Defence Research and Development Canada
Recherche et développement pour la défense Canada

Modular Capabilities for the Canadian Navy's Single Class Surface Combatant

A Perspective on Flexibility

Scott C. MacKenzie and Rohit Tuteja
Consulting and Audit Canada

Defence R&D Canada
CONTRACT REPORT
DRDC -CR-2006-004
February 2006

Modular Capabilities for the Canadian Navy's Single Class Surface Combatant

A Perspective on Flexibility

Authors:
Scott C. MacKenzie
Consulting and Audit Canada

Rohit Tuteja
Consulting and Audit Canada

Date:
February 2006

ACKNOWLEDGEMENTS

The authors would like to thank James King, Corwyn Moores, Brian Staples and Harold Stocker for the assistance they provided during the preparation of this report.

1.0 BACKGROUND

The Defence Policy Statement requires that the Canadian Forces (CF) acquire ships which, among other things, will be able to: support land operations, provide a sea-based national or international command capability, deploy tactical unmanned aerial vehicles and sustain naval task group operations worldwide.

The current Iroquois Class Destroyers are nearing the end of their operational life, and the Halifax Class Canadian Patrol Frigates (CPF) will reach theirs in the 2018-2025 time frame. These two classes of ships make up the surface combatant force of the Canadian Navy, and the capabilities inherent in them will need to be replaced in order for the CF to meet the maritime defence and security requirements of Canada, both at home and abroad. Haydon [Ref. 5] calls for "replacement of the CITY-class frigates [i.e., Halifax Class] and for new general-purpose patrol vessels able to sail into the northern waters." He states that "these may, in fact, be the same or very similar vessels."

The Single Class Surface Combatant (SCSC) will be designed to address all areas of the key characteristics identified as necessary for effective operations in the future security environment. These include but are not limited to: facilitate net-enabled operations, enhance interoperability, operate in a complex environment, provide future relevance and reduce risks to CF personnel in combat situations.

The provision of the SCSC will not only allow for the replacement and enhancement of the maritime capabilities delivered by the current surface combatants of the Navy, but will allow for the more efficient use of scarce defence resources in the fulfillment of Canada's defence and security needs.

The single surface combatant design will utilize a common hull form, engineering plant, common core equipment fit and will use open-concept engineering and modularity wherever feasible. As a result, the flexibility of the CF and the Navy will be increased with respect to tailoring the capabilities and capacity of a naval Task Group (or single vessel). As the ships will be designed using a modular weapons/sensors package concept, ships may be employed in a general-purpose configuration or can be task-tailored for specific missions.

The use of such a plug and play design concept would reduce the number of fixed, non-core systems allowing for increased capability for mission-specific systems. Through the use of common core systems and the ability to enhance specific capabilities, such as Support to Forces Ashore, Command and Control or Force Anti-Air Warfare, the likely availability of any particular capability will be increased as it will not necessarily be tied to specialized and limited hulls as is currently the case. Furthermore, when specialized capabilities are not required for a given mission, a reduction in personnel should be possible since those capabilities will not be fitted.

The common nature of the major systems of the SCSC will allow cost savings and a number of other benefits. With a single class of major combatants to support, major naval and support infrastructure such as jetties, connections and shore facilities can be standardized.

With the majority of fitted and ancillary systems being common to all of the SCSC, logistic support services can be simplified and inventories of unique parts reduced. Afloat support capability will be increased through the use of common spares for all surface combatants. And with most systems being common, training and employment of personnel will be simplified. There will be a general understanding of the capabilities and limitations of vessels common to most personnel

It is in the context of the post-9/11 era and the expanded roles and responsibilities of DND (in particular, the requirements for the SCSC), that a review of technologies related to modularity in the CF, and the concept of modular capability itself, is being undertaken by Defence Research and Development Canada (DRDC).

2.0 OBJECTIVE

The primary objective of this report is to conduct an assessment that will:

- Identify world benchmarks for the *Modular "Plug and Play" Equipment* concept;
- Outline risks and possible mitigations associated with the concept;
- Present technology readiness levels for the concept; and
- Consider the applicability to the various environments within the CF.

With respect to the various technologies involved in instituting such a concept, the assessment should address technology readiness levels (TRL) for three distinct time frames – 2010, 2020 and 2030.

3.0 SCOPE

The scope of this document is limited to a review of the modular capabilities for the SCSC. It does not address modular construction or other engineering issues associated with the SCSC except in cases where such issues overlap with the modular capabilities.

4.0 METHODOLOGY

Most of the material used in this report was from the open-source literature and interviews with subject matter experts. The material was aggregated and used to make assertions and draw conclusions, which are presented herein.

5.0 ACRONYMS

CF: Canadian Forces
CPF: Canadian Patrol Frigate
DND: Department of National Defence
DRDC: Defence Research and Development Canada
LCS: Littoral Combat Ship
SCSC: Single-Class Surface Combatant
SONAR: Sound Navigation and Ranging
TRL: Technology Readiness Level
UAV: Unmanned Aerial Vehicle
USV: Unmanned Surface Vehicle
UUV: Unmanned Underwater Vehicle

6.0 MODULARITY: SHIPS AND CAPABILITIES

A deliberate differentiation between ships with modular capability and ships of modular construction is made herein.

For many years, ships have been constructed in a modular fashion. That is, significant portions of the ships are built as modules, and the modules are then put together as a final assembly (see Reference 14, Royal Navy Type 45, for an excellent animated version of modular construction). It is expected that the SCSC will incorporate levels of modular construction exceeding that of the Halifax class CPF built in Canada in the 1990s which were substantially modular in their construction.

Modular capability focuses not on the overall construction of the ship but rather on the rapid plug and play installation of capabilities such as guns, missiles, unmanned vehicles, SONARs, special forces accommodations, etc. This concept is illustrated by the Naval Platform model outlined presented in Figure 1, page 4.

7.0 ANTICIPATED CAPABILITY REQUIREMENTS

In order to understand the implications of modular capabilities, the capabilities themselves must be identified. Accordingly, the anticipated capabilities which will be required for the SCSC ships are outlined in Table 1, page 5. An effort has been made to assign a difficulty level to each capability vis-à-vis modularity. Technology Readiness Levels (TRLs) for each capability for the years 2010, 2020 and 2030 are also provided. A complete listing and appropriate definitions for the TRL concept is provided in Annex A.

The primary conclusion that can be drawn from Table 1 is that most of the technology required for modular capabilities is either in place or will be soon. The exceptions to this are Command and Control and Advanced Technology/Directed Energy Weapons.

Naval Platform

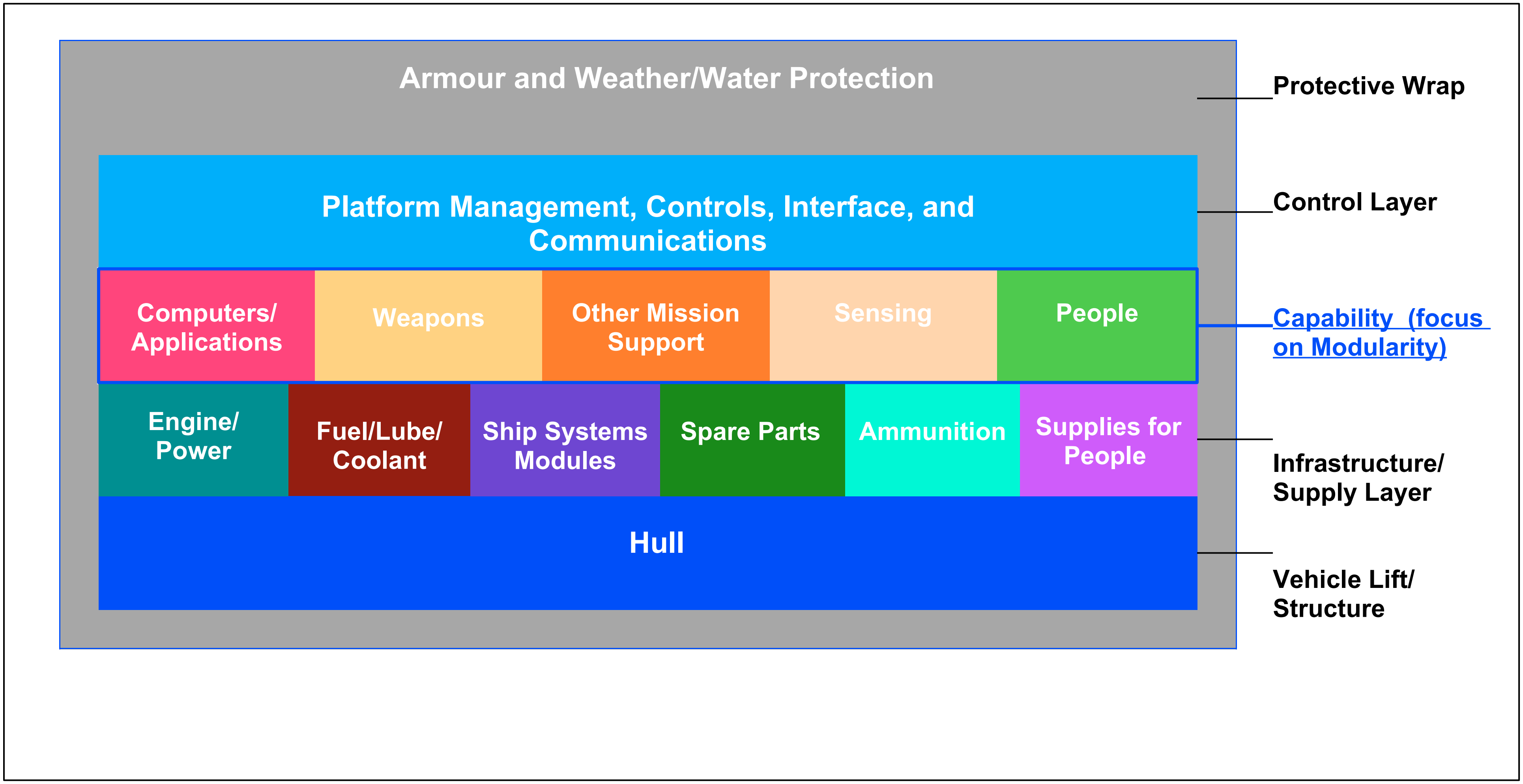


Figure 1

Capability	Level of Difficulty for modular application	TRL 2010	TRL 2020	TRL 2030
Command and Control	**High** – software architecture, etc.	4-7	6-9	8-9
Plug and Play sensors	**Medium** – due to C&C	6-9	7-9	8-9
Helicopter	**Very Low** – considered modular now	9	9	9
Helicopter Maintenance and Support	**Low to Medium** – potential crew morale and integration concerns	7 – 9	9	9
UAV	**Low** – providing size is appropriate	7 – 9	9	9
UUV	**Low** – providing size is appropriate	7 – 9	9	9
USV	**Low** – providing size is appropriate	7 – 9	9	9
Advanced Technology Guns	**High** – unknown interface requirements and possibly extreme power requirements	5-6	5-7	7-9
Direct Energy Weapons	**High** – unknown interface requirements and possibly extreme power requirements	4	6-8	8-9
Missiles	**Low to Medium** – handling, mounting and exhaust gas energy require care	9	9	9
Torpedoes	**Low to Medium** – handling and mounting require care	9	9	9
SONAR modules	**Low** – should be achievable	9	9	9
Naval Boarding Party	**Low to Medium** – potential crew morale and integration issues	7 – 9	9	9
Provide engineering/maintenance support to platforms	**Low to Medium** – potential crew morale and integration issues	7 – 9	9	9
Provide Submarine Search and Rescue	**Medium** – complexity of equipment and mission may be a concern	7 - 9	9	9
Special Forces Accommodation	**Low to Medium** – potential crew morale and integration issues	7 – 9	9	9
Special Forces Deployment	**Low to Medium** – complexity of equipment and mission may be a concern	7 - 9	9	9

Table 1 Capabilities, Difficulties to Modularize and TRLs

8.0 ASSUMED CHARACTERISTICS OF SCSC

Inherent in this paper are some fundamental assumptions regarding the SCSC design:

- Stable for worst-case weight/module location scenario;
- Equipment installed to handle a standard 20-foot container/module;
- Platform/module integration is therefore manageable;
- Space aboard the SCSC is adaptable; and
- Signature/stealth impacts from modular capabilities are acceptable.

Modularity should be used as a feature of the SCSC design, but it should not be a key determinant of the ship's architecture. The fundamental design drivers are likely to be sea-keeping, speed, endurance, etc. And it is these drivers which will dictate the size of the ship, not modularity.

9.0 MODULARITY, COST AND THE SHIP LIFE CYCLE

Ideally, the cost benefits associated with modular capability should extend to every stage of the ship life cycle. In practice, this is probably not feasible. However, significant savings are likely to be realized in a number of the life cycle stages. A cost reduction table is presented below.

Activity	Cost Reduction (Yes/No)
Requirements Definition	No (Probably cost neutral)
Design	No (Cost increase)
Procurement	Yes (significant)
Construction	No (Cost increase due to additional complexity but could be offset with advanced modular construction techniques)
Operations	Yes (based on the assumption that only those modules that are deemed necessary will be on-board for a particular mission)
Support	Yes (significant, but only after port infrastructure costs are ignored)
Training	Yes
Mid-life Modernization	Yes (significant)
Decommission	Yes (probably minor)
Disposal	Yes (probably minor)

Table 2 Modularity and the Ship Life Cycle: Likelihood of Cost Reduction

10.0 MODULARITY BENEFIT/COST CONSIDERATIONS

According to *Naval Forces* [Ref. 11], the general objective and eventually the success of the modular ship design concept is based on:

- Considerable cost reduction during the construction phase;
- Shorter construction time for the complete system. Both the platform and the modules are built and tested in parallel – time for integration is considerably shorter;
- Greater choice in the selection of available on-board systems in the marketplace;
- Greater operational flexibility by the in-built capability to either change roles within hours on base or during a planned maintenance period in a shipyard;
- Shorter and cheaper maintenance periods;
- Reduction of cost for mid-life conversion;
- Considerable cost savings for training of personnel; and
- Reduced logistical stocks.

Scheibach and Lamb [Ref. 15] indicate that "by utilizing the modular multimission and outfit zones approaches, compared with the traditional way of building ships, the benefits could be:

- Reduction in build time from 20% to 40%;
- Reduction in Hull, Mechanical & Electrical (HM&E) cost from 4% to 7%;
- Even more cost saving from reduction in number of mission systems/weapons required to meet the planned scenarios;
- Reduction in life cycle costs;
- Reduction in maintenance costs."

Note that these benefits are not solely due to modular capabilities – advanced outfitting is also a significant factor.

Advanced outfitting is the installation of machinery, piping, electrical and hull outfit items at a significantly earlier time in the shipbuilding process than is traditional [Ref. 15].

11.0 CANADA-SPECIFIC FACTORS

The following factors may present issues concerning the implementation of modular capabilities of the SCSC:

- First-year ice capability – the SCSC ships may need to tackle first-year ice. Vibration and other ice-related effects need to be considered in relation to the installation and operation of certain modules (see Reference 3, Environment Canada, for ice thickness terminology).

- Port Facilities – Canadian Navy ports must add the necessary infrastructure and equipment to handle, maintain and store modules.

- Construction capability – modular capability (as opposed to modular construction) will add additional complexity to warship construction. Canadian designers and shipyards will need to develop the necessary expertise.

12.0 TECHNOLOGY SURVEY SUMMARY: WHAT'S OUT THERE

The conclusions drawn from this technology survey (documented in Annex B) align with the assertions made in the report. The survey results are indicative of the following: There are three key modular design types within the naval ship context:

- Stanflex concept of the Royal Denmark Navy;
- MEKO concept of Blohm + Voss GmbH; and
- Modular Platform Concept (MOPCO) of Abeking & Rasmussen (A&R).

Of the three design types, MEKO is most popular internationally. MEKO vessels are employed by Australia, Turkey, Greece, Germany, South Africa, etc. It is interesting to note that although MEKO naval ships are modular in design, there is little evidence that modularity is actually being used in the operation of these vessels.

The key benefits of modularity are:

- Operational flexibility (i.e., the ability to reconfigure ship for various missions);
- Increased availability of the ship (i.e., reduced operational downtime)** ; and
- Reduced total number of mission modules for the fleet, resulting in cost savings.

** Note: *this is highly dependent on how and where the modules are stored.*

Challenges include:

- Inefficient space utilization;
- Maintaining ship stability under varying loads/configurations; and
- Logistics/integration issues – making it all work (e.g., variable crew with various missions).

The ship should be reasonably large since small ships are ineffective in rough weather (i.e., they cannot carry out sustained operations).

Most modular ships have provisions for missiles (SAM/SSM), guns, torpedoes and at least one helicopter. In addition, provision is made for Sonar, Radar as well as command systems on-board. In terms of future capabilities, the Littoral Combat Ship (LCS) will incorporate unmanned vehicles such as UAVs and USVs. Possible future weapon additions include an electromagnetic gun and directed energy weapons. Almost all ships provide some flexibility in terms of crew size/levels.

13.0 A CURRENT EXAMPLE OF MODULAR CAPABILITY

Note: this text is drawn from Blohm + Voss information and is presented here to provide an illustration of modularity in practice.

The Blohm + Voss "MEKO®" concept has existed for 20 years. Throughout this period, there has been ongoing development of the three basic design principles:

- Modularity
- Improvement in survivability
- Signature reduction

Figure 2 Blohm + Voss MEKO Concept

MEKO® platforms are designed specifically for the varied deployment of standardized modules (weapons, electronics and the ship's technical equipment) which, in addition, are connected with the power supply, the air-conditioning and ventilation system and the data network, for example, via standardized interfaces. All the components needed to run a specific system are accommodated in a single module.

Depending upon the particular task they are required to perform, a distinction is made between weapons, electronics and the ship's technical modules. Containers, pallets and mast modules are installed during the construction phase.

Modularity offers a range of choice in the selection of the on-board systems, whether it be with regard to the integration of customer supplied systems or the use of products that the customer already has in service from various manufacturers.

By simultaneously building the ship's platform at Blohm + Voss and the modules at the suppliers' premises, a significant saving in both time and cost can be achieved. The modular construction principle also reduces the costs of maintaining and modernizing the vessels. Availability and readiness for action are thus improved.

Accurately defining the interfaces for the modules clearly delineates responsibility between the yard and the suppliers. Furthermore, building and testing the modules in the suppliers' workshops decidedly improves product quality.

14.0 MODULAR CAPABILITY TYPOLOGY

The are different types of modularity, and capabilities can be mapped against this typology in a practical manner. The modularity types are as follows:

Type I

Modular containers or other modular installations (modular plug and play space with minimal installation time).
Examples: UAVs, Special Forces Accommodation

Factors to consider:

- Stealth – use flush doors over hull openings;
- Ease of installation, removal and use/deployment; and
- Standard interfaces for water, cooling, electrical power, etc.

Type II

Modular installations (plug and play, but with significant installation time).
Example: Primary Gun could be replaced with Directed Energy Weapon

Factors to consider:

- Ensure equipment is self-contained (true modules plugging into interfaces);
- Moderate ease of installation and removal; and
- Standard interfaces for water, cooling, electrical power, etc.

Type III

Modular space potential (space normally reserved for other capabilities – but which could be used for modules).

For example: Helicopter hangar could provide accommodation for humanitarian relief.

Factors to consider:

- Use ergonomics experts (e.g., at the level of current state-of-the-art automotive mini-van ergonomics; every space is well thought-out and components may be removed or may fold into something that has a different function);
- Emphasize packaging and flexibility; and
- Make the most of what you have.

These types of modular capability are illustrated in Figure 3.

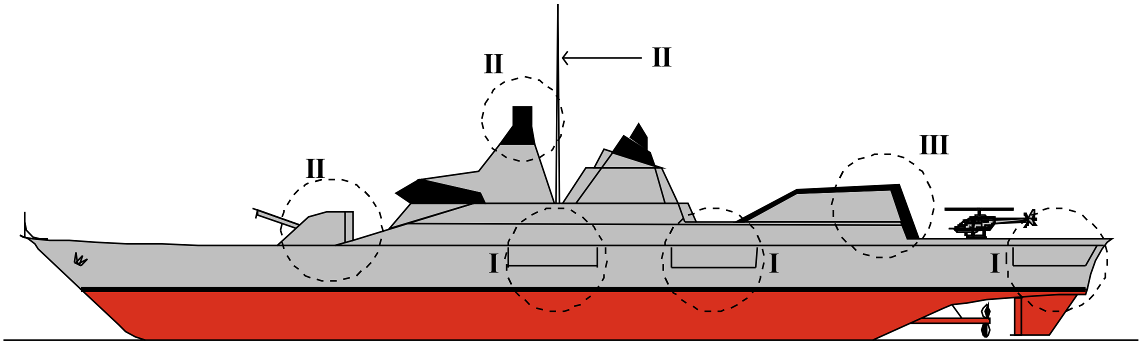


Figure 3 SCSC Concept

See Annex C for a larger-scale version of this Figure.

15.0 RISK AND RETURN: SOME OPTIONS

The Navy has at least three capability options it can pursue for the SCSC:

Modular Capability: this ship would allow plug and play capabilities and could incorporate the three types of modularity outlined in Section 14.

Multi-batch Multi-role ships: The SCSC ships would not be modular but would carry a balanced approach to probable mission requirements. However, consideration would be given to evolving the class over time in terms of batches (e.g., batches 1, 2 and 3). The United States Arleigh Burke class of ships currently have two distinct batches: DDG 51 to 78 are Batch 1/2 (also referred to as Flight 1/2); DDG 79 – 112 are Batch 2A. Please refer to Annex D for an appreciation of the capabilities provided by such ships. The Canadian Patrol Frigate program, in its early stages, incorporated a multi-batch approach. However, the ships which were intended to be Batch 2 models (starting with HMCS *Montreal*) were built as Batch 1 versions to reduce program costs. See Reference 6 (Canadian Navy Section).

Note: an analogy to the multi-batch ship concept would be the multi-version software application. Each subsequent version of a given software application has more or different features. But the versions are still built on the same base code and have a similar look and feel.

Multi-role ships: This option would not be significantly different from the approach taken for the Canadian Patrol Frigate program – one class of ship with essentially all ships nearly identical.

Item	Attribute	Modular	Multi-batch Multi-role	Multi-role
1	**Flexibility**	3	2	1
2	**Upgradeability**	3	2	1
3	**Interoperability**	3	2	1
4	**Operational Ease**	1	2	3
5	**Training Ease**	2	1	3
6	**Availability**	3	1	2
7	**Maintainability**	2	1	3
8	**Cost to Build (factors in procurement savings)**	3	1	2
9	**Design/Build Complexity**	1	2	3
10	**Build Time**	3	1	2
11	**Hull Space Efficiency**	1	3	2
12	**Facility Impact**	1	2	3
	Total	**26**	**20**	**26**

Table 3 Ship Options vs. Modular attributes

Ranking: 3 = Best, 2 = Medium, 1 = Worst

This analysis indicates that in terms of overall benefits, the modular and pure multi-role ships are very close. However, weighting factors on specific attributes can clearly shift these results.

One could argue that the first eight attributes are more important than the last four in terms of mission success, future capability and long-term cost. If one assigns a weighting factor of 2 (as opposed to 1) for those eight attributes, the modular case is stronger. The results of such an analysis are presented in Table 4.

Item	Attribute	Weight	Modular	Multi-batch Multi-role	Multi-role
1	**Flexibility**	**2**	3	2	1
2	**Upgradeability**	**2**	3	2	1
3	**Interoperability**	**2**	3	2	1
4	**Operational Ease**	**2**	1	2	3
5	**Training Ease**	**2**	2	1	3
6	**Availability**	**2**	3	1	2
7	**Maintainability**	**2**	2	1	3
8	**Cost to Build**	**2**	3	1	2
9	**Design/Build Complexity**	**1**	1	2	3
10	**Build Time**	**1**	3	1	2
11	**Hull Space Efficiency**	**1**	1	3	2
12	**Facility Impact**	**1**	1	2	3
	Total		**46**	**32**	**42**

Table 4 Ship Options vs. Weighted Modular Attributes

Ranking: 3 = Best, 2 = Medium, 1 = Worst

The weighted values provide an end-result in favour of the modular ship. Interestingly, the multi-batch multi-role vessel falls even further behind. This is perhaps a bit misleading and is likely related to the coarse resolution of the rating system (1, 2 or 3). If a more precise, and subjective, approach were used (e.g., each option is rated on a scale of 1 to 10 for a given attribute), the multi-batch multi-role ship would likely fare better.

The authors have not used the finer resolution due to time, data and modelling constraints. As such, the coarser analysis is less arbitrary.

Item	Attribute and modular ship ranking	Modular Ship Ranking Rationale
1	**Flexibility [3]**	Modular will provide the most flexibility with multi-batch offering intermediate solution.
2	**Upgradeability [3]**	Modular will provide easiest upgradeability with multi-batch offering intermediate solution on a per batch basis.
3	**Interoperability [3]**	Items 1 and 2 point to better interoperability with the modular approach.
4	**Operational Ease [1]**	Modular ship is the most complex whereas multi-role is the simplest approach, and most static. Simplest approach should yield the best ease of operation – providing installed capabilities are adequate for task at hand.
5	**Training Ease [2]**	Since training can be performed off-board, the modular approach should offer a clear advantage. But the ship is more complex; so more training is required.
6	**Availability [3]**	Since modules can be exchanged, a modular ship is less likely to be unavailable due to a single capability failure (i.e., put in another module).
7	**Maintainability [2]**	For the modular approach, some modules can be maintained off-board – but there are more capabilities to maintain.
8	**Cost to Build [3]**	Modular ship class is likely to be cheaper since there will be fewer total capabilities – but this requires great care if cost reductions are to be realized – the ship is more complex.
9	**Design/Build Complexity [1]**	Modular ships will be more complicated to design and build initially.
10	**Build Time [3]**	Modular ships should be faster to build since capabilities can be built in parallel.
11	**Hull Space Efficiency [1]**	Not all capabilities will be installed at any one time; so hull space efficiency will be lower for the modular ship.
12	**Facility Impact [1]**	Handling, maintaining and training modules will require new facilities and dollars.
	Total Score Modular Ship [26]	

Table 5 Attributes vs. Ranking Rationale

The key points from this analysis are:

- Weighting factors can significantly change results; and
- The trade-off is flexibility vs. overall complexity (a common technological problem).

The most sensible approach is to optimize modularity with respect to complexity (i.e., risk). So, one can build modularity into the ship in a complementary fashion – but not let it drive the design.

Note that this analysis is not founded upon the idea that modularity implies a requirement for fewer ships. There is a possibility that such an assumption may hold true. However, Canada has a vast coastline as well as significant international and coalition force responsibilities. Furthermore, the current (and probably longer-term) security environment is, and will be, at best demanding. Therefore, it would seem that reducing the number of platforms based on the application of modularity would be unwise. The number of platforms would need to be determined by the larger foreign policy and defence picture.

16.0 INTEGRATION NOTES (PUTTING IT ALL TOGETHER)

This topic primarily distils down to two issues:

- Command and Control systems; and
- Port Infrastructure.

The Command and Control topic is well beyond the scope of this report and is a separate topic in itself. Key issues include, but are by no means limited to:

- Scaleability;
- Support;
- Backward Compatibility;
- Verification and Validation;
- Interfaces; and
- Intellectual Property.

The variety of capabilities, approaches and software, coupled with the complexity of large-scale software and hardware systems, makes Command and Control a very difficult topic in relation to modular capabilities.

Port infrastructure is perhaps less complex in terms of innovation – but is also on a much larger physical scale. Modules must be installed/removed, handled, stored and maintained. Furthermore, training facilities for personnel training on each module would be useful. All of this is possible and well within the technical grasp of the Navy and its suppliers. However, it will require space, time and money.

17.0 MULTI-ENVIRONMENT CONSIDERATIONS

An approach to building a multi-environment (Air Force, Army, Navy) modular capability resource system may be worth considering. Despite its clear focus on naval applications, there is nothing in this report that suggests that modules could not be deployed, in principle, by the Army and Air Force as well as the Navy. UAVs, certain weapon systems and specialist accommodations should have broad-based applicability to these environments. However, factors such as handling, deployment and interfaces as well as size and weight need to be reconsidered in terms of the land and air scenarios.

18.0 APPROACHES THAT COULD UNDERMINE MODULARITY BENEFITS

The following is a list of factors that require careful consideration. Failure to do so can undermine the potential benefits of incorporating modular capabilities in the SCSC vessels:

- Overemphasis on modularity – essentially a form of sub-optimization.

- Deployment of a modular capability design while still maintaining every capability on-board the ship most or all of the time – the end-result is a multi-role vessel with the complexity of a modular one.

- Linkages between modular capabilities and modular ship design – the latter is required to realize a number of the benefits of modular capabilities. Such capabilities are useless if the ship is in extended refit due to other ship factors or cannot get out of port due to ship systems maintenance issues.

- Command and Control complexity – modular capabilities will plug into the Command and Control system. Even though software and hardware systems have certain inherent flexibility, this is a challenging task for software architects. This concern is amplified by the sheer number, variability and complexity of capabilities, technologies and suppliers.

- Reduction of the total number of platforms (hulls) to optimize savings in relation to modularity – this will create an overall lack of capability if such reductions do not align with the long-term requirements of the Navy. No matter how modular a ship may be, it cannot be in two places at the same time.

19.0 CONCLUSIONS

The primary conclusions of this report are as follows:

- Modular capabilities provide the Navy with potential benefits in terms of mission flexibility, upgradeability and overall cost.

- Modular capability should be pursued as a feature of the SCSC – but not be a key driver of the overall ship architecture.

- All three types of modular capability, as outlined in this report, should be considered for the SCSC. Capabilities should be aligned with this typology.

20.0 NEXT STEPS

The following activities should be carried out to further develop the Navy's conceptual approach to modular capabilities within the SCSC.

- Advance the modular attribute analysis presented herein (Tables 3 to 5) using a finer resolution. For example, each attribute could be rated on a scale of 1 to 10 for the three types of ships considered. The increased subjectivity of this analysis would dictate that more data be collected and that some financial cost models be used.

- Construct a small model or make a detailed drawing of the SCSC concept outlined herein (or other representative model). Interview a select number of Navy Operators and capture as many benefits and issues associated with the concept as possible.

- Conduct a thorough investigation into Command and Control systems in relation to modular capability systems integration.

- Investigate the viability of a joint modular capability resource system (for the Air Force, the Army and the Navy).

21.0 REFERENCES

1. Blohm + Voss GmbH MEKO Website, http://www.blohmvoss.com/

2. Clark, G.A. and Burch, I.A., May 2001. *Emergent Technologies for the Royal Australian Navy's Future Afloat Support Force*, Maritime Platforms Division, Aeronautical and Maritime Research Laboratory.

3. Environment Canada, *Ice Terminology*, http:www.ec.gc.ca

4. Defence Science and Technology Lab, UK.

5. Haydon, Peter T., November 2004. *Canadian Naval Future: A Necessary Long-Term Planning Framework*, IRPP Working Paper Series no. 2004-12.

6. Hazegrey World Navies Today Website, http://www.hazegray.org/worldnav/

7. Jane's Information Group, http://www.janes.com

8. Lacroix, F.W. and Blickstein, I. N., 2003. *Forks in the Road for the U.S. Navy*, prepared by RAND for the U.S. Navy.

9. Littoral Combat Ship (LCS) Website, http://peoships.crane.navy.mil/lcs/default.htm

10. National Defence, May 2005. *Securing Canada's Ocean Frontiers: Charting the Course from Leadmark.*

11. *Naval Forces*, Volume Number 1, 2003, pp36-44.

12. Naval Team Denmark, Standard Flex 300: *The True Multi-role Ship*, STANFLEX promotional Document, http://www.navalteam.dk

13. O'Rourke, Ronald, August 2004. *Defense Transformation: Background and Oversight Issues for Congress*, CRS Report for Congress (RL32238).

14. Royal Navy, Video Gallery, Type 45 Destroyer http://www.royal-navy.mod.uk/static/pages/2084.html

15. Scheibach, K. and Lamb, T., 2005. *Producibility Impact of Multimission Modular Cells and Outfit Zones in Naval Ships*, ASNE Reconfiguration and Survivability Symposium 2005.

16. Ulrich III, H. G. and Edwards, M. J., October 2003. "The Next Revolution at Sea," U.S. Naval Institute *Proceedings* Magazine.

17. United States Government Accountability Office, March 2005. *Plans Need to Allow Enough Time to Demonstrate Capability of First Littoral Combat Ships*.

18. Work, R.O., February 2004. *Naval Transformation and Littoral Combat Ship*, Center for Strategic and Budgetary Assessments.

ANNEX A: TECHNOLOGY READINESS LEVELS

The following table is an excerpt from the DoD 5000.2-R document [DoD 02], which specifies TRLs from a systems approach. TRLs thus are intended to be appropriate for both hardware and Software.

Technology Readiness Level	**Description**
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytical studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is a well-simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle or space. Examples include testing in a test bed aircraft.
8. Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

See next page for definitions

Definitions

Breadboard: Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

High fidelity: Addresses form, fit and function. High-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

Low fidelity: A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low-fidelity assessments are used to provide trend analysis.

Model: A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

Operational environment: Environment that addresses all of the operational requirements and specifications required of the final system, including platform/packaging.

Prototype: A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item or system.

Relevant environment: Testing environment that simulates the key aspects of the operational environment.

Simulated operational environment: Either (a) a real environment that can simulate all of the operational requirements and specifications required of the final system, or (b) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

Source: Carnegie Mellon University, Software Engineering Institute

http://www.sei.cmu.edu/publications/documents/02.reports/02sr027/02sr027.html#app-a

ANNEX B: TECHNOLOGY SURVEY RESULTS

Ship Characteristics	**Naval Team Denmark** Standard Flex 300, Denmark (http://www.navalteam.dk/300.htm)	**Blohm + Voss GmbH** MEKO Technology A-200 Frigate Germany (http://www.blohmvoss.com)	**MEKO 200TN Yavuz** class Frigate Turkey http://www.globalsecurity.org/military/world/europe/yavuz.htm
Crew	19-29	130 (+20)	184
Dimensions			
Length overall	54 m	118.7 m	110.5 m
Beam overall	9 m	15.8 m	14.8 m
Depth			
Displacement	320-450 t	3800 t	2800 t
Propulsion	Codag	CODAD OR CODOG	CODAD
Gas Turbine	1x 5450 hp		
Diesel turbine	2x mtu 16v 396 TB94, 5800 hp		
Speed	30 kn	>29 kn	>27kn
Weapons			
Missiles	8 harpoon missiles (SSM); SAM	Yes	8xHarpoon SSM; 16xSea Sparrow SAM
Guns	1 x 76 mm	127 mm	1x127 mm; 3 x 25 mm
UAV			
Torpedoes	2x533 mm tubes for TP13 torpedoes; anti-submarine torpedoes (ASW role)	Yes	2 x 324 mm
Helicopter		1 x 10 t or 2 x 5 t	1xAB 212 ASW
Other	60 mines; 8 harpoons; 6 sea sparrows	ASW guided weapons	
Systems			
Command system	C3I Saab tech/terma electronik		
Sonar	Saabtech, Thales, EADS (ASW role), thales side scan (MCM role)	TASS & VDS	SQS-56
Radar	BAE systems AWS-6 (first 7) EADS TRS-3D/16 (last 7)	Phased array and long-range search	DA 08; AWS 6 Dolphin, STIR, TM 1226, WM 25, URN 25
Other	ESM, ECM, gyro systems		
Modules			
Number	4		5 Weapon 15 Electronic 8 Pallet 2 mast
Size	3 x 3.5 x 2.5 m (stainless steel)		

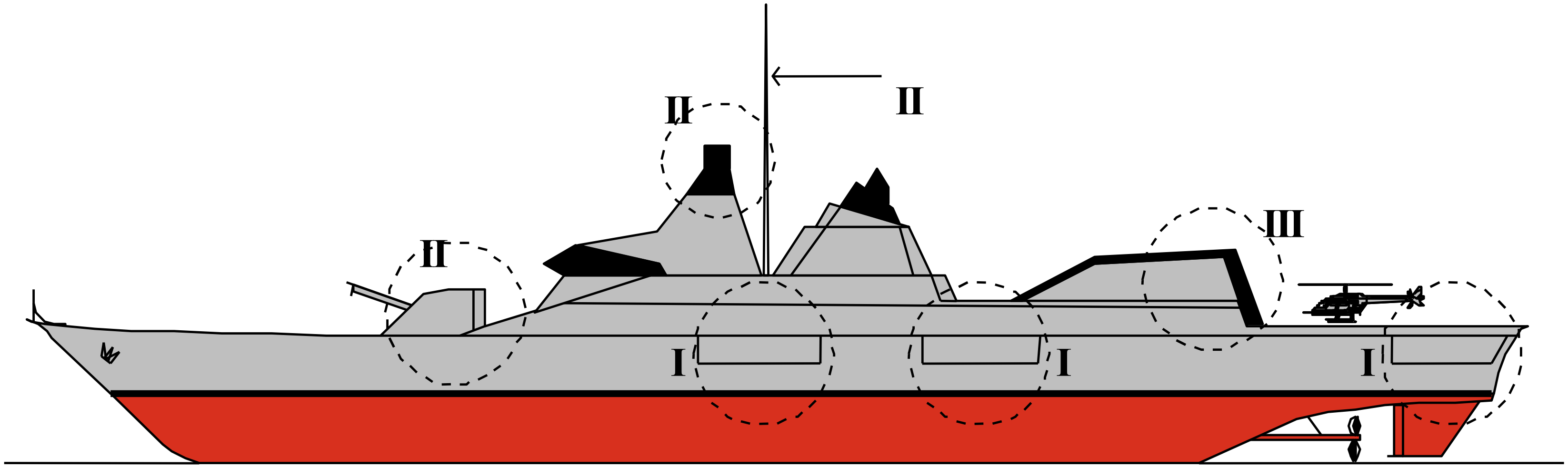
Ship Characteristics	**Hydra Class Multi-purpose Frigates** Greece http://www.naval-technology.com/projects/hydra	**Valour Class Frigates (MEKO 200)** South Africa http://www.wikiverse.org/south-african-valour-class-frigates	**Class 123 Frigate** (MEKO) Germany http://www.naval-technology.com/projects/brand
Crew	189	100 (+24)	230 (118?)
Dimensions			
Length overall	117 m	121 m	138.85 m
Beam overall	14.8 m	16.34 m	16.7 m
Depth	9.1 m	9.7 m	
Displacement	3200 t	3500 t	4500 t
Propulsion	CODOG	CODAG WARP	CODOG
Gas Turbine	2x22300 kw each	1x 20000 kw	2x 19000 each
Diesel turbine	2x3830 kw each	2x 5920 each	2x 4070 kw each
Speed	>30kn	>27kn	>29kn
Weapons			
Missiles	8xHarpoon, 16xSea Sparrow	8xMBDA MM 40 Surface-to-Surface 16x Umkhonto surface-to-air	2 x twin MM 38 surface-to-surface 16 x sea sparrow surface-to-air
Guns	127 mm, 2x phalanx mark 15 mod 12	1 x 76 mm, 2x35 mm, 2x20 mm canons	1 x 76 mm, 2x20 mm
UAV			
Torpedoes	2xtriple torpedo tubes	2xtwin 324 mm tubes	2 x twin 324 mm tprpedo tubes
Helicopter	1xHelicopter (10 t)	1xHelicopter	2 x Sea Lynx Mk 88
Other	Decoys		
Systems			
Command system	Thales Nederland STACOS Model 2		
Sonar	SQS-56 DE 1160		Atlas Elektronik DSQS-23BZ
Radar	DA-08 early warning MW-08 air/surface search		Thales Nederland Smart 3D Thales Nederland LW08
Other			Decoys
Modules			
Number	4 Weapon 10 Electronic 10 Pallet 2 Mast 9 Ventilation		4 Weapon 8 Electronic 5 Pallet 2 Mast 13 Ventilation
Size			

Ship Characteristics	**Littoral Combat Ships (LCS)** General Dynamics Trimaran USA http://www.naval-technology.com/projects/littoral	**MEKO A-100 multi-purpose corvette** Malaysia http://www.naval-technology.com/projects/meko/specs.html	**Naval Team Denmark** Standard Flex 3000, Denmark http://www.hazegray.org/worldnav/europe/denmark.htm
Crew	15-50 (75 max)	78 (+15)	65 (+11)
Dimensions			
Length overall	127.8 m	91.1 m	122.5 m
Beam overall	28.4 m	12.85 m	14.4 m
Displacement	2637 t	1650 t	3500 t
Propulsion		2 x controllable pitch propellers	
Gas Turbine			
Diesel turbine		2 x caterpillar 3616, 5450 kW each	3 diesels, 1 shaft, 6,366 bhp
Speed	50 kn	>22kn	21.5 kn
Weapons			
Missiles	Rolling Airframe Missile (RAM)	1 x ram rolling airframe missile (SAM) 2 x MM40 exocet surface-to-surface	2x 8-cell vertical launch sea sparrow 8 Harpoon SSM
Guns	Bofors 57 mm, 50 caliber machine gun mount	1 x oto melara 76/62 Rapido 1 x oto Melara/mauser 30mm 2 x 0.5 inch small caliber machine gun	1 x 76 mm; 1 x 20mm
UAV	UAV, NTUAV		
Torpedoes			2x triple 12.75" torpedo tubes
Helicopter	Yes (MH60 R/S)	1 x sikorsky SH-70	1 x Lynx Helicopter
Other	Unmanned boat, Torpedo decoy	Decoy	Decoys
Systems			
Command system	Integrated Combat Management System (ICMS), Northrop Grumman Electronic Systems	COSYS-110 M1	
Sonar	Yes (AQS 20)	mds 3060	CTS-36 hull, Salmon VDS
Radar	Yes	TRS-3D/16ES	AWS-6 Air search
Modules			
Number	Mine warfare systems Anti-submarine systems Anti-surface warfare systems		
Size	Standard size containers?		3 m x 3.5 m

Ship Characteristics	**MEKO 200 ANZAC** Class Frigate Australia http://www.janes.com/defence/naval_forces/news/jfs/anzac_class_frigate.shtml	**Vasco da Gama class** (MEKO 200) frigates Portugal http://www.hazegray.org/worldnav/europe/portugal.htm	**Naval Team Denmark** Flexible Support Ship (FSS), Denmark http://www.navalteam.dk/supportship.htm
Crew	163 (22 officers)	182	70
Dimensions			
Length overall	118 m	115.9 m	137 m
Beam overall	14.8 m	14.8 m	19.5 m
Depth			
Displacement	3500 t	3200 t	6000 t
Propulsion	CODOG	CODOG	
Gas Turbine	1x30,172 hp	2 x LM2500, 60000 shp	
Diesel turbine	2 mtu 12v 1163 TB83, 8840 hp	2 cuise diesels, 8840 bhp	2 x MTU 8000
Speed	>27kn	32kn	23 kn
Weapons			
Missiles	8xSSM, SAM	8x Harpoon SSM, 1x 8 sea Sparrow SAM	
Guns	1x127 mm	1x100 mm/55DP; 1x20 mm Phalanx CIWS	Mk 45 Mod 4 127mm/54 gun
UAV			
Torpedoes	6x324 mm	2 triple 12.75"	
Helicopter	1 Helicopter	2x Sea Lynx	2 x Medium size EH-101
Other	Decoys		
Systems			
Command system			
Sonar	Thomson Sintra Spherion B Mod 5, hull-mounted	SQS-510 hull	
Radar	Air/surface search (Raytheon & Celsius Tech)	DA-08 early warning MW-08 air/surface search	
Other	ESM		
Modules			
Number	5 Weapon 7 Electronic 1 Pallet 2 Mast 9 Ventilation		Optional modules for hospital facalities or accomodation for emergency evacuations
Size			3 m x 3.5 m

Ship Characteristics	**Multi-Purpose Frigate** MEKO 360 H2 Argentina http://www.hazegray.org/worldnav/americas/argent.htm	**HSV 2 Swift** DoD USA http://federalvoice.dscc.dla.mil/federalvoice/040714/swift.html	**DD(X) Class Multimission Destroyer** USA http://www.naval-technology.com/projects/dd21
Crew	200	350?	TBD
Dimensions			
Length overall	125.6 m		
Beam overall	15.0 m		
Depth	9.3 m		
Displacement	3600 t	11000 t	12,000 t
Propulsion	COGOG		All-electric drive with an integrated power system, (IPS)
Gas Turbine	2x19100 kw each, 2x3700 kw each		
Diesel turbine		4x jet diesel engines, 40000 hp	
Speed	>30kn	40kn (high speed)	
Weapons			
Missiles	8x MM 40 Surface-to-Surface 1x8-cell Albatros SAM		Tomahawk, Standard and ESSM
Guns	1x5/54 DP, 4 dual 40 mm AA, 2x 12.7 mm Ms		2x155mm Advanced Gun System 1x57mm Mk 110 naval gun
UAV		Crane to recover up to 26,000 pounds of unmanned vehicles	
Torpedoes	2xtriple 12.75” torpedo tubes		
Helicopter	2xHelicopter	60 t M-1A1 tank, helicopter	2xHelicopters
Other		Ramp can hold 615 t of equipment	
Systems			
Command system			
Sonar	Krupp-Atlas 80 hull		Dual frequency bow array and multi-function towed array
Radar	DA-08 early warning		SPY-3 X-band active phased-array; L-Band
Other	Jammer		
Modules			
Number	6 Weapon 9 Electronic 9 Pallet	(Seal, mine sweeping, flight ops role)	
Size			

ANNEX C: SCSC CONCEPT SKETCH

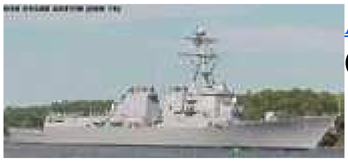


Modular Capability Types:

Type I	- - > modular containers or other modular installations (plug and play concept with minimal installation time)
Type II	- - > modular installation (still a plug and play concept, but with significant installation time)
Type III	- - > modular space potential (space normally reserved for other capabilities - but which could be used for modules)

ANNEX D: A CURRENT SURFACE COMBATANT

MULTI-BATCH, MULTI-ROLE



Arleigh Burke class large multi-role destroyers (Flight IIA) (8+26+? ships)

Displacement: 9,200 tons full load
Dimensions: 510 x 67 x 30.5 feet/155 x 20.5 x 9.3 meters
Propulsion: 4 LM2500 gas turbines, 2 shafts, 100,000 shp, 30+ knots
Crew: 362 + 18 aviation detachment
Radar: 4 SPY-1D phased array multifunction
Sonar: SQQ-89(V)15 suite with SQS-53C LF active/passive bow mounted with Kingfisher mine detection system
Fire Control: Aegis AAW system; 3 Mk 99 SM-2 guidance systems with SPG-62 radars
EW: SLQ-32(V)3 intercept/jammer or SLQ-32(V)2 intercept, Mk36 or Mk53 SRBOC decoy RL, SLQ-25A Nixie torpedo countermeasure, SRS-1 Combat D/F ELINT system
Aviation: aft helicopter deck with RAST and two hangars; 2 SH-60B
Armament: 1 32 cell Mk41 VLS, 1 64 cell Mk41 VLS (96 Standard SM-2, Tomahawk, VLA), 1 5"/62cal DP (5"/54cal DP in DDG 79-80), 2 20mm Phalanx CIWS (DDG 79-84 only), 2 triple 12.75 inch torpedo tubes (Mk46 torpedoes), 2 25mm Bushmaster low-angle (most ships), 4 12.7mm MG.

Concept/Program: Improved *Burke* class ships, incorporating a number of additional systems, modernizations and upgrades. These ships could be considered an entirely separate class due to the extensive changes included in the Flight IIA upgrade. They will be the mainstay of the surface fleet in the early decades of the next century.

DDG 89-101 were ordered in 1998 under a Multi-Year Procurement (MYP), covering 1998-2001; this resulted in significant savings. DDG 102-112 were ordered under the 2002 program, although DDG 102 will be built to the 1998 design. The exact number of ships to be built is uncertain, and additional ships may be added beyond the current construction plan.

Builders: Bath Iron Works, Maine (lead) and Northrop Grumman Ship Systems/Litton-Ingalls, Pascagoula, MS.

Design: The major change from Flight II to Flight IIA was the addition of dual helo hangars and full aviation support facilities. This required lengthening the hull by 5' at the stern, significant internal changes to accommodate RAST, and raising the aft VLS by one deck, with hangars placed on either side of it. Additional berthing has been added to accommodate the helicopter crews. A much larger torpedo/missile/rocket magazine is provided to store helicopter-launched weapons, and maintenance shops have been added. The aft SPY-1D panels are raised by one deck level, and the reload cranes have been eliminated from the VLS, resulting in 6 additional VLS cells. New-design propeller blades are fitted, and the transom is modified to improve fuel efficiency. The entire electrical system has been completely redesigned for greater survivability. Phalanx CIWS has been deleted from DDG 85+, in anticipation of the Evolved Sea Sparrow Missile (ESSM) being available as a self-defense weapon. SQR-19 TACTAS and Harpoon SSMs have been deleted, but could be reinstalled if necessary, given sufficient advance notice. These ships also have a number of enhanced automation, survivability and crew-reduction measures.

DDG 81+ are fitted with the new 5"/62cal gun and revised magazine arrangements to allow storage of ERGM rounds. Retrofit of this gun to previous ships has been proposed, but may not be practical.

Arleigh Burke class large multi-role destroyers (Flights I/II) (28 ships)

Displacement: 8,850-9,000 tons full load
Dimensions: 505 x 67 x 30.5 feet/153.6 x 20.5 x 9.3 meters
Propulsion: 4 LM2500 gas turbines, 2 shafts, 100,000 shp, 30+ knots
Crew: 337
Radar: 4 SPY-1D phased array multifunction
Sonar: SQQ-89(V)4 suite with SQS-53C LF active/passive bow mounted, SQR-19 TACTAS towed array
Fire Control: Aegis AAW system; 3 Mk 99 SM-2 guidance systems with SPG-62 radars
EW: SLQ-32(V)2 intercept (**DDG 68-78:** SLQ-32(V)3 intercept/jammer), Mk36 or Mk53 SRBOC decoy RL, SLQ-25A Nixie torpedo countermeasure, **DDG 72-78:** SRS-1 Combat D/F ELINT system
Aviation: aft helicopter deck; 1 SH-60B can be embarked
Armament: 1 29 cell Mk41 VLS, 1 61 cell Mk41 VLS (90 Standard SM-2, Tomahawk, VLA), 1 5"/54cal DP, 2 20mm Phalanx CIWS, 2 triple 12.75 inch torpedo tubes (Mk46 torpedoes), 2 25mm Bushmaster low-angle (most ships), 4 12.7mm MG.

Concept/Program: These ships, the first all-new US Navy surface combatant design in many years, are fully multi-role ships. Their primary emphasis is AAW, but they are very capable in all other warfare areas. They were designed with "lessons learned" from previous classes, and are among the finest surface combatants in the world. The Flight IIA variant of this class is listed separately (above). It is reported that most of the SQR-19 towed arrays have been placed in storage ashore. *Cole* (DDG 67) was attacked by suicide bombers 12 October 2000 and was repaired at Ingalls.

Builders: Bath Iron Works, Maine (lead) and Litton/Ingalls, Pascagoula, MS.

Design: The design emphasizes seakeeping, stealth and survivability. Their construction is all-steel (except the aluminum mast), and they have some passive protection systems; they are provided with a collective protection system to protect against CBR attack. Their seakeeping is excellent, and they can maintain high speed in heavy weather. There has been a significant effort to reduce radar cross-section. Although there is no helo hangar, they can land, refuel and re-arm helos, and are fully outfitted with the LAMPS III system datalinks and processors, so they can operate with another ship's LAMPS helo. The SPY-1D system in these ships is considerably more modern than the SPY-1A/B in the *Ticonderoga* class, but there are only 3 missile directors, rather than 4. The differences between Flight I (DDG 52-71) and Flight II (DDG 72-78) are minimal. Contrary to some reports, SLQ-32(V)3 is fitted starting in DDG 68, not DDG 72; SLQ-32(V)5 "Sidekick" has not been retrofit in these ships. DDG 51 lacks some features included in the later ships, notably helo fueling and arming facilities.

Source: Hazegrey World Navies Today Website, http://www.hazegray.org/worldnav/

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY
Consulting and Audit Canada

1b. PUBLISHING AGENCY
Defence R&D Canada

2. SECURITY CLASSIFICATION
Unclassified/Unlimited

3. TITLE

Modular Capabilities for the Canadian Navy’s Single Class Surface Combatant: A Perspective on Flexibility

4. AUTHORS

Authors: Scott C. MacKenzie, Rohit Tuteja

5. DATE OF PUBLICATION

February 2006

6. NO. OF PAGES

36

7. DESCRIPTIVE NOTES

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency: Defence R&D Canada

9. ORIGINATORS DOCUMENT NO.

DRDC-CR-2006-004

10. CONTRACT GRANT AND/OR PROJECT NO.

11. OTHER DOCUMENT NOS.

DRDKIM System Number: 526474
DRDKIM Accession Number: CA028314

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited Announcement

14. ABSTRACT

The primary objective of this report is to conduct an assessment that will: identify world benchmarks for the modular "plug and play" equipment concept; outline risks and possible mitigations associated with the concept; present technology readiness levels for the concept; and, consider the applicability to the various environments within the CF. With respect to the various technologies involved in instituting such a concept, the assessment addresses technology readiness levels for three distinct time frames: 2010, 2020 and 2030. The scope of this document is limited to a review of the modular capabilities for the Single Class Surface Combatant. It does not address modular construction or other engineering issues associated with the Single Class Surface Combatant except in cases where such issues overlap with the modular capabilities. Most of the material used in this report was from the open-source literature and interviews with subject matter experts. The material was aggregated and used to make assertions and draw conclusions, which are presented herein.

L’objectif premier de ce rapport est de procéder à une évaluation qui identifiera des points de référence mondiaux pour le concept d’équipement modulaire « prêt à utiliser »: décrira brièvement les risques et les atténuations éventuelles associés au concept; présentera les niveaux de préparation de la technologie du concept et étudiera les possibilités de son application dans les différents environnements au sein des FC. En considération des différentes technologies intervenant dans la mise au point d’un tel concept, l’évaluation prévoit trois échéanciers distincts pour les niveaux de préparation de la technologie, soit 2010, 2020 et 2030. Le document se limite à un examen des capacités modulaires pour le bâtiment de combat de classe unique. Ni la construction modulaire ni les autres questions techniques liées au bâtiment de combat de classe unique n’y sont traités, sauf dans les cas où ces questions empiètent sur les capacités modulaires. La plupart des éléments matériels utilisés dans ce rapport provenaient de documents de sources ouvertes et d’entretiens menés auprès d’experts en la matière. Nous avons regroupés ces matériels et les avons utilisés pour confirmer des assertions et tirer des conclusions, lesquelles sont présentées dans le rapport.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS