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Roadmap for a

Future Ready Naval Force

KOAN

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Introduction

With the advent of nanotechnology, robotics, directed energy technology, among other scientific developments, there has been a paradigm shift in the pace of evolution of capabilities of naval forces. Navies of the future are likely to make use of lasers, nanotechnology, electromagnetic railguns, unmanned vehicles, space assets, next-generation sensors, stealth technologies, and information-centric combat systems. These concepts and technologies will form the substance of deliberations during the conference on “Make in India Paradigm: Roadmap for a Future Ready Naval Force”, between April 17 and 18, 2016.

Missiles have played a critical role in determining battle outcomes. The reliance on missiles is expected to continue in the future as indicated by the growth forecast of the global missile systems market which is expected to reach US$ 20 billion in 2021.Trends indicate that missiles of the future will be faster and stealthier with increased lethality. Future missile systems will incorporate a range of options for airframe design, rocket propulsion, seeker heads, guidance systems and precision ordnance such as re-deployable payloads.

Gun systems are also expected to witness fundamental changes in the future with the advent of new technologies such as the electromagnetic railgun. These guns are capable of shooting a projectile at 7.5 times the speed of sound over a distance of 125 miles. Using kinetic energy, railguns will be useful in taking on a wide range of threats. They are also likely to allow significant savings as each shell fired using electromagnetic railguns costs about a hundredth the cost of firing a conventional missile.

Operations in littoral waters have thrown multiple technological challenges such as the need for torpedoes to navigate complex environment involving local ship traffic, false targets and bottom clutter. This has necessitated improvement of counter-countermeasures performance, greater endurance, flexible speed control, stealth, lethality, and for urgent-attack weapons, shorter reaction times. Techniques such as ‘super-cavitation’ enable torpedoes to become underwater missiles cruising at greater speeds inside vapour pockets. With multi-purpose configurations, it could be used not only for anti-submarine warfare, but also as an anti-torpedo torpedo, or for defence against high-speed surface crafts.

Navies of the future are likely to increase their reliance on directed energy weapons such as high-energy lasers (HEL) and high-power microwaves (HPM). These weapons will utilise directed energy to incapacitate, damage or destroy enemy equipment, facilities and/or personnel. It is expected that the cost of operating such weapons will also be significantly lower than conventional weapons. With the US Navy commencing trials of its Laser Weapon System (LAWS), this technology is at the cusp of being inducted into regular service.

Despite the advancement of all-electric and nuclear propulsion technologies, diesel propulsion is likely to continue as the mainstay of mid and small-level navies. However, due to increasing environmental concerns, designers are focussing on reducing emissions and carbon footprints. Simultaneously, future designs are likely to incorporate measures to increase fuel efficiency and enhance output delivery.

Development of technologies such as air-independent propulsion system also enable diesel-powered submarines to stay underwater for prolonged periods. Nuclear propulsion, on the other hand, will be a preferred choice for advanced navies. With minimal emissions and the ability to power underwater vessels or prolonged periods without resurfacing, nuclear propulsion is going to be a prominent feature of modern navies.

Today navies are using multiple technologies for surveillance and detection. These include use of space-based assets, use of UAVs, advanced radars and sonars, among others. While the reliance on these technologies is only going to increase in the future, the focus is on greater integration of these systems.

Over the years, reliance on electronic warfare systems has also increased substantially. The need to perform tasks including electronic attack, electronic support and electronic protection are driving technological developments that will define electronic warfare operations in the future. Key growth areas include development of algorithms and implementations for signal detection and characterisations, frequency intercept systems and multiple redundant sensor modes.

The operationalisation of the submarine was an important development that redefined the naval warfighting narrative. Submarines are going to remain an indispensable platform for navies in the future. Development of air-independent propulsion systems, lithium ion batteries, active noise cancelling systems, advanced anechoic coatings and optronic masts, among others are going to enhance the capabilities of modern day submarines manifold.

Simultaneously, anti-submarine warfare technologies such as low frequency active sonar, non-acoustic detection methods employing lasers or LED light, long-range light weight torpedoes will continue to challenge submarine dominance in the maritime domain.

Future of naval aviation will be defined by developments in functional areas including avionics technology, sensors, propulsion and power, structures and materials, survivability and the core technologies of aerodynamics, modelling and simulation. Low-observable signature technologies including visual signature reduction could make it possible for aircraft to change colour, hue, reflectivity or emittance. Development of autonomous UAVs will reduce the need for human interface to only on a need basis. Smart sensors, nanotechnology and perfect imaging capabilities will augment efficiency of sensors substantially. Various materials and component technologies are being studied to achieve about 20 percent improvement in fuel consumption and 30 to 35 percent improvement in thrust, range, payload, and maintenance cost of aero engines. Key focus areas include use of carbon nanotubes and self-healing composites.

Network Centric Warfare (NCW) and advancements in combat management systems (CMS) have the potential to increase warfighting capabilities by orders of magnitude. Smarter real-time sensors, increased computing power, guided precision munitions are some the key technologies that will impact NCW capabilities. Future CMS development will focus on coping with mass information while using minimum crews.

While advancement in these domains will be significant in the future, allocation of budgets and build-up of manpower resources are going to be critical variables that will determine adoption of these technologies. Cost benefit, long-term sustainability, maintenance requirements and interoperability will also have a bearing on technology adoption in the future. The following chapters will discuss important trends and developments that will shape the future of naval forces.

Naval Missile and Gun Technology

Missiles

A naval-technology report of 13 December 2011 states, "The global missiles and missile defence systems market, estimated to be worth US$ 15.2bn in 2011, is projected to grow at a CAGR of 2.71% during the forecast period to value US$ 19.8bn in 2021. Demand for missiles is anticipated to be driven by internal as well as external security threats, territorial disputes and modernisation initiatives undertaken by armed forces across the world. "The global defence industry is investing in research and development which has led to the development of advanced technologies." Cumulatively, the market for missiles and missile defence systems during the forecast period is expected to value US$ 187.8bn.

Technological developments in the realm of missile warfare have greatly dominated strategic and operational thinking in the 21st century battle space at sea. Since the first victim claimed by a Styx missile half a century ago, missile technology has evolved exponentially. In less than a decade we have seen missile technologies rapidly transit from the first generation to 'smart' and then to 'brilliant' and now to 'sub sonic and intelligent' or 'fast but dumb' to describe the amazing missile technology at sea veering in several innovative directions which rapidly swings in favour of the attacker at one point to another where the defender succeeds.

In a maritime combat environment the basic classification of missiles for surface warfare would be cruise and ballistic depending upon the travel geometry, the launch platform be it ship, submarine or integral aircraft. In the anti air/anti missile case the classification would be based on the method of guidance/homing, i.e line of sight, active seeker heads etc.

Missile systems designers, working on the next generation missiles, are keenly aware that emerging technologies would make possible a new range of options for airframe design, rocket propulsion, seeker heads, guidance systems and precision ordnance as smart re-deployable payloads. These new sub systems could be conceptualised drawing from advances made in futuristic technologies such as the internet of everything, big data analytics, robotics, automation systems and nano technology materials, among others. Manufacturers today are aggressively visualising scramjet engines for hypersonic weapons, throttle-able ducted rocket propulsion systems that enables long range and high average speed, nanotechnology based surfaces to reduce drag, intelligent processors using big data and cloud computing for detection, identification and recognition of targets combined with optronic and RF sensors using terahertz electronics and highly advanced and super-fast processing techniques that can only come about by integrating genomics with bio computing techniques and miniaturised to be packed into a missile with low RF and IR signature. Designers are developing high-density reactive material that integrate the casing with the warhead explosives thereby increasing lethality. Simultaneously launch and guidance systems are also seeing revolutionary improvements that would transform missile warfare at sea. Potentially additive manufacturing and modular designs can lay open a range of options to the commander at sea depending upon the hostility of the environment.

Anti-ship cruise missiles too are not being left behind in the technology race. The characteristics of these missiles today include:

- multiple-effects rocket system (MERS) that can fire missiles without emitting any smoke.;
- extended ranges using nano fuels and better aerodynamic and propulsion systems;
- waypoint navigation;
- ability to loiter and wait;
- stealth capability;
- supersonic terminal speeds;
- hardening against anti-missile weapons;
- high-G terminal manoeuvres;
- and complex seeker and homing technology.

An important facet of missile naval warfare is the capability to attack targets on land several thousand kilometres away with pin-point accuracy and lethality. As land attack missiles have and can be used to demonstrate political and military intent and resolve, they are of importance not only to the military commander but also to the political decision makers of a nation and is useful tool to influence events on land from the sea. Advances in inertial and satellite guidance, and terrain contour matching role has been made possible through several disruptive technologies mentioned earlier.

In missile warfare, the edge has traditionally been with the attacker. To counter this, focus of several navies has shifted to missile defence systems and, over the next decade, they are likely to account for the highest proportion of spending in the global missiles systems market. In

Figure 1: BAE Electromagnetic Railgun

the past, missile defence systems were focussed primarily on countering the anti-ship cruise missile threat, but now technology is ripe enough for anti-ballistic missile systems to be inducted on board ships.

The Indian Navy operates super-sonic cruise missiles and sophisticated long range SAM systems. For a future ready naval force, combatants at sea may need to develop a ballistic missile capability and a defensive system to neutralise nuclear tipped ballistic missiles. It has been reported that India has developed an indigenous two-tier ballistic missile defence system capable of intercepting enemy missiles at exo-atmospheric altitudes of 150 kilometres and endo-atmospheric heights of 80 kilometres. Perhaps such a system would be at sea in the next generation destroyers that the Navy may acquire after the P-15B program with all its potential for indigenous industrial participation.

Guns

A gun on a man-of-war has for centuries symbolised Sea Power. The advent of missile warfare at sea had pundits sounding the death knell on the naval gun. They could not be more wrong as newer technologies have resulted in the strong resurgence of the gun at sea in a variety of roles.

The exciting new technology on the horizon is the Electromagnetic Rail Gun, which is expected to begin trials at sea later this year. The gun uses electromagnetic force to send a projectile to a range of 125 miles at 7.5 times the speed of sound and cause extensive damage with sheer kinetic energy and thus represents an incredible new offensive capability that can effectively counter a wide range of threats at an estimated cost of about $1/100^{th}$ the price of current missiles. It also enhances ship safety and survivability by reducing propellants and high-explosive ammunition on board.

Laser weapons have long fascinated weapon developers. After nearly a half-century quest, designers are now on the cusp of fielding operationally relevant directed energy weapons. At sea they will have wide application from anti-missile defence, against both ballistic and cruise missiles, to destroying small craft. More importantly, the directed energy source never runs out of 'ammunition', and is expected to cost less than 100 per shot! This provides a prodigious alternative to firing costly munitions especially at inexpensive threats. A laser warfare system is already under trails in the US Navy.

Advanced gun systems today combine advanced propellant technologies with rapid sensor and computational ability to destroy targets 63 miles away. That's three times farther than what existing destroyer can engage with their guns. These extended range precision guided munitions cannot be countered with existing technology available at sea. So potentially these systems may be developed for the future ready naval force.

In addition to high tech guns, there is still a place for lower technology guns for force protection and in scenarios of low intensity conflict. While leading navies may usher in the 'star wars' type of gun systems in the foreseeable future, lesser navies will have to wait for another decade or two before they can embrace these technologies on their platforms. Till then, the existing gun systems will continue to be relied upon in their present dominant roles of anti-air/ anti-missile defence, surface action, naval gunfire support, and for firing 'one across the bow' when so required.

The raison d'etre of naval warfare through the ages has been about delivering ordnance on target, be it from a ship, submarine, or aircraft. Even so in the future, the side that can harness technology that provides for longer range, greater speed, higher precision and lower signature will certainly have the decisive edge in battle. A future ready naval force should begin to work with industry to develop these winning capabilities.

The conference deliberations will provide a common platform for industry and the navy to explore various firm-specific and generic technologies that offer the best potential to transform the war at sea and thereby generate the specifications for a future ready Indian Navy.

Propulsion and Power Generation: Diesel and Gas

Diesel

Diesel engines have been the principle mode of propulsion for naval ships for many years. While some ships, due to their design and operational profile, use either slow or medium speed diesel engines as the principal mode of propulsion, most ships are fitted with additional medium or high speed diesel engines to drive generator sets for auxiliary power purposes. Particularly, warships require rapid acceleration and de-acceleration, and quiet performance

Since the 1970s, the development of slow and medium speed diesel engines has been driven by the need for better fuel economy. The result has been increased stroke/bore ratio, peak pressures, turbocharging efficiency, fuel injection technology and mean piston speeds that allow significant reductions in specific fuel consumption. Typical of these developments have been flow studies in injector nozzles with particular reference to the effects of cavitation on fuel atomisation and spray structure and repeatability.

However, since last few years, the drivers for diesel engine development are changing. The focus is increasingly shifting to emission control, more robust, reliable and compact engines, fuel efficiencies and easy maintainability by reducing the time between overhauls and, in the future, by reducing the number of moving parts and operational temperatures.

The primary method of limiting NOx production in the combustion process include reducing the peak temperature and duration of the process, by much higher-pressure fuel injection over a shorter period, accurate timing and control of the injection, the use of Miller inlet valve timing and higher-pressure turbocharging. This will lead to significant enhancement in two-stage turbocharging for even higher operating pressures but with significantly lower fuel consumptions, thereby making way for further efficiency improvements in diesel engines. Such improvements will be supported by advances in meta materials, nanotechnology and better processors for precisely timed fuel injection. Exhaust after-treatment systems are required which comprise diesel particulate filters, diesel oxidation catalysts and selective catalytic reduction (SCR). SCR systems use precious metals, zeolites or are vanadium based all of which are exotic high cost materials. Also, such systems require additional space for storage, dosing, and control systems, and selective catalytic reduction elements which may replace the existing exhaust system.

Heat recovery for other applications from flue gases is also an area of interest. To reduce fuel consumption there has been a tendency to run large marine engines at part load. While such restrictions have largely been confined to continuous powers above 60 percent of maximum continuous rating (MCR), more recently these limitations have been as low as 10 percent MCR. To achieve these very low loads, the lubricating oil supply has to be reduced together with the introduction of digitally controlled engine tuning methods for part and low load operations. Of significance in this context are exhaust gas bypass; variable turbine area; engine control timing and high-pressure tuning.

Figure 2: Kawasaki 4-Stroke Marine Diesel Engine

Stoichiometric direct injection spark ignition (DISI) engines are now being used by most OEMs across the world for marine engines. The technology trend is moving toward higher injection pressures and more sophisticated injection strategies such as pulsed-injection.

The 1st generation lean burn DISI engines achieved mixture formation through a special combustion chamber design which is referred to as "wall-guided" mixture formation. The technology did not achieve wide success since combustion was difficult to control at different engine speeds. The newer technology variants being researched uses a centrally placed injector to achieve a "spray guided" charge which use high pressure piezo-injectors to achieve the desired level of mixture control, with attendant high injection system cost.

Theoretically, an engine's efficiency will increase with increased Compression Ratio (CR). Modern marine diesel engines generally operate in a CR range from 10:1 to 11:1 but the trend is to develop engines with higher CR, particularly with DI available to cool the charge mixture.

Engine developers are constantly looking to achieve friction reduction and some have reported very aggressive targets of as much as 50 percent friction reduction in subsystems such as valve trains. The partial list of friction reduction technology includes: low mass pistons and valves reduced piston ring tension, reduced valve spring tension, surface coatings on the cylinder wall and piston skirt, improved bore/piston diameter tolerances in manufacturing offset crankshaft for inline engines. Diamond-Like Coating (DLC) technology is a relatively new trend in friction reduction. DLC is a family of coatings made up primarily of carbon chains in an amorphous base material. In addition to friction reduction, the DLCs are known to improve self-lubrication and resistance to wear. Efforts are underway to define a new, lower viscosity, 0W-16 oil for release as early as 2017.

New weight reduction studies are now publically available and in general, many of these studies now conclude that the low-level weight reduction, in the range of 5 percent to 10 percent, can be accomplished with near net "zero" cost, if the primary weight reduction is complemented by cost reduction from secondary weight reduction in powertrain, structures and suspension. Another area that has emerged in the last 5 years is active thermal management of the drivetrain. There have been a number of developments in marine diesel engine technology which include, adjustable camshafts, variable inlet valve control, improved combustion chamber design, higher boost pressures, greater mechanical strength in engine architecture, two-stage turbocharging, exhaust gas recirculation waste-gate technology etc.

It is evident that to optimise potential benefits of a diesel propulsion option, or combination of options, in terms of efficiency and minimising the impact on the environment, an integrated ship design procedure based on a systems engineering approach must be employed. Fundamental to this process is the proper definition of the intended warship's operational profile and the perceived tolerance on this profile to meet unforeseen operational fluctuations.

Gas Turbines

Today's marine propulsion systems must provide faster vessel speed, enable greater payloads or deliver more power per square foot of machinery space. When vessel speed is critical and space is a premium, gas turbines can be an ideal solution. The advantages of gas turbine propulsion systems have led to their adoption in naval combatant ships, but these advantages lead to increased reliance on automatic control systems and much greater attention to system dynamic performance.

Gas turbine technology remains attractive for next-generation marine propulsion because it offers the potential to significantly reduce NOX emissions compared with conventional diesel engines. Other advantages include smaller size and lighter weight, higher power output, reduced maintenance, and low vibration and noise, which are expected to reduce acoustic and thermal signature of warships. However, higher fuel consumption and higher component prices deter their adoption on a wider format. Subsequently, gas turbine technology applications are limited to high-speed high value warships.

Gas turbines are compact, lightweight and provide many times the horsepower over diesel engines for the same installed weight at a lower installed volume. With a cold-end drive, the gas turbine can be integrated into the propulsion package system by cantilever mounting directly to the reduction gear, or mounting to a horizontal support frame and coupled to the reduction gear with a shaft and coupling. Such turbines can provide efficient power to a variety of propulsors including fixed and variable pitch propellers, waterjets and, in the case of hovercraft, air props. The small size and light weight features of modern gas turbines also allow for the installation of single or multiple gas turbines in combined system configurations. These are usually in hybrid configuration with either other low power gas turbines or diesel engines in CODAG, CODOG or COGAG configuration.

Therefore, it is not surprising that aero-derivative marine gas turbine engines adopted by navies for ship propulsion are lightweight, fast-responding, high-performance engines with certain mandatory automatic control requirements. The engines and propulsion control systems comprising the propulsion plants of these ships require a relatively high degree of automatic control since the number, speed and accuracy of control actions required exceed the capabilities of human operators. However, recent trends aims to develop a low NOx and high efficiency gas turbine for a next-generation marine propulsion system based on industrial gas turbine technologies.

Although an increase in combustion temperature leads to a rise in overall thermal efficiency, the completely effective use of heat energy with a maximum possible combustion temperature of 2000° to 2500°C which can be achieved by fossil fuels involves many technological issues that are yet be solved. The combination of gas turbines with fuel cells uses the fuel remaining after most is chemically converted into electricity in a gas turbine combined cycle to increase overall thermal efficiency.

Fuel flexibility and intermediate capacity peak power generation are the future trends, while further increases in the combustion temperature of gas turbines and challenges to new cycles are mid- and long-term trends. In recovering energy obtained from fossil fuels, it is important to efficiently convert the thermal energy of the fossil fuels with a maximum combustion temperature of 2000° to 2500°C to electric power through cascades achieved by combining cycles. The means for accomplishing this goal include: increasing the maximum temperature of the present 1500°C gas turbines; achieving a new cycle to recover thermal energy at the 2000°C level by other methods; and developing a combined cycle to recover thermal energy without combustion

Future gas turbines would require some standard features such as "no warm up" required, start capability down to -50C, extremely low vibration and ultra-low noise and thermal emissions, modularity, high operational readiness combined with easy on-board installation and change out.

At the prevailing technology level simple gas turbine cycle cannot exceed a thermal efficiency of 38 percent even at a turbine inlet temperature of 1200°C. Researchers around the world are working to develop systems achieving combustion temperatures of 1700°C and a combined cycle thermal efficiency of 62 to 65 per cent (LHV) as the next standard values. To achieve this, technological breakthroughs based on new concepts that differ from simply extending conventional technologies are required in the form of new materials, cooling technologies, aerodynamic technologies, and low NOx combustion technologies.

In addition, new generation technologies such as rotating detonation engines, pulse detonation engines and standing wave detonation engines are being explored which could increase efficiencies by as much as 15 percent. About twenty years ago, intensive research was reinitiated on Pulsed Detonation Engine (PDE) and nearly ten years ago on Rotating Detonation Engines (RDE) and patent for RDE was obtained in 2005. Currently, most gas-turbine engines operate on the Brayton cycle, which is what the RDE is based on. Unfortunately, the only drawback is that the engine cannot be modified to improve the energy output or efficiency.

These concepts continue to develop as advances in materials and manufacturing techniques provide solutions which were otherwise merely a dream.

Surveillance and Detection Systems

Space Based ISR and Communications

Satellites are an essential part of contemporary intelligence, surveillance and reconnaissance (ISR) capabilities of all modern navies. The space-based ISR architecture is comprised of satellites in low earth orbit (LEO), 500 to 2,000 kilometer altitude; medium earth orbit (MEO), 8000 to 20,000 kilometer altitude; highly elliptical orbit (HEO) with a perigee (closest point to the earth) of 500 kilometers and an apogee (furthest point from the earth) of 50,000 kilometers; and geostationary orbit (GEO), with an altitude of approximately 36,000 kilometers.

Space-based ISR systems will be able to provide vital contributions to maritime safety, security of the sea lanes of communications and regional stability by being able to transmit continuous information for making actionable decisions well ahead of a developing crisis whether they relate to natural disasters, terrorism and piracy or even upsetting legitimate governments. These space based systems could provide data across multiple sensor types enabling continuous and intelligent information upgrades of areas or activities.

Satellite communications offer a survivable means of transmission that will become particularly important when the Navy operates further and further away from the littorals. Data relay satellites and other beyond line of sight communications systems could transmit targeting data to and from the battlespace in a secure and non-DF manner ensuring greater survivability of its platforms.

Similarly Cyber-space will be a major element of a multi-sensor, multi-domain, real-time intelligence capability that would transform information into actionable knowledge, thereby allowing machines to execute human intent at machine speeds. Developments in big data analytics and quantum computing would enable better analysis in a crowded and dense environment. Future ISR technologies may use tandem satellites to produce large synthetic apertures for higher resolution, and rapidly change in-orbit configurations in response to evolving mission sensing requirements.

It is evident that a myriad of organizations will have access to space in the future. The space environment will continue to be congested, contested, and competitive as the radio frequency spectrum for space applications continues to become more congested, and as more nations get into the space business by developing their own satellites. Resultantly, space based systems would be subject to denial, degradation, or destruction which may snip the "network of networks", so critical to modern day warfare.

However, the effects of adversary actions could be mitigated by introducing robust and redundant systems for which technologies have to be developed. Potential short term solutions include use of high altitude air platforms and airships. However, they sacrifice speed in exchange for endurance and would have to be prepositioned which could give away their coordinates for potential neutralisation by the adversary. Additionally, their coverage compared to satellites is more limited since they are closer to the earth's surface.

In the long term a potential solution could be a fleet of small satellites with what is described as "an Operationally Responsive Space (ORS)" launch capability on a more robust platform which provides a distributed but integrated multi-sensor, multi-domain approach to ISR date collection and analysis.

As manufacturing processes and equipment develop further it may be possible to migrate to mass production of such smaller satellites, which can be launched on high power miniature boosters thereby lowering costs and making the future space-based ISR systems more competitive. Continued research in nanotechnology and additive manufacturing will help develop new materials for computing, propulsion and sensing capabilities and miniaturisation. Future miniature satellites could be flown in formation with low RF signatures and be more difficult for adversaries to track or target but yet provide accurate information and reliable communications.

In addition to space-based, near space, and airborne sensors, over the horizon backscatter (OTHB) radar systems would be a central element of an extended-range air and maritime surveillance architecture. An OTH radar system could define the range of maritime precision strike capability. Skywave OTH radar systems emit a pulse in the lower part of the frequency spectrum (330MHz) that bounces off the ionosphere to illuminate a target—either air or surface—from the top down. As a result, detection ranges for wide area surveillance can extend out to 1,000 to 4,000 km.

Electronic Warfare

The main purpose of an electronic warfare system is ensuring the survivability of the platform, naval or airborne, and providing electronic cover for units at the frontline. A typical electronic warfare system can perform tasks like electronic attack, electronic support, and electronic protection. The global electronic warfare market is estimated to reach $24.25 billion by 2020.

Need for spectrum control and evolution of electronic warfare systems into smaller systems have been the main driving forces for this market. Over the years, the system has become a vital necessity since there are no defined borders within the electromagnetic spectrum. The wide ranges of threats like stealth aircrafts, GPS jamming, and remote controlled improvised explosive device (RCIED) that are currently present are driving factors for electronic warfare systems. Furthermore, there is a future threat of hypersonic platforms and cruise missiles. Since battle space is moving from the traditional battlefield to the urban environment, the challenge will be to ensure efficient management of the spectrum. The threat of all these entities forces nations to acquire or develop a suitable electronic warfare system.

Various factors such as changes in the battle space, increasing exploitation of electromagnetic spectrum, and integration of EW systems with other warfighting equipment are driving the electronic warfare market, globally. Rise in the asymmetric warfare and counter insurgencies are propelling the growth of EW market.

Key technology areas in electronic warfare operations are likely to be:

- Development of next generation systems & architectures for multifunction RF intercept systems
- Development of algorithms and implementations for signal detection & characterisation
- RF phenomenology and technologies for future RF sensors & effectors
- Novel sensor technologies, Multiple redundant sensor modes, new spectral domains
- Advanced laser development and demonstration to support electronic warfare

Integrated Sonar Systems for Ships

The advances in signal processing promoted by an exponential growth in computation power and a thorough study of sound propagation in the underwater realm, have led to remarkable advances in sonar technology in the last few years. The changes in enabling technology, processing algorithms and systems architecture have made revolutionary changes in sonar systems; from unitary systems to composite systems where fusion of data from multiple sensors makes sonar displays highly user-friendly. Using commercial off-the-shelf (COTS) hardware has also resulted in size as well as cost reductions. The emerging technologies/research in the area are:

Transducer Technology: Transducer technology is leading to the adoption of LF flextensional type transducers instead of the tonpilz type since the former has much better power handling capacity, and power-to-weight and power-to-size ratios. Flextensional Transducers (FTs) are electro-acoustic transducers, which make use of flexural vibrations of shells and are driven by the extensional vibrations of a driver. The two major components of FTs are the Shell and the Driver. FTs can be characterized into several classes based on the shape of the shell. The driver types can be piezoelectric, magnetostrictive or electrodynamic. Since FTs use flexural modes of vibration of shells, they resonate at low frequencies, and are much lighter when compared to other designs of low frequency transducers. One of the challenges of engineering a class IV FT is the insertion of the driver stacks in the element. The transducer is designed and developed with a transmitting voltage response of 140 dB re μPa/Vrms for towed array sonar. In the future, as thin line towed arrays for small unmanned sea vehicles (USVs) become common, the focus will shift to micro-electromechanical systems (MEMS) based transducers that are miniaturized sensors integrated with signal conditioning, interface circuits and other electronics.

Low Frequency Active Sonar: The degradation in active sonar performance in the littorals due to background interference and environmental volatility coupled with quietening techniques has steered research in the area of low frequency active systems (LFAS). LFAS are able to suppress reverberation by means of broadband pulse processing and frequency-agile techniques, in conjunction with environmentally adaptive processing, to enable the sonar system to adjust not only to different types of background interference but also to the characteristics of the acoustic channel. The processing chain suitable for this system is established to allow the exploitation of broadband technology and the incorporation of in situ environmental information to counteract the effect of complex propagation conditions.

Synthetic Aperture Sonar: One of the major developments in modern sonar technology is synthetic aperture sonar (SAS). Synthetic aperture is a technique that enables high resolution through the coherent processing of consecutive displaced echo data. Instead of using one static large array of transducers, it uses the along-track displacement of the sensors to synthesize a large virtual array. The resolution thus obtained is in the order of the transducer size and, most importantly, independent of the range between sensor and target. While a modern high frequency real-aperture sonar system can have a beam width below 1°, this translates into a resolution of half a meter at a range of just 25 meters. A synthetic aperture system using the same transducer can obtain a resolution of about 5 centimeter across the whole range. Moreover, the transducers used for synthetic aperture can be much simpler and less expensive. Because there is no need to have a small real aperture, the frequency employed can be considerably lower, which enables longer reach due to better propagation of lower frequencies in water.

Integrated Surveillance Radars for Ships

The first radar was patented in 1904 by Christian Hülsmeyer. Numerous innovations in radar system technology with transformational developments in radar system technology and signal processing electronically scanning radar, frequency-modulated continuous wave (FMCW) radar technology and the invention of imaging synthetic aperture radar (SAR). As the technology developed, radars were classified according to functions; from air and surface surveillance, fire control, missile seeker heads, navigation and vessel traffic management systems amongst others.

Although radars became equipped with new semiconductor devices and signal processing technologies, the system-level radar concepts have remained the same since many years; these radars still:

- Transmit the identical signal during operation. Functionality-wise, this is inefficient since the radar will be limited to a narrow field of operation, when there are many different tasks/scenarios that are encountered even for a single radar, e.g. near range/far range, tracking, low/high range resolution, etc.
- Transmit only one frequency band at a time (e.g. FMCW). For overcoming EW the radiation of uncorrelated signals is a necessity. Technologies that exploit the spectrum for opportunistic spectrum usage i.e. cognitive radio, or dual-funtional systems i.e. radar-communication systems, are already being extensively researched to take full advantage of the limited spectrum.
- 'See' only a small area at a time (e.g. phased array). For scanning radars, the conventional method is still to use a narrow beam, which is either mechanically or electronically scanned (i.e. phased arrays). This approach of scanning a wide area for target detection is highly inefficient. Mechanical scanning is cheap, but slow; the phased array method is faster, but rather expensive. In both cases only one beam-width area is scanned at a time.
- Scan mechanically (e.g. airport radar). For scanning radars, the conventional method is still to use a narrow beam, which is either mechanically or electronically scanned (i.e. phased arrays). This approach of scanning a wide area for target detection is highly inefficient. Mechanical scanning is cheap, but slow; the phased array method is faster, but rather expensive. In both cases only one beam-width area is scanned at a time.

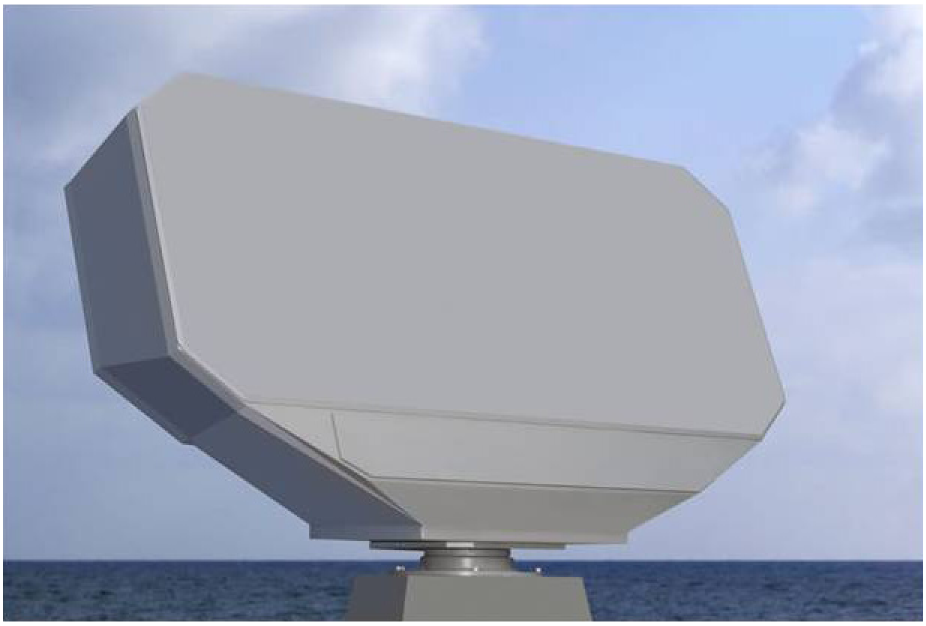

Figure 3: EL/M-2258 ALPHA Radar

Over the last couple of decades, the number of radars being used at sea are rapidly increasing. It is foreseeable that within a few years there will be thousands of radars at sea on ships submarines and aircraft equipped with several different radar systems. Consequently, there will be a selective inoperability in these radar systems due to strong inter-system interferences. Interference within the same frequency band can be avoided if the radar signals are properly coded and are continuously changing for low cross-correlation, like in communications.

The development in SAR systems mainly manifests itself in the utilization of refined processing techniques, which take into account (and mitigate) various geometrical and system error sources. Most advanced digital hardware is used for the signal processing. The main change in the instrument hardware is the incorporation of transmit/receive modules, which enable advanced SAR modes and techniques, but are accompanied by a number of disadvantages regarding complexity, cost and calibration.

The drawbacks of conventional radars mentioned above and some other deficiencies of the current state-of-the-art radars must be overcome in the next ten years. The potential strategies for future radar system concepts will include:

- intelligent signal coding, e.g. OFDM, CDMA
- MIMO Radar – multiple transmit

and receive antennas
- digital beamforming for a higher angular resolution with wide coverage without mechanical moving parts
- array imaging, efficient systems, reduced size and cost
- combination of radar and communication (RadCom)

Other significant developments include the possibility of cognitive radar that relies on a perception-action cycle in which echoic flow is the perception and steering instructions are the actions would enable a robotic vehicle to overcome obstacles and narrow areas.

Passive radar, a different type of radar technology, takes in existing electromagnetic signals from the atmosphere to support imaging and tracking capabilities. Passive radar would be less expensive to operate and is more covert than traditional radar.

Metamaterials (materials engineered to have properties that have not yet been found in nature) may be the next big leap in conventional radar technology. These enhanced materials would drastically reduce the size, weight, and ultimately price of radar devices and find applications outside their target military markets, such as in cars and personal drones.

In addition to revolutionary metamaterials, radar technology now uses standard printed circuit boards and copper wire tracing for its electronic components. By using common electronic parts, this radar technology can take advantage of the existing methods of electronic circuit board repair for maintenance.

These new system technologies will cause a revolution in many basic concepts of electronics particularly the huge potential that Terahertz electronics provides for surveillance and communication systems. In addition to the technical features, these will also allow cost reduction of the systems, increase the efficiency and the development of smart radars drawing upon radar technologies leading to revolutionary radar systems.

Futuristic Torpedoes and Directed Energy Weapons

The past several decades has witnessed dizzying advances in warfare system and component technologies. Modern warfare systems have benefited from exponential increases in computation and signal-processing capabilities while at the same time achieving ever-smaller size, weight, power configurations and innovative software approaches. The explosion in warfare technology sets the stage that provide unimaginable new insights and solutions, unprecedented opportunities, and relentless innovative forces for development of new weapon systems. Against this backdrop, this background paper will examine the future of underwater weapon systems and directed energy weapons.

Figure 4: French Heavyweight Torpedo - F21

Torpedoes

Undersea warfare has changed considerably with the end of the Cold War, in the early 1990s. The focus of naval strategy moved to the littorals, where depths can vary considerably. In deeper littoral waters, the challenges of quiet submarines and torpedo counter-countermeasures remain. In shallow littoral waters, the ASW problem is even more complex and difficult as the operating environment is noisy because of acoustic reverberation, poor sound propagation, local ship traffic, false targets, and bottom clutter. To meet these environmental challenges, future torpedoes need to have significantly improved characteristics, including reduced size to permit more weapons on platforms; reduced acquisition and life-cycle costs; longer shelf life; better deep- and shallow-water and counter-countermeasures performance; greater endurance; flexible speed control; stealth; lethality; and, for urgent-attack weapons, shorter reaction times.

Guidance and Control: Weak and false targets can be dealt with using sophisticated waveforms, enhanced processing, and improved sensors. Enhanced processing and waveforms have the potential to significantly improve performance in a complicated noise environment. Advances in computational processors and software technology are the key enablers that allow "smart" behaviour in a hostile combat environment. In addition to improved signal and tactical data processing, acoustic and fibre-optic communications will provide the connectivity to allow fusion of torpedo sensor data with platform information to yield an improved tactical picture for combat control systems. An intelligent torpedo controller will enable the weapon to adapt to dynamic situations, using neural nets and fuzzy logic, and an ultra-broadband array will dramatically improve its sonar capabilities. Such an ultra-broadband, multi-beam array, which in conjunction with new waveforms, signal processing algorithms and improved torpedo tactics will allow for greatly improved countermeasure rejection in shallow water, while maintaining current performance in deep water. Overall, by using transparent array technology in a new front end, with many narrower beams to resolve closely spaced objects and countermeasures, this combination will provide a quantum improvement over today's torpedo effectiveness. The technology will lead to a formidable new littoral weapon. Advances in Nanotechnology, which is a very strong innovation driver should lead to higher protection, more lethality, longer endurance and better self-supporting capacities. Substantial advantages are expected to be gained which include threat detection, novel electronic display and interface systems, as well as for the development of miniaturised systems.

Use of countermeasures is very dependent on the detectability and classification of incoming weapons. Improved weapon stealth and stealthy launch shorten the time available to

Figure 5: "Super Cavitating" Torpedo - Shkval

detect and identify an attack and then deploy effective countermeasures, and thereby improve the ability of the weapon to acquire a target by reducing self-induced noise. This problem can be solved with advanced passive homing techniques, covert active waveforms with LPI (Low Probability of Intercept) and LPR (Low Probability of Recognition) properties, and associated signal processing along with a further reduction in radiated noise from the propulsion system. The quiet electric or hybrid propulsion system employing the Integrated Motor Propulsor (IMP), which incorporates a radial-field electric motor directly into the torpedo propulsor, thereby completely eliminating an internal motor, through-hull shafts and seals, and creating a single connection point to the hull, where advanced isolation can be utilized for increased stealth. This closed-cycle propulsion will be quiet, wakeless, and depth-independent. Additional quieting will be achieved using active noise-cancellation techniques and smart materials.

Speed: As these new torpedo technologies take shape, they promise some dramatic departures from the configuration of the current weapons. Pushing the speed envelope, for example, will greatly affect torpedo performance and resulting effectiveness - the ability to kill a target before it can react provides a distinct advantage. Using "super cavitation" techniques, the torpedo becomes an underwater missile, capable of reaching its target before the threat can respond. In this approach, the water near the tip of the projectile - or torpedo - literally vaporizes from the high speed, producing a pocket in which to "fly" the weapon underwater. Traveling in such a vapour pocket provides dramatic reductions in drag, which allows developing extremely high velocity for a given input power. Such a weapon would be well suited for close-range submarine encounters. With multi-purpose configurations, it could be used not only for anti-submarine warfare, but also as an anti-torpedo torpedo, or for defence against high-speed surface craft

Warhead Improvements: Torpedo payloads will also see improvement in the future. Warheads will be capable of multi-mode detonation, offering both bulk-charge and directional alternatives. They will provide higher lethality and use increasingly energetic materials to create more powerful effects, while still meeting the requirement for insensitive munitions. This would provide the torpedo more "bang for the buck," and provide the potential for weapons to be smaller and lighter, with increased range capability or room for additional sensors and signal processing. With high speed torpedoes perhaps warhead may not be required as the torpedo can deliver a "kinetic" kill.

The operating environment for torpedoes continues to change. Undersea networks for communications, sensors, and tactical engagement continue to develop through advances in acoustic communications and fibre-optic links. Fusion of data from platform, weapon, and off-board sensors will require a next generation of torpedoes that can communicate with the network and benefit from intelligent control. They may be deployed not only from submarines, but also from unmanned undersea vehicles that become remote firing platforms and keep the submarine out of harm's way.

Anti-Torpedo Technology: The advances in technology has also led to development of a weapon system that seeks out other weapons, by solving the technical challenge of

Figure 6: Vehicle Mounted DE Weapon System

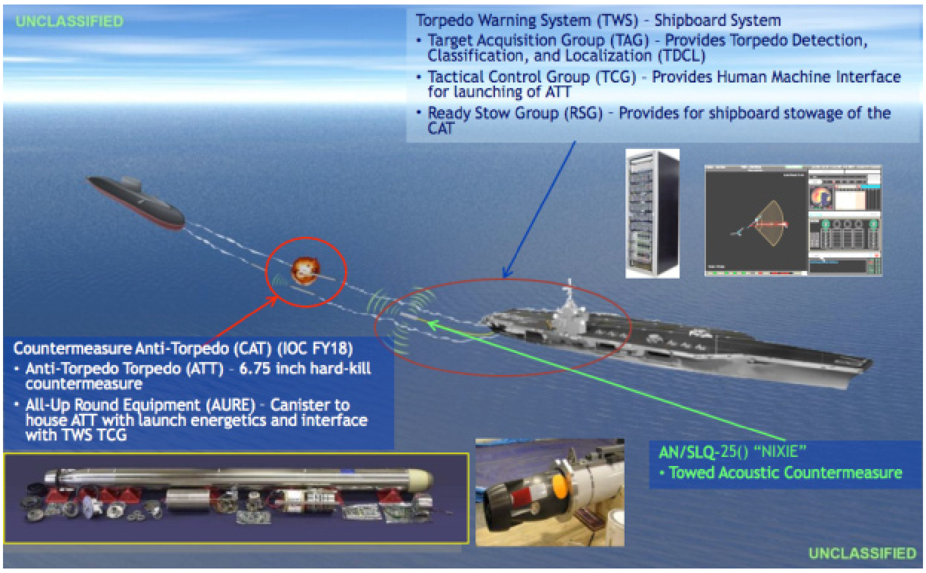

Figure 7: Torpedo Countermeasure

being able to locate and track another fairly small object using a very small array with limited directivity and also overcome significant amounts of self-noise and flow. noise. The Surface Ship Torpedo Defence (SSTD) program under development pairs a Torpedo Warning System (TWS) towed behind the ship with a highly manoeuvrable Countermeasure Anti-Torpedo (CAT) that seeks and destroys the incoming enemy weapon

Directed Energy Weapons

Directed energy (DE) as an umbrella term covering technologies that produce concentrated electromagnetic energy and atomic or subatomic particles. A DE weapon is a system using DE primarily as a means to incapacitate, damage, disable or destroy enemy equipment, facilities and/or personnel. These weapons can inflict casualties and damage equipment by depositing energy on their intended target. Compared with conventional weapons, which rely on the kinetic or chemical energy of a projectile, DEWs hit a target with subatomic particles or electromagnetic waves that travel at speeds at or near the speed of light. DEWs generate very high power beams and typically use a single optical system to both track a target and to focus the beam on the target in order to destroy it. With the maturation of DE technology, weaponized DE systems are becoming more prolific and powerful, and a significant subset of the electronic warfare mission area.

DEWs, including high-energy lasers (HEL), high-power microwaves (HPM) and related radiofrequency technologies, offer the prospect of cost-effective precision attack or enhanced point defence and can provide war fighters with flexible non kinetic employment options. High-power microwaves open up new avenues for non-kinetic effects, a significant advantage for controlling escalation or limiting collateral damage. Lasers--the most mature form of directed-energy weapon that can counter airborne threats--form intense beams of light that can be precisely aimed across many kilometres to disable a wide range of targets: from satellites to missiles and aircraft to ground vehicles. Additionally, the laser beam can be redirected by mirrors to hit targets not visible from the source--all without compromising much of the beam's initial power.

High-energy lasers, afford the prospect of effects ranging from temporary sensor-dazzling through system destruction. Some chemical lasers, designed for strategic missile defence purposes, have demonstrated megawatt-level output. But the large footprint, complex logistics and various technical challenges associated with chemical lasers eventually led to their cancellation. Current developmental megawatt-class systems emphasize free-electron and diode pumped alkali laser technologies. More recent developments in solid-state and fibre lasers, designed primarily for tactical engagement, feature lower-power systems designed for forward-deployable platforms. High-power microwave weapons have proven capable of gigawatt-class power output that can disrupt or even destroy modern electronics, but at comparatively short range. Radiofrequency weapons can also use millimetre waves for antipersonnel applications such as crowd control or perimeter security.

Figure 8: US Navy's Laser Weapon System (LAWS) aboard USS Ponce

Present Status: DE weapons have demonstrated sufficient technical maturity that they may be integrated into naval, air and ground force structure for various mission applications within the next decade. While more modest in power and capability than previous large-scale DE programs, modern HEL and HPM weapons can help defend ships and bases from some forms of attack; enhance the performance of existing combat identification, self-protection and other systems; and provide novel counter electronic attack options.

During the past two decades, areas such as power, beam-control, and pointing and tracking techniques have been resolved. However, for the weapon to become serious contenders the technical and attendant problems to be addressed are that these weapons should:

- Be scalable, offering both high and low power output potential;
- Demonstrate the ability to operate effectively at a wide range of frequencies;
- Be compact and highly efficient, to minimize power, cooling and other system component requirements;
- Feature modular designs, able to fit within and operate from a variety of platforms;
- Require little training or special handling;
- Have a light logistics tail and consumables footprint; and
- Be available when needed, capable of rapid and sustained operation.

Effectively meeting technical challenges including, beam quality and thermal management — and packaging for use on appropriate operational platforms — are key to their future prospects. These and similar emerging concepts and technologies will form the substance of the discussions of this session.

Submarines and Anti-Submarine Warfare

Recent Advances in technology, particularly submarine detection have the potential to fundamentally change the way ASW is conducted. The submarine as a platform will lose some of the immunity it enjoyed and this will push torpedo engagement ranges further out or force a reversion to long-range anti-ship missile engagements. Some advances will help the submarine too. Either way, the submarine engagement dynamic will change. What would happen if the nuclear attack submarines—some of the most sophisticated and expensive weapons of war—suddenly became obsolete? Imagine a scenario where they become the hunted instead of the hunter. This is what new technologies will lead to.

Submarines for long have been considered immune to adversary A2/AD capabilities. However as each successive decibel of noise reduction becomes more expensive to hide and as new detection methods mature that rely on phenomena other than sounds emanating from a submarine, this immunity will soon be challenged.

Some of the technologies that are challenging the invincibility of the submarine are listed below. Most of the technologies will ensure that the submarine can no longer loiter at will close to enemy shores:

- *Lower frequency active sonar (LFA):* LFA systems will soon be ready and would be deployed throughout 80% of the world's oceans. LFA uses intense sound, (at levels of 235 decibels or greater) generated by massive sound transmitters towed behind suitably fitted surface ships. Low frequency sound [100-1000 Hz] to travel great distances and detect quiet submarines. LFA will attack the shallow-water acoustics problem which has gained importance due to the increased salience of regional conflicts where Navies will deploy diesel submarines or UUVs close to shore.
- Non-acoustic methods that detect submarine wakes or wave effects on the surface and in the water, (at short ranges), bounce laser or light-emitting diode (LED) light off a submarine hull are also developing at a rapid rate and could be deployed from UAVs for localisation. These will become tactically useful, with processing and modelling improvements to enable real-time detection. The technologies include radar, electro-optical and infrared detection of surface effects.
- Today, "big data" processing is enabling navies to run sophisticated oceanographic models in real time to exploit these detection techniques. This means that inputs from various sources can be collated on a real time basis and compared with existing surface pictures, making the oceans virtually transparent. Improved processing has also ensured increasing detection ranges passive sonar technology.
- A revolution is also occurring in undersea communications; wired systems, fibre optic, laser, radio frequency, acoustics, light emitting diodes, are all being used to transfer data and information. The techniques vary widely in bandwidth capability and transmission speed, but combined into a network, they can become effective and combined with better processing, can threaten a submarine.
- Air-dropped drones and underwater craft called gliders are being employed to track enemy submarines. The US Navy is known to launch Coyote drones fitted with Magnetic Anomaly Detectors, from aircraft and, to hunt for submarines.
- The construction of large virtual arrays, coupled with the move to bi-static low frequency sonar, will dramatically increase sonar array sensitivity and submarine detection ranges.
- New anti-submarine weapons such as a cruise missile fitted with a long range but light weight torpedo will be used in ASW operations. These will be launched

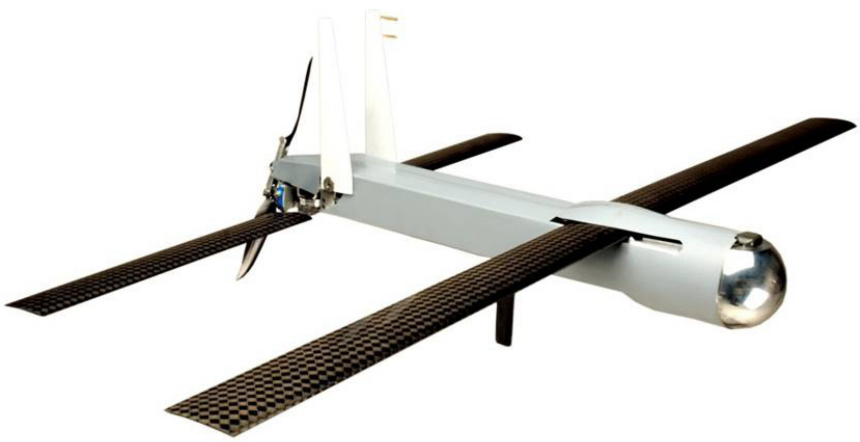

Figure 9: BAE Cayote UAV

from ranges way beyond the sensor capability of the submarine.

The submarine as a platform too is benefiting with the developments in technology in the following areas:

- *Lithium Ion Batteries:* Lithium Ion Batteries will improve the performance of conventional submarines greatly. These batteries are lighter, have a greater capacity and charge faster than the existing Lead Acid batteries. The Soryu class will be the first class of submarines to use them. These batteries will also greatly enhance the loiter capabilities of long range UUVs.
- *Air Independent Propulsion Systems:* The over 300 conventional submarines that will populate the worlds navies in the next 10 years have fuelled the quest for the perfect AIP. All the existing systems such as the Fuel Cells, Closed Cycle Diesels, and External Combustion Engines etc are expected to see great improvements and will continue to provide a cheaper and less controversial alternative to nuclear propulsion. The DCNS super-sized "SMX-Ocean", an AIP fitted submarine will offer an incredible 18,000 mile range at an average of 10 knots submerged, and the ability to patrol for 90 days.
- *Active Noise Cancelling:* While the physics has been long known, now systems exist that continuously record the generated noise and vibrations of a platform and balance them with counter noise and balancing.
- *Optronic Masts:* Electro-optical masts that can sweep the horizon with high-definition in seconds and drop out of sight. The US Navy experience of operating of the coast of Libya has contributed greatly to this and the latest Virginia Class of submarines is the first submarine with no optical periscope.
- *New torpedoes and other weapons:* The ranges and capabilities of missiles and torpedoes have risen considerably, allowing the submarine to engage targets at much greater ranges and also keeping it away from the shallow coastal areas. The Russians launched their cruise missiles at a range of over 1500 km recently.
- *Docking Capabilities:* Submarines can now mate with manned and unmanned air and underwater vehicles (UUV), allowing for launches of specialised teams at extended ranges, providing safety to the platforms (seen on the latest Virginia class).
- *Advanced Anechoic Coatings:* Anti sonar coating for submarines that will allow them to become virtually invisible during combat service is being developed by the Russians in St. Petersburg. This coating will not just absorb the sonar signal (as do the existing passive coating materials of submarine hulls), but neutralize incoming radiation. The embedded electronics in the coating will determine the frequency at which the radar/sonar of the opponent operates and launch its own signal of the same frequency but in opposite phase. The development will be universal for all submarines and will have to work wit h advanced computer systems for the submarine fleet.

Figure 10: OMS 200 Low Profile Optronic Mast

The list of technologies is by no means comprehensive but draws attention to where we are headed. The impact will be that submarines will cease to be front-line tactical platforms (like strike aircraft) and become more host and coordination platforms like aircraft carriers. The erstwhile traditional tasks of operating near the enemy's coast will be taken over by extremely capable and intelligent UUVs with extended ranges such as the "Anti-Submarine Warfare Continuous Trail Unmanned Vessel" (ACTUV) that weighs 140 tons and is over 40 metres long and is in an advanced stage of development by the US Navy. The ACTUV is completely autonomous, and will be aided by sonar buoys. The ACTUV will use its own sonar to detect diesel electric submarines. Unmanned, the ACTUV can follow these submarines for months with no need to dock or resupply. It can also be used for reconnaissance missions, as well as deliver supplies to other vessels and counter undersea mines.

The above are only some of the many emerging technologies that will impact how navies structure their submarine forces in the future. Interesting and innovative solutions will also enter the anti submarine arena as the fight for the underwater domain intensifies for control and access to the littoral and the global commons. The deliberations of this session would throw light on some of these matters and provide some direction to Indian industry and the Navy for fostering partnerships of the future.

Naval Aviation and Future Technologies

Aircraft technology has changed enormously over the last century from the early Wright Flyer flown at Kittyhawk to the supersonic SR-71 Blackbird that took to the skies during modern times. The main claim of the Wright brothers was that they were the first to design and build a flying craft that gave the pilot adequate control while in the air. The unique feature of the Wright brothers' aircraft, beginning with their 1902 glider, was the ability to roll the wings right or left, to pitch the nose up or down, and to yaw the nose from side to side. This development was perhaps the Wrights' greatest contribution to aviation. Military aviation has adapted the advances in technology in aeronautical engineering into their aircraft well. The requirement to seek advances in aeronautical engineering is being driven by the futuristic requirements of military aviation. However, in some aspects the advances made in commercial aircraft technology are also being adapted by the military aviation for a better airborne platform.

There are many studies being undertaken towards incorporation of future technologies into naval aviation. Such studies have identified several functional areas as highly relevant to naval aviation: Some of those are avionics technology, sensors, propulsion and power, structures and materials, survivability and the core technologies of aerodynamics, modelling and simulation.

Avionics Technology

The superiority of naval aviation and the realization of the "know quickly and act decisively" concept are critically dependent on situational awareness, excellent communication and coordination, rapid precision strike and greater employment of unmanned aircraft. Advancement of avionics technology is integral to each of these concepts. Towards these advances in computing speed, memory density, wireless networks and distributed computing are being driven by commercial market forces and the military aviation by itself would need to focus towards the advanced avionics technologies in multispectral defense, unmanned air vehicles and intelligent combat information management. Advancement in these technology areas is expected to be central to the future of naval aviation.

- *Multispectral Defense:* Current low-observable (LO) technologies rely primarily on shaping and materials. Naval aviation can expect to encounter today and in the future adversarial air platforms with varying degrees of LO signature. Shaping and materials can achieve significant reductions in signatures, but they will not be sufficient for naval aviation in the future. The next LO frontier is visual signature reduction. It could possibly involve active systems that change colour or hue, reflectivity, or emittance. Active systems would require advanced high-speed electronics with robust sensors and detectors, high-speed networks and advanced processing algorithms.
- *Unmanned Air Operations*: Significant advancements in the level of autonomy will be required to improve the effectiveness of UAVs. Operating such vehicles from a rolling ship deck as part of a mixed bag of manned and unmanned systems is unique to naval aviation. Constellations of self-organizing and self-directing UAVs with human "control by exception" for automatic surveillance, reconnaissance, targeting, and attack; Self-contained automatic carrier/ship landing capability with very-low-probability-of-intercept emissions from the aircraft platform and the ship that does not have to emit a signal; and reduced need for human involvement in UAV operations is the technological need of the future.
- *Intelligent Combat Information Management*: Naval aircraft need a new digital high-speed intelligent combat information management and display system (IMDS) that prioritizes and synthesizes the volumes of information generated on board the aircraft. It would automate many of the functions and lower-level decisions made today by the pilot to enhance situational awareness and avoid information overload. Research and development into IP-based, high-bandwidth, optical aircraft intranet structures for on-board data management systems is going to greatly reduce the cost and weight of the avionics infrastructure.

Sensors

The key to the success of network-centric war-fighting concepts in naval aviation is the cooperation of multiple sensors and sensor platforms and the successful implementation of multi-sensor fusion, exploiting the information from multiple sensors distributed throughout the battle space to create, in real time, continuous and complete battle space awareness. Development in technology towards sensors for multispectral defense, micro UAV's, hypersonic weapon delivery system, omniscient intelligence is already in progress. Few sensor related technologies under development are:

- *Digital Creep*: As the performance of digital chip technology continues to increase exponentially, the trend in sensor systems is to convert the signal to digital, closer and closer to the front end of the system and produce very capable "smart" sensors.
- *Nanotechnology*: Nanotechnology has much to offer for enhanced sensor capabilities. Operating at nano-level, it is becoming possible to construct many artificial materials that do not appear in nature and that could have novel and unusual mechanical, electrical, or optical properties.
- *Perfect Imaging*: A few years ago, artificial materials consisting of oriented wires and embedded rings were constructed and the possibility of "perfect imaging" or super-lenses was demonstrated. With the potential to bypass the diffraction limitations of radar antennas, so-called perfect imaging could offer major advances in radar sensors, particularly for MMW imaging from small platforms.

Propulsion and Power

Various materials and component technologies are being studied so as to achieve about 20 percent improvement in fuel consumption and 30 to 35 percent improvements in thrust, range, payload, and maintenance cost in the aero engines. Lot of research work is also being undertaken globally towards Jet engine noise reduction. Towards this, active combustion control is a promising research area from which several valuable enabling technologies may develop. Simple and inexpensive engine designs are being studied so that costs for weapons delivery systems reduces substantially.

Structures and Materials

Navy aircraft do everything that land-based aircraft do but in a more hostile environment and under more adverse conditions, demanding readiness to respond in all sea states, in all weather conditions, and from both large and small ships. Deck landings, catapult take-off and arrested landings impose high-impact structural loads that threaten either fracture or low-cycle fatigue failure of landing gear and other structural components. The environment exposes all structural components to extremes threatening both corrosion and stress-assisted failures. Limited storage space leads to design options that differ markedly from those of comparable land-based aircraft, and these design differences impose materials selection options that may differ radically from those for their land-based counterparts. As with all naval aviation, affordability and supportability in a maritime environment cannot be sacrificed in the name of higher performance. Two important new advances in materials development that promise to herald a new generation of organic matrix composites are:

- *Nanotubes*: Carbon nanotubes offer the opportunity for control of strength and electrical conductivity in the materials used as strengthening fibre for organic matrix composites. Single-walled tubes remain expensive and difficult to process, although that may change in the near future as a result of many research endeavours worldwide. Multiwall tubes are already available in large quantities at reasonable prices and may be quite suitable for composites fabrication.
- *Self-Healing Composites*: Current strategies for self-healing composites are based on inclusion of microscopic encapsulated epoxies that are activated by crack propagation and polymerize to strengthen the material ahead of the moving crack tip and arrest its further motion. This proven concept needs further development to eliminate their current composite mechanical property degradation. BAE systems is currently working on a program where a lightweight adhesive fluid inside a pattern of carbon nanotubes is released when damaged to quickly 'set' mid-flight and heal any damage. This advanced use of materials would create a highly survivable jet, helicopter capable of entering even the most dangerous of scenarios to complete vital missions.

Survivability

Survivability is achieved according to a multidiscipline approach involving avionics, sensors, propulsion/power, structures and materials, and so on. These areas must be worked on collectively as an integrated product to arrive at an affordable and survivable design.

Core Technologies

In addition to the aviation technologies discussed above, efforts are being made towards advancement of fundamental core technologies of aerodynamics and dynamic modelling and simulation.

- Advancement in aerodynamics would play a substantial role in hypersonic flight technology. Computational fluid dynamics (CFD) capabilities is being studied in detail to handle unsteady transitioning flows.
- Noise and vibration of Helicopters can lead to detection by an enemy force and also to fatigue of the helicopter crew and structure. Development process towards capability to create designs with dramatically reduced noise and vibration requires fundamental improvements in dynamic modelling and simulation is already underway.

Designs of the Future

With environmental legislation becoming ever so strict it is imperative that new concepts for lightweight and fuel efficient aircraft are found swiftly. Major development and research work is in progress to develop advanced composite materials. Significant research and development is being undertaken to map out and resolve all issues related composite materials Apart from carbon fibre and other composites other researchers have been looking into completely redefining the shape of aircraft. Few such futuristic designs include:

- *Blended Wing Concept*: NASA and its industry partners are investigating a blended wing aircraft concept for potential use as a future air transport for both civilian and military applications. The concept is called the blended wing body (BWB). The BWB is a hybrid shape that resembles a flying wing, but also incorporates features from conventional transport aircraft. This combination offers several advantages over conventional tube-and wing airframes. The BWB airframe merges efficient high-lift wings with a wide aerofoil-shaped body, allowing the entire aircraft to generate lift and minimize drag. This shape helps to increase fuel economy and creates larger payload (cargo or passenger) areas in the center body portion of the aircraft.
- *Transformer*: NASA is exploring the technology of morphing or shape-changing aircraft (Transformer), taking inspiration directly from nature.
- *Disc Rotor Compound Helicopter*: US Defense Advanced Research Projects Agency (DARPA) is funding this development. This intriguing design is a cross between a helicopter and a fixed-wing airplane, with the helicopter blades extending from a disc sitting atop the aircraft and letting it take off and land like a helicopter. However, once those blades are retracted into the disc, drag is minimised and the aircraft can fly like a fixed wing aircraft, powered by engines beneath each wing.
- *On board 3D Printing*:BAE systems is spearheading this project. Smaller UAVs are created by super high-tech on-board 3D printers, via additive layer manufacturing and robotic assembly techniques. The 3D printers respond to data fed to them by a remote control room where a human commander decides what should be produced. After use the UAVs could render themselves useless through dissolving circuit boards or they might safely land in a recoverable position if re-use is required.

Network Centric Warfare and Combat Management Systems

Network Centric Warfare

War is a product of its age. The tools and tactics of how we fight have always evolved along with technology. Warfare in the Information Age has to embody the characteristics that distinguish this age from previous ones.

Often in the past, military organizations pioneered both the development of technology and its application. Such is not the case today. Major advances in Information Technology are being driven primarily by the demands of the commercial sector. Furthermore, Information Technology is being applied commercially in ways that are transforming business around the globe. These characteristics affect the capabilities that are brought to battle as well as the nature of the environment in which conflicts occur.

Network Centric Warfare is based around the achieving Information Superiority by networking sensors, decision makers, and shooters to achieve shared situational awareness, increased speed of command, and higher tempo of operations. Information Superiority is then to be translated into increased combat power across the spectrum of operations. Improved collaboration and other attributes of command and control will not make up for weapons that are insufficient or inappropriate for the task at hand. Thus, it is important to remember that we need balanced mission capability packages to satisfy our operational warfighting requirements. To reach its full potential, Network Centric Warfare must be deeply rooted in the art of warfare. We cannot simply apply new technologies to the current platforms, organizations, and doctrine of warfare.

Building Blocks

At the entry level of building a Network Centric capability is an infostructure that provides all elements of the warfighting enterprise with access to high-quality information services. What separates the future from the present will be the provision of nearly ubiquitous information services to all elements of the warfighting enterprise.

At the intermediate level are various types of command and control activities, such as coordination of tactical combat operations, which can tolerate information delays on the order of seconds. These operations are typically supported by tactical data links.

At the high end of the performance spectrum is cooperative sensing and engagement of high-speed targets. Accomplishing this requires high data rate and very low latency information transport capabilities.

Technological Aspects

Information technology is one of the obvious force multipliers, which is based on three technological revolutions. The first one is the revolution in sensor technology. The new sensors are able to achieve near-real-time surveillance over vast areas, while they are becoming smaller and cheaper. More and more sensors can be netted to detect, locate, identify, and track targets. The second revolution is the gigantic increase in computing power necessary to process, collate, analyze, store this vast quantity of data, and means to distribute information to any recipient anywhere in the world at near-real-time speeds. The third one is in weapons technology. The weapons revolution is a matter of increasing numbers of precise munitions by reducing costs, time and the grade of the unnecessary destructions.

Engagement Envelope

Real payoff of Network Centric Operations involve a transfer of intelligence from the weapons or sensors to an information infrastructure or “info-structure”; and decoupling of sensors from weapons platforms. This provides us with the ability to enlarge the engagement envelope, increase operating tempo and responsiveness, improve manoeuvrability, and achieve higher kill probabilities.

One good example is use of the Cooperative Engagement Capability (CEC) to improve Navy’s ability to conduct Air Defence by enabling incoming targets to be engaged in depth with multiple shooters, with increased probability of kill. In this mission area, time is a key factor since there is a limited amount of time available to detect, track, classify, and engage targets. Engagement time is further compressed for high-speed or low-observable targets. This stresses all elements of the combat power value chain: sensors, command and control, and weapons. CEC increases combat power by changing the relationships between battlespace and battletime. The CEC is enabled by the close coupling of an integrated communications capability with a computational capability. This infostructure provides a high

Figure 11: SAAB 9LV CMS

performance backplane which is key to increasing the velocity of information among sensor, C2, and fire control nodes. The netting of sensors generates a level of battlespace awareness that far surpasses the ability of sensors operating in stand-alone mode.

Another example of extending the engagement envelope involves enabling forces to engage beyond their line of sight. A necessary condition for engaging targets without organic sensors or beyond line of sight of organic sensors is for engagement quality information to be generated externally and made available to the weapon or weapons system.

Asymmetric Capabilities

Wealth and power have always been closely interrelated, with significant capital being necessary to obtain the instruments of power (weapons and armies). Today's world is, in some ways, a far more dangerous place because more players can afford the investments needed for weapons of mass destruction (WMD) and terror. They can now be increasingly found in the arsenals of terrorists, financed by rogue states or even wealthy individuals. The increasing availability and affordability of information, information technologies, and information age weapons increases the potential for creating formidable foes from impotent adversaries.

Combat Management Systems

Naval Combat Management System (CMS) is a software intensive system which has to be flexible enough to operate in a complex naval battle environment A Naval CMS has to perform the following key functions:

- *Situational Awareness*: To be aware of the battle environment at sea which includes surface, subsurface and air. This is collected through sensors like radars, electro–optical systems and sonar.
- *Intelligence*: Convert the above information into actionable intelligence by interpretation, collation, evaluation thereby producing a common operational picture.
- *Planning and decision-making*: This step helps the commanders to rapidly make an actionable plan for decision-making and implementation, in a rapidly changing complex battle environment.
- *Weapon systems command and control*: An effective NCMS will also direct weapon sensors and weapons to engage and destroy incoming threat.

The above functions are carried by the CMS through the crew, sensors and weapon systems. The whole system could be part of the network centric warfare (NCW) where each system becomes a separate node with similar nodes on other vessels. NCW concept is more autonomous than hierarchical. NCMS is a software intensive system which has to be flexible enough to operate in a complex naval battle environment, electronically interact with other subsystems and be interoperable with systems of vessels of own navy as well navies of friendly countries. It should be able to cope with mass information with minimum crews. CMS is simple in concept but complex in designing as it has to be tailor-made to suit the operational doctrines and hardware held by a specific navy.

Summary

Network Centric Warfare has the potential to increase warfighting capabilities by orders of magnitude. The conference deliberations will provide a common platform for industry and the navy to explore various firm-specific and generic technologies and concepts that offer the best potential to transform the war at sea and thereby generate the specifications for a future ready Indian Navy.

Futuristic Trends in Nuclear and Electric Propulsion and Power Generation Technologies

Nuclear Propulsion

Submarine operations during World War II navies demonstrated that the submarine was most vulnerable when on the surface to recharge its batteries. The key advantage of nuclear fuel over conventional fossil-fuel propulsion is its atmosphere independent ability and to operate for long stretches at a time without refuelling/surfacing. Therefore, a propulsion package that would free the submarine from its requirement to surface and operate for extended durations continuously would be a true game changer in naval warfare and if it could outrun a torpedo the balance would clearly shift from air and surface to sub surface. The solution lay in nuclear power since it operated in a closed cycle independent of the atmosphere and once fuelled the propulsion plant could operate over several years.

Early investigations of the feasibility of nuclear propulsion for submarines began in 1946 when the US Atomic Energy Commission and the US Navy, assisted by GE and Westinghouse, commenced studies on a suitable nuclear power plant for a submarine. These studies considered two different types of reactors--water-cooled and liquid metal-cooled.

In a Pressurised Water Reactor (PWR), the primary coolant is water which in the primary system is pumped under high pressure to the reactor core where it is heated by the energy generated by the fission of atoms. The heated water then flows to a steam generator where it transfers its thermal energy to a secondary system where steam is generated and flows to turbines which, in turn, spin an electric generator. Boiling Water Reactors (BWRs) circulate water which is radioactive outside the reactor compartment, and are also considered too noisy for submarine use.

On the other hand, a Liquid Metal Reactor (LMR) uses a molten metal for the reactor coolant and, because of very little moderation, the neutrons maintain their energy and these are termed “fast.” The molten metal coolant circulates through heat exchangers to generate steam to drive a power turbine. The most common LMR coolants are sodium, sodium-potassium, and lead-bismuth.

It was also evident that unlike shore based installations, naval reactors must have ruggedness to withstand extreme shock loads that might occur in a collision or an attack without losing integrity or compromising the ability to operate the reactor; support rapid and frequent power changes to accommodate manoeuvring; endurance to preferably last the lifetime of the platform, while ensuring safety of the crew and preventing environmental damage.

The nuclear era began with the PWR commissioned on the USS Nautilus in 1954 which was followed by a LMR on the USS Seawolf. The first Soviet nuclear submarine, also using PWR, Leninsky Komsomol, joined in 1958. The icebreaker Lenin was the world’s first nuclear-powered surface vessel (20,000 dwt), commissioned in 1959. The first batch of nuclear powered surface ships of the US included the cruiser USS Long Beach and carriers USS Enterprise and the USS Bainbridge. All of them used PWR propulsion plants for a variety of reasons. First, LMR were noisy and thus could be detected several hundred miles away requiring these submarines to operate deeper which meant that the casing had to be strengthened using Titanium which drove up the production cost. Second, the LMR operated at a much higher temperature and more corrosive medium requiring better insulation. The key operational problem was in ensuring that the coolant did not freeze when the reactor was shut down and therefore either the plant was kept running or required shore infrastructure to utilise the power. The LMR could deliver higher speeds but the accompanying hydrodynamics, noise and tactical benefits did not require speeds in excess of 33 knots.

But the challenge lay in being able to overcome replenishment of the nuclear fuel and disposal of the spent fuel at periodic intervals. The Sturgeon-class attack submarines had to refuel every eight years, or three to five times over its lifespan. The Los Angeles-class, refuelled only once or twice over its 33-year lifecycle. The Virginia-class managed to do away with the process over its 33 year life span. Now, the onboard nuclear power plant for the Ohio-class ballistic missile submarine which may be in service in the next 15 years is expected to have a life-of-the-ship reactor.

Since the reactor must be small enough to fit in the confined space of a ship/submarine at sea, most naval reactors have relied on highly enriched uranium (HEU) for their fuel, which can generate more energy by volume than low-enriched uranium (LEU) as a result of the greater density of fissile Uranium-235 present in HEU. Navies of the US, Russia, the UK, and India are known to utilize HEU to fuel their nuclear-powered submarines and surface ships. Though some of France's earlier generation submarines utilized HEU, its newer submarines and the aircraft carrier Charles de Gaulle utilize fuel enriched to less than 10 percent Uranium-235, known as "caramel" fuel. Caramel fuel increases the efficiency of the burn-up of Uranium-235 so that lower enrichment levels and/or smaller reactor volumes can be employed with a greater energy yield.

So, as nuclear technology matured, navies froze the nuclear propulsion option by opting for PWR reactors for their fleet of carriers and submarines. In the case of surface ships, however, the nuclear- conventional power issue remains controversial. Aircraft carriers beginning with the USS Enterprise had eight A2W units of 26 shaft MW and were refuelled three times. The Nimitz class uses two A4W units of 550 MW each. The Gerald Ford-class carriers have A1B reactors which are reported to be 25 percent more powerful than A4W but adequate to run fully electric ships including the electromagnetic aircraft launch system (EMALS). The latest Ford-class carriers are designed to be refuelled in mid-operational life of 50 years. At the other extreme are the French Rubis-class submarines which have a 48 MW integrated PWR reactor. The Indian Arihant class is powered by a single 85 MW PWR.

PWRs have evolved over the times. Innovations and improvements include higher level of steam pressure and plant efficiency using an axial economiser, neutron reflector surrounding the reactor core which lowers uranium consumption, fully automated digital controls and modular designing, passive protective safety measures, burnable absorbers that contain "poison" etc that make PWRs safer, economical and add years to its life.

Now new technologies are developing which may transform the way nuclear power is utilised at sea. One example is TerraPower's travelling wave reactor (TWR) which is liquid sodium-cooled fast reactor based on existing fast reactor technologies. Though Uranium-235 is the main fuel for today's nuclear reactors where Uranium-238 is a set aside as waste, the new generation TWR will use a new method to extract energy from Uranium-238. Innovations in metallic fuel, cladding materials such as advanced steel alloy, HT9, allow TWRs to utilize Uranium-238 as their primary fuel. These innovations would eliminate or reduce the need for enrichment, reprocessing, waste storage and disposal, greatly improving fuel efficiency and are presently targeting a 40 year life span of the TWR.

The design process is itself driven by developments in technology which have fast tracked the concurrent design and testing process. These combine proven fast reactor technology, pairing cutting-edge computing power with real-world data, high-performance computing simulations and testing in a "virtual reactor" to study the reactor's operation from start-up to full power which may make the TWR concept a "naval" reality perhaps in the next 10-15 years.

Other Technologies in Propulsion

Various ship requirement factors drive the type of propulsion system that is selected for a ship. These include the maximum sustained speed required, operating profile, acquisition cost constraints, industrial base capabilities, and the maturity of any new technology being considered. Ships under construction are already utilising a variety of newly designed propulsion systems such as diesel-electric propulsion system, hybrid propulsion system consisting of gas turbines, for high-speed use, and diesel engines, for efficient low-speed cruising. For example, US Navy's DDG 1000 will have an Integrated Power System consisting of four gas turbines and two advanced induction motors. The amphibious replacement ship, LHA 6, will utilize a combined gas turbine and electric propulsion system instead of the steam propulsion systems used in many amphibious warfare ships.

Conventionally, propulsion and power generation packages have been separated on war ships. Now, various improvements have been made to conventional propulsion systems, such as the Integrated Power System, which produce electrical power for both the propulsion system and ship's support systems. Instead of the propeller drive shaft being connected to the engine through reduction gears, the Integrated Power System enables the propeller to be connected directly to an electric motor without the use of reduction gears. Such an Integrated Power System would provide the electrical power for transformational weapons systems on future ships, improve survivability by allowing rapid reconfiguration of power, and reduce acoustic signature or detection by sonar. The design of the Integrated Power System will require fewer components to the system, which, may result in reduced maintenance requirements and life cycle costs. However, such electric propulsion options have a limited speed envelope.

Navies are exploring new technologies to improve propulsion and support systems such as superconducting motors, fuel cells, and high-speed generators. Superconducting motors, using special materials to reduce resistance and employing cryogenics to reduce temperatures within the motor, will be more powerful and smaller, thereby reducing weight and saving space for other purposes. High-speed generators, also projected to be smaller, will make it possible to couple high-speed gas turbine engines directly to the generators without the use of reduction gears, thereby reducing weight, saving space, and making the engines more fuel efficient. Eliminating these reduction gears will also help future ships to reduce their acoustic signatures.

Another area of advancement is the use of fuel cells which require hydrogen in its natural state. Hydrogen is difficult and dangerous to store in large quantities. An alternate solution being studied involves extracting hydrogen from diesel fuel, which can be safely stored and transferred at sea. The "extracted" hydrogen is used to produce electrical power without the use of diesel or gas turbine engines. The use of fuel cells would also permit a ship's power system to be dispersed throughout the ship, increasing the ship's ability to survive fuel cell technology is promising for naval application and has already completed some prototype testing. However, officials stated that the technology is at least 3 to 5 years away from acquisition consideration.

None of these technologies are immediately ready to be implemented in ship designs. As advancements and innovations continue in nanotechnology, higher level robotics and automation and new materials develop, they would yield better size, weight, power and cost benefits for future propulsion systems for navies.

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About KOAN

India is at the centre of a major redefinition of global economic power. Given the complexities of development in India, there is constant flux in its business and political landscape. There exists a dynamic interplay between the internal and external, the local and global. Stakeholders interested and invested in India should be able to anticipate the pace and texture of this dynamism. They must equally be able to develop intuition that factors the uncertain into decision-making.

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