared with compressed air and hydraulic catapults. Steam generated from the ship's boilers and water from the steam system provides sufficient pressure for the launch of an aircraft from the flight deck. A brief operating principle of the system is explained as under.

4.2 Operating Technique for Steam Catapults

Steam catapults are built into the surface of a carrier's flight deck. A tow bar on the catapult slides in a holder on the nose wheel of the aircraft. When the catapult is activated, it(the tow bar) pulls the aircraft down the catapult track and provides sufficient velocity towards the end of the track for takeoff .

Before launching, the aircraft is set to full throttle, carrier is steered against the wind as far as possible and various control surfaces are set at right position. During launching, as the tow force applied on the aircraft by the shuttle exceeds the limit of holdback bar, the aircraft is released for the launch run .

Towards the end of the run, the piston approaches the water break (used to stop the shuttle) and a switch is actuated which stops the flow of steam into the cylinder by closing the launch valves. At the same time the exhaust valves are opened for letting out the spent steam. During the process of stopping the shuttle and the piston, the retraction engine is set into motion for returning the shuttle and the pistons to the battery position.

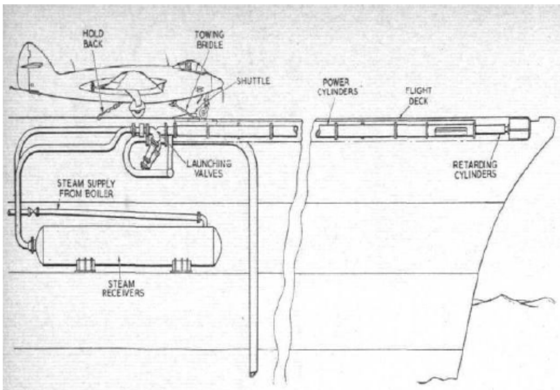


Fig.2 Diagrammatic representation of typical steam catapult

4.3 Advantages of Steam Catapults over STOBAR

Although steam catapult require more crew to operate, complex mechanical and electronic systems for their operational readiness and frequent maintenance and regular checks, but these factors are outweighed by its advantages like the ability to launch wide range of aircrafts varying in weight and operational capabilities, which is the primary and the most important function of a carrier.

Whereas for this purpose STOBAR basically relies on thrust produced/vectoring by the aircraft itself. As discussed earlier STOBAR configuration is not suitable for aircraft with low thrust to weight ratio but steam catapult system are able to overcome this limitation to a great extent and hence more weaponry can be added. Use of steam catapults decreases the stress on the airframe, which in turn leads to decreased maintenance periods. Steam catapults are also able to launch aircraft in unfavorable wind conditions and even when the vessel is stationary whereas wind on deck plays an important role in STOBAR as mentioned earlier. Steam catapults provide extra launch energy for the aircraft to launch, instead of aircraft using only their own thrust for takeoff. Therefore, heavier aircraft can be launched from the flight deck even with low value of thrust to weight ratio.

4.4 Limitations of Steam Catapults

Steam catapults use extensive network of pipes, hydraulic fluid and fresh water to accomplish a successful launch. These systems require more crew members to operate and maintain. Moreover, a regular check of these systems is required from time to time. For instance certain systems like steam seal and cylinder cover have to be employed to ensure that steam does not escape during launch. Various valves, pipes and cylinders are required to be preheated so as to bring the metal to operational temperatures. Various valves, pipes and cylinders are required to be preheated so as to bring the metal to operational temperatures. This complex system of electro-mechanical components leads to decreased efficiency of the steam catapult.

4.5 Need for a New Launch Mechanism

The need of a new system for catapult assisted take-off arose because the steam catapults are currently operating near their operational limits. The persistent trend towards both light and heavier aircraft will require launch energies which have operational flexibility and certainly exceed the capabilities of steam catapults for their allocated space (95-100 MJ) , therefore leading to the requirement of a new launch mechanism which is more efficient as compared to steam catapults (4-6%), compact in terms of space and would require less crew members to operate and maintain the mechanism. Modifying steam catapults to adjust for future changes in naval aviation is not a viable option as it will result in a bulkier system. Moreover a large amount of system's weight is topside, affecting stability and righting ability of the carrier. Even if the current steam systems were supplemented with closed loop feedback control system it would have resulted in a very complex control system .

V. ELECTROMAGNETIC AIRCRAFT LAUNCH SYSTEM (EMALS)

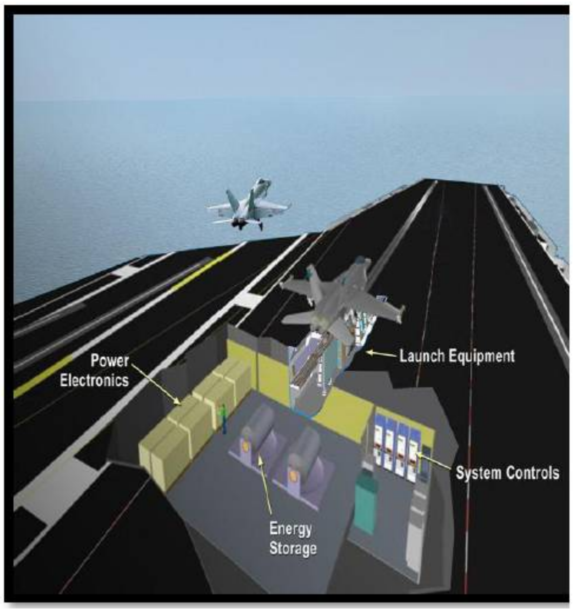


Fig.3 EMALS Operating Mechanism

The use of electromagnetic force to launch aircraft from the flight deck is not a new technology. In the mid 1940's Westinghouse Corporation started working on a system which used electromagnetic to provide thrust to launch aircraft. Known as the Electropult, the system was first tested as a prototype in 1946. Nevertheless, theoretically sound, Electropult posed certain hurdles which led to an inefficient system (<50%). One of the major difficulties faced with electropult was the transfer of energy to the moving part (shuttle) through sliding contact brushes which led to high operational costs . Due to these problems the carriage and the aircraft were never able to reach synchronous speed during actual flight.

The development in power electronics and induction motors led to the development of Electromagnetic Aircraft Launch System (EMALS). This system uses a wave of electromagnetic force to launch the aircraft off the flight deck. Towards the end of the launch run the direction of electromagnetic wave is reversed for returning the shuttle back to starting position. The motor uses the same principle as by the electromagnetic rail gun . The projectile experiences a Lorentz force due to magnetic field (produced by the current flowing through rails) and current flowing across the armature itself. The magnitude of this magnetic force is given by:

$$F=BIL.$$

Where F= Lorentz force experienced by the projectile; I= current through armature; L= length of rail. Therefore, force applied by the shuttle on the aircraft is directly proportional to the current supplied by the energy conversion systems and the length of the rails. Greater the amount of current, more will be the force applied, leading to requirement of power sources that can provide such amounts of current. Due to design constraints increasing the current to produce sufficient force is more viable as compared to increasing the length of the rails.

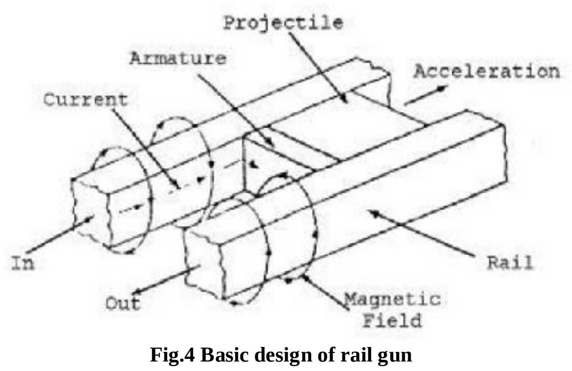


Fig.4 Basic design of rail gun

EMALS is currently being developed and tested by General Atomics (G.A.) a defence contractor based in the United States for the Gerald R. Ford (CVN 78) aircraft carrier. The company was awarded Program Definition and Risk Reduction (PDRR) contract in December 1999. Following a series of other contracts and developments G.A. launched the first aircraft F/A-18 from its land based site at NAVAIR Lakehurst, New Jersey in December 2010. Since then G.A. is continuously testing its system for different types of aircraft. The aircraft used in testing include McDonnell Douglas F/A-18 Hornet and T-45 C, Grumman C-2A, Northrop Grumman E-2 Hawkeye, Lockheed Martin F-35 C and Boeing EA-18 Growler. The tests also included launching dead weights (which are sleds of different weights) aboard CVN-78. Till recently, EMALS has been tested for 452 successful flights and 3,400 dead weights at the land based test site in New Jersey .

5.1 Subsystems of EMALS

The various subsystems involved in successful launching of an aircraft from flight deck using EMALS are depicted below:

- **(i)** Prime Power Interface
- **(ii)** Energy Storage Systems
- **(iii)** Power Conversion Systems
- **(iv)** Linear Induction Motor
- **(v)** Control System
- **(vi)** Energy Distribution Systems

The launch motor which tows the aircraft attached with the shuttle is of linear induction configuration. Electric power from carrier's electrical distribution systems is supplied to energy storage systems. Energy Storage systems are disk alternators which store energy kinetically and release them in a 2-3 second pulse during launch. There are four disk alternators each storing energy of about 121 MJ while rotating at 6400 rpm. Due to stability issues alternators are rotated in counter rotating pairs in a torque frame. The rotors in the alternators take 45 seconds between successive launches to regain required rpm.

Power Electronics or cycloconvertors is the reason behind successful operation of EMALS as compared to Westinghouse Electropult. Using power electronics, only that part of the system is energized which are in the vicinity of the shuttle rather than energizing the entire launch motor, leading to minimum losses . Electrical power from energy storage systems is amplified using cycloconverters which increases its voltage and frequency to provide sufficient launch energy. The same technology allows EMALS to operate at variable speed according to varying loads. This high frequency power is supplied to the linear induction motor to launch the aircraft via. energy distribution system using the towing shuttle as an interface.

The launch profile is continuously monitored by the control systems in real time. Closed loop feedback control system allows the crew to keep a track of the various parameters even when the launch has initiated. The general performance parameters of EMALS are given in the table below:

Table 1: Parameters of EMALS

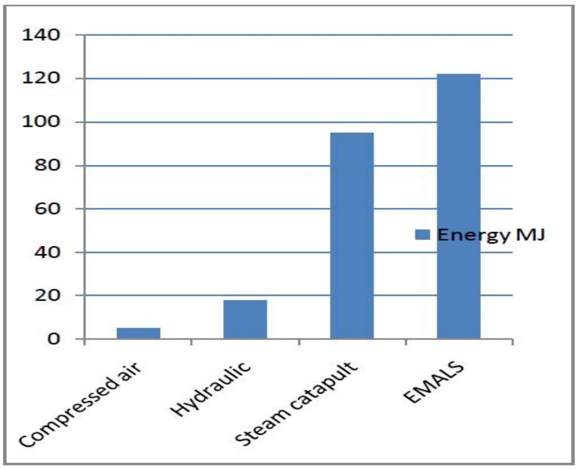
End speed	28-103 m/s
Maximum peak to mean tow force ratio	1.05
Launch Energy	122 MJ
Cycle Time	45s
Weight	<225,000 kg
End Speed Variation	-0 to +1.5 m/s

5.2 Advantages of EMALS

1. Higher Launch Energy. The primary reason to switch to EMALS is its capability to launch both heavy and light aircraft which will be the part of near future naval air wing. EMALS has demonstrated launch energy of 122 MJ, which is a 29% increase over the current operational limit of steam catapult (95 MJ). With this energy carriers will be capable of launching aircraft beyond those possible by steam catapult. In general a steam catapult requires about 615 kg of steam per launch. After a successful launch it takes the steam accumulators nearly 80 seconds to build up the pressure again for consecutive launches. This time period is significantly reduced by EMALS to about 45 seconds. A comparison of relative launch energies for different launch mechanism is depicted in the graph.

2. Increased Service Life of Carrier Based Aircraft. Another major proposed advantage of EMALS over steam catapult is it increases service life of carrier based aircraft, leading to their decreased maintenance and less frequent airframe inspection. This is beneficial for countries having budgetary constraints as it would save up on maintenance costs. EMALS would be able to provide this feature due smooth and flat acceleration profile resulting in gradual acceleration rather than large transient loads imparted to the airframe by steam catapults. Steam catapults have high peak to mean tow force ratio (1.25, with excursions up to 2.0) relative to maximum value of 1.05 delivered by EMALS. Fracture Mechanism analysis show a significant increase in airframe life of 31% due to reduced stresses.

Table 2: The Power capacity of different catapults.



3. Real time feedback: EMALS is a closed loop feedback control system which allows it to monitor health and performance parameters of the system in real time. Steam catapults are open loop system and operate without feedback control.Due to this reason extra energy is always imparted to the steam catapult system to ensure minimum launch energy; the extra energy serves another reason for unnecessary stress on the airframe . A closed loop system is used to constantly monitor the speed and other launch related parameters to create a launch profile specific for each type of aircraft, resulting in reduced manpower required to keep constant checks of the system. General Atomics claims that there is a decrease in manning by 30% if the carriers are equipped by EMALS due to its self-diagnostic feature. The closed loop monitoring system also allows EMALS to adjust according to the weight of the aircraft which is very crucial for light unmanned surveillance aircraft. Being constructed modular in nature EMALS would be more efficient in terms of maintenance and future upgrades.

4. Reduced Volume and Weight. EMALS is proposed to be light in weight and consumes less volume as compared to its steam counterpart, this extra space can be used for other crucial elements of the carrier. Electromagnetic system can provide a thrust density of 1322 psi over its cross section which is significant increase over steam catapult's 450 psi. The increased densities in both launch engine and energy storage devices results in decreased volume of the system from 1133 m3 (steam catapult) to less than 425 m3 (EMALS). Decrease in volume also tends to decrease in weight from 486 metric tons to less than 225 metric tons .

5. Elimination of Complex Mechanisms. EMALS eliminates the use of complex network of tubes that carry steam, valves, pumps, hydraulic system, motors, gallons of fresh water for steam boilers and hydraulic fluid, water brakes, and significant change in retraction process. Instead of using a separate retraction engine to reposition the shuttle, launch motor itself is used for this purpose in electromechanical system, thereby making the system simpler and reducing auxiliary units. Same principle applies for braking, which uses reversal of current to stop the shuttle in about 20 feet rather than using water brakes. Finally an EMALS equipped Indian aircraft carrier will be able to launch aircraft widely varying in their capabilities such as heavy fighter aircraft (MiG 29K and FGFA which is still under development), Light Combat Aircraft (LCA), Airborne Early Warning (AEW) aircraft (Northrop Grumman E-2D Hawkeye which India wishes to procure), Unmanned Combat Air Vehicles (UCAVs) and Unmanned Aerial Vehicles which enhance situational awareness.

5.3 Limitations of EMALS

1. Requirement of High Power Generation Sources. Proposed and experimental benefits of EMALS over Steam catapults and STOBAR tend to favour the need of a new system but there are certain technical limitations and hurdles, which need to be addressed. Carriers configured with EMALS will require large amount of electric power in comparison to steam pressure required by steam catapults. The force applied by the shuttle on the aircraft is directly proportional to the current supplied by the energy systems. A single launch using EMALS can consume up to 100 MW of electricity in three seconds, an amount a small town uses in the same time . On comparing the energy requirement of EMALS with the designed power generation capacity of India's first indigenous aircraft carrier INS Vikrant (Gas Turbines developing a total power of 80 MW and diesel alternators capable of producing about 24 MW)it comes out that a power source generating much higher outputs is required. The average power required by this system is 6.35 MVAFor such purposes only aircraft carriers like USS Gerald R. Ford will have the capability to generate 13,800 volts of electricity, more than three times the Nimitz class could produce.One option is modifying conventional power systems such as diesel generators and other being the use of nuclear naval reactors. Increasing the number of steam boilers will only lead to increase in weight of the vessel and reduce space for other vital equipment. Therefore nuclear power is suggested to be suitable solution for power requirements of EMALS. According to the power required for carrier propulsion, EMALS and other auxiliary systems it could be said that atleast three reactors would be required . Naval reactors have low thermal efficiency (20-25%) because they are aimed to produce flexible power in contrast to steady production of maximum output by land based reactors

2. Unreliability for Carrier Operations. However, EMALS has not been upto its mark as it was expected according to the scheduled time period. EMALS has a reliability rate of 240 launches without failure which is much lower than desired for actual shipboard operations; the system should have reached a value of 1,250 by April 2014 when aircraft compatibility tests ended . In recent tests in June 2015 EMALS was not as efficient as expected in a test carried out aboard Gerald R. Ford aircraft carrier when the system was not able to launch dead weight from the flight deck.

3. Electromagnetic Interference. With the development of electronics and Fly By Wire (FBW) technology, most of the aircrafts carry sensitive avionics onboard. These systems play a very important role in maneuvering, positioning systems and communications, therefore any kind of damage to these systems will severely affect the performance of the aircraft. EMALS can emit electromagnetic waves, which can interfere with sensitive aircraft avionics and the electronic, and navigation system of the vessel itself. Proper magnetically closed design of various subsystems is required to ensure that electromagnetic interference is reduced . A similar limitation is posed by the rotating components of the system associated with energy storage. These components are required to be specifically designed for carrier based platform.

4. Requirement of Separate Cooling systems. In comparison to steam catapults EMALS does not require separate mechanical components to ensure safe operation (such as steam seal, cylinder cover, preheating system, steam smothering system, cable tensioning in retraction engine etc.), but EMALS does require cooling systems and heat exchangers due to flow of enormous amounts of current within the setup. Even though EMALS uses a better method to transfer electrical energy to the moving part (shuttle)i.e. brushless commuted motors rather than sliding contact brushes used in Electropult, but due to very high current a large amount of heat is dissipated in the stator which can be of the order of 10 MegaWatt . Therefore, separate cooling equipment and mechanisms are required for disk alternators and Power Conversion Units.

Apart from these technical challenges introduction of EMALS into carrier platform will require transition and training of crew and engineers from mechanical to electrical and electronic systems.

VI. CHALLENGES FOR INDIA

Using nuclear reactors for carrier propulsion is suitable to meet the power requirements of EMALS efficiently. Therefore the first question arises whether India is ready for nuclear propulsion in its carrier ships. Nuclear power is expensive to maintain, acquire and need specialized personnel to operate. Indian Navy in collaboration with DRDO and Bhabha Atomic Research Center has already developed a nuclear reactor for INS Arihant submarine. Although the exact technical specifications of the system are not known but the reactor is rated to produce around 83 MWe. The question arises here is whether the nuclear reactor technology for INS Arihant can be scaled up to power a vessel which is about ten times its size and with conditions much harsher than those faced by a submarine due to resistance from surface waves. USS George H.W. Bush consists of two nuclear reactors each producing an output of 550 MWt and even the large nuclear submarines are not rated above 200 MWt . Therefore India might have to either make severe changes in Arihant's reactor or develop a new kind of nuclear reactor. However, nuclear propulsion will have its own advantages over conventional power systems in terms of decreased time intervals between consecutive refueling, decreased occupancy of space beneath the deck and increase in power output for propulsion and other electrical equipment.

EMALS has proved its capabilities and worthiness on land based test sites but has still not proven itself on a naval platform. The technological challenges faced during the development of EMALS, its testing and delays in its procurement aboard Gerald R. Ford aircraft carrier, cannot be overlooked. Moreover, inculcating this mechanism for carrier based aircraft launch has different challenges for different countries, especially for India and the United States. The United States being the developer of this technology and its previous versions has admirable experience in this field. Hence any technological challenge regarding this never adopted mechanism is likely to be addressed and sorted out first by the United States itself. The United States also has dominance over carrier based naval reactors, which India still needs to nurture. Also so far the United States has shared details relating its naval reactors only with Great Britain, which is a case in point.

There are certain downsides related to acquiring defence technology from the United States such as higher costs and restrictive policies. Keeping in mind that the United States shares its defence technology only with few allied nations, another very important area of concern rises that whether the United States is ready to share its one of the most advanced defence technologies till date. This gives rise to another question that in what manner India will procure this technology i.e. whether transfer of technology will occur or can India participate in joint development or else it will have to buy EMALS off the shelf. The acquisition of off the shelf EMALS may not be a suitable option when it comes to technologies related to aircraft carriers operating across the oceans considering the restrictions related with obtaining it. These challenges are very crucial and need to be addressed before making any decisions related to EMALS.

VII. A WAY AHEAD

INS Vishal is a project that is likely to become operational not before next 10-12 years . Therefore it will support India’s future naval air wing. Acquisition of EMALS depends largely on the type of aircraft which India will procure over the next two decades. If India has plans to significantly increase its naval air fleet over the next two decades consisting of both heavier aircraft like FGFA and AEW systems and also UCAVs and UAVs which are light in weight, then under such circumstances EMALS can be considered as a viable option. Unmanned aerial vehicles are likely to be an indispensable part of the near future air wing. Considering the wide variety of aircraft that Indian Navy may procure in the future it can be concluded that assisted takeoff will be more suitable for such aircraft. Since EMALS is designed to provide launch profiles specific to each aircraft therefore it is an ideal choice keeping in mind the variation in aircraft capabilities. Development of a nuclear reactor may pose some problems economically and technically but those can be resolved over time.

However, if much variation is not expected in the future naval air wing then India can instead choose another STOBAR configured vessel which will have the capability to launch current naval aircraft and the ones under development such as the naval variant of Light Combat Aircraft (LCA). EMALS can be kept as an option for the aircraft carriers that will be introduced after INS Vishal. Till then India would have developed sufficient naval nuclear capabilities and knowledge about the feasibility of EMALS.

EMALS is one of the many options that India has for its future aircraft carrier and is definitely not the only one. Keeping in mind the technological limitations and challenges faced with nuclear propulsion, India can instead choose a simpler mechanism/method to launch aircraft aboard its future aircraft carrier. Chinese aircraft carriers might use a combination of both ski-jump and a catapult launch system for its future aircraft carrier is a case in point.

Naval nuclear reactor technology is yet another issue that needs to be resolved before making any decisions related to EMALS. It needs to be remembered that other great powers such as the United Kingdom have not equipped their aircraft carriers with nuclear propulsion for its exorbitant costs, They are pragmatic in their belief that several years of conventional refueling would be far less expensive as compared to incorporating a nuclear reactor aboard an aircraft carrier. The cost of a nuclear propelled aircraft carrier can be about three times more than the cost of a conventionally propelled aircraft carrier.

"To put it simply, India could build two STOVL or two STOBAR non-nuclear carriers for the cost of one nuclear CATOBAR carrier" . Therefore, India has to make a wise decision keeping in mind economic feasibility and current status of its research and development organizations. EMALS does not only come with technological limitation but it also has issues related to its economic feasibility.

Therefore we can conclude that choosing EMALS depends upon the type of air fleet India wishes to have in the next two decades. Otherwise, EMALS will be an expensive equipment aboard INS Vishal, launching the aircraft which could either have been launched using STOBAR or steam catapults.

CONCLUSION

India is striving towards manufacturing indigenous defence systems. The two aircraft carriers under the Vikrant class will help Indian Navy establish strategic dominance in the Indian Ocean and achieve its goals for Blue water navy. The first indigenous aircraft carrier (IAC-1) will be commissioned soon by 2016-17, featuring STOBAR configuration. The second Vikrant class aircraft carrier is likely to be developed within the next 10-12 years. India has a wide range of options for its second indigenous aircraft carrier in terms of size, propulsion, launch systems, etc.

Electromagnetic Aircraft Launch System (EMALS) is one such option. As mentioned above, EMALS poses many advantages over conventional steam catapult and ski-jump systems in terms of reduced manning, maintenance, volume and weight, increase in service life of carrier based aircraft, increased sortie generation and operational flexibility in terms of launching wide range of future aircraft. Steam catapults are far behind EMALS in terms of its performance parameters and operational capabilities. However, EMALS has yet to prove its reliability for carrier operations. If the United States is able to efficiently manage and operate EMALS aboard USS Gerald R. Ford aircraft carrier, then other countries that wish to acquire this technology would step forward. Any technological challenge related to EMALS is likely to be resolved by the United States being its only user till now. Therefore, India may require technical assistance for maintenance and operating purposes. Hence, with the support of its initial developer (the US) and development of a new kind of nuclear reactor, an Indian aircraft carrier equipped with EMALS will have advantages over its regional rivals especially for its future operations in the Indian Ocean Region. Use of EMALS is a wise choice given the vast ocean areas of interest to India. Carrier vessels with such capability can host larger air wings composed of high performance fighters capable of carrying heavy ordinance loads, integrate the requisite number of support aircraft and mount substantial amount of cyclic air operations, meaning the rapid launch and recovery of aircraft . But as highlighted earlier, the acquisition of EMALS depends on the naval aircraft fleet India will have over the next two decades. Along with EMALS India should be ready to address the challenges that come with it, whether in terms of nuclear reactor technology or economic feasibility.

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