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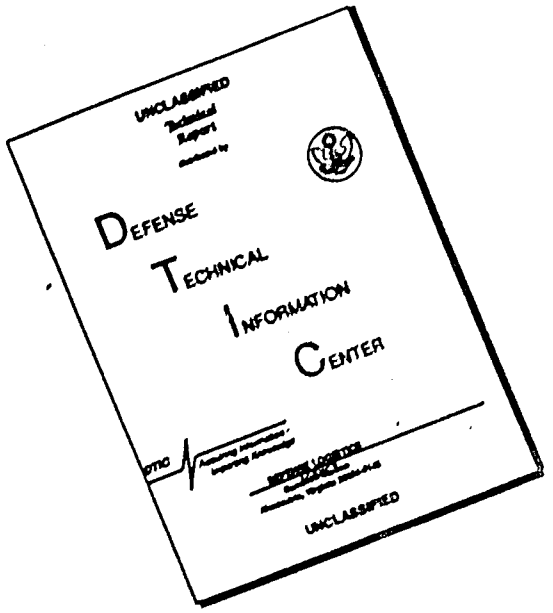

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A.R.F. Contract
Nonr 2389(00)
Notes Concerning
Final Report On
Hydroduct And
Hydroductor

CONFIDENTIAL

ONR:463:CEB:bmw
1 May 1959

File

C. E. Burns, Jr.

Armour Research Foundation Contract Nonr-2389(00) - Notes on A.R.F. Final Report concerning Aerojet Hydroduct - Hydroductor Project

Ref:

(a) Clearance Memorandum dtd 28 Mar 1949 - Incorporated into Contract N60nr-244(24) (CONF) with CIT entitled "Hydrodynamic Problems Associated With Underwater Jet Propulsion" (Restricted)

(b) Aerojet ltr to the Office of Naval Research, Attn: Dr. E. H. Seymour dtd 25 Oct 1949 concerning comparative performance of underwater Power Plants

(c) First and Second Endorsements (ONR & BAR Pasadena) forwarding Aerojet's Proposal for Range Testing of the Hydroduct and Hydroductor dtd 25 June 1952, ONR, Code 463, Attn: CDR F. B. Tucker (CONF)

(d) Memo to File from C. E. Burns dtd 31 Aug 1953 (NR 234-004) outlining Probable Deficiencies of Proposed Aerojet Hydroduct and Hydroductor Range Testing Program (CONF)

(e) Memo to File from LT H. Bucknell dtd 10 Nov 1953 (File NR 234-004) reporting on a visit to Aerojet in Oct 1953 concerning the Hydroduct Contract Nonr-1002(00) (CONF)

(f) BuOrd ltr to CNO Ser 30992 dtd 5 Dec 1956 forwarding notes on Hydroduct Program prepared by Re3d of BuOrd and dtd 27 Dec 1955 (CONF)

(g) Memo to CDR Roper from C. E. Burns dtd 10 Oct 1956 (NR 234-004) concerning rough draft of Conference Report prepared by Mr. Congwer as a result of 28 Oct 1956 meeting with ONR (CONF)

(h) Bar Azusa First End. to ONR, Ser 01014 dtd 15 Nov 1956 forwarding Final Draft of Conference Report prepared by Mr. Congwer concerning 28 Oct 1956 Meeting with ONR (CONF)

(i) Memo to CDR Roper from C. E. Burns dtd 27 Nov 1956 (NR 234-004) recommending analysis of Hydroduct and Hydroductor project by an impartial group (CONF)

(j) Memo to CDR Roper from C. E. Burns dtd 26 Dec 1956 (NR 234-004) concerning discussions with NOL and Catholic University Representatives (CONF)

(k) Memo to CDR Roper from C. E. Burns dtd 21 May 1957 (NR 234-004) concerning cost of and future support of Hydroductor Program at Aerojet (CONF)

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(l) Annex "A" to contract Nonr-2389(00) with Armour Research Foundation dtd 15 Aug 1957 (CONF)

(m) Ltr to Dr. Ritter from Code 429 dtd 10 Jan 1958 outlining answers to questions concerning the Hydroduct and Hydroductor which had been discussed with Aerojet (CONF)

(n) Memo to File dtd 28 Apr 1958 Reporting Conference with Armour Research group, Apr 22 through 24, 1958, concerning preliminary draft of Hydroduct - Hydroductor Final Report (CONF)

(o) A.R.F. Report D143 dtd May 1958, entitled, "Evaluation of an Underwater Rocket" (CONF) (Superseded by Sept 1958 Report)

(p) Memo from ONR/Chicago (Mr. Mindak) to Code 463 (Mr. Burns) dtd 6 Jun 1958 concerning Final Report A.R.F. D143 dtd May 1958 (CONF)

(q) Aerojet ltr to ONR Code 429 of 10 July 1958 commenting on Armour Report D143 dtd May 1958 which was cancelled and replaced

(r) ONR ltr (Code 429) to C. A. Congwer, Aerojet General dtd 16 Oct 1958 requesting return of Armour Report D143 dtd May 1958

(s) Memo to File concerning telephone conference with Dr. Ritter of A.R.F. in Chicago, Ill. and Dr. Vincent Cushing of A.R.F. in Washington, D. C. and Mr. C. E. Burns of ONR in Washington, D. C., 24 July 1958 (CONF)

(t) A.R.F. Report D143 dtd Sept 1958 entitled, "Evaluations of An Underwater Rocket"

(u) ONR ltr Ser 01947 to Aerojet dtd 18 Nov 1958, forwarding two (2) copies of Revised Armour Report reference (t) for comment as previously agreed.

(v) Aerojet Report No. 1556 dtd Feb 1959 submitting Comments on Armour Research Foundation Report D143 dtd Sept 1958

(w) Aerojet Report No. 12815-43 dtd 15 Nov 1956 (Example of Inconclusive Tests, Results reported by Contractor)

(x) Memo from C. E. Burns, Code 463 to ONR/Chicago (Mr. R. Mindak) dtd 26 Mar 1959, requesting Armour Research to review the Aerojet Report 1556

Encl: (1) Copies of references (a) through (x)

1. Beginning in about 1947 the Aerojet Corporation was looking for uses for a metallic base propellant which they had developed and were attempting to sell under the trade-name Alclo. One of their interests was in the work being done under our contract at CIT with Dr. R. Knapp, under which we were attempting to solve some of the problems associated with underwater jet propulsion. The work under this contract was pointed toward the development of a new type of underwater missile as contained in clearance memorandum, reference (a). Among

the items incorporated in the contract which was initiated in April 1949 were drag affects, jet configurations and body shapes as related to an ultimate vehicle which it was hoped would require no depth control or steering at ranges less than 300 yards. In fact Aerojet had been "cut in" on the efforts of the Germans to develop an unguided short range underwater rocket for use by their submarines; but which would have required the submarines to be "trimmed." Several other types of underwater rockets which had been under development by the Germans in World War II were also considered and referred to Aerojet; including the "Ursel Projectile" a short range (100 to 300 yards) rocket which could be fired by a submarine lying on the water or by a surface ship against enemy targets such as ships of the "Picket Class."

2. As work at CIT continued, our relationship with Dr. Knapp became strained, because his available time had been over-committed and work on our project was being delayed. Later Aerojet hired him as a consultant and this again reduced his time available to work on our contract. This situation became so critical that this Branch allowed the CIT contract to lapse in 1953, and the final report was prepared by Mr. J. P. O'Neill who took over Dr. Knapp's position, after rather extensive organizational changes within CIT. This report was rather inconclusive and was not finally completed until late in 1954. In the intervening period, Aerojet had submitted a letter, reference (b) dated 25 October 1949 to Code 429, Attention: Dr. E. H. Seymour, concerning "Performance of Underwater Power Plants" among which were the Hydroduct and Hydroductor. The vehicle used to test the latter two power plant types propulsion devices was originally a MK.45 torpedo body which later took on the "Lyons" form, based on work done at NOTS and that done by Dr. Knapp at CIT. Since none of the work done under Dr. Knapp at CIT or that done by Aerojet was conclusive, we in Code 463 were not enthusiastic about undertaking development of either the Hydroduct or Hydroductor.

3. During the "Korean Crisis" in June 1952, Aerojet submitted a formal proposal, reference (c), to develop the Hydroduct and Hydroductor. After presenting this proposal, Aerojet put extensive sales pressure on Codes 429 and 463 and perhaps elsewhere to have the project activated. My reactions and objections to Aerojet's proposal is contained in reference (d) which delineates the areas considered basically deficient and which would subsequently stall any attempt to develop an underwater missile except through a "Manhattan Project" type of approach. However, ONR, including CDR F. B. Tucker, then Head of the Armament Branch, were looking for a weapon and my efforts to limit the work to certain initial areas of research failed. As a result, in September 1952, Code 463 and Code 429 entered into an extensive development program with Aerojet entitled "Range Testing of Hydroduct and Hydroductor Test Vehicles." This situation was later verified, and amplified by LT H. Bucknell in his memo of 10 November 1953 reference (e) when reporting on the status of the Aerojet work as of 10 November 1953. He was not only concerned with their efforts to unreasonably advance development, but also their efforts to sell the Hydroduct as a weapon rather than to "carry out research." In this memorandum, he advised CDR F. B. Tucker as follows, "It is desired that further "selling" of the Hydroduct as a weapon be held in abeyance pending completion of various analyses." However, action to prevent further development was never initiated by CDR Tucker for reasons beyond my comprehension and we proceeded merrily on our way. Had work been

maintained at a basic research level even at this point the technical deficiencies of the project would have been aware to all. We could also have saved a large percentage of the $1,300,000 spent by ONR, plus funds spent by BuOrd and NOTS on a project which was beset with "basic deficiencies", yet treated as a "clear cut development."

4. The financing of the "Range Testing of Hydroduct and Hydroductor Test Vehicles" was divided between Codes 463 and 429. Certain elements of the propulsion system development for the Test Vehicle were supported by Code 429 under Contracts N6ori-10 and Nonr-1863(00) both of which cover general projects in the field of propulsion. Code 463 in turn, supported only the Range Testing of the "Test Vehicles" known as the Hydroduct and later on the Hydroductor both under contract Nonr-1002(00). This program covered a period of something over five years and cost somewhat over $4,000,000 as pointed out in reference (k). Since all work under Code 429 contracts were not chargeable to the Hydroduct or Hydroductor, we prorated their effort as being approximately $600,000 plus Code 463's expenditure of approximately $700,000. On this basis the Hydroduct and Hydroductor program as of October, 1957, had cost the Office of Naval Research approximately $1,300,000 which did not include the use of facilities at Morris Dam that were provided by the Bureau of Ordnance. Neither did it include the salaries or overhead of personnel at the NOTS facility who assisted Aerojet to carry out the test program.

5. In carrying work in this program, it should be bore in mind that the original requirement for this type of underwater weapon was 500 yards -- an extremely short range -- and 1000 foot depth, the latter an extremely optimistic hope. The weapon,as envisioned, was to be fired from one of our submarines against an enemy submarine or surface ship and would carry a relatively small warhead. On this basis the original vehicle had been considered as carrying a 10 pound warhead but after review and discussion, this was increased to approximately 30 pounds, thus basically fixing the configuration of the vehicle which Aerojet was planning to design and develop. From time to time an examination of the work being done by Aerojet indicated that little was being accomplished as previously mentioned by LT Bucknell in reference (e) and that we were emeshed in a development and sales pitch type of program for which fundamental basic weapon design knowledge was lacking. In addition to "short comings" such as depth sensitivity, lack of depth and azimuth control, and fluctuations in flight velocity other adverse factors related to the combustion and propulsion system were evident. Some of the test results indicated that the Hydroduct fired in shallow water and for short ranges 300 to 400 feet had a fairly flat trajectory and might be useful for some application other than a submarine. At one time it was suggested the Hydroduct might be used in shallow underwater, fixed installation as an anti-torpedo motor boat defense weapon or as a defense weapon against similar sneak attacks by larger ships. It was clear, however, that it would be difficult to increase the range of this type of device and to fire it from variable depths because of its "depth sensitivity" and lack of azimuth control. In addition, there were many more problems to be solved before it could become a weapon, including sealing against water pressure at various depths up to 1000 feet.

6. The status of the Hydroduct and Hydroductor was rather heterogeneous as far as the Bureau of Ordnance was concerned, although notes prepared by them

and forwarded to CNO by reference (f) indicated that there were some people in that Bureau who had an idea that the Hydroduct might be placed on the shelf as a finished design or transferred to BuOrd. Actually this hope was not borne out since further research and development has demonstrated that the Hydroduct and Hydroductor were both "depth sensitive", lacked range and do not have underwater trajectories necessary to "kill" underwater or surface targets. A recent review of reference (f) again indicates that it was more a "statement of the work" than a weapon analysis. Actually the requirements to be met by the weapon are not spelled out, neither are the tactical situations under which it could be used stated. Had any one or all of the several important factors been considered, reference (f) would have been a useful document rather than to have indicated that the "weapon and launcher" are regarded as approximately ready for placing on the shelf or transferring to BuOrd.

7. On October 28, 1956, a meeting between representatives of their Branch and Code 429 and Aerojet was held to discuss further support of the Range Testing Program. The purpose of this meeting as it turned out was an attempt to "Sell this Branch" on the idea that further support of the Aerojet Hydroductor project was worth while. The results of this meeting are summarized in references (g) and (h). It will be noted that while some of Aerojet's effort was basic, most of the work with respect to the Hydroductor was "cut and try." In other words, they were attempting to develop components such as, an "ignitor" that would function under one set of specific starting conditions that were critical due to "sequence." They were also attempting to develop a new "after end" of the missile designed to "eliminate depth sensitivity." In all of these approaches, they were attempting to develop gadgets or components and assemble into a unit. Reference (g) outlined my disagreement with any further support of this development and also suggested that if we did any further work, it should be at a research level and that we should secure the services of a facility staffed to do basic research. As a result of this situation, this Branch withheld further support of the Hydroductor program pending results of some tests which Aerojet was going to run with a "new configuration" designed to eliminate "depth sensitivity." Realizing that further tests by Aerojet could not be conclusive, I prepared reference (i) in which I again pointed out areas of deficiency in the Hydroduct and Hydroductor designs which should be investigated before we put any more money in the program, also the little likelihood of achieving "depth insensity." Reference (i) also pointed out that if Codes 400 and 460 felt that the Hydroductor program in its present form should be continued, they should give Code 429 funds for complete support "even though there is some doubt whether the work should be done or belongs in the latter code." In this memorandum reference (i), it was further recommended that we withhold funds desired by Aerojet to "continue range testing" until an independent analysis of the Hydroduct and Hydroductor program could be made by an "impartial group." Reference (j) summarizes the results of our discussions with NOL and Dr. Hertzfeld of Catholic University concerning our desire to make an impartial analysis of the Hydroduct and Hydroductor Program. Later on other groups, including the University of Utah and Armour Research Foundation were contacted to learn whether they were interested in this sort of program. As a result, Dr. A. L. Ritter of Armour Research submitted a proposal in which he essentially outlined a method

for the analysis of the Hydroduct and Hydroductor Missiles. Reference (k) which was prepared in support of the Armour proposal, outlined our difficulty of arousing the interest of potential contractors to do this analytical work and pointed out that the Armour approach was acceptable. This reference also delineated the excessive cost of the Hydroduct and Hydroductor programs which had produced nothing, but had cost over $1,300,000 as of November 1957. In addition this memorandum recommended we undertake the study with Dr. Ritter's group at Armour Research Foundation in the hope that we would obtain useful information which might direct our future efforts in the underwater rocket field.

8. Negotiations with the Armour Research Foundation and their representatives resulted in Contract Nonr-2389(00) under which they were authorized to begin work on 15 August 1957 in accordance with reference (l) which is Annex "A" of the Contract. In the meantime, this Branch forwarded to Armour copies of all reports which had been received from Aerojet under contracts N6ori-10, Nonr-1863(00), and Nonr-1002(00), that is those reports which were pertinent to the Hydroduct and Hydroductor research and development program. Dr. Ritter and his group in reviewing these reports found that there were other reports mentioned which were also pertinent to the project. The Chicago Branch Office was requested to obtain these from the several sources and furnish them to Armour on an indefinite loan basis. In the meantime, Dr. Ritter and one of his representatives came to Washington to discuss a number of technical problems and presented a list of technical questions which he would like to have answered by Aerojet. Since Mr. S. W. Doroff of Code 429 was going to visit Aerojet, the list of detail technical questions was taken up with him for a discussion with Mr. C. A. Gongwer of Aerojet. Mr. Doroff, upon his return from Aerojet prepared a letter to Dr. Ritter, dated 10 January 1958 in which he set forth the answers he had obtained as a result of his discussion with Mr. Gongwer of Aerojet. These answers which are contained in reference (m) were not conclusive and both Dr. Ritter and the writer had a feeling that other test data as well as information considered propietary by Aerojet, (or not officially transmitted to the Office of Naval Research) was being withheld. In view of this situation and since we were dealing with basic engineering principles, further effort to obtain test data or other information from Aerojet was not pressed. The analysis was continued on a theoretical basis using all bona-fide test and other data which had been presented in report form to the Office of Naval Research.

9. In early April of 1958, we were advised that the preliminary draft of the Armour Hydroduct and Hydroductor report was ready for review. Accordingly, Mr. R. Mindak of the Chicago Branch Office and the writer met with the Armour Research group in Chicago on April 22 through 24, 1958. The purpose of this meeting was to go over the draft of the report with Dr. Ritter and his group, consisting of Messrs. D. S. Hacker, Paul Lieberman, and several others who were called in for specific items contained in the report. As a result of this meeting, a large number of corrections, both typographical and technical were uncovered. In particular, the conclusion portion of the draft required revision both as to scope and content since they were too brief to "stand on their own feet." In addition, the conclusion did not clearly delineate the real differences between the Hydroduct and Hydroductor types of missile. Some

of the typographical errors both in text and on the graphs in some instances distorted the entire meaning and were at variance with the conclusions. As a result of their review reported in reference (n)all of the group fully agreed that a comprehensive review and correction period was necessary to insure a factually correct report. Actually the Armour group not only agreed to undertake the review and make necessary corrections, but also indicated they would include any other item which further study revealed as pertinent to the revised draft. The question of further reviewing the revised draft was also discussed but since there had been no disagreement as to the need or type of corrections required, it was suggested that the Armour group make all the necessary corrections and revisions without further review on our part. It was agreed that after a thorough review within their own organization, the report could be released. The Armour group proceeded on this basis and in late May, 1958 released for distribution reference (o), which is ARF report D143, dated May, 1958, entitled "Evaluation of an Underwater Rocket" (CONF).

10. A copy of ARF Report D143 dated May 1958 had been transmitted to Mr. R. Mindak at the Chicago Branch Office in accordance with the distribution list and he called me on the phone to advise that from his first reading it appeared the report had been distributed without proper corrections and that Armour was preparing a lengthy "errata sheet" which they were going to distribute in an attempt to clear up the errors. Subsequently, Mr. Mindak followed up this telephone conversation with a memorandum reference (p) in which he delineated some of the more flagrant errors which had not been pointed out in our discussions. A copy of this report had also transmitted to Aerojet by Code 429 which was contrary to our agreement since we had set aside two copies of the report for their official review and comment. This turned out to be a serious error since Armour had not revised the draft before issuing the Final Report. On this basis Aerojet's unfavorable reaction, as outlined in reference (q) are not on firm ground. We contacted Armour and requested they recall all copies of the report and also asked Code 429 to do likewise with Aerojet. In reference (r) Code 429 asked Aerojet to discount the Armour Report and return their copy to ONR. Their copy of the report was returned but not until they had reviewed the uncorrected report which was their basis for preparing reference (q) and again raising their general objections to our having Armour do the analysis independently.

11. Obviously the issuance of an uncorrected "Final Report" had created an unsavory situation and placed us in a position for all sorts of criticism. During conversations with Dr. Ritter of Armour he was asked to bring a copy of the errata sheet they had prepared into our Office for discussion. As a result of his visit to this Office and discussions, we opposed "the errata sheet method" of correcting a poorly unrevised, and uncorrected report. Dr. Ritter was very disturbed by what had happened and asked for time to discuss the entire situation with the Armour Research Foundation management of his group, namely Dr. Vincent Cushing. On 24 July 1958, Dr. Cushing visited this Office and suggested we arrange a telephone conference with Dr. Ritter in Chicago and Dr. Cushing and the writer in this Office. This discussion outlined in reference (s) resulted in Dr. Cushing deciding that the final report dated May 1958 as prepared was in poor taste, had not been properly edited or corrected and should not have been reproduced and distributed. He directed Dr. Ritter to take the necessary action to prepare a new final report in correct form and context and re-issue to the holders of the original document. The new report dated September 1958, reference (t) was subsequently compiled and distributed with the request

that the previous copy dated May 1958 be returned to Armour or destroyed in accordance with existing regulation.

12. Two copies of the September 1958 Armour Report were also transmitted to Aerojet by reference (u) with the request that they submit their comments to this Office for review and distribution by this Branch to holders of the Armour September 1958 Final Report. The fact that we had gone ahead with an independent analysis of Aerojet's Hydroduct and Hydroductor program and had issued a Final Report that indicated basic difficulties in their vehicle design resulted in Mr. C. Congwer's preparation of reference (v). In fact their review of the corrected report dated September 1958 as contained in reference (v) is an elaborate attempt to defend their Hydroduct and Hydroductor Program. In this report Mr. Congwer alludes to "other experimental evidence" contained in recent reports which had not been available to Armour. This rather pointed statement was checked and found generally incorrect as all reports found available under the contracts had been sent to Armour officially. In addition, Mr. Doroff of Code 429 had visited Aerojet and obtained specific information desired by Dr. Ritter which he had transmitted to Armour by reference (m). Consequently, Mr. Congwer's feeling that we did not attempt to secure all data is fundamentally incorrect. If data was missed it was because it had not been included in the contract reports by Aerojet or was insufficient statistically to be of real value to Armour. An example of this latter situation is contained in reference (w) which indicates that many of the reports furnished by Aerojet contain little if any "substance". The fact that we did not request Aerojet to sit in on the Armour Study or review their work was that we wanted an independent analysis on a non-interference and non-sales basis.

13. The writer is cognizant that while the Armour Report of September 1958 is not a perfect document it attempts to delineate the basic technical deficiencies of the Hydroduct - Hydroductor program and that in so doing it "stirred up" political implications. The writer was also disappointed when Aerojet submitted reference (v) containing their comments on the Armour Report of September 1958 to the entire distribution list without advising us of this action. As a consequence in reference (x) we requested that Armour review Aerojet Report No. 1556 and submit their comments for our review. Pending receipt of their comments the following is a summary of my review of Aerojet Report No. 1556 which essentially restates their belief in the Hydroduct and Hydroductor Program. However, their report <u>does not</u> mention any of the following recognized <u>deficiencies</u> or adverse factors in their program nor delineate how they can be corrected:

(a) Lack of a flat or identical trajectory except at short ranges (estimated 250 yards or less).

(b) Design factors preventing an increase of flat or identical trajectory to 500 to 1000 yards.

(c) Tactical deficiencies of the present devices for use in a weapon system having a range beyond 250 yards (assuming that adequate detection and fire control equipment is available).

(d) Logistic disadvantage of "flock shooting" of the Hydroductor type missile from; a submarine, a surface ship and fixed installations.

(e) Lack of "depth insensitivity" so that either the Hydroduct or Hydroductor could be fired at various depths and yet retain a flat or identical trajectory.

(f) Means for controlling the trajectory for various depths from 100 feet up to 1000 feet.

(g) Means for overcoming adverse effect of buoyancy at short range 250 yards and at long ranges 500 to 1000 yards.

(h) Fundamental reasoning behind elimination of depth control when obviously it is needed if ranges in excess of 250 yards are required to kill the target. ("Except for "flock shooting" from a fixed underwater installation where ranges up to 1000 yards against a surface target might be considered in spite of logistic problems". However, under these conditions we should compare the Hydroduct - Hydroductor system against a mine field for effectiveness).

(i) Fundamental reasoning behind elimination of azimuth control when obviously the target is moving with respect to the missile launcher or carrying ship and some azimuth control is needed, except for "flock shooting" at short range. (Experience has shown that "lead angle" and "dead time" are important items when firing against high speed targets. On this basis the high speed (100 knots) of the Hydroductor cannot be fully compensating and some sort of control or homing seems needed particularly at ranges of over 250 yards or when target is capable of evading).

14. In summary it is clear that during the first part of the program we could have easily verified the deficiencies of the Hydroduct and Hydroductor program at a very low cost had such an approach been approved. In addition the cancellation of the 500 yard range requirement in the "Original Operational Requirement" by CNO could have been used to recast the work being done by Aerojet. At least we could have saved a large part of the manpower and funds put into a program which had so little in its favor with respect to its development as a weapon for inclusion into a worthwhile weapon system.

C. E. BURNS, Jr.

(a)

CLEARANCE MEMORANDUM

NR 230-042/3-14-49
N6onr-24424
California Institute of Technology

Restricted
March 28, 1949

I. Negotiations

On February 21, the Office of Naval Research wrote the Hydrodynamics Laboratory requesting information as to whether the Laboratory would be in a position to undertake a research project on some of the hydromatical problems associated with underwater jet propulsion. This Office advised that if the Laboratory was in a position to undertake such a program that a proposal should be submitted prior to March 10, 1949.

By letter dated March 3, 1949, Miss A. H. Walter, Contract Administrator for the California Institute of Technology, advised the Los Angeles Branch of the Office of Naval Research that the program would be undertaken under the direction of Dr. Robert T. Knapp of the Institute staff covering a one year period at a total estimated cost of $30,000.00. Miss Walter further advised that an alternate budget for a one year period in the amount of $45,000.00 was also being offered for consideration by ONR. Enclosed with Miss Walter's letter were six copies of a proposal covering the study of the hydromatic problem associated with underwater jet propulsion.

II. Description of the Work

Under this proposed Task Order the Contractor will conduct research in connection with hydromatic problems associated with underwater jet propulsion. The proposed research as planned will undertake to investigate the following:

(a) The effect of gas jets on the stability and drag of an underwater missile.

(1) The determination of the effect of the presence of the jet on the pressure distribution on the surface of the missile body ahead of the jet.

(2) The investigation of the factors which fix the size and shape of the gas-liquid boundary of the jet. Some of these factors are volume flow rate of the gas, velocity of the missile, rate of entrainment of gas from the jet by the liquid, and submergence. (ie Depth)

(3) Effect of yaw of the missile on the shape and behavior of the jet and the influence of these jet changes on the pressure distribution on the missile body.

(b) Body shapes suitable for underwater rocket propulsion.

(1) The analysis of body requirements for satisfactory underwater missile performance.

(2) The effect of the jet on the cavitation characteristics of the body.

(3) The effect of body shape on the prevention of forward migration of the gas along the missile body.

(c) Design of a hign speed, unguided straight line trajectory, short range, rocket propelled underwater missile.

III. Information Regarding the Contractor

The California Institute of Technology has the necessary facilities and trained personnel for successfully conducting this research program. In addition, the Contractor's free-surface water tunnel is well adapted to this study. Instrumentation and high-speed photography equipment will be available for this work. The jet propulsion laboratory, which is located off-campus from the California Institute of Technology, which is currently performing Bureau of Ordnance Contract NOrd-9112, will if necessary provide equipment and other available assistance for this program. The Office of Naval Research is contributing approximately 25% of the funds under that contract.

IV. Analysis of Cost Estimate

The budget for a one year period beginning April 1, 1949 and ending March 31, 1950 is as follows:

Staff		
Research Engineer	$5,400.00	
Research Assistant	3,600.00	
Part-time service of Hydrodynamics Laboratory staff ($500 per month)(4% of $12,500 per mo.)	6,000.00	
Supervision by existing supervisory staff	1,000.00	
TOTAL		$16,000.00
Overhead 40% of staff salaries		6,400.00
Total Staff		$22,400.00
Completion of high pressure air supply for jets and modification of existing equipment for jet studies	2,500.00	
Model and instrument construction	2,500.00	
Operating supplies, photographic materials, books, report preparation, etc.	1,700.00	
Travel (Two round trips to Washington, D. C.)	900.00	
		7,600.00
Total		$30,000.00

V. Overhead

In accordance with an agreement between Mr. Fitzpatrick, ONR Cost Accountant, and Mr. Green, Business Representative, CIT, the subject Task Order will provide for a fixed overhead rate of 40% of direct salaries and wages. The rate will apply from April 1, 1949 to March 31, 1950.

VI. Subcontracting

No subcontracting is contemplated under this Task Order. However, one item of the budget specified an expenditure of $2,500.00 for model and instrument construction.

VII. Facilities

As set forth in paragraph III, hereof, in more detail, the Contractor's facilities are adequate for this work.

VIII. Other Pertinent Information

The Contractor will not accept foreign patents clause or the new termination clause. The same should not be included in this Task Order.

IX. Reasonableness and Recommendation

Based upon the information set forth above and the recommendation of the Scientific Branch, Office of Naval Research, this proposed contract appears to be fair and reasonable to the Government.

James F. Ball

ENGINEERING CORPORATION

AIR MAIL

25 October 1949
10:1772

CONFIDENTIAL

To: Office of Naval Research
Power Branch
Navy Department
Washington 25, D. C.

Attention: Dr. E. H. Seymour

Subject: Comparative Performances of Underwater Power Plants

Enclosures: Curve No. 4031 - Direct Hydropulse Lithium-Fired
Curve No. 4032 - Pumpjet Lithium-Fired
Curve No. 4033 - Hydroturbojet Lithium-Fired
Curve No. 4034 - Hydroduct Lithium-Fired
Curve No. 4035 - Aluminum Potassium-Perchlorate Hydroduct
Curve No. 4036 - Aluminum Potassium-Perchlorate Hydroductor
Curve No. 4037 - Condensing Steam Turbine Aluminum Potassium-Perchlorate Fired
Curve No. 4038 - Self-Contained Rocket with Conventional Fuels

1. In response to a recent verbal request by a representative of the Office of Naval Research, Power Branch, the following analysis of comparative performances of underwater power plants is submitted.

2. As a method of comparison, the power plants have been applied to the Mark 40 torpedo envelope. It is assumed that the drag, D, of this envelope is KV^2, where K is a constant, .1098, and V is speed in feet per second. Drag calculated by this formula for a velocity of 80 knots is 2000 pounds. This is approximately correct for the Mark 40 envelope.

3. The propulsion systems considered are:

a. Using Molten Lithium as the fuel,

(1) Direct Hydropulse
(2) Pumpjet
(3) Hydroturbojet
(4) Hydroduct

b. Using Aluminum and Potassium-Perchlorate as the fuel.

(1) Hydroduct
(2) Hydroductor
(3) Condensing Steam Turbine

c. Self-contained rocket with conventional fuels.

4. The fact that the Mark 40 envelope will cavitate when operated near the surface at some speed less than 80 knots has been neglected. Presumably the length could be increased and the diameter decreased, keeping the displacement and resistance about the same. With these changes the Mark 40 envelope would not cavitate until much higher speeds were reached. The envelope cavitation limit does not invalidate a comparison of the power plants, and we are therefore justified in using the Mark 40 for comparative purposes.

5. The performances of the various power plants are presented as plots of speed versus range at different depths. The result is a family of curves on each chart, each curve showing performance at a different depth. These curves can be considered as contour lines on a topographic map representing a surface inside a cube with the three axes, speed, range and depth. Wherever it could be done readily, curves of constant β have been included on the plots. β is defined as $\frac{w_f}{w_w + w_f}$ where w_f is the fuel flow rate and w_w is the free water flow rate. β is a useful parameter for application to the Zwicky universal thrust equation:

$$U_{eff} = \frac{U_o}{\beta}\left[\beta - 1 + \sqrt{1 - \beta + \frac{2 K \beta \eta_{th}}{U_o^2}}\right] \qquad (1)$$

where: U_{eff} is the effective exhaust velocity of the fuel = $I_{sp} \times g$

U_o is the forward velocity

$K \times \eta_{th}$ is the fraction of the calorific value of the fuel which is converted to useful work on the free stream plus propellant mass. This work appears as part of the kinetic energy of the exit jet.

6. To keep the charts as comparative and pertinent as possible, some arbitrary assumptions have been made. This was necessary, since otherwise a rigorous and detailed design analysis and some experimental investigations would be required for each installation.

a. One of these assumptions involves the amount of fuel available to each power plant. For comparative purposes the engine-like

power plants were allotted 1 cubic foot of fuel each. In this category are the Pumpjet, the Hydropulse and the Steam Turbine drive. One cubic foot (33 pounds of lithium) is roughly the amount of fuel the Mark 40 torpedo with a pumpjet power plant is designed to carry and is a reasonable figure on which to standardize. Because of its high density, this volume permits carrying 144 pounds of Al + $KClO_4$ propellant for the steam plant. The fuel allotment is not based on weight because this factor is relatively unimportant for the type of missile being considered. Energy density and the volume required, rather than the weight of the fuel, are the significant items for underwater missile power plants. The simpler jet and rocket power plants are allotted two cubic feet of fuel because the reduction in the amount of machinery makes about this much more fuel space available, while maintaining the same over-all volume for power plant and expendables.

b. The hydropulse, when operated with magnalium, would give the same performance as when fired with lithium, only presumably it could not be adapted to a missile of this small size and is only of interest for larger craft.

c. For some of the engines, range is directly affected by thermal efficiency, η_{th} which is affected by the back pressure, P_d, and hence the depth. The higher the maximum practical reaction chamber pressure, P_c, the higher the pressure ratio $\frac{P_c}{P_d}$, and thus the efficiency attainable at depth, will be. It was assumed that strength and pressurizing requirements will limit the excess of P_c over P_d to 1500 psi so that $P_c - P_d = 1500$. The pressure ratio is then about 3:1 at 1000 feet.

7. Using the maximum reaction pressure assumed above, the variation of η_{th} with depth can be computed by the applicable Rankine cycle formula.

$$\eta_{th} = 1 - \left(\frac{P_d}{P_d + 1500} \right)^{\frac{\gamma - 1}{\gamma}} \qquad (2)$$

The value of γ was arbitrarily taken as 1.3, a representative value for most of the working fluids. Equation (1) gives the following table for η_{th} versus depth:

TABLE I

Depth - feet	0	50	100	200	400	800	1600
η_{th}	.658	.58	.53	.47	.395	.31	.25
$\eta_{th}/\eta_{th(o)}$	1	.882	.806	.715	.600	.472	.380

When the thermal efficiency of the hydropulse is determined considering only the heat in the hydrogen as available, good agreement with the values given in Table I is obtained. Of all the other power plants covered herein, only the self-contained rocket approaches the values of the η_{th} given in Table I. The values of $\eta_{th}/\eta_{th(o)}$ are not completely accurate either, but seem suitable for comparative purposes, in view of the other assumptions it has been necessary to make.

8. PUMPJET

For the pumpjet operated with lithium, the following calculations apply:

$I_{sp} = \frac{\text{lbs thrust secs}}{\text{lb fuel}}$, specific impulse

V = velocity - feet/second

Thrust = KV^2 pounds

K = .3125 for V in knots

or K = .1098 for V in feet/second

W = fuel load in pounds

A good experimental performance value for the turbine is 2.2 pounds of lithium per shaft horsepower hour, and it is expected that the effective propulsive efficiency will be 57%.

Therefore, the fuel consumption is 2.2/.57 = 3.87 pounds of lithium per thrust horsepower hour.

The value of 3.87 for over-all economy is related to the product I_{sp} x V by the following formula:

$$I_{sp} \times V = \frac{1,980,000}{3.87} = 513,000 \text{ propulsive foot pounds per pound of lithium} \quad (3)$$

where 1,980,000 is the foot pounds in a horsepower hour, and $I_{sp} \times V$ is the foot pounds of propulsive work per pound of fuel.

Range, S, times resistance or drag is equal to the propulsive work per pound of fuel times the pounds of fuel available, so:

$$S \times KV^2 = I_{sp} \times V \times W$$

$$\text{or} \quad S = \frac{I_{sp} \times V \times W}{KV^2} \quad (4)$$

This is the range and speed relationship at the surface. To obtain range vs speed at any depth the surface range for a given speed is multiplied by the ratio of the thermal efficiencies, at the desired depth and at the surface. This ratio is obtained from Table I. A change in thermal efficiency directly affects the range since it directly affects the $I_{sp} \times V$, or the foot pounds of propulsive work per pound of fuel. Propulsive efficiency also affects this quantity, but it is a function only of the ratio of jet velocity to advance speeds and would not vary with depth or speed for a given design.

Thus, by the definitions of η_{th} and η_p

$$I_{sp} \times V = h_f J \, \eta_{th} \, \eta_p \quad (5)$$

where:

h_f is the calorific value of the fuel

J is the conversion factor from heat units to mechanical units of work

$\eta_{th} = 1 - \left(\frac{P_d}{P_c}\right)^{\frac{\gamma-1}{\gamma}}$ and varies only with depth or P_d/P_c

$\eta_p = \frac{2}{2 + \frac{\Delta V}{V}}$ and varies only with $\frac{\Delta V}{V}$ which is independent of speed and depth for a given design.

ΔV is the relative jet velocity minus the forward speed, V.

9. HYDROPULSE

For the hydropulse the curves are obtained in the same way using, in this case, the experimental value of 5.2 pounds of fuel per thrust horsepower hour obtained at the surface.

10. HYDROTURBOJET

For the hydroturbojet the curves are obtained from an experimental specific impulse of 1400 sec. for surface operation and are adjusted by the same depth law as before. The value of η_p is corrected for speed in this case since $\Delta V/V$ is not independent of speed as before.

11. HYDRODUCT

For the hydroduct the value of $P_c - P_d$ is set equal to the ram pressure. Therefore, the pressure ratio, and hence η_{th}, is adjusted for depth and speed by this consideration. η_p is also adjusted for speed. The curves are based on an experimental specific impulse of 1200 sec. for surface operation. The aluminum potassium-perchlorate propellant gives considerably greater range than lithium because of its greater energy density.

12. HYDRODUCTOR

For the hydroductor each point of speed and depth is computed separately. Since no experimental performance figures were available, the calculated ranges were multiplied by .85 to allow a typical reduction from theory to practice.

13. CONDENSING STEAM TURBINE

For the condensing steam plant neither η_{th} nor η_p is affected by depth or speed, and the range curve at the surface applies at all depths. A word of caution is offered in regard to this propulsion system because its successful operation is based on a process just being developed. This is the burning of the aluminum plus potassium-perchlorate propellant in long trains through the metal block of the steam boiler. The capacity of the condenser and boiler surface is so restricted as to limit the speeds attainable with this system to 40 knots.

14. SELF-CONTAINED ROCKET

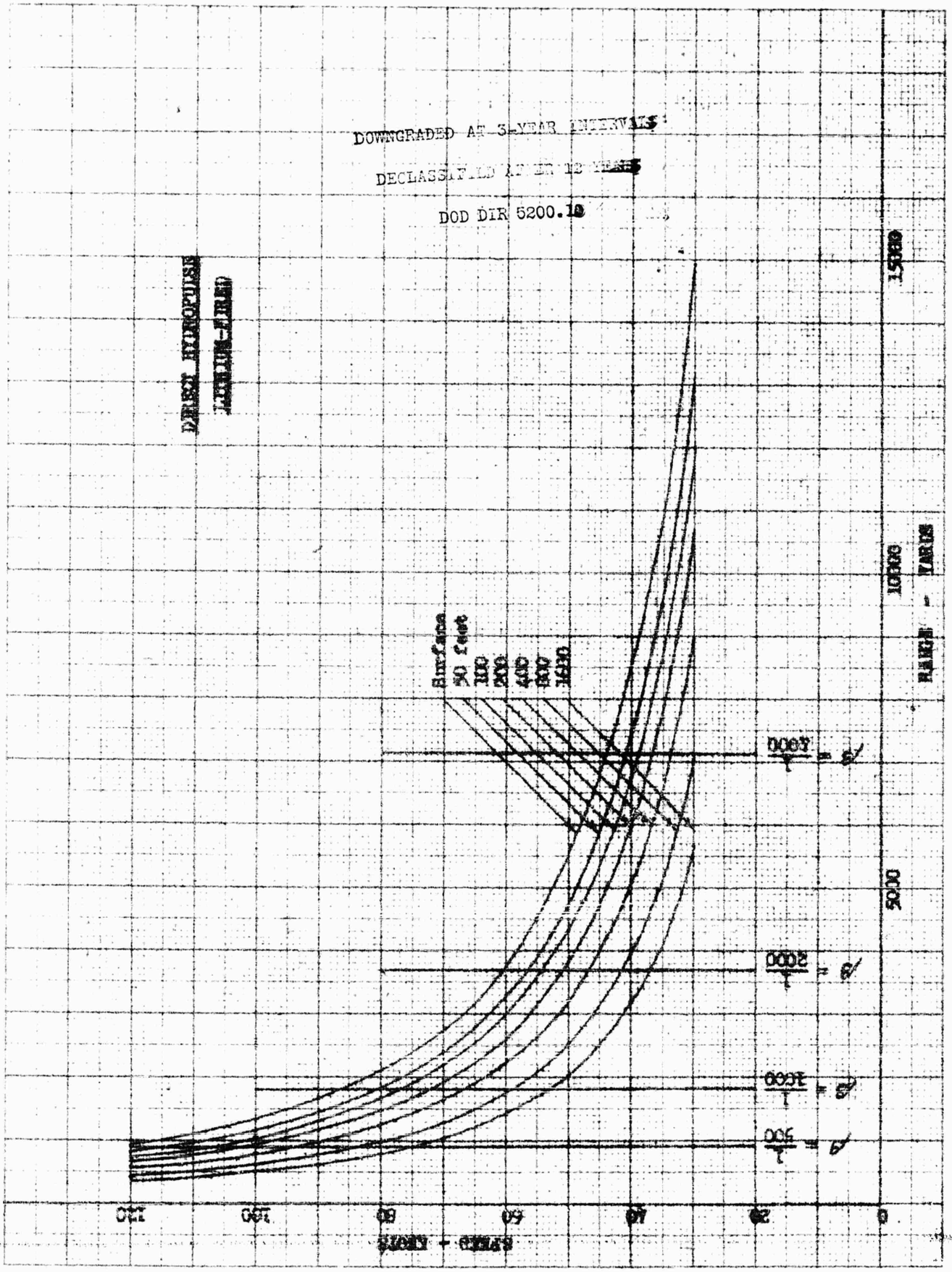
For the self-contained rocket power plant, the allowable chamber pressure was assumed to follow the same law as for the hydropulse and pumpjet.

In this case, however, the range varies as the square root of η_{th}, instead of as the first power of η_{th} as it does for the other types previously discussed. It is assumed that the nozzle throat would be increased in size with depth to hold the thrust constant at a given speed. This would necessitate varying the propellant flow rate. An I_{sp} of 200 sec. was assumed for surface operation of rocket motors. The propulsive efficiency of rocket driven vehicles is proportional to forward velocity in the speed range covered by this analysis.

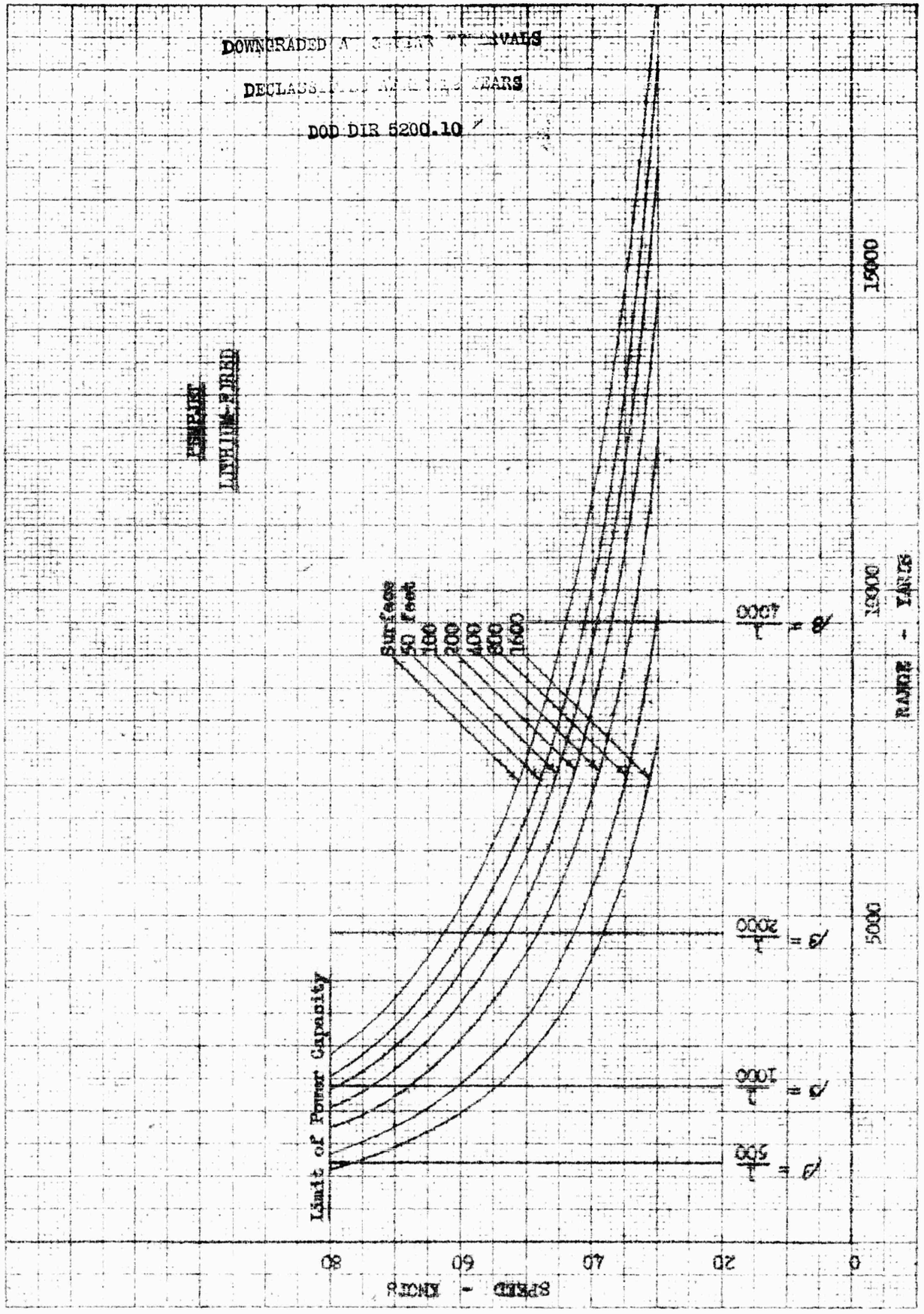
AEROJET ENGINEERING CORPORATION

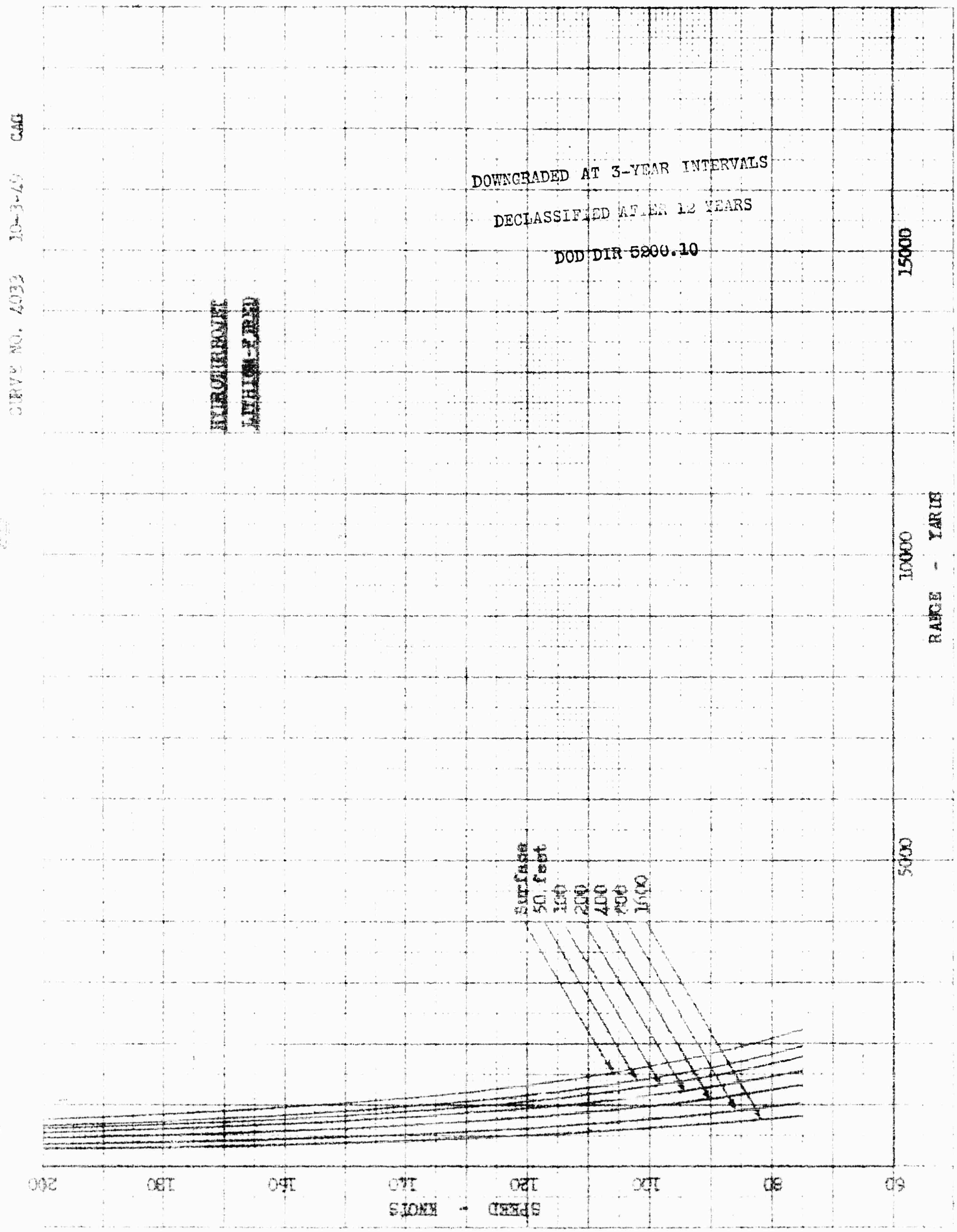
J. S. Warfel
Manager of Research

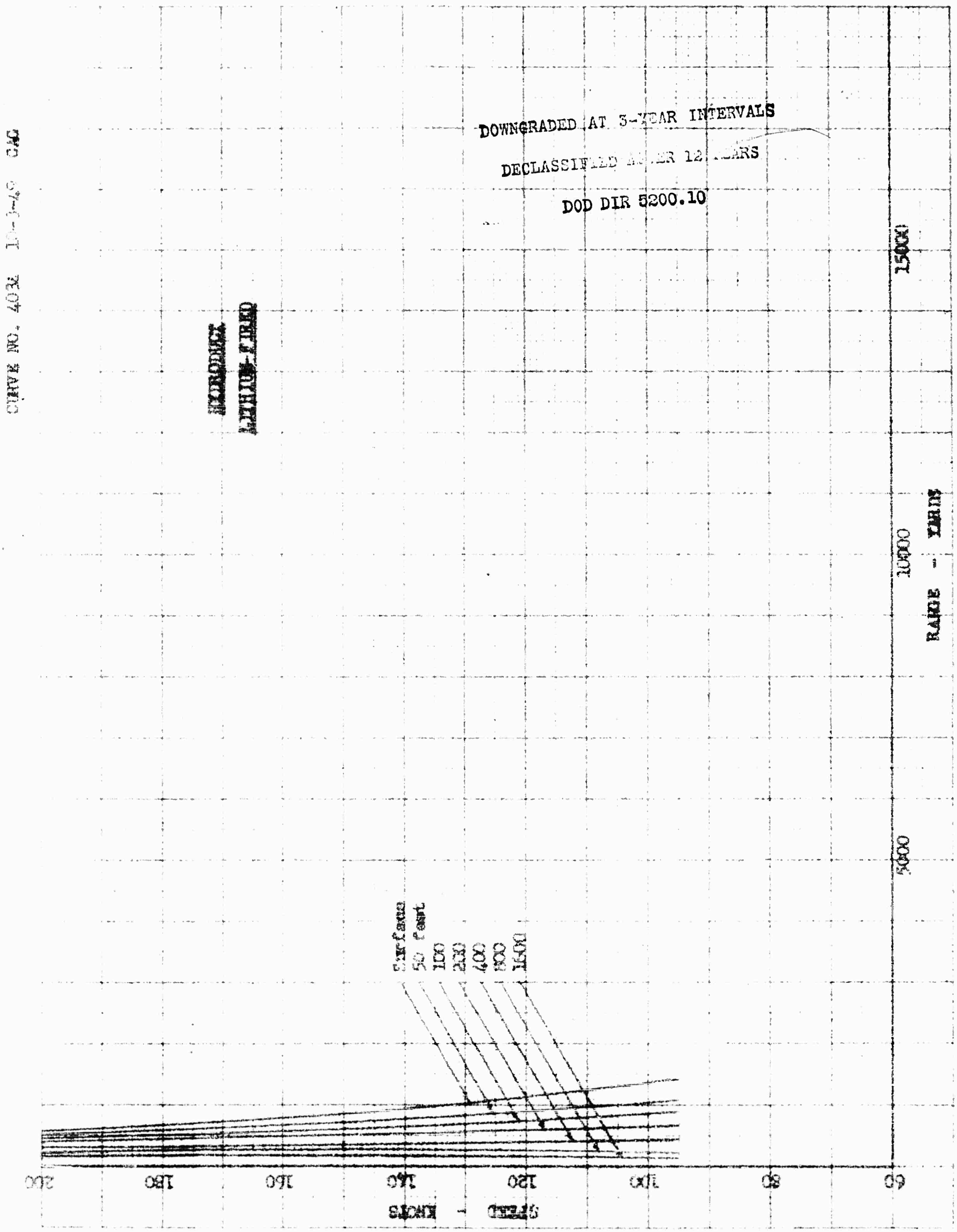
JSW:CAG:co

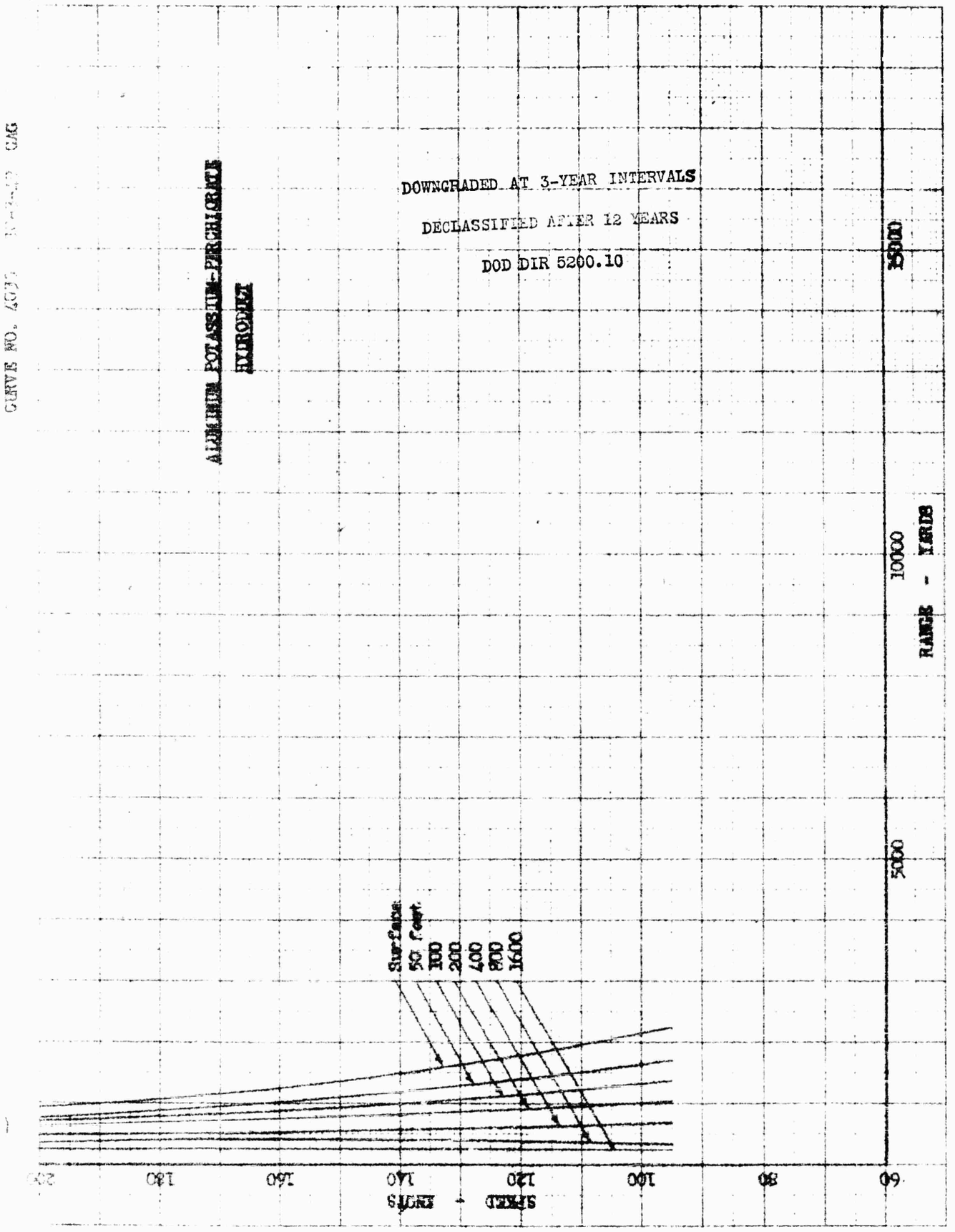


CURVE NO. 4032 10-3-49 CAC









CURVE NO. 4096 10-3-49 CAG

ALTITUDE EQUIVALENT-PRESSURE

ALTITUDE

15000

10000

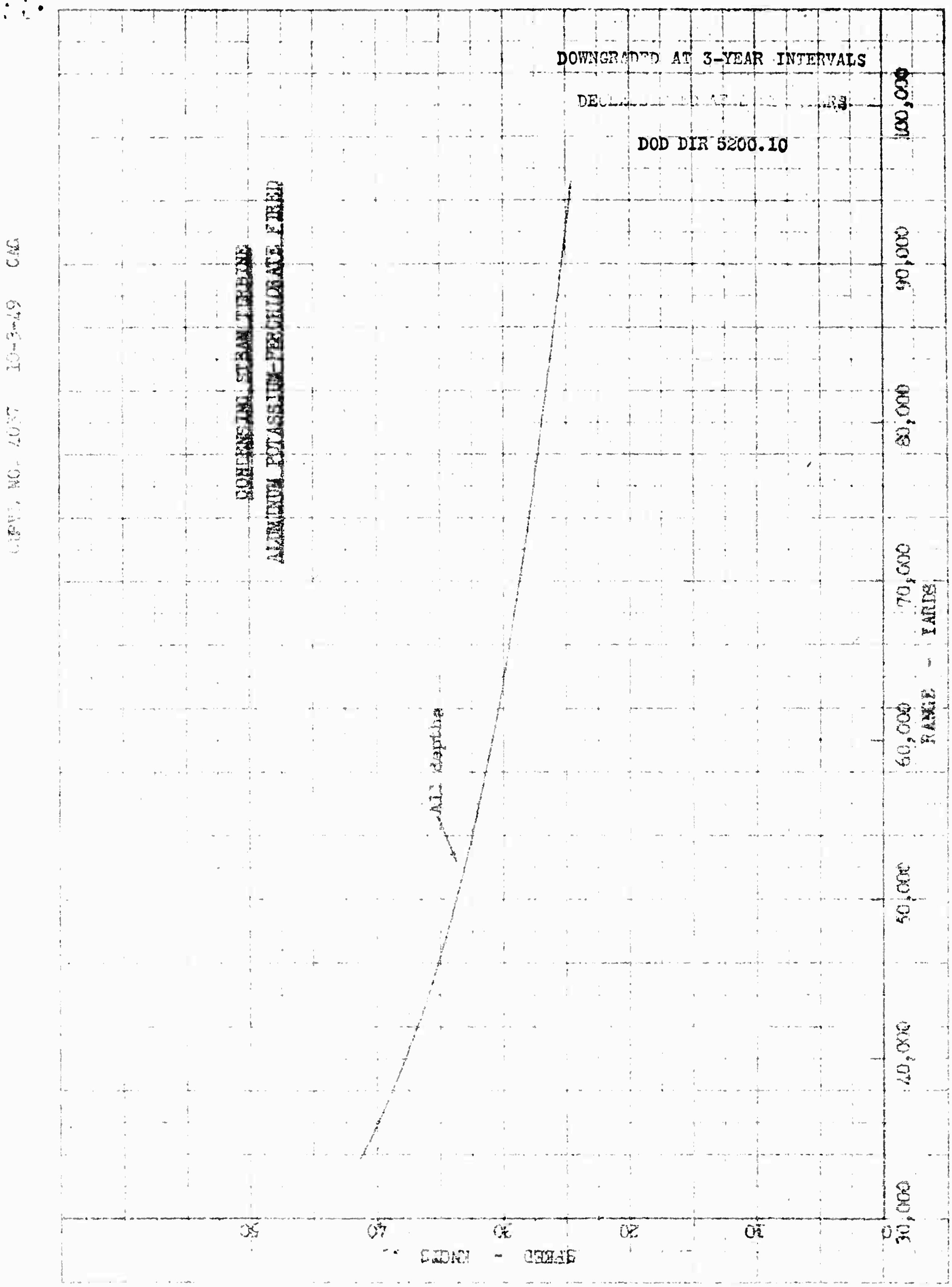
5000

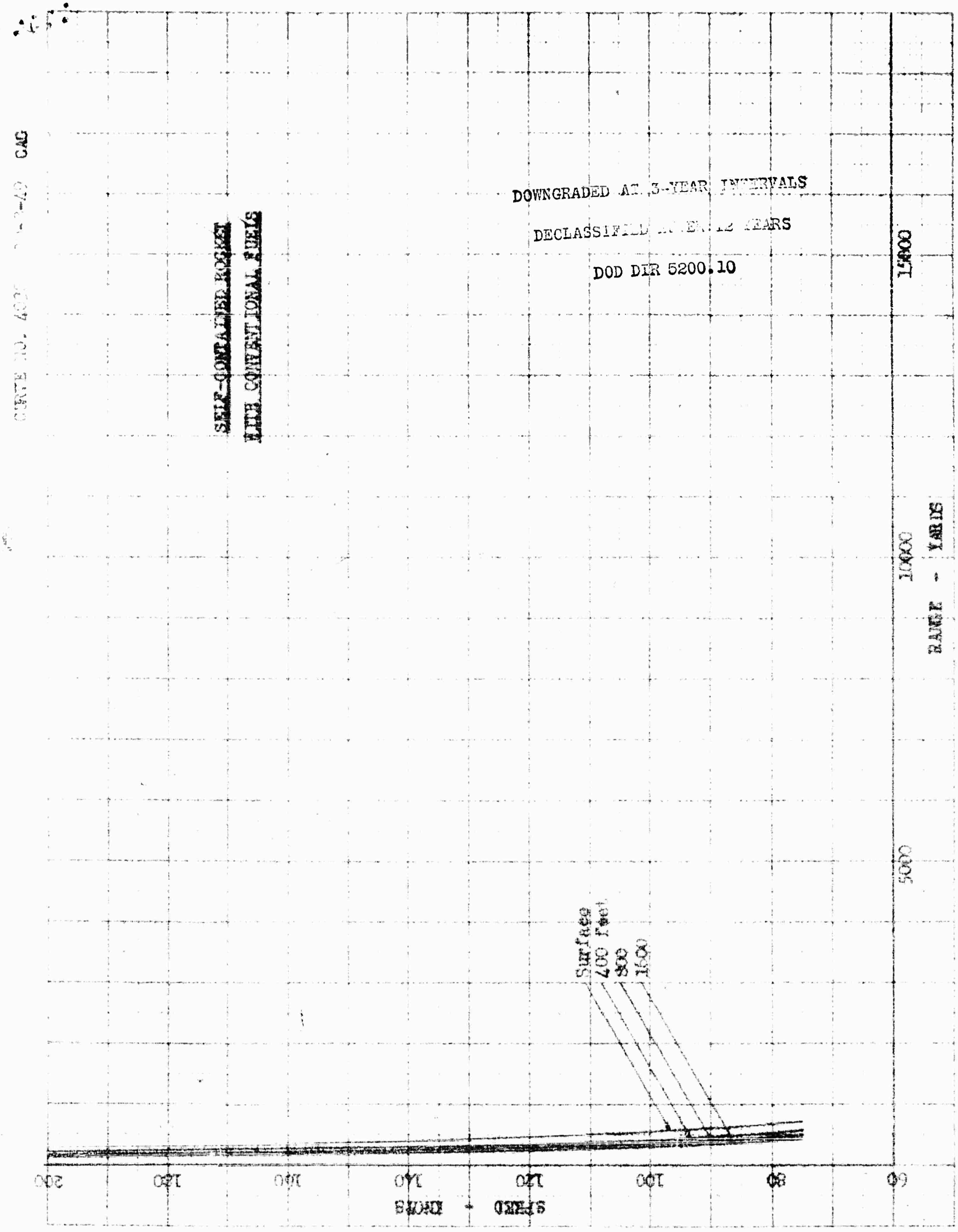
RANGE - YARDS

Sea Level
800 f/sec
K=0

200 180 160 140 120 100 80 60

SPEED - KNOTS





460
463

47304

VIA AIR MAIL

(C)

CONFIDENTIAL
SECURITY INFORMATION

ONR:Pasa/PSC:lw
L4-3/31
Serial SC-1604
9 July 1952

SECOND ENDORSEMENT on Aerojet Eng Corp Conf ltr PW-2193:bk of 25 June 1952

From: Director, Office of Naval Research Branch Office, Pasadena
To: Chief of Naval Research (Code 463)

Subj: Proposal for Range Testing Hydroduct and Hydroductor Test Vehicles

1. Forwarded.

2. It is understood that overtime premium to accommodate the Aerojet 44-hour standard work week is placed in the item of "overhead".

3. It is recommended that favorable consideration be given the support of the work proposed in the basic letter. However, in view of the large expense connected with the preparation and instrumentation of a test range at the Naval Ordnance Test Station Morris Dam facility and the firings conducted thereafter, it is suggested that every effort be made to obtain the cooperation of the Bureau of Ordnance in the support of this portion of the program, particularly since the test facilities will probably remain at Morris Dam and will be useful on other Bureau of Ordnance projects.

Wm. A. RICE
By direction

BAR, Pasadena
Serial 813-Q
L4-2(B)
LWM:mlb

JUL 3 1952

CONFIDENTIAL

FIRST ENDORSEMENT on Aerojet Eng. Corp. Conf ltr PW-2193:bk of 25 June 52

From: Bureau of Aeronautics Representative, Pasadena
To: Chief of Naval Research
Attn: Code 463
CDR F. B. Tucker
Via: Commanding Officer
Office of Naval Research
Pasadena, California

Subj: Proposal for Range Testing Hydroduct and Hydroductor Test Vehicles

1. Forwarded.

L. W. Mullane

ACTING

DOWNGRADED AT 3-YEAR INTERVALS

DECLASSIFIED AFTER 12 YEARS

DOD DIR 5200.10

CONFIDENTIAL SECURITY INFORMATION

CONFIDENTIAL

Aerojet

ENGINEERING CORPORATION

AZUSA CALIFORNIA • TELEPHONES LOS ANGELES CUMBERLAND 3 2755 • AZUSA FLEETWOOD 4 1211

PW-2193:bk

June 25, 1952

To: Office of Naval Research
Department of the Navy
Washington 25, D. C.

Attn: Code 463
Commander F. B. Tucker

Via: (1) Bureau of Aeronautics Representative
15 South Raymond Avenue
Pasadena 1, California

(2) Office of Naval Research
Pasadena Branch Office
1030 East Green Street
Pasadena, California

Subject: Proposal for Range Testing Hydroduct and Hydroductor Test Vehicles

Reference: (a) Aerojet Conf Ltr
PW-2192 dtd 6/25/52

1. Recent conferences in Washington, in which representatives of the Office of Naval Research, the Bureau of Ordnance and Aerojet participated, have resulted in formulation of a tentative program for development of the hydroduct and hydroductor power plants, and range testing of the articles developed. Accordingly, Aerojet is pleased to submit its proposal for the desired range testing.

2. It is generally understood that the hydroduct and hydroductor are primarily propulsion systems, however, the nature of these systems is such that the design of the test vehicle must consider both interior and exterior ballistic requirements in relation to the motor design for proper performance of the complete unit. Aerojet has developed and fired successful motors of this type, which ran with outstanding propulsive performance.

ONR

PW-2193:bk
June 25, 1952

C. 1. Range firing of the free-running Alclo hydroduct test motor in the Morris Dam Torpedo Range - As many as 75 to 100 firings of the test motor are planned for the coming year. These rounds will be fired to determine velocity, range, trajectory, dispersion and other ballistic characteristics of the test motor.

2. Analysis and presentation of the statistical data obtained from the Range Firing Program.

6. It is proposed that the range testing program outlined herein be conducted on a term type cost-plus-fixed-fee procurement. It is suggested that the work be performed under a new contract or by Amendment to Contract N6ori-10. The estimated costs for the twelve (12) month period are broken down below.

Direct Labor

Engineering	11,850 hrs @ $3.21	$38,038.00	
Other	35,470 hrs @ 2.23	79,098.00	
			$117,136.00
Direct Labor Overhead	113%		132,363.00
Material			30,000.00
Range Firings at Morris Dam			200,000.00
Administrative Expense	6%		28,769.00
		Estimated Cost	$508,268.00
Fixed Fee	10%		50,826.00
		Total	$559,094.00

7. Labor rates used in this proposal are weighted averages for the groups of personnel anticipated to be concerned with performance of the program of work outlined. Overhead rates are based upon Aerojet's recent accounting experience. This proposal assumes that work will be performed on the basis of Aerojet's extended work week in effect at that time. Currently Aerojet's standard work week is forty-four (44) hours.

8. Should the government find this proposal acceptable but be unable to formalize action thereon within thirty (30) days from this date, it is respectfully requested that Aerojet Engineering Corporation be permitted to review it for currency and applicability at that time.

ONR

PW-2193:bk
June 25, 1952

3. In furtherance of the recent conferences, it was decided to divide the hydroduct program into three phases which would be delineated in separate proposals from Aerojet to the Navy Department. Phase I is to comprise the continuation of the basic development of the power plants and the propellant and is being proposed to the Office of Naval Research, Power Branch, Code 429 reference (a). Phase II is to involve range testing of the experimental motors and programs closely associated therewith. This phase is for the Office of Naval Research, Armament Branch and is the subject of this proposal. This proposal is broken down into subdivisions such that the support can be supplied jointly by the Office of Naval Research and the Bureau of Ordnance, if desired. Phase III is for a prototype hydroduct program of approximately two years' duration. This phase is for the Bureau of Ordnance, and involves press works construction for propellant manufacture and prototype motor production and tooling for the delivery of approximately 100 hydroducts for proof testing and 500 hydroducts for service evaluation.

4. The three phases together make up an integrated program which will bring about the delivery of hydroducts to the Navy in the most efficient and economical manner. In the course of development when the hydroductor becomes a reality, it will be added to the hydroduct in the succeeding programs of the three phases.

5. Phase II, which is the subject of this proposal, is for the fabrication and range testing of the hydroduct motor. This program will take the following course, for a period of twelve (12) months:

A. 1. Design a series of hydroduct test motors to conform with the results of the interior and exterior ballistic developments of Phase I, reference (a). Designs will be changed or modified as development of better motor performance or improved grain formulation progresses.

2. Design a free-running Alclo hydroductor test motor when the development of the interior and exterior configurations of the jet condenser section have progressed to a satisfactory point.

3. Fabricate the required number of test motors to adequately prove each new development in the design. At the present time, it is felt that recovery of the test motors will be feasible. Therefore, a complete series of tests can be made on each model without fabricating a great number of units as each one can be reloaded and fired again.

B. 1. Preparation and instrumentation of the Torpedo Range at the Morris Dam Test Facility of the Naval Ordnance Test Station - During the month of June 1952, two firings of the free-running 4.5-inch Alclo hydroduct are contemplated to check out the instrumentation presently available on the Torpedo Range. It is felt that the type of instrumentation used on these two tests will be adequate for the subsequent test program but that some modifications and also normal repairs will be needed during the program.

ONR

PW-2193:bk
June 25, 1952

9. Should the Office of Naval Research desire further information concerning this proposal Aerojet will be pleased to provide it upon request.

AEROJET ENGINEERING CORPORATION

W. E. Zisch
General Manager

STANDARD FORM NO. 64

(d)

Office Memorandum • UNITED STATES GOVERNMENT

CONFIDENTIAL

TO : File NR234004

DATE: 31 Aug 1953

FROM : C. E. Burns

SUBJECT: Range Testing of "Alclo" Hydroduct and Hydroductor - Comments Concerning

1. Aerojet's proposal of 25 June 1952 to fabricate and range test the Hydroduct test vehicle is an outgrowth of their earlier efforts in 1949 to initiate a development program in underwater propulsion. At that time, development was not undertaken in view of the Hydrodynamic Program at C.I.T. which was just starting. Since then, the C.I.T. program has produced little basic information of a reliable nature and this coupled with the development mindedness of our organization makes this project some-what of a likely bet (even though debatable).

2. Unfortunately, the initial cost of $317,000 of Armament Branch funds plus $200,000 of hoped for BuOrd funds does not feeze us since a weapon is needed and who knows but this is it. If some of the basic questions set up for C.I.T. to answer had been answered we would be in a much stronger position. To merely hope to improve on the unguided rocket work of the Germans and NOT's without developing basic information can result in a costly O.S.R.D. type of development for which we are not prepared financially or technically. Since it is not my responsibility, I can only hope to get as much for our money as possible, and let the chips fall where they may.

3. For the record, it is desired to point out that the Hydroduct as an underwater propulsion device driving an unguided rocket like body is deficient as follows:

(a) Difficulty of controlling velocity in water to insure the proper generation of steam, i.e. burning of propellant, delivery of water (coefficients of discharge).
(b) Lack of detail knowledge of effect of jets (condensing and/or noncondensing) on rocket like body.
(c) Effect of condensing and/or noncondensing rates of gases on velocity.
(d) Effect of Yaw on frontal orifice and internal orifice water discharge.
(e) Method of establishing hydrodynamic configuration for both Hydroduct and Hydroductor.
(f) Effect of Yaw on trajectory.
(g) Basic data upon which to design the jet condenser end of Hydroductor.
(h) Probable launching and running velocity limits.
(i) Effect of water depth on launching depth limits (i.e.) depth insensitivity.
(j) Effect of external and internal finishes on reproducibility of performance.

4. I plan to discuss at a later date as I may be unduly pessimistic.

C. E. Burns

CONFIDENTIAL

STANDARD FORM NO. 64

(e) (f)

Office Memorandum • UNITED STATES GOVERNMENT

CONFIDENTIAL SECURITY INFORMATION

CONFIDENTIAL - SECURITY INFORMATION

ONR:463:HB:jm
NR 234-004

TO : File (NR 234-004)

DATE: 10 November 1953

accept file

FROM : LT H. Bucknell, USN

SUBJECT: Visit to Aerojet-General Corporation Facility at Azusa, California, period 26 October thru 30 October Regarding Contract Nonr 1002(00) - Hydroduct

1. Visits were made to the Azusa plant during subject period. The following is reported:

a. Launcher design is proceeding rapidly and shows every prospect of success. A method has been evolved for ensuring additional stability of the missile in the launcher barrel.

b. A test stand is partially completed for the plant testing of the launcher.

c. It was stated that hydroductor firings can be expected to proceed upon the opening of the Morris Dam Range.

2. As instructed, the Company was informed of the following points:

a. Their new proposal had been afforded scientific approval by Code 463.

b. 150 primers M13-2 had been ordered for modification by BuOrd. Aerojet was requested to contact Seal Beach as to the details of modification.

c. It was desired that further reports be classified no higher than "CONFIDENTIAL" unless containing information as to operational characteristics or ballistic test results. Monthly reports were to be eliminated upon receipt of the new contract so stating (Note: ONR Pasadena questions the wisdom of this) -- reports then to be made as necessary only.

d. It was desired that a range test program be forwarded to Code 463 as soon as possible.

e. The $85,000 in BuOrd funds remaining at NOTS was to be used up by 30 June 1954. (Note: ONR Pasadena questioned the wisdom of this statement.)

f. The priority of work at the NOTS range was to be:

(1) Hydroductor firings to evolve a reproducible pattern

(2) Launcher tests if work progresses rapidly enough

(3) Hydroduct firings

How can firings evolve a pattern without internal analyses?

CONFIDENTIAL
SECURITY INFORMATION

(e)

ONR:463:HB:jm
NR 234-004
10 November 1953

Subj: Visit to Aerojet-General Corporation Facility at Azusa, California, period 26 October thru 30 October Regarding Contract Nonr 1002(00) - Hydroduct

(Note: Concerning hydroduct firings, ONR Pasadena expressed the opinion that Aerojet might unnecessarily fire hydroducts and informed me that the mention of possible hydroduct firings was in direct contrast to Mr. Wiesner's instructions to Aerojet in which he stated positively that no further consideration of the 4".5 hydroduct was desired by ONR --- this should be clarified.)

g. The major decisions resulting from the BuOrd, CNO, ONR hydroduct meeting.

h. A letter was desired describing the possibilities of utilizing the NOTS press for the pilot manufacture of large ALCO grains. (Note: ONR Pasadena was requested to check on this also with NOTS.)

i. A letter was desired describing the reasons for using the M-6 propellant.

j. Early information was desired by Code 463 if launcher work progressed rapidly to permit a reasonable expansion of the program provided significant gains could be achieved over those already contracted for.

k. It was desired that further "selling" of the hydroduct as a weapon be held in abeyance pending completion of various analyses.

3. The Company requested:

a. That they be informed informally as to whether the Navy was interested in hydroduct as a weapon per se or actually only in hydroductor (ie. for which is San Clemente Range intended?)

b. The memo formerly prepared for transmittal to NOL regarding the burning rates of propellants, etc. be forwarded to NOL as previously requested.

c. Code 463 be informed that regarding launcher design:

(1) The gas generator was the critical item.

(2) 20 or 30 burning tests have been completed on the M-6 propellant.

d. There may be prospect of reducing, or perhaps eliminating, the fall of hydroduct trajectory by the design of a "neutrally buoyant missile".

e. There may be prospect of utilizing shaped charges underwater for hydroduct (in contrast to DuPont tests). This is based on recent NOTS tests.

H. BUCKNELL
Lieutenant, USN
Armament Branch

Copy to:
LCDR Killingsworth, ONR/Pas

DEPARTMENT OF THE NAVY
BUREAU OF ORDNANCE
WASHINGTON 25, D. C.

(f)

23452 463 opto 429

IN REPLY REFER TO
Re3-GBP:emc
C10-1/6
Ser

CONFIDENTIAL
From: Chief, Bureau of Ordnance

To: Director of Naval Intelligence
Chief of Naval Operations
Op 922F2, Pentagon
Washington 25, D. C.
(Attn: E. R. Shute)

30992

5 DEC 1956

Subj: Report on Hydroduct Program; forwarding of

Encl: (1) Re3-d-GBP:bc rpt. of 27 Dec 1955 "Hydroduct Program, Status of and Summary of Reports for"

1. In response to your telephone request of 5 November, 1956, there are forwarded herewith some informal notes (encl. (1)). These notes were prepared in December, 1955 for personal use in connection with the Bureau of Ordnance work, and are somewhat sketchy. If detailed and up-to-date information is needed, it is suggested that the cognizant personnel in the Office of Naval Research be contacted.

F. S. WITHINGTON

A. WERTHEIMER
By direction

Copy to:
ONR (Armament Branch)
ONR (Power Branch)

CONFIDENTIAL

23452

Re3-d-GBP:bc

27 Dec 1955

CONFIDENTIAL

Subj: Hydroduct Program, Status of and Summary of Reports for

Ref: (a) NOTS confi ltr P8084/MVR:hh, X25/L10 Ser 0851 of 14 Dec 1955 to ONR (Code 463) - "Aerojet General Corporation, Hydroductor Test Program".
(b) Confi. ltr of 22 Jan 1954 from Lt. Robert E. May to CNO - "The Use of Rocket Type U/W Missiles by Small Escort Vessels as a Primary ASW Weapon" (BUORD Serial 020454 0461)

Encl: (1) Summary of technical reports under Contract N6ori-10
(2) Summary of technical reports under Contract Nonr-1002(00)
(3) Notes on Hydroduct Program (typed 10/28/55)

1. The vapor-jet hydroduct is an underwater propulsion device in which free water flowing through a submerged duct, either reacts with a hydro-fuel to generate steam or is converted to steam by the heat of reaction of a solid propellant. Thrust is produced by the expansion of the steam to ambient pressure. An initial forward velocity of the hydroduct is necessary for building up ram pressure before self-operation can be obtained. Development work was done using both lithium and Alclo propellant as hydrofuels.

2. Aerojet uses the term "vapor-jet" in contradistinction to hydroducts designed to operate on the expansion of a bubbly mixture of gas and water (as in CIT report by R. G. Anderson, C. W. Rush, and T. R. McClellan, Development of a Hydroduct dated 1947). The compressibility effects in a gas-water mixture do not permit the development of high jet velocities that can be obtained with a vapor jet.

3. The Hydroduct was evolved by Aerojet under contract Noori-10. This contract was formerly under ORI and later under the ONR, Power Branch. Under the contract research, development and testing have been done on the following projects A--L:

A. Direct Hydropulse
B. Gaseous and Inverted Hydropulse
   a. Gasoline - air)
   b. Compressed air) Gaseous hydropulses
   c. Steam)
   d. Nitromethane)
   e. Water-reactive fuel (Inverted hydropulse)
C. Hydroturbojet
D. Chemical work

E. Reaction Experiments with Lithium-Water Systems
F. The 80-ft. rotating boom
G. The Hydroduct (includes Lithium fueled Hydroduct, Alclo fueled Hydroduct, and Hydroductor)
H. Fuels for U/W Propulsion (includes subprojects on Alclo, Lithium, Instantaneous melting of Lithium, and Alclo grain preparation for the Hydroductor.)
I. The Alclo-Fueled Submarine Power Plant
J. Vertical Steam Generator Mk III
K. Solid-Propellant Gas-Turbine Torpedo Power Plant
L. High-Speed, Long Range Torpedo Design Study

The only projects now being worked on are G, K, and L. The other projects have either been completed, transferred to a development Bureau, or discontinued. A summary of Aerojet's technical reports under N6ori-10 is given by enclosure (1).

4. Free-flight range testing of the hydroduct and hydroductor and the development of a recoilless gun launcher have been carried out under the Armament Branch of ONR, Contract Nonr-1002(00). A summary of the technical reports under this contract is presented in enclosure (2). A fairly large number of free-flight launchings of hydroduct has been carried out, but only about six hydroductor launchings have been made. Services to Aerojet for the range testing have been provided by NOTS. BUORD has supplied financial assistance for the range firings. NOTS has prepared the following report on the hydroduct firings:

"U/W Performance of the 4.5-Inch Alclo Hydroduct Test Missile" by Robert H. Hornidge - 6 June 1955 (NAVORD 3510, NOTS 1139). Secret.

Abstract (Confidential): 56 free-flight U/W performance tests were conducted at the Morris Dam Test Range of the 4.5-Inch Alclo Hydroduct U/W Rocket. The test missile, a scale model of the prototype, was designed and developed by Aerojet-General Corporation of Azusa, California. Analysis of the data obtained from these tests indicated that the dispersion of the test missile in the horizontal and vertical planes was satisfactory. The U/W rocket range at Morris Dam is described and the results of the test program are presented.

5. The work on the hydroduct program is tapering off and no further sponsorship is contemplated after FY 56. The missile and launcher are regarded as approximately ready for placing on the shelf or transferring to BUORD. Remaining work now planned consists of (a) further proof testing of the recoilless gun launcher (using hydroduct), (b) a few firings to test the overall performance and expected insensitivity to depth of the hydroductor. Ref (a) indicated that 15 hydroductor launchings are planned during the first half of 1956.

6. Applications of the hydroduct propulsion system to weapons have been proposed by Aerojet and in reference (b). As yet no hydroduct-powered weapon has been found to be clearly superior to competitive arament.

7. The Naval Ordnance Test Station report on the free-flight firings are of some ballistic interest in that they supply some information on the trajectories of slowly spinning, powered, U/W vehicles. The trajectory data given are experimental. No calculations using measured forces and equations of motion were made.

ENCLOSURE (1) DOD DIR 5200.10

Summary of Aerojet Technical Reports under Contract N6ori-10

References

1. Aerojet Engineering Corporation Report No. R-68 - "Research and Development on the Hydropulse" - July 30, 1946 (for Jan-June 1946 work) - Contract ORI N6ori-10.

2. Aerojet Engineering Corporation Report No. R-69 - "Research and Development on the Hydropulse" - 31 Dec 1946 - (for July-Dec 1946 work) - ONR Contract N6ori-10.

3. Aerojet Engineering Corporation Report No. R-77 - "Research and Development on the Hydropulse" - 30 June 1947 - (for Jan-June 1947 work) - ONR Contract N6ori-10.

4. Aerojet Engineering Corporation Report No. R-86 - "Research and Development on the Hydropulse" - 31 Dec 1947 (for July-Dec 1947 work) ONR Contract N6ori-10.

5. Aerojet Engineering Corporation Report No. R-97 - "Research, Development and Testing of U/W Propulsion Devices" - 3 September 1948 (for Jan-June 1948 work) - ONR Contract N6ori-10.

6. Aerojet Engineering Corporation Report No. 357 - "Research, Development, and Testing of U/W Propulsion Devices" - 18 Feb 1949 - (for July-Dec 1948 work) - ONR Contract N6ori-10.

7. Aerojet Engineering Corporation Report No. 387 - "Research, Development, and Testing of U/W Propulsion Devices" - 7 September 1949 (for Jan-June 1949 work). ONR Contract N6ori-10.

8. Aerojet Engineering Corporation Report No. 419 - "Research, Development, and Testing of U/W Propulsion Devices" - 17 Feb 1950 - (for July-Dec 1949 work) - ONR Contract N6ori-10.

9. Aerojet Engineering Corporation Report No. 464 - "Research, Development, and Testing of U/W Propulsion Devices" - 31 July 1950.

10. Aerojet Engineering Corporation Report No. 495 - "Research, Development, and Testing of U/W Propulsion Devices" - 12 Feb 1951 (for July-Dec 1950 work).

11. Aerojet Engineering Corporation Report No. 533 - "Research, Development, and Testing of U/W Propulsion Devices" - 15 Aug 1951 (for Jan-June 1951 work).

ENCLOSURE (1) Cont'd

12. Aerojet Engineering Corporation Report No. 579 - "Research, Development, and Testing of U/W Propulsion Devices" - 7 Feb 1952 - (for July-Dec 1951 work).

13. Aerojet Engineering Corporation Report No. 631 - "Research, Development, and Testing of U/W Propulsion Devices" - 12 Aug 1952 - (for Jan-June 1952 work).

14. Aerojet Engineering Corporation Report No. 675 - "Research, Development, and Testing of U/W Propulsion Devices" - 9 Feb 1953 - (for July-Dec 1952 work)

15. Aerojet-General Corporation Report No. 725 - "Research, Development, and Testing of U/W Propulsion Devices" - 5 Aug 1953 (for Jan-June 1953 work)

16. Aerojet-General Corporation Report No. 791 - "Research, Development, and Testing of U/W Propulsion Devices" - 26 Feb 1954 (for July-Dec 1953 work)

17. Aerojet-General Corporation Report No. 859 - "Research, Development, and Testing of U/W Propulsion Devices" - 16 Aug 1954 - (for Jan-June 1954 work)

18. Aerojet-General Corporation Report No. 938 - "Research, Development, and Testing of U/W Propulsion Devices" - 17 Feb 1955 (for July-Dec 1954 work)

19. Aerojet-General Corporation Report No. 1008 - "Research, Development, and Testing of U/W Propulsion Devices" - 27 Sept 1955 (for Jan-June 1955 work)

Reference 1. Work was performed as follows:

A. Direct Hydropulse. (Definition: The direct hydropulse is an U/W propulsive device in which water reactive, gas producing chemicals are injected intermittently into the water within a submerged duct equipped with mechanical valves at the forward end). Work was continued using liquid NaK_2 as fuel. The unit being tested consists of two alternate-firing 4-in. diameter straight pipe barrels with entrance valves and injectors. A slant faced reed type entrance valve resulting in improved streamlining of the front of the unit has been developed. Several different types of injectors were tried. As a result of the work the speed with which the hydropulse drove the rotating boom was increased from 10 kts to 20.3 kts during this report period. Specific impulse was low compared with surface ship engine-propellor combinations.

B. Gaseous and Inverted Hydropulses. These hydropulses use high temperature high pressure gases from an external reaction chamber. The gas from the chamber enters a water-filled duct and discharges water from the tail of the duct. The duct for this work was 4 in. diameter straight pipe. The interior of the duct is supplied with water by valves in the nose of the duct. Gases being tried are obtained from -

a. gasoline-air
b. compressed air
c. steam
d. nitromethane
e. water-reactive fuel

The water-reactive fuel being tried is NaK_2. When a water reactive fuel is used the unit is called an inverted hydropulse.

Units corresponding to a--e have been fabricated but few tests have been made as yet.

C. Analysis of the Hydroturbojet Cycle. In the hydroturbojet a turbine drives a water pump and a propellant pump which raise the pressure of the water and propellant to reaction chamber pressure. Chemical reaction then takes place in a reaction chamber from which most of the gas flows to a nozzle expansion to produce thrust and the remainder of the gas flows to the turbine.

The specific impulse of the hydroturbojet is computed for the case where all exhaust products are in the gas or vapor states. (Cases where water is contained in the exhaust product were not computed due to lack of necessary information on two phase systems.)

Reference 2.

A. Direct Hydropulse. Peak chamber pressures have been increased and the unit has driven the boom at speeds of 27 kts. Work was done to replace the relatively weak alloy NaK_2. Molten lithium indicates that it will be a powerful propellant.

B. Gaseous and Inverted Hydropulses.

a. The gasoline air hydropulse has been considerably improved. Thrust has reached 50 lbs.

b. Intermittent valving of cold compressed air worked well.

c. The steam hydropulse was found to be inoperative because the steam condensed immediately upon admission to water.

d. The nitromethane hydropulse does not work well due to burning of seals and sticking of metal parts.

e. Inverted Hydropulse. Plans are to try water-molten lithium instead of NaK_2. A reaction chamber for this purpose has been built and tested.

C. Hydroturbojet. Computations were continued and indicate a high power high speed torpedo propulsion system of this type could be built.

D. Chemical Work to develop new fuels has been authorized under the contract and was started. Studies are being made of (a) lithium alloys (b) temperature dispersion, and (c) Ethyl aluminum sesquihydride.

a. The hydropulse is being operated on NaK_2 (32.2 % Na and 66.8% K). The addition of lithium is being investigated as a means of increasing the gas yield. Tests indicate that the melting point of the lithium - NaK_2 alloy may be higher than that of lithium alone. The melting point of lithium is about as high as it appears feasible to have in a water reactive fuel.

b. A study of the rate of reaction of metals with water as a function of temperature was undertaken to determine if a critical temperature existed above which the rate was greatly accelerated. It was felt that if such a temperature did exist, metals of lighter equivalent weight than that of NaK_2 could be used. Preliminary experiments indicated that above an approximate constant ratio of temperature of metal to melting point of metal, a metal would react explosively with water. Further tests showed that proper mechanical dispersion of the alloy in water could produce explosive reactions before the temperature ratio, previously found, was reached. This study lead to the idea of trying to eliminate the necessity that a hydropulse driven torpedo either carry water or pump in water for injection into the stream of fuel entering the reaction chamber of the hydropulse.

ENCLOSURE (1) Cont'd

c. A test lot of ethyl aluminum sesquihydride was prepared as a possible fuel substitute for aluminum borohydride. This substitution was recommended in OSRD Report 6207.

Reference 3.

A. Further work was done on streamlining duct entrance diffusors, types of entrance valves, and fuel injection. Also, tests were made using two fuels in lieu of NaK_2. Molten lithium showed good promise but ethyl aluminum sesquihydride did not come up to expectation, although its performance was slightly better than NaK_2.

B.

a. A thrust of 62 lbs. was obtained. Tests are now being carried out in a recently completed static test pit.

b. Discontinued.

c. Discontinued.

d. The nitromethane hydropulse tests were discontinued because of the great difficulty of valving the hot gas from the reaction chamber to the duct.

e. Proper operation was not obtained and work on this unit was discontinued.

C. Calculations were made for lithium. BUORD (under NOrd-9768) has picked up support of this work and no more computations are necessary under this contract.

D. Sufficient ethyl aluminum sesquihydride was prepared to enable the test of this compound in the hydropulse. Tests lots of aluminum borohydride are being prepared. Corrosion tests were made on metals and packing materials for use with molten lithium.

E. Lithium-Water Reaction Experiments. Very high specific impulses have been obtained from this fuel. The fuel could be used for a high speed long range torpedo. Gas generators suitable for experimentation with lithium have been investigated, and one gas generator using a solid lithium cartridge and water injection was built and tested.

Reference 4.

A. Work was continued using molten lithium, but no runs were made due to mechanical, electrical, and thermal difficulties.

B.

a. The performance was improved and the unit was used to drive at 15 ft. skiff at 6 kts.

E. Some work was done under E which may eventually be applicable to this unit.

D. Preparation of aluminum borohydride has been accomplished on a laboratory scale.

E. A lithium-water reaction chamber with a solid cartridge of lithium has been experimented with. Development of this type chamber is in a very early stage.

Work continued on continuous injection molten lithium reaction chambers. Tests verified theoretical values of performance.

F. The 80-foot rotating test boom. This boom is being built to permit the testing of larger and faster units than can be handled by the 40-ft. boom. The boom and channel are described. An appropriation was made to construct the facility after an estimate of cost was submitted to ONR.

Reference 5.

A. The bulk of the work was directed toward the use of molten lithium as a fuel. Many difficulties were overcome and a speed of 26.8 kts was attained on the boom.

B.

a. A static thrust of 145 lbs. was obtained, and a skiff speed of 7.6 kts was obtained.

D. Two fuel combinations have been prepared for testing in the gasoline-air hydropulse.

Factors affecting the preparation of sodium borohydride were determined during the study of preparation methods for the potential hydropulse fuel, aluminum borohydride.

E. Stable reaction of solid lithium and water was achieved. Gas generators using water reactive solid fuels were developed in anticipation of two uses: a pressurized gas source for driving a turbine in an U/W projectile such as a hydroturbojet and a thrust source for driving a jet-propelled missile.

F. Progress on construction of the facility is described.

G. The Hydroduct is an U/W propulsive device in which a hydrofuel is injected continuously into the water in a submerged duct. The duct is open at both ends permitting the flow of water through it. Forward velocity to produce ram pressure is required before operation can begin. The hydrofuel being considered is molten lithium. Thermo- and hydro-dynamic calculations have been made, and a 4-in. hydroduct design has been initiated.

Work on the vapor-phase hydroduct was proposed in order to develop a simple highspeed device with a high specific impulse. Experiments at several institutions has indicated that operation of a hydroduct at high speeds with a gas-water mixture is not feasible because of compressibility effects in a two phase flow.

At the point of fuel injection, the cross section of the tube is so designed that a stagnant region exists at nearly full ram pressure. The mixture ratio of 20:1 (water to lithium by weight) is such that the heat of reaction flashes nearly all the water to steam at the pressure of the stagnation region. Thrust is produced by the expansion of the steam and reaction products to ambient pressure. Only a small part of the water is used in the chemical reaction.

The external form of the hydroduct was determined from an extrapolation of Mk 40 torpedo minimum pressure coefficient data.

Reference 6.

A. The major effort was spent in developing motors powered with molten lithium. Several improved fuel injectors were built and tested and mathematical analyses of the internal operation of the hydropulse were made. A speed of 41.6 kts was maintained while producing 387 lbs. thrust.

B.

a. Further work was done on combustion chamber exhaust valves, water entrance valves, poppet valves, and the ignition system. One motor drove a 15 ft. boat at 8.2 knots. One unit gave a static thrust of 169 lbs. at a specific impulse of 32,000 lbs/(lb/sec).

F. Further descriptive material is given.

G. Further design computations were made and manufacture of some of the components were completed.

The motor under development is termed a vapor phase hydroduct as distinguished from the hydroduct of Anderson, Rush and McClellan (CIT Report by R. G. Anderson, C. W. Rush and T. R. McClellan, Development of a Hydroduct dated 1947.) which operates with a bubbly water mixture. The compressibility effects in a gas-water mixture do not permit the development of the high jet velocities that can be obtained with a vapor exhaust.

Reference 7.

A. A speed of 63.5 kts was attained. The thrust was brought to 1380 lbs. Other performance data is: Specific impulse = 3300 lbs thrust per lb of fuel per sec., Specific power = (I_{sp} x V) = 340,000 and specific fuel consumption W_f = 5.8 lbs of fuel/thrust horsepower hour.

B.

a. Emphasis was placed on the development of a light weight unit for use on small boats. A 15 ft. boat was driven at 8.1 knots. In a static test, a 180 lb. thrust was obtained at I_{sp} = 32,000 lb-sec/lb.

G. An extensive static test program was carried out. A mixture of Al metal and potassium perchlorate particles (Alclo) was recommended for study as a fuel due to its high energy density.

Reference 8.

A. Lithium is an excellent fuel. A W_f value of 5.1 was obtained which is superior to the value for most modern torpedoes. Lithium is not available in quantity and is thus not useful for ship propulsion. Attention was directed toward the use of magnesium, Al, and their alloys as possible substitute fuels.

G. Further static tests and mathematical analyses were made.

Tests were made to determine the hazards involved in handling and use of Alclo. It is recommended that the steam injector principle (Aerojet Research TM No. 60 - The Hydroductor Propulsion System for U/W Missiles of 9 Jan 1950 to ONR) be applied to the hydroduct to increase performance of hydroduct with increase in depth.

Reference 9. (This reference not obtained.)

Reference 10.

A. No dynamic test runs were made.

G. U/W static testing was completed and dynamic testing on the rotating boom were successfully begun on the (lithium) hydroduct.

I. Development of low-melting and high-energy density alloys was continued.

Development work was continued on Alclo.

ENCLOSURE (1) Cont'd

A study was made of the vibration (singing) of thin submerged struts or vanes. A complete report will be made under separate cover as discoveries have been made which are of importance in the design of marine propellors, struts, and vanes.

Tests were made of the drag of a stepped body with air flowing through the shell. Extrapolations indicate that above 100 kts a reduction in drag can be effected.

Reference 11.

B.

a. Studies are being made with the aim of obtaining a supercharged inlet mixture to improve the efficiency of the device.

G. Lithium Hydroduct. Practical operation of this hydroduct was demonstrated by dynamic test-firings on the rotating boom.

It was found that a critical-pressure exhaust nozzle (nozzle throat area contracts but does not then expand) is operable. This shows that a variable exit-area exhaust nozzle is not necessary to provide effective expansion at varying back pressures if external flow is subsonic and the ratio of the ram pressure to the difference between the nozzle-throat pressure and the ambient pressure is greater than one.

Alclo Hydroduct. Basic operating characteristics of the Alclo motor were determined by tests. Using this basic motor data, an Alclo Hydroduct was designed. Design studies of steam-injector condensers were begun for purpose of trying to make the hydroduct insensitive to depth.

H. Alclo. The effects of compacting pressure and of propellant temperature on the burning rate of Alclo were measured. Work was done on a 400-ton hydraulic press designed for pressing Alclo charges in sizes large enough for full-scale hydroduct testing.

Lithium alloys and other alloys were studied to get basic data such as melting temperature.

I. Work was concentrated on the design and building of a test steam-generating unit.

A report (Aerojet Research TM No. 76 - A Study of Vanes Singing in Water, 3 May 1951) was submitted to ONR.

Reference 12.

B.
a. A motor has been designed and its construction is 90% completed which will operate with compressed air, at 100 psig, and gasoline.

G. Lithium Hydroduct. The practical operation of the hydroduct using the critical-pressure exhaust nozzle was established by continued successful testing.

Alclo Hydroduct and Hydroductor. Testing of 2-in. and 4-in. motors was continued to determine basic data. A free running Hydroduct missile was designed for range testing at San Clemente Island to provide data for comparison with rocket data. A steam-injector condenser was fabricated and a test set up for the condenser is almost complete. The design of a 4.5-in. Alclo hydroductor for free running tests was initiated.

H. Testing of lithium alloys was continued. Means of chemically melting rather than electrical melting of lithium were studied.

I. A test steam generator has been assembled and is ready for testing. The problem of obtaining a burner for Alclo in powdered form was studied.

Reference 13.

B.
a. Dynamic testing of a new compressed air-gasoline motor was begun.

G. Alclo Hydroduct. The hydroduct test vehicle was successfully tested at San Clemente and at NOTS.

Alclo Hydroductor tests continued to get info on optimum water-to-steam ratios, size of condenser, limiting discharge pressures, and stability properties.

H. Alclo Studies. Work was done on increasing the burning rate and energy density of Alclo. Improvements were made in the 400-ton hydraulic press used in pressing grains.

I. A number of feeders have been built and tested to produce steady flow of constituents to the burner to eliminate flame "flicker."

J. The Vertical Steam Generator is a generator in which all water necessary for steaming as well as the Alclo heat source is contained in a chamber. When the Alclo is ignited and burns the surrounding water is instantly flashed into steam and discharged at the top of the chamber at a rate dependent upon the mass rate of burning of the Alclo and the exposed burning surface. Tests of a unit (Mk III) were conducted and the unit was shown to

be a practical power source of emergency power and for short-duration super-performance of any steam-powered vehicle. Power outputs in multiples of 500 hp and of durations in multiples of 30 sec. can be obtained by coupling units. A unit is an aid in the development of Alclo propellant in that it provides data on the burning characteristics of Alclo under pressure and on the steam generation process.

Reference 14.

B.

a. Mechanical improvements were made on the flap and air valves.

G. Alclo Hydroduct. Continued successful testing of the hydroduct test vehicle was carried out at Morris Dam. This work is reported under Contract Nonr-1002(00).

To increase the performance of the hydroduct, an Alclo motor incorporating water-spray injectors was designed and tested. The development of a short combustion chamber was undertaken to make room for the condensing section.

Hydroductor. Detailed drawings of the Hydroductor Mark I have been completed.

H. Alclo Studies. Work was done on a pressing technique which would result in consistently acceptable 3.75-in. diameter grains.

I. Several [illegible] have been tested with increasing success.

J. The practicality of the unit for driving a turbine was demonstrated. A unit is 1.75 ft^2 by 6 ft high and produces approx. 5 hp-hr of energy.

Reference 15.

B.

a. A unique fuel-vaporizing device has been developed. The air-control valve has been improved. The static thrust has been increased from 70 to 140 lbs. at 5 cps.

G. Alclo Hydroduct. Successful firings under Nonr-1002(00) continued at Morris Dam.

Work was done on the design and development of a short combustion chamber for use with hydroductor. A shorter combustion chamber is needed to make room for the condensing section of the hydroductor.

ENCLOSURE (1) Cont'd

Hydroductor. Tests of the small-scale steam-jet condenser was concluded. Numerous tests have been performed on the full-size steam jet condenser utilizing the 4 5-in. Alclo motor. The Hydroductor Mk 1 free-running missile has been completely fabricated.

H. Alclo Studies. Further improvements were made in the 400-ton hydraulic press.

I. The Alclo-fueled test steam generator was successfully operated

Reference 16.

B.

a. A brief summary of work from 1 April through 31 August 1953 is given. Work on this project was terminated at the direction of the Navy.

G. Alclo Hydroduct. Pictures were made of the ignition phase in an attempt to develop a better igniter. Full-ignition time was reduced from 750 to 55 millisec

Hydroductor. A new design employing condensation along a surface in the stream of the exhaust steam has been evolved and will be tested.

I. A small steam generator has been constructed as a test unit for the proposed, closed-cycle, steam-operated submarine propulsion system. The steam generator was successfully operated for half an hour. Work was terminated on this project at the direction of the Navy.

K. A solid-propellant torpedo power plant for the EX-2 was presented to BUORD in July, 1953. The system being tested is similar to the one proposed to BUORD. It consists of a gas generator, a turbine and reduction gear, and a speed controller. In the torpedo application an alternator and lubricating pump would also be required.

A small high-speed impulse turbine powered by the gaseous discharge of a high-energy, slow-burning solid propellant is the heart of a deep-running torpedo power plant under development.

A gas generator has been designed and an existing turbine and gear box have been modified. Testing has begun. The practicality of a turbine-driven power plant using energy from one of the AN-2000 series of Aeroplex propellants was demonstrated.

Reference 17.

G. Hydroductor Static tests of the full-scale steam-jet condensor have continued. An expanded static test station has been designed and is being built.

H. Alclo Gain Preparation for the Hydroductor. Emphasis was placed on quality control, improvements of pressing techniques, and igniter improvements.

K. All the power plant components have been designed and built. A mechanical turbine-speed controller has been built which should increase the operating time of the power plant at any torpedo depth less than 1000 ft.

Reference 18.

G. An expanded static-test facility was installed, making it possible to simulate depths down to 1000 ft. Three configurations have been extensively tested on the rotating boom. One design proved superior and was selected for further testing and possible application to a modified design of a free-running test missile.

H. Alclo Grain Preparation. Only limited work directly applicable to the hydroductor test firings was done.

K. During this period the objective was changed to compliment another program (NOrd-14993) and was to develop an optimum design speed controller suitable for use in a power plant for the Mk 41 torpedo.

Test pit equipment was improved. Some gas generator, speed-control valve, and complete engine tests were made.

Reference 19.

G. Hydroductor. Testing continued on a static-test motor of the same configuration as the motor section of the free-running hydroductor except for a difference in the area of the condensing-water scoop passages. Simulated depth changes were applied and the motor continued to operate, indicating depth insensitivity.

K. The objective of this program is to develop an optimum-design speed controller which will keep the speed of a solid-propellant torpedo engine constant during operation at depths from 0 to 1000 ft. The development of the speed controller augments the work of NOrd-14993, and in its final form it will be suitable for use with a power plant in a Mk 41 type torpedo.

A speed control valve was modified to operate hot gas directly from the gas generator. Tests were made in which speed was controlled to within 1.5%.

ENCLOSURE (1) Cont'd

L. The main objective of this project is to derive specifications for a 21-in. 75 kt. torpedo of 30,000 yd. range. The torpedo length is to be 123 in., the warhead weight not less than 600 lb, and the power plant to operable down to 1000 ft. The overall space shall be generally comparable to those for the modern anti-ship torpedo as printed in NOTS TM No. 1256.

Two types of propellant systems showed promise. One was hydrogen peroxide and diesel oil and another was the Aerojet solid propellant AN-2091AX. The latter was selected as more desirable. Propulsion is achieved by means of a high-speed, single stage impulse turbine driving a single-stage rear mounted external pump jet.

ENCLOSURE (2)

Summary of Aerojet Technical Reports for Armaments Branch of ONR under Contract Nonr-1002(00)

References

Aerojet General Corporation informal reports of progress on Contract Nonr-1002(00) as follows:

Report No. L2815-1 of 12 May 1953 - SECRET.
Report No. L2815-2 of 2 June 1953 - SECRET.
Report No. L2815-3 of 29 June 1953 - SECRET.
Report No. L2815-4 of 31 July 1953 - SECRET.
Report No. L2815-5 of 26 Aug 1953 - SECRET.
Report No. L2815-6 of 28 Sept 1953 - CONFIDENTIAL.
Report No. L2815-7 of 4 Nov 1953 - SECRET.
Report No. L2815-8 of 17 Dec 1953 - CONFIDENTIAL.
Report No. L2815-9 of 14 Jan. 1954 - CONFIDENTIAL.
Report No. L2815-10 of 12 April 1954 - CONFIDENTIAL.
Report No. L2815-11 of 10 March 1954 - CONFIDENTIAL.
Report No. L2815-12 of 22 April 1954 - CONFIDENTIAL.
Report No. L2815-13 of 27 May 1954 - CONFIDENTIAL.
Report No. L2815-14 of 1 June 1954 - CONFIDENTIAL.
Report No. L2815-15 of 30 June 1954 - CONFIDENTIAL.
Report No. L2815-16 of 5 August 1954 - CONFIDENTIAL.
Report No. L2815-17 of 26 August 1954 - CONFIDENTIAL.
Report No. L2815-18 of 28 Sept 1954 - CONFIDENTIAL.
Report No. L2815-19 of 1 Nov 1954 - CONFIDENTIAL.
Report No. L2815-20 of 24 Nov 1954 - CONFIDENTIAL.
Report No. L2815-21 of 29 Dec 1954 - CONFIDENTIAL.
Report No. L2815-22 of 7 Feb 1955 - CONFIDENTIAL.
Report No. L2815-23 of 25 Feb 1955 - CONFIDENTIAL.
Report No. L2815-24 of 4 April 1955 - CONFIDENTIAL.
Report No. L2815-25 of 29 April 1955 - CONFIDENTIAL.
Report No. L2815-26 of 25 May 1955 - CONFIDENTIAL.
Report No. L2815-27 of 7 July 1955 - SECRET.
Report No. L2815-28 of 2 Aug 1955 - CONFIDENTIAL.
Report No. L2815-29 of 30 Aug 1955 - CONFIDENTIAL.
Report No. L2815-30 of 5 Oct 1955 - CONFIDENTIAL.

Objectives:

A. Range testing of 4.5-in. Alolo hydroduct and hydroductor test missiles to determine range, velocity, trajectory, dispersion, and other ballistic characteristics.

B. Design of a recoilless gun suitable for launching hydroduct.

12 May 1953 (For Sept. 1952 through March 1953 work) - Secret Report L2815-1. The Alolo hydroduct was developed under N6ori-10 and was first fired at San Clemente (NOTS TM No. 661, 27 June 1952, Secret). Report L2815-1 summarizes the results of several Hydroduct firings at the Morris Dam Torpedo Range.

Launchings were made using a rail launcher and a rocket booster.

2 June 1953 (for April work). Eleven firings were made.

29 June 1953 (for May work). Ten firings were made.

31 July 1953 (for June work). Five firings made. Preliminary designs of a recoilless gun launcher for hydroduct or hydroductor were made.

26 Aug 1953 (for July work). No firings. Fire hazard. Work on recoilless gun continued.

28 Sept '53 (for August work)

A.

1. Fire hazard - no firings in August.
2. 10 hydroduct rounds previously fired were recovered by divers using magnetic locators. Recovery points added to trajectory.

B.

1. Calibration tests were made in a vented chamber to determine burning rate function of M6 propellant.

2. Test fixture fabricated and several muzzle closures of lucite tested. Diaphram scored in a star pattern broke satisfactorily when nose poked through it.

3. Firings of tests aland and assembly drawings being prepared.

4 Nov. 1953 (For Sept work) see Secret Report L2815-7.

Dec. '53 (For Oct. work)

A. No data.

B.

1. Vented chamber tests of M6 propellant completed and data being reduced to obtain burning rate function for chamber pressures of about 5000 psi.

2. Fabrication of test assembly of the launchers and launcher test stand about 25% complete.

3. Studies being made to compare slotted barrel with barrel large enough to accommodate full missile fin span. Slotted barrel looks more promising.

4. Three rail launchers used in San Clemente hydroduct firings being modified so hydroductor can be launched from dry chamber to simulate firing from the recoilless gun launcher.

Jan. '54 (For Nov. '53 work)

A.

1. The first 4.5-in. Alclo hydroductor was launched on Morris Dam torpedo range. Launching velocity was satisfactory, but the missile did not reach an equilibrium running condition. Missile recovered on bottom (depth about 80') after traveling only 250 ft. Apparently a vented flow of condensing water through the scoops was not established and drag was therefore excessive. Attempts to be made in future to keep water out of condensing chamber until the missile leaves the launcher as an initially water-free condensing chamber may help flow to start through the condensing water scoops. Studies to be made on rotating boom with the steam accumulator to check the design for starting and free-running operational stability.

B.

1. Fabrication of the test assembly of the launcher and the launcher test stand about 50% complete.

2. Mk 13 Mod 2 primers with the main black-powder charge removed have been received. These to be reloaded with varying amounts of black powder and tested with the gas generator. The gas generator design has been completed and released for fabrication.

3. The study and testing of closure diaphragms has been continued.

12 April '54 (For Dec '53 work)

A. Fire hazard - no tests.

B.

1. Fabrication of launcher test stand complete except for the thrust-calibration equipment. The load cell has been delivered. Design study being made of a ballistic recovery box for recovery of piston, dead weight, or dummy missile.

2. Design of slotted barrel and piston for the gun completed and released for fabrication.

March '54 (For Jan work)

A.

1. First firing of HDR No. L-1 (external condensing hydroductor) was attempted. Alclo grain failed to ignite.

2. Round reloaded with a new grain and launched. Round swerved to the left excessively; the only difference in this missile and hydroduct that might influence the trajectory is a pin bob (used in attaching fins to body) at 1.5° to steam jet. Rd. being reloaded with the "bob" support piers aligned with axis of missile.

B.

1. The gas generator for the recoilless-gun launcher was fired using only the primer, to determine the peak pressures from the primer. Mk 13-2 primer to be tested with M6 propellant.

2. Slotted barrel for the gun is about 50% complete.

22 April '54 (For Feb. work)

A. Hydroductor No. 2 (4.5 in. Alclo hydroductor with condensing water scoops and internal condensing section) launched on Morris Dam torpedo range. Water scoops were covered by shoes during launcher travel of missile. This system had been found satisfactory on rotating boom. $V_o \simeq 175$ ft/sec but missile did not run properly; hit bottom after about 250 ft fwd. travel. Vented flow of water through scoops evidently not established.

B. Firing tests of gas generator with 2-lb. charges of M6 propellant started. Various materials and methods of installation tried on burst closures for the generator nozzles. Starting pressures varied from 1000 to 1500 psi, and satisfactory ignition of the propellant was obtained with the Mk 13-2 primers. Tests with varying K - ratios have produced peak pressures

from 5250 to 7500 psi with very regular pressure vs. time curves. Loading densities of 0.2 and 0.25 were used. Force measurements were made on this multi-orifice gas-generator chamber, and the magnitude of the ignition impulse loading was well within the structural requirements of the gas-generator supports.

May '54 (for March work)

A.

1. Two firings made of hydroductor. The piers that support the condensing "bob" were aligned with the axis of missile in one case and at 1° in another. Both missiles swerved to the left about 100 ft in 900 ft. of forward travel.

2. Six hydroducts with tail 6 fired. Two rounds seemed to run properly.

B.

1. Firing tests of the gas generator with 2 lb. charges of M6 propellant have been continued. Changes in pressure-time curve due to changing the area ratio (K) and loading density (Δ) were determined. Recalculations using data obtained with M6 propellant indicate charge weight of between 2 and 3 lbs. will be needed for test firings. A test-model generator for 3-lb. charges is being fabricated.

2. Ballistic recovery box has been designed and released for fabrication.

3. Drawings being prepared and material ordered for the fabrication of another gun assembly for use in underwater tests in ring channel.

June '54 (For April work)

A. No range firings but changes were made in Alclo grain to improve ignition and burning.

B. Firing tests of gas generator using 2-lb. charge of M6 propellant continued.

June '54 (For May work)

A. Hydroduct test missile No. 40 reloaded with improved grain and refired with satisfactory results. Rd deviation: 6.9 ft. left at 900 ft.

B.

1. Firing tests completed of the gas generator using the 2-lb. charge of M6 propellant.

2. The slotted-barrel gun assembly was completed and an initial check made using a 2-lb. charge of M6 propellant. Performance of the recoilless gun was very satisfactory. V_o = 245 ft/sec, max. breech pressure = 900 psia, peak recoil force = 3600 lbs. The recoil force was approximately 20% of the normal gun recoil for the recorded pressure; this expected as recoil nozzle designed for positive recoil force.

5 Aug (for June work)

A.

1. Another hydroduct was fired to confirm the performance of the Alclo grain with improved igniter and restriction.

2. Hydroductor No. L-1 refired for fourth time with another condensing bob change. Nothing proved as bob was lost at launching.

B.

1. Firing tests of slotted gun assembly continued. Recoil nozzle throat area increased and recoil force reduced from 20% to 8% of force for normal gun.

2. Initial tests of the 3-lb. gas generator were made.

26 Aug (for July work)

A. No range tests

B.

1. Recoil force further reduced to 200 lbs ($\simeq$ 2.5% that of normal gun).

2. 16 firings of gun made with a test missile loaded with a dummy grain. No evidence of grain damage.

3. Gun No. 2 (aluminum) about 10% complete. Test stand for mounting gun about 50% complete.

Sept. (for Aug. work)

A. No range firings.

B.

1. Fabrication initiated on an aluminum breech section of smaller caliber. This will reduce space requirements if several launchers are clustered.

2. A .134 in. lead diaphragm as a muzzle closure was incorporated in test gun design and found to function satisfactorily. Diaphragm found to withstand hydrostatic pressure equivalent to 200 ft. of water.

1 Nov (for Sept. work)

A. No range tests. Tests of model hydroductor on rotating boom being reported under N6ori-10.

B.

1. One firing of the launcher with gun propellant gases entering nozzle of missile. The gases fired a squib and gases may satisfactorily ignite the missile. If this happens, then the separate electrical circuit for missile ignition can be eliminated.

2. High-speed movies of the missile emerging from the muzzle show there is little gas leakage as missile passes through the lead diaphragm.

3. The recoil nozzle closure was improved to give greater uniformity of fail pressure.

4. Firings started to estimate V_o variations.

24 Nov (for Sept. work)

A. No range tests.

B.

1. Sixteen firings made to estimate V_o variations. Data being reduced.

2. The 9-in. aluminum breech section approx. 75% complete.

Dec. (for Nov. work)

A. No tests.

B.

1. Five more rds fired. $V_o = 221 \pm 2$ ft/sec. The recoil momentum varied about 3%.

2. Some reworking of parts (unsatisfactory welds had been found) being done for 9-in. Al breech and gun.

7 Feb '55 (for Dec. '54 work)

A. Modified free-running hydroductors being assembled. Increasing cross-sectional area scoops, suggested by rotating-boom program, to be used.

ENCLOSURE (2) Cont'd

B.

1. Al breech section modified in an effort to obtain a satisfactory weld.

2. Fabrication of parts for the ring-channel test installation completed.

25 Feb. (for Jan. work)

A. No firings.

B. Ring-channel installation for underwater firing of recoilless-gun launcher almost completed.

4 April (for Feb. work)

A. Missile scoops being redesigned in accordance with analysis of hydroductor development studies, reported under N6ori-10 (Report T800-102) to cut ratio of condensing water to steam from about 25 or 30 to 20.

B. No work.

29 April (for March work)

A. Hydroductor test missile with water-to-steam ratio of 20 being fabricated.

B.

1. Three underwater test firing of the recoilless-gun launcher were made. Chamber pressure and MV were similar to air firings.

2. Camera bells being fabricated. Accelerometer has been mounted and calibrated.

25 May (for April work)

A. Preparations are being made for range testing of Hydroductor No. 4. The rotating boom and static-test pit work has shown that the condensing process starts properly when the flow of condensing water can be delayed until steam flow is established. In order to launch the hydroductor under these conditions, it was decided to use a rail launcher modified with a closed tube section at its after end. This launcher was first used at San Clemente with hydroduct and was subsequently replaced at Morris Dam by another rail launcher. The tube section has its ends closed with Plexiglas diaphragms and contains guide rails. The missile and booster remain dry until booster fired. The hydroductor is fitted with shoes to delay entrance of condensing water into scoop.

ENCLOSURE (2) Cont'd

B. Two underwater firings of recoilless-gun launcher made to complete checking out of instrumentation.

7 July '55 (for May work). Hydroductor No. 4 was fired.

2 Aug (for June work)

A.

1. Hydroduct Test Missile No. 39A was range-fired to determine if the procedure of firing the Alclo grain and booster simultaneously would be satisfactory. The launching was satisfactory but grain burning time was so long that the missile descended to the mud before completing burning.

2. Firing of Hydroductor Test Missile No. 5 canceled because of fire hazard.

B.

1. Two underwater test firings of the gun were made and photographs taken.

2. Plans being made to complete testing of gun at Morris Dam using hydroduct missiles.

30 Aug (for July work). Very little work done during this period. The few tests made to be included in next report.

5 Oct (for July and August work)

A. No firings due to fire hazard.

B.

1. Five underwater test firings of the gun were made in the ring channel. Integrated recoil momentum was found to be essentially zero.

2. Deep water testing of gun started at Morris Dam, one firing made at 10 ft. depth, four at 20 ft., one at 30 ft., and one at 40 ft. The dummy missiles were recovered by divers about 200 ft. ahead of the launcher. Oscillograph performance records to be analyzed. Additional tests to be made at 85 ft. depth.

ENCLOSURE (3)

1. The hydroduct work consists of -

(a) Launcher design, fabrication, and testing - sponsored by Armament Branch.

(b) Power studies, e.g. to prove out the expected insensitivity to depth of the hydroductor - sponsored by Power Branch of ONR.

(c) Studies of the condensation of the exhaust - sponsored by Mechanics Branch of ONR.

The work is all tapering off. No further sponsorship contemplated after FY 56. Work now is mostly on carry over funds. Launcher is fabricated and ready for proof testing.

2. Six runs have been made with Hydroductor. The following tests (at Morris Dam) are planned:

(a) 10 runs with hydroduct to test launcher-get dispersion. (Launcher is essentially a recoilless gun.)

(b) 20 runs of Hydroductor at different depths to test insensitivity to depth - not to test launcher.

3. 9/19/55 - According to BUSHIPS RDB project "Underwater Rocket" (Project Number NS 321-019), the Mare Island Naval Shipyard, During FY 56, is developing a prototype shipboard and/or submarine facility that will stow, handle, assemble, check-out, and transport to the launcher an U/W rocket. a 9" U/W rocket (for greater range than 4.5") is being considered but decision on providing funds held up pending CNO's opinion of practicality of such a weapon. Aerojet has sent in a proposal for compacting the propellant grain, the principal problem in the development of such a rocket.

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

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ONR:463:CEB:mg

TO : CDR J. C. Roper

DATE: 10 October 1956

FROM : C. E. Burns

SUBJECT: Range Testing of Hydroduct Notes Concerning Attached Conference Report of 28 Oct 1956

1. The idea that we should fire the Hydroduct with a modified scoop (ie round leading edge) and a new igniter seems to be sending good money after bad.

2. We should realize "basic engineering" data is lacking and that we are involved in a propulsion system problem not merely a simple air rocket design. Aerojet is not in a strong position to defend their program. Neither is ONR in a position of being an omnipotent critic since the whole approach by Aerojet was "development" and our people accepted it on this basis. As a matter of fact Gongwer's desire to explore other exhaust designs is probably due to a realization that the shroud design is a fallacy that won't work.

3. What we need is a facility where this vehicle can be examined fully component wise (ie combustion, steam formation, velocity limits and water rate to sustain required steam discharge into nozzle, nozzle performance thrust developed within missile velocity range, detail analysis and tests of rocket exhaust with respect to effect of condensing, establishing location of condensing boundaries, effect on condensing of steam discharge rates). Lacking such a facility and including personnel as part of our problem, it is possible we can obtain a disinterested group to examine the present hydroductor design and recommend possible avenues of attack.

4. I am aware that both Weisner and Eisenberg feel that we should support the final tests mentioned at the start of this memo. With this I do not agree as there seems little likelyhood of a "depth insensitive on the shelf weapon"ever resulting. If we could tackle the problem at "basic level" our money would be useful and to do this we should attempt to secure a facility properly staffed otherwise not go any further into development.

C. E. BURNS

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To: Office of Naval Research
Codes 463, 429, 438
Washington, D. C.
Office of Naval Research
Green Street
Pasadena, California

Subject: Conference at ONR, Washington, D. C., on Hydroductor Program

Reference: (a) Aerojet- General Proposal PW-6817 for Continuation of Range Testing of Alclo Hydroductor, Contract Nonr 1002(00)

(b) Aerojet-General Proposal PW-6818 for Continuation of Research and Development in the field of Underwater Propulsion Devices, Contract NOnr 1863(00)

On October 28, a meeting was held at the Office of Naval Research, Washington, D. C., in the Office of Mr. F. C. Wiesner, Code 429. The purpose was to coordinate the program on the hydroductor development now underway at Aerojet under Contracts Nonr 1002(00) and NOnr 1863(00), and proposed for continuation under References (a) and (b). Those in attendance at this meeting were as follows:

Mr. F. C. Wiesner, ONR

Mr. A. G. Lundquist, ONR

CDR W. T. Sawyer, ONR

Mr. C. A. Lejonhud, ONR

CDR J. C. Roper, ONR

Mr. C. E. Burns, ONR

Mr. P. Eisenberg, ONR

CDR Waldo Simons, ONR

Mr. J. W. Smith, ONR

Mr. C. A. Gongwer, Aerojet

Mr. H. F. Osborn, Aerojet

Mr. G. G. Loehr, Aerojet

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This letter is to confirm the conclusions reached at this meeting.

It was the consensus that the division of support between Codes 463 and 429 should remain as at present and as proposed in Reference (a) and (b). Namely, the range work, now in the ring channel facility at the Aerojet plant, would continue under Code 463 and the research and development work on the application of the condensation principle would continue under Code 429. This will include two dimensional studies of both the internal and external jet condensers in the steam-water tunnel facility.

It was emphasized that for the internal condensing hydroductor the starting sequence was critical and probably responsible for the failure of this system to develop thrust on range tests so far as determined by deceleration data. This was in contrast to the successful tests of this device in the ring channel, the steam-water tunnel and the test pits with live grains of propellant. As a result the program will concentrate on insuring the successful sequencing of the starting process in the ring channel range tests as well as in the two dimensional tests.

The tests methods employed will utilize the gun launcher previously developed under NOnr 1002(00) to fire the test missile loaded with a short grain of propellant to correspond to the length of free flight path available on the ring channel range. High speed and micro-flash photography and time-distance data obtained from magnetic loops will be utilized to determine the degree of motor performance and proper starting sequencing. It is planned that about 24 range firings will be made and the data analyzed during the year.

For the two dimensional studies the instrumentation will provide measurements of static and dynamic pressures and high speed and micro-flash photography in conjunction with tracers in the flow.

Aerojet-General appreciates very much the opportunity afforded by this meeting to review and plan the program for the successful development of the hydroductor to provide depth insensitivity. It is recommended that another conference of this type be held in the near future.

(463)

23049

BAR, Azusa
Serial 01014
100:mh
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REGISTERED AIRMAIL - CONFIDENTIAL

FIRST ENDORSEMENT on Aerojet-General Corp Conf ltr 400:491:RMV:br of 7 Nov 56

From: Bureau of Aeronautics Representative, Azusa
To: Chief, Office of Naval Research, Department of the Navy, Washington 25, D.C.
Attention: F. G. Wiesner, Power Branch, Code 429
Attention: CDR J. G. Roper, Armament Branch, Code 463
Attention: P. Eisenberg, Mechanics Branch, Code 438

Subj: Conference at ONR, Washington, D. C., on Hydroductor Program

1. Forwarded, readdressed directly to the addressee.

Copy to:
ONR, Pasadena
Aerojet-General, Azusa (C. Gongwer)

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Aerojet-General CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

AZUSA, CALIFORNIA · TELEPHONES [illegible] · AZUSA EDGEWOOD 4-6211

7 November 1956 400:491:RMV:br

To: Office of Naval Research
Department of the Navy
Washington 25, D.C.

Attention: F. C. Wiesner, Code 429
Power Branch

Attention: CDR J. C. Roper, Code 463
Armament Branch

Attention: F. Eisenberg, Code 438
Mechanics Branch

Via: Bureau of Aeronautics Representative
Aerojet-General Corporation
Azusa, California

Via: Office of Naval Research
1030 E. Green Street
Pasadena, California

Subject: Conference at ONR, Washington, D.C., on Hydroductor Program

Reference: (a) Aerojet-General Proposal PW-6817 for Continuation of Range Testing of Alclo Hydroductor, Contract Nonr 1002(00).

(b) Aerojet-General Proposal PW-6818 for Continuation of Research and Development in the Field of Underwater Propulsion Devices, Contract Nonr 1863(00).

1. On October 28, a meeting was held at the Office of Naval Research, Washington, D.C., in the office of Mr. F. C. Wiesner, Code 429. The purpose was to coordinate the program on the hydroductor development now underway at Aerojet under Contracts Nonr 1002(00) and Nonr 1863(00), and the proposed

continuation of this program under References (a) and (b). Those in attendance at this meeting were:

Mr. F. C. Wiesner, ONR
Mr. A. G. Lundquist, ONR
CDR W. T. Sawyer, ONR
Mr. C. A. Lejonhud, ONR
CDR J. C. Roper, ONR
Mr. C. E. Burns, ONR
Mr. P. Eisenberg, ONR
CDR Waldo Simons, ONR
Mr. J. W. Smith, ONR

Mr. C. A. Congwer, Aerojet
Mr. H. F. Osborn, Aerojet
Mr. G. C. Loehr, Aerojet

This letter is to confirm the conclusions reached at this meeting.

2. It was the consensus of the above group that the division of support between the Power Branch, Code 429, and the Armament Branch, Code 463, Office of Naval Research, should remain as at present and as proposed in Reference (a) and (b). Namely, the range work, now in the ring channel facility at the Aerojet plant, would continue under cognizance of Code 463 and the research and development work on the application of the condensation principle would continue under cognizance of Code 429. The research portion of the program will include two-dimensional studies of both the internal and external jet condensers in the steam-water tunnel facility.

3. It was emphasized that for the internal condensing hydroductor, the starting sequence was critical and probably responsible for the failure of this system to develop thrust on range tests so far, as determined by deceleration data. This was in contrast to the successful tests of this device in the ring channel, the steam-water tunnel and the test pits with live grains of propellant. As a result, the program will concentrate on insuring the successful sequencing of the starting process in the ring channel range tests, as well as in the two-dimensional tests.

4. The test methods to be employed will utilize the gun launcher, previously developed under Contract Nonr 1002(00), to fire the test missile which will be loaded with a short duration grain of propellant to correspond to the time of free flight travel available on the ring channel range. High speed and microflash photography, and time-distance data obtained from magnetic loops will be utilized to determine the degree of motor performance and proper starting sequencing. It is planned that about 24 range firings will be made and the data analyzed during the year.

5. For the two-dimensional studies, the instrumentation will provide measurements of static and dynamic pressures, and high speed and microflash photography in conjunction with tracers in the flow.

6. Aerojet-General appreciates very much the opportunity afforded by this meeting to review and plan the program for the successful development of the hydroductor to provide the Navy with an underwater power plant with depth insensitive performance characteristics. It is recommended that another conference of this type be held in the near future.

AEROJET-GENERAL CORPORATION

C. A. Congwer, Manager
Underwater Engine Division

STANDARD FORM NO. 64

Office Memorandum · UNITED STATES GOVERNMENT

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ONR:463:CEB:mae

TO : CDR J. C. Roper DOWNGRADED AT 3-YEAR INTERVALS DATE: 27 November 1956

DECLASSIFIED AFTER 12 YEARS

FROM : Mr. C. E. Burns

DOD DIR 5200.10

SUBJECT: Range Testing of Hydroduct and Hydroductor; NR 234-004, Nonr 1002(00)

Ref : (a) BAR Azusa 1st end Ser 0885 (CONF) of 5 Oct. 1956 forwarding Aerojet General ltr of 28 Sep 1956 Proposal #PW-6817 to continue Range Testing of the Alglo Hydroductor under Contract Nonr 1002(00) with Code 463

(b) Aerojet General proposal #PW-6818 for continuation of Research and Development in the field of Underwater Propulsion Devices under Contract Nonr 1863(00) with Code 429

(c) Memo to Code 463 file (CONF) dtd 31 Aug 1953 signed by C. E. Burns Outlining deficiencies of Hydroductor Range Testing Program

(d) Contract N6onr 244(24) (CONF) with C.I.T. entitled "Hydrodynamic Problems Associated with Underwater Jet Propulsion."

1. The question whether we should continue to support the Range Testing portion of the Hydroductor Program as covered by reference (a) is tied in with agreements between Codes 463 and 429 with which I have never fully concurred, also information contained in references(c) and (d). For example, in reference (c) a number of deficiencies in the Hydroduct and Hydroductor Program as I saw them were delineated. It was my recommendation at the time that we tackle these deficiencies individually as basic problems before attempting to establish an O.S.R.D. type of "Crash Program." Similarily reference (d) is a project in basic underwater hydrodynamics which we initiated but were forced to drop because of its poor results. I have a feeling that others agreed with this approach. However, there was pressure within the Navy for an Underwater Rocket Weapon rather than more research. As a consequence, FY 1953 funds available, were utilized to push the development of the Hydroduct as a weapon. Based on a similar philosophy a modified device known as the Hydroductor has also likewise been developed. Regardless of commitments to financially support the Range Testing portion of Code 429's program we should re-evaluate the vehicles technically before authorizing further funds.

2. My concept of both the Hydroduct and Hydroductor is that we are dealing with a System Problem not merely a Rocket Propulsion Problem and that specific answer in the following areas are needed:

(a) Since the hydroduct and hydroductor rocket engine is a steam generator, would other types of non-metallic propellants been more efficient and useful?

(b) Has it been firmly established, from a propulsion standpoint, that a condensing or relatively non-condensing jet is required?

(c) Is the basic design of the condensing portion of the rocket jet exhaust fully understood? i.e. The rate of which the condensing gas(steam) must be expelled thru nozzle to: (1) maintain rocket thrust (2) prevent

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gas from condensing within nozzle and thus "Kill thrust" and (3) effect of variables such as water temperature on the underwater condensing jet.

(d) How is the correction for buoyancy, as the missile approaches "Burn Out" obtained? Is it possible to obtain some degree of correction by pointing the launcher?

(e) What is the basis for establishing present missile velocity limits: (1) during launching and (2) while running?

(f) If the amount of gas and rates of flow to properly propell the missile underwater over an established range are known, would some means for controlling the rocket engine combustion be advantageous?

(g) Is present gas generation critical or may we accept the propellant combustion rate plus water as providing the correct amount of gas(steam) needed?

(h) Has the hydrodynamic shape of the nose with water entrance openings been examined for water intake variation due to: (1) changes in angle of attack of missile (2) variations in missile velocity over a given range (3) change in missile running depth i.e. from 10 feet to 500 feet depth and (4) effect of normal missile roll and oscillation.

3. There are no doubt some answers to the preceding questions based on development of the Hydroductor vehicle as a Unit. It is not clear that any attempt has been made to isolate items 2b (condensing or non-condensing gas), 2c (rates at which gas must be expelled), 2e (velocity limits for established range,) 2f (possible control of gas generation) and 2g (Hydrodynamics of missile interior and exterior). Perhaps these items cannot be tackled individually at this stage of Aerojets contract since we have a vehicle which "runs" and the contractor no doubt, feels that with a modified scoop i.e. round leading edge and new igniter will vastly improve the missile. Actually Mr. Gongwer's desire to explore other exhaust design is in line with the developmental approach upon which this project has been based and will continue to operate as long as funds are available.

4. A totally new facility, instrumentation and general approach seem needed if we are to obtain answers to the more important basic questions as yet unanswered. Once some of these have been answered other parts of the design can be tackled in order to fully understand and if possible, correct functional deficiencies. It does not seem that the "development-testing-modification approach" by Aerojet should be continued unless greatly increased funds are available. I am aware that both Mr. Weisner and Eisenberg feel that we should support the tests of the modified scoop for the present hydroductor and a new igniter designed to improve the starting sequence. I have a feeling that further testing will not cure the basic difficulties and will result in a request for additional funds. If Codes 400 and 460(front office)approve the Hydroductor development and test program in principle they should give Code 429 funds for complete support even though there is some doubt whether the work belongs in the latter Code.

ONR:463:CEB:mas
27 November 1956

Subj: Range Testing of Hydroduct and Hydroductor; NR 234-004, Nonr 1002(00)

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5. Based on the foregoing, it is recommended that we defer the allocation of funds requ requested by Aerojet in reference (a) to continue Range Testing pending the results of further analysis preferably by an impartial group. Assuming such a group is established and should not approve the developmental approach by Aerojet we could then plan a new program, contact new facilities including personnel and attempt to advance the "State of the Art" in certain areas of deficiency. When this has been completed the basis for further development should be more clearly established. In the meantime, I recommended the establishing of the technical group mentioned and the withholding of funds for the Range Testing Program.

C. E. MUNNS

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

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ONR:463:CEB:jah

TO : CDR J. C. Roper

DOWNGRADED AT 3-YEAR INTERVALS DATE: 26 Dec 1956

FROM : C. E. Burns

DECLASSIFIED AFTER 12 YEARS

DOD DIR 5200.10

SUBJECT: General Discussion Concerning Hydroduct and Hydroductor Test Vehicles

Ref : (a) BAR Azusa 1st end Ser 0885 (CONF) of 5 Oct 1956 forwarding Aerojet General ltr of 28 Sep 1956 Proposal #PW-6817 to continue Range Testing of the Alclo Hydroductor under Contract Nonr 1002(00) with Code 463

(b) Aerojet General proposal #PW-6818 for continuation of Research and Development in the field of Underwater Propulsion Devices under Contract Nonr 1863(00) with Code 429

(c) Memo to Code 463 file (CONF) dtd 31 Aug 1953 signed by C. E. Burns outlining deficiencies of Hydroductor Range Testing Program

(d) Contract N6onr 244(24) (CONF) with C.I.T. entitled "Hydrodynamic Problems Associated with Underwater Jet Propulsion".

(e) Memo to CDR J. C. Roper (CONF) dated 27 Nov 1956 signed by C. E. Burns Testing of Hydroduct and Hydroductor NR 234004 Nonr - 1002(00)

1. On Dec 10, 1956 a meeting was held at Naval Ordnance Laboratory to discuss the subject test vehicles.
Those attending were:

Dr. Z. I. Slawsky	Naval Ordnance Laboratory
Mr. P. A. Thurston	Naval Ordnance Laboratory
Dr. A. H. Seigel	Naval Ordnance Laboratory
Dr. Carl F. Herzfeld	Catholic University
Lt. A. F. Kennedy	Office of Naval Research (463)
Mr. C. E. Burns	Office of Naval Research (463)

2. During this meeting the above group discussed general design of the Hydroductor in order to establish a basis for our continuance of the test phase of the program under Contract Nonr 1002(00) with Aerojet. Prior to this meeting rather complete information concerning the Hydroductor design as being developed under Code 429 Contract Nonr 1863(00) with Aerojet was turned over to Naval Ordnance Laboratory for review. None of the references were furnished the Naval Ordnance Laboratory representatives or Dr. Herzfeld as we were after their opinions not mine. After the general discussion a copy of reference (c) was circulated as a matter of general information as it did not affect the conclusions reached.

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ONR:463:CEB:jah
26 Dec 1956

Subj: General Discussion Concerning Hydroduct and Hydroductor Test Vehicles

3. Among the items discussed at this meeting were:

(a) Condensible versus non-condensible gas (technical not tactical)

(b) Effect of depth on jet assuming constant velocity, reduced velocity and increased velocity during its nominal range.

(c) Effect of (b) on combustion rate of propellant and generation of gases.

(d) Effect of (b) on rate of water supplied to burning propellant to form gases including effect of Yaw.

(e) Probable advantages and disadvantages of the external condensing portion of hydroduct.

(f) Probable launching and running velocity limits.

(g) Choice of alclo as the propellant.

(h) Effect of external and internal finishes on reproducibility.

4. No minutes of the meeting were kept. It was however the general opinion that we should go ahead with a detail mathematical analysis of the design for the present hydroductor configuration, considering several depths up to 500 feet and a nominal launching velocity of 100 to 125 knots. Dr. Herzfeld suggested that it might be desirable to consider the condensible jet as the most advantageous tactically and the non-condensing the best for efficiency.

5. Based on the reactions of the group Dr. Herzfeld suggested that he would like to present this to several members of the Physics Branch of Catholic University including Mr. John L. Lackler who may want to consider submitting a proposal to undertake the analysis. Later the same matter was discussed with Dr. M. A. Cook of the University of Utah who is greatly interested in this problem. He is going to discuss with his organization for possible undertaking.

6. Pending completion of the proposed analysis it is recommended that Aerojet's proposal to continue Range Testing be held in abeyance.

C. E. BURNS
Chief Engineer, Armament Branch

21 May 1957
ONR:463:CEB:ep

CDR J. C. Roper

(12)

Mr. C. E. Burns

UnderWater Rocket Analysis; Contractor for

Ref: (a) Memo to File from C. E. Burns dtd 31 Aug 1953 (NR 234-004), outlining suspected deficiencies of Hydroductor Range Testing Program (CONF)
(b) Memo to CDR Roper from C. E. Burns dtd 27 Nov 1956 (NR 234-004), recommending Analysis of Hydroductor by an Impartial Group (CONF)
(c) Memo to CDR Roper from C. E. Burns dtd 26 Dec 1956 (NR 234-004), concerning discussions with NOL and Catholic Univ Representatives (CONF)

1. As you are aware, we have discussed the matter of having an impartial group study and evaluate the present hydroductor in order to determine its capabilities and to obtain information upon which to decide future support of the project.

2. To date, ONR has expended the following in "New Underwater Propulsive Devices" which includes the Hydroduct and Hydroductor:

Code 429 - N6ori-10 General Project (Thru 26 Aug 1954)		$3,287,655.00
Code 429 - Nonr 1863(00) Gen. Project (New contract thru 17 Dec 1956)		149,853.00
	Sub Total	3,437,508.00
Code 463 - Nonr 1002(00) Range Testing of Hydroduct and Hydroductor		668,826.00
	TOTAL	$4,106,334.00

Without attempting to go into a detail cost breakdown, a conservative estimate seems to indicate that the Hydroduct and Hydroductor programs have cost ONR approximately $1,250,000.00.

3. Our decision not to continue support of the Range Testing Portion of the Hydroductor Program was based on a review of the results, several conferences and the depth sensitivity factor. The latter factor, along with other items was mentioned in reference (a) and summarized in reference (b). In line with this situation, we have discussed informally some of the technical phases with several independent groups who might have an interest in analyzing the problem. Among these groups were NOL and Catholic University, whose reactions are summarized in reference (c). NOL was too busy but interested while Dr. Herzfeld wanted to discuss with others on the University Staff. Dr. Herzfeld actually made an unofficial proposal which was withdrawn as a result of some personal difficulty

ONR:463:CEB:ep
21 May 1957

Memo to CDR Roper from Mr. Burns
Re: UnderWater Rocket Analysis; Contractor for

between Professor John L. Lackler and the Engineering Department Head which could not be resolved. Later, Dr. A. M. Cook of the University of Utah and Dr. A. Ritter of Armour Research Foundation were contacted. The former did not show any great interest and the matter was dropped. Dr. Ritter who had been in ONR and was quite familiar with the Hydroduct, expressed interest and my meeting with his group in Chicago resulted in a proposal.

4. The operational failures of the Hydroductor give evidence of technical deficiencies and the manner in which Dr. Ritter proposes to solve them should bear fruit. Actually, the proposal made by them is proprietary as we had no hand in preparing the document. At the time we contacted Dr. Ritter, it was understood he would like to study the problem and then decide upon a proposal directed toward its solution.

5. My recommendation to go ahead with the study is based on a review of Dr. Ritter's proposal which seems to cover all essential phases related to the evaluation. The results are expected to be useful in directing our future efforts in the UnderWater Rocket Field.

C. E. BURNS

(2)

ANNEX A

CONTRACT NUMBER: Nonr-2389(00) 15 August 1957

The Contractor shall conduct an investigation and analysis of an underwater rocket. This work shall include, but not necessarily be limited to, the following:

(1) an operation phase, which will include study and analysis of the entire heat cycle beginning with the Combustion of ALCLO through the formation and dissipation of the water jet;

(2) a performance phase, which will include study of the vehicle shape, its operability at various water depths and the launching problem, in order to permit evaluation of the present design with respect to speed, range and trajectory; and

(3) a summary phase which will invlude consideration of improvements, new avenues of approach, additional research and new concepts of underwater rockets.

Code 463

(m)

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

IN REPLY REFER TO
ONR:429:SWD:fd
Ser 048
10 January 1958

AIR MAIL

Dr. A. Ritter
Armour Research Foundation
10 West 35th Street
Chicago, Illinois

Dear Dr. Ritter:

This information is being furnished in reply to your questions on the hydroductor submitted to Mr. Doroff.

As indicated to you previously, current emphasis is on the external condensing hydroductor. Most of the latest data refer to this configuration only.

Item Numbers, when used in the following, correspond to those used in your list of questions.

a. Item I. (3). No measurements of thrust have been made for the vehicle under actual (free-running) operating conditions. Thrust and drag have been measured on the ring channel rotating boom--with pressurized steam admitted to combustion chamber to simulate results of alclo grain combustion (the nose hole was closed off). See progress reports of 5 September and 1 October 1957 for net drag and thrust data. We know of no high velocity water tunnel capable of tests that will provide required conditions of pressure and velocity without prohibitive wall effects.

b. Item I. (5). Gongwer claims that they do have numbers for specific impulse. Do you want these?

c. Item I. (6). The problem of water entry into the stagnation intake is not considered overly serious. No measurements have been made to determine whether flow separation occurs at the intake of the missile.

d. Drag measurements and thrust data, under simulated conditions, are available in the two above referenced progress reports. (i.e. for externally condensing hydroductor)

e. Grain length can readily be controlled to give controlled burning times and thus maintain thrust or velocity for desired range.

f. Alclo grain burning velocity is a function of pressure and increases slightly with increasing pressure. See Fig. 125 in Aerojet Report 1106, Vol. II dated 31 May 1956.

(m)

ONR:429:[illegible]:id
Ser 048
10 January 1958

g. In all cases of recovered missiles, grain has been completely burned. Once started combustion cannot be stopped--if grain were in completely burned at end of "flight", body of vehicle would be melted down by remaining undissipated heat of combustion.

h. Actual chamber pressures under operating conditions are not available. Data from simulated tests appears in progress reports of September and October 1957.

i. No data is available on velocity--distance--time and chamber pressure of typical run.

We hope this provides all the information you desire.

Sincerely yours,

A. G. LUNDQUIST
Acting Head, Power Branch
By direction of
Chief of Naval Research

Copy to:
Code 463 (Mr. Burns)

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : File (n) DATE: ONR:463:CEB:bmw 28 April 1958

FROM : C. E. Burns, Jr.

SUBJECT: Conference with Armour Research Contract Nonr-2389(00) concerning Hydroduct and Hydroductor Final Report

1. On April 22 through 24, 1958 the following persons met in Chicago to discuss the preliminary draft of the subject Armour Final Report:

Mr. R. Mindak	ONR, Chicago, Illinois
Dr. L. Ritter	Armour Research, Chicago, Illinois
Mr. D. S. Hacker	Armour Research, Chicago, Illinois
Mr. Paul Lieberman	Armour Research, Chicago, Illinois
Mr. C. E. Burns	ONR, Washington, D. C.

2. During the meeting, a large number of both technical and typographical errors were uncovered and several persons other then those listed were brought into the meeting to discuss particular items in the report for which they were responsible. In particular the conclusions portion of the draft required revision both as to scope and content. Similarly the conclusions were too brief and did not clearly delineate the real differences between the Hydroduct and Hydroductor types of missile. Other errors of a technical nature were found, which in some instances failed to "jibe" with the conclusions and test data.

3. Without attempting to go into further detail it can be reported that all of the group fully agreed that a comprehensive review and correction period was needed. In addition the Armour group also agreed to include in the Final Report any other items which further study revealed as pertinent to the revised draft of the report. Since there was no disagreement as to the need for or scope of the corrections, Dr. Ritter was authorized to make the necessary revision and after a thorough review, released the report to the distribution list which had been furnished him.

C E Burns Jr.

C. E. BURNS, Jr.

REFERENCE O

Armour Project No. D143, "Evaluation Of An Underwater High Velocity Missile (Hydroduct And Hydroductor) dated May 1958 -- Superseded by Report dated September 1958

STANDARD FORM NO. 64

All/Armour Res. Fndn/2389(00)
NR 234-008

Office Memorandum • UNITED STATES GOVERNMENT

TO : ONR Washington, Code 463 (2) DATE: 6 June 1958

FROM : Physical Science Coordinator, ONR Chicago

SUBJECT: Final Report from Armour on Hydroduct Evaluation project.

1. An errata sheet is being prepared by Armour. The most glaring typing error occurs in the abstract; second paragraph, third line; the word decrease should be increase.

2. I was disturbed by the fact that the trajectory was not touched. I discussed this with Dr. Hacker and he said that a theoretical study was too costly, but he would say something concerning the measured trajectory in the letter accompanying the errata sheet.

3. In general, I have mixed feelings about the report. Perhaps with the information available from Aerojet, the report could not have been written any other way. The one glaring point obvious throughout the entire report is the apparent woeful lack of fundemental information provided by the Aerojet reports. It is hard to believe that an apparent unscientific approach was used by Aerojet for so many years. An explanation may be that the reports tell only a small part of the story.

ROBERT J. MINDAK

463
38564

9

10 July 1958

400:370:CAG:lb

To: Chief of Naval Research
Office of Naval Research
Department of the Navy
Washington 25, D.C.

Attention: Code 429

Via: Bureau of Aeronautics Representative
Aerojet-General Corporation
6352 North Irwindale Avenue
Azusa, California

Subject: Comments on Reference (b)

Reference: (a) ONR Letter ONR:429:SWD:cc, Ser 01116, 26 June 1958
(b) Armour Research Foundation Report, "Evaluation of An Underwater High Velocity Missile (Hydroduct and Hydroductor)" - Contract Nonr 2369(00)

1. The subject report of Reference (b) has been studied carefully by the people concerned on Contract NOnr 1863(00). It has been found that the conclusions, which are unfavorable to the hydroduct - hydroductor project, are based largely on assumptions contrary to experimental evidence. Perhaps the recent reports which contain the more significant information were not available to the investigators. Also, a search of our records indicates that a contributing factor may be that no investigator or representative from Armour has visited the project or interviewed any member of the project staff.

2. It is respectfully requested that the Armour investigators be asked to continue their investigation by visiting the project, and a most cordial invitation is hereby extended for them to do so.

AEROJET-GENERAL CORPORATION

Original signed by C. A. Congwer
C. A. Congwer, Manager
Underwater Engine Division

cc: Office of Naval Research, Pasadena
~~Report~~ Distribution List

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

IN REPLY REFER TO
ONR:[illegible]
NR 097-005

16 OCT 1958

(2)

AIR MAIL

Mr. C. A. Gongwer
Aerojet-General Corporation
Azusa, California

Dear Mr. Gongwer:

The Armour Research Foundation Report, A.R.F. Project No. 1145, dated May 1958, which we forwarded to you by our letter Ser 01116 of 26 June 1958 has been superseded by a new report dated September 1958.

It is requested that your copy of the original ARF report be returned so that it may be destroyed. As stated in the ONR Surface Branch letter to you of 29 July 1958, two copies of the new report will be furnished you for review and comment as soon as the earlier copy has been returned.

Sincerely yours,

F. C. WIESNER
Head, Power Branch
By direction of
Chief of Naval Research

Copy to:
ONR Pasadena
BAR Azusa
Mr. C. E. Burns (Code 463)

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

(S)

TO : File

ONR:463:CEB:bmw
DATE: 24 July 1958

FROM : C. E. Burns, Jr.

SUBJECT: Memo of telephone conference with Dr. Ritter concerning Contract Nonr 2389(00) on 24 July 1958 concerning Final Report

1. On 24 July 1958, Dr. Vincent Cushing of the Armour Research Foundation visited this Office to discuss difficulties which had arisen due to the release of a apparently uncorrected and unrevised final report prepared under the subject contract. It was evident that the recommendations concerning corrections and revisions agreed to during a previous meeting in Chicago in April had not been met and that somehow or other the final report had been printed and distributed without corrections or revisions. This was a rather untenable position which the writer of this memorandum considered must be rectified at the earliest possible date and in a "clean cut manner".

2. During the discussion with Dr. Cushing, we mentioned the errata sheets which Dr. Ritter had proposed to issue. He had seen these errata sheets and considered them unsatisfactory and suggested that we set up a telephone conference with Dr. Ritter in Chicago. This telephone conference with Dr. Ritter in Chicago, Dr. Cushing, and the writer in Washington resulted in a decision to recall all of the final reports dated May 1958 which had been issued together with any errata sheets which had been sent out. Further a revised final report was to be prepared for Armour Research and would be fully reviewed by Dr. Ritter's group before release. On this basis and with assurances from Dr. Cushing and Dr. Ritter that the final report would be carefully documentated and reviewed we agreed to its issuance to replace the original report.

C. E. Burns Jr.

C. E. BURNS, Jr.

REFERENCE T

Armour Project No. E143,"Evaluation Of An Underwater High Velocity Missile (Hydroduct And Hydroductor)," dated September 1958

(U)

[redacted]
Copy

CONFIDENTIAL

01947

NOV 18 1959

From: Chief of Naval Research
To: Aerojet-General Corporation (C. A. Gongwer)

Via: Office of Naval Research Branch Office, Pasadena

Subj: Revised Armour Research Foundation Reports; transmittal of

Ref: (a) ONR ltr to Aerojet dtd 29 Jul 1958

Encl: (1) ARF Rpt No. D143 dtd September 1958, copies #7 and #8 (for Aerojet-General Corp)
(2) ARF Rpt No. D143 dtd September 1958, Copy #10 (for ONR/Pas.)

1. Supplementing reference (a), two (2) copies of the subject report are attached as Enclosure (1).

2. Enclosure (2) is for retention by ONR, Pasadena.

J. C. FISHER
By direction

DOWNGRADED AT 3-YEAR INTERVALS
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10

Copy to:
Armour Research Foundation
ONR, Code 429

REFERENCE V

Aerojet General Report No. 1556, Comments On The Armour Evaluation Of The Hydroduct And Hydroductor, dated February 1959

Aerojet-General CORPORATION

AZUSA, CALIFORNIA

INFORMAL REPORT OF PROGRESS

Copy No. 3

15 November 1956

TO: Office of Naval Research
Department of the Navy
Washington 25, D. C.
Attn: Code 463

VIA: Bureau of Aeronautics Representative
Aerojet-General Corporation
6352 N. Irwindale
Azusa, California

SUBJECT: Range Testing of the 4.5-in. Alclo Hydroductor

CONTRACT: Nonr-1002(00)

PERIOD COVERED: 1 September through 30 September 1956

This informal progress report is submitted in partial fulfillment of the contract.

AEROJET-GENERAL CORPORATION

C. A. Gongwer
Manager
Underwater Engine Division

NOTE: The information contained herein is regarded as preliminary and subject to further checking, verification, and analysis.

I. OBJECTIVE

Range tests of the 4.5-in. Alclo hydroductor test missiles are being conducted to determine velocity, range, trajectory, depth sensitivity, dispersion, and other ballistic characteristics. The recoilless gun launcher is being used for these tests to determine whether this method of launching the hydroductor test missile is satisfactory.

II. RANGE-TEST PROGRAM

A. Two checkout test firings were made of the short ballistic range in the ring channel, using a previously fired hydroduct test missile (see Figure 1 of Aerojet Report L2815-42). For these tests, the Alclo grain igniters and the gas-generator primer in the recoilless-gun launcher were fired simultaneously; ignition of the Alclo grain was satisfactory in both tests. The test missile hit the ballistic recovery on the vertical center line in both runs and was recovered in a reloadable condition 8 in. above the horizontal center line for Run No. 4, and 11 in. below the horizontal center line for Run No. 5.

B. Time-distance data were not obtained for either test firing, as the plastic coating around the loops was damaged and did not properly shield the coils. To avoid delaying the program, the tests were run with this part of the instrumentation inoperative. The loops will be reinforced with aluminum angle so that they will not bend when handled and then recoated with plastic. The Berkeley counter-loop system is very sensitive, and stray signals from the underwater light circuits will trigger the counters when the loops are not adequately shielded.

C. The cause of malfunctioning in the two tests which were reported just previous to this report period has been determined. A mechanical interference had developed between the center pressure pickup (used to measure barrel pressure) of the recoilless gun launcher, which resulted in the bore of the gun launcher being deflected when the pressure pickup was screwed into position. The clearance between the piston body and the barrel of the gun launcher was not adequate for the piston to slide through freely. This condition was remedied in Runs No. 4 and 5, and the test missile had a straight

flight. From the high-speed motion picture film on Run No. 5, the average velocity of the missile was 194 ft/sec between Loops 3 and 4.

III. WORK PLANNED FOR NEXT REPORT PERIOD

A. To provide adequate shielding, the loops will be reinforced and recoated with plastic.

B. A hydroductor test missile will be prepared for test firing on the short ballistic range, inasmuch as the instrumentation, camera equipment, and launching technique appear to be satisfactory.

[redacted] (W)

Report No. L2815-43

DISTRIBUTION LIST

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Commanding Officer Office of Naval Research Branch Office 1030 E. Green Street Pasadena 1, California	1
Internal Distribution	4

[redacted]

CER/Chicago - Mr. Robert Minick

26 March 1959

Mr. C. E. Burns, Jr.

Aerojet General Comments on Armour Research Report #2143 dtd Sept 1958

Encl : (1) 1 copy of Aerojet report #1556 dtd Feb 1959, copy #7
(2) 2 copies of Aerojet report #1556 dtd Feb 1959, copies #8 and #9

1. You will recall that after the preparation and distribution of Armour report #2143 dated September 1958, we wrote Aerojet suggesting that they submit comments to us and we would distribute. Their comments are contained in the enclosed Aerojet reports, 3 copies which are being transmitted to you for information, review and comment by yourself and Dr. Hacker of the Armour Research Foundation. You will note the large amount of effort contained in the Aerojet report, also that it does not seem to change the conclusions made by Armour concerning the Hydrodust and Hydroductor as contained in their report #2143 dated September 1958.

2. During the time that Armour was conducting their analysis of the Hydrodust and Hydroductor, considerable difficulty was experienced in obtaining complete reports concerning all areas related to Aerojet's development and testing program. On this basis, you might ask Dr. Hacker to examine the references contained in Aerojet's report #1556 to determine which ones were not available at the time their project was in operation. You might also ask Dr. Hacker if he desires any of the reports mentioned which he has not previously seen or was unable to obtain, since Aerojet may be willing to furnish those which were not available to Armour during analysis period.

3. There is a possibility, I will be in Chicago during the latter part of May of this year and it might be desirable for me to discuss the Aerojet report with you as well as the Armour people. It is regretted that Aerojet transmitted the copies of their report direct, however, I cannot see that it makes any difference provided the receiver has in front of him a copy of the Armour report #2143 issued in September 1958. It is suggested that you transmit copies 8 and 9 of the Aerojet report along with extra copy of this memorandum to Dr. Hacker for his review.

CHARLES E. BURNS, Jr.