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TITLE:

NSMV Phase 3 Design

NSMV Stability Analysis

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I. Introduction

A. Summary

This report summarizes the intact and damage stability analyses run for the National Security Multi-mission Vessel (NSMV), with the aim to obtain approval in principle from ABS. The NSMV beneficial owner will be the US Maritime Administration, and these ships will fly US Flag. The NSMV is designed to comply with requirements for a Special Purpose Ship, under the IMO Special Purpose Ship Code, but will likely receive certificates of voluntary compliance in lieu of the standard SOLAS Statutory Certificates. It will likely be registered as an undocumented Public Nautical School Ship. The USCG has advised it intends to accept SPS Code as the basis for the vessel design. Regarding stability, the NSMV is designed to meet IMO IS Code and SOLAS 2009 stability regulations. The design was also checked to meet the damage stability requirements of the MARAD Design Letter No. 3 (1991), and CFR 2013 Title 46 Vol. 7 Ch. I Subchapter S, Subpart C—Subdivision and Damage Stability.

The vessels primary use will be as training ships for the state maritime academies, with secondary use in hazardous assistance and disaster relief (HA/DR) as requested by the US Government (FEMA). Maximum number of persons onboard is 750. However according to CFR 2013, Subpart C—School Ships, § 173.051 “Public nautical school ships”, these vessels must comply with § 171.070(a) of that subchapter as a passenger vessel carrying 400 or less passengers. The full load conditions in the sample load conditions presented in this report will occur when the vessel is in HA/DR operation with containers on the main deck and vehicles in the RoRo space in support of its relief mission. Loading conditions with no cargo refer to the normal operation of the NSMV as a training ship.

This report provides:

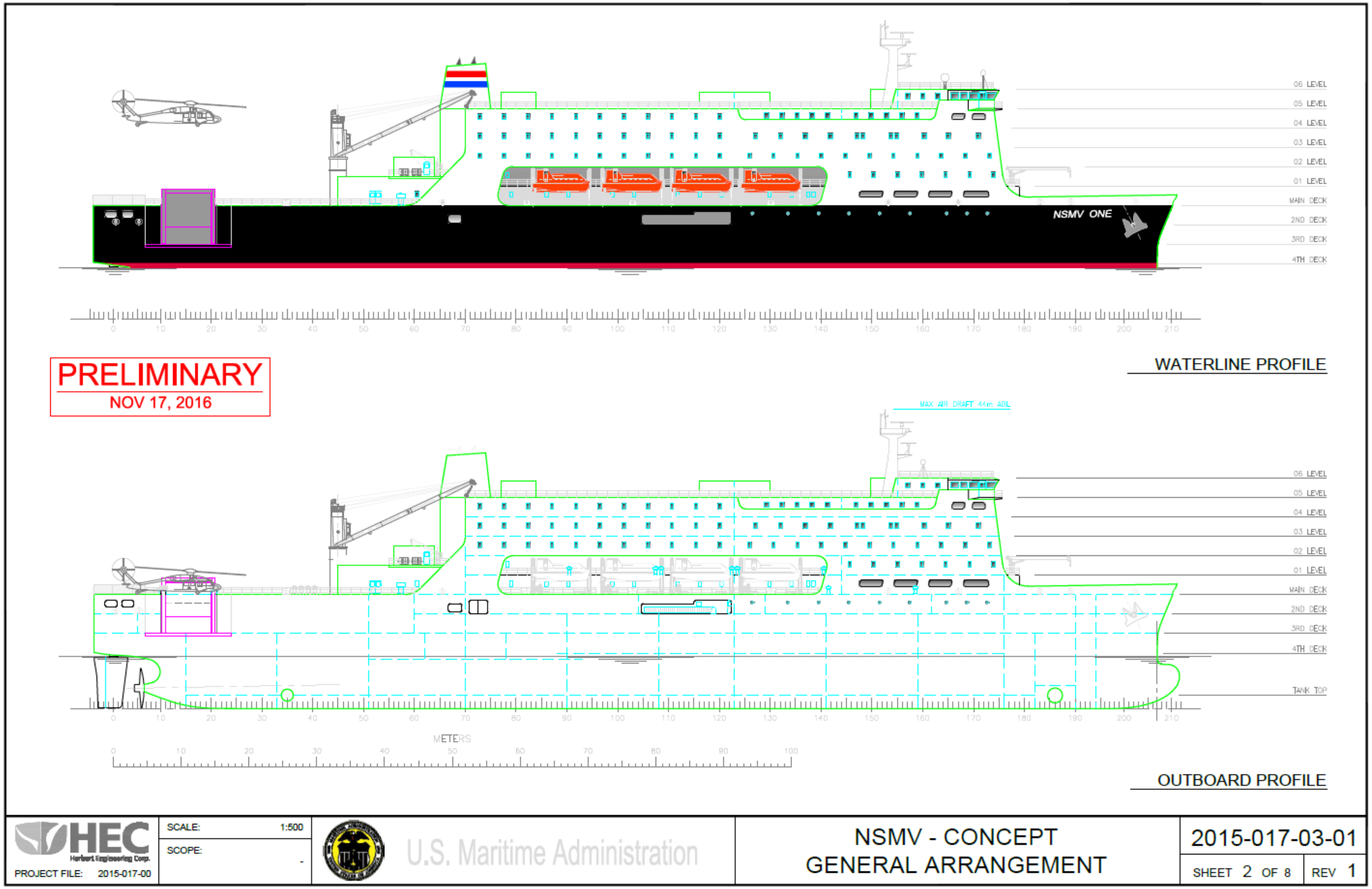
- Description of the vessel main particulars and operating envelope, including route designation, number of passengers, total persons carried, and any operating limits and/or restrictions (such as draft and trim limits);
- Description of the vessel buoyant and watertight spaces, including details on bulkheads, partial bulkheads, decks and all downflooding points;
- Details on MSC.362(92) cross-flooding arrangements;
- Intact stability calculations according to IS Code;
- Details on SOLAS 2009 heeling moment calculations;
- Damage Stability calculations according to SOLAS 2009;
- Description of the vessel primary loading conditions and their compliance with SOLAS 2009;
- Damage stability calculations according to MARAD Design Letter No. 3 (1991), and CFR 2013 Title 46 Vol. 7 Ch. I Subchapter S.

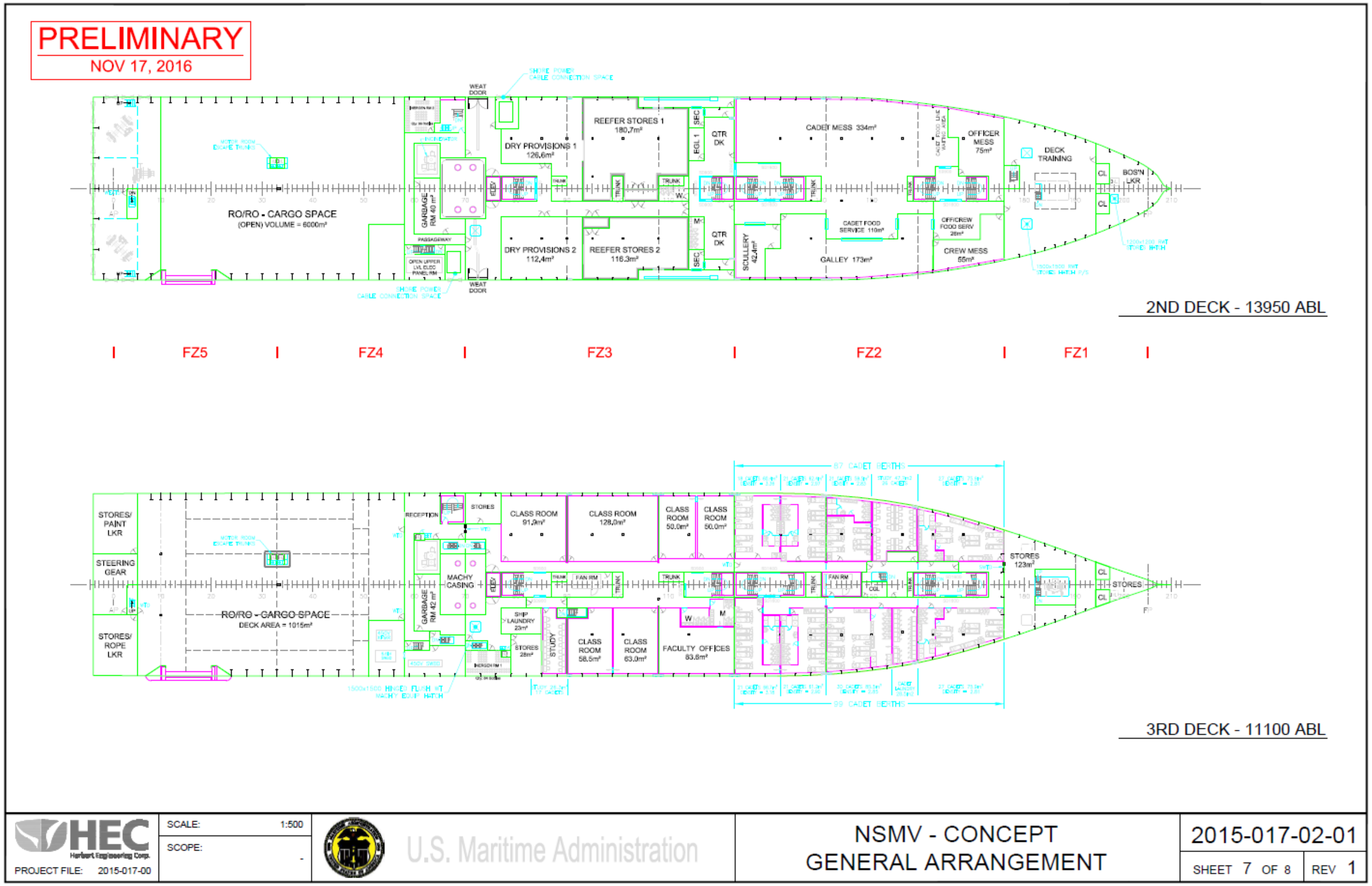
All stability calculations were carried out with Herbert-ABS HECSALV 8.1. The calculations presented in this report show that the vessel complies with all of the above regulations for the operational loading conditions considered.

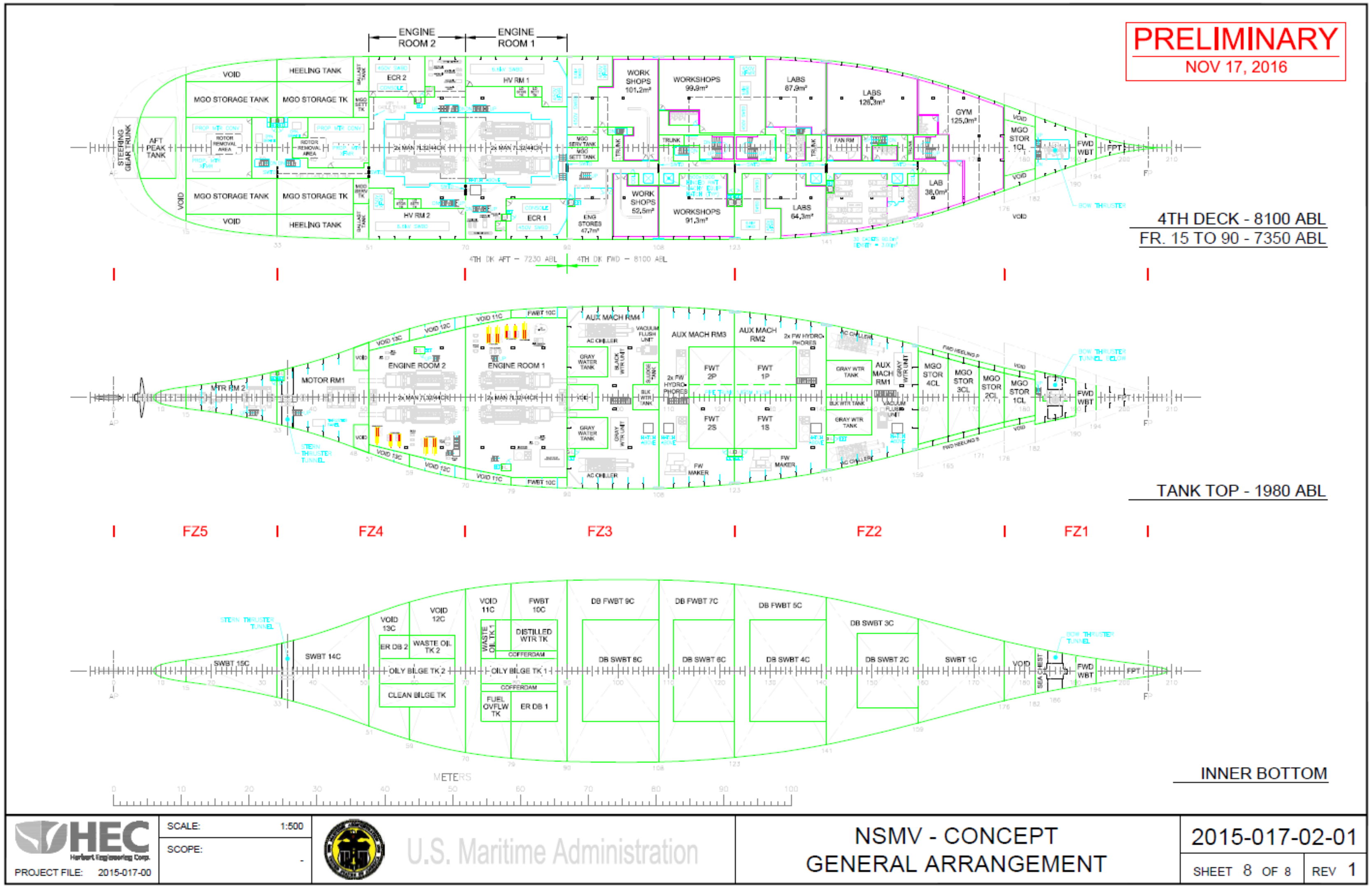
B. Ship Particulars

Ship's Name:	NSMV
Type/Purpose:	Training Vessel/Emergency Relief Vessel
Register:	ABS
Flag:	USA
LBP:	154.000 m
Depth (ABL):	16.800 m
Beam (molded):	27.000 m
LOA:	160.807 m
Subdivision Length:	159.800 m
Subdivision Draft (ABL):	7.250 m
Intermediate Draft (ABL):	6.725 m
Minimum Draft (ABL):	5.750 m
Allowed Trim Range (BP):	0.000 m forward to 0.799 m aft
Keel Thickness:	13 mm
Lightship Weight:	10,750 MT
Lightship LCG:	75.618 m forward of Aft Perpendicular
Lightship VCG:	13.010 m above Baseline
Lightship TCG:	0.090 m starboard of CL
Operating area:	Unrestricted
Number of Passengers/Cadets:	715
Number of Crew:	35
LSA (Total Persons On Board):	750
Bulkhead Deck (3rd Deck) Height (ABL):	11.100 m
Gross Tonnage:	25,500 GT (Estimated)
Deadweight:	8,487 MT
Max RORO Cargo Weight:	733 MT
Max Deck Cargo Weight:	796 MT (6 x 20-ft; 32 x 40-ft)
Design Speed:	18 knots

C. General Arrangement




PRELIMINARY
NOV 17, 2016
RO/RO - CARGO SPACE
(OPEN) VOLUME = 6000m³
DRY PROVISIONS 1
126.6m²
REEFER STORES 1
180.7m²
QTR DK
CADET MESS 334m²
OFFICER MESS
75m²
DECK TRAINING
BOS'N LKR
DRY PROVISIONS 2
112.4m²
REEFER STORES 2
116.3m²
SCULLERY
42.4m²
GALLEY 173m²
CADET FOOD SERVICE 110m²
CREW MESS
55m²
WEAT DOOR
TRUNK
2ND DECK - 13950 ABL
FZ5
FZ4
FZ3
FZ2
FZ1
STORES/ PAINT LKR
STEERING GEAR
STORES/ ROPE LKR
RO/RO - CARGO SPACE
DECK AREA = 1015m²
RECEPTION
STORES
MACHY CASING
CLASS ROOM
91.9m²
CLASS ROOM
128.0m²
CLASS ROOM
50.0m²
CLASS ROOM
50.0m²
SHIP LAUNDRY
23m²
STORES
28m²
STUDY
CLASS ROOM
58.5m²
CLASS ROOM
63.0m²
FACULTY OFFICES
83.6m²
FAN RM
STORES
123m²
STORES
87 CADET BERTHS
89 CADET BERTHS
3RD DECK - 11100 ABL
HEC
Herbert Engineering Corp.
PROJECT FILE: 2015-017-00
SCALE: 1:500
SCOPE: -
U.S. Maritime Administration
NSMV - CONCEPT
GENERAL ARRANGEMENT
2015-017-02-01
SHEET 7 OF 8
REV 1



PRELIMINARY
NOV 17, 2016
ENGINE ROOM 2
ENGINE ROOM 1
4TH DECK - 8100 ABL
FR. 15 TO 90 - 7350 ABL
TANK TOP - 1980 ABL
FZ5
FZ4
FZ3
FZ2
FZ1
INNER BOTTOM
METERS
SCALE: 1:500
SCOPE:
PROJECT FILE: 2015-017-00
U.S. Maritime Administration
NSMV - CONCEPT
GENERAL ARRANGEMENT
2015-017-02-01
SHEET 8 OF 8
REV 1

D. Watertight Subdivision

Watertight boundaries

The watertight boundaries assumed for the NSMV are shown in Figure 1. The diagram also shows in green the main transversal bulkheads mandated by MARAD Design Letter No. 3 (1991), and CFR 2013 Title 46 Vol. 7 Ch. I Subchapter S. The ship's bulkhead deck is the 3rd Deck (11.100 m), although the RORO garage is considered buoyant up to the Main Deck (16.800 m ABL), and partial transverse bulkheads are arranged between the 2nd Deck (13.950 m) and the 3rd Deck, extending from the outer shell to 3.200 m from CL. The end of these partial bulkheads on the 3rd Deck is modelled as an unprotected downflooding point connecting two adjacent compartments, and it limits the GZ curve when either (but not both) compartment is damaged.

The 2nd Deck is watertight in way of the partial bulkheads from frame 58 to frame 176, and from the shell to 3.200 m from CL P&S for this length. The 2nd Deck is also watertight aft of frame 5, and forward of frame 176, shell to shell port to starboard, except in way of the bow thruster room access. The Main Deck is watertight from frame 5 to frame 58, shell to shell port to starboard. The full list of downflooding points is given in Appendix A – Ship Data. All vents, doors, hatches and partial bulkhead cross-connections are included.

All major tanks, voids and dry spaces are modelled as separate watertight compartments with the exception of smaller tanks in the ER's double bottoms, and the small sludge tank in the auxiliary machinery room. A detailed description of each watertight space is given in Appendix A – Ship Data.

MARPOL & CFR subdivision

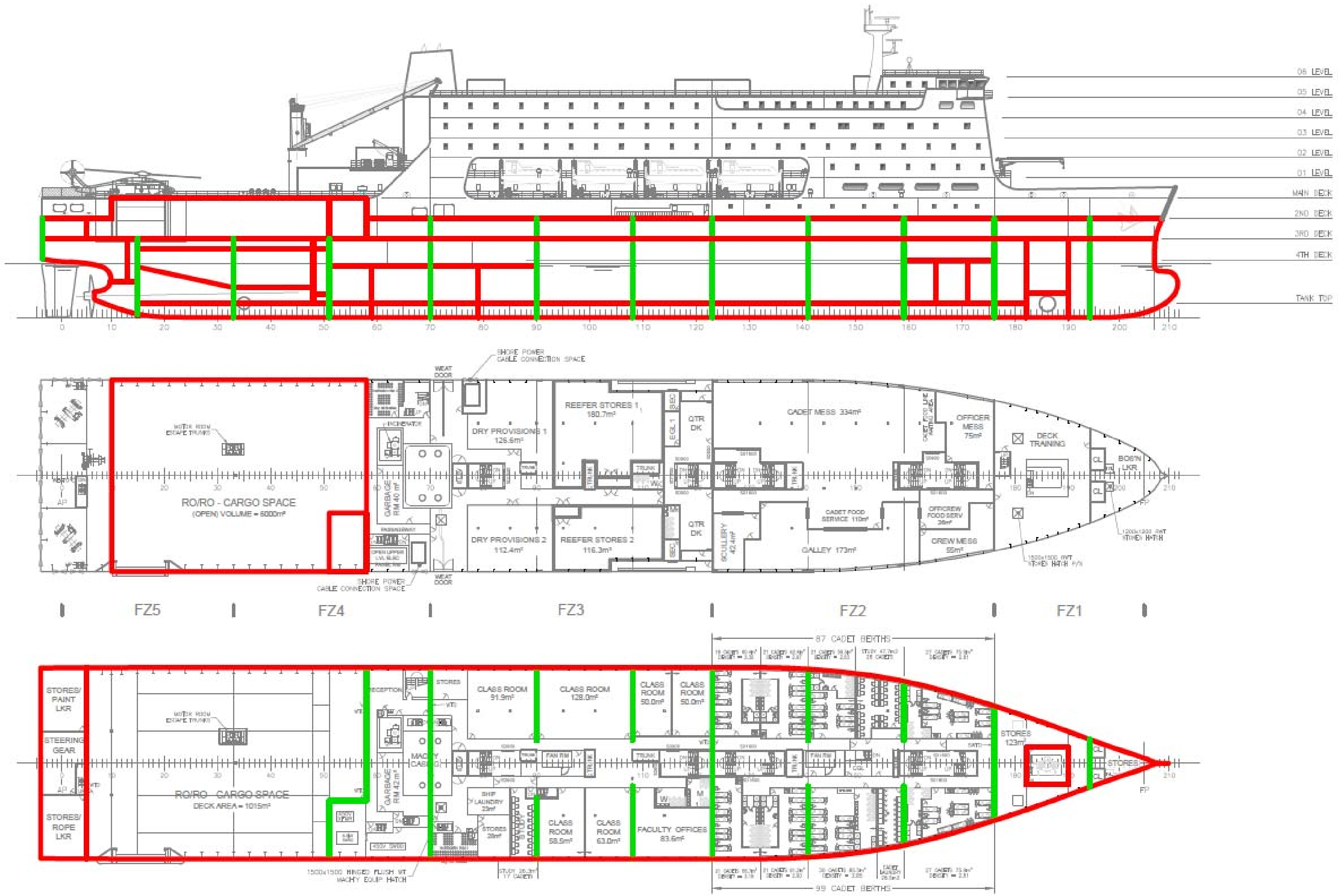
According to according to CFR 2013, Subpart C—School Ships, § 173.051 "Public nautical school ships", these vessels must comply with § 171.070(a) of that subchapter as a passenger vessel carrying 400 or less passengers. This means that – according to CFR 2013 Title 46 Vol. 7 Ch. I Subchapter S, Subpart C – the relevant standard of flooding is one compartment, limited by transversal bulkheads that should comply with the following: "Unless otherwise permitted, if the LBP of the vessel is 143 feet (43.5 meters) or more, or the vessel makes international voyages, each main transverse watertight bulkhead must be at least 10 feet (3 meters) plus 3 percent of the vessel's LBP from:

- (i) Every other main transverse watertight bulkhead;
- (ii) The collision bulkhead; and
- (iii) The aftermost point on the bulkhead deck.".

For the NSMV this is equivalent to a minimum distance equal to 7.620 m.

According to MARAD Design Letter No. 3 (1991), the distance between main watertight bulkheads should be instead at least: "$0.495*L^{2/3}$ or 47.5', whichever is less (L is the length between perpendiculars in feet)", i.e. 9.571 m for the NSMV. The main watertight bulkheads for the NSMV in relation to the above regulations are therefore:

Frame #	m-AP	Dist. (m)	Frame #	m-AP	Dist. (m)
15	10.650	0	123	91.650	11.250
33	24.150	13.500	141	105.150	13.500
51	37.650	13.500	159	118.650	13.500
70	51.900	14.250	176	131.400	12.750
90	66.900	15.000	194	144.900	13.500
108	80.400	13.500			


06 LEVEL
05 LEVEL
04 LEVEL
03 LEVEL
02 LEVEL
01 LEVEL
MAIN DECK
2ND DECK
3RD DECK
4TH DECK
TANK TOP
RO/RO - CARGO SPACE
(OPEN) VOLUME = 6000m³
DRY PROVISIONS 1
126.6m²
REEFER STORES 1
180.7m²
CADET MESS 334m²
OFFICER MESS
75m²
DECK TRAINING
DRY PROVISIONS 2
112.4m²
REEFER STORES 2
116.3m²
CADET FOOD SERVICE 110m²
GALLEY 173m²
CREW MESS
55m²
SHORE POWER CABLE CONNECTION SPACE
FZ5
FZ4
FZ3
FZ2
FZ1
87 CADET BERTHS
STORES/PAINT LKR
STEERING GEAR
STORES/ROPE LKR
RO/RO - CARGO SPACE
DECK AREA = 1015m²
CLASS ROOM
91.9m²
CLASS ROOM
128.0m²
CLASS ROOM
58.5m²
CLASS ROOM
63.0m²
FACULTY OFFICES
83.6m²
STORES
123m²
99 CADET BERTHS

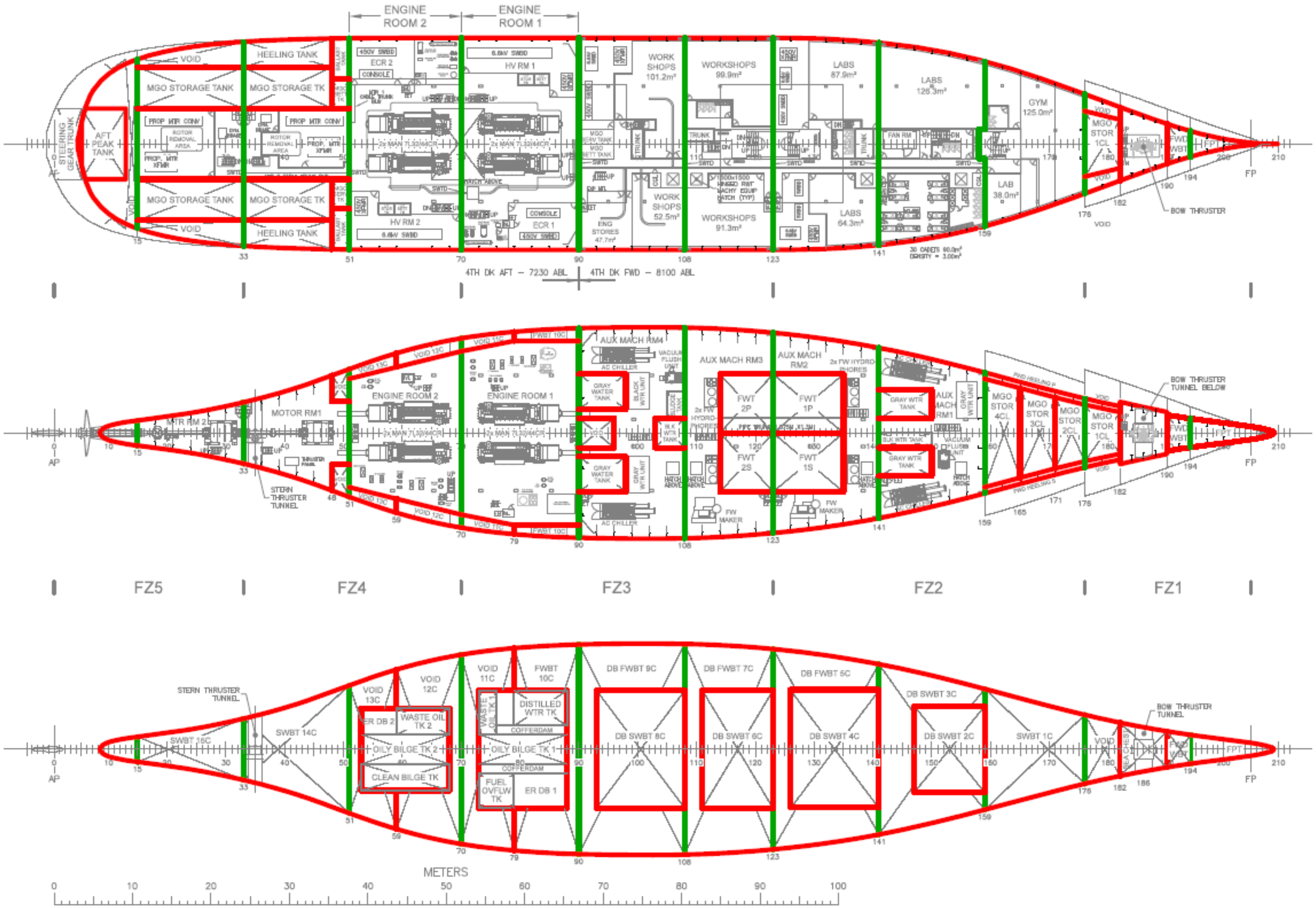


Figure 1: Watertight boundaries

E. Tank Arrangement

The ballast tank system is composed of a fixed fresh water portion, and a set of trim, heeling and other salt-water tanks. The use of fixed fresh water is employed to reduce corrosion since these tanks need to be full in all loading conditions to achieve required forward draft and propeller immersion. It also avoids having to deal with the large FS values these tanks have during the ballasting process. The remaining salt-water ballast tanks are designed to achieve maximum flexibility in the management of the ship loading conditions for all quantities and distributions of cargo and consumables.

The forward trim tank was located aft of the collision bulkhead in order to meet regulations. Furthermore, two sets of heeling tanks are provided (forward to be used when lightly loaded and aft to be used when heavily loaded) to be able to achieve zero heel even when asymmetrically loaded or/and with significant wind loading from the beam.

Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO) tanks were arranged to comply with MARPOL Regulation 12A on oil fuel tank protection, which forbids all fuel oil tanks from being located next to the ships outer skin. This was achieved by placing all MGO tanks inboard of the minimum distances from the outer hull dictated by MARPOL. In addition, all MGO tanks were placed in way of the two Motor Rooms aft and forward of the other ancillary machinery spaces to optimize volumes utilization and achieve the necessary MGO capacity.

The Fresh Water and Black Water capacity requirements were satisfied by adding symmetrical tanks close to Centerline over the tank top of the forward compartments. This arrangement minimizes flooding asymmetries and keeps these tanks from being damaged.

F. Cross-flooding Devices

In order to meet SOLAS damage stability requirements without the need to assess intermediate stages of flooding, it is necessary to ensure that equalization of symmetric tanks connected by cross-flooding devices is achieved in less than 60 seconds. To achieve this capability, the following cross flooding devices are provided:

- SWB 9C Frame: 90-93 Manhole Cross-sectional area: 0.883 m^2
- SWB 9C Frame: 106-107 Pipe Cross-sectional area: 0.237 m^2
- SWB 7C Frame: 108-111 Manhole Cross-sectional area: 0.883 m^2
- SWB 7C Frame: 121-122 Pipe Cross-sectional area: 0.237 m^2
- SWB 5C Frame: 123-126 Manhole Cross-sectional area: 0.883 m^2
- SWB 3C Frame: 141-147 Manhole Cross-sectional area: 0.883 m^2

The available cross-sectional areas have been verified in accordance with the requirements of IMO MSC.362(92). Details of these calculations are given in Appendix B – Cross-Flooding Calculations.

In the compartments where a passive equalization ducts are fitted, the air pipes have a sufficient cross section to ensure that the flow of water into the equalization compartments is not slowed down. The diagram below shows a typical cross-flooding arrangement. Green denotes the water flow channels, purple the tank boundary bulkheads.

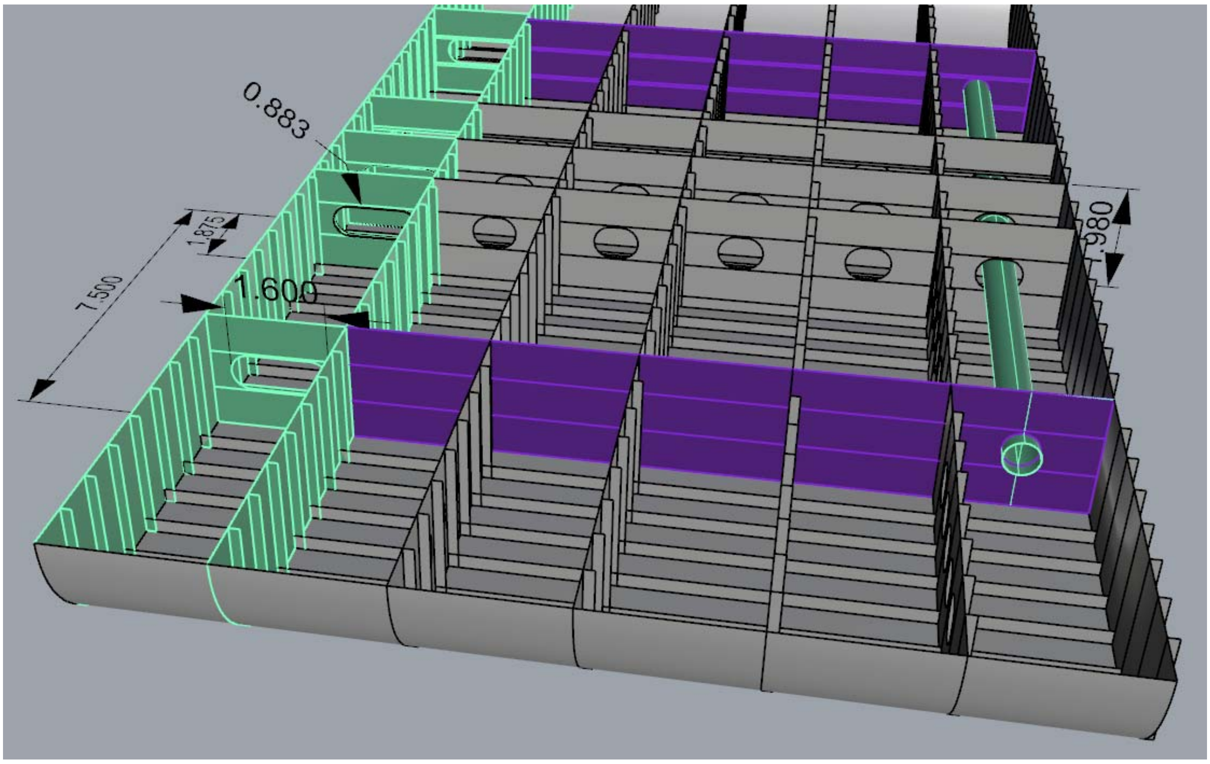


Figure 2: Typical cross-flooding arrangement

II. Stability Analysis

A. IS Code Intact Stability Analysis

A simplified limiting GM curve according to the IMO Intact Stability Code was derived for the three drafts mandated by the SOLAS 2009 probabilistic damage stability regulations. The purpose of this curve is only to show that the IS Code requirements for this ship are significantly lower than the SOLAS 2009 damage stability requirements, thus removing the need for a detailed IS Code analysis involving several draft and trim values.

The analysis was run in HECSALV applying a fixed solid weight to the vessel to match the draft and trim needed, and then varying the ship's VCG until the IS Code requirements were met with a very small margin. Appendix C – IS Code Results shows the results of this analysis. It should be noted that for all three drafts, the governing criterion is the Weather Criterion area ratio, where the windage area used is according to the ship profile shown in Appendix A – Ship Data.

The resulting minimum GM curve is as follows:

Intact

	Dl	**Dp**	**Ds**
Draft (m)	5.750	6.725	7.250
GMt (m)	0.788	0.384	0.3185

B. SOLAS 2009 Damage Stability Analysis

In the process of designing the NSMV, it was found that the governing criterion determining the minimum GM curve is the SOLAS 2009 probabilistic damage stability, which requires the attained subdivision index A for this ship to be larger than the required subdivision index R. The latter is equal to 0.710, given the vessel needs to cater for 750 people, and having estimated the largest heeling moment (due to passenger crowding) to be 683 m-MT.

The attained subdivision index A of the designed ship is equal to 0.766, having considered all damages up to three zones and the following minimum GM values:

Damage

	Dl	**Dp**	**Ds**
Draft (m)	5.750	6.725	7.250
GMt (m)	1.830	1.630	1.5

However, a number of design features were dictated by Regulation 8.2 of the SOLAS 2009 probabilistic damage stability, which imposes a minimum value of 0.9 for the survivability index s_{final} for each "shallow" damage (one and two compartment damages with minimal penetration). In practice, this implies that some of the larger compartments (such as the twin Engine Rooms) had to be protected with symmetrical cofferdams at the sides.

The reason for this is that the survivability index s_{final} is particularly sensitive to the angle of heel at equilibrium, quickly dropping under the minimum 0.9 value when heel in the damaged condition is larger than 8.5 degrees. The survivability index s_{final} also depends on the residual GZ range and GZ max value, also losing value if these parameters drop below 16 degrees and 0.12 m, respectively.

It should be noted that heel at equilibrium in a damaged condition can only be kept under control by adopting a high measure of symmetry in all the major floodable areas. In turn, this imposes that large asymmetric tanks or compartments should be avoided. This is the reason the NSMV design has all symmetrical tanks in the lower part of the hull, including cross connects between the port and starboard double bottom tanks. The only non-symmetrical tanks are the small heeling tanks forward and aft, which are needed to allow the vessel to be placed in an upright condition in case of small heel angles caused by unsymmetrical loading or from persistent wind blowing against one side of the large sail area of the passenger type vessel.

Moment Calculations for SOLAS 2009 Damage Stability

The following table shows details of the heeling moment calculation carried out for the NSMV. Lateral area was calculated using the same profile also used for the IS Code Weather Criterion. The weight of the bare lifeboats was provided by their manufacturer.

B (Moulded beam)	27			m
	Min Draft	Intermediate Draft	Max Draft	
T (Condition draft)	5.75	6.725	7.25	m
A (Projected lateral area above waterline)	3,330.99	3177.19	3,023.39	m^2
Centre of total hull lateral area above CL	17.258	17.986	18.378	m
Z (Centre of lateral area to T/2)	14.383	14.624	14.753	m
Max offset of Lifeboat TCG from Side during launch	2	2	2	m
Passengers	715	715	715	
Crew	35	35	35	
Persons (total)	750	750	750	
Percentage of people intended for the lifeboats	75%	75%	75%	
Max number of persons in lfeboats	563	563	563	
Number of Lifeboats	8			
Perons per lifeboat (100% capacity)	70	70	70	
Perons per liferaft (100% capacity)	6	6	6	
Weight of bare lifeboat	4.7	4.7	4.7	t
Weight of bare liferaft	0.025	0.025	0.025	t
Weight of average person	0.0825	0.0825	0.0825	t
Nominal wind pressure	120	120	120	N/m^2
	0.0012	0.0012	0.0012	bar
Pressure coefficient f1				
M passenger	683.44	683.44	683.44	tm
M wind	**586.29**	**568.57**	**545.84**	tm
M survival craft	681.69	681.69	681.69	tm
M heel (=max of the above)	683.44	683.44	683.44	tm

Regulation 7

The calculation of the Attained Index according to Regulation 7 was performed on an Excel sheet linked to HECSALV 8.1 through a set of macros. The generation of the damage cases and the probability values associated with them was carried out using HECSALV 7.9 DamStab. The results were then imported into the Excel sheet. The damage zones considered were created according to the following data:

Aft terminal (m-MS)	-79.8
Fwd terminal (m-MS)	80
SubDiv Length (m)	159.8
Highest HMax (m-BL)	19.737

Zone Number	**Transverse Bound**	**Longitudinal Bound**			**Vertical Bound**			
	m-MS	**m-CL**	**m-CL**	**m-CL**	**m-BL**	**m-BL**	**m-BL**	**m-BL**
		1	**2**	**3**	**1**	**2**	**3**	**4**
1	-73.500	4.500			11.100			
2	-66.350	4.500			5.000	11.100		
3	-52.850	9.750			1.980	9.600	11.100	
4	-41.600	9.750			1.980	3.326	9.600	11.100
5	-39.350	8.250			1.980	3.280	9.600	11.100
6	-34.100	5.500	11.200		1.980	7.230	11.100	
7	-33.350	5.500	11.200		1.980	7.230		
8	-25.100	5.500	11.200		1.980	7.230		
9	-18.350	7.500	11.200		1.980	7.230		
10	-10.100	7.500	11.200		1.980	7.230		
11	3.400	1.875	7.500		1.980	8.100		
12	14.650	7.500			1.980	8.100		
13	28.150	7.500	12.727		1.980	8.100		
14	41.650	1.875	5.500	10.839	1.980	8.100		
15	46.150	9.191	10.506		1.980	8.100		
16	50.650	7.684	10.506		1.980	8.100		
17	54.400	6.139	10.506		1.980	8.100		
18	58.900	8.087			1.980	11.100		
19	64.900	6.589			11.100			
20	67.900	4.443			11.100			
21	70.000	3.344			11.100			
22	78.050	3.344			11.100			

The HECSALV database had to be pre-processed using a second set of macros to create partial asymmetric portions of WBT 3C, WBT 5C, WBT 7C, WBT 9C, WBT 10C, VOID/WBT 11C, VOID/WBT 12C, VOID/WBT 13C, WBT 14C, and the AFT VOID, that would allow the calculation of intermediate phases of flooding for all these watertight spaces. The software would then select the smallest survivability factor amongst all intermediate phases and the final equilibrium, to assess the contribution of each damage to the Attained Index.

For all spaces, two intermediate phases were considered, in accordance with the SOLAS 2009 guidelines: one only involving the portion of the space to starboard without the cross-connecting duct, and one involving the portion of the space to starboard and the cross-connecting duct. It should be noted that, although cross-flooding calculations showed that the equalization time for WBT 3C, WBT 5C, WBT 7C and WBT 9C is generally less than 60 seconds, all intermediate phases were retained in the calculation of the Attained Index as this is simpler and more conservative than attempting to filter these phases out.

Regulation 7 also requires that the smallest survivability factor be chosen amongst those of damage cases only differing for the location of the lower bound of the vertical damage extension. Appendix D

– SOLAS 2009 Reg.7 Results shows detailed results for the list of damage cases thus filtered. The table is split in two parts. The first part reports the damage case description, including the starting condition and damage zone. The second part of the table reports the results of the probabilistic calculation, including the intermediate phases.

The end summation leading to the Attained Index is as follows:

Indices	1	2	3	Combined
R				0.710
A	0.7559	0.7681	0.7687	0.766
Prob	0.825	0.825	0.825	

Regulation 8

Regulation 8 of SOLAS 2009 is only applicable to passenger ships and imposes minimum s-factor values for all shallow damage cases. Compliance with Regulation 8.2 was verified with an Excel macro linked to HECSALV 8.1 that generates these shallow damages assuming a box-shaped damage the location and dimensions of which are varied to scan the entire ship side. For each of the damage cases generated, the s-factor is calculated exactly in the same way as for Regulation 7, including s_{mom}, s_{int}, and s_{final}.

The results of this check are given in Appendix E – SOLAS 2009 Reg.8 Results. In there, it is shown that some of the s-factor values obtained for the intermediate phases of flooding are lower than the minimum 0.9 value. However, all the failing intermediate phases are shown to lead to equalization in less than 60 seconds in Appendix B – Cross-Flooding Calculations. For this reason, these failing cases can be ignored when assessing compliance with Regulation 8.

C. Loading Conditions and Required GM

For the purposes of the concept design, three main loading conditions were considered, each including departure, 50% intermediate, and arrival consumables. The three main loading conditions considered were No Cargo (normal training ship operating mode), Full Load (normal emergency relief operating mode), and Max Draft, representing the vessel operating at its subdivision draft. Figure 3 shows the conditions GMt (corrected for free surface effects) versus the intact and damage stability minimum GM curves. Appendix C – IS Code Results contains the detailed analysis results and definition of the sample loading conditions.

It should be noted that several other variations were also created to explore the ship's capacity and derive the maximum Shear Force & Bending Moment curves used to calculate the minimum required structural section modulus and shear force area.

A minimum GM Margin of 0.085 m was obtained over the four main loading conditions, having applied variable Free Surface (FS) and Center of Gravity values for all tanks, and maximum group FS values for each consumable group as mandated by MARPOL and CFR. In addition, maximum group FS values were also applied to the SWB tanks used during navigation for each of the three loading conditions, so that stability compliance would be demonstrated as these ballast tanks are emptied and filled underway for purposes of controlling trim and draft.

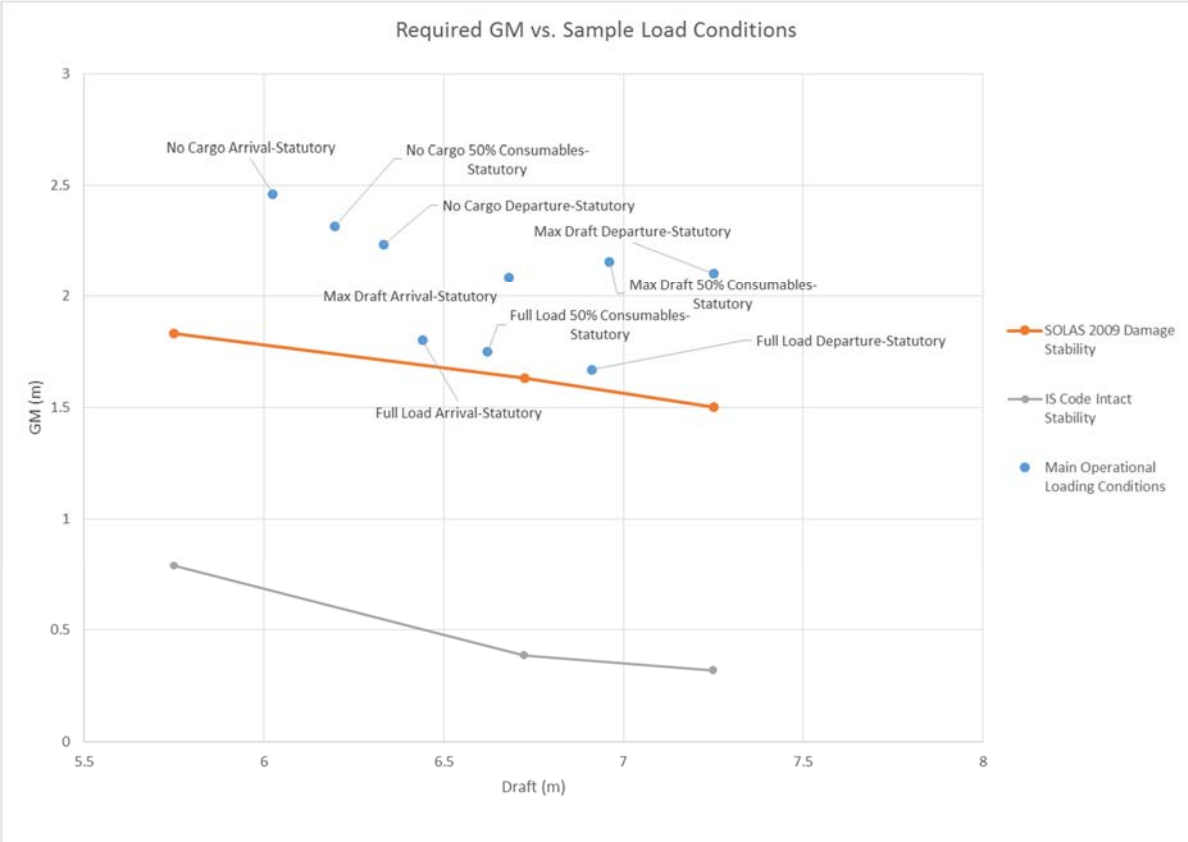


Figure 3: Sample Loading Conditions

D. MARAD Design Letter No. 3 and CFR 2013 Title 46 Subchapter S Damage Stability Analysis

The design of the NSMV training ships was carried out to satisfy the requirements of SOLAS 2009 probabilistic damage stability provisions for passenger ships, as well as those of the Intact Stability Code (General and Weather criteria). In addition, the design was then verified against the requirements of MARAD Design Letter No. 3 and CFR 2013 Title 46 Subchapter S for all the standard operational loading conditions.

These damage stability requirements apply to one-compartment damages only. One compartment standard is applied for damage stability requirements in Subchapter S based on 46CFR 173.051 (a), which states that public nautical school ships shall apply the requirements contained in 171.070(a) as a passenger vessel carrying 400 or less passengers. 171.070(a) applies the standard of flooding contained in Table 171.070(a), which states that for a passenger vessel with 400 or less passengers, a one-compartment standard of flooding is applied.

A one-compartment standard is not as demanding as SOLAS 2009, which is approximately equivalent to a two to three-compartment damage standard. Although the MARAD and CFR criteria are roughly equivalent to a s_{final} value of 1, the requirement that all one and two compartment damages meet SOLAS 2009 Reg. 8.2 practically guarantees that the design would also automatically pass both the MARAD and CFR requirements.

It should be noted that no required GM (GMr) curves were calculated for MARAD and CFR criteria. Rather, each loading condition was checked directly by verifying the MARAD and CFR criteria for the

79 one-compartment damages that were found to be applicable. Detailed results are given in Appendix G – MARAD Design Letter No. 3 and CFR 2013 Title 46 Subchapter S Results.