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FEB 12 1954

From Lewis
To NACA Headquarters **Attention: Mr. A. M. Rothrock**

Subject: **Transmittal of "Review of Rocket Research at Lewis" prepared by Mr. John L. Sloop**

Reference:

Please take the action indicated below:

A Advise status.
XX B For your information, proper action, and files.
C For reply by your office.
D Forward (on loan) (for our files).
E Translate for laboratory files.
F There (is) (are) transmitted herewith the following:
G The following visited the laboratory on dates given:
H Hold for further information.
I Copy of this letter enclosed with shipment.
J Advise whether order will be placed soon.
K Return catalogs and literature furnished by low bidder.
L Return samples submitted with letter of award.
M Send catalog and price list applying to general schedule.

Remarks:

1. In accordance with your request of February 9, 1954, we are herewith enclosing three copies of "Review of Rocket Research At Lewis".

E. J. Manganiello

Abe Silverstein
Associate Director

JLS
WTO
JLS:dk

Enclosure:
1. 3 cys. subj. review

REGISTERED NO 652978

CC: Gen. Files
A. Silverstein
F&C
C.1 John Sloop

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FEB 9 1954

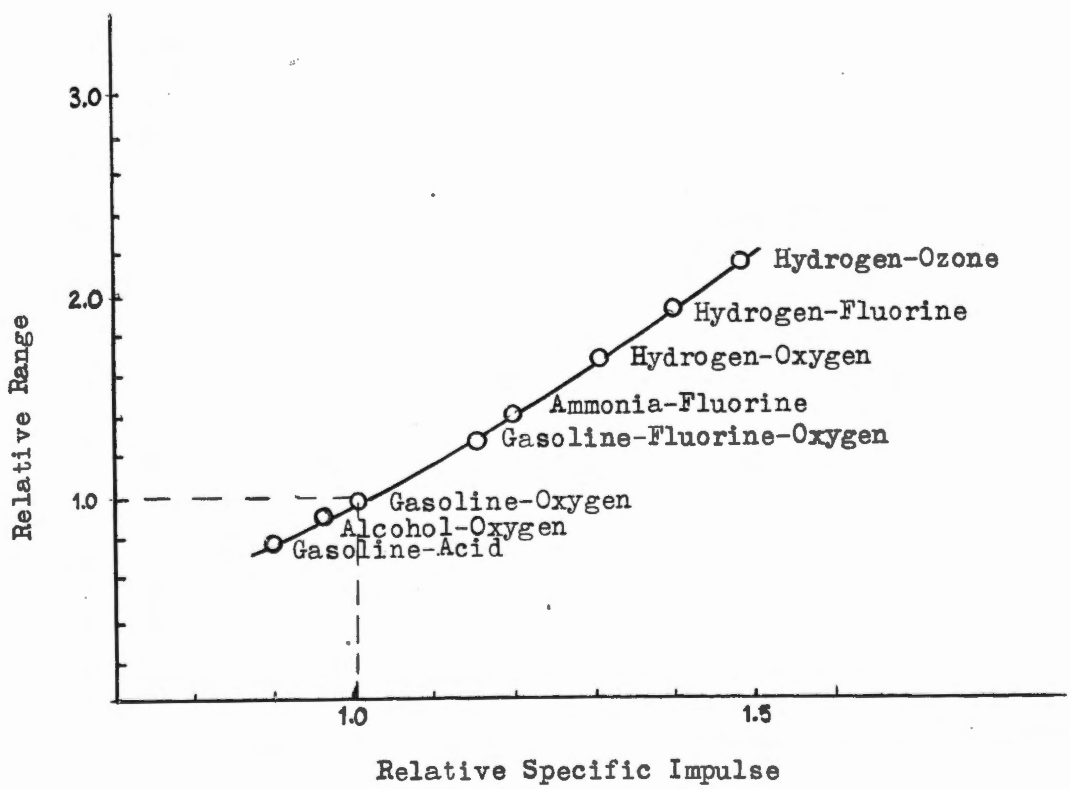
NACA - Lewis

REVIEW OF ROCKET RESEARCH AT LEWIS

Research on liquid propellant rocket engines is directed toward the utilization of: (1) high-energy propellants for long-range missiles, and (2) propellants for aircraft and short-range missiles. The need for research, accomplishments, and plans are summarized.

NEED FOR RESEARCH ON HIGH-ENERGY PROPELLANTS FOR LONG-RANGE MISSILES

High-energy propellants increase specific impulse and increase missile range.



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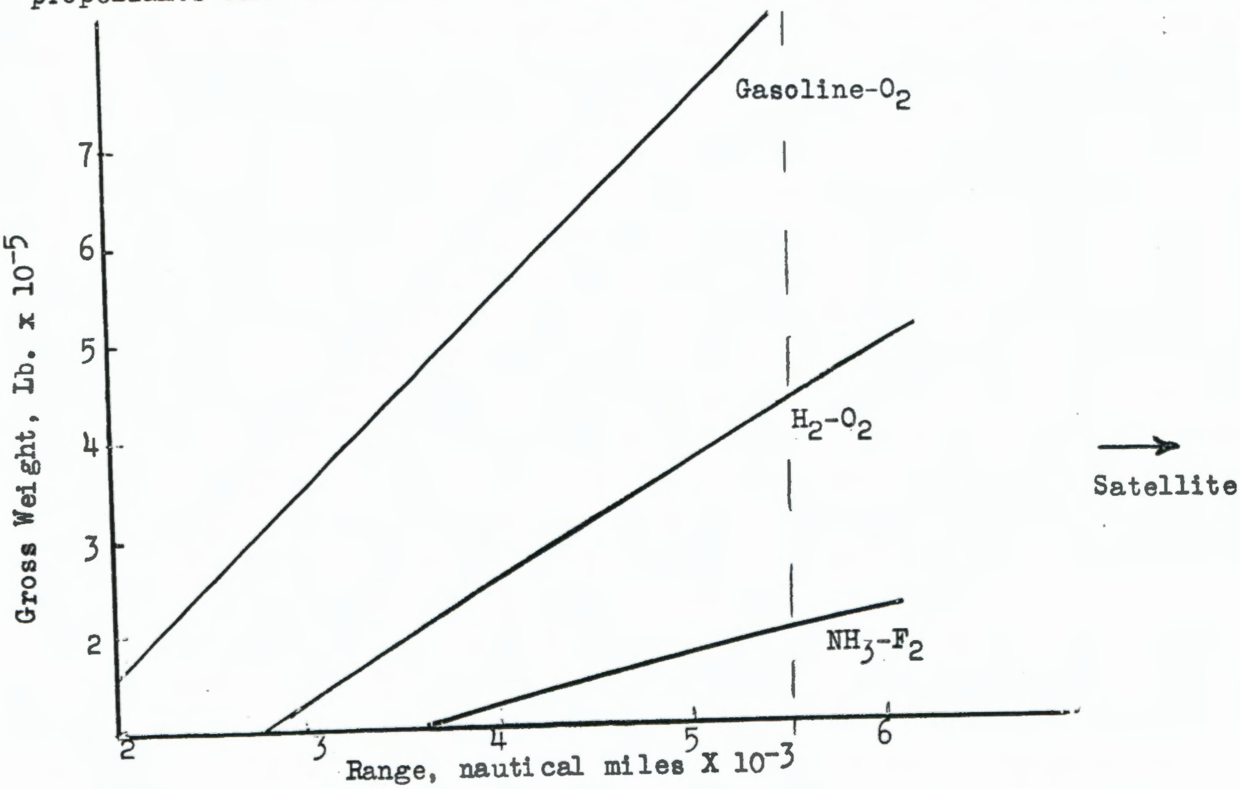
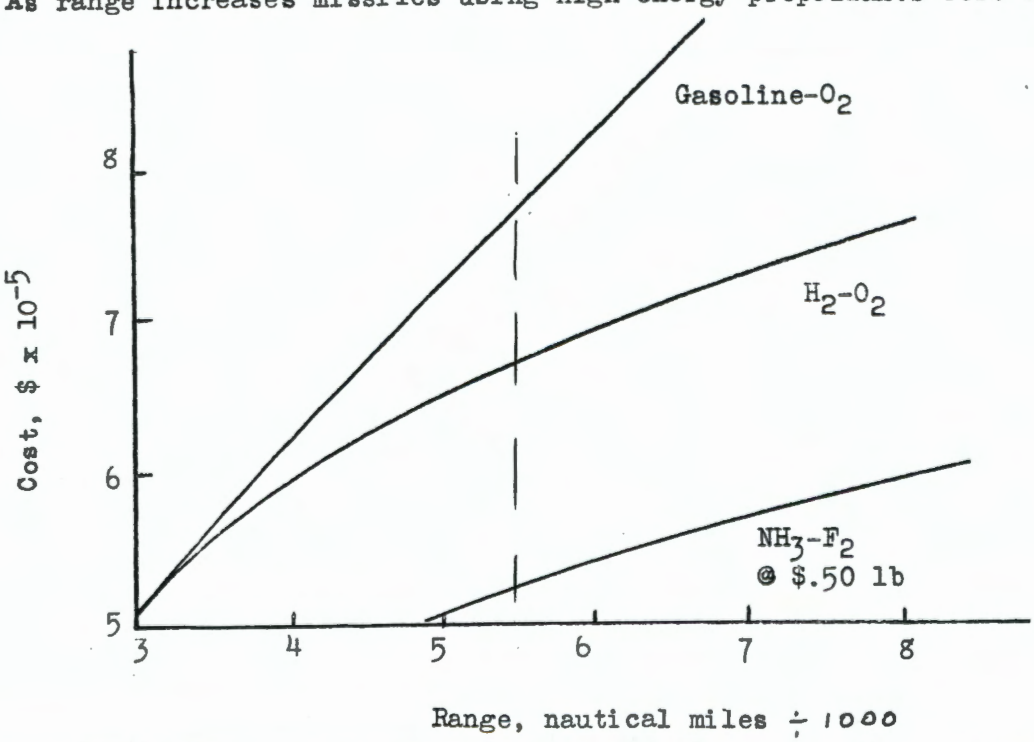
Design studies by the laboratory and others of a long-range missile show that the use of high-energy propellants rather than conventional propellants can better than halve the missile weight and thrust requirements.



This figure also shows that as range increases the need for high-energy propellants increase.

As range increases missiles using high-energy propellants cost less.



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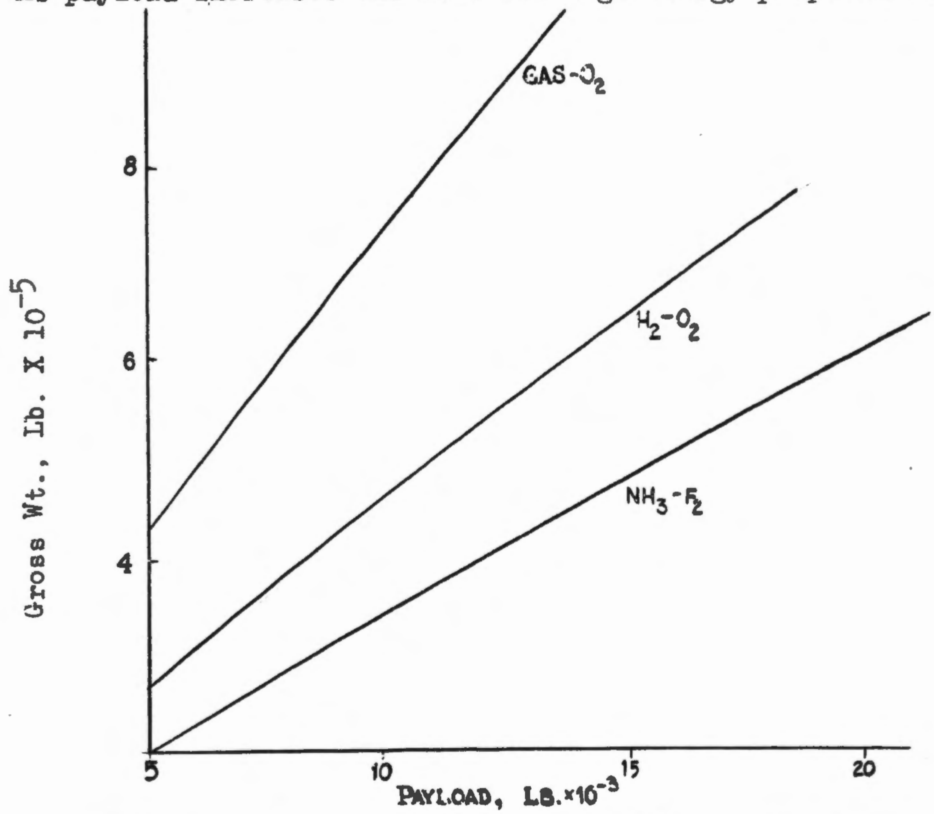
As payload increases the need for high-energy propellants increases.



RESEARCH ON HIGH-ENERGY PROPELLANTS FOR LONG-RANGE MISSILES

The first objective of research on high-energy propellants for long-range missiles is to provide information for the selection of promising propellant combinations. This is done by a combination of analyses and experiments to reveal propellant characteristics, handling methods, theoretical performance, and burning characteristics. Such work has been the primary emphasis of rocket research at the laboratory with results that narrow propellant selection to fluorine, ozone, and oxygen as oxidants and hydrocarbons, ammonia, and hydrogen as fuels but keeping an open-minded attitude for other possibilities.

The second objective of research on high-energy propellants is to provide information on engine performance, durability, pumping, systems, and controls on engines of practical size. Work on phases of engine performance (injection, combustion, expansion), durability (heat rejection, cooling), and pumping are starting.

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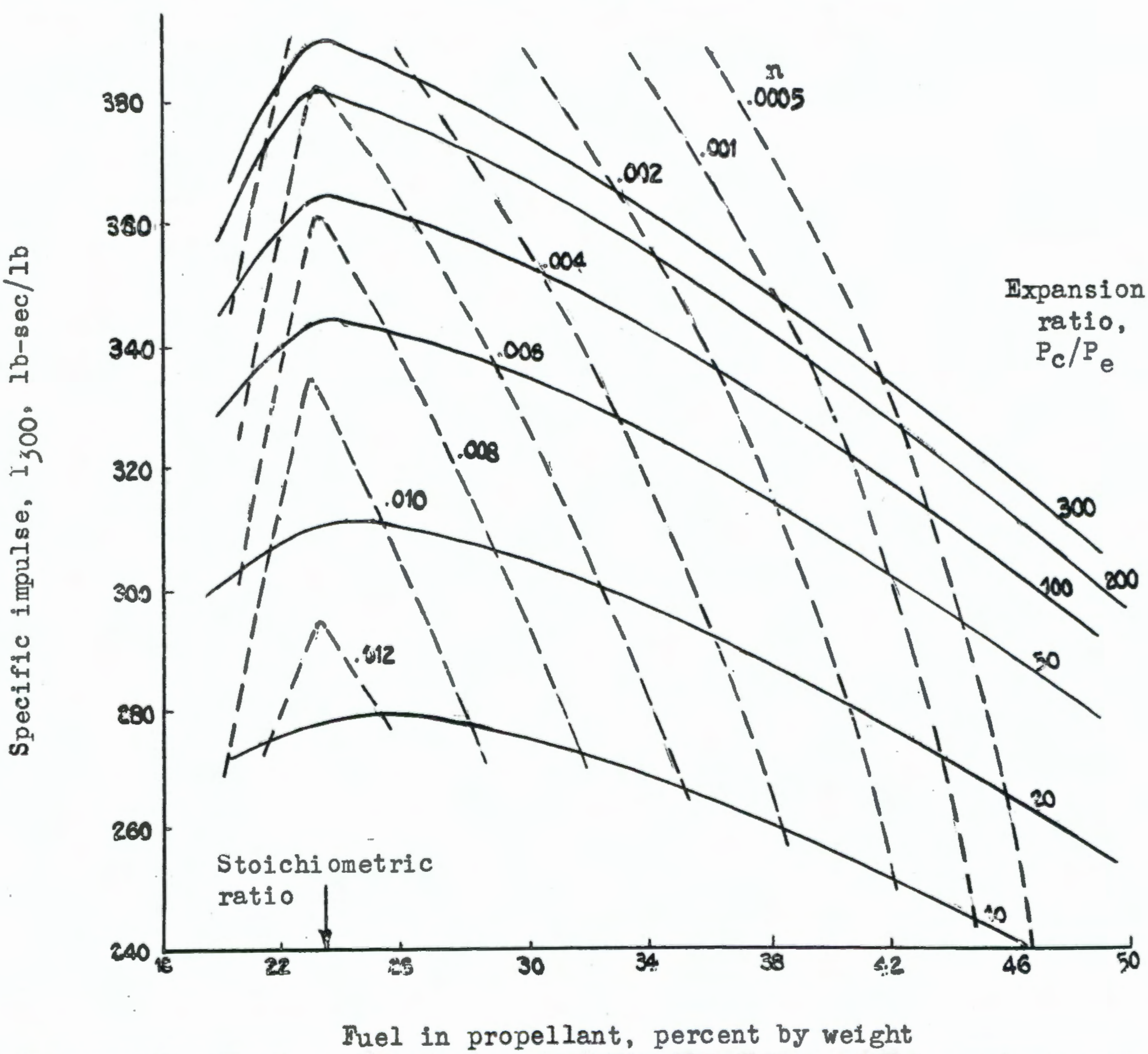
Theoretical Performance

Calculations of rocket performance are made for high-energy propellants of interest for long-range missiles and to support experimental programs. The calculations give composition, molecular weight, temperature, specific impulse, characteristic velocity, thrust coefficient, and area expansion ratio as functions of mixture ratio and exhaust pressure. Also included are estimated transport properties of the combustion gases.

Accomplishments: Developed a general method for computation of equilibrium compositions and temperatures of chemical reactions that is widely used (R 1037) and charts for combinations in the CHON series (TN 1653). Showed that performance gains from increasing chamber pressure are almost entirely the result of increased expansion rates (RM E50C30). Computed performance of 14 combinations including some in support of experimental programs and some for future consideration (RM E8I17a, E51C01, E8A30, E51L11, E52G09, E52H14, E52L11, E53A26, E53F08, E53E12). A correlation was developed that permits the determination of specific impulse, characteristic velocity, and ratio of nozzle exit area to throat area for a wide range of mixture ratios, chamber pressures, and expansion ratio. Such a correlation for the specific impulse of ammonia-fluorine (RM E53F08) is shown.



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To obtain the specific impulse at any pressure use the equation

$$I = I_{300} (P_c/300)^n$$

Plans: More detailed computations on combinations selected for more intensive study such as gasoline-oxygen, gasoline-fluorine-oxygen, ammonia-fluorine, hydrogen-oxygen, and hydrogen-fluorine. Additional calculations on future possibilities such as ozone, oxygen-ozone mixture, and fluorine-ozone mixtures as oxidants. Calculations on storageable propellants and some monopropellants for aircraft and short-range mixxiles are also planned. The use of the IBM 701 calculator in New York is being considered for many of the calculations.

Relation of Propulsion System to Mission

Analyses are made to determine the optimum combination of flight path, structure, propulsion method, and propellants for long-range missiles.

Accomplishments: Compared effect of using gasoline-oxygen and ammonia-fluorine combinations in a long-range missile. Suggested a missile and booster combination that has weight saving advantages over other methods. Collaborated with another laboratory unit in preparing analysis presented in the NACA Conference on Supersonic Missile Propulsion (March 1952). Continued study of propulsion systems for long-range missiles (report in preparation). The study showed that two factors were critical in the design and operation of long-range missiles. First, all the propellants carried must be utilized because of the kinetic energy stored in it over the earlier part of the flight. For example, if 2 percent of the propellant is not used, the 5500 nautical mile missile would fall 1000 miles short of its target.

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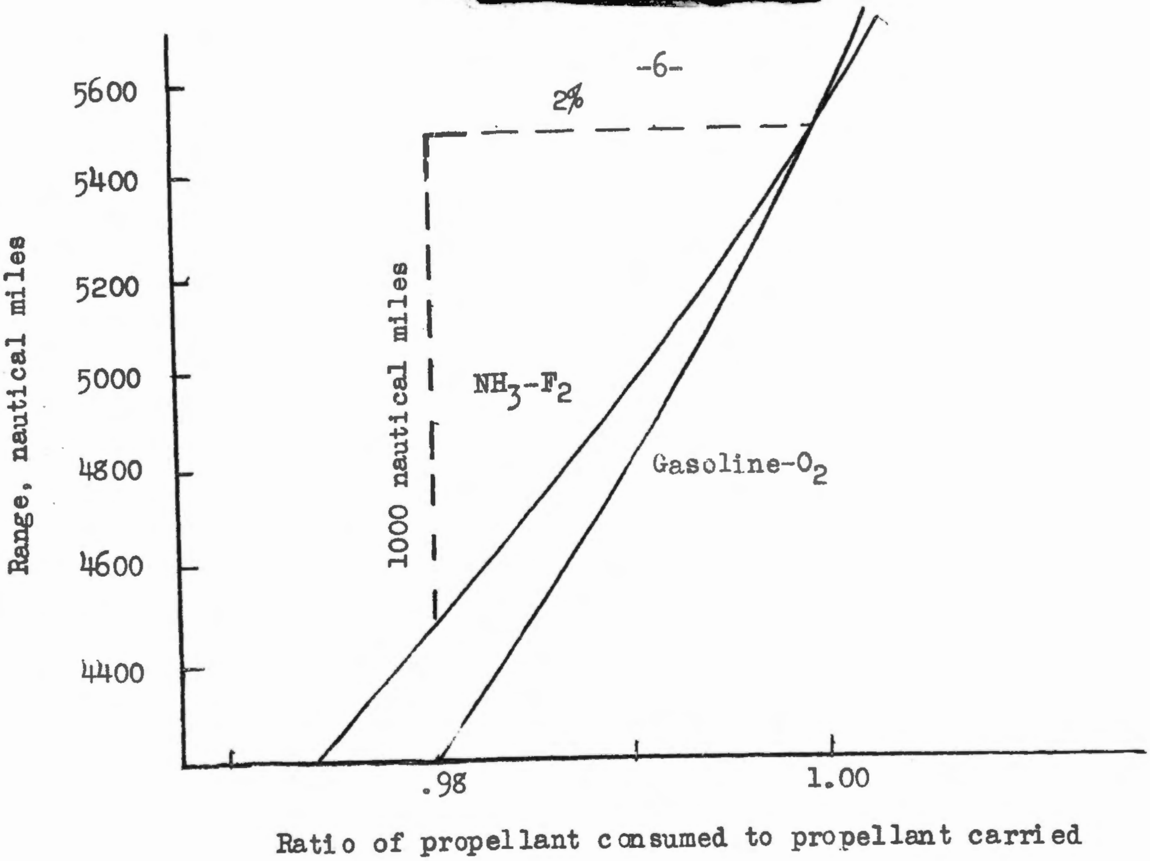
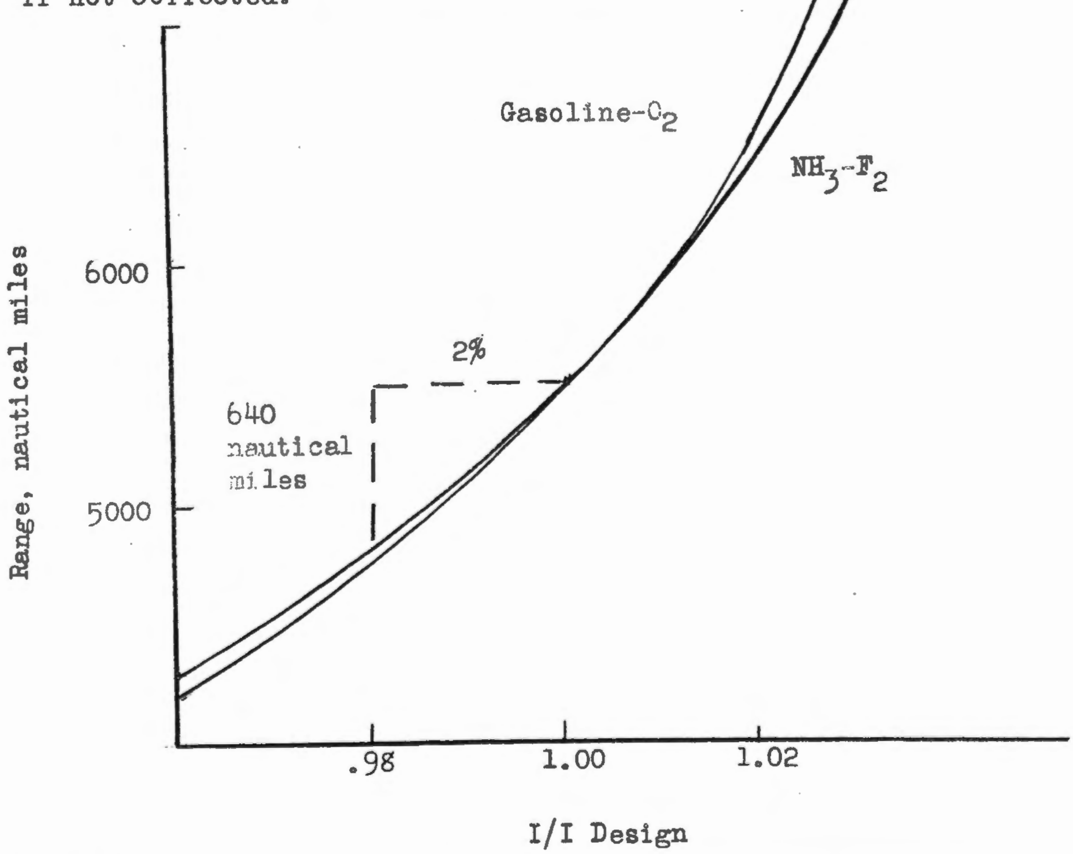


Second, large changes in range result from small changes in engine performance. For example, engine performance variations of 2 percent can cause a change in range of a 5500 nautical mile missile by 640 nautical miles if not corrected.



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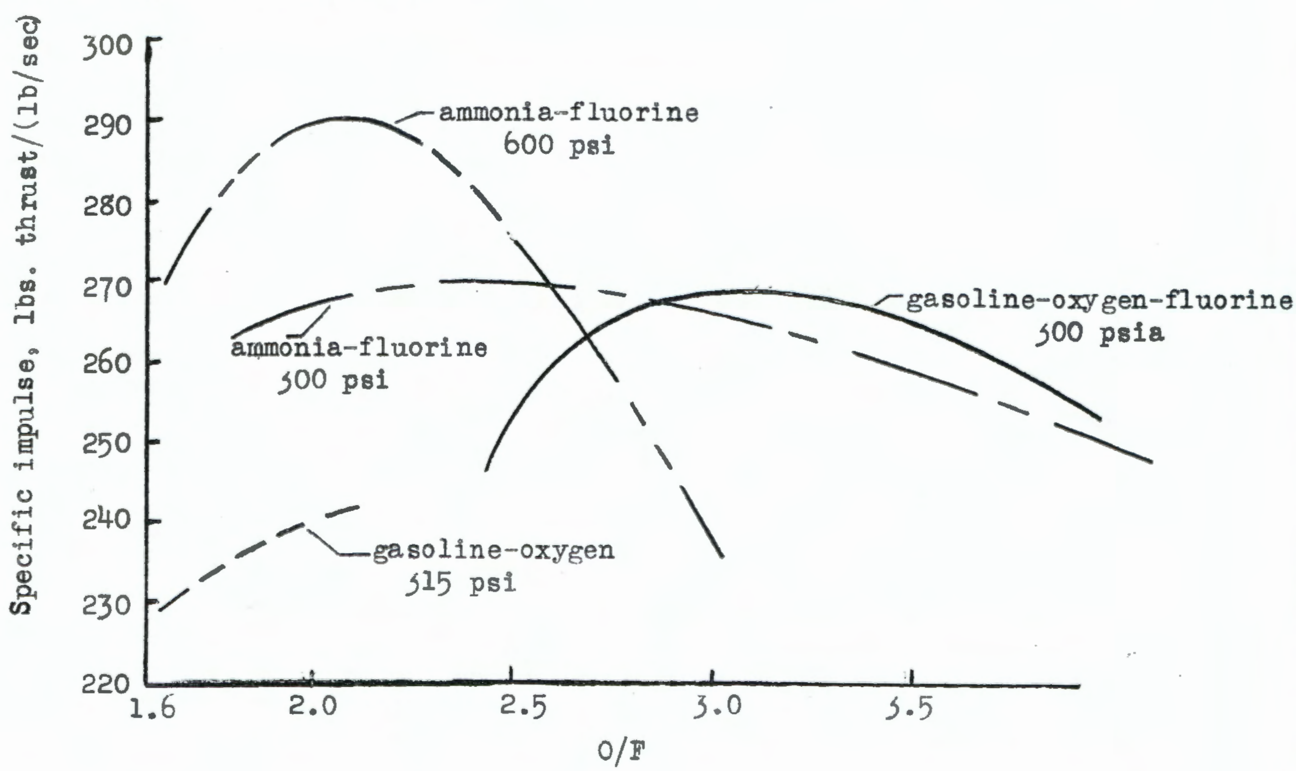
Experimental Performance

Engine experiments are conducted to reveal the problems associated with using high-energy propellants and of obtaining high performance with them. This is done by operating thrust chambers of 100 to 1000 pounds thrust and measuring thrust, flow rates, pressures, and heat rejection over a range of mixtures and combustion pressures. Usually several injection methods and sometimes different combustion volumes must be tried before getting performance close to theoretical values. Following the initial work, engine experiments will be conducted with thrust chambers of more practical size (to 5000 pounds thrust) to reveal and solve problems in injection, combustion, expansion, and cooling that will be applicable to scaling to larger thrust engines eventually needed.

Accomplishments: The most promising high-energy oxidizer is fluorine and more work has been done with it here than anywhere else. Fluorine with diborane, ammonia-hydrazine mixtures, ammonia, and fluorine-oxygen mixtures with gasoline have been evaluated in engines of 100 to 1000 pounds thrust (RM E51I04, E52H22, E53E08, E53J20, and one in preparation). Performance comparisons have been made and ammonia-fluorine and gasoline-oxygen-fluorine have been singled out for more intensive study in larger engines. Experimental performance obtained with ammonia-fluorine and gasoline-oxygen-fluorine is shown.



These performance values are from 86 to 91 percent of theoretical based on equilibrium expansion or from 91 to 96 percent based on frozen expansion.

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RESEARCH ON PROPELLANTS FOR AIRCRAFT AND SHORT RANGE MISSILES

One objective of research on propellants for aircraft and short-range missiles is to provide information on current and anticipated problems which will lead to their solution. Work is being done on propellant properties, engine starting (at request of BuAer), and combustion oscillations. Work has started on injectors for variable thrust at the request of the USAF.

A second objective is to provide information on fundamentals of propellant injection, mixing, and combustion needed to achieve maximum combustion efficiency in a minimum volume. Three investigations with this objective have started.

Physical Properties of Nitric Acid

Physical properties needed for propellant handling, engine operation, cooling, or pumping problems are measured and solutions to alleviate undesirable properties are sought.

Accomplishment: A survey and evaluation of the literature on nitric acid (RM E52J01) not only served to compile in a compact form the reliable data on nitric acid for industry use, but also served to indicate areas where research on physical and chemical properties of this material was needed. A large number of additives for lowering the freezing point of white fuming nitric acid were investigated (RM's E51J01, E52K20) and it was found that all of those tried either failed to decrease the freezing point sufficiently or greatly increased the ignition lag with representative fuels. On the other hand, it was shown that red fuming nitric acid containing large amounts of nitrogen dioxide had a very low freezing point and gave shorter ignition lags than WFNA. Additional work (RM E53G31) has served to establish the optimum composition on the basis of ignition lag as: nitrogen dioxide, 16-18%, water 3-5%. Addition of nitrogen dioxide and water (to form RFNA) effectively reduced the decomposition pressure as would be expected from the equilibrium relation:

$$2\,HNO_3 \rightleftarrows 2NO_2 + H_2O + \tfrac{1}{2}O_2$$

No other additives investigated appreciably altered the decomposition pressure (RM E52J16). The optimum low freezing point acid previously mentioned is also suitable from the decomposition standpoint. Thus, we have an oxidizer with low freezing point, short ignition lag, and low decomposition potential, but with a higher vapor pressure than white fuming acid.

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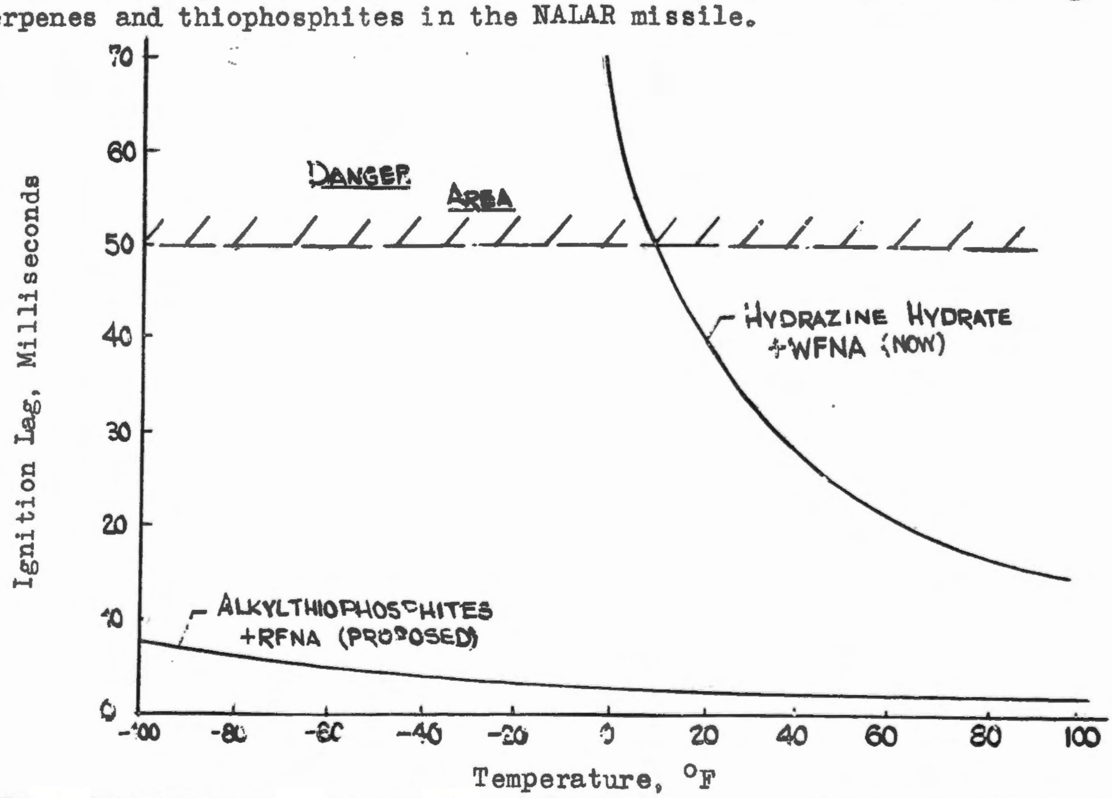
It was found, in addition, that small amounts of fluoride ion would effectively inhibit corrosion of stainless steel and aluminum by nitric acid (RM's E52J16, E53L17b). Projection of these data indicate that a storage time of two years at 160°F is quite feasible. The vapor pressures of the system HNO_3-NO_2-H_2O were measured over a temperature range from 20° to 80°C, for compositions of 0 - 10 percent water and 0 - 20 percent nitrogen dioxide by weight (RM's E53G08 and E53L14).

<u>Plans</u>: Viscosity and thermal conductivity of nitric acid over a range of temperatures and pressures.

Starting Engines Using Spontaneously Reacting Propellants

The time interval between propellant contact and flame (ignition delay) is measured for various fuel-oxidant combinations as a function of temperature and initial pressure. Promising combinations are used in starting experiments with small-scale engines over a range of temperatures and initial pressures.

<u>Accomplishments</u>: This laboratory was the first to observe that engines that start normally at moderate temperature can explode violently at low temperatures (RM E50D20). The difficulties were found to be associated with: (a) chemical reactivity, and (b) engine flow sequencing. Bench-scale and engine research yielded several fuels suitable for use at temperatures as low as -95°F (RM's E51J01, E51J11, E52K19, E52K20, E52K25, E53H21 and one report in preparation). Of approximately 100 fuels examined, seven have been found with low ignition lags at temperatures to -95°F. Some of these are being considered for use in rocket-propelled vehicles, e. g. terpenes and thiophosphites in the NALAR missile.



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The laboratory has also cooperated with BuAer in its program to develop a standard ignition lag tester (RM's E53D03 and E53E29).

The research conducted to date has led to several new design criteria:

a. The effect of pressure altitude is primarily to break up the solid jets and decrease mixing efficiency. Because of rapid increase of pressure in the rocket chamber, the effect is minor compared with the effect of temperature on ignition lag.

b. Viscosity of the propellants is an important factor in determining ignition lag. As temperature is decreased, viscosity generally increases and mixing energy must be increased if the minimum ignition lag of the system is to be achieved.

c. Ignition lag alone is not a suitable criterion for the applicability of a fuel. The product of ignition lag and pre-ignition flow rate must be set to prevent accumulation of enough propellant to give pressure surges or explosions.

Plans: No further work of this nature contemplated as results show several propellant systems which will start at low temperatures.

Starting Engines Using Gasoline-Acid

Starting experiments with a small-scale engine using a chemical ignition source are conducted over a range of temperatures and initial pressures and propellant flow schedules. Most work has been done using a slug of ignitor fluid ahead of the gasoline that reacts with the acid and the resulting flame serves to ignite the gasoline that follows.

Accomplishments: Preliminary experiments (200 pounds thrust) indicated that slug starts (hypergolic fuel preceding gasoline) are unreliable at low temperatures (RM E52K21). With hydrazine-hydrate, if a small amount of gasoline (immiscible with hydrazine hydrate) is allowed to enter at the same time as the starting fuel, smooth starts are attained down to -40°F. Work is now being completed (report in preparation) which establishes the temperature limits for slug starting with hydrazine-water mixtures as a function of water content. For compositions having more than 60 percent hydrazine, the freezing point of the starting fuel appears to be the limiting temperature.

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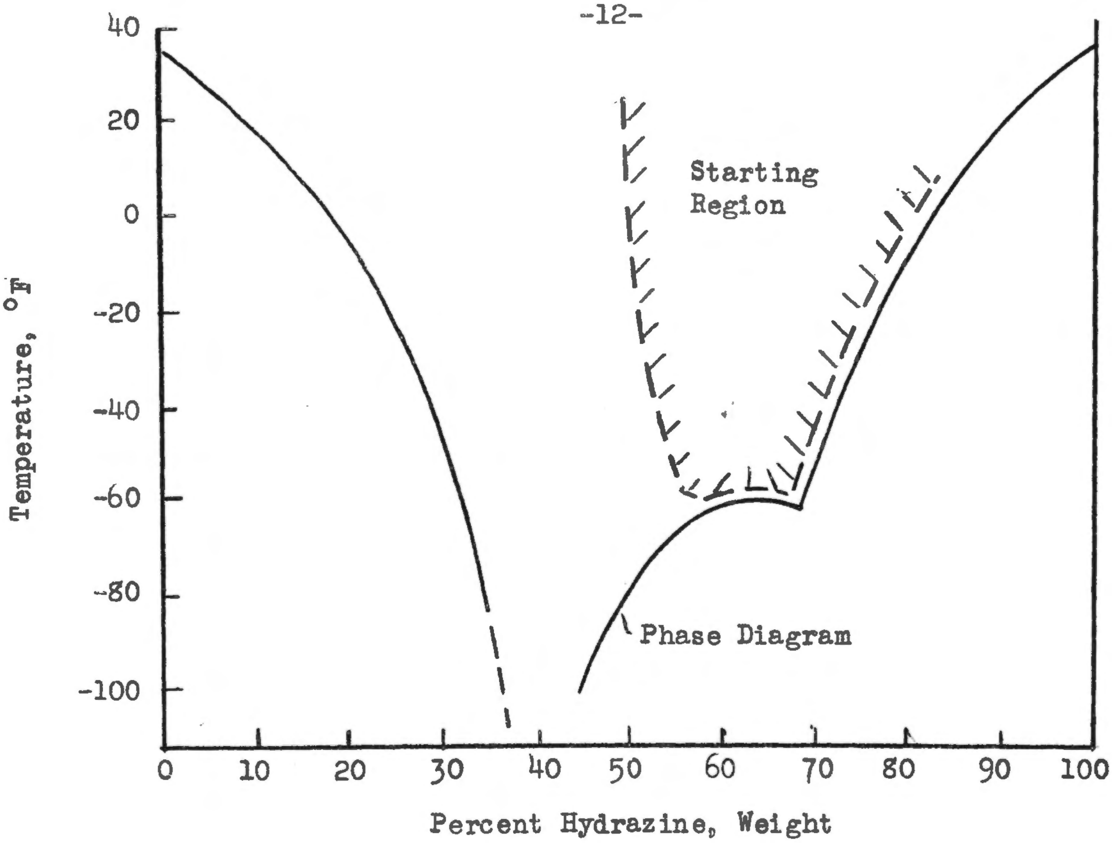

Starting fuels which are miscible with gasoline do not behave in the same way, and this suggests that a separate ignitor chamber directing a flame into the combustion chamber would be more reliable and would permit attainment of satisfactory starts at -76°F or below.

<u>Plans</u>: An investigation of the design criteria for separate ignitor chambers, as previously mentioned.

Starting Engines Using Ammonia-Mixed Oxides of Nitrogen

Starting experiments with small scale engines are conducted over a range of temperatures using alkali metals as reaction catalysts.

<u>Accomplishments</u>: Experiments reported in RM E53F05 indicate that starting is satisfactory at temperatures as low as -85°F if lithium catalyst is added in the fuel flow line. Additional data (report in preparation) show that starting, with lithium catalyst, is also satisfactory at temperatures to 160°F. This work was done in a 200-pound-thrust engine.

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Plans: The effective catalysts other than lithium will be more fully investigated over a temperature range.

Combustion Oscillations

Combustion oscillations are produced in engines, their characteristics studied, and methods of attenuation tried on basis of knowledge gained. Interaction effects between different waves and between waves and engine walls are determined. Experiments are made to reveal the role of combustion kinetics in the initiation and propagation of combustion waves. Experimental techniques for better understanding the combustion mechanism are devised.

Accomplishments: The laboratory was first to observe and recognize the problem of low frequency oscillations (chugging) (RM E8F01 and R 1134). Through analysis and experiment, the phenomenon was explained as a coupling between combustion chamber pressure surges and the flow in the propellant feed lines (RM E51G11 and TN 2936). By the use of a NACA developed flowmeter (RM E50L12) flow reversals were observed. It was shown that decreasing the propellant mixing time and increasing injection pressure drop eliminated chugging. The results were presented nationally at a symposium at the Naval Air Rocket Test Station, December 2, 1950.

High frequency oscillation (screaming) has been encountered by industry; this type was found to be strong pressure waves, sometimes shocks, travelling back and forth in the combustion chamber. Predominant frequencies could be correlated with engine geometry and showed the driven oscillations were acoustical in nature (RM E53B27). The laboratory developed unique techniques for studying this phenomenon such as very high-speed photography (40,000 frames/second) and continuous measurement of rapidly fluctuating combustion temperatures by optical methods (TN 3033). Transparent rocket engines had to be devised, the first of which was widely copied (RM E8F01). Using an improvement on this technique a transparent cylinder was incorporated in a 1000 pound thrust engine. For the first time, high-speed pictures have been obtained that reveal the transition from normal combustion to oscillatory combustion and from longitudinal waves to a recently discovered high-speed rotary wave that is especially destructive. These results were reported at a symposium at the Naval Air Rocket Test Station, October 28-29, 1953 and in RM E54A29.

Supporting investigations in combustion have been the study of fluctuations in a spray (TN 2349), development of economical experimental engines (RM E53B27), and development of a modified sodium line reversal technique for measurement of combustion temperatures (Journal ARS, vol. 23, No. 4, July-August 1953).

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Plans: Attenuation methods based on present knowledge will be tried. Engine geometry and propellant combinations will be varied to determine the interaction between longitudinal and rotary oscillations, and whether or not the waves are propagated by detonation reactions.

Combustion Fundamentals

Plans: Experiments are starting on studying the flammability and spontaneous ignition temperature of several fuels and oxidants, reactivity of several fuels with acid oxidants, and the fundamentals of injection and mixing of hydrocarbons and oxygen.

Variable Thrust Engines Using Ammonia and Mixed Oxides of Nitrogen

Plans: Work has started on investigation of injectors for variable thrust using small-scale engines. The propellant combination is of particular interest as a possible substitute for gasoline-white fuming nitric acid used in the BOMARC missile. After initial investigations, work is planned for engines of a more practical size.

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