DEVELOPMENT OF A VALUE-ENGINEERED NOMAD BUOY

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ABSTRACT

Since the mid-1970s, the National Oceanic and Atmospheric Administration (NOAA) Data Buoy Office (NDBO) has used Navy Oceanographic Meteorological Automatic Device (NOMAD) buoys as part of their ocean data gathering network. These U.S. Navy-built, 20-ft long, boat-shaped hulls, have proven to be extremely seaworthy buoys. The hulls are reliable, easily transportable, and for many applications, they are an attractive alternative to the conventional 40-ft and 33-ft diameter discus-shaped buoys. As a result, NDBO, in early 1979, began actively pursuing the idea of designing and constructing a second generation, value-engineered (VE) version of the NOMAD buoy. A consulting firm was contracted to redesign the NOMAD hull, and in June 1981, construction was started on a series of five new NOMAD buoys. This paper describes the design and construction of the VE NOMAD buoy, and details the efforts of industry and government working together to produce a reliable, cost effective data buoy.

NOMAD DEVELOPMENT

The NOMAD hull is well-documented to have been developed from the "Roberts buoy" or "current radio buoy."[1-3] The Roberts buoy was a 6.67-ft long, 400-lb, boat-shaped buoy developed in the early 1940s, by the U.S. Coast and Geodetic Survey, to measure strong tidal currents. The buoy's performance was satisfactory, but its limited size restricted the buoy's use in other areas.

The successor to the Roberts buoy was the Naval Research Laboratory (NRL) Mark 3 buoy. This hull was designed by NRL for housing sono-radio equipment, moored in a strong current in deep water. It was 12.58-ft long and displaced approximately 4700 lb. The buoy resembled the Roberts buoy, but with increased dimensions to accommodate a larger payload. There were two tentative designs of the NRL Mark 3 buoy, designated Buoy A and Buoy B. The two designs had the same dimensions in plane; however, Buoy B had an approximately 8-in. greater draft than Buoy A. NRL tasked the David Taylor Model Basin (DTMB) to conduct model tests on both hull types to determine their performance.[2] The results of these model tests caused DTMB to recommend the further development of Buoy B because of its greater load-carrying capacity.

In July 1946, the Bureau of Ships became involved in a program to develop automatic weather station buoys. As a perspective part of this program, they requested DTMB to conduct a preliminary investigation into the feasibility of mooring a buoy, similar to Buoy B, in 3600 ft of water with a 3-kn current.[3] This investigation concluded that a hull the size of Buoy B could not support the static weight of an anchor line of sufficient length to be moored in 3600 ft of water. To support such a mooring, a similar shaped hull had to be 20-ft long and displace approximately 20,000 lb. This was to become the prototype of the buoy now called the NOMAD.

In 1952, the first NOMAD buoy, NOMAD-1, was built accordingly to specifications prepared by DTMB,[3,4] and was delivered to the National Bureau of Standards (NBS), who was tasked with the job of evaluating the buoy.[5] From 1954 to 1971, 20 additional NOMAD hulls were built and subsequently operated by the NBS, Naval Air System Command, and Naval Underwater Systems Center (NUSC), with favorable results.[6-9]

20-ft NOMAD VS 40-ft DISCUS

In 1959, at the behest of the Office of Naval Research (ONR), the Convair Division of General Dynamics (GD) Corporation was contracted to generate the design of a general purpose telemetry oceanographic buoy,[10,11] for long distance (2500 mi) transmissions of HF radio data. The design criteria called for the survival of the buoy in the following environmental conditions: current velocity of 10 kn, wind velocity of 150 kn, 60-ft high breaking wave, and an unspecified ice loading. Model tests were conducted on ten candidate hull forms, with preliminary indications showing that the two leading contenders were the 40-ft discus buoy and the NOMAD. In 1965, it was concluded that the 40-ft 200,000 lb discus buoy was the best choice, and, as a result, the "Monster Buoy" was developed. The NOMAD hull was rejected principally because the buoy's excessive roll motion resulted in high antenna radiation losses, and also because the hull was not symmetrical. Another problem with the NOMAD (although not mentioned in the references) was the buoy's relatively small displaced volume. In the mid-1960s when the "Monster Buoy" was conceived, the vacuum tube electronics used for data processing and transmission required diesel or propane motor generators to provide the necessary power. It would have been impossible to fit such a power system into the confines of a NOMAD hull. Today, integrated circuits and CMOS technology have drastically reduced the power requirements. This, coupled with the use of the UHF satellite communications, has eliminated, for NDBO's use, the previous objections to the NOMAD hull.

THE NOMAD AND NDBO

In July 1974, NUSC transferred three NOMADs to NDBO for evaluation and use, followed by the five more hulls in June 1975. NDBO has since acquired title to 15 of the 21 NOMAD buoys built. Of these 15 hulls, 14 are still in use in the NDBO buoy inventory. One hull, designated 6N9, broke its mooring off the New Jersey coast in October 1980, and was subsequently lost at sea. The final NOMAD buoy acquired came from Washington, DC Navy Yard in 1981, and is believed to be the first NOMAD built, NOMAD-1.

The NOMAD hull has become a reliable part of NDBO's hull inventory. In fact, in many areas, such as cost and ease of transportation, the NOMAD is a superior hull to NDBO's 40-ft and 33-ft discus buoys. NOMAD hulls are smaller and cheaper to build than the larger discus hulls. In 1981, the price of a NOMAD hull was roughly 20 percent of that of a 40-ft discus. In addition, the biannual maintenance cost of an aluminum NOMAD is less than half of that of the large discus buoys. There are also economical advantages in other areas. The NOMAD's small size makes the buoy transportable by truck or rail, whereas the large discus hulls must be towed or transported by ship from location to location. The reduced drag on a NOMAD hull permits the use of smaller, more economical mooring components. In spite of its being an unsymmetrical buoy with only a 15-ft instrument height, the NOMAD produces data quality (including one-dimensional wave data) equivalent to the larger discus buoy. There may be limitations on directional wave measurement due to the hull's being nonsymmetrical, but this problem is under study. Due to its smaller size, the NOMAD is slightly more vulnerable to collision and vandalism than the larger discus hull; however, all-in-all, the NOMAD's advantages far outweigh its disadvantages.

SEVERE ENVIRONMENT BUOY

In a four-year period, five of NDBO's discus buoys have capsized during severe weather events. Three of these were 33-ft buoys that capsized while moored in the North Pacific. One was a 40-ft buoy that became unmoored and capsized while adrift northeast of Bermuda. One was a 16-ft buoy, which capsized while moored in the Gulf Stream off the coast of Florida. Environmental conditions associated with these capsizing were analyzed.[12,13] In addition, in 1977 studies[14,15] were initiated in an attempt to identify the capsizing mechanism, and from that determine the size of buoys required for present and perspective NDBO buoy sites. These studies concluded that discus buoys as large as 49 ft might not survive on some northern Pacific and northern Atlantic sites.

In December 1978, NDBO sponsored a "Severe Environment Workshop" to discuss the problem of discus buoy's capsizing in a severe environment and to seek possible solutions.[16] Among the many conclusions of the workshop were that 40-ft buoys should be used in lieu of 33-ft buoys in severe sites, and solid ballast should be used in lieu of water ballast for 33-ft hulls on severe sites. It was further suggested that the NOMAD buoy should be considered as a possible solution to the severe environment problem. In their many years of use, no capsizing of a moored NOMAD has been known to occur.

NDBO fostered and seriously pursued the possibility of the NOMAD as a solution to the severe environment problem. In 1979, a NOMAD was moored next to a 40-ft buoy at 45.9°N latitude and 131.1°W longitude, the site of the first 33-ft buoy capsizing. The objective was two-fold: to test for the survivability of the buoy and instruments and to check the resulting data quality. A mooring failure cut short the experiment, but sufficient data were collected to indicate that the NOMAD satisfied both of the test requirements. Subsequently, the NOMAD was independently deployed at the site, and during that period significant wave heights as large as 33 ft were encountered. This test, combined with mooring design changes that expanded the use of inverse catenary type moorings,[17] led to the tentative conclusion that the NOMAD buoy was capable of replacing a 40-ft or 33-ft hull on any site. Because of this, the decision was made not to build 40-ft or 49-ft hulls as severe environment buoys, and instead go forward with the design and procurement of a second generation NOMAD buoy. However, only years of experience with NOMAD buoys in severe environments will answer the question.

VE NOMAD DESIGN

In June 1979, NDBO contracted the consulting firm of Chi Associates, Inc., to examine the original NOMAD buoy design and suggest possible modifications to the design to reduce the buoy's fabrication cost. The Chi Associates work was performed in three stages. First, given the operating environments of the buoys, Chi Associates was to develop the design criteria for the VE NOMAD. The resultant design criteria, detailed in Table 1, follows the same general lines as the design criteria developed for NDBO's VE 33-ft discus buoys. Second, the original structural design was modified slightly, after which the fabrication cost of the original design was compared to that of the modified hull constructed of aluminum and to that of the modified hull constructed of steel. The cost analysis showed that a substantial cost reduction was possible by altering the buoy's structural design. The material cost of the buoy accounted for only approximately 25 percent of the total fabrication cost of the buoy. As a result, the fabrication cost of a steel hull was only marginally less than that of an aluminum hull. Comparing the two hulls on a life cycle cost basis, the lower maintenance and associated transportation cost favored the use of aluminum as the hull material; thus, the decision was made to progress with the buoy redesign with aluminum as the structural material. The third part of Chi Associates work involved the actual design work of value engineering the NOMAD hull structure. The effect of the modifications, such as reducing the number of hull compartments, reducing the number of structural elements by increasing the span length and plating thickness, and using more economical element shapes and sizes, was entered into the design process and analyzed. Once the hull design was optimized, a cost analysis revealed that the value-engineering modifications reduced the labor cost associated with fabrication by approximately 50 percent and lowered the total fabrication cost by approximately 40 percent. The Chi Associates VE NOMAD design was initially delivered in June 1980. After alterations and revisions, the design was accepted by NDBO in March 1981.[18]

Table 1. VE NOMAD Design Criteria

I. Hull Loading
   a) Deck Plating — 450 psf
   b) Bottom and Side Plating — 1,000 psf
   c) Mooring Forces — 20,200 lb maximum

II. Superstructure Loading
   a) Wind Loading — 37 psf (100 kn wind)
   b) Inertial Loading
      - Heave 2.0 g
      - Sway 0.5 g
      - Surge 0.6 g
      - Pitch 2.6 rad/sec^2

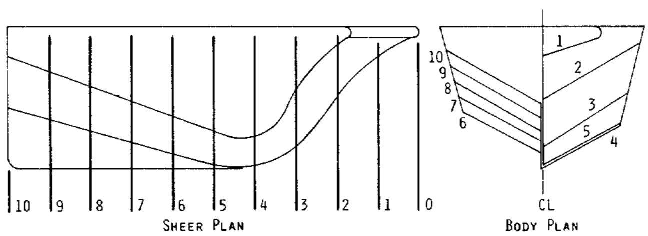
III. Buoyancy: Ensure that the buoy has sufficient reserve buoyancy such that any two compartments may be flooded, and the buoy will still remain afloat.

Once the Chi Associates VE NOMAD design was delivered, work was begun to prepare the design for eventual procurement. Working within the framework of the Chi Associates design, NDBO's Engineering Division performed the extensive detail design work required for the hull. Structural element intersection and termination details, structural mast foundations, handrail and deck layout, a buoy compartmental venting system required by the air-depolarized batteries, and a revised forward mast design were incorporated into the basic Chi Associates work to complete the VE NOMAD design.

In June 1981, after competitive bidding, Aldi Corporation, a San Diego based manufacturing and repair facility, was awarded the contract to construct a series of five VE NOMAD buoys. The contract called for the basic hull and superstructure to be fabricated, with the battery racks and associated mounting brackets for the buoy's meteorological package to be installed once the buoy has been delivered to NDBO's facility at the National Space Technology Laboratories (NSTL) in Mississippi. After the award of the contract, Aldi Corporation reviewed the VE NOMAD design and recommended several modifications that would improve both structural efficiency and ease of fabrication of the design. These modifications were all analyzed, and ultimately the majority of them were approved by NDBO. The first two VE NOMAD buoys, hulls 6N16 and 6N17, were delivered in early 1982. The buoys were modified, integrated with their meteorological packages, and were subsequently deployed at National Weather Service (NWS) sponsored stations in the Great Lakes. The remaining three buoys in the Aldi Corporation contract are scheduled to be delivered by early summer 1982.

PHYSICAL CHARACTERISTICS

The VE NOMAD buoy is a boat-shaped hull, 20-ft long, approximately 10-ft wide and 7-ft deep, with exterior lines virtually identical to those of the original NOMAD buoy (Fig. 1). In its deployed configuration, the buoy has a displacement of 19,250 lb and a reserve buoyancy of 19,500 lb. The buoy is constructed of 5086 marine alloy aluminum, with 1/2-in. thick deck and side plating, and 5/8-in. thick bottom and transom plating. In contrast to the original NOMAD's eight compartments, the VE NOMAD has only four main compartments -- three battery compartments and one electronics compartment.



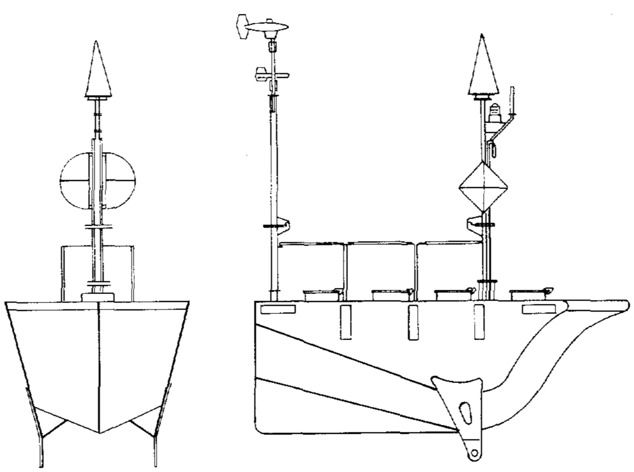
Length Overall	20.00 ft
Width	9.66 ft
Depth	7.04 ft
Design Waterline (DWL)	5.00 ft
Volume at DWL	302 ft^3
Block Coefficient C_B	0.38
Prismatic Coefficient C_P	0.51
Section Area Coefficient C_M	0.64
Waterplane Coefficient C_{WP}	0.79
Vertical Center of Buoyancy at DWL	3.54 ft Above Baseline
Longitudinal Center of Buoyancy at DWL	8.78 ft Forward of Transom
Transverse Metacentric Radius BM_T	2.53 ft
Longitudinal Metacentric Radius BM_L	9.60 ft

Figure 1. NOMAD Hull Form

The VE NOMAD buoy is a volume constrained design; therefore, it must be ballasted to its design displacement using approximately 6,300 lb of bagged lead shot. Floor plates with access points were installed in the bottom of each main compartment, making it possible to secure the hull's ballast into the voids between the floor and shell plating, thereby preventing the ballast from shifting at large angles of buoy heel.

In the past years, there has been an increasing concern about ice loading on buoys; the superstructure and deck layout of the VE NOMAD reflect that concern. The cage-type forward mast on the original hull was replaced with a hinged pipe mast in an effort to reduce the mast's projected area and thereby minimize any possible ice accumulation on the mast. In addition, the number of obstructions on the deck of the VE NOMAD were reduced from that of the original hull.

After integration, and just prior to its deployment, an inclining experiment was conducted on hull 6N16 to determine the vertical center of gravity (VCG) of the VE NOMAD class of buoy. The experimental results corresponded very closely with the expected results calculated from the hull's fabrication drawing and are therefore viewed as reliable. During the same time period, values of natural period of pitch and roll were measured by "sallying" the buoy, and from these values of natural period, approximate values of longitudinal and transverse radii of gyration were calculated.[19] Figure 2 lists all major physical parameters of the buoy. With this information, NDBO's frequency domain hull and mooring response program[20] was used to generate response amplitude operator (RAO) curves for the unmoored buoy in the heave and pitch mode. As shown by these curves in Fig. 3, the VE NOMAD buoy exhibits resonance in pitch (and to a lesser degree in heave) at a frequency of 2.6 rad/sec. However, this is far to the right-hand side of the spectrum in an area of little appreciable wave energy.



Displacement -- Delivered	8,300 lb	
Displacement -- Bare Hull	9,400 lb	
Displacement -- Integrated (W/O Ballast)	12,700 lb	
Displacement -- Deployed	19,250 lb	
Metacentric Height (GM) -- Deployed	1.70 ft	
Vertical Center of Gravity -- Deployed	4.24 ft	Above Baseline
Longitudinal Center of Gravity -- Deployed	8.78 ft	Forward of Transom
Roll Period -- Deployed	3.5 s	
Pitch Period -- Deployed	2.4 s	
Radius of Gyration About Longitudinal Axis	4.13 ft	
Radius of Gyration About Transverse Axis	6.32 ft	

Figure 2. VE NOMAD Buoy

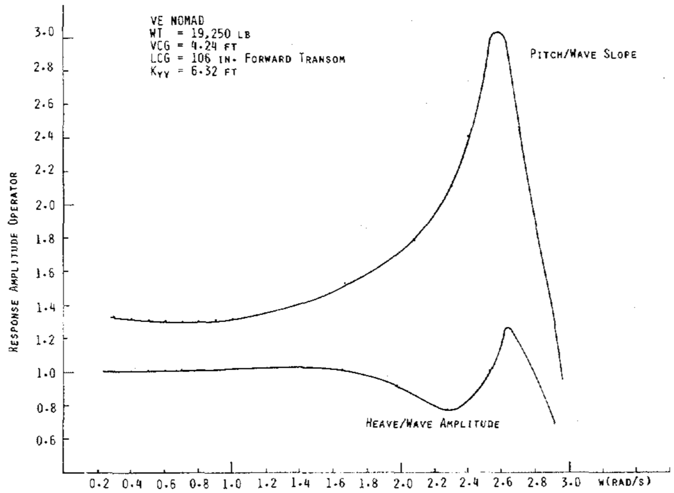


Figure 3. VE NOMAD Response Amplitude Operators (RAOs)

CONCLUSION

The VE NOMAD buoy was developed as a result of extensive design work by Chi Associates, Aldi Corporation, and NDBO. The buoy incorporated the proven performance of the original NOMAD, such as its reliability, reduced maintenance, and ease of transportation, with an optimized structural design, to produce a reliable, cost effective data buoy. Although somewhat limited, the experience with the VE NOMAD has been good, and as a result, NDBO is currently planning construction of a second series of VE NOMAD buoys, with probable delivery in early 1983.

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