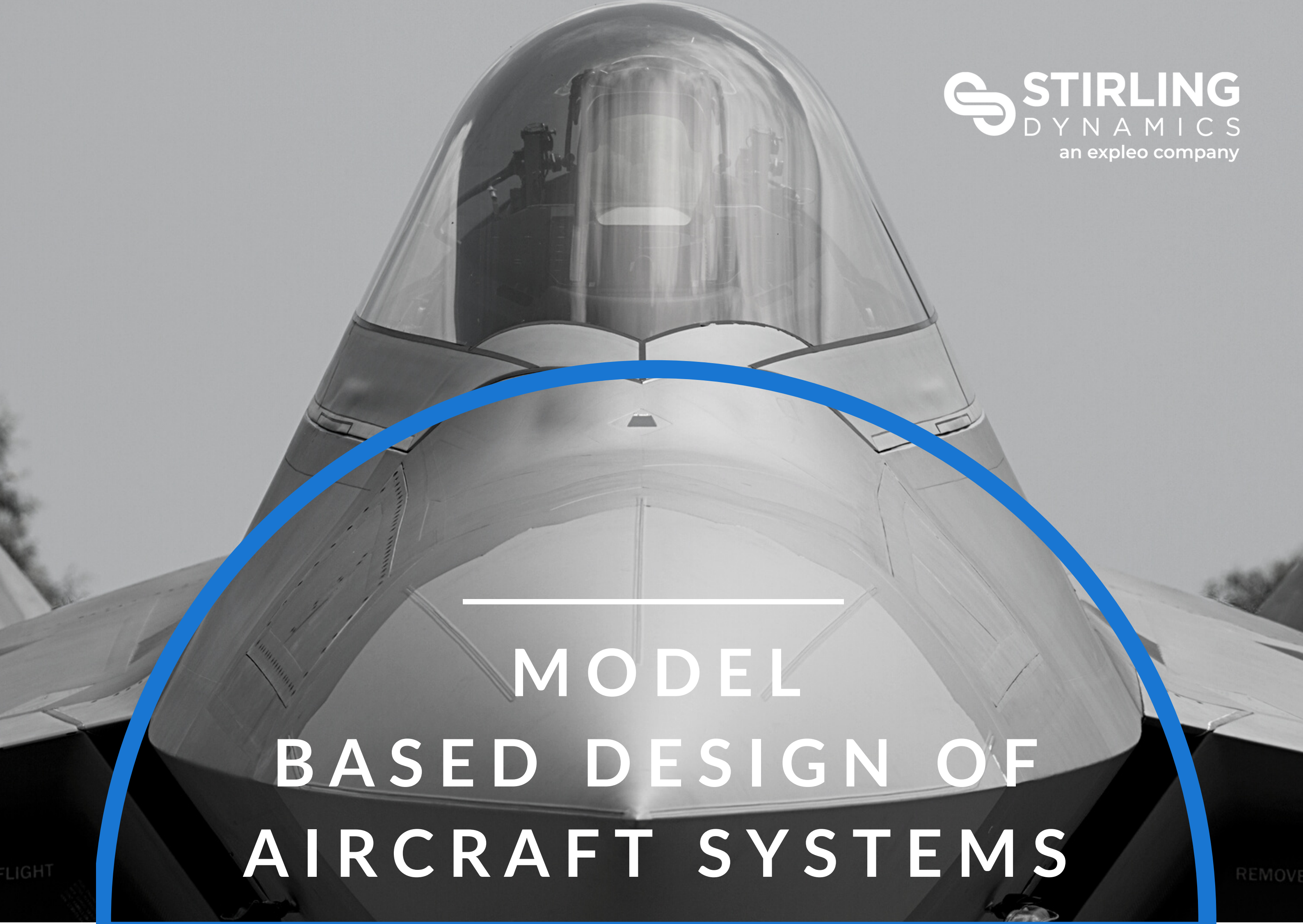

STIRLING DYNAMICS
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MODEL BASED DESIGN OF AIRCRAFT SYSTEMS

A MODERN APPROACH TO AIRCRAFT DESIGN

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EXECUTIVE SUMMARY

INFORMING BETTER DECISIONS

Aircraft systems have become increasingly complex over recent years, particularly within the military domain. Many of the systems have safety-critical elements, redundancy, and an increasingly high level of interaction. It is becoming increasingly difficult to specify and validate the requirements for these systems and to further validate the proposed technical solutions, particularly when the systems may be developed by multiple different suppliers.

Such systems can include flight control systems, landing gear systems, hydraulics power generation and distribution systems, electrical power generation and distribution systems, weapons systems, fuel systems, engine systems, weight and ballast management systems and propulsion systems.

Conventional system design approaches require the capture of requirements, validation of these requirements and specification of the system through a series of interconnected textual documents. For a complex system, it can be difficult to trace these dependencies, with design updates being manually propagated through related documents, and being prone to error.

Furthermore, text-based requirements can be ambiguous leading to misinterpretation and are not a suitable format for use in a formal verification and testing process. Adopting Model-Based Design processes and associated methods can help address many of these issues as part of the system development process.

WHAT IS MODEL-BASED SYSTEMS ENGINEERING?

Model-based systems engineering (MBSE) is a systems engineering methodology that focuses on utilising a set of interconnected models and exploiting these as the primary means of information exchange between engineers, and within the supply chain.

The benefits of MBSE include increased clarity in requirements and communication, reduced development risk, improved quality, and increased integration within the design life cycle.

1. REQUIREMENTS VALIDATION AND DERIVATION

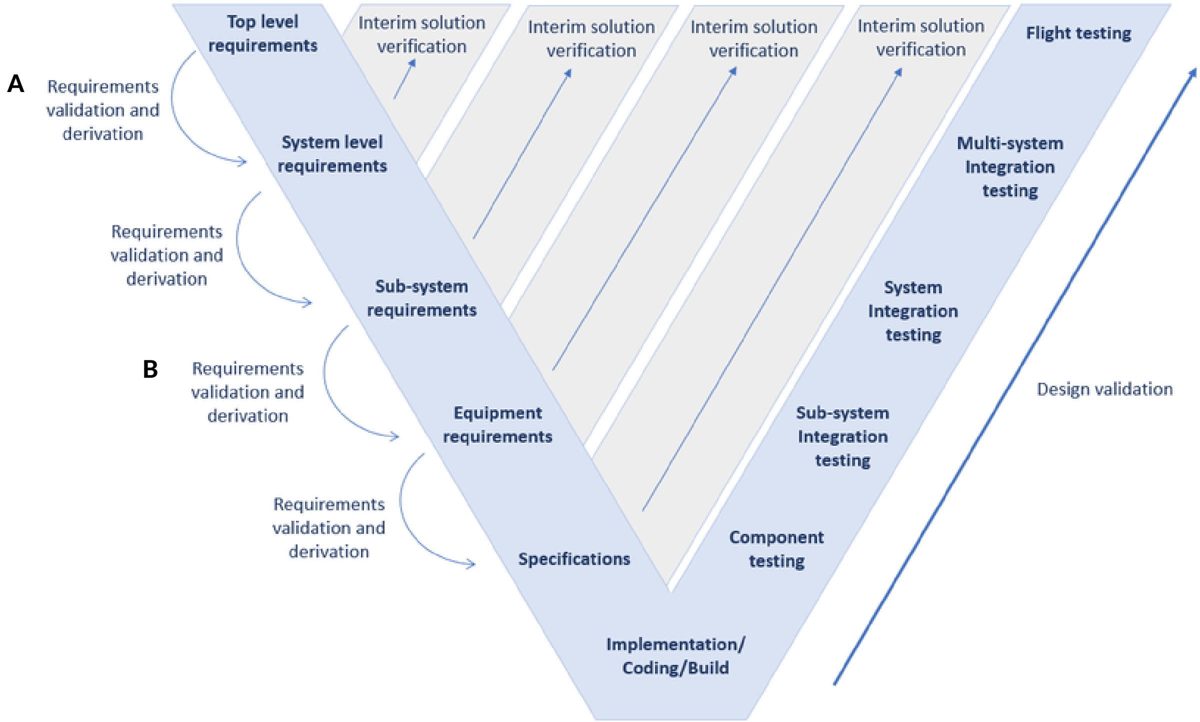

Figure 1.

The top-level requirements for an aircraft can be classified into several categories including:

- Aircraft manoeuvrability requirements
- Aircraft stability and control requirements
- Safety requirements
- Operational requirements
- Functional requirements

In keeping with the validation and verification strategy and plan on the project, these requirements can be validated using high-level models of the aircraft. Simultaneously, the validation tests performed in a virtual environment can check for requirements consistency and derive top-level system requirements. This ensures traceability of requirements and a consistent approach across systems, refer to point A in Figure 1.

As a simple example, the requirement to perform a certain manoeuvre within an operational envelope may derive the load and rate requirements for a flight control surface. These requirements could then be analysed with other design factors to derive mechanical linkage, actuator size, structural strength requirements, hydraulic requirements, etc.

The requirements analysis would then continue into the individual systems, down to equipment and component level, refer to point B in Figure 1. When delivering requirements to suppliers (both internal and external), the models produced at this stage can be shared to ensure no ambiguity in the performance requirements.

Generally, requirement documents will be required in addition but should be used to supplement the requirements models and not to replace them. As the lower-level system and sub-system requirements are developed in parallel, following a similar process, the models can be used to verify that the proposed solutions meet each level of the requirements. Models can be delivered and integrated together following a programme wide defined method and process, such as the use of the FMI standard, to assess the interaction between the systems. This can allow issues to be found earlier in the development when it is easier and cheaper to find solutions. For example, understanding the hydraulic flow draw during landing gear extension and the impact on the flight control system (via the hydraulic system) can ensure that enough power is available, actuators are sized appropriately, and sequences are timed correctly.

In Figure 1, this part of the process is identified as the interim solution verification branches. The verification tests can be performed at interim steps against all higher-level requirements (in addition to the current level requirements). This testing can identify potential issues early, can reduce the level of testing required later in the development process, and ensures strong traceability through the verification and validation process.

2.TRADE-OFF STUDIES AND SOLUTION DOWN SELECTION

During design development, multiple solutions can be proposed to meet the required requirements. Using the model-based design approach, these alternate solutions can be compared with sensitivity studies, trade-off studies and optimisation, to find the most robust and optimal solution. The multiple solutions can be integrated with other systems (as described above) to choose the best multi-domain solution.

3.CODE GENERATION

Progressing down the systems V-cycle, as the models are expanded following a safety-critical software program such as DO-178 (Figure 2), the models could be utilised with automatic code generation to form the core of the flightworthy software. The approach and toolsets used must support DO-178.

If other project constraints prevent the models being used as the core of the code, then the models can still be used as part of the software verification process, as an independent check, to ensure the software code meets the required performance and functionality.

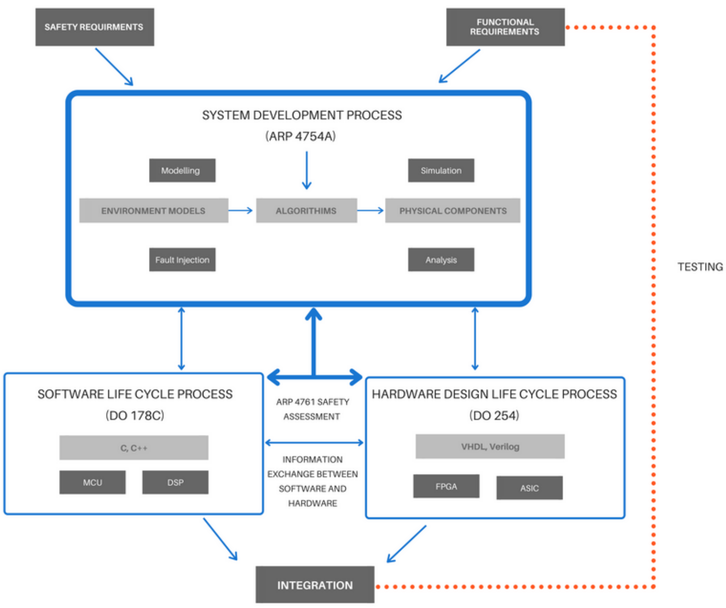

Figure 2. Interface between the system and software development processes.

4.INTERFACE BETWEEN THE SYSTEM AND SOFTWARE DEVELOPMENT PROCESSES

The models developed through the design process can also be used as part of the system verification process, by direct use (or following some level of simplification, to meet the real-time constraints) and integrating onto test rigs. These allow comprehensive testing across simulated environments and operations. With a defined approach, this can reduce the quantity of physical testing required, and can reduce the required complexity of the test rigs, reducing development time and cost.

Figure 3 shows a possible test rig strategy, the blue boxes represent those components that are simulated. Initial testing may look at individual components, or in this example representing the code, which could be hosted on a computer with a fully virtual environment with all necessary components simulated. As the testing moves up the right-hand side of the V-cycle in Figure 1, the additional "real" components are added.

In Figure 3, moving up from the bottom row, testing could be performed with software loaded on the real avionic hardware, and interfaced with all other elements of the systems simulated.

Moving to the next row, associated real system components, such as hydraulic elements can be added, with additional systems and the aircraft dynamics still simulated, the next row shows more systems added (such as on an iron bird rig), and finally, the top row represents the real flight test aircraft. Virtual testing can also be used to test phenomenon which would be unsafe or impractical to test physically, such as failure cases.

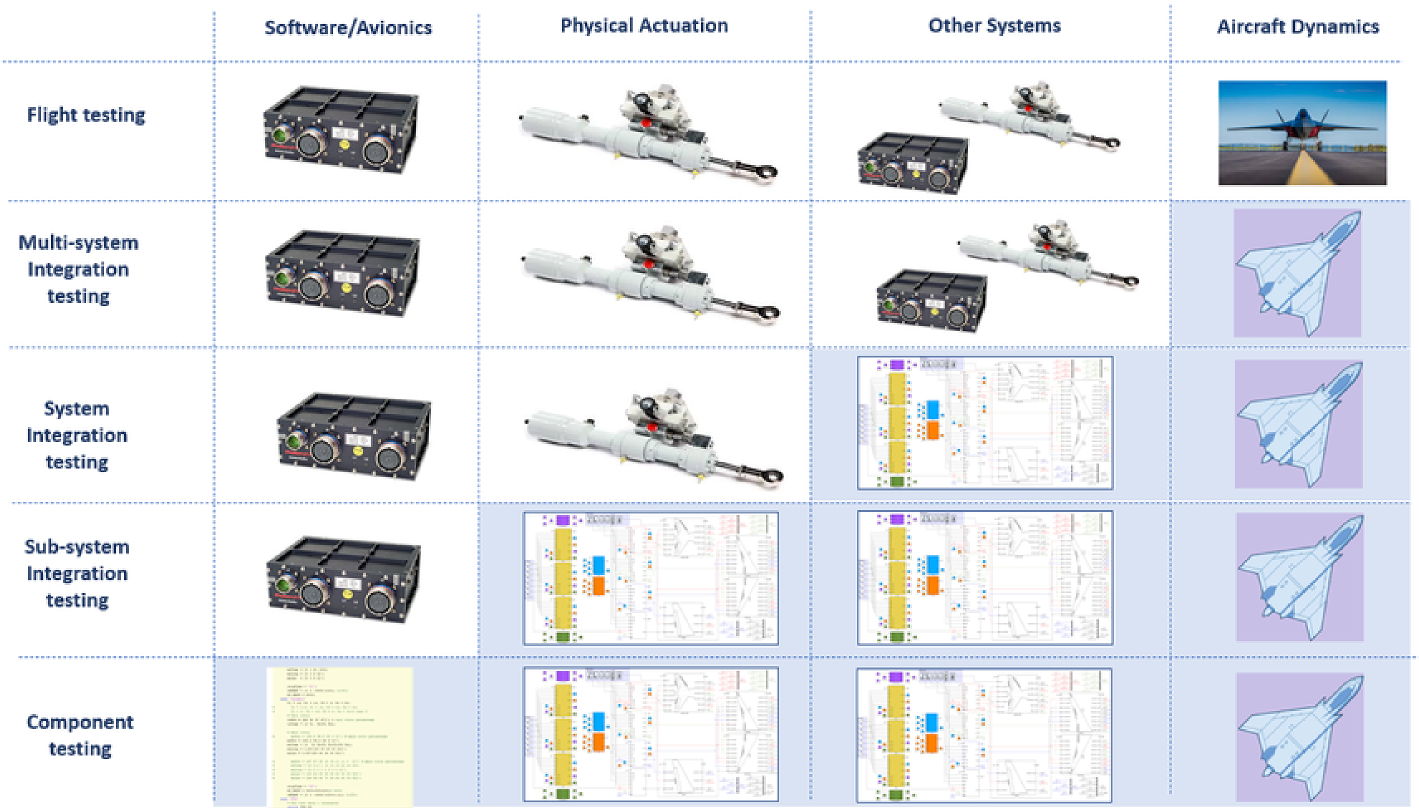

Figure 3. Model uses in testing

5.FULL LIFECYCLE SUPPORT

The models can continue to support the aircraft post-flight-test and following entry into service, as any proposed modifications and updates can be assessed against what would now be validated models.

Additionally, any in-service incidents and problems can be studied using the model, to support root-cause analysis. Maintaining the models in parallel to the final product has become to be known as the 'Digital Twin' concept.

EXAMPLES AND CASE STUDIES

To illustrate the concepts discussed in this paper, we have provided a case study of a recent project undertaken by Stirling Dynamics to support a major integration programme.

Stirling Dynamics developed an Integrated systems model (ISM) for an aircraft programme which included:

- Primary flight control systems
- Secondary flight control systems
- Extension retraction system
- Nose landing gear (NLG) steering system
- Main landing gear (MLG) braking system
- Centralised hydraulics system
- Electrical power generation and distribution system
- Thrust reverse actuation system

The ISM (Figure 4) could be operated and run on the individual systems, to explore and develop the system in isolation, or any combination of multi-system modelling could be carried to investigate the interaction between systems.

Example of analyses performed include:

- **Impact of uncontained engine rotor failure (UERF) on rudder control during take-off**
  This involved using the primary flight control system, aircraft dynamics, and centralised hydraulic system. A rupture in the hydraulic system was simulated, which produced a dynamic degradation of the rudder control. The monitoring system would then identify the failure and command a reconfiguration, so the standby rudder actuator and control system takes control. The timings and impact on aircraft performance were assessed. The result of the analysis was a change in the initial configuration of the actuator systems.

- **High return pressure spikes**
  During the on-ground retardation phase, high pressures were seen in the hydraulic return line system during thrust reverse deactivation (stowing). This was caused by high hydraulic volumes being returned from the thrust reverse actuation system and created a pressure wave, which created

increased pressures through the pipework, particularly where the pipework narrowed. Through modelling, the control valve was tuned and optimised to give a more controlled and smooth release of hydraulic pressure, reducing the pressure spikes and negating the need for an accumulator or increased strength pipework, both of which would have added weight.

- **Monitoring system tuning**
  The flight control system includes an array of monitors to ensure that no faulty sensors or equipment impede the ability of the aircraft to be flown safely. The models were used to tune the monitor thresholds and persistence by first assessing the limits and types of surface out of position failures that could be tolerated from a handling, stability and loads perspective. The level of biases, noise, and drift across the full flight control system was then assessed and tuned to detect the faults before within the defined limits. These were finally verified further to ensure nuisance trips were minimised.

- **Real-time models**
  Reduced models were developed for all systems, to be integrated on the engineering test rigs to be used for certification and acceptance testing of real hardware and software for clearance for flight test. The models were used for pilot in the loop simulation and had failure conditions added, so the pilot response under these conditions could be observed.

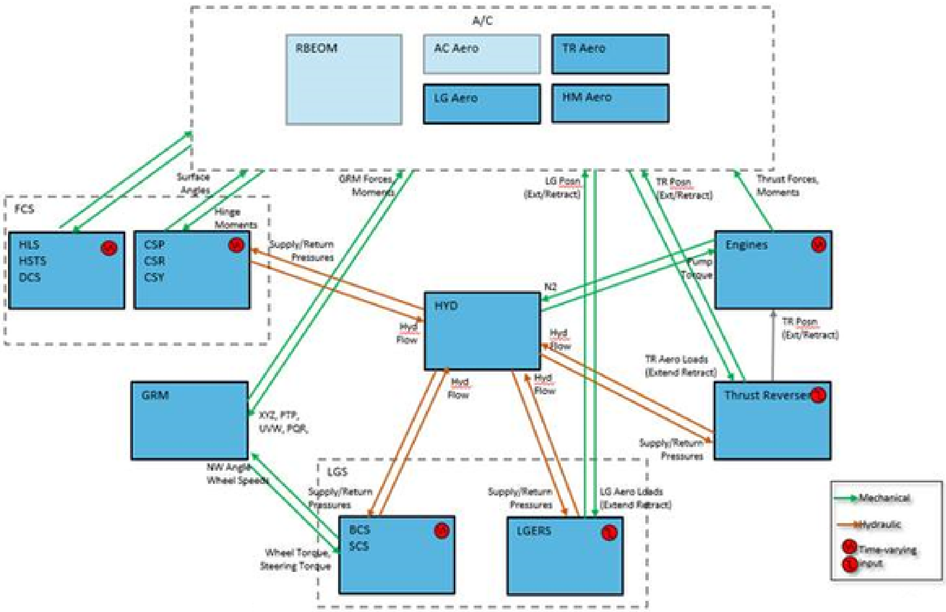

Figure 4. Integrated system model

SUMMARY

In this paper, we have looked at the benefits of Model-Based Systems Engineering (MBSE) and shown how this approach can reduce the time for developing complex systems and improving accuracy. A case study has been presented demonstrating how Stirling Dynamics has used an MBSE approach to develop an integrated model for an aerospace client, shortening the time required to bring the project to completion and certification.

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Luke has 20 years of experience in applying modelling and simulation practices to multiple industries and disciplines. He has worked in all areas of the design lifecycle using modelling for concept studies, developing design maturity, rapid prototyping, real-time engineering simulators and in-service support and root cause analysis. Luke has particular experience with aerospace applications including landing gear systems (braking, steering, extension/retraction), landing gear design, flight control systems (primary and secondary), hydraulic power generation and distribution and electro-mechanical and electro-hydrostatic actuation for aerospace application.

ABOUT STIRLING DYNAMICS

Stirling Dynamics is an advanced engineering company that provides high-end engineering and consultancy services to support programmes in the aerospace and marine industries – including those with demanding safety-critical requirements. The company's strength is in providing world-leading technical expertise and the ability to work collaboratively with customers to build strong relationships with a focus on open communication and transparency. Trading since 1987, Stirling Dynamics has accumulated a wealth of knowledge on over 70 different aircraft types and 11 naval platforms around the globe, covering both civil and military programmes, ranging from conceptual design through to in-service support.

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