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COMMITTEE V.5

NAVAL VESSELS

COMMITTEE MANDATE

Concern for structural design methods for naval ships and submarines including uncertainties in modelling techniques. Particular attention shall be given to those aspects that characterise naval ship and submarine design such as blast loading, vulnerability analysis and others, as appropriate.

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1 DISCUSSION

1.1 Official Discussion by Paul James

1.1.1 General Discussion

Historic and future development

The different approaches taken by classification societies and naval ship designers can be seen in their historical approach to global bending, the class societies traditionally relying on an empirical formulae such as IACS Unified Requirements URS7 to derive wave bending, and the navies utilising a static wave balance, Chalmers (1993). This fundamental load along with a design wave height for local structure defines the primary loads for structural design and, in conjunction with an assessment criteria, determines the structural steel weight.

Validation work undertaken by the classification societies demonstrated that the wave bending moment was similar if an allowance was made for a naval vessel's fine hull form. However, naval ship designers tended to use different assessment methods involving a greater degree of structural optimisation, for example use of grillages, and in some areas less conservative criteria. However the most significant factor which impacted steel weight was the use of a net scantling approach for naval ship design.

The development of the High Speed Craft (HSC) Code in 1990's and the subsequent classification society rules written for these ship types meant that an approach existed which was more akin to naval ship design. A net scantling approach, with rules that were transparent that could also facilitate structural optimisation.

It is probably fair to say that commercial ship design and naval ship design have met somewhere in the middle.

The future of naval ship design will probably be in two directions

- High value highly capable assets for specific roles and purposes. Submarines, Aircraft carriers or Air Defence Platforms. These will have highly specialised equipment and the platform is basically the casing around a weapon system. These vessels will probably be in the minority.
- Less capable but flexible semi-militarised vessels which carry a variety of equipment for a variety of roles. LPDs, RFA, OPVs or Corvettes. These will have the ability to transport, launch and recover a wide range of unmanned and manned equipment.

Both will rely on classification society rules for the basic structural scantlings because fewer naval ship design standards will be available; even now a designer's choice is limited as many naval standards are not maintained. Many navies are using class society's survey services and have configured their own procurement and certification processes accordingly.

It is likely that only the high value vessels will require design features for specific military loads. Even then designing structure for military loads is often a last resort as it is seen as the most expensive and least convenient option. Significant advances in capability can be achieved through careful placing of equipment, redundancy/duplication and separation, all of which can cost very little if implemented early in a project's life. In addition, the preference will be to spend money on not getting hit rather then dealing with the after effects of a hit, so the focus will be on reducing signatures and adding countermeasures.

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This means that there will be less focus in the future on the military load aspects of ship structural design and fewer projects on which knowledge and experience can be developed.

Similarities between naval and commercial ship design

There are a large number of similarities between naval and commercial ships' design because the fundamental physical environment is the same, for example the similarity of global loads derived from the long term wave environment. However, there are some important differences, these arise because of the way in which a naval ship is used in its environment. With more equipment being derived from the commercial supply chain, the lack of appreciation for the way a naval ship is used can lead to incorrect specification and ships that are not fit for purpose.

Some examples of this for the ship design elements chosen in the paper are:

- Hull bottom, sides and main deck forming the hull girder. These may require assessment against a higher wave bending moment because a naval ship may be subject to extreme bending loads from different operational scenarios, for example, sailing in extreme sea states for a rescue mission or hull whipping from an underwater explosion. Commercial ships are typically assessed to a 10^8 probability of encounter whereas some naval ships may need to be assessed to a higher probability of encounter to account for extreme sea loads.
- Watertight bulkheads, will usually be assessed against a much higher load from extreme flooding events due to multiple compartment flooding, see Sarchin (1962) for the definition of watertight structure, however the plastic collapse criteria used for assessment is generally the same as commercial ships. This has been important for ships that were originally commercial ships and converted into naval ships which are then expected to withstand greater levels of flooding.
- Foundations and supporting structure for equipment and the design of equipment such as cranes, ramps and lifts need to reflect the operational requirements. Stern ramps may get used as slipways, docks, and swimming platforms, all of which may not be appreciated by the equipment designer. This equipment is also used in a variety of sea states, whereas merchant ships usually use their cargo handling gear only in harbour. Munitions will also impose higher safety factors and test loads which need to be addressed in the design of the supporting structure. These requirements must get passed down the supply chain to the lowest tier.
- Weapon systems can also place unusual constraints on the structure for example, some weapon systems such as a CIWS require a certain seat stiffness which is usually easy to achieve locally but it may require global stiffening of superstructure which could be more of a challenge.
- Tanks in classification society rules are designed with certain allowances for the settling of fluids in pipes and filling systems, these may not be appropriate for a naval ship fitted with filling trunks which place a large static pressure head on double bottom tanks when replenishing. For the supplying ship operation with slack tanks may lead to significant sloshing loads which need to be addressed.

The NATO Naval Ship Code ANEP 77 attempts to address some of these issues by requiring a concept of operations to be defined, in short this document should define what a navy is going to do with to ship and be used as a reference for all subsequent design and approval activities and also all future operational guidance when in service.

Scope of Military loads

Whilst the major difference is the military loading, it is clear from the above that this is wider than just the "military action" loads listed in the paper. A navy uses a ship in a way which will impact on the "normal" structural loads too. It is these less obvious military operation aspects that are often overlooked and lead to the majority of problems in naval ship design and they are often discovered late in the build process.

Consideration of the military loads discussed is important and they can have quite a significant impact on structural arrangements, scantlings and steel weight. Therefore it is important to assess their cost and benefit through a formal survivability analysis. However as discussed in 1.1 the output from this is usually centred around equipment layout, and improvement of strength is usually the design team's last resort.

When assessing the survivability of a ship and the military loads to design for, it is important to understand the range of naval ship types a navy operates. This can be very varied and include: harbour tugs, research ships, auxiliary supply vessels, corvettes, frigates and landing platforms. All will have some form of Military role to a greater or lesser degree and this will determine the applicability of commercial ship approaches to design.

It is also interesting to note that some of the assessments and processes applied to naval ships are being applied to commercial ships too. Cruise ships are reducing underwater noise signatures Linden (2008), and the new common structural rules for tankers and bulk carriers LR (2011) Ch. 5 Sec. 2 require an ultimate strength assessment which is further discussed in section 5 of this report. Following the USS Cole incident in the Persian Gulf (October 2000), a number of commercial ship operators undertook analysis against military threats, especially those operating LNG ships.

Commercial and naval design conclusion

The narrowing of the gap between commercial ship design and naval ship deign has a number of good outcomes for the industry in particular the opportunities for joint research mentioned in the paper. Colleagues in both industries should look for more opportunities to collaborate and co-operate; one area of common research currently developing is in assessment of damaged ship structure. Underwood *at al.* (2011).

It is important to recognise that the way in which a navy uses a ship may impose fundamentally different loads on a ship which the designer must take account of and this is wider than just the direct military action type loads. Efforts to capture the manner in which a ship is used in a common format should be encouraged.

Ensuring that these routine naval load scenarios are correctly specified will allow classification societies to take up this work and allow Navies to focus scarce resources on the ship types with the greatest military role and concentrate on military action loads. In doing so they can determine the most effective means of enhancing the military capability of a ship.

Therefore the future direction of the committee should be on the military action loads including residual strength but it should also identify areas where the use of a naval ship can impact the more routine loads.

1.1.2 Optimisation of Naval Structures using Lightweight Materials

Why consider using lightweight materials?

It is important to put the weight equation into perspective, around 50-60% of a ship's weight is from the structure and there are significant gains to be made in the use of lightweight materials, but the full impact on the material system should be considered when evaluating the different technologies. It is quite correct that it is often the non structural performance of alternative materials that restricts their use in naval vessels, e.g. fire resistance or production costs.

Requirements and decision criteria for naval vessels

The total value of a change in a material system should consider the whole structural system. For example for relative capital investment, the structure and its protection systems e.g. Fire or corrosion, and the full costs of purchase and manufacture also need to be taken into account. Manufacturing costs will vary for each place of manufacture depending on the skills and experience available.

In-service costs should also take account of likely volume of in-service defects, for example use of high strength steels typically leads to increased fatigue fractures because of the higher field stresses in the structure. The cost of work in-way can be many times more than the cost of the actual steel work repair.

The costs of recycling and environmental impact also need to be taken into account when considering the full costs of a material system and FRP may not perform as well as steel and aluminium in this respect.

Light weight materials as a means of optimisation

The low modulus of Aluminium and FRP tends to restrict their use. However, some of this is due to traditional approaches being taken to panel stiffening. The use of some novel materials such as steel sandwich allows secondary stiffening to be omitted, and extruded close spaced thin walled aluminium sections can provide very rigid panel structures. Neither of these structures looks like the conventional stiffened steel panel but they can provide efficient structural support. That said, the limitations of flexural rigidity under global loads means that steel will continue to be used for frigate type ships and larger, though discrete structural elements such as hull appendages and superstructure blocks may use aluminium or FRP.

In Table 4, the impact of high ambient temperatures which can be encountered in normal operations in the Gulf should be noted in the performance characteristic for FRP. Enhanced scantlings may be required to provide sufficient flexural rigidity in hot weather.

Further challenges for mitigation of weight in naval vessels

Fire protection is rightly identified as a key issue for non steel materials, and several projects have investigated fire protection issues e.g. EUCLID RTP3.21. However there is also potential for a steel structure to fail in an extreme fire scenario where a single point of failure exists for a particular load path. It is not normal to insulate a steel ship structure for preservation of strength as it rarely sees maximum load coincident with an extreme fire event. However, it is common to provide protection for a building's structure as defined in EN 1993-1-2. Protection of steel may be relevant for a naval ship where the expectation is to regain use of the ship following a significant fire and expect the structure to carry load. The new edition of the Naval Ship Code requires critical structure to be identified for all materials and suitably protected.

Whilst FRP structures will require fire protection to limit smoke and toxic products, some navies have stricter requirements than the IMO criteria which could restrict a number of FRP materials.

For the other challenges raised in Table 7 the impact of production, coatings and consequences for ship signatures should be considered

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- The corrosion resistance of unprotected steel is poor but there are efficient paint coating systems that are enduring which would elevate steel to an average or good corrosion performance. Corrosion resistance is typically addressed through improved coatings rather than steel thickness as this is more cost effective through life. Few naval ships have substantial corrosion margins. The Superior corrosion resistance of FRP is tempered somewhat by the long term degradation due to water absorption and UV attack.
- For FRP production, the quality of the material is very dependent on the environmental conditions for manufacture; it may be more costly to produce a good product. This also means repairs are more difficult as controlled conditions may be required.
- One important property of metallic materials is the ability to screen electromagnetic emissions and this often leads to FRP materials having metallic screens added. Conversely, metallic materials need insulation, to improve thermal signature.

Hull monitoring

Hull girder monitoring has taken place historically on naval ships to help validate design assumptions such as long term wave bending moments, and on commercial ships for real time feedback to ship operators. In light of the discussion in 1.1 above, there is likely to be less measurement on naval ships in the future as classification societies are used to provide the routine ship design loads. If continued validation is required, it may be necessary for navies to engage with classification societies collaboratively through organisations such as Co-operative Research Navies.

Currently, there is more interest in the use of hull monitoring systems on local structure of naval ships to monitor crack growth in order to validate crack growth predictions and justify the delay of repairs.

1.1.3 Military Loads

With military loads being an essential and integrated part of the ship structural design, it is necessary for the classification societies to begin developing expertise in these areas. Most of the classification society naval rules have notations or requirements for military design of the ship's structure and where these notations exist, classification societies need to have specialist resource to undertake assessments. In most cases, it is the loading that is different, the structural analysis undertaken has similarities with the non-linear methods used by classification societies for non-military engineering applications. Once the threat has been translated into an engineering load time history, the process of analysis or review of test data is relatively straightforward.

There are some advantages to applying the classification process to a military feature which will require the plan approval, assessment of material characteristics, survey of production, installation and through-life monitoring. The classification process can be used to provide assurance that the capability specified is designed, built and maintained in a naval ship. Classification societies are currently issuing type approval certificates for blast doors, shock mounts and appliqué armour panels, and this will provide assurance in the supply chain.

1.1.4 Residual Strength after Damage

As discussed, the subject of residual strength after damage is becoming an increasingly popular topic for both commercial and naval ships and common assessment methods are used. Whilst the overall approach to progressive collapse is the same, using beam

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elements and load shortening curves, there is a degree of variation in the determination of the beam element load shortening curves. The introduction of common rules for commercial ships has standardised this to a certain extent but there will be a variance, with results derived from a navy's traditional database of load shortening curves, many of which will have been derived from experimental and analytical data. Alternative approaches are being developed which may look at panel collapse rather than beam element collapse, Underwood (2011).

For a naval ship, it is important to assess the damage from peacetime events as well as those from a military threat. Development of reliable peacetime damage extents is difficult, Zhu (2001), and quite often naval ship designs are assessed to determine the capability inherent in a ship designed for normal environmental loads. It is rare that a residual strength assessment will be allowed to drive the scantlings of a ship design. Similarly, the commercial ship common structural rules stop short of mandating a residual strength assessment against a prescribed peacetime damage.

Military damage extents are either prescribed based on past experience and analytical methods, or they are derived from the extent of damage described by a vulnerability analysis which identifies the number of compartments damaged for a given weapon threat. Empirical calculations can be used to determine the effectiveness of structure in resisting damage propagation.

Whilst flooding may not be explicitly addressed by the residual strength calculations of the classification societies, the use of a damaged waterline or "V" line to determine bulkhead and deck strength will ensure that internal structure is adequate for the damaged condition, provided the damaged extent assumed for structural calculations does not exceed that assumed in stability assessments.

1.1.5 Conclusions

Commercial ship design and naval ship design have clearly been moving towards each other and are nearly at the point of meeting. This is certainly the case for normal sea loads. However, it is important to recognise that the way in which a navy uses a ship may impose fundamentally different loads, which the designer must take account of, and this is wider than just the direct military action type loads.

Opportunities for joint research should be sought so that there are more opportunities to collaborate, co-operate and understand some of these naval differences.

This delegation of some areas of design and assessment should enable navies to refocus on the military loads and retain a specialist core of experts in these areas. If this is done, it is still important for navies to develop joint projects, attend conferences and encourage secondments with the classification societies so that knowledge and experience can be shared.

Lightweight materials do have potential to provide savings in weight, but at a cost, and the full impact of the material across all other ship systems, features and requirements needs to be rigorously assessed. The full costing of a material system from manufacture to disposal is difficult to determine and some standardisation of criteria would help in any objective assessment.

The focus on military loads and residual strength is supported but there may be some benefit in looking at the impact of naval operations on normal ships' load scenarios to ensure that classification rules provide adequate scope for structural safety.

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1.2 Floor and Written Discussions

1.2.1 Matthew Collette

I thank the committee for an excellent and interesting report. On the comparison between commercial and naval structure design, I wonder if the committee can comment it they examined differences on methods for predicting costs, outfitting impacts and other aspects of the "wider" design problem between commercial and naval vessels, and if we have adequate tools to support such analyses?

1.2.2 Albert Frederiksen

DNV's experience is that the military loads, such as shock and blast, have to be treated differently from the ordinary loads. The reason for this is that the military loads are related to the vessel *performance*, and are therefore more an optimisation issue than a question of "pass/fail".

In DNV, military loads are treated as verification of "owner's requirements" instead of "class requirements".

1.2.3 Stuart Cannon

Firstly I would like to congratulate the committee on a very good report. I have a comment and a question. Naval vessels cover a spectrum of requirements depending on the role they are intended for. This ranges from the constabulary role for patrol boats, which are dominated commercial rules, through auxiliaries to front end warships and aircraft carriers which are predominantly warship rules. If we use this approach we may need to include thermal loads from aircraft, such as the J.S.F. on flight decks.

My question is related to ageing warships. We have seen a general increase in the life of warships – some being 40 – 50 years old. This means corrosion and cracks of varying size and sites. Is this included in the analysis of shock and residual strength?

1.2.4 Akihiro Yasuda

I would like to congratulate the Committee in producing a very comprehensive report. I have two comments:

1. As suggested in the report, it is concerned that how the technique and knowledge about naval vessel design are taken care of. Especially for military loads, it is well known that almost all the results and experience about ship shock trials are confidential. In this situation, it seems difficult for class societies to review such results.

On the other hand, recent progress of numerical simulation makes it possible to predict large and complex phenomena including full-scale ship shock trial. As for the structural

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response to an underwater explosion, the analysis results of full ship shock trial are gradually conducted and published by the researchers. Therefore, it seems realistic that the class societies should clarify the phenomena which can be predicted by the numerical simulation or cannot be predicted in the present computational resources. In addition, the numerical results are to be validated through the model scale testing.

2. It is well known that strain rate effects on yield stress affect material behaviour when the material deforms in high rate under large impulsive loads like blasts. In the section about the benchmark of the blast analysis, the description about the strain rate effects on the results, are there any comments for that?

1.2.5 Mirek Kaminski

I have found the committee recommendations very short. Probably this is caused by the restriction of number of pages of the report imposed by the Standing Committee. I think the ISSC community needs more directions for the future research from the committee. Would it be possible to include these directions in Volume 3 of the ISSC Proceedings?

1.2.6 Stuart Cannon

The report does not comment on classification society rules for submarines. Where do you think this will go in the future?

1.2.7 Glenn Ashe

One significant challenge we face as a community is the realisation that naval vessels are primarily manned with younger and less experienced personnel. As a result, we must consider two realities when we do naval structural design:

- We must expect unusual loadings resulting from operation of the vessel outside of its expected design envelope, and
- we must expect the possibility of unforeseen corrosion or structural degradation resulting from inattention to maintenance.

2 REPLY BY COMMITTEE

2.1 Reply to Official Discussion

2.1.1 General Discussion

The members of committee V.5 would like to thank Mr James for his interesting and valuable discussion of our committee report, it is always difficult for an official discusser when he has not seen the content of the previous reports of this committee. Mr. James's discussion makes a number of valuable contributions to the report of our committee and we consider this to be a valuable addition to the committee report.

The discussors comments on chapter 1 of the committee report are generally supportive, the official discussion provides some excellent supplementary information which is of relevance to the committee report and would have been included in the committee report had it not been for page restrictions. The discussors report comments on the similarity between naval and commercial ship structural design and physical environment this supplements the information contained in the committee report.

2.1.2 Similarities between naval and commercial ship design

The difference in usage as mentioned by the official discussor is covered in the report but could perhaps have been given more weight, here we thank the discusser for his

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input. Usage is covered in the report as part of the 'Concept of Operations' statement, (CANOPS) as defined in the new Naval Ship Code (ANEP77).

The committee agrees with the discussers comments on the limitations of the use of lightweight materials, but the discussion in 2.1 of the report is intended as a general discussion on the possible advantages of these materials.

The committee agrees with the discusser that when looking at requirements and decision criteria for lightweight materials both initial procurement and through life cost considerations should be taken into account.

The committee agree with the discusser about the resistance properties of Aluminium and FRP which inhibit their use in general ships structure for larger vessels. We would also like to draw attention to the example within the report as a representation that sound engineering practice could still yield beneficial weight savings using alternative materials.

One of the major unspoken reasons for the continual use of steel in ship construction is realistically the comfort level among Naval Administrations, Classification Societies, designers, shipyards, etc. with known behaviours of steel naval ships through service history. Pioneering efforts for naval ship designs using alternative materials to steel will always be strongly resisted and highly scrutinized because of the uncomfortable idea of deviating from the norm.

The committee also agrees that there are considerations, other than fire protection of the structure, which are challenges facing the use of alternative materials that can and should be considered, these have been highlighted in previous reports of the committee and are in broad agreement with the discussers comments.

2.1.3 Scope of Military loads

The committee think that the comments on Military Load effects are overly simplified by the discusser, he comments that more effort should be spent in avoiding taking a hit rather than investigating how we mitigate the effects of a hit. This is a simple thing to say but unfortunately weapon designers tend to lead defensive systems design and ships will get hit, therefore to protect people and equipment detailed studies on vulnerability have to take place.

This committee fully agrees with the comments to this chapter 4, mainly based in the idea that Class Society (CS) involvement in the definition of the military loads will be beneficial for the design process and classification of a naval ship. The need of CS to develop as much expertise as possible on the definition of such loading is also agreed. The committee also would like to make reference to committee report for ISSC 2009, where the role of CS in naval ship design were deeply revised including recent advances in military loads definition.

The committee is also less optimistic than the discusser that class rules can handle military loads " just like any other loads". The levels of damage inflicted by weapon effects are varied and improving weapon yield and weapon design means that damage levels will become more severe leading to the need to improve the ships structural design to mitigate these effects.

Characterisation of data this complex in simple expressions is difficult if not impossible Also the underlying data used to develop the rule based criteria is old and based on experimental data, these experiments are expensive to reproduce and new data on more modern weapon effects is being developed, based on the use of multi-physics, models to investigate the effects of the weapon loads.

2.1.4 Residual Strength after Damage

The calculation of the residual strength of damaged structure from a naval vessel point of view is a critical technology which is required to assist in the recoverability phase when a warship is damaged in action. This assists in the captain's decision as to whether his vessel is capable of continuing with its mission or has to seek shelter and undergo repairs.

The assumption that we can use the same empirical models to calculate the strength of damaged ships that are used to calculate the strength of undamaged ships, with some assumptions about the extent of the damage, could be both incorrect and non-conservative. More up to date methodologies are being developed which improve our ability to predict the damaged strength of a ship taking into account different modes of collapse due to the presence of the damage. Some of the references to this work are included at the end of this discussion. These methods need to be further considered and incorporated into rule based design for all ships, never mind just naval vessels.

2.1.5 Conclusions

The official discusser's conclusions are in broad agreement with the committee's own conclusions and make a very useful addition to the conclusions of the report. Again I will take the opportunity to thank Paul James for his considered discussion of our committee report. The committee think his discussion of our report makes a very useful addition to the committee' own report on naval vessel design.

2.1.6 References

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2.2 Reply to Floor and Written Discussions

2.2.1 Matthew Collette

The costs of naval vessels are heavily influenced by weapon and equipment outfitting, the vast majority of the costs lying in this area. With commercial vessels there is more of an influence on cost from structural design and production. It is therefore very difficult to compare the costs of producing these vessels, there are tools available for carrying out this type of comparison but whether they are adequate or not is open to discussion.

2.2.2 Albert Frederiksen

The committee agree with Mr. Frederiksen comments about military loads having to be treated differently from ordinary environmental loads. All structures will have some capability to withstand military loads and local as well as global structural designs can be incorporated to improve this military load capability. I think current design techniques are not accurate enough to produce a straight forward pass/fail criteria but will give a relative measure of the level of improvement in the structural performance when certain design changes are made.

This can be implemented as either a class requirement or an owner requirement I think both approaches can be made to work for improving designs for military loads.

2.2.3 Stuart Cannon

The committee thinks that for Progressive Collapse and Residual Strength of a Naval Vessel current approaches can account for both the effects of corrosion and cracking. In the case of shock loads where the loading will excite both local and global natural frequency response of the structure that corrosion effects can be dealt with but fatigue cracking and propagation of the fatigue crack due to shock loading is not adequately dealt with and requires further research.

2.2.4 Akihiro Yasuda

The committee agree with the comments of Dr. Yasuda about the lack of availability of shock trials data, which have been carried out on naval vessels, due to classification reasons. It is also true to say that commercially available codes are now available which have the potential to carry out complex analysis involving fluid structure interactions for shock, blast and UNDEX loading events. That is why the committee said in reply to Mr James that the role of the classification society in the area of military loads will be severely limited and may remain an area which is dealt with by specialist researchers.

As Dr. Yasuda comments the effect of high strain rate on the material yield stress is well known, and has been used in a number of areas of research such as collision and grounding modeling, the effect of the much higher strain rates involved in shock and blast loadings will have a much more marked effect and these have to be included in any analysis involving shock, blast and UNDEX loadings.

2.2.5 Mirek Kaminski

The committee acknowledge Professor Kaminski's comments and would suggest that this comment would be better addressed by the next Naval Vessel design Committee.

2.2.6 Stuart Cannon

The committee is aware that some Classification Societies already have rules for Submarine Design and other Classification Societies are actively pursuing the development of Rules for Submarine design. The committee assume that these developments will continue and in the future a number of Classification Societies will have Rules for Submarine Design available for use.

2.2.7 Glenn Ashe

Mr Ashe has made some valuable comments on the future considerations for the design of Naval Vessels and the committee are in agreement that these have to be taken heed of.