Modularity in aerospace and defence manufacturing

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Foreword

With the emerging requirements to operate in varied environments using available assets and resources optimally, the expectations from a modern military force have been redefined, and the principles of agility, flexibility and resilience have gained prominence. This has been demonstrated in recent global conflicts where the ability to adapt to developing situations has proved to be decisive. The traditional iterative approaches to platform design and development have often resulted in extensive cost and time overruns to platform and system development programmes, both globally and in India. A few relevant Indian cases in point include several Naval Shipbuilding programmes as well as DRDO weapon, sensor and platform development programmes as outlined in the respective CAG reports.

Given the above scenario, the onus is upon the aerospace and defence (A&D) manufacturing sector to invest in developing innovative technologies and development approaches that inherently facilitate a reduction in development timelines and cost, while also affording greater flexibility for future upgradation. Modularity is one such approach wherein platforms and systems are viewed as an integration of independent inter-related subcomponents or modules whose design and development can be delinked from the design and development of the platform, thus reducing the number of iterative development cycles.

Modularity provides the option to pursue independent system development, adopt upgradation with optimal reuse of existing hardware, and exploit breakout solutions in the emerging technology domain. Moreover, modularity facilitates reasonable cost and time savings while also affording role felxibility and interoperability.

The A&D industry partners will benefit from the modularity approach with a focus on concurrent multi-tier, multi-location product development. There are opportunities for collaboration between traditional defence stakeholders and non traditional entities, especially MSMEs, other defence parties, stakeholders, etc. where combining niche capabilities would be critical to address future requirements within operationally relevant timelines.

Through this paper, we seek to explore the concept of modularity in greater detail and study its applications, challenges and the way ahead for this approach. The modularity concept outlines an approach that A&D manufacturers, both globally and in India, can adopt while establishing plans, processes and infrastructure for the development and manufacturing of platforms/systems in a manner that significantly improves delivery timelines and costs, while also affording agility, flexibility and resilience.

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Terms and abbreviations

Abbreviation	Expansion
A&D	Aerospace and Defence
AC	Air Conditioning
AI	Artificial Intelligence
CAD	Computer-Aided Design
CAG	Comptroller and Auditor General of India
CG	Centre of Gravity
ERP	Enterprise Resource Planning
GUI	Graphical User Interface
HVAC	Heating, Ventilation, and Air Conditioning
IPDE	Integrated Platform Data Environment
NASA	National Aeronautics and Space Administration
OEM	Original Equipment Manufacturer
PGD	Power Generation and Distribution
PWBS	Platform Work Breakdown Structure
QA	Quality Assurance
SAR	Search and Rescue
UAV	Unmanned Aerial Vehicle

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01

Introduction to modularity

Introduction

Aerospace & defence manufacturing is emerging as one of the focus areas in the Indian industry. The current thrust on self-reliance is providing an unprecedented impetus to indigenous design and manufacturing in this sector, at the platform/system integration level and also at the system/subsystem level. However, this ongoing impetus can be leveraged fruitfully only if manufacturers are able to achieve global competency, primarily by overcoming legacy issues in platform/system development such as time and cost overruns, limited flexibility, reliability etc. To remain globally competitive and deliver state-of-the-art platforms in a timely manner, indigenous manufacturers need to adopt innovative technological approaches. System modularity is one such approach that would be crucial for the Indian industry as a whole to embrace in order to be efficient, effective and globally competent, while also providing flexibility to the end user.

Modularity in design and manufacturing primarily involves breaking down a platform or a system into distinct interrelated sub-systems or modules that are, in an ideal scenario, independently designed and developed for subsequent integration at the platform/system level. A&D platforms represent a complex integration of systems and subsystems. However, on account of extensive interdependencies between systems, most of the current approaches in design, development and manufacturing, more often than not, involve inter-linked, iterative design and development of systems/sub-systems. This leads to extended timelines on account of a few systems holding up the development of other systems or the platform along with an overrun of budget. As highlighted in CAG reports, these time and cost overruns, presumably on account of an iterative approach to design and development, have repeatedly plagued several indigenous development programmes in weapons, sensors, platforms and in also in naval shipbuilding. Modularity can potentially assist in efficient design, development and manufacturing, owing to its inherent system of systems approach and its potential to delink system development from platform development.

System of systems approach

A&D platforms, starting with drones, land platforms, missiles, aircraft, spacecraft right up to large warships and submarines are essentially a system of systems integrated into a functional platform to perform specific roles. Broadly, each of these platforms can be viewed as an integration of interlinked systems which can be categorised and broken down into Fundamental, Functional and Payload Systems.

Fundamental systems

These are systems that form the basic framework of the platform in terms of strength, mobility and support which include:

A

Structural systems

which provide the shape, strength and structural elements of the platform onto which other systems are installed and integrated

B

Mobility systems

which provide the propulsive and manoeuvring capabilities required for the platform to carry out its role, i.e. propulsion engines/motors, transmission systems, propulsors, wheels, steering, rudders, hydro/aerodynamic wings, etc.

C

Auxiliary support systems

which provide support and services for the functioning of other systems, i.e. power generation and distribution systems, fluid systems, ventilation and air conditioning systems, human/crew support systems, safety systems, etc.

Functional systems

These are systems/subsystems which are necessary for the platform to perform its primary and secondary functions such as:

A

Communication and navigation systems

which facilitate internal as well as external communication, while also aiding safe navigation in the domain of operation.

B

Sensory systems

which equip the platform to detect and provide feedback about other objects and external environment in the domain of operation, i.e. radars, sonars, electro-optic sensors, etc.

Payload systems

These comprise any system(s) that aid in carrying out the primary role(s) of the platform and can typically include weapon systems, cargo delivery systems, search & rescue systems, human aid delivery systems, etc., depending on the role envisaged for the platform. Payload systems may also include any of the sensory systems as indicated above:

Weapon

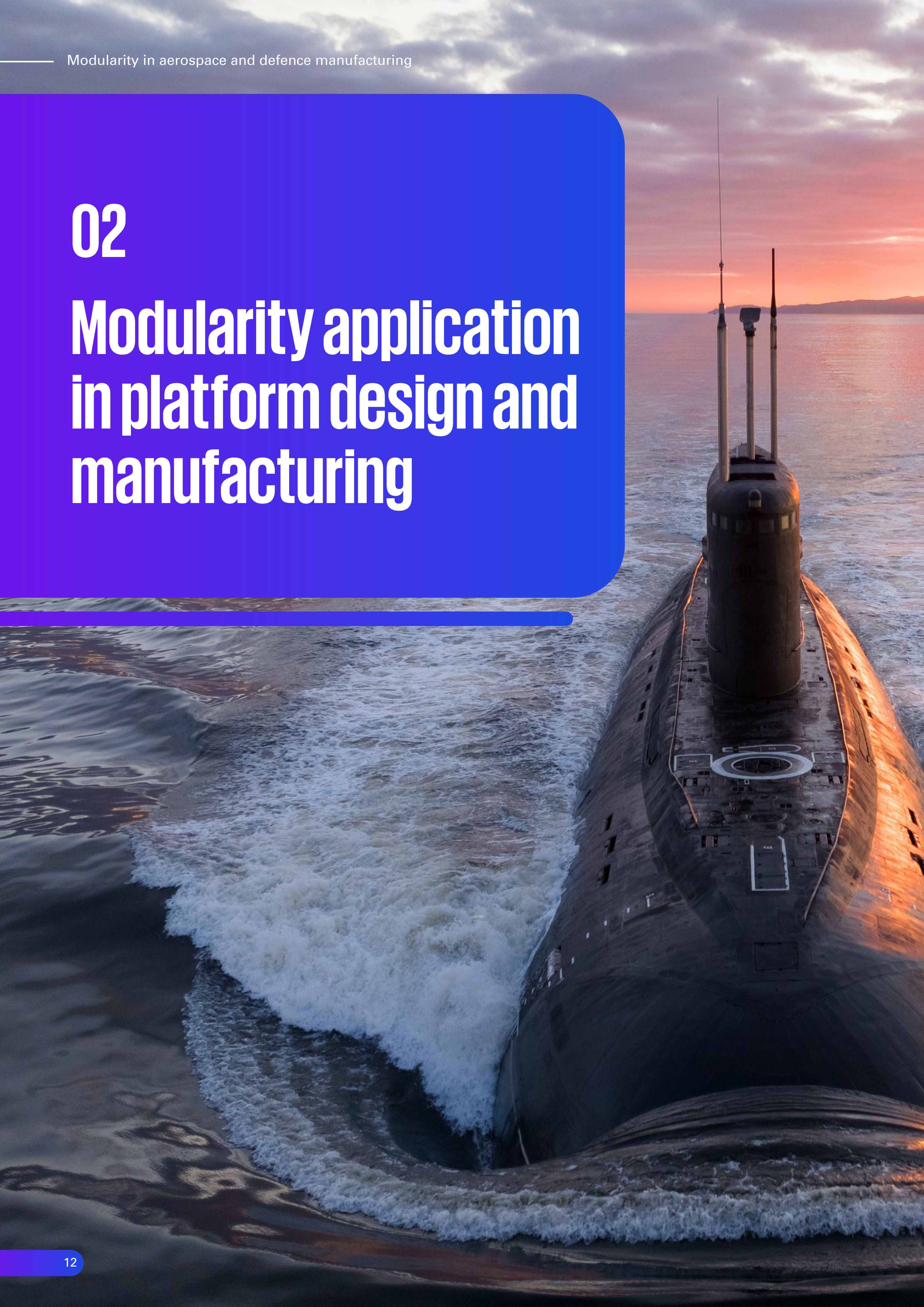
Humanitarian Aid Delivery

Cargo delivery

Search and Rescue

02

Modularity application in platform design and manufacturing

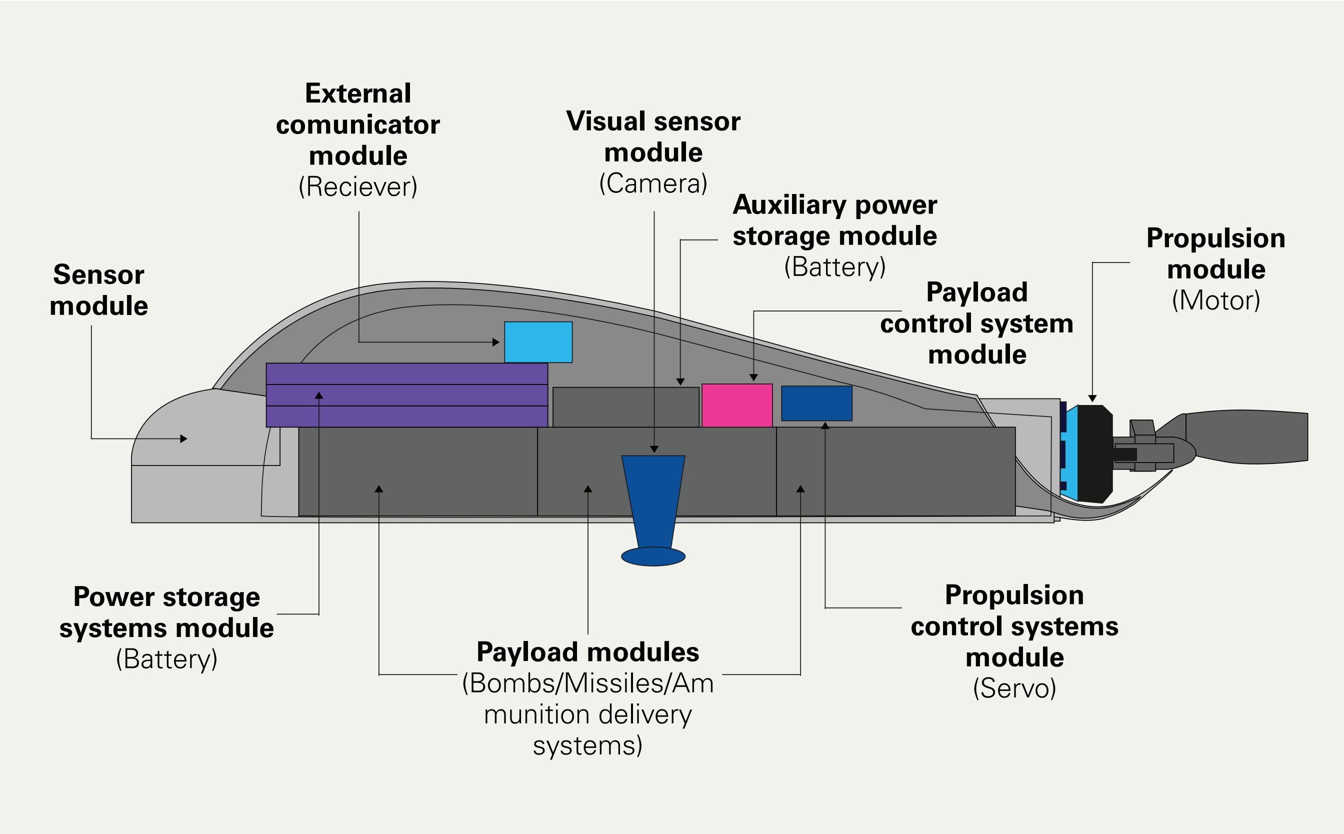


Current approach to platform design and manufacturing

More often than not, each of the systems indicated above and their subsystems are designed, manufactured/customised and tested for proof of performance by different OEMs, and the platform designer/manufacturer configures, assembles and integrates these systems. The existing interdependencies constrain system/subsystem manufacturers as well as the platform integrator to wait for the development of a system before integration. To illustrate this, let us look at a small platform in terms of size, i.e. UAV and a warship as a larger platform.

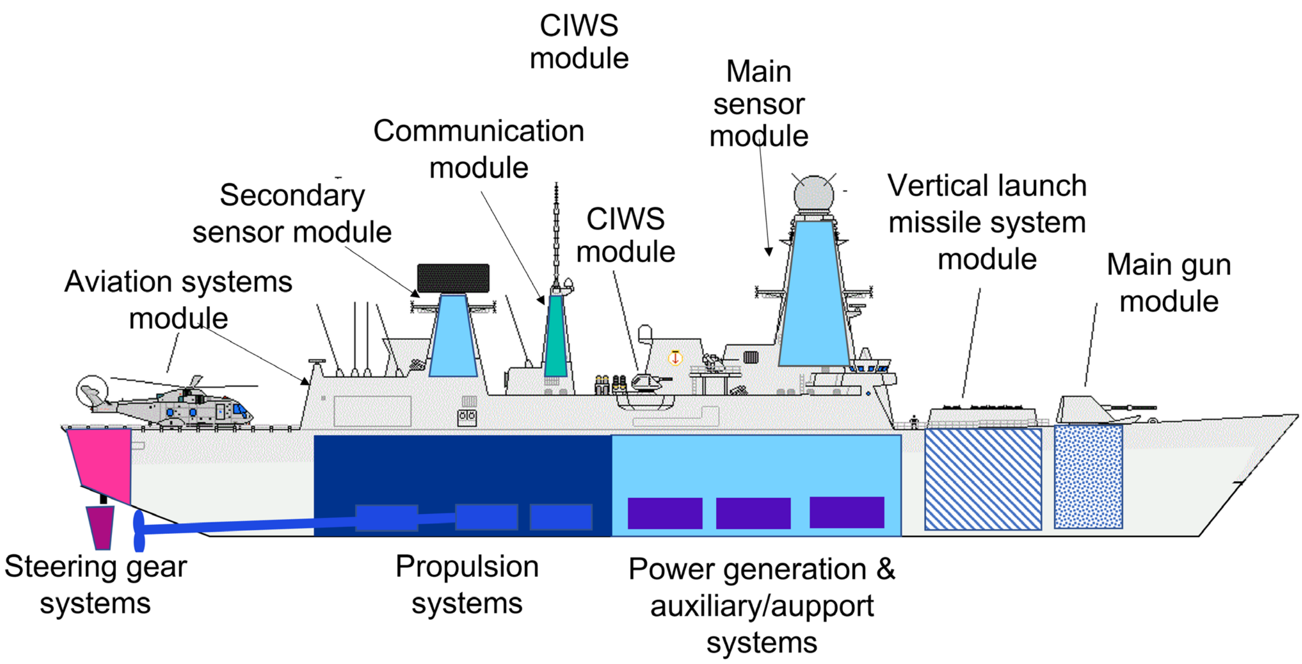
Unmanned Aerial Vehicle (UAV)

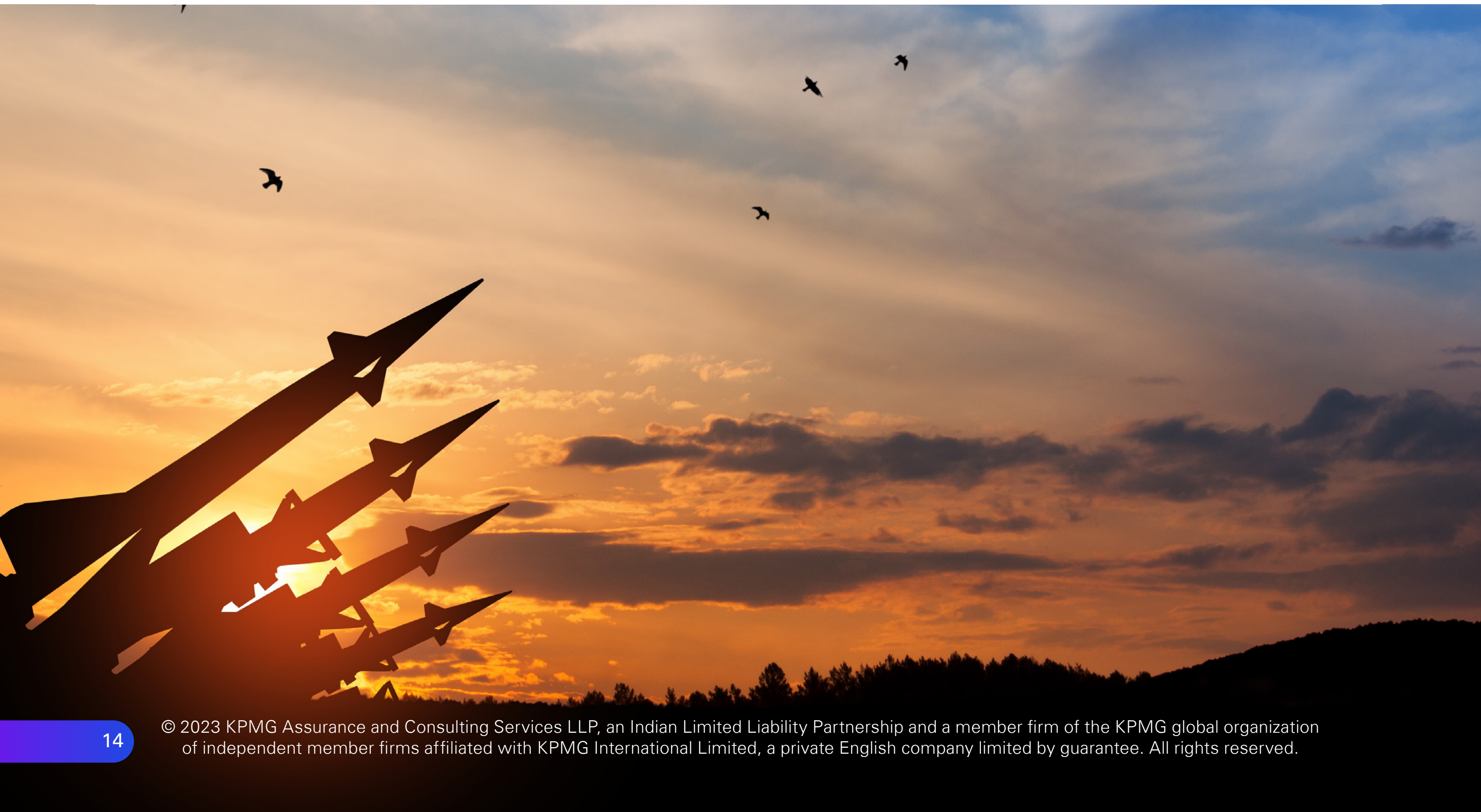
UAV can be considered to be an integrated platform of modules each of which can be developed and tested independently. Practically, each of these modules are designed and manufactured by various Original Equipment Manufacturers (OEMs) and then integrated by the platform manufacturer. As part of the iterative platform design process, some of the systems may need to be redesigned and customised in terms of size, shape, interfaces, performance parameters, etc. in order to fulfil the interdependencies with other systems and also meet the platform requirements. This design and developmental work at the system level constrains the progress of platform design, which is forced to be held in abeyance until each of the systems/subsystems are developed/fine-tuned.



Warship

Similarly, a warship can also be viewed as a platform wherein various modules are independently designed, developed, tested and integrated. The sheer size and scale of the systems make this a complex integration, with each of these systems requiring interaction with each other as well as with the platform. Warship design and construction is an inherently evolutionary process, with the design evolving as the ship is built. Therefore, the design and developmental work at the system level has an even more telling effect on the progress of platform design and construction, which is typically held waiting for long durations until each of the systems/subsystems are developed/ fine-tuned.





System modularity approach to platform design and manufacturing

System modularity involves modularising as many systems as possible in a manner that the individual system design and development can be progressed independently of the platform, without any need for iterative changes to the platform or the systems. This can be achieved by following this basic approach for decoupling the systems from the platform.

Dimensional constraint definition

a. The platform designer/integrator stipulates the dimensional constraints of the system module by specifying the maximum possible dimensions and shape, the maximum and minimum limits of the weight and the range of permissible centre of gravity for the module.

b. The system designer can now progress with the design/fine-tuning of the system independently as long as the system, when delivered, falls within the dimensional constraints stipulated by the platform designer.

Physical and functional interface standardisation

In addition to the dimensional constraint, there is also a need to standardise the module in terms of:

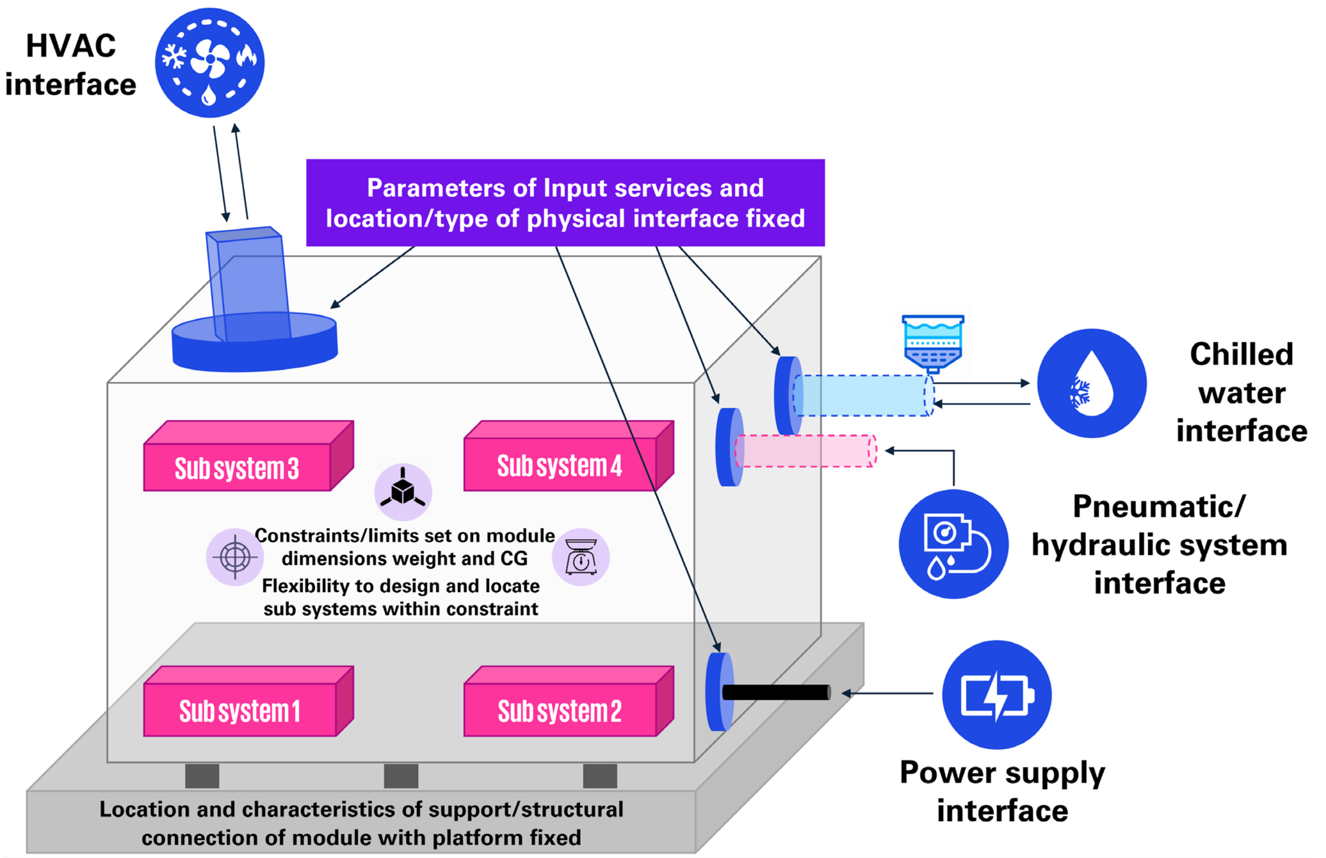
a. Physical interfaces, i.e. standardising the positions, size and specifications of structural support for the module/system, etc.

b. Functional interfaces i.e. standardising the type, positions and specifications of interfaces/connections for power supply, ventilation/AC interface, fluid systems, etc.

Control system/software interface protocol standardisation

Achieving smooth interfacing and handshake between systems can become extremely challenging, particularly when the systems are procured from different countries/sources each following different software protocols and design philosophies. Therefore, there is also a need to standardise the software interface protocols with the control system(s) and also between the individual system software, by adopting open architecture philosophy as much as possible.

The figure below conceptually illustrates the adoption of modularity for a system with predefined dimensional constraints as well as predefined and standardised physical, functional and software interfaces.

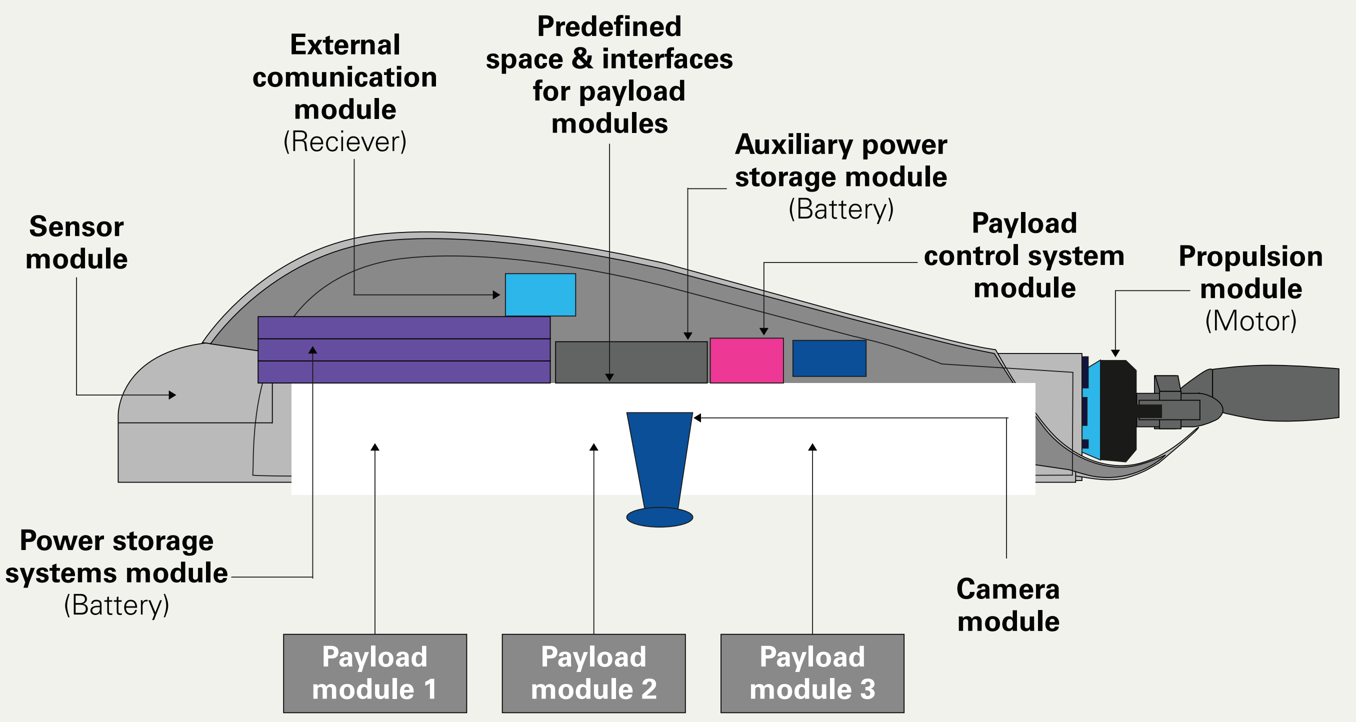


With the dimensional constraint applied and the standardisation of the physical, functional and software interfaces achieved, the module design and fine-tuning can be progressed as a constrained optimisation problem with the respective OEM carrying out design optimisation within these predefined boundaries. Platform integrators can now possibly consider multiple candidates for the design and development of the system, each of which satisfies the dimensional constraints and required interface standardisation.

Modularity use case - UAV/drone

To illustrate the same, we can once again take up the example of the UAV highlighted in the previous chapter. Adopting a modular approach would mean that by modularising and pre-defining the dimensional and interface constraints, it would be possible to decouple the design and development of the modules from the design and development of the platform and some of its fundamental systems. This decoupling is particularly relevant for the payload modules and to some some extent even some of the fundamental and functional systems such as auxiliary power storage, and sensor modules.

By standardising the dimensions and payload interfaces. multiple types of payloads can be strapped onto the same platform, making it possible to adopt a "plug and play" approach to payload deployment.



Payload & camera modules developed Independently within space & interface pre-definitions

Potential for modularisation

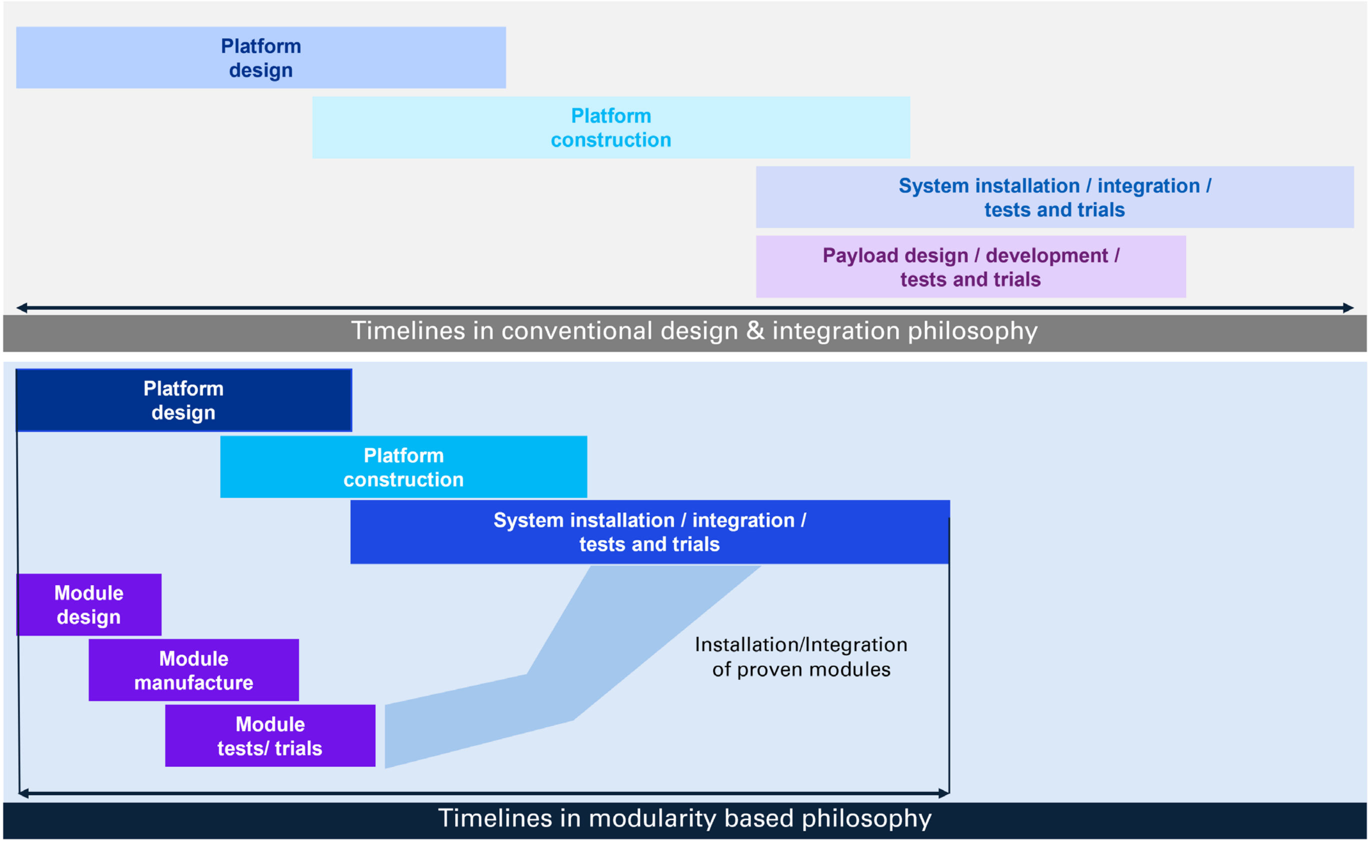
All major military systems including weapons, sensors and platforms have the applicability of modular systems and are suitable for adopting modularity. It is pertinent to note that for smaller platforms it may be feasible to modularise most of the systems, i.e. some fundamental systems as well as most functional systems. For larger platforms, flexibility is difficult to achieve across fundamental systems, but most of the functional systems, particularly payload systems can be the ideal systems for modularisation. The typical systems and platforms that can be considered for modularisation are:

a. Drones/UAVs
b. Missiles and weapon systems
c. Sensors, i.e. radars, sonars, etc.
d. Spacecraft and satellite systems
e. Remote-operated and autonomous vehicles
f. Assault vehicles and battle tanks
g. Fixed and rotary wing aircraft
h. Warships and submarines.

03 Modularity advantages

Platform development timelines

Significant advantages in terms of platform delivery timelines can be accrued by adopting modularisation. For platforms wherein prototype development is feasible, these advantages are accrued during prototype development which is then translated to series production. For platforms like warships, which follow an evolutionary process, the advantages are accrued in terms of project timelines.



Multi-location multi-tier design, development and manufacturing

As modularity enables independent design and development of the modules and the components, it is possible to carry out design, development and manufacturing at different locations through different manufacturers. For major system integrators and platform manufacturers, this obviates the need to invest and create captive facilities in their premises, particularly when space and infrastructure are at a premium. This also facilitates offloading the entire design, development and manufacture of systems/ subsystems to entities lower down in the value chain (Tier 1/Tier 2). Through a modular approach, the multi-tier based manufacturing stations can utilise their regional expertise and specialisation. This results in efficient utilisation of the production facilities and resources with a pronounced focus on cost optimisation. By exercising the interchangeability of manufacturing locations, the risks associated with supply chain disruptions can also be handled efficiently.

Obsolescence management

Many of the systems, particularly functional systems such as communication systems, payload systems, etc. are subject to rapid technological advancements, often rendering existing systems obsolete in quick time, much before the end of the life of the platform. This necessitates mid-life changes/ upgrades, and more often than not, in conventionally designed platforms, this necessitates major structural modifications, besides significant changes to the capacity required for power generation, auxiliary systems etc, each of which, in turn, have undesirable cascading effects on the platform design and also the mid-life upgradation programme timelines and costs. By adopting a modular approach with dimensional and interface pre-definitions, it would be possible to upgrade functional systems with minimal changes required to the platform.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04 Modularity approaches used globally

Civil/commercial applications

A leading German auto manufacturer is utilising the modularity approach for building the next-generation cars using virtual assembly technologies integrated with Artificial Intelligence (AI) enabled robots. The digital twin technologies facilitate detailed process simulation whereas the modular approach helps the assembly of components at multi-locations, termed as production islands. The world's first modular assembly system realised at the automotive manufacturer has boosted its productivity by up to 20%[3].

Similarly, a California-based subsidiary of a leading aircraft manufacturer has developed a concept which focuses on rethinking the cabin design and architecture of a narrow-bodied passenger aircraft. The most prominent feature is the separate cabin modules, which could be designed to give different inflight experiences to passengers, all the while being compatible to be plugged into existing aircraft variants[4]. Modular multi-role UAV platforms[5] for air pollution profiling are also being developed with capabilities for varying the mission payload when different types of sensors and measurement devices are required to be carried on different missions.

Military applications

Modular multi-role UAV platforms are also being developed with capabilities for varying the mission payload when different types of sensors and measurement devices are required to be carried on different missions. Some of the platforms/systems wherein the modularity concept has been deployed effectively are:

a. NASA modular spacecraft design[6].

b. South African Navy's Meko class corvettes[7].

c. Optionally manned fighting vehicle concept design with modular open system architecture, developed by a leading global defence manufacturer

d. Modular air-to-air missile concept[8], developed by a leading American aerospace and defence manufacturer

e. Integrated mast[9], developed by a leading European A&D manufacturer

f. Littoral combat ship.

Role flexibility

By modularising the payload packages and locations on the platform, the platform can be reconfigured to hold different types of payload for different roles, with a quick turnaround. For instance, the same UAV/drone/aircraft, when modularised, can carry a payload with combat systems on one mission and can be reconfigured to replace the same with a Search And Rescue (SAR) module for another mission. Mission module reconfiguration is relatively easier to achieve in smaller platforms but this has been demonstrated successfully even in large platforms such as warships i.e. the Danish Stanflex systems and US Navy's Littoral Combat Vessels.

3. "Modular Assembly: Innovative assembly and logistics concept is about to be ready for serial production", a leading German automotive manufacturer's press release, July 2022
4. "The future of flight is customizable: Introducing Transpose", a leading European aerospace manufacturer's press release, December 2016
5. "Developing a Modular Unmanned Aerial Vehicle (UAV) Platform for Air Pollution Profiling", Gu, Qijun & Michanowicz, Drew & Jia, Chunrong. (2018). Researchgate Publication 18. 4363. 10.3390/s18124363.
6. "A New Design Approach: Modular Spacecraft", NASA Press release (website), January 2009
7. "Modular Design of Frigates", a leading German aerospace and defence manufacturer's press release 2004
8. Contracts For Sept. 29, 2022: Navy, U.S. Department of Defense Press release (website), September 2022
9. "Above water warfare", displayed on a leading French aerospace and defence manufacturer's website.

05

Challenges in modularity implementation

Platform design and manufacture

Physical challenges

Individual modules/systems which are being developed independently are constrained to be designed and developed within these preset boundaries and fixed interfaces. This can pose physical challenges and may even lead to a situation in which the design of the module/system is not necessarily the most optimal from a system point of view but fits the overall requirements of modularity. Physically, this may sometimes lead to higher margins to be allocated for space/volume/weight, power supply, and other consumer services like fuel/freshwater/cooling requirements/compressed air, etc. This design trade-off to accrue advantages in terms of time and cost saved, however, can be more beneficial in the overall scheme of things.

Data management

The design, development and manufacture of platforms primarily involve collating, organising, analysing, interlinking and conjugally using different types of data across different systems/sub systems generated by different stakeholders. It consequently emerges that for the process of design, development and manufacture of a platform/system to be efficient and effective, the management of all the data related to the sub-systems/modules would also need to be managed efficiently throughout the entire process cycle. While the modular approach offers a plethora of advantages for manufacturing units, there are certain data management challenges that are associated with modularity implementation.

Complex interconnected systems and related data

A&D platforms and systems are complex products with several interconnected systems/subsystems typically sourced from different suppliers. These may not be inter-compatible to exchange data with each other.

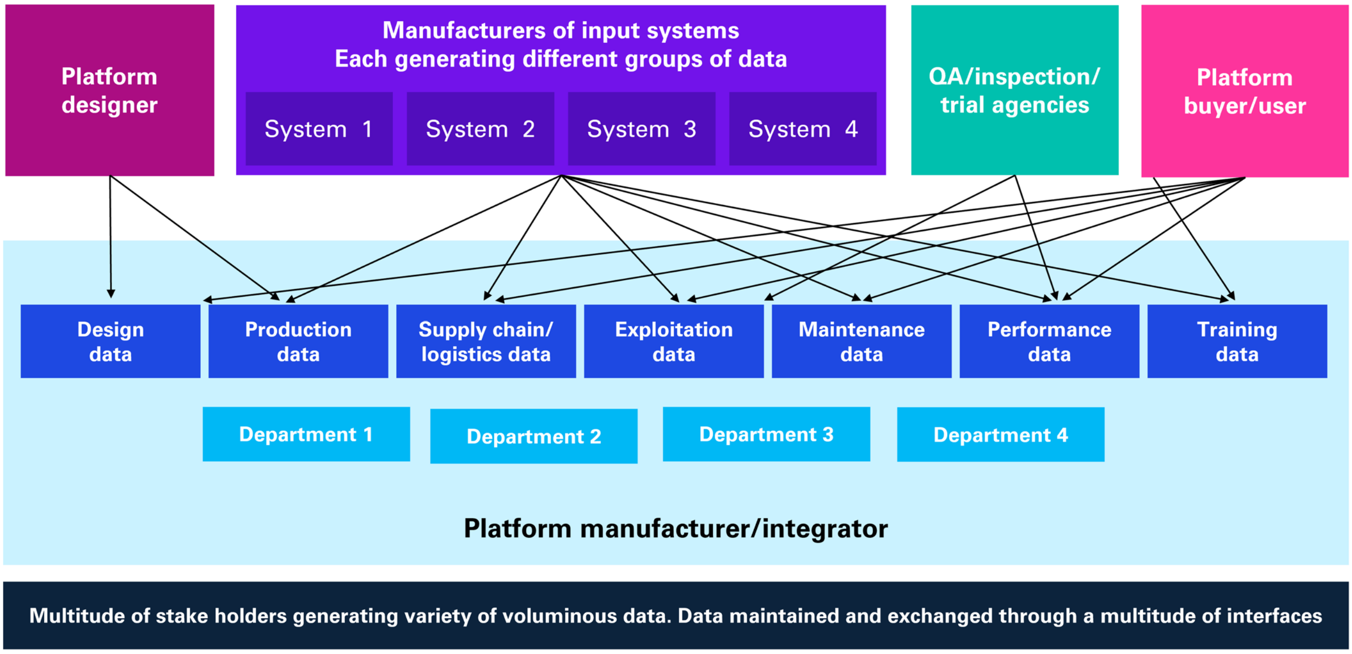
Voluminous data

High volume of information generated by a multitude of internal as well as external stakeholders, each potentially adopting their own data structure and format.

Data structure/format mismatch

The data structure mismatch and lack of information interoperability causes proliferation of unstructured and unconnected databases.

The figure below indicates a platform design and development scenario, highlighting the complex nature of interdependencies and interconnectivity among various stakeholders, involving different kinds of data connected through multiple interfaces.



The use of ERP systems and other tools is supposed to ensure data and data format synchronicity across various departments in an organisation. Practically, it has been observed that each department tends to follow its own set of data formats and structures. Therefore, this data format/structure asynchronicity often limits the interoperability of data even within the integrator's organisation.

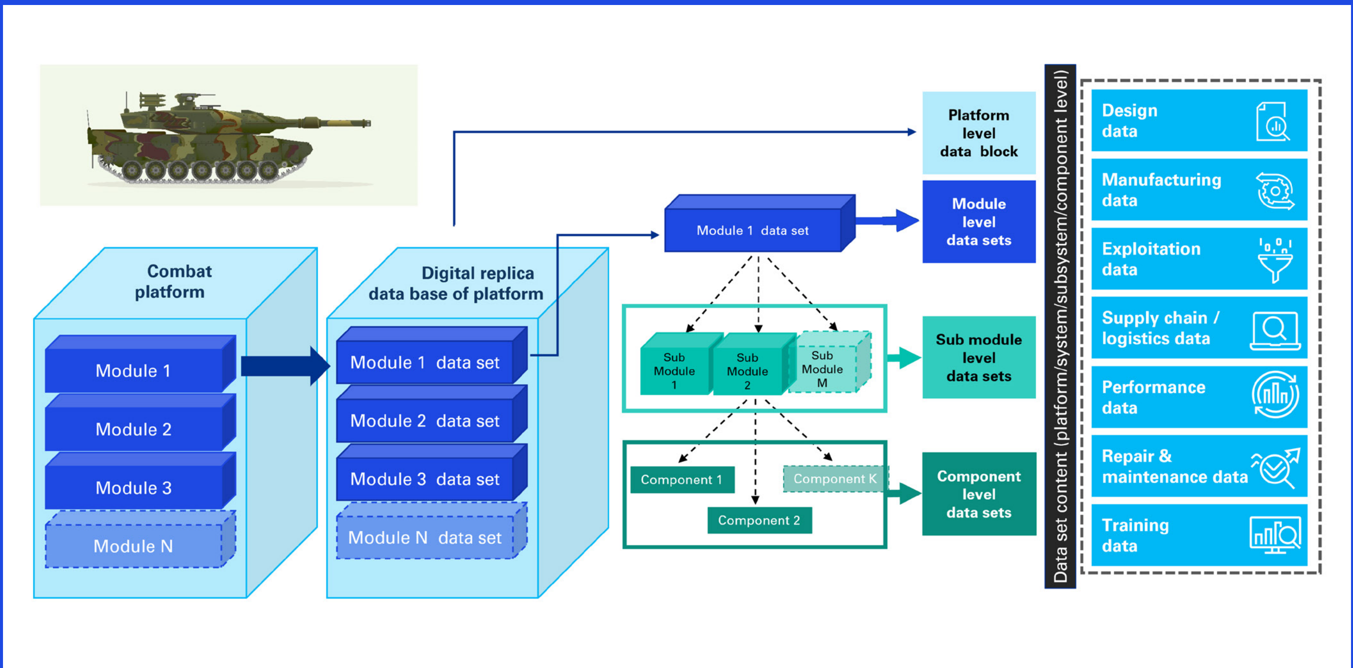
To add to the above internal data management complexities, there are several external stakeholders who generate, populate and update various types of data. The major stakeholders are the OEMs of different systems/modules and each of these OEMs also tend to adopt their own data formats and structures unique to their system/ product and their internal organisation. Further, there are other stakeholders in the process cycle such as the design agency, quality assurance agency and the end user (i.e armed forces/ paramilitary forces, space agencies, other platform operators etc) who also tend to adopt their own data structures and formats for describing and managing the platform/system. This asynchronicity in internal and external data format/ structure leads to expending significant time and resources towards archiving, retrieving and matching data, thereby hindering the efficient and effective progress of the project even in the conventional design and development approach. In the context of modularity-based design, development and manufacture, wherein data interoperability is vital for achieving standardisation and smooth interfacing, this challenge becomes even more pronounced.

Way ahead

Adopting Integrated Platform Data Environment (IPDE)

To implement modularity, overcoming the challenges of data management is essential. It is important that the data of internal and external stakeholders is integrated in a centralised data platform using a standardised hierarchy. It is essential that this data platform practically replicates the physical platform in the digital database environment with the same hierarchical breakdown and interlinkages as the physical platform.

The IPDE[10] framework involves replicating the hierarchical breakdown of the physical platform into equivalent digital data blocks that capture and store different types of data at each hierarchical level. The figure below indicates the digital data block breakdown into systems and subsystems at each level of the hierarchy. In the context of modularity, the breakdown into systems and sub-systems would translate into breaking down into modules and sub-modules, up to the component level.

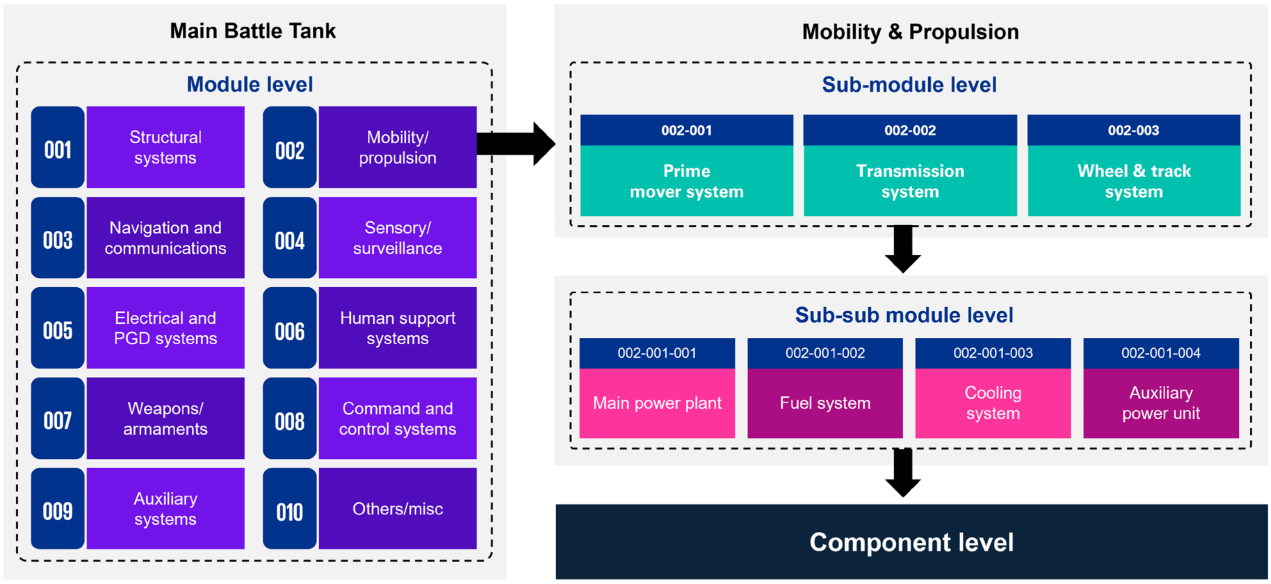


10. "Developing a Product data model during design and construction for efficient life cycle support of Ships"- Cmde AK Saxena & Cdr R Jaikumar, IN - Seminar on Lifecycle support for Ships and Submarine, Naval Dockyard Mumbai October 2010.

A fundamental requirement for enabling such a digital data block structure connecting multiple levels of data generated by multiple stakeholders is a standardised Platform Work Breakdown Structure (PWBS). The PWBS would need to be developed for the specific type of platform by standardising the hierarchies and identifiers associated with each system/sub-system/component and defining the interconnectivity in this hierarchy.

Platform Work Breakdown Structure (PWBS) standardisation framework

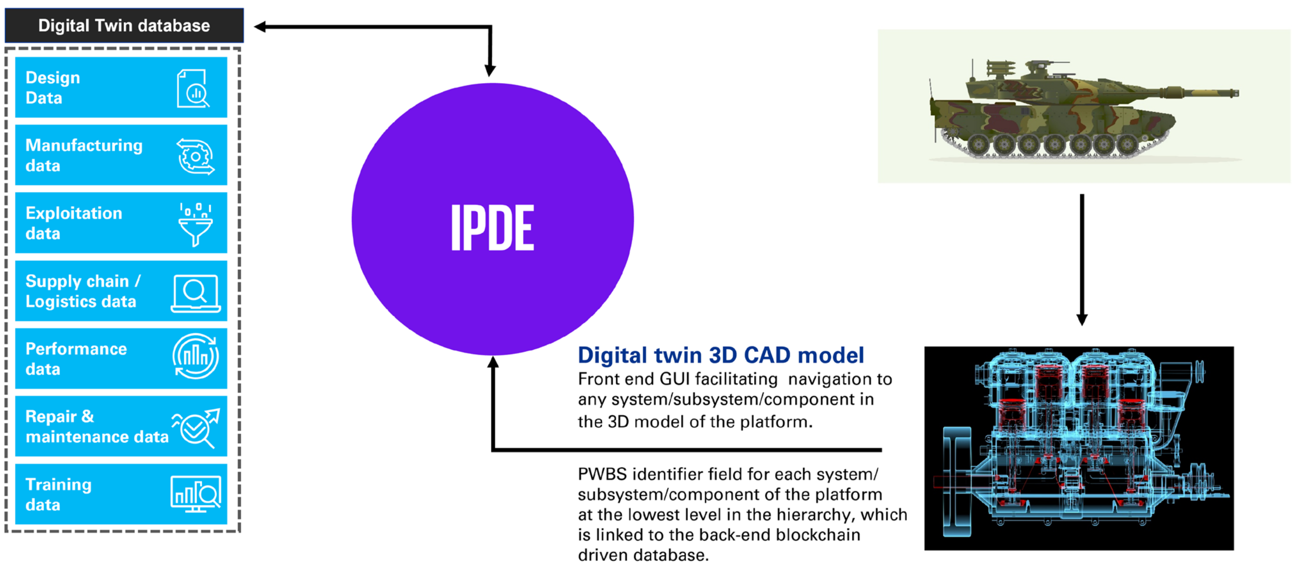
Indicative example (Non exhaustive hierarchical PWBS)



The IPDE is critical for ensuring that data is consistent, and integrity of data is maintained across the interconnected systems/modules and sub-systems/sub-modules. The figure below illustrates the concept of IPDE[11] with a front-end 3D CAD model of the platform, which serves as the GUI and a centralised backend IPDE database, which stores all information of the platform/ system/sub-system/component using the standardised data block structure, identifiers, hierarchies and interconnectivity defined through the PWBS. In the course of design, development and manufacture, the IPDE would permit any stakeholder to navigate through the model to access any system/subsystem/component and through its identifiers, also access/update all the data/information relevant to that system/sub-system/component stored in the backend database in the digital twin database. This ensures data currency and interoperability, which is vital for modularity to be implemented. Besides the implementation of modularity, the IPDE framework can be used for several applications, including platform lifecycle management.

11. "Integrated Product Data Environment for Design and Construction of Ships on distributed Wide Area Networks"- Cdr R Jaikumar, Directorate of Naval Design Golden Jubilee Seminar, September 2014

Integrated Platform Data Environment (IPDE)



Conclusion

Adopting modularity offers significant advantages in the design, development and manufacture of A&D platforms in terms of increased efficiency, improved timelines/productivity, manufacturing flexibility, obsolescence management and mission reconfigurability. Given these distinct advantages, it is important for stakeholders to consider and implement modularity for the design, development and manufacture of A&D platforms and systems.

Major platform/ system manufacturers

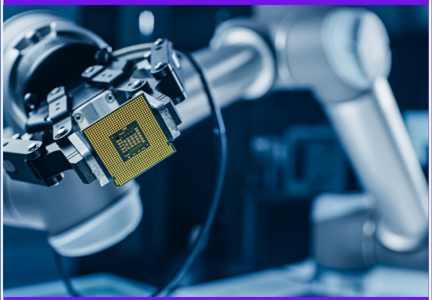
Major platform and system manufacturers of drones/ UAVs, land combat vehicles, aircraft, marine vehicles, spacecraft, etc. may consider adopting an approach towards standardisation of the PWBS being adopted and identify specific pathways for modularisation of the platforms and systems, by involving their respective supply chains. Progressively, it would be prudent to evolve a digital transformation strategy and develop IPDE solutions for each type of platform/system.

Armed forces

Armed forces play a critical role in the design and development of platforms, particularly given the current emphasis on indigenisation, coupled with the inherent need for customisation to suit the specific operational philosophy adopted by the users. It is, therefore, crucial to involve the user through suitable feedback mechanisms for developing the PWBS as well as the IPDE with a view to embrace modularity.

Manufacturing hubs and supply chain stakeholders

Based on the inputs from major manufacturers and end users, it would be prudent to plan upcoming defence manufacturing hubs and corridors in a manner that these hubs/ facilities are inherently suitable for adopting modularity with multi-tier multi-location construction.



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