

**DESIGN AND REGULATORY
INFORMATION FOR THE UNMANNED
AUTONOMOUS WATERCRAFT
*NEMATON I***

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1 INTRODUCTION

In response to an inquiry from the Federal Communications Commission (FCC), this document provides a brief overview of the unmanned autonomous submersible watercraft *Nematon I*. Both the general design assumptions as well as the legal status of the watercraft are reviewed.

Note that, for reasons discussed in Chapter 4, *Nematon I* will be referred to specifically as a “watercraft” in this document. The author contends that the *Nematon I* is not a “vessel” or a “means of transportation” under the customary and regulatory usage and meaning of the terms.

2 STATEMENT OF INTENT

The purpose of the *Nematon I* is to serve as an experimental platform, demonstrating the capabilities of low-cost electronic, autonomous watercraft designed and constructed using materials and techniques available to individual hobbyists. The initial mission of the craft is to successfully navigate from interior to coastal waters of California, submerge, surface, and return, while gathering data on environmental and navigation conditions.

Assuming this initial mission is successful, the *Nematon I* will then make at least one international journey, navigating from US to international to friendly foreign waters and back. This will demonstrate that such a low-cost craft can successfully navigate over long distances using multiple means of communication and control.

For reasons of safety, the author believes that the *Nematon I* should be equipped with AIS (Automated Identification System) equipment, to alert shore and ship stations to its presence and therefore prevent it being a hazard to navigation. A consequence of the use of AIS equipment during travel into foreign waters is that the *Nematon I* must necessarily communicate with foreign AIS stations.

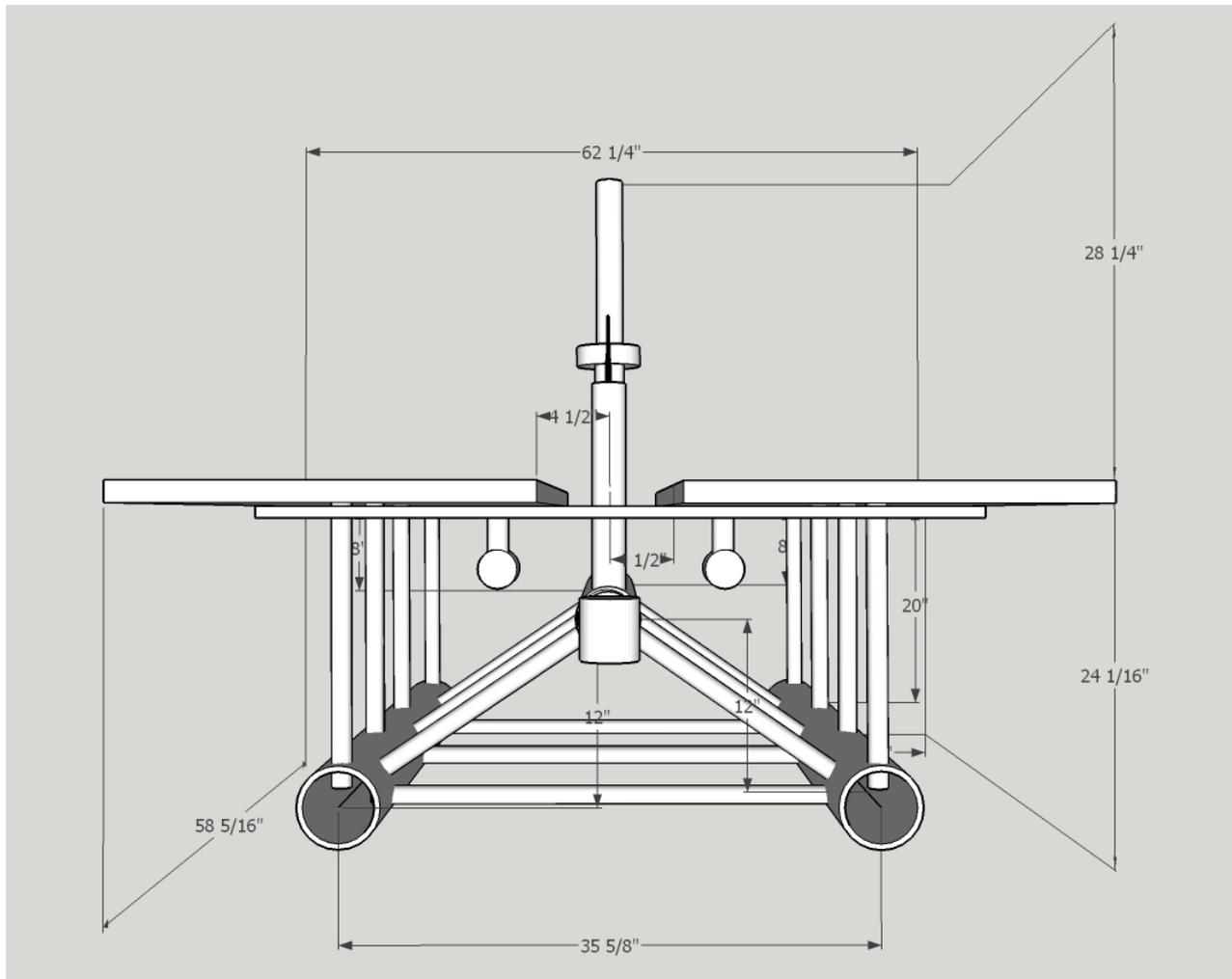


Figure 2 - Nematon I Physical Structure, Front View

The watercraft has no “hull” or body per se. Instead, a central cylinder houses electronic systems, discussed below, while two additional, larger cylinders will house the batteries. The watercraft will have at least three masts for navigation lights, plus GPS, AIS, Iridium and other communication antennae. Two large solar panels form the main deck of the watercraft. Motive power is supplied by two stern horizontal thrusters, while diving capability is achieved through a vertical thruster at the bow.

Note that the figures omit or simplify some structural features, including end caps on the cylinders, lights, rangefinding apparatus, camera housings, additional antennae on the masts, and the details of the thrusters. The volume of the entire craft is roughly five (5) cubic feet, as discussed below.

3.1.1 GROSS TONNAGE

The US Coast Guard has published the formulae necessary to calculate the gross and net tonnage of a watercraft. A fundamental fact is that “tonnage” is a measure of volume and not of mass or weight on land.

Using the simplified tonnage calculation¹, a generous and pessimistic approach would treat the *Nematon I* as a solid cube or block, rather than as a monohull with a bridge, a catamaran or a trimaran. This approach allows the dimensions to be defined simply as:

- Overall Length = $L = 58 \frac{5}{16}'' = 4.859$ feet
- Overall Breadth = $B = 62 \frac{1}{4}'' = 5.188$ feet
- Overall Depth = $D = 28 \frac{1}{4}'' + 24 \frac{1}{16}'' = 4.359$ feet

US Coast Guard calculations define a “shape factor”, which adjusts the tonnage based upon the profile of the vessel. The fullest shape factor is 0.84, which will maximize the volume used for tonnage calculations. The calculations also include a “keel factor”, which reduces the volume based on the size of the keel. As *Nematon I* has no keel, the factor is set here at 1.0.

This allows the calculation of hull volume in cubic feet and gross tonnage in Gross Register Tons (GRT) as follows:

Hull volume = $S \times K \times L \times B \times D$ (where L, B and D are in units of feet), where:

$$S = 0.84$$

$$K = 1.0$$

$$L = 4.859$$

$$B = 5.188$$

$$D = 4.359$$

$$\text{Hull volume} = 92.30 \text{ cubic feet}$$

$$\text{Gross Tonnage} = \text{Hull volume}/100$$

$$\text{Gross Tonnage} = 0.9230 \text{ GRT}$$

The gross tonnage of *Nematon I* is therefore 0.9230 GRT.

3.1.2 NET TONNAGE

Net tonnage is a simple adjustment to the gross tonnage. Net tonnage is calculated as:

$$\text{NRT} = \text{GRT} * M$$

¹ http://www.uscg.mil/hq/msc/tonnage/docs/TG-1_Current.pdf ; Simplified System Regulatory Measurement applies to watercraft under 79 feet in length.

The M, or machinery, factor is a unitless adjustment of value 0.8, 0.9, or 1.0 depending on whether the machinery is completely internal, partially internal, or completely external to the hull of the watercraft, respectively.

While the thrusters on the *Nematon I* will be outside the battery and electronics cylinders and the M factor would therefore be 0.8, a more pessimistic value is 1.0. This maximizes volume and would therefore be more likely to cause the watercraft to be designated a “documented vessel”:

$$\text{NRT} = \text{GRT} * \text{M} = 0.9230 * 1.0 = 0.9230 \text{ NRT}$$

Therefore, the most pessimistic (largest) net tonnage of *Nematon I* is 0.9230 NRT. As the US Coast Guard requires truncation, rather than rounding, of decimal values less than 1 for net tonnage², the US Coast Guard would actually define the net tonnage of *Nematon I* as 0 net register tons. As noted in Chapter 4, this means that the *Nematon I* is ineligible to be considered “documented” under US Coast Guard regulations.

3.2 CONTROL

The main control system on the *Nematon I* is the Arduino Mega 2560 printed circuit board³. All of the communication and sensor systems documented below will be connected to the Arduino Mega 2560 board. A modified version of the C programming language, called Wiring, is used for the software control system of the watercraft.

The craft has two basic modes of operation: direct remote control via radio link, and autonomous control with obstacle avoidance using GPS “waypoints” along a pre-determined course.

A solid-state drive will be used for data storage, including position, speed, video and still images, system states and environmental conditions

Commands can be relayed to, and information about the status of the craft sent from, the *Nematon I* using the communication systems described below in Section 3.6.

3.3 SENSORS

The sensors on board the *Nematon I* include:

- Internal temperature and humidity⁴
- External water temperature, depth, and acceleration/orientation⁵
- Location (GPS)⁶

² ibid

³ <http://arduino.cc/en/Main/ArduinoBoardMega2560>

⁴ <https://www.virtuabotix.com/product/virtuabotix-dht11-temperature-humidity-sensor/>

⁵ <http://store.openrov.com/products/openrov-imu-depth-module>

⁶ <http://www.dexterindustries.com/site/?product=gps-shield-arduino>

One or more cameras are being considered for addition to the design, for still image and short video recording.

3.4 PROPULSION

The *Nematon I* will be propelled through the water using three T100 ESC-enabled thrusters from Blue Robotics⁷. Two thrusters provide forward and reverse motion, plus turning capability. The third thruster enables diving. As the craft will be nearly neutral in buoyancy, all three thrusters must be operating to dive successfully.

3.5 POWER

The main power supply for the *Nematon I* thrusters and lights is a bank of 8 (eight) 12 V rechargeable batteries, stored in the two lower tubes shown in Figure 1 and Figure 2. A second set of two (2) 6 V batteries will be used for powering the processor, communication, and sensor systems. The batteries will be recharged via a pair of solar panels mounted to the top surface of the watercraft. The power system of the watercraft will enable it to operate for up to two days in any combination of these control modes without sunlight, assuming 17 hours of travel, 1 hour of diving operations and 6 hours of fixed-position “hovering” to capture available sunlight, per day.

3.6 COMMUNICATION

The *Nematon I* will feature several means of communication. The specific systems, and ranges (where known), are listed below:

- IEEE 802.11 wireless Ethernet (~100 feet)
- IEEE 802.15.4 “XBee”⁸ (less than 25 miles, line-of-sight)
- Cellular SMS using a GSM/GPRS Arduino shield⁹ (distance to closest cellular tower)
- Iridium satellite SMS using Rock 7 Mobile’s RockBLOCK+¹⁰ (worldwide)
- AIS, to enable tracking via Internet and to prevent collisions (distance to nearest AIS station)

These systems enable tracking of and communication with the watercraft using commercially-available Internet sites and applications, including Twitter and various AIS tracking sites.

Per US Coast Guard and FCC regulations, a VHF radio will also be installed on the *Nematon I*. As a result, an NMEA 2000 bus is under consideration as an internal “backbone” for the watercraft, which can be used to connect power, AIS equipment, VHF radio, and other internal systems. This will permit relay of messages received via VHF to be reransmitted using one of the other communication links.

Note that all of these methods, with the exception of AIS and VHF, permit direct transmission of commands to the *Nematon I*, including commands to proceed to new waypoints, report position and environmental information on demand, and even to control individual subsystems, such as

⁷ <https://www.bluerobotics.com/store/thrusters/t100-thruster/>

⁸ <http://www.digi.com/xbee/>

⁹ http://www.seeedstudio.com/wiki/GPRS_Shield_V1.0

¹⁰ <http://www.rock7mobile.com/products-rockblock-plus>

lights and individual thrusters.

3.7 SUPPORT SYSTEMS

Several other systems, not detailed here, will be required for the missions outlined for *Nematon I*. These include:

- Lights, both navigational and diving
- Emergency ballast release, in case of flooding
- Emergency automatic light beacon, on a separate power supply, should the watercraft become disabled
- Sonar and ultrasonic rangefinding, for surface and sub-surface obstacle avoidance

3.8 ADDITIONAL DESIGN INFORMATION

A significant amount of design information can be found online at the *Nematon I* blog, <http://stainlesssteelhead.mirmak.com>. Links to similar design projects from other hobbyists are available there.

4 LEGAL STATUS

This section provides an overview of the relevant US Federal and state (here, California) regulations governing watercraft. A brief analysis of these regulations will demonstrate that they do not, in fact, apply to the *Nematon I*. Specifically, it will be demonstrated that:

- Due to its small size (less than 1 net register ton), US Coast Guard “documentation” is not required for the *Nematon I*, even if it were considered a “vessel”
- California state regulations regarding numbering and registration only apply to “vessels” which are not documented by the US Coast Guard
- FCC regulations regarding watercraft, while much more precisely written than other parts of the US or California state code, still only apply to watercraft which are considered a “means of transportation”
- Because the *Nematon I* watercraft is not a “means of transportation” for cargo or people, it is not a “vessel” under US or California state regulations

4.1 US COAST GUARD REGULATIONS

The US Coast Guard is the governing authority in the United States regarding navigable waterways, including the rules of navigation upon them. In addition, the US Coast Guard has, as a statutory mission, ensuring marine safety, including setting the rules regarding certification and inspection of certain types of watercraft.

4.1.1 DEFINITION OF DOCUMENTATION

A key concept in both US and California state regulations is “documentation”. Documentation is required of a “vessel” under 46 CFR Volume 2, Chapter 1, Subchapter G if the “vessel” is at least five net tons in size. As specifically stated in § 67.9, “[a] vessel of less than five net tons is excluded from documentation.”¹¹ Per the discussion of the *Nematon I*’s actual dimensions and net

¹¹ The general section of 46 CFR may be found at:

<http://www.gpo.gov/fdsys/pkg/CFR-2001-title46-vol1/content-detail.html>.

The specific Subchapter G text may be read at:

<http://www.gpo.gov/fdsys/pkg/CFR-2001-title46-vol2/pdf/CFR-2001-title46-vol2-chapI-subchapG.pdf>.

The relevant text is shown below:

46 CFR Ch. 1
Subchapter G - Documentation and Measurement of Vessels
Part 67, Subpart A - General
§ 67.1 Purpose.

A Certificate of Documentation is required for the operation of a vessel in certain trades, serves as evidence of vessel nationality, and permits a vessel to be subject to preferred mortgages

§ 67.7 Vessels requiring documentation.

Any vessel of at least five net tons which engages in the fisheries on the navigable waters of the United States or in the Exclusive Economic Zone, Great Lakes trade, or coastwise trade, unless exempt under § 67.9(c), must have a Certificate of Documentation bearing a valid endorsement appropriate for the activity in which engaged.

tonnage in Design Assumptions, even if the *Nematon I* were considered a “vessel” (see below), it does not meet the key documentation requirement of 5 or more net tons under USCG regulations. This has an implication for California state regulations as well, as will be shown.

4.1.2 DEFINITION OF VESSEL

Both USCG and FCC regulations, as well as California state regulations, use the word “vessel”.

“Vessel” is defined in 33 CFR, Chapter I, Subchapter E, Part 83 to include “every description of water craft, including non-displacement craft, WIG [wing in ground] craft and seaplanes, used or capable of being used as a means of transportation on water.”¹²

The meaning of “vessel” in plain language is synonymous with “container”. In the context of both US Coast Guard regulations, as well as other Federal and California state regulations, “vessels” refer to craft that are “containers” for transporting cargo intended for trade (loaded and unloaded at different ports) and/or for people. Examples are readily available generally on the Internet as well as in the Code of Federal Regulations.¹³

§ 67.9 Vessels excluded from or exempt from documentation.

- (a) A vessel of less than five net tons is excluded from documentation.
- (b) A vessel which does not operate on the navigable waters of the United States or in the fisheries in the Exclusive Economic Zone is exempt from the requirement to have a Certificate of Documentation.
- (c) A non-self-propelled vessel, qualified to engage in the coastwise trade is exempt from the requirement to be documented with a coastwise endorsement when engaged in coastwise trade:
 - (1) Within a harbor;
 - (2) On the rivers or lakes (except the Great Lakes) of the United States; or
 - (3) On the internal waters or canals of any State.
- (d) A vessel exempt from the requirement to be documented by paragraph (b) or (c) of this section may be documented at the option of the owner, provided it meets the other requirements of this part.

¹² The specific text of 33 CFR, Chapter I, Subchapter E, Part 83 as quoted may be found at:

http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=44ea27a99044190570e727f6c928657a&n=pt33.1.83&r=PART&ty=HTML#se33.1.83_103

The relevant text is shown below:

33 CFR Ch. 1, Subchapter E – Inland Navigation Rules

Part 83, Subpart A - General

§83.03 General definitions (Rule 3)

For the purpose of these Rules and Subchapter E, except where the context otherwise requires:

- (a) The word vessel includes every description of water craft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transportation on water.

¹³ A specific example related to land vehicles and watercraft can be found at:

<http://www.gpo.gov/fdsys/pkg/CFR-2011-title49-vol2/pdf/CFR-2011-title49-vol2-sec171-8.pdf>

The relevant text is shown below:

49 CFR Ch. 1, Subtitle B – Other Regulations Relating to Transportation

Part 171

§171.8 Definitions and Abbreviations

As the *Nematon I* cannot transport people or cargo intended for trade, due to its size and design, it does not conform to the basic assumption of the word “vessel” as used by US Coast Guard regulations. Further, as will be seen, the same language defining “vessels” is used with few modifications in FCC and California state regulations. As a result, these regulations regarding “vessels” simply do not apply to the *Nematon I*.

4.2 CALIFORNIA STATE REGULATIONS

Watercraft in the state of California are regulated through the Department of Motor Vehicles (DMV) and the California Vehicle Code.

4.2.1 DEFINITION OF VESSEL

The language used for defining “vessel” in the California Vehicle Code is almost identical to that used in the US Code of Federal Regulations. Specifically, the Code states that the term “includes every description of watercraft used or capable of being used as a means of transportation on water”¹⁴, except a seaplane, a craft mechanically restricted to a permanent, fixed course, or a houseboat without its own means of propulsion.¹⁵

... *Transport vehicle* means a cargo-carrying vehicle such as an automobile, van, tractor, truck, semitrailer, tank car or rail car used for the transportation of cargo by any mode. Each cargo-carrying body (trailer, rail car, etc.) is a separate transport vehicle.

Transportation or *transport* means the movement of property and loading, unloading, or storage incidental to that movement. *Vessel* includes every description of watercraft, used or capable of being used as a means of transportation on the water.

¹⁴ The complete California Vehicle Code can be found at:

http://www.dmv.ca.gov/portal/wcm/connect/c3d57c91-d5e5-4af7-96d0-d9470b4262f3/veh_code.pdf?MOD=AJPERES

¹⁵ The specific text may be found at:

<https://www.dmv.ca.gov/portal/dmv/detail/pubs/vctop/vc/d3.5/c1/9840>

The relevant text is quoted below:

California Vehicle Code
Division 3.5 - Registration and Transfer of Vessel;
Chapter 1. General Provisions and Definitions

Section 9840 -Definitions

9840. As used in this division, unless the context clearly requires a different meaning:

(a) "Vessel" includes every description of watercraft used or capable of being used as a means of transportation on water, except the following:

(1) A seaplane on the water.

(2) A watercraft specifically designed to operate on a permanently fixed course, the movement of which is restricted to or guided on such permanently fixed course by means of a mechanical device on a fixed track or arm to which the watercraft is attached or by which the watercraft is controlled, or by means of a mechanical device attached to the watercraft itself.

(3) A floating structure which is designed and built to be used as a stationary waterborne residential dwelling, which (A) does not have and is not designed to have a mode of power of its own, (B) is dependent for utilities upon a continuous utility linkage to a source

4.2.2 DEFINITION OF DOCUMENTATION AND SIGNIFICANCE TO REGISTRATION

The California Vehicle Code applies to “undocumented vessels”, and requires that such vessels be numbered.¹⁶

The specific definition of “documented” refers to documentation issued by the “Bureau of Customs of the United States or any federal successor agency thereto.” At the present time, this Federal successor agency is the US Coast Guard, and the regulations regarding documentation are cited above.

Only undocumented vessels must be registered and numbered in California, in a manner similar to the registration and numbering of motor vehicles.¹⁷

4.3 FCC REGULATIONS

The FCC regulations relevant to watercraft use highly similar definitions to the other Federal and California state regulations cited above. Specifically, the FCC regulatory definitions under 47 CFR Chapter 1, Subchapter D, Part 80 state that “*Ship or vessel* includes every description of watercraft or other artificial contrivance, except aircraft, capable of being used as a means of transportation on water whether or not it is actually afloat” (italics in original).¹⁸

originating on shore, and (C) has a permanent, continuous hookup to a shoreside sewage system.

¹⁶ The relevant text is quoted below:

California Vehicle Code
Division 3.5 - Registration and Transfer of Vessel
Chapter 1. General Provisions and Definitions
Section 9840 -Definitions

g) "Undocumented vessel" means any vessel which is not required to have and does not have a valid marine document issued by the Bureau of Customs of the United States or any federal agency successor thereto.

¹⁷ The relevant text is quoted below:

California Vehicle Code
Division 3.5 - Registration and Transfer of Vessel
Chapter 2, Registration

9850. Every undocumented vessel using the waters or on the waters of this state shall be currently numbered. No person shall operate nor shall any county, city, or political subdivision give permission for the operation of any undocumented vessel on those waters unless the undocumented vessel is numbered in accordance with this chapter, or in accordance with applicable federal law, or in accordance with a federally approved numbering system of another state, and unless (1) the certificate of number issued to such undocumented vessel is in full force and effect, and (2) the identifying number set forth in the certificate of number is displayed on each side of the bow of the undocumented vessel for which the identifying number was issued. [errors in original]

¹⁸ The specific text can be found at:

http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=1&SID=8165bddd4aac38631341563667f4a4&ty=HTML&h=L&n=pt47.5.80&r=PART#se47.5.80_15

The relevant text is cited below:

4.4 CONCLUSIONS REGARDING REGULATIONS

While the author is not an attorney, a reading of the plan language of the relevant regulations, in context, leads to the following conclusions:

- US Coast Guard regulations exempt a watercraft the size of the *Nematon I* from documentation requirements, meaning that the watercraft cannot be considered a “documented vessel”.
- California regulations regarding registration and numbering apply only to “undocumented vessels”.
- Both Federal and California state regulations define a “vessel” as a “means of transportation” on water.
- The context of the regulations implies generally, and states in several locations specifically, that “means of transportation” applies to movement of persons or cargo intended for trade. As the *Nematon I* cannot serve as a “means of transportation” for persons or cargo intended for trade, it cannot be considered a “vessel” under Federal or California state regulations.

47 CFR, Chapter 1, Subchapter D, Part 80 - Stations in the Maritime Service

Subpart A - General Information

§80.5 Definitions.

Ship or vessel. *Ship or vessel* includes every description of watercraft or other artificial contrivance, except aircraft, capable of being used as a means of transportation on water whether or not it is actually afloat.

5 GENERAL CONCLUSIONS

As requested by the Federal Communications Commission, this document has explained the size, purpose, missions, control and design details, and regulatory issues (including registration and documentation) related to the *Nematon I* watercraft.

To summarize, the *Nematon I* is designed to help demonstrate and develop design, construction, and operation techniques appropriate for autonomous watercraft, within the capabilities of individual hobbyists. Its intended purpose will require it to communicate both with US domestic and foreign ports. To ensure safety for other watercraft in its vicinity, appropriate FCC licensing, including that required for AIS operation, is requested. As it is not a “vessel” under the conventional or regulatory definition of the term, it is exempt from “documentation” and other Federal and California state registration requirements. However, to enable it to alert surrounding ship and shore stations to its presence and prevent it becoming a hazard to navigation, it should be eligible to use AIS equipment while operating.

Low-cost electronic and manufacturing technologies, including compact and powerful communication and computing devices, are proliferating. These, combined with 3-D printing techniques, and the burgeoning “Maker” community, suggest that the *Nematon I* will not be the first or only watercraft of its kind. Should licensing for AIS equipment by *Nematon I* be denied, the Commission may be setting a precedent for the rest of the appropriate regulatory authorities related to watercraft. In that case, either the regulations permit the large-scale operation of autonomous watercraft without any communication devices at all, or self-propelled objects as small as a child’s toy boat will be effectively defined as “vessels” subject to regulation. As neither would be in the interests of the public, the author respectfully requests an affirmative ruling on the *Nematon I* licensing request, as well as a larger effort by the Commission and related authorities to define the “rules of the road” for such watercraft in the future.