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BB3: A Generic BB2 Based Submarine Design Using Sternplanes, Rudder, and Bowplanes

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Abstract (U)

Generic unclassified submarine geometries are very useful for comparing hydrodynamic assessment tools with those from allied countries. The generic BB2 diesel submarine geometry has been widely used for this by international working groups. However, BB2 uses an 'X' tailplane configuration and sailplanes whereas Canada is more interested in a conventional '+' tailplane geometry and bowplanes. This report describes a new BB3 design that replaces the BB2 sailplanes and tailplanes with bowplanes, a rudder, and sternplanes while retaining the same BB2 hull, deck, and sail. BB3 is shown to have good stability in the vertical and horizontal planes.

Résumé

La géométrie des sous marins génériques non classifiés est très utile pour comparer certains outils d'évaluation hydrodynamique à ceux de pays alliés. Ainsi, la géométrie BB2 du sous-marin diesel générique a été largement utilisée à des fins de comparaison par des groupes de travail internationaux. Cependant, la géométrie BB2 nécessite des gouvernes arrière ≪ X ≫ et avant, alors que le gouvernement du Canada est plus intéressé par celle des gouvernes arrière ≪ + ≫ classiques et par les barres de plongée avant. Le présent rapport décrit un nouveau modèle BB3 dans lequel on remplace les gouvernes avant et arrière de la géométrie BB2 par des barres de plongée avant, un gouvernail de direction et des barres de plongée arrière tout en conservant la même coque, le même pont et le même kiosque que dans la BB2. La BB3 permet une bonne stabilité dans les plans vertical et horizontal.

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1 Introduction

Generic unclassified submarine geometries are very useful for comparing hydrodynamic assessment tools with those from allied countries. In recent years, the generic BB2 theoretical diesel submarine geometry has been widely used by international working groups to evaluate and compare their computational fluid dynamic (CFD) and six degree-of-freedom simulation capabilities. These evaluations have been aided by BB2 scale model experimental data obtained in different experimental facilities by a number of countries who have shared this data with the working groups. This allows different experimental facilities to be evaluated as well as the software tools. This is an excellent way of acquiring confidence in tools that are primarily used on classified geometries, the data from which cannot be shared.

Development of the BB2 geometry was initiated by the Australian Defence Science and Technology Organisation (DSTO) who sponsored a study carried out by Joubert [1,2]. DSTO did several wind tunnel experiments with a scale model of this geometry (eg, [3]) which was then used in a collaborative international exercise [4] where it acquired the name 'BB1'. To make the geometry more realistic and improve stability, MARIN made changes to the sail and tailplanes [5] and called the revised submarine geometry 'BB2'. The BB2 geometry is available from MARIN in either '.3dm', '.igs', or '.stp' solid body formats.

The BB2 geometry uses an 'X' tailplane configuration and sailplanes (Figure 1). However, Canada is more interested in a conventional '+' tailplane geometry and bowplanes. Furthermore, a recent study looking at the impact of sail height on the ability of a submarine to recover from a sternplane jam [6] required a boat with horizontally oriented sternplanes. The 'BB3' geometry presented herein was designed to facilitate this study.

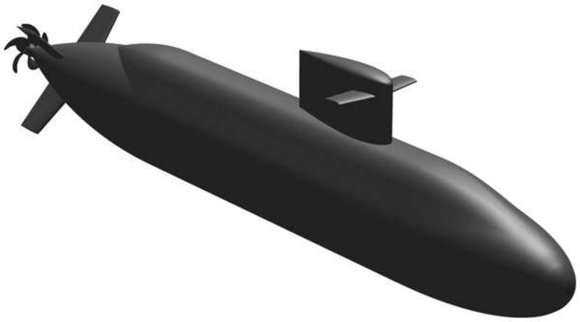


Figure 1 *The generic BB2 geometry uses sailplanes and tailplanes oriented 45 degrees to the vertical and horizontal planes of the boat.*

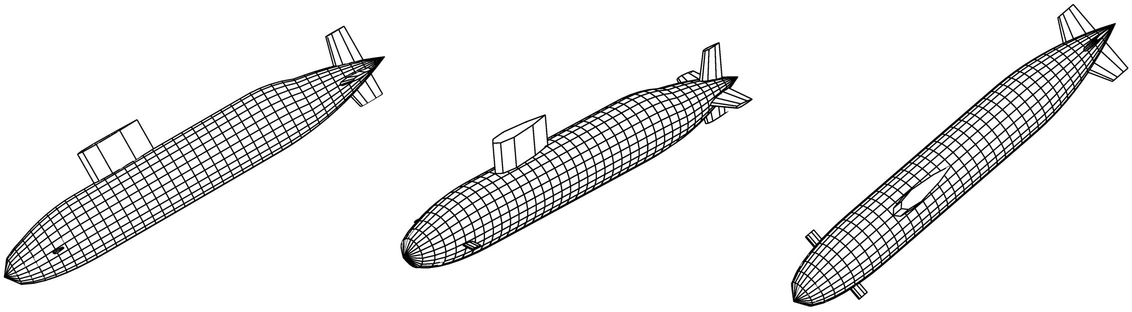


Figure 2 *The BB3 geometry with bowplanes, symmetrical sternplanes, and an asymmetrical rudder, as modelled by DSSP.*

2 The BB3 Design

BB3 uses the same hull, deck, and sail as BB2. BB3 is created from BB2 by removing the BB2 tailplanes and sailplanes and replacing them with a rudder, sternplanes, and bowplanes. These are sized to provide the necessary stability and effectiveness.

The BB3 design (Figure 2) was created for use with the DRDC Submarine Simulation Program (DSSP). DSSP requires only high level details of the boat geometry so that is as far as the current BB3 design goes. To use this design in experimental or CFD studies requires additional appendage tip, trailing edge, and root shoulder details (see next Section).

The BB3 rudder is asymmetrical to help protect the bottom portion of the rudder when the submarine sits on the ocean floor. Unlike the BB2 tailplanes, which act independently of each other, the BB3 top and bottom rudder components are fixed to a common shaft. The BB3 sternplanes are symmetric and their port and starboard planes are also fixed to a common shaft. This simplifies vehicle control but at the expense of flexibility.

The BB3 tailplanes are sized to provide the required vertical and horizontal plane stability. This is done by using DSSP to analyze the boat geometry and predict the hydrodynamic coefficients for the vehicle. These coefficients are typically referenced to a point near the center of buoyancy of the boat and on the centerline of the pressure hull. The axial location of the reference point was found by extracting transverse splines of the hull and deck from MARIN's file:

`03_BB2_with_casing_and_appendages.igs`

at 40 evenly spaced axial stations. From these splines, local cross sectional areas were calculated and themselves splined as a function of the hull axial coordinate x. This latter spline was integrated to give the volume V_{hd} of the hull and deck, and to get their axial centroid. The axial centroid of the hull and deck is used by DSSP as the hydrodynamic reference center x_{ref}:

$$V_{\mathrm{hd}} = 0.012229\ell^3 \tag{1}$$

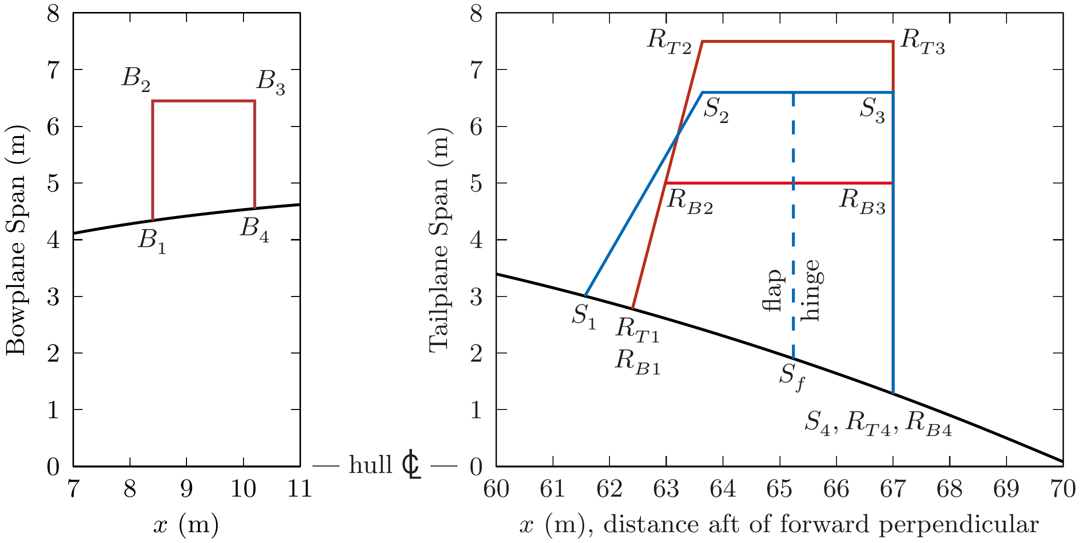
$$x_{\mathrm{ref}} = 0.46073\ell \tag{2}$$

where ℓ is the length of the boat and x_{ref} is a distance aft of the nose (forward perpendicular).

The BB2 hull and deck breadth values where also obtained from the 40 station sections discussed above. These were splined as a function of x as well and the spline used to find the root coordinates of the BB3 appendages.

The BB3 tailplanes (Figure 3) have a common trailing edge axial location. This was set to:

$$x_{\mathrm{TE}} = \frac{67.0}{70.2}\ell \tag{3}$$



Rudder, top:

$$[R_{T1}, R_{T2}, R_{T3}, R_{T4}] = [(62.4, 2.7796), (63.6358, 7.5), (67.0, 7.5), (67.0, 1.2834)]$$

Rudder, bottom:

$$[R_{B1}, R_{B2}, R_{B3}, R_{B4}] = [(62.4, 2.7796), (62.9813, 5.0), (67.0, 5.0), (67.0, 1.2834)]$$

Sternplanes:

$$[S_1, S_2, S_3, S_4] = [(61.5619, 3.0079), (63.6358, 6.6), (67.0, 6.6), (67.0, 1.2834)]$$

$$S_f = (65.2395, 1.9044)$$

Bowplanes:

$$[B_1, B_2, B_3, B_4] = [(8.4, 4.34), (8.4, 6.45), (10.2, 6.45), (10.2, 4.55)]$$

Figure 3 *Bowplane, rudder, and sternplane corner coordinates at full scale. The planes have NACA 0015 thickness profiles which have finite thickness trailing edges.*

by moving a reasonable distance forward of the BB2 propeller location given in [5]. That is, the trailing edges are 67 m aft of the forward perpendicular on the full scale BB2/BB3 hull [5] for which $\ell = 70.2$ m. Note that the aft perpendicular, located 70.2 m aft of the forward perpendicular, is the theoretical apex of the aft hull profile and is aft of the actual end of the hull because the hull has been rounded to avoid an infinitely sharp point.

The sternplane and rudder leading edge sweepback angles are:

$$\lambda_s = 30 \text{ degrees} \tag{4}$$

$$\lambda_r = 15 \text{ degrees} \tag{5}$$

This gives the sternplanes a good chance of shedding any cables the boat may encounter, something that is of less concern for the rudder. This works for the sternplanes because the forward portion of these planes is fixed to the hull while the rudder is all-moving, and the smaller the root chord of an all-moving appendage the easier it is to rotate relative to the curved hull. The sternplanes provide vertical plane control through full span trailing edge flaps. This provides finer, more sensitive depth control than the robust horizontal plane control provided by the all-moving rudder.

The rudder root-chord and tip-to-tip span length were chosen first. Then the rudder was shifted up so the bottom portion barely extended past the maximum hull diameter at the keel. To simplify manufacture of the rudder, the bottom rudder planform is a duplicate of the top planform but with a truncated tip.

The sternplanes' tip chord was made equal to the top rudder tip chord and, initially, the sternplanes were given the same tip-to-tip span as the rudder. However, this span had to be increased during the stability assessment as vertical plane stability requirements are greater than horizontal plane requirements. The sternplane flap chord was set to 40% of the average sternplane chord length.

The bowplanes were scaled up from a previous generic model design. The ratio of the bowplane to sternplane planform areas was kept constant during the scaling. The BB2 hull has a relatively low length to diameter ratio necessitating larger tailplanes to achieve stability for a given length, and the bowplane dimensions were scaled accordingly.

The margins of stability in the vertical plane G_v and horizontal plane G_h, as described by Feldman [7], are used to fix tailplane dimensions:

$$G_v = 1 - \frac{M'_w \left(Z'_q + m'\right)}{Z'_w \left(M'_q - m' x'_G\right)} \tag{5a}$$

$$G_h = 1 - \frac{N'_v \left(Y'_r - m'\right)}{Y'_v \left(N'_r - m' x'_G\right)} \tag{5b}$$

Feldman suggests that good dynamic performance is obtained in the vertical plane with $0.5 \leq G_v \leq 0.7$ and in the horizontal plane with $G_h \approx 0.2$. DSSP was used to predict the hydrodynamic coefficients and, hence, stability. The tailplane and bowplane sizes were adjusted in DSSP, inline with the above discussion, until the margins of stability were finalized at $G_v = 0.54$ and $G_h = 0.20$ by the geometry defined in Figure 3.

For the record, the final BB3 DSSP input file is listed in Appendix A.

3 Solid Model BB3 Design Issues

When extending the DSSP BB3 design to a solid model for use with CFD or experiments, the appendage planforms should not be changed. If trailing edges are rounded, as are those for BB2, do so by adjusting the thickness distribution only; do not change the chord length. If the tips are rounded, try to keep the total planform area constant.

The National Research Council (NRC, St. John's, Newfoundland) has already developed a preliminary BB3 solid model for use with CFD [9] based on an earlier draft of this report. This model retains the conventional NACA flat trailing edges for the appendages and adds small end-caps to their tips, but has not made the appendages deflectable.

4 Concluding Remarks

This short report documents the design of a BB3 variant to the well known BB2 generic submarine geometry. The BB3 design has enabled Unclassified maneuvering studies with a boat using '+' tailplanes and bowplanes, studies of specific interest to Canada.

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APPENDIX A: BB3 DSSP Input File

The DSSP Input Reference manual [8] explains in detail how a DSSP input file is constructed. The BB3 input file below uses input reference axes with an origin on the hull centerline at the nose, with x pointing forward, y pointing to starboard, and z pointing downwards. After some initial preliminaries, the file defines the origin of the output reference system followed by the BG value of the boat. Then the hull breadth, height, area, and camber at each of 40 equally spaced stations is tabulated. This is followed by the appendage planform coordinates and other associated parameters. Finally a generic propeller is defined followed by autopilot depth and heading control gains. The latter were obtained by trial and error using the DSSP six degree-of-freedom simulation capability.

This is file `/home/watt/BB2/BB3/bb3.geo` last modified on 23 January 2019. Comments within the file are preceded by either of the symbols ‘`!`’ or ‘`"`’.

```
Text BB3: fullscale BB2 hull and deck with bowplanes and + tail
Text December 2018

Warnings Quiet

Plot
  Maple

Reference
    -32.343  0.0  0.0    ! Puts Ref at Hull CB
!    -35.1    0.0  0.0    ! puts Ref at midpoint
     0.0     0.0  0.0

BG 0.40

Hull Default 40
Label #Hull
  Nose    0.0  0.0 0.0
  Tail  -70.2  0.0 0.0
  Deck 1.2 1.0            ! Factors for Y and N due to deck.
  RoughAllow 0.0
  Station 40
!   B        T        A        F
   0.000    0.000    0.000     0.000
   4.788    4.788   18.005     0.000
   6.451    6.452   32.685     0.000
   7.536    7.585   44.731    -0.025
   8.298    8.582   54.980    -0.142
   8.837    9.353   63.449    -0.258
   9.209    9.927   70.161    -0.359
   9.448   10.320   74.970    -0.436
   9.562   10.536   77.571    -0.487
   9.600   10.600   78.310    -0.500  ! capped at next line values
   9.600   10.600   78.310    -0.500
```

```
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.600   10.600   78.310    -0.500
   9.589   10.585   78.055    -0.497
   9.487   10.397   75.300    -0.455
   9.256    9.980   69.943    -0.362
   8.898    9.335   63.044    -0.218
   8.414    8.435   55.603    -0.011
   7.804    7.804   47.829     0.000
   7.067    7.067   39.227     0.000
   6.205    6.205   30.235     0.000
   5.216    5.216   21.365     0.000
   4.100    4.100   13.206     0.000
   2.859    2.859    6.420     0.000
   1.492    1.492    1.747     0.000
   0.000    0.000    0.000     0.000

Lift
  Label #Sail
  Sail 5.300
  Planform
  -19.860  0.0   -5.800
  -19.860  0.0  -11.173
  -30.847  0.0  -11.173
  -30.847  0.0   -5.800
  ToC 0.22

Lift
  Label #StbdBowplane
  SBowplane 4.455 0.0
  Planform
    -8.4   4.340  0
    -8.4   6.45   0
   -10.2   6.45   0
   -10.2   4.550  0
```

```
  ToC 0.15
  AllMoving 1.0
  DeltaLim 20, -20
  DelRateLim   5
  DeltaDyn 0.9 2.5
  WeightDCI 1 0 0
  Save

Lift
  Label #PortBowplane
  Rotate 180

Lift
  Label #TopRudder
  Rudder  2.083 5.3
  Planform
    -62.4     0.0  -2.7796
    -63.6358  0.0  -7.5
    -67.0     0.0  -7.5
    -67.0     0.0  -1.2834
  AllMoving    1.0
  DeltaLim     30   -30
  DelRateLim   6.0
  DeltaDyn     0.9   2.0
  ToC          0.15
  TailEff  Dempsey
  WeightDCI 0 1 0

Lift
  Label #BotRudder
  Rudder  2.083 4.8
  Planform
    -62.4     0.0  2.7796
    -62.9813  0.0  5.0
    -67.0     0.0  5.0
    -67.0     0.0  1.2834
  AllMoving    1.0
  DeltaLim     30   -30
  DelRateLim   6.0
  DeltaDyn     0.9   2.0
  ToC          0.15
  TailEff  Dempsey
  WeightDCI 0 1 0

Lift
  Label #StbdSternplane
  Sternplane  2.218  4.8
  Flapped  0.0  1.0  0.4
```

```
  Planform
    -61.5619  3.0079  0.0
    -63.6358  6.6     0.0
    -67.0     6.6     0.0
    -67.0     1.2834  0.0
  ToC  0.15
  TailEff Dempsey
  DeltaLim 25  -25
  DelRateLim   6
  DeltaDyn     0.9 2.0
  PReverse Ums           ! critical speed = 1.86 m/s
    1.46 1.66 2.06 2.26
    -0.5 0 0 1
  WeightDCI 1 0 0
  Save

Lift
  Label #PortSternplane
  Rotate 180

Prop
    Location   -68.856
    Diameter    5.0
    RevLimit    130.0
    RevRateLim  6.0
    RevDynam    0.9 0.5

WagBInit
    PoD   0.84
    Ums   3.0

AutoDepth PID
  PID 0.5 1 1 0.0 1     " 0.6
  DepConGain  25.0      " plane limit
  DepErrGain   0.1      " default 12/ell; reduce to dampen autopilot response
  LookAhead    60       " ell/2 by default; increase to reduce overshoots
  PitchLimit   10.0     " 10 by default; increase so it doesn’t impact result

AutoHead PID
   PID 0.5 0.1 1 0.0 1
   HedConGain  30.0       " Rudder limit
   HedErrGain  0.05
```

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