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5 April 1935 NRL Report No. M-1144

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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Progress Report

on

Development of Exothermic Torpedo

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 14 Plates - 3 Tables - 1

Authorization: BuOrd Project Order 5037-Ord., and Bu.Ord.let.NP14(9)(R1) of 7 July 1934.

Dates of Test: 23 January 1934 to 28 March 1935.

Prepared by: Robert H. Canfield, Assoc.Physicist

Reviewed by: Homer Ambrose, Lieutenant, USN.

Approved by: H.R.Greenlee, Capt.,USN, Director.

Distribution:
BuOrd (5)
BuEng (1)

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APPENDIX

ABSTRACT

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The experiments reported here deal with the use of hydrogen peroxide (Navol) as a source of oxygen in torpedo power plants. Preliminary calculations indicated that it would be possible to replace air entirely by Navol, if a solution of about 45 percent concentration could be obtained. Forty runs on a reaction stand have been made, first using 30 percent Navol with air; and, later, higher percentages, up to 60 percent, of Navol alone, without auxiliary air supply. Nozzle temperatures of 1400°F and pressures of 450 pounds have been attained without the use of air, and with solutions of about the predicted strength.

Several different catalytic agents for the decomposition of Navol prior to its entry into the combustion zone have been studied — it having been found that this prior decomposition is essential to a successful start. A satisfactory agent is a solution of potassium permanganate, and the amount necessary is small. A combustion pot of the type used in the oxygen torpedo has been found satisfactory.

Studies have been made of storage tank materials which will not accelerate decomposition of Navol. Plain 13 percent chromium, and 18-8 stainless steels appear the best. Chrome plate is satisfactory.

A method of concentrating 30% Navol to strengths of 45 to 60 percent has been worked out and is in use. Limited supply of high strength Navol is the greatest difficulty in pursuing the experiments.

Plans for applying this power plant to a complete torpedo are discussed.

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AUTHORIZATION

1. This investigation was authorized by references (a) and (b). Other references pertinent to this report are listed from (c) to (g).

Reference: (a) Bu.Ord. Project Order 5037-Ord.
(b) Bu.Ord. let. NP14(9)(R1) of 7 July 1934.
(c) History and Status of Torpedo Research at Naval Research Laboratory enclosed with NRL let. C-S73-1/S75-1(90) of 8 May 1930.
(d) Survey of Torpedo Propellants, NRL let. S-S75-1(63) of 31 January 1931.
(e) NRL let. S-S75-1 of 6 July 1932.
(f) Report of Exothermic Torpedo, NRL let. S-S73-1/S75-1(90) of 30 August 1932.
(g) Report of Exothermic Torpedo, NRL let. S-S75-1(112) of 3 June 1933.

OBJECT OF INVESTIGATION

2. The object of this investigation is to improve the performance (i.e. range or speed) of torpedoes, without increasing the weight or displacement of the air flask and afterbody. In this project, too, it is assumed that the gyro, steering and depth engines are to be left substantially as at present, and that no change in the working temperature and pressure of the propulsive gases is to be made. It is presumed that the increased performance is to be accomplished by substituting some chemical substance for the air ordinarily used to support combustion. Subsidiary objectives are, therefore: (a) to find such a chemical oxygen supply as will be easy and safe to transport, will withstand the rigorous temperatures both of the tropics and of northern winter seas, and will be obtainable in requisite quantities in the United States; and (b) to eliminate as far as possible such exhaust gases as are insoluble in water, thereby eliminating the wake of the torpedo. The chemical agent discussed in this report is hydrogen peroxide (Navol). The chemical formula of this substance is H_2O_2. It decomposes, with the evolution of heat, to form water (H_2O) and oxygen (O).

KNOWN FACTS BEARING ON THE PROBLEM

General Information Regarding Hydrogen Peroxide (Navol)

3. The production of H_2O_2 (30%) in the United States runs to probably 5,000 tons per year, of which the Roessler and Haslacher Company, a DuPont subsidiary, produces more than half; the Buffalo Electrochemical Company is its largest competitor, and other production is negligible. Both firms use large scale electrolytic methods, followed by rectification, and their equipment is not readily changeable to produce other strengths. The pharmaceutical (3%) solution is produced by other firms and by the decomposition of barium peroxide. Up to two years ago a certain amount of 30% solution was imported. Over half of the peroxide production is used for bleaching in the textile industry, the remainder in the manufacture of other chemical products.

4. The Roessler and Haslacher Company has no experience in producing or storing solutions as strong as 50%, their highest having been 34%. Each increase in strength creates a new problem in stabilization. Their methods of stabilization are secret, but the fact was elicited that they do not depend on any organic stabilizer, and the opinion of the Laboratory is that the main

factor is high purity, except for a definite trace of acid (say 1 part in 100,000). Mr. White, a high official of this firm, says his company would undertake to furnish stable 50% solutions were there a demand amounting to 200 to 400 tons in one contract.

5. There appears to be only one hazard associated with the handling of peroxide: if spilled on paper or wood, the water evaporates and the residual peroxide may ignite the material. There is an instance of a freight car fire due to this cause. In contact with the body the substance (30% produces a white burn of the outer surface of the skin, but apparently causes no great pain or infection. Dirt, or especially pieces of metal, falling into containers may cause rapid, but not violent, decomposition. The Interstate Commerce Commission's shipping regulations for this solution are similar to those for acids. There have been no serious accidents at the Roessler & Haslacher plant in handling this product.

6. The bulk of the 30% peroxide is stored and shipped either in standard 12 gallon glass carboys as used for acids, or in aluminum drums holding 250 pounds (about 27 gallons). The aluminum containers are specially treated by a secret process to prevent decomposition of the product. Both types of containers are vented to allow escape of oxygen — the glass carboys by pierced porcelain stoppers, the aluminum drums by a specially devised metal cap. In both cases the loss of strength, even at summer temperatures, does not exceed 0.1 to 0.2% per month, but the Roessler and Haslacher Company regards this as a great accomplishment and guards its secrets of stabilization from everyone. Mr. White thinks that stainless steel containers could be made to work, but is certain that most other metals would decompose the product. It has been shipped in aluminum tank cars in large quantities. The Roessler and Haslacher Company would give an aluminum container furnished by this Laboratory special treatment, but withholds information about the treatment.

7. The 30% solution may be purchased in quantity for 18 to 19 cents per pound f.o.b. Niagara Falls. Mr. White estimates that the 50% solution could be sold for 35 cents per pound in orders of around 100 tons, which would allow some money for experiments in stabilization, changeover of plant, etc. He considers that they might make up a 1,000 pound order for $1.00 per pound on the chance of its proving to be the forerunner of larger orders. The Roessler and Haslacher Company later (May 1934) submitted a quotation of 90 cents per pound for a 1200 pound lot of 50% Navol.

8. The question as to whether a 50% solution will be required to produce a worthwhile gain in torpedo efficiency is now thoroughly settled by results given later in this report. It is to be noted that even at 18 cents per pound for 30% solution, oxygen from this source costs $1.30 per pound as compared with 15 cents per pound for oxygen gas purchased in tanks. Other considerations, however, outweigh that of cost.

9. An inquiry addressed to the Interstate Commerce Commission elicited the statement that shipment of peroxide is considered no more hazardous than that of strong acids, and is governed by the same regulations.

10. Since one of the troubles with strong ammonium nitrate solutions was the fact that at low temperatures part of the salt would crystallize, it is interesting to examine the behavior of strong Navol solutions under like conditions. Plate 1 is the freezing point-composition curve as determined by

Maas and Herzberg (Journal of American Chemical Society, Vol. 42, page 2569) for mixtures of Navol and water. It will be seen that a 50% solution does not commence to freeze until a temperature of about 58°F **below zero** is reached.

11. Another important fact to which Navol owes its great promise is that of the heat developed when it decomposes into water and oxygen. The heat balance given in paragraph 12 shows that this heat of decomposition alone is sufficient to raise the temperature of a strong solution over 100°C and plays a considerable part in making up the total energy. Results given later in this report substantiate the expected gain, since more energy is obtained from oxygen combined as Navol than has **ever** been obtained from the same quantity of gaseous oxygen. It is this property which justifies the term "exothermic" as applied to this power plant.

THEORETICAL CONSIDERATIONS

Calculation of Percentage Navol Required

12. Before starting any experimental work, calculations similar to those made for other proposed power sources, ref. (d), were carried out. Thermodynamic calculations of this type have little claim to absolute accuracy, but the method used was designed to keep close to actual conditions in the following way. The actual consumptions of fuel, water, and air in a Mark VIII torpedo were used as data for calculating the theoretical flame temperature, which turned out to be 1830°F. Since the true nozzle temperature is about 1400°, the 430° difference between actual and theoretical temperature represents in a lump the heat losses from conduction, the failure of complete combustion, and so on. If, therefore, we calculate any other kind of power supply so as to get a theoretical flame temperature of 1830°F, we will probably not come far from getting an actual temperature of 1400°F. It is the above method that is used in the following calculations. Only the main assumptions are presented in detail, and the only calculation presented is that based on the assumption that all the oxygen for burning fuel is supplied by Navol.

CALCULATIONS ON THE USE OF NAVAL IN EXOTHERMIC TORPEDOES

(a) Numerical data used as basis for calculations:

Heats of formation in calories per gm-molecule

Gaseous CO_2 from carbon and gaseous O_2	-	97,000
Liquid H_2O from gaseous H_2 and O_2	-	69,000
Liquid Navol from gaseous elements	-	47,000
Liquid C_2H_5OH from carbon and gases	-	70,000

Heats of solution	-	neglected
Work of compression	-	neglected
Heat to evaporate water from 0°C to 220°C, 336 psi	-	12,100
Molecular specific heat (constant pressure) for all gases		9.2

(b) Further assumptions:

That alcohol is completely burned, i.e. to H_2O and CO_2
That excess alcohol can be neglected.

(c) Calculation based on one gm-mol of C_2H_5OH:

Heat Balance

Reactions

$$\begin{cases} C_2H_6O + 3O_2 = 2CO_2 + 3H_2O \\ 6H_2O_2 = 6H_2 + 6O_2 = 6H_2O + 3O_2 \end{cases}$$

		Gain Calories	Loss Calories
Part 1.	Decomposition of Navol		
	$6H_2O_2 = 6H_2 + 6O_2$ (as gases)		282,000
	$6H_2 + 6O_2 = 6H_2O + 3O_2$ (liq. and gas)	414,000	
Part 2.	Combustion of fuel		
	$C_2H_6O = 2C + 3H_2 + 1/2O_2$		70,000
	$2C + 2O_2 = 2CO_2$ (gas)	194,000	
	$3H_2 + 3/2O_2 = 3H_2O$	207,000	
Part 3.	Heating products to 220°C (336 psi)		
	(Let x = additional mols of H_2O)		
	Evaporating 9 + x mols H_2O at 220°		109,000 + 12,100 x
	Raising $2CO_2$ to 220°C		4,000
	Totals	815,000	465,000 + 12,100 x

Net gain = 350,000 - 12,100 x

Part 4. Heating all products as gases to 1000°C (1832°F)

$9H_2O + x\ H_2O + 2CO_2 = 11 + x$ mols

requires (1000 - 220) x 9.2 x (11 + x)
= 78900 + 7170x calories

Equating: 350,000 - 12100 x = 78900 + 7170x
19270x = 271,100
x = 14.1
14.1 molx H_2O = 263 grams

1 mol 95% alcohol carries with it 3 grams water
Leaves 260 grams water for diluting Navol
6 mols Navol = 204 grams
Total weight of solution = 464 grams [redacted]
Percentage Na[redacted] by weight = 44%

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19. Early in 1934 it was decided to abandon work on the ammonium nitrate power plant and take up the very promising, if expensive, agent hydrogen peroxide, which is termed Navol in the body of this report and in most correspondence.

20. The following preliminary steps were taken: (a) The calculations, part of which are quoted in paragraph 12, were made. (b) An interview was had by two of the Laboratory staff with Mr. L.H. White of the Roessler and Haslacher Division of the E.I. DuPont de Nemours Chemical Company, which brought out many of the facts listed in paragraphs 3 to 10, inclusive. (c) A search was made of the literature to obtain the published knowledge of the chemical behavior and characteristics of this substance. (d) Some preliminary experiments on combustion of fuel with the agent in glass apparatus were made, but it was found that these had little value.

21. However, since all the information indicated that a successful outcome could be hoped for, it was decided to undertake reaction-stand experiments, but on as small a scale as practicable in order to conserve Navol. At this time, 30% Navol in one pound glass bottles was the only available supply. Later the substance was purchased in 250 pound drums and rectified to the required strength in apparatus built at the Laboratory.

22. Early suggestions for the use of Navol contemplated its injection into a flame already started in air, later shutting off the supply of the latter and depending on the high temperature of the combustion zone to decompose the Navol.

23. It may be proper to anticipate later paragraphs and state that no real success was achieved in the use of the above scheme. If possible at all, it demands an accuracy in adjusting the rates of delivery of all constituents and likewise in timing the attempted changeover, which renders it entirely impracticable. The first really promixing results were obtained with the scheme, originated by Dr. R.H. Canfield, the author of this report, of predecomposing the Navol by means of a catalyst and having it enter the combustion zone in the form of oxygen and water.

DESCRIPTION OF APPARATUS AND METHODS

24. The principal piece of apparatus used in this work is, of course, the reaction stand. The one used in these experiments is almost precisely the same as the one already described and pictured in the report on the ammonium nitrate experiments, ref.(e), and will be only briefly described here.

25. It consists of a heavy platform resting on casters so that it can be moved outdoors when ready for a run. On the platform stand are four weighing scales with visible dials. These support respectively the air flasks (ordinary oxygen tanks), the Navol tanks (stainless steel containers), the fuel flask, and the combustion pot. The latter is fastened inside a heavy brass box filled with water. The combustion pot is connected to a Mark VIII - 4 nozzle plate so arranged that the nozzles point upward as nearly vertical as possible. Necessary connections between the various flasks and the pot are provided by copper tubing with enough flexibility not to disturb the scale readings. Lines conveying Navol are of stainless steel with fittings of the same material. When a liquid catalyst is used, it is stored in a stainless

steel container fastened to the main platform, and the consumption is determined by weighing the liquid before and after the run. The usual pressure gauges, clock, and pyrometer are mounted on a board above and to the rear of the other apparatus, so that during runs records of all significant data can be made by photography.

26. When the combustion pot is in operation, the jets of steam issuing from the nozzles produce a reaction which results in an increase of weight on the scale supporting the pot. From this reaction and from the known weights of constituents introduced into the pot, and hence issuing from the nozzles in one minute, the horsepower is calculated from the well known formula:

$$hp = \frac{1.76\ R^2}{w}$$

where R stands for the jet reaction in pounds and w for the total weight of all substances entering the pot in pounds per minute.

27. In most of the present experiments, since the available quantities of Navol were small and the runs necessarily short (of the order of two minutes), the rates of consumption of all constituents were determined by accurate weighings prior to and after the run.

EXPERIMENTS

Early Reaction Stand Runs.

28. Because the preliminary studies outlined in paragraph 12 showed that Navol solutions of about 45% concentration merited investigation, experiments on the reaction stand were commenced on 23 January 1934 (run 139).

29. The early runs demonstrated that good results could be obtained only if the Navol was decomposed into oxygen and water prior to entering the combustion zone. Fortunately, there are several substances which act as catalysts for the spontaneous (exothermic) decomposition of this unstable compound. Parallel with the reaction stand runs using the combustion pot, tests were made in the chemical laboratory to discover the most desirable catalysts, and each new development in the latter investigation received a trial in the power plant laboratory.

30. A tabular synopsis of the runs is given in Table 1. It is necessary to discuss results in giving this summary, since each change in results occasioned a change in procedure.

31. **Runs 139 to 145.** These consisted of preliminary experiments in which the burning mixture consisted of fuel, air and either pure water or a 30% Navol solution, without a catalyst. Runs 139 to 141 were made with water instead of Navol. A comparison of these with the Navol runs (142 to 145) demonstrates the superiority of the latter. The results showed, however, that full use could not be made of the oxygen in the Navol, much of the latter leaving the nozzle while still undecomposed. In addition, the use of <u>any air atall</u> for combustion is a compromise with the "wakeless" requirement of the torpedo and should be adopted only as a last resort. Catalytic decomposition of the Navol was then resorted to for all subsequent runs.

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32. Runs 146 to 148. Sold Contact Catalysts. In these runs, use was made of a palladinized pumice, a material which experiment had shown to decompose Navol rapidly. This material, in the form of small granules, was packed in the Navol sprayer just behind the orifice. (At this time, a combustion pot was being used which had conventional sprayers for Navol and fuel.) This quantity of catalyst proved ineffective.

33. From here on, 50% solutions of Navol were used, a vacuum rectifying still having been built and put in operation for concentrating 30% Navol to a strength of 50% or stronger.

34. Runs 149 to 151. Using Old Oxygen Combustion Pot. In these runs, another combustion pot was used; in fact, the same pot that had been used in the oxygen torpedo during tank runs was used. This pot is sketched in Plate 2. Since decomposed Navol consists of oxygen and water, it is logical to expect that a combustion pot which had proved efficient for oxygen should likewise prove efficient for Navol. In fact, this proved to be the case, and this same pot has been used for all runs from that time until the present. In the case of runs 149 to 151, the space B outside the inner liner was packed with the same granular catalyst as in the three previous runs, thus greatly increasing the amount of the catalyst. However, these runs were not successful and the Navol was decomposed only to the extent of about 25% of its oxygen.

The Decomposition of Navol

35. Because experience had shown the ineffectiveness of a solid (surface) catalyst, effort was then directed toward finding a liquid catalyst which could be injected into the Navol stream as it entered the combustion pot. The first such solution which seemed satisfactorily active was a colloidal solution of cobalt oxide in ammonia and ammonium chloride. Here it may be mentioned that all of the substances most active in decomposing Navol were found to be either already in a colloidal state or to form temporary colloids on contact with the Navol. For example, the following are very active:

Copper ammonium salts (temporary colloid probably cuprous oxide).
Argyrol (permanent colloidal silver).
Potassium permanganate (temporary colloid manganese dioxide).

36. The activity of a substance in catalyzing this decomposition seems to be in proportion to its degree of dispersion; thus, all metals when finely dispersed, like platinum black or palladium black, produce the effect. On a bright metal surface decomposition takes place at the edges of scratches. Even glass, where broken edges are exposed, promotes decomposition. Any small particles, such as dust, which have fallen into the solution, are centers of decomposition.

37. On the other hand, most true, or crystalloid, solutions are inactive. For instance, alcohol may be mixed with Navol without any action taking place. Indeed, the majority even of colloids, such as ferric hydroxide, gelatine, etc., are also without effect.

38. Experiments were made to find which metals could be used for containers. Without detailing the experiments, the least active metals were found to be stainless steel and chrome plate. On the other hand, any alloy containing copper is extremely [redacted]nel metal falls in this

[redacted]

category. All aluminum and magnesium alloys tested were found to be quite active. Lead is extremely active. Cadmium and zinc are medium in their effects. Tin (pure) is fairly inactive.

39. Of all the catalyst solutions tested, the cobalt oxide solution, when properly prepared, was the most active. Added to a 50% Navol solution in the amount of 1/15th the volume of the latter, the cobalt catalyst produces complete and almost explosive decomposition in one to two seconds.

Reaction-Stand Runs Continued

40. Runs 152 to 166. Cobalt Oxide Catalyst. In these runs, the catalyst solution was injected into the Navol solution just as it entered the water-jacket space B, Plate 2, surrounding the interior of the pot, the object of which was to decompose the solution so that by the time it entered through the holes in the conical baffle or dome C, it would consist of oxygen plus water plus steam (plus a small quantity of sludge from the catalyst). In this way, the heat of decomposition of the Navol is largely conserved, and the combustion zone itself is effectively water-jacketed. The heat exchange accomplished in this manner is almost ideal, and its effect is visible in the greatly increased efficiency of these runs.

41. The only drawback to the cobalt solution was found to be a tendency to crystallize and stop up the tiny (#80 drill) orifice by which its delivery was regulated. There is also a tendency for the cobalt solution to become inactive on standing, through causes which have not been determined. Under good conditions, the runs were highly satisfactory. Clear dry steam was produced. Run 164, for example, yielded an oxygen efficiency of 1,430,000 foot pounds per pound of oxygen. This efficiency is much higher than ever was obtained at this Laboratory with gaseous oxygen, where an efficiency of about 1,000,000 was the highest ever reached.

42. Runs 167 to 178. Permanganate Catalyst. It had been discovered meanwhile that a 6% solution of potassium permanganate acted as an extremely active catalyst for the decomposition of Naval and was free from the tendency to crystallize which characterizes the cobalt solution. Furthermore, it maintains its activity in storage. On admixture with Navol, it produces an immediate and complete decomposition, the effective agent being manganese dioxide in colloidal form produced on contact with Navol. This colloid almost immediately flocculates into much larger particles which are almost inactive. In the combustion pot, these particles are driven forward with the hot gases, escaping with them through the nozzle in an invisible smoke. Later on, sodium permanganate was found to be equally active, and to have the advantage of being more soluble.

43. All of runs 167 to 181 were made with this catalyst, all but two of the runs being hot and successful. Beginning with run 137, both nozzles were wide open so that the pot could develop full power. As will be noticed, the overall efficiency and the oxygen efficiency of the later runs were very high, and run 178 was ideal in every respect. This last run demonstrates fully the successful use of Navol with a catalyst, and shows that as far as the question of obtaining good combustion is concerned, the problem is solved.

Rectification of Navol in the Laboratory.

44. Mention has already been made of the necessity of "rectifying" or increasing the strength of the commercial "30%" Navol to the "55%" strength needed for these runs. Inquiry had elicited an offer of 1200 pounds of "52%" Navol at a cost of 90 cents per pound; but it was deemed economical, for the preliminary experiments at least, to rectify the weaker solution in the Laboratory, since the "30%" solution costs only 18 or 19 cents per pound. One reason for this procedure was that it would give complete control over concentration, even up to 70%, if necessary. Another was that the experience gained in the actual handling of the material would be of value. Both of these reasons were perfectly valid at the time this course was adopted.

45. Results of runs have now shown that a "55%" (actual weight percentage 45%) solution is the correct one. It has been impracticable to make a laboratory rectifying still to produce more than 8 or 9 pounds per day without going to unjustifiable expense. Both vacuum distillation and air distillation have been tried. The former having been found the more efficient, the apparatus will be briefly described: A pyrex glass tube about 4" diameter and 36" long is sealed off at both ends. At one end, a 1/2" tube is sealed on and connected to three water aspirators in parallel, which produce the necessary vacuum. At the other end is a small inlet tube closed with a glass stopper. Through this tube the 30% Navol is introduced, and through it, after rectification, the concentrated Navol is withdrawn. The whole flask lies on its side and is about half filled with Navol, thereby exposing a large surface for evaporation. It is surrounded by a water bath maintained at a temperature of 155°F. In this still a 9 pound charge can be rectified to 55% in 7 hours. Naturally, this equipment is useless for large scale preparation of the solution.

CONCLUSIONS AND RECOMMENDATIONS

Discussion of Results

46. Runs 156, 158, 161, 162, and 164 demonstrate that Navol can be used successfully to obtain nearly theoretical efficiencies at various temperatures and at the pressures necessary in torpedo engines. This really settles the question of its effectiveness. However, these runs utilized the cobalt oxide catalyst; and the objectionable tendency of this material to crystallize and to deteriorate remained as a difficulty.

47. Runs 176 to 181, inclusive, were made with a permanganate catalyst, and show good performance at a number of temperatures.

48. The question of temperature is an important one. Due to causes familiar to those who deal with torpedoes, individual runs are apt to deviate to a certain extent in rates of delivery of different constituents and therefore in temperature. If the efficiency drops off very suddenly below a certain temperature, there is risk of a very bad run or even of a cold shot and a lost torpedo. The fact that good runs can be secured with Navol at widely different temperatures and ratios of constituents is, therefore, very favorable.

Efficiencies

49. It has been customary to use the "air-efficiency", i.e., the foot pound of energy per pound of air, as a criterion of torpedo power plant per-

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formance. In the Navol power plant, air efficiency means nothing, for the air consumed is merely that which is necessary to displace the liquids taking part in the combustion.

50. After some consideration, it has been decided to record two kinds of efficiency for this power plant. The "oxygen efficiency" is the foot pound of energy per pound of available oxygen contained in the Navol entering the pot. This gives an idea of the extent to which the available energy is being utilized. The "overall efficiency" is the foot pound of energy per pound of all constituents entering the pot.

51. The only true gauge of efficiency in comparing a variety of torpedo power plants is one that would take account not only of the weights of constituent materials, but also the weight of the various thicknesses of steel shell necessary to confine them. This computation is tedious and has not been used in this report.

Correct Proportions of Reacting Liquids

52. Final results of these experiments verified quite accurately the preliminary calculation of the necessary strength of Navol solution. Runs made with 30% Navol were definitely deficient in oxygen- and overall-efficiency. Several of the runs with 55% (actually 46% by weight) gave temperatures and efficiencies in the expected range.

53. It will be noticed in runs 179 and 180 that the amount of catalyst (6% potassium permanganate) which gives good results is about 1/12 to 1/15 that of the Navol. Later experiments may make it possible to decrease this proportion. Naturally, the water added as solvent for the catalyst acts to decrease materially the effective strength of the Navol. Experiments are now under way on the use of <u>sodium</u> permanganate, a substance having a much greater solubility than the potassium salt, and which can therefore be used in more concentrated solutions.

54. The drawback to the use of concentrated solutions of catalyst (and this applies as well to very concentrated fuels) is that since the delivery of these liquids is governed by passing them through small orifices, the exact dimensions of the latter will be hard to maintain should the quantities delivered become too small.

55. In the air torpedo it is customary to use about one-third more alcohol than is required for theoretically complete combustion. This mixture has been found to give a maximum of uniformity, combined with high efficiency and little smoke. In the Navol power plant, the fuel should, on the basis of complete combustion, be about 1/8 the amount, by weight, of 55% Navol solution. Here, again, it is found that this mixture gives unsatisfactory runs (runs 157 and 159) as compared with richer mixtures. For instance, the best runs seem to be with ratios of between 3 and 6 to one. The ideal mixture appears to be:

Fuel = 1; 55% Navol = 4.5; 6% Catalyst = 0.3.

Plans and Recommendations for Future Work

56. At present, [redacted]inuing experiments on the reaction stand with the idea of determining whether a more concentrated catalyst may be

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used, and also with the purpose of obtaining the most accurate possible knowledge of correct proportions. Metals for storage and piping are also under test.

57. It is believed that the Bureau will concur with the Laboratory's conclusion that this power plant has reached a stage where it should be installed in a torpedo and tested on the range at Newport.

58. A representative of the Laboratory visited the Newport Torpedo Station on 20 February 1935 and discussed with officers and engineers of that station the feasibility of this project and the best type of torpedo to which to apply it. There are two courses open in such a project: (1) Attempt immediately to attain the utmost limit in increased range (or speed); or (2) aim for a significant (say 75%) increase in energy, demonstrating the reserve potentialities of the plant by leaving spare space (to be occupied by ballast, etc.) forward of the air flask. The latter proposal is deemed the more practicable in the range trials for the following reasons:

(1) The ballast space will be of value in permitting considerable leeway in adjusting the trim and buoyancy of the torpedo.

(2) The required quantities of Navol will be smaller. This item is of importance when the present high quoted price for 55% Navol is considered.

(3) A greatly increased range would require provision of greatly increased stowage space for lubricating oil — not an easy matter in a crowded afterbody. A great speed increase involves even more troublesome engineering changes than does the range increase.

Remembering always that the present proposal means only a range trial — not a final torpedo design — it is considered that the best torpedo for testing this power plant is the Mark X-3, for the following reasons:

(1) The Mark X-3 is a submarine torpedo of which a large number are being withdrawn from service.

(2) It has a short air flask and a short range — the amount of Navol per charge will be small.

(3) It provides ample space in the afterbody for 75% additional lubricating oil.

(4) Its running characteristics are well known and are good.

(5) A suitable flask can be made out of a stock of forgings now on hand at Newport.

59. It is believed that a Mark X-3 torpedo can be modified and tested with the following changes: a completely new air flask; modified or new reducing valve to handle the very small trickle of air now to be drawn from the air flask; additional saddle-shaped oil compartment in afterbody.

60. The Newport Torpedo Station has a number of specially thickened air flask forgings from which special Navol air flasks can be constructed.

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61. If the Bureau approves this recommendation or decides to select an alternative type of torpedo for range trial, the Laboratory requests to be notified of this fact and to be furnished with an afterbody and air flask of the type selected. Using these as a basis, the Laboratory will design and build a suitable combustion pot, adapting it to the nozzle plate of the given torpedo, and proceed with further reaction stand runs in order to ascertain the necessary adjustments to secure proper performance.

62. At the same time, the Bureau is requested to authorize the Newport Torpedo Station to design and turn out of the forgings on hand there either one, or preferably two, air flasks. The Laboratory will furnish data on the necessary space required in the various compartments. The Torpedo Station should also select or design a suitable reducing valve, and design and build the proper additional oil-storage compartment and install it, or them, in afterbodies.

63. When these items are finished, they can be assembled and dynamometer tank runs made either at Newport or at this Laboratory. The Laboratory is equipped with a Mark I dynamometer capable of handling 160 horsepower, which is about the rated power of the Mark X-3 torpedo.

64. Satisfactory performance in the tank having been secured, range trials should be made at Newport. With energetic action, this may be hoped for in the fall of 1935.

65. The principal impediment to rapid prosecution of this work is the lack of a large supply of Navol of 50 to 55% concentration. The Bureau is requested to make a suitable allotment of funds and authorize the Laboratory to invite bids on a supply of 2000 or preferably 3000 pounds of 55% Navol, to be delivered in about 1000 pound lots on order. It is believed that framing the contract in this way will enable a better price to be secured.

Comparison of Navol Air Flask and Mark VIII Air Flask

66. Plate 3 illustrates in graphic form the distribution of materials in a Mark VIII-4 and in a hypothetical Navol air flask having the same weight and displacement. The principal feature to be noticed is that the space occupied by necessary constituents in the Navol torpedo is so small that empty space must be provided, either forward or elsewhere, to furnish the displacement necessary for buoyancy. Of course, an alternative design would be to enlarge the high pressure air storage section to occupy the whole available space, at the same time charging it to a lower pressure, and at the same time using a thinner wall. This procedure would, of course, involve additional useless air charge, the amount represented by 500 pounds pressure; but as a practical solution, it might be well justified. The Mark VIII-4 was selected as an example for comparison merely because the information was on hand at this Laboratory.

67. It will be noted that the available foot pounds of energy in this air flask is nearly three times that which is carried by the Mark VIII-4 at the same buoyancy.

[redacted]

[redacted]

Naval Application of the Navol Torpedo

68. The oxygen torpedo has already demonstrated at Newport that the expected freedom from wake is realized; there is no reason to believe the Navol Torpedo will be otherwise. The latter offers the great additional advantage that there is air available with which to operate the gyro and other auxiliaries. The only difficulty with the oxygen torpedo is that of operating auxiliaries for any length of time, either on gaseous oxygen or on steam.

69. The question of how the very great additional energy provided by this power plant can best be utilized is one for determination by others. There is little doubt, however, that it promises to make a very valuable weapon.

70. The actual stowage space on shipboard required for Navol is only about a quarter greater than for the amount of fresh water which would be used in developing the same energy in any torpedo. Thus, it offers no great stowage problems in vessels which already carry fresh water for torpedoes.

71. Information available indicates that Navol, even of the strength required here, can be stowed in suitable containers for months without significant deterioration. In the service it will undoubtedly be necessary to furnish it at somewhat above the needed strength and dilute with fresh water if necessary (or dilute the catalyst) to bring the "make-up" to the proper proportion.

72. Supply and stowage of the permanganate catalyst presents no problems which can be foreseen at present.

[redacted]

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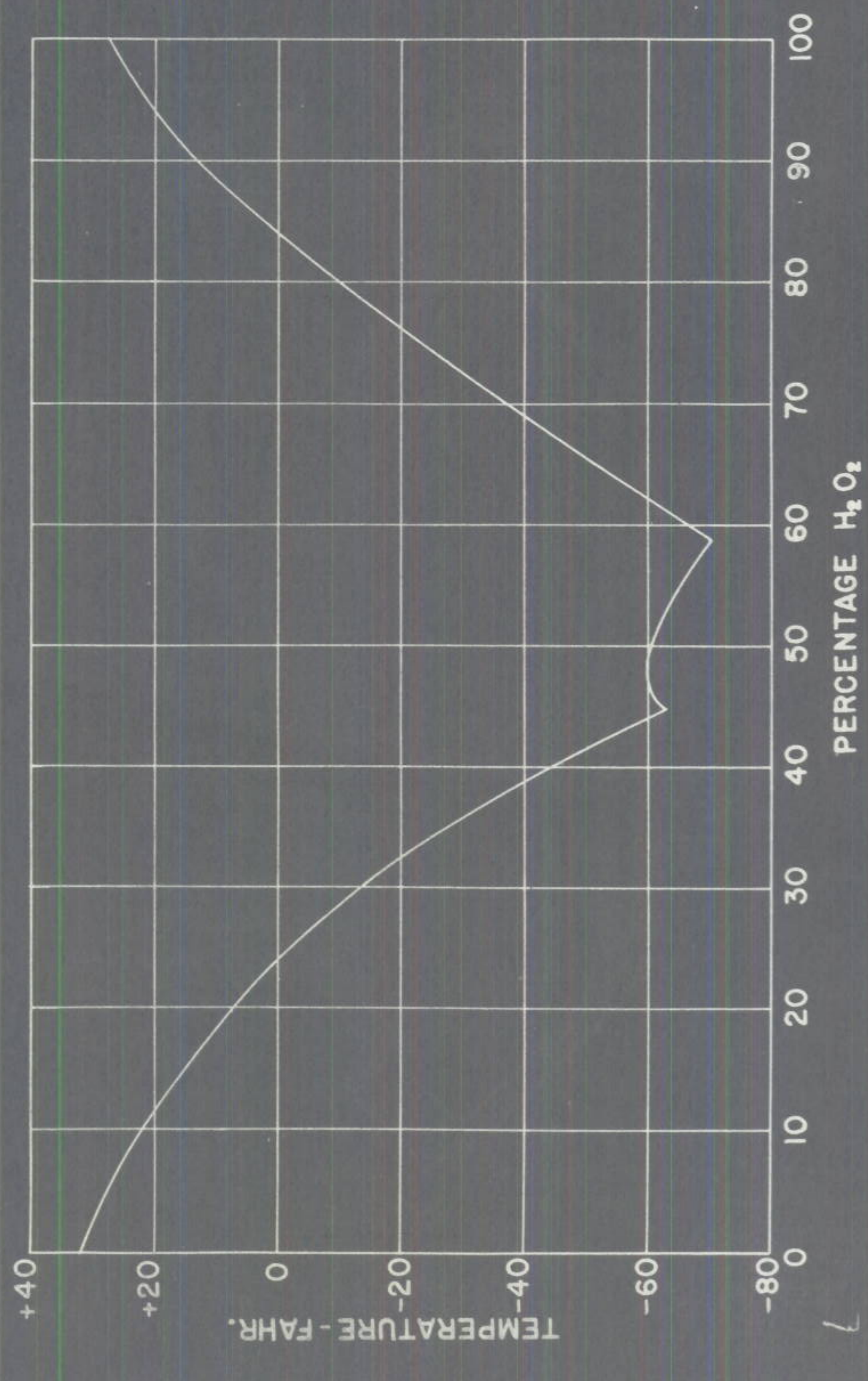

PLATE 1

[redacted]

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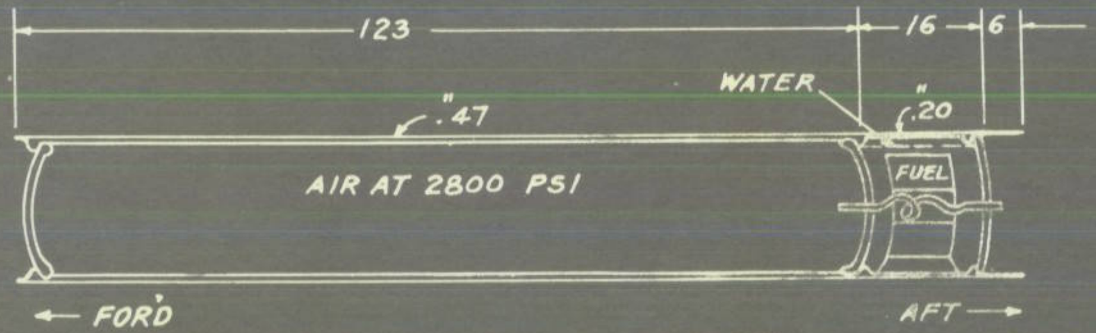
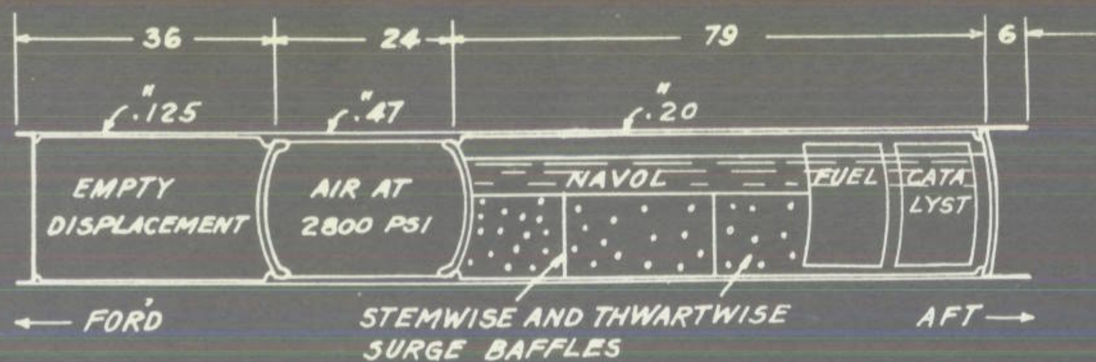


CHARGED MK. VIII-4 AIR FLASK
ENERGY ABOUT 45,000,000 FT. LBS. (BRAKE)

MK. VIII - 4

WEIGHTS

AIR	—	332 LBS.
WATER	—	117 "
FUEL	—	41 "
FLASK	—	1468 "
TOTAL	—	1958 "



CHARGED AIR FLASK OF NAVOL TORPEDO
HAVING SAME WEIGHT AND DISPLACEMENT
AS MARK VIII-4. ENERGY ABOUT
131,000,000 FT. LBS. (BRAKE).

EQUIVALENT NAVOL

AIR	-	75 LBS.
NAVOL	-	730 "
FUEL	-	100 "
CATALYST	-	80 "
FLASK	-	975 "
TOTAL	-	1960 "

PLATE 3

[redacted]

DATE	RUN NO	PER CENT NAVOL	H.P.	OXYGEN EFF.	OVERALL EFF.	LENGTH OF RUN	TEMP. F°	FUEL PER MIN.	NAVOL PER MIN.	CATALYST PER MIN.	REMARKS
1-23-34	139	WATER	65		143,000	1'-32"	1000	2.0 LBS	WATER 3 LBS		
"	140	"	72.5		172,000	1'-14"	930	1.21	WATER 3.0		5/16" NOZZLE
1-24-34	141	"	61.6		132,000	1'-10"	870	1.71	WATER 3.16		PRELIMINARY EXPERIMENTS
"	142	30 %	108.7		282,000	1'-32"	1665	1.63	1.63		NO CATALYST USED.
"	143	"	99.5		279,000	1'-30"	1815	1.6	1.67		COMBUSTION POT SIMILAR
3-7-34	144	"	56.5		130,000	1'-32"	1400	1.63	2.94		TO ONE USED WITH
"	145	"	72.2		150,000	1'-30"	1630	1.5	3.5		AMMONIUM NITRATE
4-17-34	146	50 %									
"	147	"									OPEN AIR RUNS (NO NOZZLE)
4-18-34	148	"									SOLID CATALYST
6-27-34	149	"				3' TO 4'	300				
7-3-34	150	"				2'-20"	300				SOLID CATALYST. "OXYGEN"
7-19-34	151	"					375				COMBUSTION POT, 1/8" NOZZLE
9-18-34	152	"				NOT RECORDED	350				
"	154	55 %	9.2		138,000	7'-54"	400	0.177	1.9		
"	155	46.9 %	9.86		88,000	3'-45"	367	.506	3.04		LIQUID CATALYST —
9-20-34	156	55 %	22.0	1,560,000	280,000	3'-53"	370	.645	1.8		COLLOID COBALT OXIDE.
"	157	58 %	17.2	470,000	105,000	1'-45"	450	0.4	4.46		"OXYGEN" COMBUSTION POT,
10-9-34	158	55 %	33.0	1,350,000	184,000	2'-10"	1330	1.74	3.13		3/16" NOZZLE
10-16-34	159	50 %	29.3	1,150,000	171,500	1'-57"	1330	.51	3.59		
10-23-34	160	52 %	18.5	380,000	59,700	1'-36"	400	1.12	6.57		
10-24-34	161	50 %	40.2	1,500,000	213,000	1'-50"	1330	1.1	3.28		
"	162	60 %	54.0	1,730,000	281,000	1'-50"	1700	1.0	3.66		
"	163	70 %									
11-20-34	164	55 %	49.0	1,430,000	327,000	2'-54"	1100	0.96	4.37		
11-22-34	166	"						3.1	5.6		
1-4-35	167	"	29.2	940,000	177,500	1'-24"	900	.786	3.93		3/16" NOZZLE
1-9-35	168	30 %	19.3	490,000	57,600	1'-53"	600	.796	9.3		LIQUID CATALYST - 6 %
1-10-35	169	"	30.1	1,040,000	118,000	2'-44"	450	.915	6.77		POT. PERMANGANATE
"	170	"	30.6	940,000	113,000	2'-14"	410	.895	7.62		"OXYGEN" COMBUSTION POT
"	171	"	30.3	940,000	105,000	2'-16"	400	1.1	7.53		
1-11-35	172	"	42.7	770,000	72,300	1'-0"	400	5.0	13.0		1 — 5/16" NOZZLE
2-12-35	173	55 %	158	1,300,000	242,000	35"	750	4.3	15.45		
"	175	"				13"	335				
3-6-35	176	52 %	122	1,070,000	564,000	1'-10"	810	2.56	15.4		2 — 5/16" NOZZLE
"	177	55 %	103	695,000	128,000	1'-0"	910	3.5	19	2.03	
3-8-35	178	"	157.4	1,340,000	277,000	1'-12"	1345	2.08	15	1.42	
"	179	"	124		136,000	36"	1345	5	25	1.67	
3-21-35	180	"	149	1,300,000	274,000	1'-15"	1435	3.2	14.4	1.20	
3-26-35	181	"	145	1,230,000	248,000	1'-45"	1025	2.86	15.4	1.12	

TABLE I