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February 25, 1944

Colonel L. A. Whittaker
New Developments Division
War Department Special Staff
3C960, The Pentagon
Washington 25, D. C.

Dear Colonel Whittaker:

In accordance with your oral request earlier this week, Mr. Jacobs has prepared a Supplement to the Secret Preliminary Analysis, "Discussion concerning Intended German Attack on England from 'Cross-Bow Ski Sights,'" two copies of which were delivered to you with letter of February 16, 1944, addressed to Dr. Alfred Loomis. Two copies of the Supplement are enclosed for your information.


Very truly yours,

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

G. W. Lewis

G. W. Lewis
Director of Aeronautical Research

Encs.



[REDACTED]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

SECRET PRELIMINARY ANALYSIS

DISCUSSION CONCERNING INTENDED GERMAN ATTACK ON ENGLAND
FROM "CROSS-BOW SKI SIGHTS"

Reasonably Well-Known and Reliably Deduced Facts

The planned attack using the subject weapon is one of at least two systems the Germans intend to employ shortly for cross-channel attacks against English cities. The subject program is evidently the most urgent and was started several months ago under Luftwaffe direction to provide a practical and straightforward method of launching pilotless bombs, mainly against London. To facilitate the construction of the installations, they are being built above ground in dispersed concrete buildings apparently intended to give some protection against bomb fragments.

The missile consists of a pilotless flying bomb having a wing-span of 20 feet and launched from a 120-foot track pointed at the city under attack, and having an upward slope of 3° . The base of the track terminates in a massive concrete block. Certain other valuable and definite data concerning the ski-launching stations are given in War Department sketches, photographs, and maps which are useful mainly as a check on attempts to reconstruct the probable weapon and methods of handling it; otherwise, the most important fact that seems to be reliably deduced from these data is that magnetic compass guiding is to be employed.

Discussion of Probable Detailed Characteristics

General:

From the known facts and circumstances, it seems likely that the pilotless bomb would be designed to be much like a small normal jet propulsion type airplane with which the designers would have had some direct experience. Inasmuch as the program was a practical and urgent one and intended to get under way promptly, it is not believed that the designers would in any respect go much outside the range of their practical experience. This

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conclusion means that the bomb would look and fly much like an ordinary airplane and would employ the same general type of control and propulsion systems as a normal jet-propulsion fighter.

Speed:

The speed may therefore be taken between 400 miles per hour and 550 miles per hour. The higher speeds would be favored because of the improved efficiency of jet-propulsion systems at high speeds, and because of the greater immunity the high speed gives to defensive action. On the other hand, launching and handling difficulties as well as the general considerations might favor somewhat lighter loads and lower speeds. It might be concluded, therefore, that a flight speed of 450 miles per hour may be assumed for further calculation with little danger of making a large error.

Weight:

If a wing of conventional aspect ratio, say 6, and a span of 20 feet is assumed, an upper limit of the weight of the flight missile may be estimated as follows:

$S = 66.7 \text{ sq ft}$

Assume parasite drag coefficient $C_{d_0} = 0.0130$

Take induced drag coefficient $\frac{C_L^2}{\pi R} = 0.0130$

$$C_L^2 = 0.0130 \pi R$$

$$C_L = 0.5$$

But conventional design would favor lower lift coefficients, say $C_L = 0.4$. Take mean altitude, about 6000 feet:

$$\rho = 0.0020$$

$$L = \frac{C_L \rho v^2 S}{2}$$

$$= \frac{0.4 \cdot 0.002 (660)^2 \cdot 67}{2}$$

$$= 11,500 \text{ lb.}$$

$$\frac{W}{S} = 172 \frac{\text{lb}}{\text{sq ft}}$$

This figure may therefore be taken as an upper weight limit. For a lower weight limit, a wing loading of 75 lb/sq ft, which is not much outside the range of practical experience, might be assumed. This assumption would give the weight as $75 \times 67 = 5000$ lb. It is therefore concluded that the weight, exclusive of launching carriage, is probably between 5000 pounds and 11,000 pounds. 8000 pounds may therefore be assumed for subsequent calculations without much likelihood of causing large errors. The complete unit may be considered in four parts with the weight distributed approximately as follows:

Bomb	4000 lb.
Wings	400 lb.
Structure and propulsion system	<u>3600 lb.</u>
Total flying missile	8000 lb.
Launching carriage	1600 lb.

Power Required:

For a heavy flying missile of the type considered flying near the attitude of maximum L/D, assume

$$\begin{aligned} L/D &= 10 \\ \text{Thrust} &= 800 \text{ lb.} \\ \text{Thrust HP} &= 800 \frac{450}{375} \\ &= 1200 \text{ h.p.} \end{aligned}$$

Propulsion Systems:

Four possible propulsion systems may be considered as follows, in order of increasing fuel rate and decreasing power plant weight and complication:

- (a) Engine propeller
- (b) Turbo jet
- (c) Thermo-propulsive duct
- (d) Rocket jet

(a) Engine propeller:

Using 0.75 propeller efficiency and 2 lb/installed engine h.p. for power plant weight:



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3200 lb.	Power Plant	
<u>280 lb.</u>	Fuel (0.7 lb. h.p. hr)	.25 BR

110000

Total 3500 lb.

Such a power plant would therefore probably be rejected because it is not only heavy but complicated, costly, and bulky.

(b) Turbo jet:

Weights for this type of power plant may be estimated from those of an existing unit:

850 lb.	Power Plant	.71 #/THP	1.4 #THP/2.2
<u>350 lb.</u>	Fuel	1.06 #/2 TH	

Total 1200 lb.

The above estimate indicates that this type of power plant is relatively light, but it is believed that it would be rejected owing to its relatively high production cost for an expendable bomb.

(c) Thermo-propulsive duct (Athodyd):

If losses are neglected, intake and discharge streams may be considered to have velocities corresponding to the same Mach number. Discharge velocity may then be calculated:

$$v_4 = 450 \sqrt{\frac{T_4}{T_S}} \quad \text{where } 4 \text{ refers to jet and } S \text{ to air stream.}$$

Employing suitable temperatures corresponding to burning one quarter of the air taken through the duct, gives:

$$v_4 = 450 \sqrt{\frac{1680}{540}}$$

$$= 795 \text{ miles per hour}$$

which gives:

$$\Delta v = (795 - 450) \frac{88}{60}$$

$$= 504 \text{ ft/sec}$$

Let \dot{m} = mass discharged per sec., and assume a fuel-air ratio of 15×4 , for 300% excess air.

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$$\text{Thrust} = m\Delta v = 800$$

$$m = \frac{800}{504} = 1.59 \text{ slugs/sec}$$

Fuel required:

$$\frac{1.59}{15} \frac{32.2}{4} \quad 60 \times 15$$

$$= 770 \text{ lb.}$$

or, allowing a factor of 1.2 to cover losses in the system, take:

300 lb.	Power Plant
<u>900 lb.</u>	Fuel

Total 1200 lb.

This system is therefore approximately the same weight as the turbo jet system, but is relatively inexpensive and simple and might employ almost any fuel, even a nonstrategic fuel such as powdered coal. Unfamiliarity with this system, and the increased structure and physical size of the missile associated with the necessity of handling a large bulk of diluting air, might tend to discourage its use.

(d) Rocket jet:

Jet velocities over 6000 ft/sec have been observed with jets formed from the combustion of two liquids consisting of a hydrocarbon fuel and liquid oxygen at approximately 10 atmospheres pressure. Higher pressures could be used without excessive tank weights, or a better single fuel possibly containing its own oxygen might be used to give a simpler system and higher jet velocities. In the absence of further data, a jet velocity of 9000 ft/sec is therefore assumed:

$$800 = m \ 9000$$

$$m = \frac{800}{900} \ 32.2$$

$$= 2.86 \text{ lb/sec}$$



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Fuel weight = $2.86 \cdot 60 \cdot 15 = 2500$ lb

800 lb. Tanks (Power plant)
2500 lb. Fuel

Total 3300 lb.

Although this system is relatively very inefficient and heavy, it is very simple, cheap, and reasonably compact. If a suitable economical fuel could be found, it might therefore be the one selected.

Launching system - The missile should reach a speed at the end of the 120-foot track sufficiently high so that it may be airborne and normally controllable. Such a speed would probably be at least 320 miles per hour corresponding to an acceleration of 30g. It has been suggested that considerations of allowable take-off acceleration might preclude the use of a fast highly-loaded missile. Discussions with Laboratory staff members who are familiar with the use of the instrument and control equipment, of the type that would be employed, indicate that such equipment could easily be designed to withstand accelerations up to 60g or more, which would be sufficient to reach the full flying speed of 450 miles per hour while still on the 120-foot track. It is concluded, therefore, that such considerations do not necessarily limit the wing loading and speed of the missile.

The indications are that an expendable rocket-propelled carriage is to be employed. The propellant explosive might be similar to that employed in flight, but the rocket would of course be much larger and would burn out in less than one-half second. A propellant charge more like Cordite might therefore be employed and water or other dilutant material might also be used to suppress a large jet flame which would give away the location of the firing station.

The launching rocket attached to the take-off carriage is probably charged in the compressor

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building and then set up on the launching track to receive the flying part of the missile, after it has been assembled, adjusted, and its compass swung in the nonmagnetic building. It would be economical to employ a high initial acceleration which could be obtained by expelling the take-off rocket as a piston from a cylinder anchored to the heavy concrete block at the base of the launching track. If, in this way, an acceleration of 100g could be maintained for 15 feet, the required rocket charge might be reduced to approximately one half. Otherwise, the charge weight required is given from momentum conservation, if a jet velocity of 5000ft/sec is assumed:

$$W \ 5000 = 8800 \ 660$$

$$W = 1160 \text{ lb.}$$

which permits an estimate to be made of the size of the rocket carried by the launching carriage.

Explosive Bomb - The missile is probably to be built up around a more or less standard bomb of a size approximating 4000 lb. To the bomb case may be attached wing fittings, the propulsion unit with its fuel tanks, and a tail fairing inclosing the control equipment and the tail surfaces. (See attached sketch.)

Trajectory and Control Equipment - One of three flight paths seem to be most likely: a long climb, probably until the fuel is exhausted, followed by a glide to the target area; a low level flight all the way with a final dive into the target controlled either by a timer or an airlog which would cause the final dive after a preset air distance; and finally, the favored method, which is intermediate between the other two. A 3° climb for approximately 112 miles which would bring the missile to an altitude of 25,000 feet. Then a glide at an angle corresponding to the L/D of 10 would, after the remaining 38 miles of the assumed 150-mile flight, bring the missile back to an altitude of 5000 feet. At this point, nearly over the target, a timer, or preferably an airlog consisting simply of a steep-pitch propeller driving a gear train to a trigger, would change the

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Results of Design Study:

The favored arrangement of the missile resulting from the present design study is illustrated in figures 1 and 2. Two bodies, one above the other, are employed for convenience in construction and handling, to get the desired load into a missile of a given length, and in order to avoid excessive center-of-gravity movements associated with burning the heavy fuel charge required by the rocket propulsion system. The upper, or main flying unit, consists essentially of a 4000-pound bomb to which a special tail fairing, housing the necessary instruments and control equipment, and to which the tail surfaces and wings are attached as indicated. Below the main body is attached the other comprising the rocket-jet type propulsion system. This body is built by attaching nose and tail fairings to the main fuel tank which carries liquid oxygen and a suitable liquid hydrocarbon fuel. A safety valve is provided to regulate the gas pressure above the liquid in the tank. The liquid fuels pass through metering orifices and the cooling coil shown where vaporization takes place and then to the combustion chamber as indicated.

The launching carriage is indicated in figure 1. The attached rocket would employ Cordite as a propellant.

Finally, as a result of the design study, the characteristics of the favored arrangement may be summarized in the following table:--

Speed	450 m.p.h.
Useful load	(one) 4000 lb. bomb.
Flying weight	8000 lb.
L/D (estimated)	10
Power required	1200 Thrust h.p.
Propulsion	Rocket jet using hydrocarbon and liquid oxygen fuel (2500 lb.)
Launching system	Cordite rocket
Trajectory	3° climb, glide to about 5000 ft, airlog trigger causing dive to target
Directional control,	Magnetically trimmed gyro.

Alternative Propulsive Duct System:

One alternative arrangement, although considered less likely than that specified above, is shown in figure 3. This arrangement contemplates the use of a propulsive

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duct burning a nonoxygen-carrying fuel. A cheap hydrocarbon fuel is employed in which is dissolved a sufficient quantity of a light hydrocarbon, like Methane, to give the solution the desired vapor pressure for fuel feed. This arrangement requires a special bomb and large air passages, but owing to the lower fuel weight, permits a fore and aft assembly of the component parts.

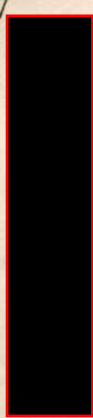
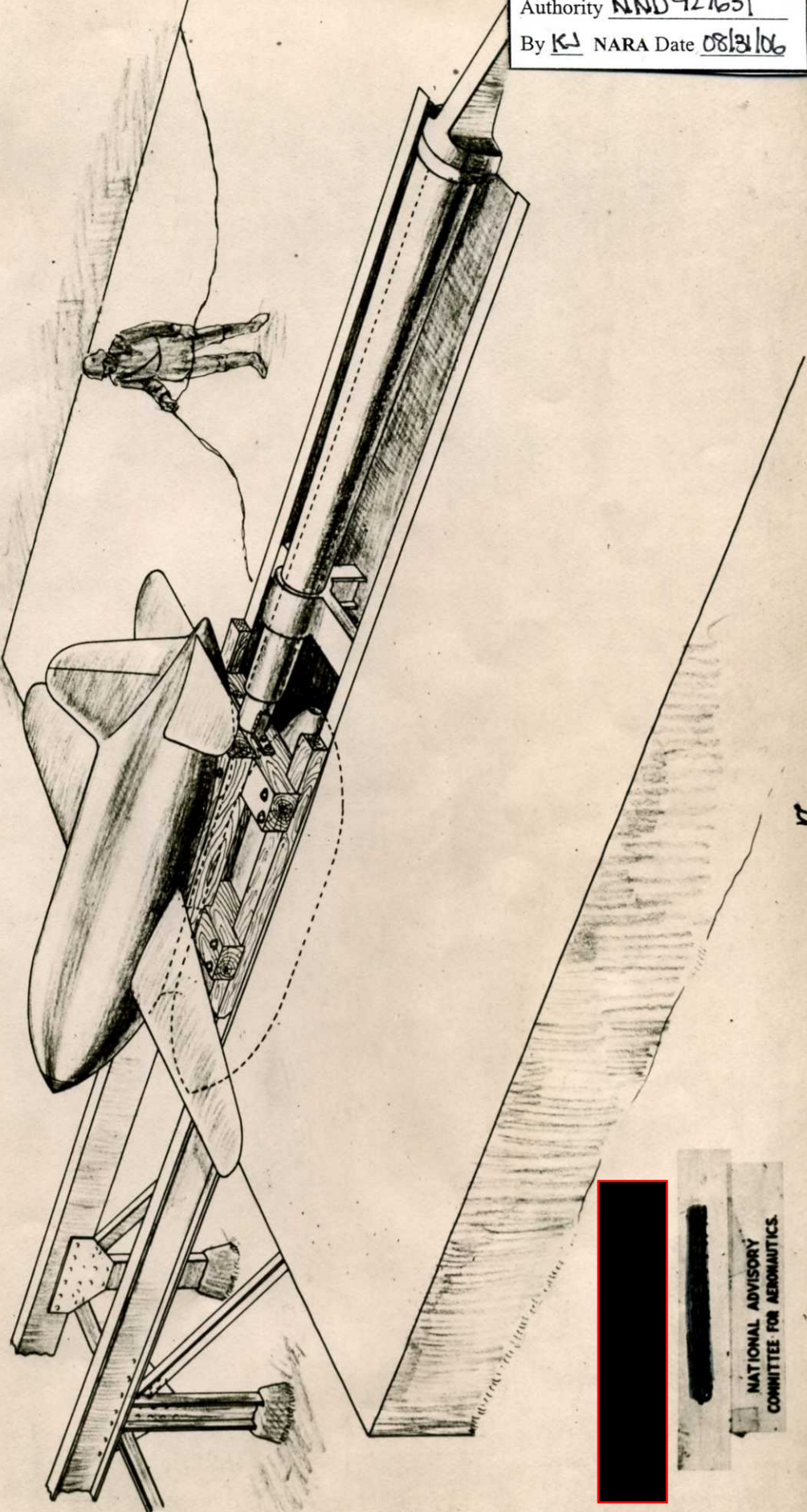
Discussion of countermeasures: - The attack may be expected to last only a few hours and may be launched in a heavy overcast. These facts, together with the probably high speed of the subject missile, discourage any action against the missiles after they are launched. Moreover, it is safe to assume that the approach altitude of the missiles is variable and that action against the magnetic control could be avoided by arranging the gyro to operate independently.

Therefore, it seems necessary to hunt down and attack the launching stations. In addition to the present high-level bombing attacks, a low-level airplane-launched rocket attack is suggested for a later date when the machinery has been installed in the compressor building and the building with three chimneys. The equipment in these buildings appears to be necessary for charging the missile and the take-off carriage with high-pressure and possibly with low-temperature fuels. The machinery in these buildings should thus be essential and relatively vulnerable.

The size of the missile suggests that efforts to interfere with the transport of major components to the launching sites may be worth while.

The probable simplicity of control apparatus makes it unlikely that a particular instrumentation bottle neck exists.

If liquid oxygen is used, as is possible, destruction of major liquid air plants is indicated.



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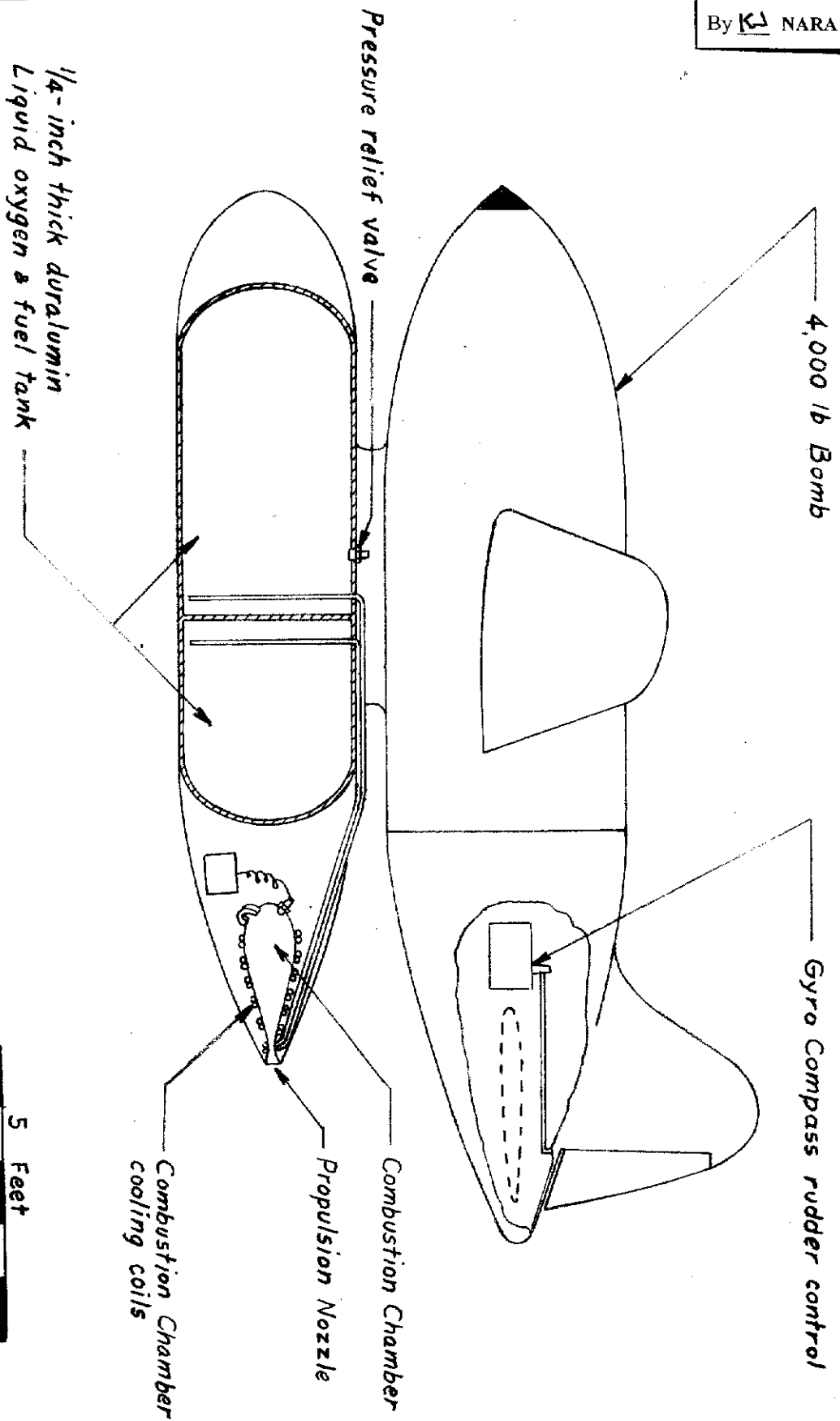


Fig. 2

5 Feet

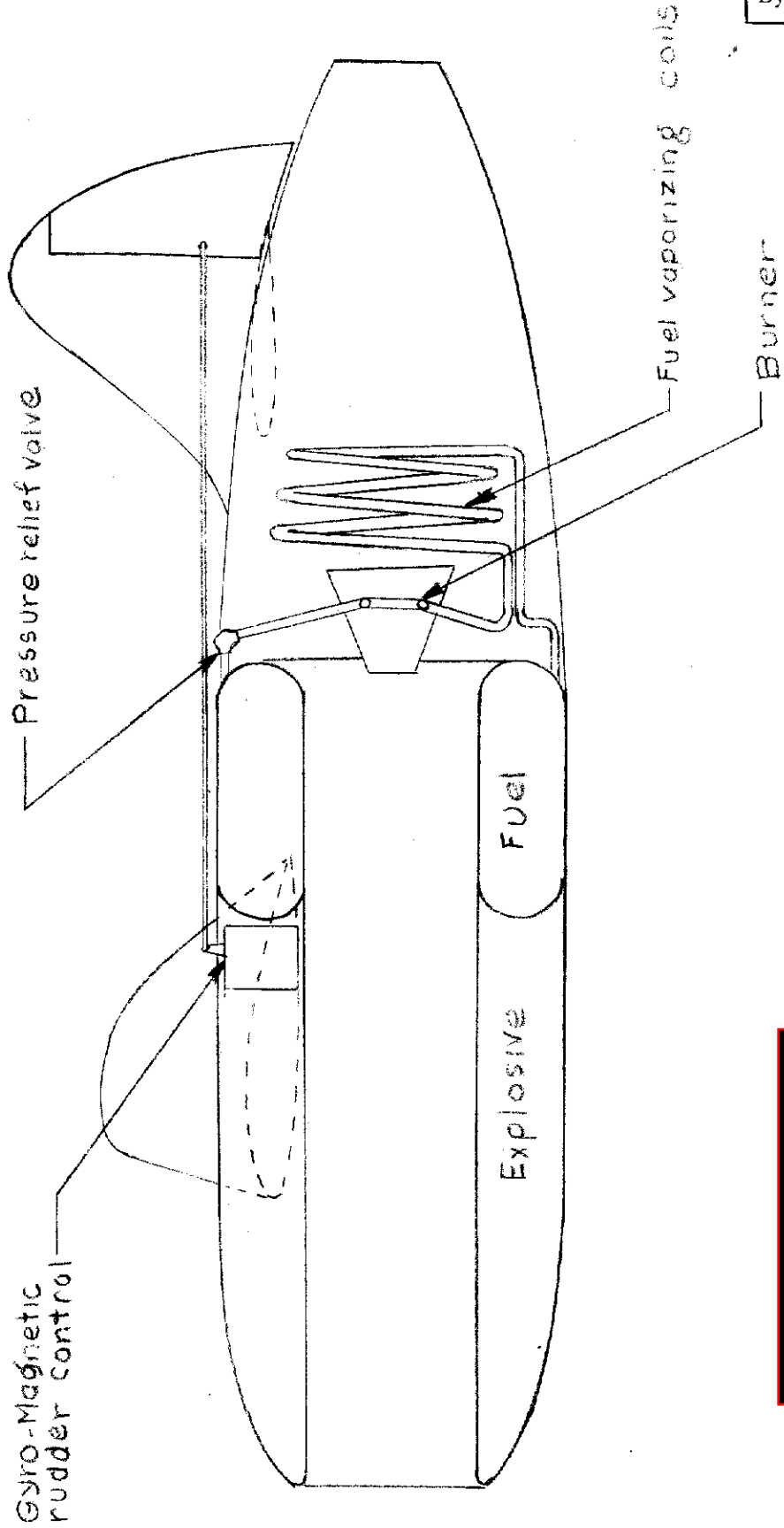


FIG. 3



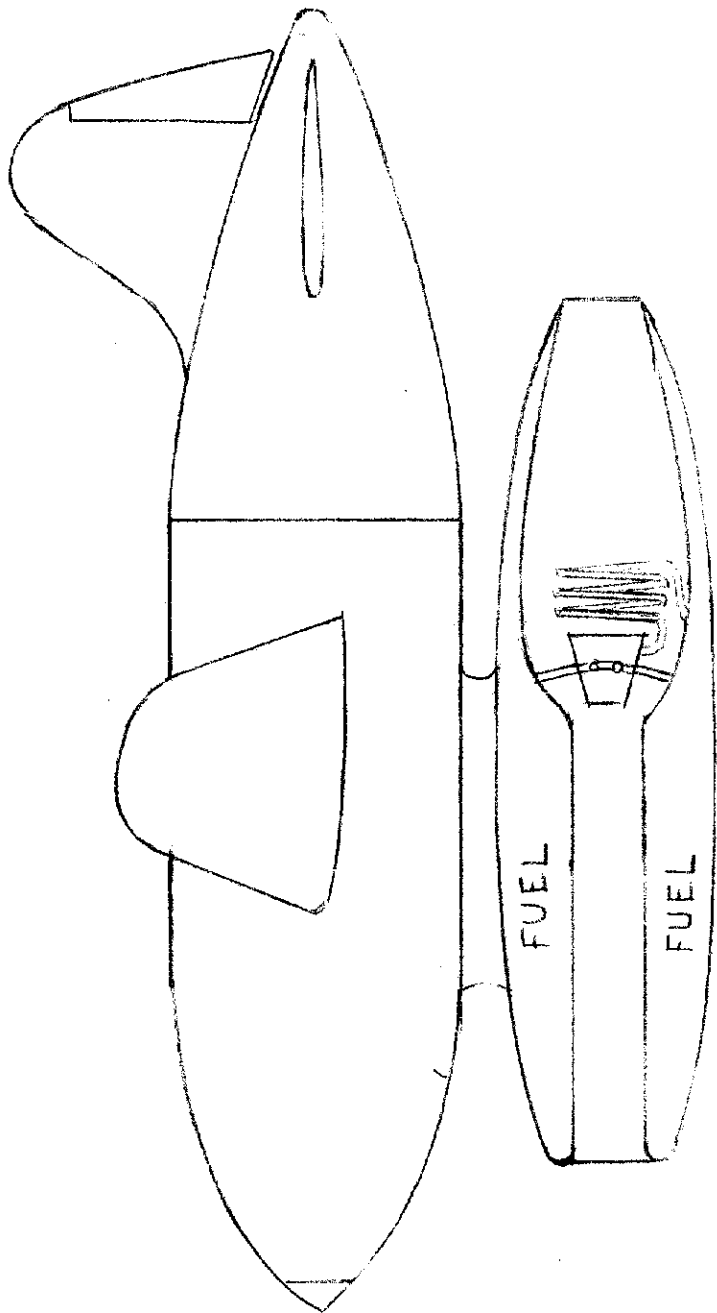
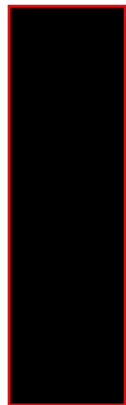


Fig. 4.

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controls or drop off the wings to produce a steep descent to the target. If a normal gliding angle were maintained all the way to the target, a comparatively large fore and aft dispersion would result, and defenses against the missile might be more easily constructed. On the other hand, with a low thrust line as shown in the sketches, a sufficiently steep glide might be determined so that sufficient accuracy could be obtained simply by employing a predetermined quantity of fuel which could be adjusted after spotting the results of the first few launchings. In any event, the very low-level flight all the way is not favored because of the possibility of defensive action and because of added control difficulties which seem to offer no compensating advantages.

The ~~lateral~~ control is believed to require the use of a simple gyroscope. In addition, a magnetic compass is evidently employed to establish quantitatively the heading to be flown. Magnetically-trimmed gyro instruments are known which could be employed to control the rudder. Otherwise no movable controls should be required. *direct*
x

Washington, D.
February 3, 19

Authority NND 927631
By KJ NARA Date 08/31/06

MEMORANDUM for Dr. Lewis

Subject: Request of J.N.W. Committee for report on a self-propelled bomb

1. The J.N.W. Committee of the War Department requests a report on the subject of a self-propelled bomb which shall embrace a preliminary design study of such a weapon and a discussion of its possible performance. Please assume the following conditions:

The range, 170 statute miles.

The bomb to consist of a central body with wings of span 20 feet.

The bomb to be launched from a ramp 120 feet long and inclined from three to six degrees above the horizontal.

The bomb to include within its structure an automatic pilot control system with correction of gyro drift by magnetic compass.

2. It is desired to know as the result of the design study, the desirable gross weight of the bomb, the area of the wings, the pay load available for explosives, and the airspeed. The method of launching and means of propulsion are left open, as well as the nature of the fuel. It is desired to have a discussion of the reasons for selection of particular methods for the tentative design.

3. It is also desired to have an estimate of the form of the trajectory for a flight of 170 miles, with indications of what parts of it are in powered and unpowered flight.

4. Suggestions are desired, further, as to how control of range might be pre-set in order to hit targets that are short of 170 miles range. An error of ten miles would be acceptable.

5. The report is eventually to be submitted by me as Chairman, on February 15, 1944, to Colonel LeRoy A. Whittaker, Room 3C960, The Pentagon; and marked "Secret."

J. C. Hunsaker

JCHseg