UDT 2019 – Really Managing to Design

Nigel Whybrow, CEng, FIMechE, FRINA, Babcock International Group, Bristol, UK.

Abstract — This paper is concerned with organisation and behaviour as the means of achieving desirable and effective products through the execution of complex design projects. The focus is upon products created for and by underwater systems enterprises – the naval users, government agents and industrial & support service suppliers.
Working as they must in an uncompromising environment, underwater systems tend to be specialised and built of relatively non-standard hardware. Consequently, underwater systems also tend to complexity and hence they may be slow, and costly, to define, design and build. This complexity of both product and design process combined with small production runs also raise the level of programme risk and so act against the introduction of new technology and design features into existing and future platforms. The fact that modern naval underwater systems mostly develop incrementally with few genuinely revolutionary changes appears to be a consequence of these issues. This need not be the case for wise and open management of the design process and players have the potential to mitigate the preceding constraints. Four aspects are required – An appropriate **Design Philosophy**; a suitable **Way of Working**, **Realistic Project Context & Enablers** for the design & product(s) and, arguably the most important, the **Controlling Mind** with *real authority* to direct the design process and manage the associated decision making and management of product performance and programme cost and schedule risks

1 Introduction

This paper and presentation explore measures that can be adopted to mitigate the issues typically associated with major design based projects in the underwater domain.

This exploration has three steps:
- Observations and Comparisons;
- Understanding how design can be done well;
- Isolating the elements of effectively managed design activities relevant to underwater projects.

Inevitably given the nature of a paper for the UDT Conference this exploration can only touch on the complexity of the issues affecting the execution of major design projects. Consequently, key issues and measures are introduced as principles and examples which should not be read as explicit or absolute templates.

2 Observations & Comparisons

2.1 Product (Output) Level

For most of the twentieth century naval underwater systems were synonymous with manned submarines. Increasingly the civil sector - science and oil/gas companies - have been responsible for developing and exploiting unmanned craft – remotely operated and latterly autonomous and developments continue in and around these areas.

Spurred on by conflict manned naval submarines made huge strides in the 20th century and were developed through a series of radical and revolutionary technology, engineering and design steps of which nuclear power & propulsion and atmosphere management systems are familiar examples. However, this pace of change has slowed markedly and despite continuing technological improvement – such as in energy storage, computing (autonomy) and materials - the manned (nuclear) submarine has become a mature product type. Regular tangible change is only seen around the Combat System and associated sensors both of which are enabled by fundamental investments and progress in the civil sector.

Few would deny that the over the 60 years or so that nuclear submarines have been a 'standard product' in the major navies they have shown marked growth in platform size that does not correlate to an increase in performance (accepting a correlation between size, performance and availability for underwater vehicles)

In parallel with this growth have been the reduction in fleet sizes and the extension of design and build durations and operational lives.

Together these increased durations result in specific designs being applied and used in-service for very long periods – perhaps 70 years i.e. 5 years in pre-concept,10 year design 10 year individual boat build, 15 year delivery of the class of similar units and 30 year service lives. Key design personnel have few opportunities to learn by experience and design protocols become highly procedural driving out innovation.

These factors apply in other reasonably comparable industries which share equivalent levels of design and functional complexity, operational and material hazards, bespoke low production runs and extreme specialisation and equipment & suppliers. However, improvements in overall design and product performance has not been restricted as greatly as in naval submarines:

- Oil production platforms:
  - Whilst not spectacular, improvements to process efficiency, safety and availability have been realised through steady iteration of platform design;
- Spacecraft:
  - By the 1990s a 'design plateau' appeared to have been reached with manned spacecraft design in the USA and in Russia, yet Space X and Blue Horizons have shown that apparently unassailable functional and performance paradigms can be challenged and supplanted. In this they have also shown that substantial technical & operational change can be achieved within reasonably short timeframes and at moderate risk. The corollary is that such

performance requires sustained vision, organisation and investment;

- Both companies are underwritten by very wealthy individuals who have been able to deploy their wealth effectively. They have displayed the 'Vision thing' and in so doing have encouraged bright, inventive and motivated individuals into these businesses. These companies are showing the combination of vision (clarity of aim), finance, tools and technical and management intellect to be extremely powerful in realising meaningfully better products.

Interestingly the construction sector in the USA has introduced a design and procurement regime – "Progressive Design and Build" to address the difficulty arising from the standard approach of successive development and approval of a design followed by the tendering to build which may identify constructive issues and generate prices beyond which the customer (the 'owner' in their terminology) is willing to accept; instead of separate designers and builders a designer-builder is used from the early stages. The following characteristic benefits[a] are cited for the approach in respect of an owner as a public body, the adoption of a PDB regime :

- Brings the design-builder to the project very early;
- Avoids the owner creating a design baseline and then "handing-off" the design to the design-builder;
- Streamlines and simplifies the procurement process;
- Enables the owner to provide substantial input on the design decisions;
- Removes some time pressure on all parties:
- Offers a high degree of cost certainty and transparency;
- Shortens the overall project schedule with a shorter procurement process and opportunity to use early work packages in phasing the work;
- Allows owner participation in subcontractor and supplier selection;
- Fosters a collaborative, integrated working environment;
- Provides a collaborative way to establish "single point of responsibility".
- Provides the owner an "off-ramp".

This is interesting precisely because such a general approach of joint engagement, definition and agreement is the basis of many past and current major underwater systems procurements. Why then does the perception exist that these processes are ineffective in the naval underwater systems sector?

2.2 Specific Difficulties

At the working level within naval underwater systems projects more specific difficulties are often apparent:

- Problems with the duration, tempo and sequence of definition and sign-off of the design solution as it matures:
  - Due to the small numbers, speciality and complexity many significant systems and sub-systems have elements with vastly different lead times. This leads to pressure on the design team towards early and heterogenous design chill and design freeze across the design solution, which often locks in unresolved compromises which may not be fully apparent.
  - Naval underwater systems tend to physical and functional complexity with high levels of interdependency between systems. This interdependency exists just as strongly during the design process with decision making relating to system and/or space being affected by many others.
- Problems with the emerging design solution (the product):
  - There is often not a clear and stable set of requirements. It is extremely difficult to generate an acceptable design efficiently where the requirements are plastic;
  - The tendency to evolve the requirements undermines the systems engineering processes which underpin the design - or put another way - the customer is frequently reluctant to sign up to a requirement *many years* ahead of delivery;
  - Limited new technology and engineering options upon to introduce into new design solutions;
  - Spirals of increasing Complexity and Cost particularly where the requirements are in flux and/or there are many unresolved and overlapping output and intrinsic (design quality) requirements and considerations;
  - It may be necessary to accept a set of requirements early in the design cycle and to permit changes subject to rigorous change control from the outset.
- Problems with the content and definition of the design:
  - Modern product design & manufacturing systems have to have accurate data in the right format. Otherwise costly work arounds are needed;
  - Data generated by the design has to have "integrity" and outputs have to integrate with

[a] Derived from https://www.leanconstruction.org/wp-content/uploads/2018/04/Progressive_Design_Build_Primer.pdf

design, analysis and verification systems without corruption;
    - Security considerations will impose growing restraints on data management systems making transfer ever slower and more fraught;
    - Great care will be required in all data transfer, alignment and fusion operations, and two responses are noted – the adoption of a common information regime and data set across the principal members of the enterprise and the possibility of the reversion to manual data transfer where integrity can be confirmed.
- Problems security and commercial confidentiality (IPR):
    - The data storage, access and manipulation abilities of modern product design & manufacturing systems present major challenges when militarily and/or commercially sensitive information is required to be processed. It is vital that such information is handled appropriately and the design/data systems must be suitable – where necessary suitably high integrity IKM arrangements must be made for the information and storage/communication hardware and, via access control arrangements for the personnel working in the project. Equally significantly care must be taken to afford such information with sufficient protection and not to over classify material.

There are many examples of ineffective compromises between the above problems and problem areas. High system investment and the employment of additional manpower and often schedule delay are the usual outcomes.

3 Doing Design Well

Design is the deliberate generation of an idea for a purpose. In the real world this is accepted as being the creation of a solution to a problem, whether that solution be in the form of a process or a tangible artefact. Indeed it may be the process to create the artefact.

The world is full of artefacts and 'design', much is adequate and some is poor; it appears to be hard to do it well as good design is sufficiently uncommon to be remarked upon.

The goodness of a design is usually only really apparent when it is completed and has been in use and has been 'tested' in all the situations anticipated during the design process. In practice designs that have been regarded as successful, as 'good' are those that proved capable - through adaptation is necessary – when applied to situations they were not explicitly designed for. Qualities such as margins, simplicity and standardisation are often the key enablers. The corollary may be noted - design solutions (i.e. 'Designs') with limited margins, complex physical & functional architectures and a high proportion of specialised components are frequently regarded as 'not good' particularly when brought into service. Such solutions should only be adopted where the achievement of a specific characteristic is crucial and cannot be realised via a more balanced/less specific approach.

For the purpose of this paper 'design' is to be read as embracing suitable combinations of science, technology engineering and operational understanding and components.

3.1 Design as an Art

Design is often seen and treated as a reductionist and derivative exercise. This is wrong - design and engineering are thoroughly creative endeavours and should be treated and encouraged as such.

Broad consideration of issues and open thinking to both resolve/understand goals and then perceive new solutions through visionary/inventive action can be very powerful.

Design as an art includes the synthesis of ideas to perceive both opportunities and the means to achieve them. Ultimately little should be excluded arbitrarily when seeking the artistic solution to design problems. Questions along the lines of 'What if…..?" and Why can't….?" should be commonplace within design teams.

3.2 Design as a Science

For Engineers, Naval Architects and Programme Managers the rigorous, reductive working 'down' from a requirement inexorably into a solution is a natural part of design of engineering products where performance and integrity are vital. Ultimately that is the author's view too BUT such an exercise must be operated to challenge and test all default notions of potential solutions such as the existing product.

All of the analytic aspects of design are required and these need to be driven by the needs for thorough, consistent and complete - i.e 'structured' - working to identify and generate evidence, evaluate absolute and comparative performance and resolve balances and meaningful trade-offs.

Beyond that, the emerging design solution must be described with clarity of form, function, operation/use/support and performance – Design Intent and Design Disclosure]. This is essential so that the potential ability of the design solution to satisfy the applicable requirements can be demonstrated. In order to obtain validation and acceptance options will be required to find the most suitable balance of characteristics to show the effectiveness of the emerging design solution against the classic precepts of performance, cost and time.

Since the generation of any complex design will involve many selections and trade-offs a clear and robust Decision Making (and recording) process is essential.

3.3 Good design - Best of Both

In a sense it does not matter how good design is arrived at only that it is generated and adopted. The particular aspects of goodness may be hard to define whilst a product is within the design process but most design practitioners would include the following practical aspects of how design processes should be managed to provide if effective design solutions are to be generated:

- Output focus;
- Insight;
- Synthesis and exploration of alternatives;
- Thoroughness to resolve discriminating knowledge;
- Functional and material robustness;
- Authoritative decision making;
- Progressive work, plausible steps from secure foundations.

4 Elements of Good/Effective Design

Within the realm of major underwater systems projects these aspects can be resolved into three core strands that can combine to generate good/effective design:

- Appropriate Design Philosophy for the products and their use;
  - With a declared system and the freedom to apply & exploit it;
  - Rigorous exposure and rationalisation around critical contribution to direct and supporting functions;
- Suitable Way of Working (management approach and processes) providing
  - Structured working regime enabling progressive definition of solution (to reduce rework and churn), this requires alignment with the Design Philosophy and compatibility with the requirement set such that material and time margins and be included in the design and design schedule – these allowances can be retired in degrees appropriate to the increasing maturity;
  - Easy, full and secure access to information across the enterprise and project – security and confidentiality issues under control;
  - Suitably skilled, experienced and resourced multi-disciplinary participation in the design process, which shall use plenty of competition and challenge to concentrate upon thoroughness of consideration and demonstration;
- Realistic Project Context for the work
  - Clarity of objectives and trade spaces;
  - Coherent Requirement ⇔ acceptance of a 'Marginned' Solution
  - Adequate project pace and timing of intermediate and final decisions.
  - Suitability, coherency and completeness of design and information tools.
  - A pool of technology & engineering developments and access to the associated developers.
- Real Authority
  - *Small and cohesive* core design team directed by the *controlling mind* to maintain and apply 'corporate knowledge and understanding';
  - Acceptance by the Customer of the authority and responsibility of the core design team – this means letting the team 'get on with it' between the planned programme level engagements and decision cycles;
  - Availability of accurate information upon which to generate & test designs and construct programmes;
  - Trusted engagement with specialist analysts and design teams /planners in industry.

5 Appropriate Design Philosophy

'Appropriate' is a special term for it carries huge implications without real specificity. Within really managed design it is intended that 'appropriate' design philosophy would be:

- consistent and coherent with the parent organisation's operational aspirations and with its expected resources and accessible technological & industrial bases; and
- directly relevant to the requirement and the solution proposed to satisfy it (i.e. a design philosophy embracing very high component integrity and life might not be relevant in an application embodied in a swarm of disposable elements.

Several substantially different design philosophies may be developed for specific situations and not attempt will be made to identify them in this paper.

One general philosophy is however, rather more appropriate in this paper and in most situations; this may be called Contribution Focussed Design.

Contribution Focussed Design (CfD hereafter) is not a recognised design philosophy as such, but is a rational approach to many design situations notably those where evolutionary design (usually iteration) has restricted deep change and has led to design solutions of progressively greater complexity without proportionate improvement in overall, i.e. measurable output, performance.

Increased complexity is a keynote of modern submarine designs which carry large burdens of specific and subtle performance requirements within expectations of high integrity – safety and availability. Interpretation of the

ALARP[b] principle/philosophy frequently involves the accretion of new supporting systems and/or the integration of separate systems both of which typically give small increments of improvements to integrity without really changing the magnitude of that performance. Such actions can be argued as 'reasonable' particularly where a contribution form an existing system is co-opted, indeed strength in depth is often invoked as a design principle to be satisfied. Care must be taken to manage developments of this sort and avoid disproportionality of provision.

CfD addresses disproportionality by consideration of the *contribution* to overall performance and integrity that could be expected from specific functions and systems individually and in combination. To use a very homely example – an individual may wish (or need) to wear a particular pair of trousers (pants). These trousers may be a little loose and the individual can choose to reassure themselves that the trousers would not slip down by adding a belt. They could use braces (suspenders) instead, or string. They could wear some extra underclothes to reduce the mismatch of sizes. They could adopt some or all of these expedients in combination. As a philosophy CfD would consider the relative contribution to integrity - the trousers not falling down – potentially provided by the different mitigations and note the improvement to overall integrity that they could make in combination. A balanced choice may be made to go with the belt alone since the other measures could have other issues (the braces could get caught on something) or may not be robust (no guarantee that the extras layers would stop the trouser from slipping). All of this is preamble to the real value of CfD which is two- fold. Initially it is through the exposure and challenge of the opening assumption – in the example extra measures should be found to make the wrongly sized trousers to stay on the wearer without slippage. A proper contribution focussed review would determine that correct fitting is the greatest contribution against trouser slippage so the rational answer would be to wear a pair that fits in the first place. Secondly, where very high integrity is required - particularly against uncertainty - then a belt would be chosen. Its contribution may be small beyond the good fitting but it would provide redundancy and confidence and could be chosen for its net additional contribution. It seems unlikely that any additional measure would be needed if the trousers fit. Where the trousers are a bad fit CfD would assist in selection of that group of complementary measures that would be most effective.

Returning to the arcane world of underwater systems design – CfD would be applied as follows:

- CfD is a design philosophy that would consider primary functional INTEGRITY of the underwater platform, essentially:
    - Safety, Availability and Effectiveness
- The focus of consideration would be on the leading providers of that INTEGRITY and the magnitude of that contribution individually and collectively
- Place attention and system/equipment investment on those design elements, SQEP and approaches that *contribute most directly* to the achievement of primary functional INTEGRITY
- Lesser design elements would be *eliminated* unless they can be shown to be a more economic alternative to further enhancement of the primary design element / contributors
- **The goal is Integrity through Simplicity** – in practice this would be achieved through *structured reduction of complexity*

This focus and investment on the leading providers of INTEGRITY and minimisation and ideally *elimination* of the lesser contributors can provide a rigorous basis for design selections as it requires each system in a design to be included and traded positively rather than being included by default.

Concentration of investment upon the greatest contributors and elimination of the marginal contributors can be very efficient when undertaken with energy and rigour. These solutions are sometimes known as ***'All or Nothing'*** types.

In principle a high integrity main element within the design solution providing key integrity and a backed up by a simple and independent complementary system will nearly always be the most efficient solution in practice.

Transoceanic passenger aircraft are a case in point. Far and away the major contributor to functionality and safety & availability integrity is engine reliability. Such is the demonstrated reliability that these aircraft designs have gone from 4 engine arrangements to 2 engine types almost universally reducing cost and increasing performance. Such is their integrity – the aircraft can fly comfortably on one engine - that alternative propulsion arrangements have been eliminated and in the event of a systematic (collective) loss of engine thrust the designs are configured with auxiliary power units and batteries to provide power for the control of good glide (and ditching) characteristics.

Margins and other provisions for uncertainty provide compliance in the design which is essential to the development of the 'good' design solution in and of itself. They are also crucial to the process of efficient design since, despite all efforts, design maturity cannot develop at the same rate across any complex design. In the latter case margins can be used to absorb uncertainties arising from partial immaturity.

The same CfD design philosophy applies to margins as they too can be assessed for contribution and utility. Similarly investment in a few fundamental and

[b] ALARP = As Low As Reasonably Possible, the key word is *Reasonable*.

accessible/tradable margins is likely to be the more productive approach than many small and ultimately unrealisable provisions scattered across the product.

The reduction in physical complexity through strict spatial rationalisation and regionalisation of spaces and systems are another provision against uncertainty that offer valuable design flexibility.

6 Approach - Progressive Definition

This section covers the approach to the development of design solutions. Consequently it tackles the anathema of parallel working and tendency to increase rework and produce compromised solutions that is the typical experience with major underwater systems projects.

6.1 Intent

The formal process used to generate a full design for a major underwater system and take that design through build is now very extended. The difficulties of this long duration are frequently compounded by long procurement and build durations. For example significant equipments can have such long lead times that they must be ordered at the time when the overall design is very immature.

Subsequent development of the overall design solution will be made around the physical reality of key hardware orders but lesser design decisions remain open to change and the cascade of consequent rework that would flow from other adjustments. This may be very costly in terms of effort and schedule and may also result in non-optimum solutions where a change in response cannot be tolerated.

A robust regime is required for the rational development of the design solution. Working in measured steps will help to ensure issues and factors are being, and will be, addressed and that informed and wise choices/decisions are being made. The aim of such a way of working will be to derive a clear and demonstrable design intent and design disclosure with a low rate of re-work and compromise within the design solution.

In principle such a regime should be able to produce finalised designs in a shorter overall duration than the less structured processes often encountered with major underwater systems, however, the need to work progressively will itself require time particularly at the start of the project. Completion of the later stages of the design process should be somewhat quicker as the uncertainty and rework that can bedevil the later design stages of traditionally managed projects should be much reduced.

6.2 Progressive Definition

The introduction of the 'Progressive Definition & Build' (PDB) regime in the US Construction industry, and now worldwide, has been discussed in section 2.1 and the benefits declared to accrue from the use of this regime have been itemised.

The working durations and the complexity of the products generated by major underwater systems projects have also been noted, and it can be seen that these projects properly expect a design/project management arrangement akin to PDB. It is no surprise that the typical arrangements align fairly closely with PDB but without the extent of benefits.

The following section explores how a re-interpretation of progressive working can address the typical difficulties afflicting naval underwater systems projects that are given in section 2.2.

6.3 Meaningful Aspects and Elements

The following segments provide examples of working arrangements applicable to well managed design processes. These may be used or adjusted to suit local protocols and circumstances as necessary.

<u>Deciders and Decision Making</u>

The following participants are recognised as being meaningful in the timely development of strong design solutions for major underwater projects:

- ***Customer***
  - Capability Owner
  - Operator
- ***Agent*** - Government design/procurement specialist project team (or Joint with the Customer(s) and the Key Suppliers and independents);
- ***Key Suppliers*** - (design and industrial specialists fundamental to the underwater enterprise and project(s)
- *Suppliers and supporters*.

<u>Objectives and Decisions</u>

Key aspects applicable to major underwater projects are the clarity of decisions and their implications in specification and programme terms and the care taken to ensure that the material considered and the participants in decision making are suitable to the impact and timeliness of the decisions being taken.

Work must follow a logical sequence of investigation and design definition – this is the progressive definition. The measured, progressive steps must be framed by explicit Decisions exercises (Panels) and standardised Design Assessments to consider test and accept the definitions generated.

All of this will need a schedule with constraining relationships for the participants such that:

- Explicit acceptance criteria are available to support various 'levels' of workstrand importance/impact upon the programme

- The measured design step, choices and required decision must be described and justified appropriately to the import of the workstrand and nature and consequences of the determination demanded.

Early quantification to the order right order of magnitude Decision Making to the value of the decision being made and the near and long term consequences to the core metrics of performance, cost and time. Balance customer engagement and delegation – lay basis for the Controlling Mind and Authority discussed later.

Expectations on Evidence and Justification

Burden of Proof - A great deal of effort can be consumed generating evidence against a high burden of proof, set this appropriately and work within the scopes of preceding decisions:

- beyond reasonable doubt;
- on the balance of probabilities.

It is important that the core Agent team have a full appreciation of its own responsibilities to the Customer in the delegated authority to trade performance with the emerging design and operational solution. This requires specific attention be given to Capability and Effectiveness (hence also to Performance) *rather* than to the engineering and project solution *per se:*

- Consequently client attention must be upon those transversals that specifically deliver Capability
  - the Key Suppliers would be expected to produce and demonstrate a design solution in which the Agent can have sufficient confidence of the projected characteristics (indicating performance) of those major functions that contribute to the key capabilities
- The Agent must participate and arbitrate in deriving the consequent capabilities and associated performance metrics and values:
  - several of these capabilities require considerations at system level beyond the single vehicles;
  - no-one else has the authority or the SQEP to define the necessary evidence criteria
- The Agent must be able to brigade the capacity to do this for these ‘Capability delivery transversals’.

Requirements, Standards & QA

Wider Requirements:

- General Technical Requirements
  - Design Transversals
  - Wider operational factors and measures manifested through Scenarios and Situations (scenes)
  - Detailed design management processes including maturity measurement, validation & verification (V&V) and configuration control
- (Presumed) benefit would be the adoption of a structured process to include *and maintain* safety within the design intent – achieved whilst being balanced against cost.

Specific (Appropriate) Work Structure and Toolset

Design work will be undertaken as design elements with task teams addressing functions & systems and using a suitable federated functional and physical model set managed through Model Based System Engineering (MBSE) toolset or similar. Ultimately this will progress to a full PLM toolset to complete detail design.

Design elements (DE) would be moderated by agreement of global factors - spatial and transverse aspects at:

- Design Assessments (DA)
- Decision Panels (DP)

DE will be part of wider Work Blocks themselves moderated through formal Design Reviews held in support of formal Certification Points (CP).

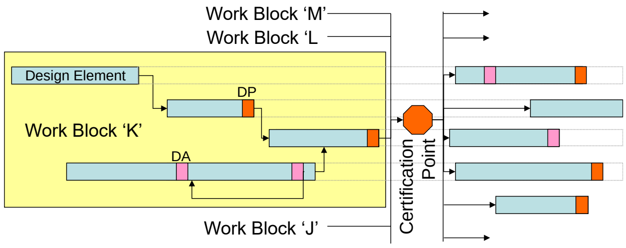

Figure 1: Typical Work Structure

Design Intent & Design Disclosure

Design disclosure goes beyond the very necessary description of the product and provision of the body of material necessary for it to be accepted, operated and supported. It is expected that these needs will be satisfied by the standard deliverables

Disclosure concerns the deeper reasoning behind the design solution and involves, at suitable levels of definition:

- Clear (structured) statement of the Design Intent
  - Including specific coverage of Safety (and other key properties)
- Key characteristics
  - Function, Performance and Operation
- Rationale for the preferred solution and intentions for its sustainment through life
  - Auditable trail of decisions and associated (suitably considered) working documents
- Exposure of the ‘capacities’ embedded within the design solution
  - assumptions and exclusions
  - allowance(s) for uncertainties

Mechanism for Disclosure

- Access control or handover of specific endorsed material

- Placement of working and mature information within secure, common working space with appropriate access control arrangements.

6.4 Progressive Working – Summary

The principal reference out will be to the notion of "Progressive Design & Build" adopted in the construction industry which offers a prudent mix of structured definition and working

The progressive definition of the design solution must embrace the balance of the three principal aspects of Integrity namely Safety, Availability and Effectiveness. Within this intent the whole design management endeavour sketched above would have a structure involving the following key aspects:

- **Specification & Design Solution refined progressively and assessed at Certification Points (CP)**
  - CP set at intervals suitable to support the project's timeline and required releases to procurement and build and of the corresponding margins and provisions
  - If the assessments are favourable then elements of the Specification & Design Solution will be frozen / chilled within a common configuration control regime and the subsequent cycle of design work commenced
- **Certification** of the design material through formal controlled processes (including at major sub-contractors and via defined interfaces)
- **Assessment of Maturity of the Design Solution** across the whole of the physical and functional model set.
- **Assessment of the Suitability of the emerging Design Solution** through engineering acceptance of specific evidence including:
  - Engineering cases demonstrating achievement of specific activities through life by addressing functional, performance and operational considerations
  - Operational cases demonstrating achievement of all the whole boat capabilities for specific phases of life by addressing the same functional, performance and operational considerations
- **Execution & Management**
  - Working Groups (functional and physical and including Transversals) to direct all agreed design aspects
- Meaningful **Measurement of Progress**
  - Work completeness, Schedule Adherence, EVM arrangements
- **Progressive Working and Acceptance**

7 Realistic Project Context & Enablers

Despite all of the merits of the preceding discussions and observations, the Agent team will be unable to generate an affordable, effective and deliverable project design solutions without endorsed objectives and scope for exploration and compromise. Hence a realistic context for the project must be available and the many specific enablers and constraints must be declared.

7.1 Ambition and Capacity

The Agent team must work to obtain from the Customer clarity of the latter's real objectives and trade spaces. This must be in terms minimum tolerable and desired levels of capability (ultimately of system performance) and of any and all other factors that the Customer may consider to be discriminating.

This will require a coherent and well-structured capture and appreciation of the Requirement. In addition the Customer must accept and understand the magnitude of provisions against uncertainty – margins and flexibility – to be assumed and built into the design solution.

It should be noted that where the Customer operates in a 'minimum enterprise' the necessary provisions against uncertainty may be explicit in terms of design and technology investments. The corollary is also likely to be true that a minimum solution may well require late adjustment (rework) with consequent severe cost and schedule impacts. The intent to work through the design progressively will reduce these complex group of technical and project risks, nevertheless the danger remains and this requires the retention of margins and provisions commensurate with the recognised uncertainties and an allowance for the truly emergent issues.

Particular design features can assist the convergence of the design at its progressive stages by enabling development and variation in the design solution but within the design philosophy and intent. Such measures include margins to ease progressive design and parallel design and build; a range of levels of modularity to assist with build and support and the use of architectural, functional and material openness and standardisation.

7.2 Project Pace

The project requires adequate pace and timing if it is to be executed effectively. Too little time will threaten simplistic assessments and errors and omissions in the design solution generated. Too great a duration threatens over analysis leading to the loss of direction and/or attention being given to marginal or spurious factors. Since cost will tend to greater for the longer projects and technical histories abound where a project undertaken at pace produced reasonable or good products then long duration, slow pace of work is considered to be the more dangerous of the extremes of pace. The question of pace applies to the intermediate as much as to the final decisions and outcome.

Crucially it is important to have sufficient time for Design & Build phases to mature separately and to manage the transit with real attention and judgement. A major, and not infrequent mistake is to let the project schedule dictate the start of build. The courageous, but stronger, choice is often to delay the start of build to avoid major commitments against an immature design basis.

It is important manage the degree of development required of contributing – and particularly of wholly new – technologies. It is important that new technology and their functional and performance contributions can be absorbed with ease – margins again.

7.3 Timing (in the Enterprise)

Major underwater systems projects will be key activities within their enterprises so it will be necessary to manage them in direct connection to their predecessors and contemporaries. In particular it may be beneficial to construct the project to keep the cadres of designers, builders and suppliers across the enterprise comfortably busy within the needs of the customer's procurement arrangements. It may be beneficial to work in terms of relatively small batch sizes – set by timing and suitability – rather than pursuit of an economy of scale that cannot be realised for most major underwater system procurements.

7.4 Access to New Components

It is self-evident that a healthy enterprise able to generate good products will require a pool of technology & engineering developments and access to the associated developers.

7.5 Processes, Tools, Data and Information

Beyond the design philosophy and way of working discussed above a suite of specific design processes will be needed to guide the actual generation of the design. Whilst they may differ between organisations a common terminology and format should be established to enable direct and error free information sharing. Attention should be drawn to the discriminating factors and provide relevant information and metrics. Suitable tools must be provided within a common data and design environment.

7.6 Location, Accessibility and Security

Design staffs must have secure but accessible working locations. Virtual presence arrangements should be adopted where they contribute but the design teams(s) and particularly any central co-ordinating team must be located so that it can receive and work *in person* with representatives from across the full membership of the project and of the enterprise.

8 (Design) Authority

Ultimately good design is about the old story……what is being contracted for - Capability/Performance, Time or Spend? and, whose design is it anyway?

- The Key Suppliers (build and support) generate the detail design solution, and they:
    - get uneasy when justification is sought against their interpretation and judgement;
    - feel all the compromises within the solution without the full appreciation of balanced benefit or the power to rebalance;
- The Customer has nurtured the Requirement as the expression of the necessary capability which he must deliver, they:
    - feel excluded by design & industrial factors limit development & trading and jeopardise delivery of the higher capabilities;
    - especially where the project/design intention is to select just sufficient performance to obtain the capability for minimum spend.

The Agent must operate as the go between and interpreter between these interest groups.

It is proposed that the Agent team be made into a capable (Design) Authority able to call upon technical and information resources and confident to use them to obtain the outputs desired by the ultimate customers.

Really this requires the Agent team to operate as the controlling mind behind the formation of the Project Design Solution. Controlling Mind may be vested in an individual or small group but it must stimulate, challenge, manage and direct the design exercises so as to meet the required performance, cost and time criteria through competent and robust work, but ideally through 'good design' as outlined in this paper.

Traditionally such controlling minds were styled Chief Engineers and Chief Naval Architects who were steeped in domain knowledge gained from participation in many prior projects. It is considered that such experience remains available, even if presented in a small group of SQEP to permit this approach to be realised now and into the future.

9 Conclusions

The manner in which design is approached within a project should be a conscious choice taken deliberately to match the project's requirements and aspirations.

Experienced practitioners will have noted that much of the foregoing reflects common experience and understanding; that is true – this paper has simply resolved that overall underwater enterprises have most of the knowledge and tools they need to operate effectively and produce good timely products. However, fresh ambition and improved organisation of design projects is needed if they are to use those tools and knowledge well.

Really managing to the design of major underwater system projects needs a commitment from the Suppliers, vision and direction from the Customer but most importantly it requires a dedicated team to work as Agent between the Customer (operators) and the broad Supplier base. That team should be given broad Authority and equipped with the following four elements (which must be complementary, consistent and coherent):

- an **appropriate Design Philosophy**;
- a **suitable Way of Working**,
- **Realistic Project Context & Enablers** for the design & product(s) and
- arguably the most important, the **Controlling Mind with real authority** to direct the design process and manage the associated decision making and trading.

Finally this paper suggests that a design philosophy in the manner of the Contribution Focussed Design (CfD) rationale complementing *and enabling* the Progressive Definition way of working will be the final components needed to make meaningful improvements in the way major underwater systems projects are executed.

Author/Speaker Biography

Nigel has spent his working life in the maritime systems arena; the great majority of which has been involved with the design and operation of naval underwater vehicles. In his current role of Future Submarines & Technology Director for Babcock International he supports early stage design activities around a number of projects for multiple customers and is involved in the development of wider appreciation of open and ambitious design and technology development in the company. He has presented numerous technical papers and studies mainly around early stage design.

Nigel is a Fellow of both the IMechE and the RINA.