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DEPARTMENT OF ENGINEERING RESEARCH
UNIVERSITY OF MICHIGAN • ANN ARBOR

SECRET

PROJECT "WIZARD"

PROGRESS REPORT NO. 5

(1 December 1946 - 1 February 1947)

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UMR-5

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PROGRESS REPORT NO. 5

PROJECT MX-794
(AAF Contract W33-038 ac-14222)

Period 1 December 1946 - 1 February 1947

Project "Wizard"

Emerson W. Conlon
Chairman, Department of Aeronautical Engineering

Wilbur C. Nelson
Project Engineer

U-11548

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UNIVERSITY OF MICHIGAN PROGRESS REPORT NO. 5, PROJECT MX-794
(AAF Contract W33-038 ac-14222)

I PURPOSE OF PROJECT

Project MX-794 is:

(a) An eighteen months' study and engineering investigation of the guidance, propulsion, launching and aerodynamic problems culminating in a recommendation for the military characteristics and design of a supersonic guided ground-to-air pilotless aircraft capable of intercepting and destroying hostile aircraft operating at altitudes up to 500,000 ft., at speeds up to 4000 mph, at ranges sufficient to prevent damage to the defended area.

(b) A twenty-six months' basic research and engineering evaluation in the field of guidance techniques, propulsion methods, supersonic aerodynamics, servomechanisms, fuel chemistry, launching procedure, fusing and missile performance.

II SUMMARY OF WORK CONDUCTED DURING THE PERIOD 1 DECEMBER 1946 - 1 FEBRUARY 1947

(a) Aerodynamics

1. Studies were completed of a two stage rocket showing the influence of the boost rocket on gross weight and time to reach altitude. Dynamic stability analyses have been made of a craft at high altitude where aerodynamic forces may be ignored.

2. Design of the supersonic wind tunnel, including most of the assemblies required for initial test operations, was completed. All required items, except the vacuum pump, have been delivered, and installation is proceeding. Tests relative to certain design and construction details have been carried out.

(b) Design

1. Design work has been scheduled for completion by 1 June 1947 of the Phase I study using rocket power.

2. Preliminary design studies of a number of single stage and multi-stage liquid rockets with and without solid rocket boost were completed, and studies of a possible test vehicle for guidance and control system tests were initiated.

3. Studies have been made of the magnitude and method of application of control forces required by the final stage of a multi-stage missile.

4. Further information on shaped charges and fragmentation warheads has been obtained.

(c) Guidance

1. A preliminary guidance systems planning report has been completed.

2. The command guidance system is in the design stage.

3. Steering equations for solution by the computer have been formulated for the case of unpowered flight.

4. Preliminary studies of the homing problem indicate that either ground illumination of the target or infra-red systems may be workable.

5. Work on the micro-wave test laboratory has continued with test equipment being assembled as complete sets of components are received.

(d) Launching

1. A general survey of launching methods, including an analysis of the electric launcher, has been completed.

2. Preliminary design studies of launching ramps and solid fuel rocket boost units have been continued.

(e) Mathematics

1. A method of solving the point mass homing problem has been developed, and may serve as a basis for computer design.

2. Studies have been initiated of paths of minimum fuel consumption within the atmosphere.

(f) Propulsion

1. Ram-jet performance studies have been extended to both lean and rich fuel-air mixtures.

2. Performance studies of the turbo-jet engine are being completed.

3. The flame speed apparatus has been completed and placed in operation. Studies of the effect of moisture on flame propagation have been initiated preparatory to undertaking the scheduled study of turbulence effects. Apparatus for the investigation of heat transfer problems has been designed.

4. Calculations for the construction of an enthalpy-entropy diagram for nitric acid - aniline with a mixture ratio of 3:1 are nearly complete.

(g) Research Techniques

1. Investigation of the absorption method of density measurement in supersonic wind tunnels has been continued.

2. Some work has been done on pulse position modulation for telemetering.

(h) Members of the staff visited the organizations listed below:

Activity Visited	Subjects Discussed
Aberdeen Proving Ground, Aberdeen, Md.	Fragmentation charges
Guided Missile Branch, AAF Washington, D. C.	Shaped charges, Fragmentation charges, solid rocket boost units
Ballistic Branch, Res. & Dev. Div., AAF Washington, D. C.	Test program on the German A-4 rocket to determine the damage necessary to effect a kill.
Bendix Aviation Corp. Eclipse-Pioneer Div.	Gyros & servomechanisms
General Motors Corp. Research Laboratory Div.	Gyros & servomechanisms
Reaction Motors, Inc. Dover, N. J.	Sizes, weights, and availability of various liquid rocket units.
Air Materiel Command, AAF Wright Field, Dayton, Ohio	Hydrogen peroxide as a liquid rocket propellant. Gyros & servomechanisms. Weights of rocket components. Supersonic wind tunnel calibration and test program.

Dr. C. W. Miller Rochester, N. Y.	Computer design
Evans Signal Laboratory Belmar, N. J.	Tracking and early warning problems.
Bell Telephone Lab. Murray Hill, N. J. and Whippany, N. J.	General guidance problems
Naval Research Lab. Anacostia, D. C.	Radar Search and tracking
Ohio State Univ. Research Foundation Columbus, Ohio	Radar reflections from rocket-type missiles
Boeing Aircraft Co. Seattle, Washington	Laboratory facilities and general progress
California Institute of Technology Pasadena, California	Laboratory facilities and general progress

(i) Personnel from the following organizations visited the contractor:

Visiting Group	Subjects Discussed
Langley Memorial Aeronautical Laboratory of the NACA Langley Field, Va.	Aerodynamics and supersonic wind tunnel
Air Materiel Command, AAF Wright Field, Dayton, Ohio	General progress and problems
Res. & Eng. Div., Hq. AAF Washington, D. C.	General progress and problems

(j) Conclusions Drawn from Visits and Conferences.

1. A single shaped charge, fixed rigidly to the missile body will probably not be an effective warhead for this project. A battery of shaped charges, and/or continuous orientation of the warhead would greatly increase the effectiveness. Cylindrical fragmentation warheads may prove to be very effective at high altitudes, and should be investigated further.

2. Hydrogen peroxide is not feasible as a fuel for this project because of the danger in handling and storing which results from instability.

3. Little theoretical or experimental information is available on effective radar reflecting area of rocket-type missiles. Experimental work is under way at OSU and Federal Telephone and Radio (under Evans contract), and at NRL which should give applicable preliminary information in 3-4 months.

4. The NRL XQD 350-mile search radar set is not specifically designed for this project and does not exactly meet requirements but it represents a notable advance in search radar design.

5. At present, materials for absorbing radar waves are not directly applicable to guided missile surfaces for mechanical reasons. Applicable materials are being investigated.

6. Recent experimental work on simultaneous lobing systems at BTL and NRL confirm many earlier theoretical predicted.

7. The control system computer and systems tester being designed by BTL for Project Nike appear to have many points in common with the requirements of this project.

8. The rather long solution time, 2 seconds, of the Mark 56 Computer is not due to its electro-mechanical design but mainly to the smoothing time required by the radar data. The settling time of the rest of the computer is about 0.2 seconds which might be reduced to 0.05 seconds, making this type of computer practical for use in connection with this project. The problem then would be one of supplying the input data rapidly enough to decrease markedly the smoothing time.

III AERODYNAMICS

Studies have been made of a two stage rocket, the first stage being a dry rocket boost and the second stage a liquid rocket. The results indicate that the total time to reach design altitude and the gross weight, are to a large degree functions of the velocity at the end of the first stage and not of the altitude at that time. The influence of the boost velocity and altitude upon the gross weight and percentage fuel required for the liquid stage are shown in figures (1) and (2).

Consideration has been given to the flight path. The calculations indicate that the trajectory of an "arrow stabilized" missile, one in which the thrust is tangential to the flight path, is a desirable type.

A study has been made of the dynamic behavior of the craft at high altitudes, where aerodynamic forces may be neglected, and its influence upon stability and control. The control response will be through the action of the jet, and is assumed to be a function of the motions of the missile.

The results indicate that:

(a) The moment of inertia change due to fuel expenditure should be kept to a minimum.

(b) For the cases investigated the control motion should lead the missile motion.

(c) It is necessary to have damping in the control system.

(d) Jet damping has a negligible effect for the cases studied.

(e) Drift is a result of the oscillation of the missile and it can be eliminated by introducing a term into the control system which tends to oscillate the control force in the desired direction, thus causing the missile to turn into the proper course.

As an example of these results, fig. (3), a plot of the pitching displacement is shown for a particular configuration and control function.

The design of the supersonic wind tunnel, including the three-component balance system, was completed. This includes the design of accessories, such as the dollies required for window removal; required instruments, such as the schlieren

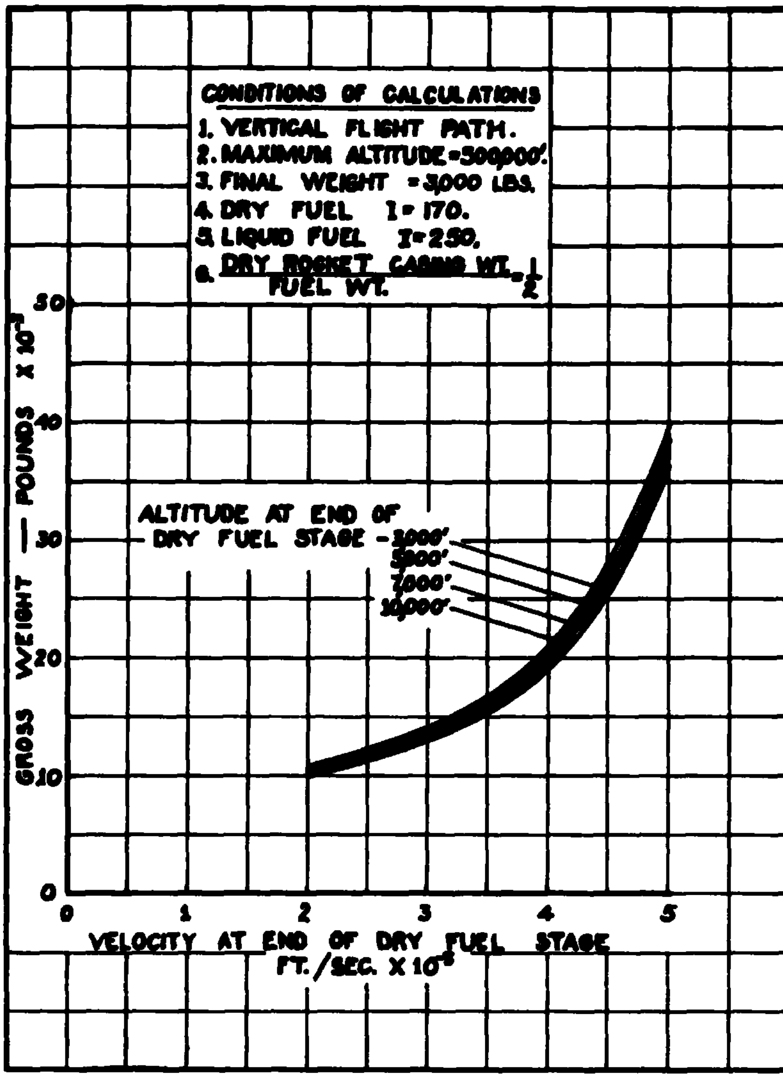

Fig. (1)

GROSS WEIGHT OF TWO STAGE MISSILE AS A FUNCTION

OF VELOCITY AT END OF FIRST STAGE

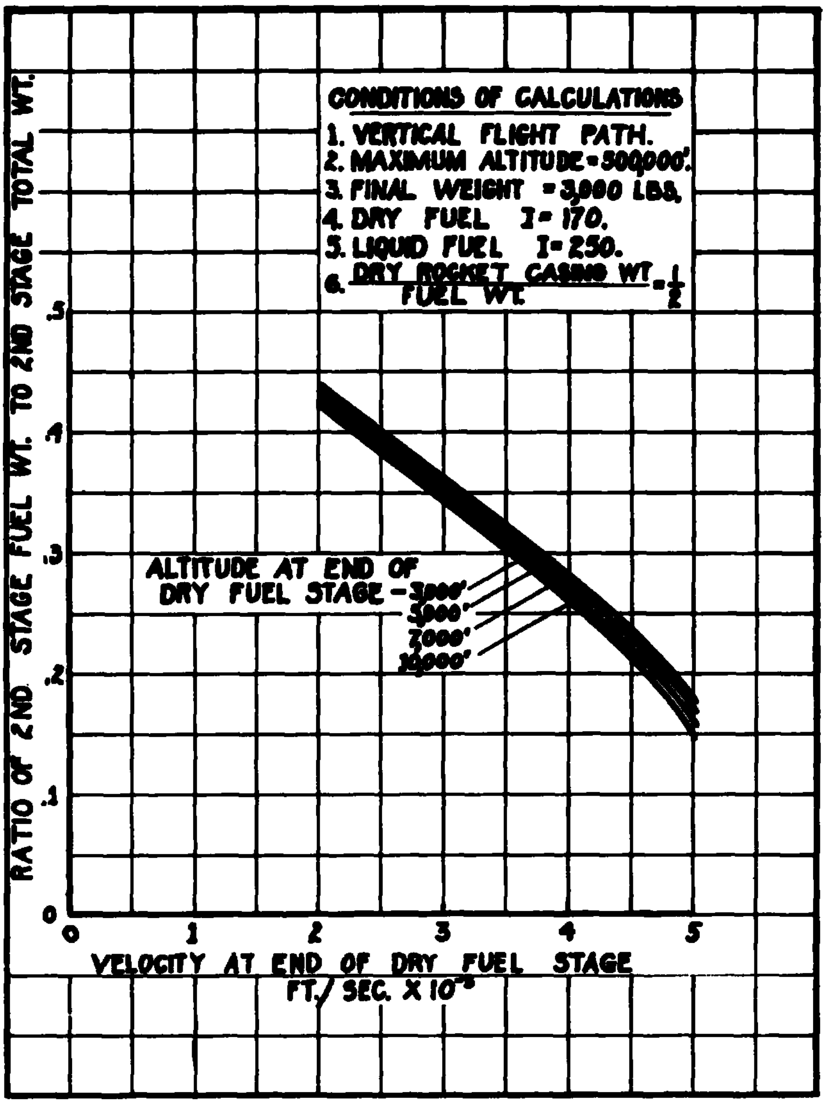

Fig. (2)

RATIO OF FUEL WEIGHT TO GROSS WEIGHT OF

SECOND STAGE OF A TWO STAGE ROCKET

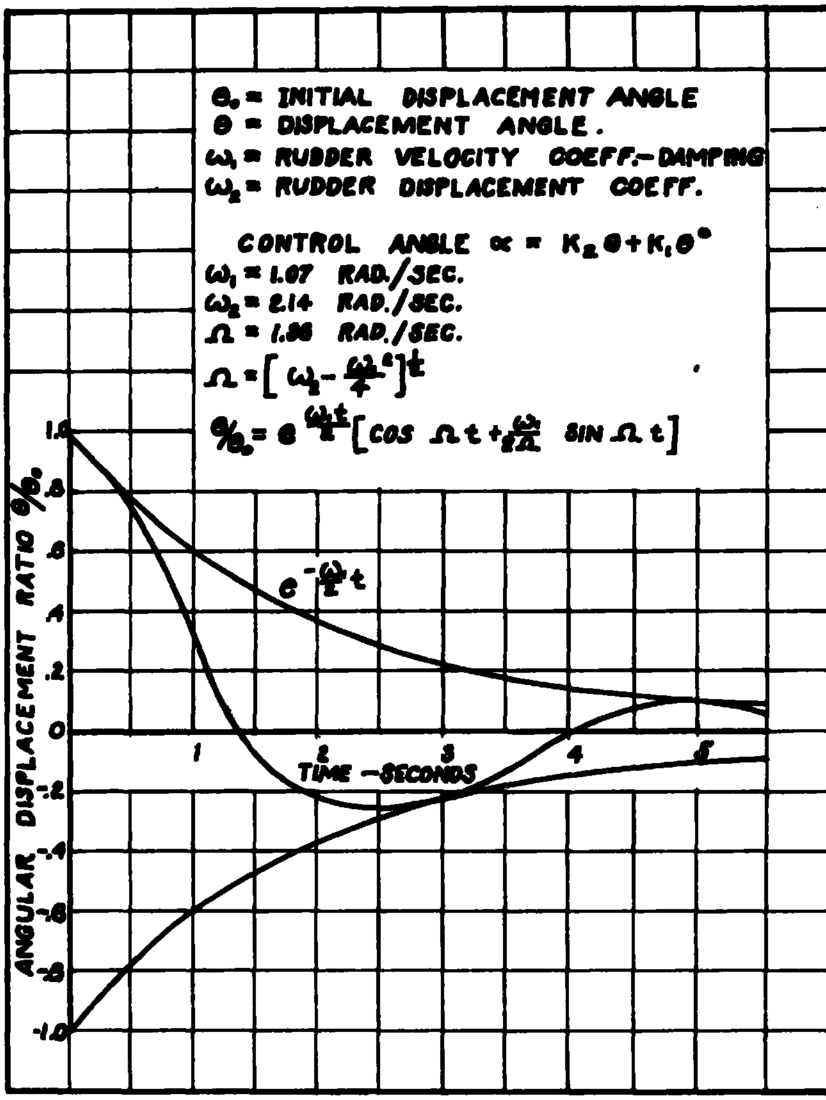

Fig. (5)

PITCHING ANGULAR DISPLACEMENT

AS A FUNCTION OF TIME

and shadowgraph equipment and the multiple mercury-manometer bank; and certain items necessary for calibration.

Steel work construction and equipment installation were nearly completed. The vacuum tanks were reinforced and their positioning and manifolding almost finished, the drier, dust collector, and heater are mounted, and the required steam, water, condensate, and electrical servicing were installed. The vacuum pump is in transit from the manufacturer and is expected shortly. All valves and piping sections, including the various transition sections, are either installed or ready for installation. The storage air bag has been checked for leaks, the nose piece is in place, and the air bag is ready for mounting. The screen section has been completed, and the main butterfly valve has been installed and rigged for hand operation.

In the test room the following items are completed and ready for installation:

(a) The slide valve section

(b) The nozzle section, including the M = 1.3 nozzle and plexiglas windows

(c) The test section with plexiglas windows

(d) The pressure box

(e) The window dollies

(f) The shadowgraph screen

(g) The diffuser section

The balance system and also apparatus for check-out tests on the strain unit are under construction.

The balance system as shown on fig. (4) operates through the use of three units which record the bending in a beam by means of wire strain gages. The loads from the model are transmitted into a semicircular ring which is rigidly fastened at the ends to steel tubes. These tubes are set into circular rings which are external to the test section; rotation of these rings controls the angle of attack of the model. The rings are supported by rollers which transmit all the forces into a steel frame. This frame, in turn, floats on a three point support, the three points being the bending beams. A

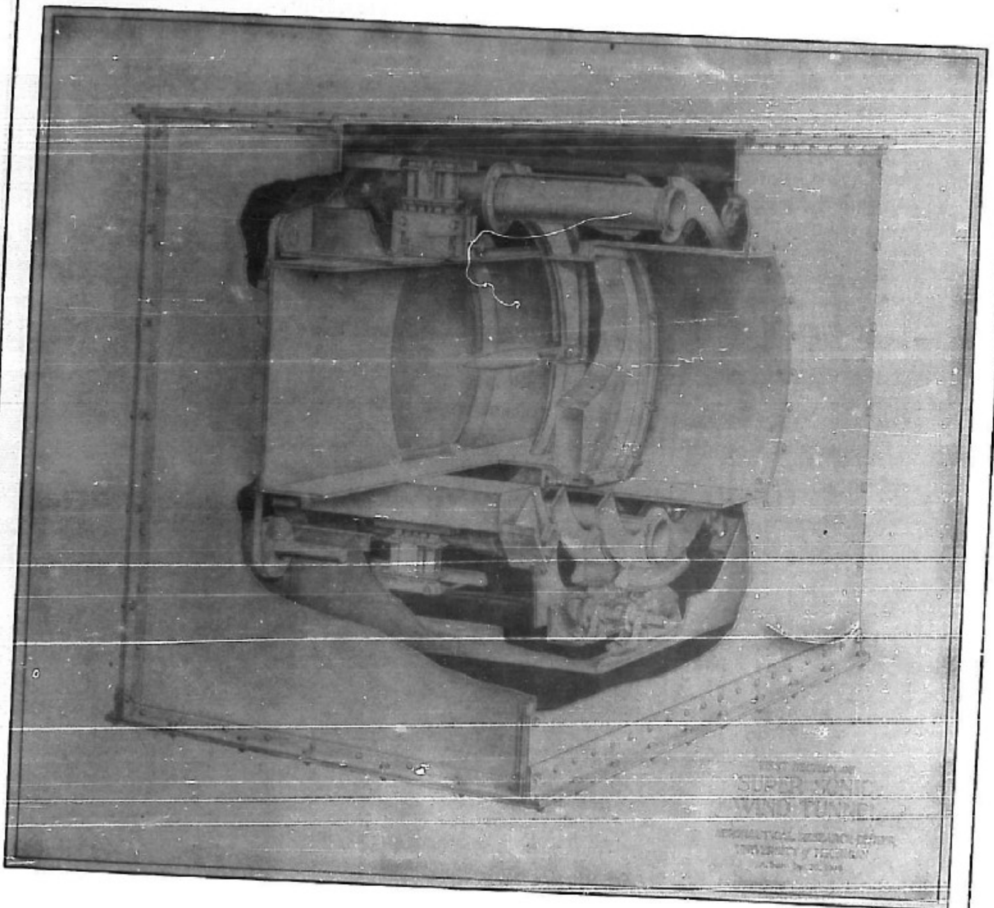

Fig. (4)

SKETCH SHOWING TEST SECTION AND BALANCE SYSTEM

OF SUPERSONIC WIND TUNNEL

windshield for the semi-circular ring is fastened to circular steel tubes which are independent of the force tubes and the loads from these tubes are carried directly into the tunnel walls. The windshield tubes tie into separate circular rings, for adjusting the angle of attack, and a clutch arrangement disengages the windshield from the force ring once the angle of attack has been set.

The manometer bank is nearly completed. Photographs of various components are shown on figures (6) - (15). Plan and section views of the tunnel were shown on fig. (6) of Progress Report number 4 (UMR-4).

A series of tests conducted on model tanks indicated that the addition of four stiffening rings would increase the failing load of the vacuum tanks under external pressure to 40 lb per sq in. Photographs of the model tanks are shown on figures (16) and (17). The full sized tanks were reinforced in accordance with the results of these tests.

Tests were conducted to determine the diameter of glass tubing and rubber tubing most adaptable for the tunnel operation. Tests were also carried out to determine whether the manometer bank can be clamped off so that pressures may be read after the tunnel has ceased operation. The method was found to be practicable, and the design of the manometer bank is being adapted to use this system.

A tentative calibration program has been established and the necessary models are under construction. This program along with an initial testing program, has been discussed with the Air Materiel Command.

The initial wind tunnel test program is to include the following:

(a) Determination of body profile shapes to give aerodynamic stability without fins or with reduced size fins.

(b) Diffuser tests to give basic information in regard to ram-jet inlets and to improve pressure recovery or efficiency.

(c) Measurement of skin friction to determine the effect of Mach number.

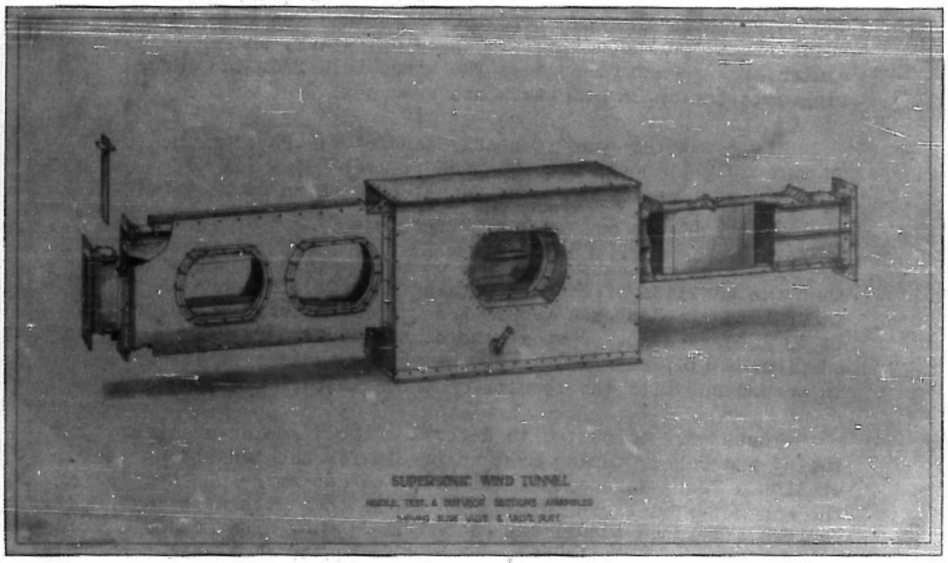

Fig. (5)

SKETCH SHOWING NOZZLE, TEST, AND

DIFFUSER SECTIONS ASSEMBLED

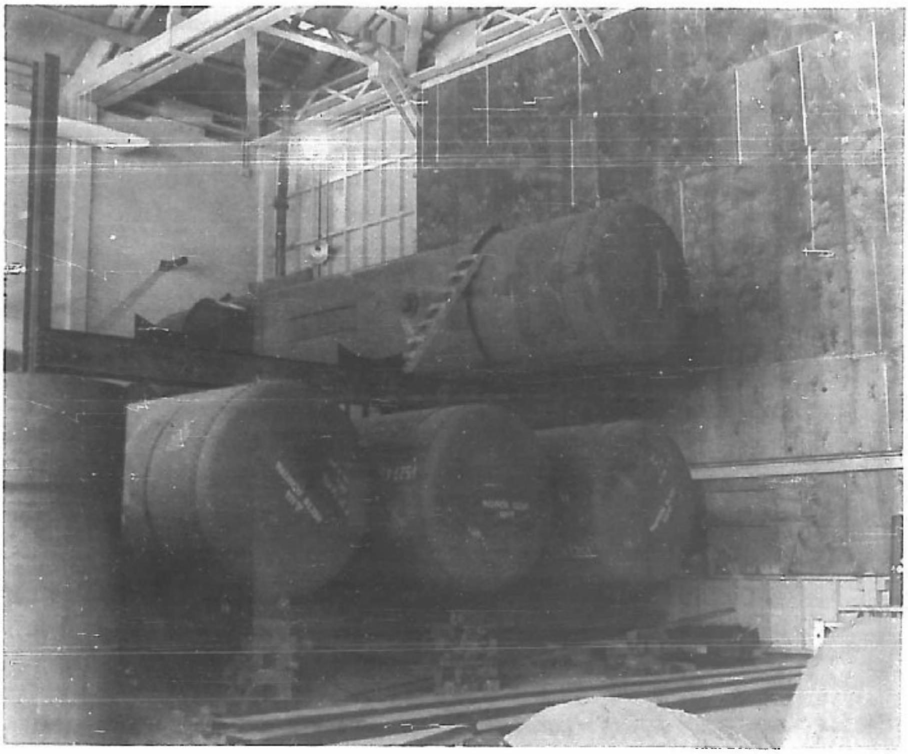

Fig. (6)

VACUUM TANK INSTALLATION - 29 JANUARY 1947

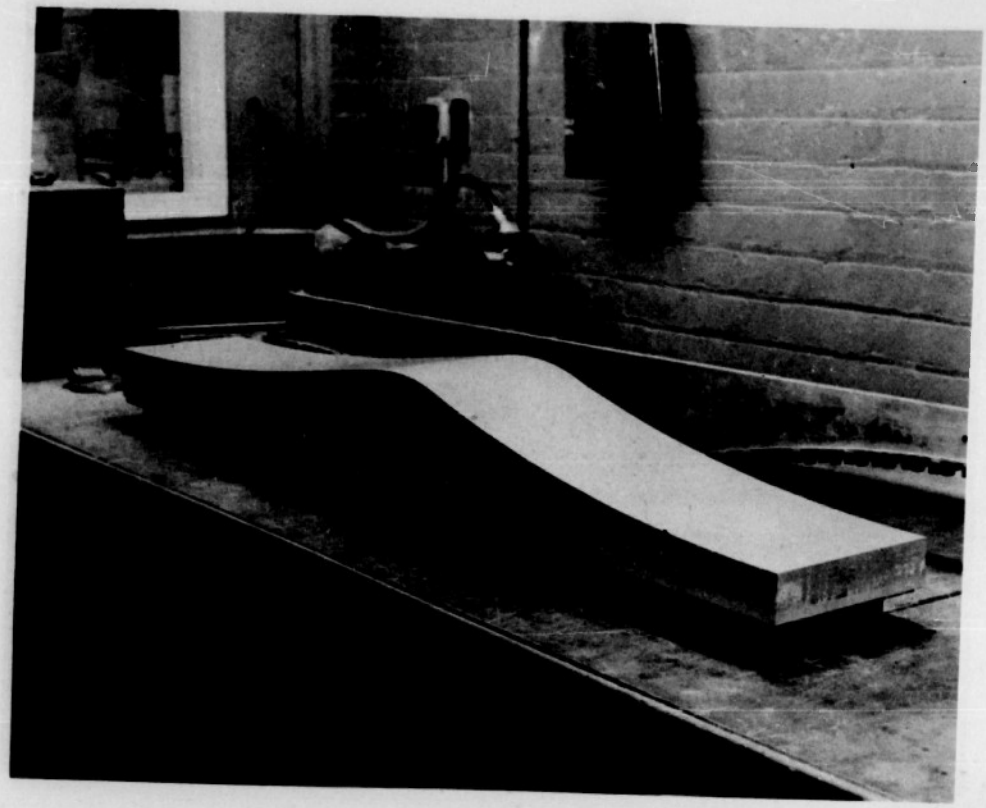

Fig. (7)

WIND TUNNEL NOZZLE FOR M = 1.9

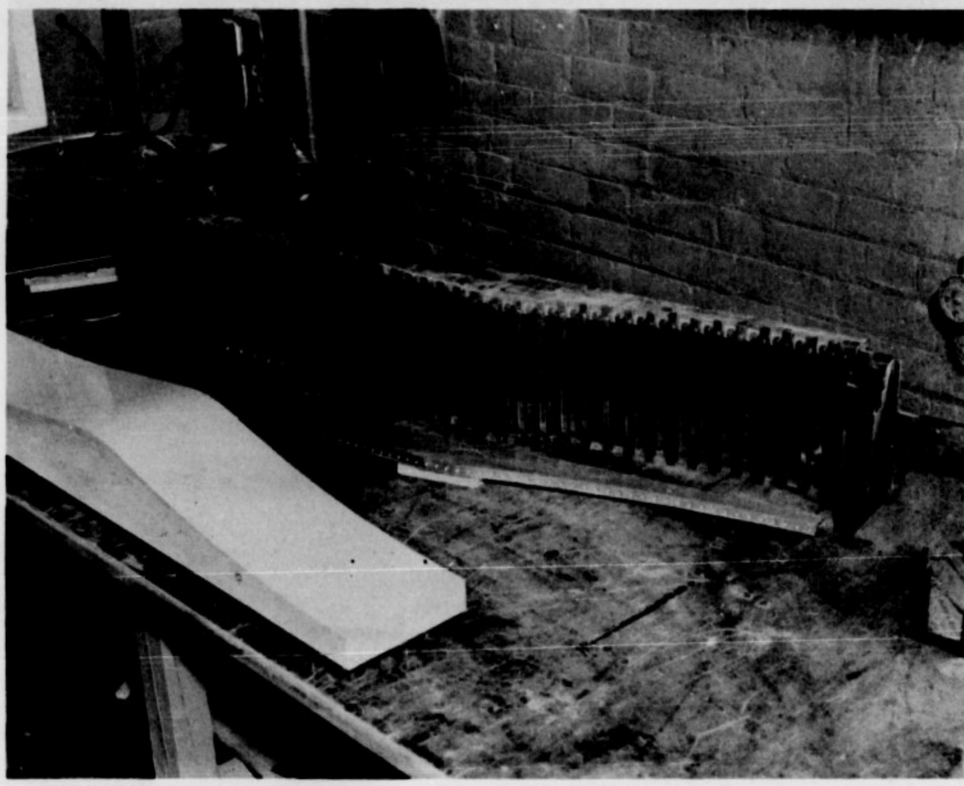

Fig. (8)

MOLD USED IN CASTING WIND TUNNEL NOZZLE

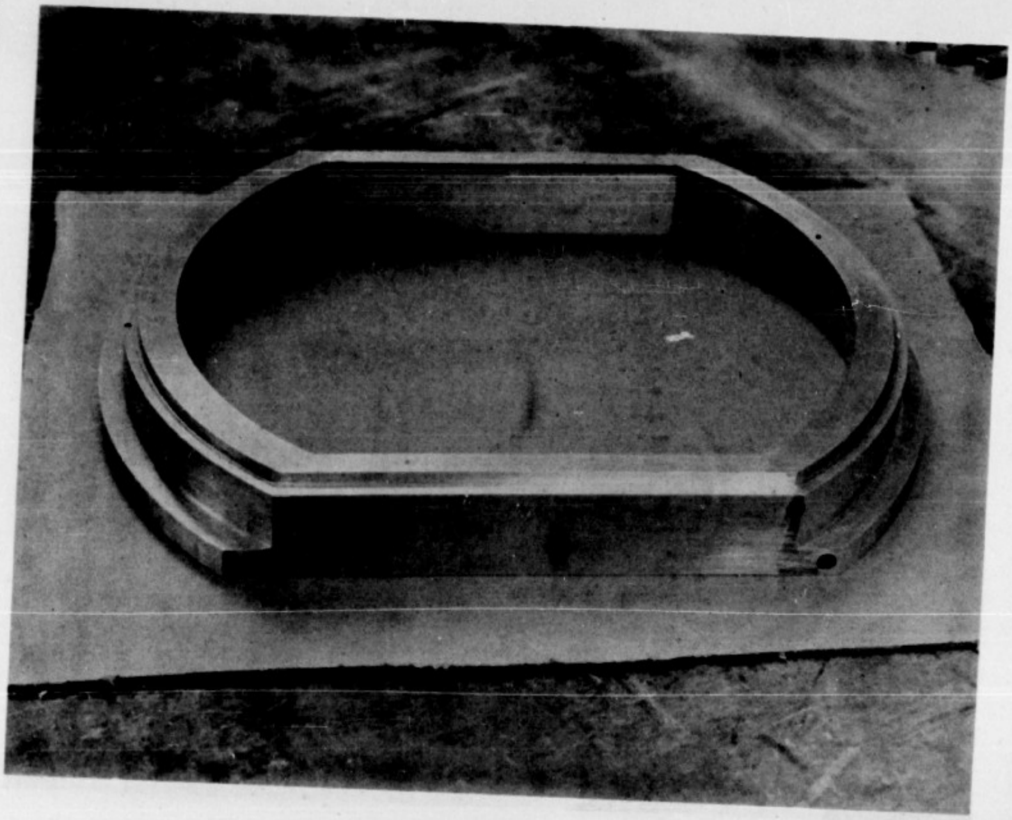

Fig. (9)

FRAME FOR TEST SECTION WINDOW

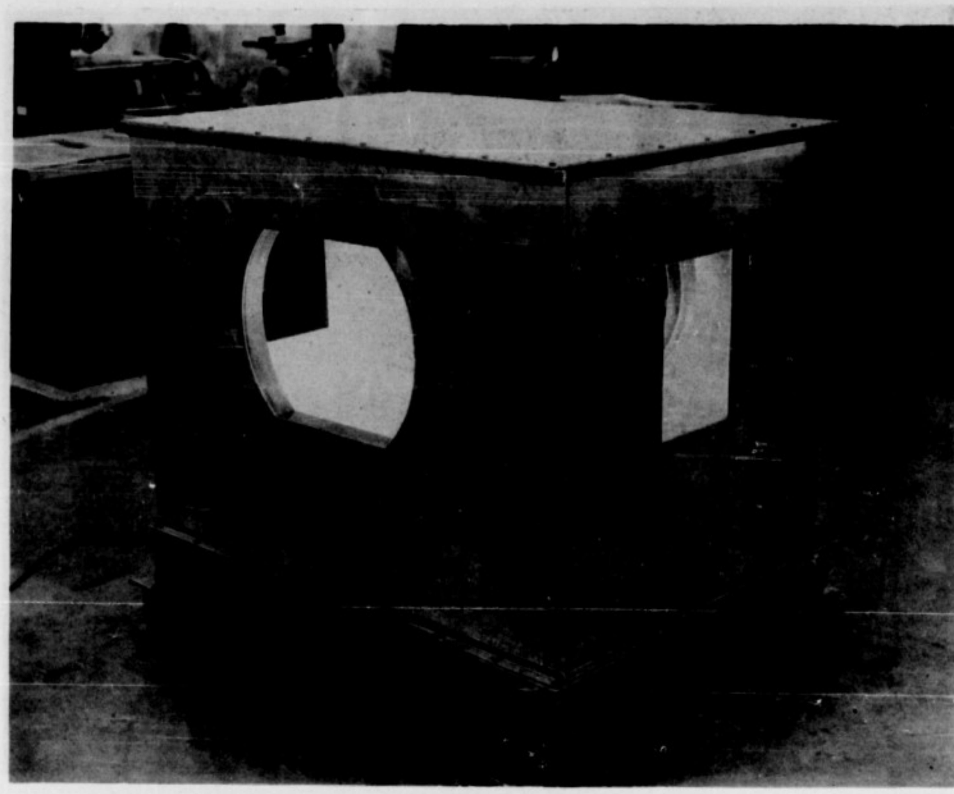

Fig. (10)

PRESSURE BOX FOR TEST SECTION

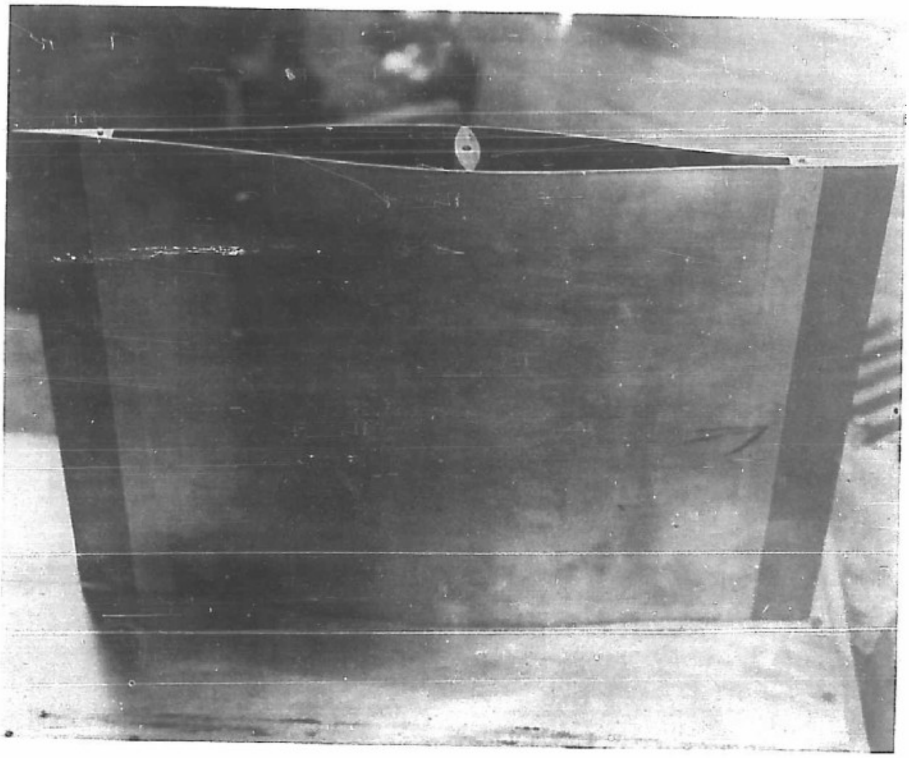

Fig. (11)

DIFFUSER SECTION

Fig. (12)

DIFFUSER BOX

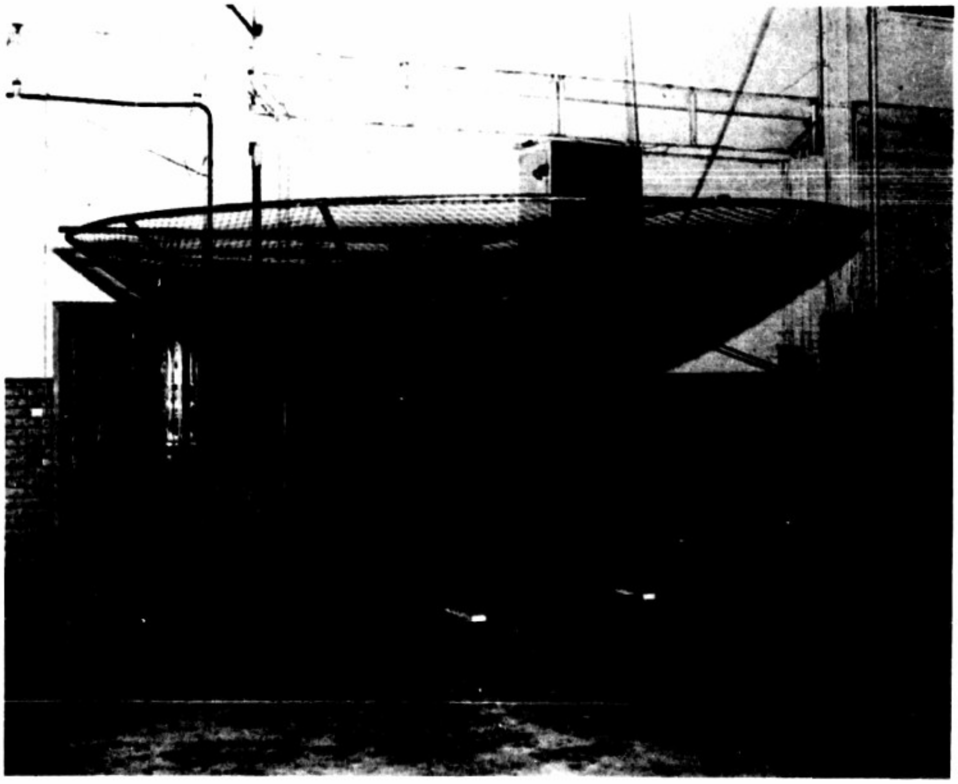

Fig. (13)

NOSE PIECE FOR STORAGE AIR BAG

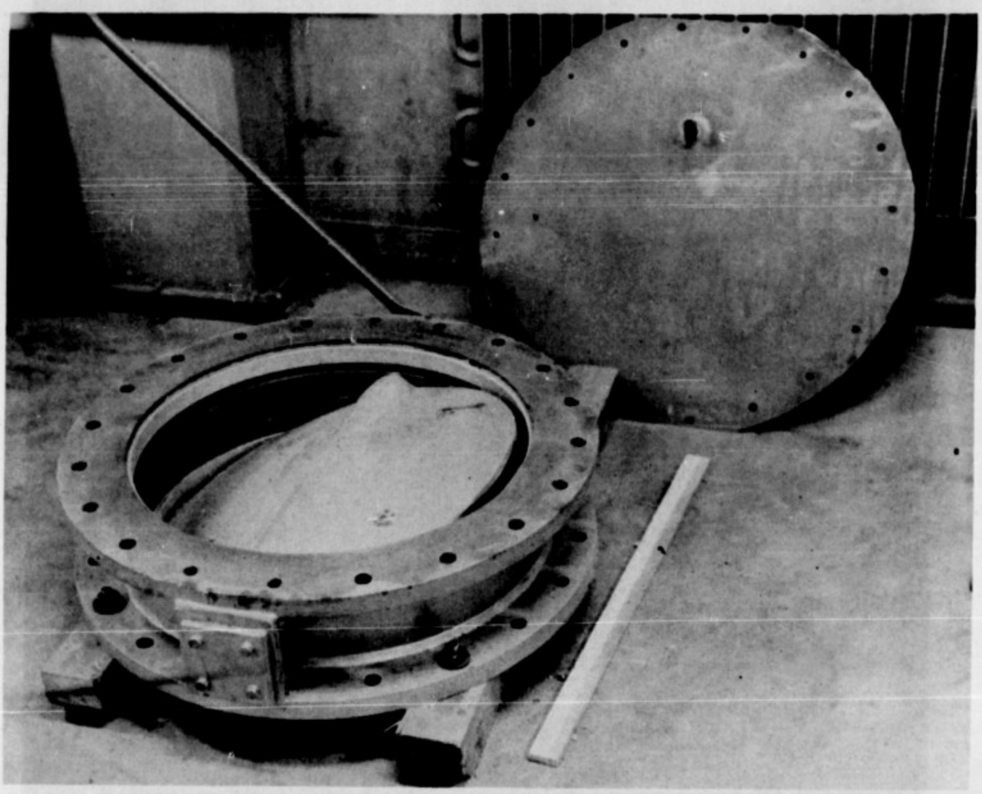

Fig. (14)

BUTTERFLY VALVE

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Fig. (15)

TRANSITION PIECE

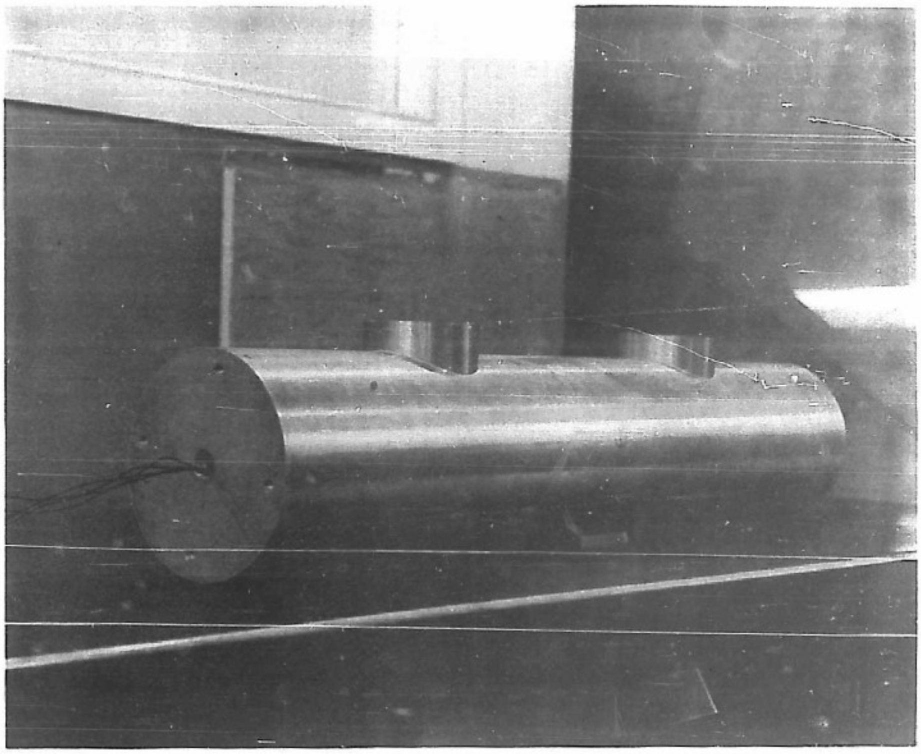

Fig. (16)

MODEL VACUUM TANK WITHOUT REINFORCEMENT

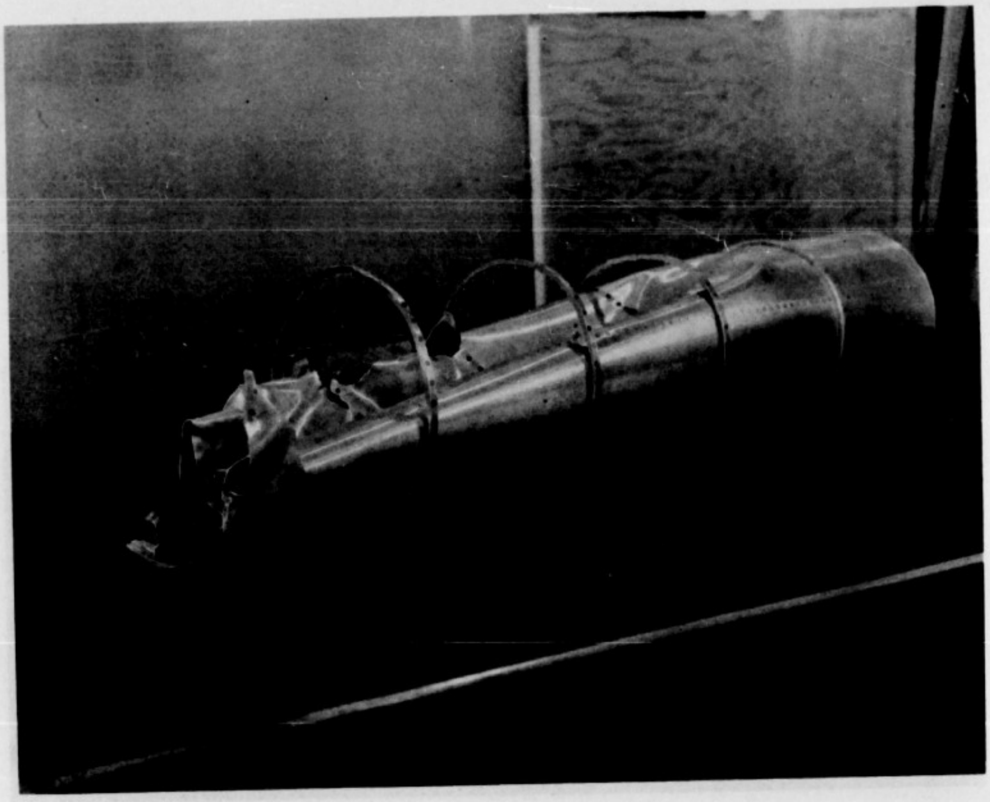

Fig. (17)

REINFORCED MODEL TANK AFTER FAILURE

IV DESIGN

Preliminary weight and performance studies of possible missile configurations meeting the specifications of this project have been continued. Studies of single stage self-launched liquid rockets indicate that this type of configuration will be excessively large and heavy in order to meet the design specifications unless new fuels of higher specific impulse can be developed. Current studies are based on nitric acid-aniline or similar fuels having a specific impulse of the order of 200 lb sec/lb.

Systematic studies of the effect of high initial acceleration in the size and weight of the second stage of a multi-stage configuration appear to indicate that initial boost accelerations of the order of 40 g for periods of 6-7 seconds may offer the possibility of very considerable reductions in the size of the final stage, although this advantage is offset to some extent by the large sizes of the solid rocket units required. Typical curves showing gross weight and component weights of a liquid fuel rocket with an initial solid fuel boost stage as functions of duration of first stage acceleration are shown on fig. (18) for a maximum acceleration of 40 g. Similar curves may be plotted for other maximum accelerations, and cross plotting will permit the selection of the proportions affording minimum gross weight or minimum first stage weight for the given configuration.

Preliminary design studies of multi-stage liquid rockets with and without an initial solid rocket stage are being completed, with systematic variation of the design parameters in an attempt to determine the most efficient proportions for each type of configuration. The results of all design studies are being tabulated to serve as a basis for selecting the most promising design or designs which are to be subjected to further and more intensive investigation in order to formulate a definite design proposal for this project. This work is being scheduled for completion on or about 1 June 1947.

A study has been made of various systems of control for the final stage of a multi-stage craft. For purposes of comparison, the craft was made as small as possible consistent with the components to be housed within the shell. These components included guidance equipment, warhead, control equipment, tanks, pumps, valves, piping, and burners. Fuel capacity was based on full control for guidance and stability for a period of 100 seconds. The assumed control required was sufficient to correct an error in heading of

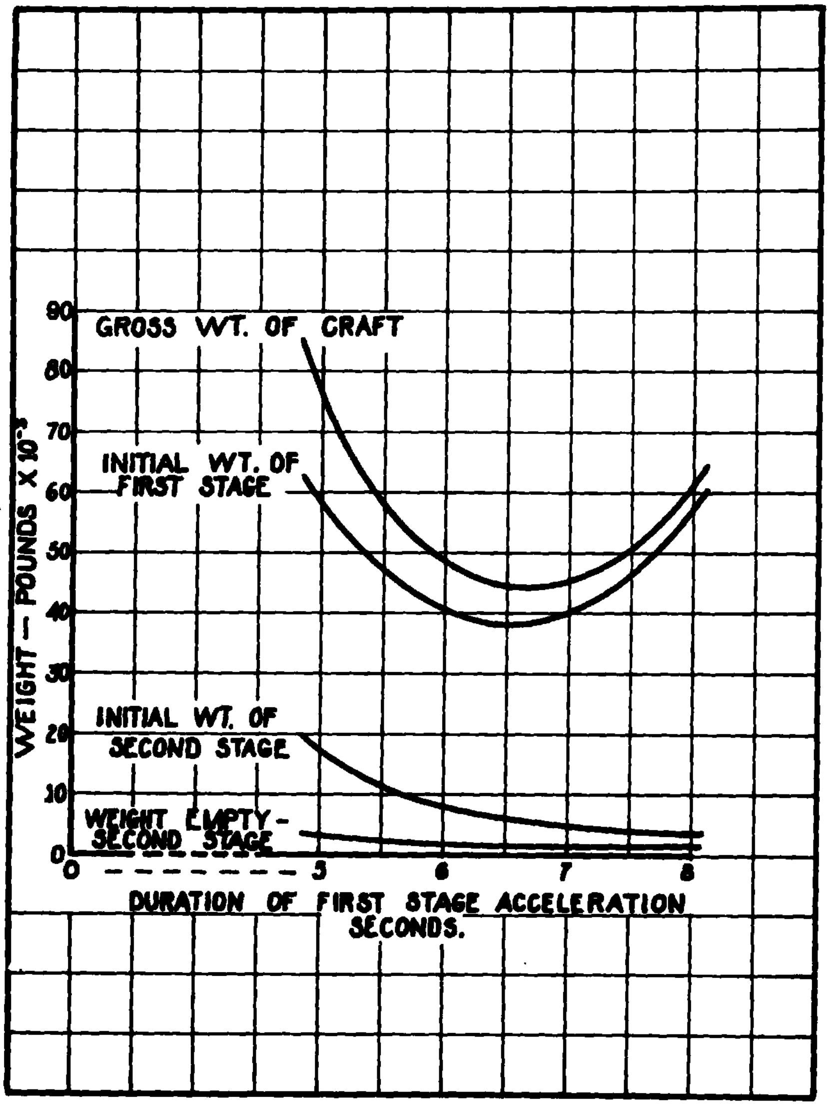

Fig. (18)

COMPONENT AND GROSS WEIGHTS OF A LIQUID FUEL ROCKET
WITH INITIAL SOLID ROCKET STAGE AS FUNCTIONS
OF DURATION OF FIRST STAGE ACCELERATION

approximately 1° with the craft ten miles from the point of interception. These values were assumed for comparative purposes only, and are not to be construed as proposed performance figures for a craft meeting the specifications of this project.

Sketches showing the principal characteristics of the control systems investigated are shown on fig. (19). The systems of control are as follows:

(a) Trajectory control, or displacement from the flight path, by means of four radial liquid rocket burners located near the center of gravity and thrusting in a direction normal to the flight path. Stability is provided by four liquid rocket burners oriented parallel to the axis of the missile and provided with jet rudders.

(b) Trajectory control as in (a), but stabilization by means of three liquid rockets thrusting parallel to the axis of the missile. Two of these burners are of small size and are placed 180° apart on the periphery of the missile. These units are pivoted and rotate in opposite directions to provide roll stability. A third unit, which is considerably larger in size, is placed directly on the missile axis, and rotates through a 40° cone to provide pitch and yaw stability.

(c) Stability as in (b), but with no radial burners, and with the central axial burner of larger size. Trajectory control is provided by rotating the entire missile so as to direct the thrust of the central burner at right angles to the flight path.

A considerable weight advantage in addition to the simplification inherent in the smaller number of burners favors missile (c). However, this advantage may be offset by the loss of time in rotation of the missile before trajectory correction can be applied, and the added complication in the required guidance, gyro stabilization, and possible warhead orienting mechanism. Differences between (a) and (b) are mainly mechanical in character and relative advantages and disadvantages cannot be resolved without additional studies. Times of rise and decay of control thrust, methods of minimizing center of gravity travel, and means of insuring minimum gross weight at the start of the homing stage are factors which must be investigated before these studies can be considered complete.

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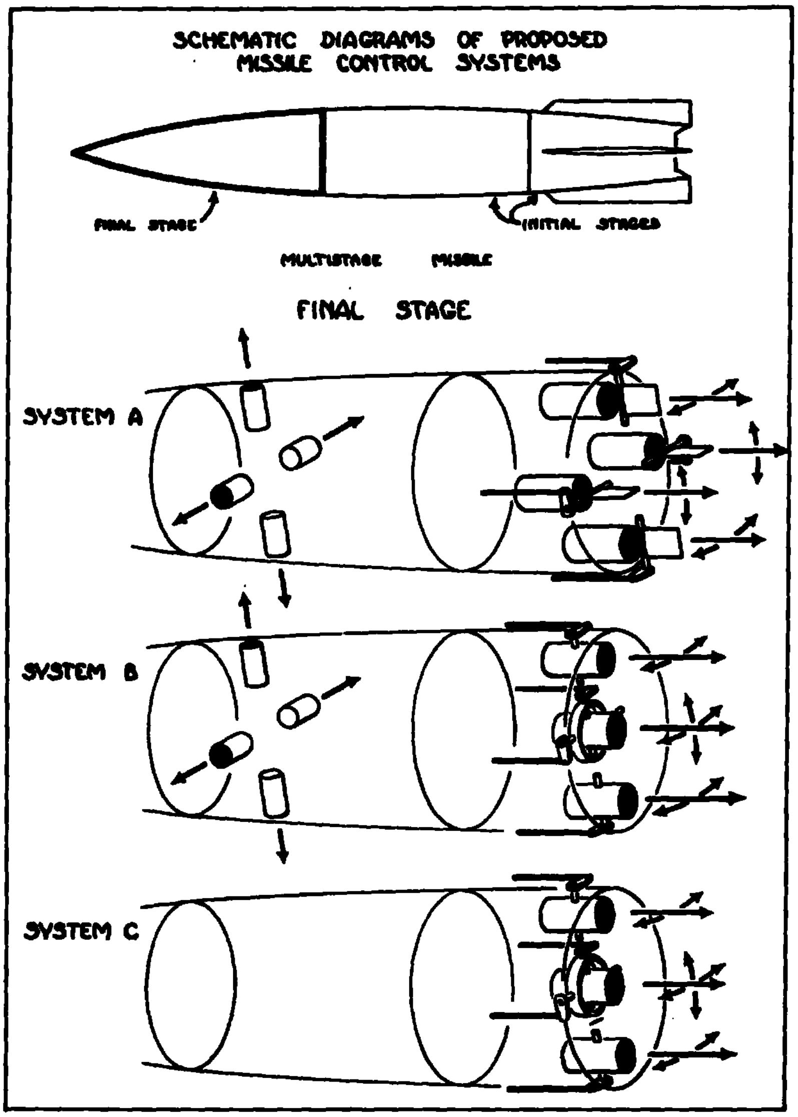

Fig. (19)

EXTERNAL CHARACTERISTICS OF THREE

POSSIBLE SYSTEMS OF CONTROL

Preliminary design studies have been made of a test vehicle which is under consideration for the determination of the characteristics of control systems such as those proposed above. Static tests in the atmosphere or in a low pressure chamber would be supplemented by flight tests of a small rocket, which corresponds to the final stage of the multi-stage rocket shown on fig. (19), and which would be elevated to the upper limits of the sensible atmosphere by means of a larger rocket. The test vehicle is predicated on the use of small burner units currently available, keeping the overall size of the rocket to a minimum. Approximate characteristics of the test vehicle are as follows:

Gross weight	350 lb
Weight empty	291 lb
Duration of stabilized flight	45 sec
Duration of control application	10 sec
Number of liquid rocket burners	4

Design studies of the large rocket which would be used to elevate the test vehicle to high altitudes have not been initiated as yet.

Further information concerning shaped charges appears to indicate that a single shaped charge, fixed rigidly to the craft, will not be an effective warhead for use in connection with this project. If shaped charges are to be used, it is advisable to have them in multiples. The added effectiveness of fragmentation at high altitudes makes it advisable to consider the possible use of a cylindrical fragmentation warhead. In either case, it would be advisable to mount the warhead so that it could be oriented in response to homing commands if it is to be used in a craft that does not continuously point toward the target, or in case oscillations of the craft in response to control forces are not highly damped.

V GUIDANCE

The general plan of attack to the guidance problem is fairly well formulated at the present time. A block diagram of this overall guidance plan is shown in fig. (20). Of the various units shown in the figure, work has been concentrated mainly on the command guidance system, the computer and the homing device.

The command guidance system has crystallized to the point where it appears desirable to increase the number of command channels from three to seven. The increase over those in the last report is primarily for the control of the homing head such that it will operate as soon as it comes within range of the target without scanning. The seven channels at present are:

(a) Roll commands
(b) Up-down commands
(c) Right-left commands
(d) Homing head elevation commands
(e) Homing head azimuth commands
(f) Arm warhead - self-destruction commands
(g) Unassigned

The tentative specifications are:

(a)	Pulse width, marker and range pulse	.7 μs
(b)	Pulse width command channels	.35 μs
(c)	Receiver Δf	6 megacycles
(d)	PRF per channel	500

A functional block diagram of the command coded transmitter is shown in fig. (21) and the receiver decoder is shown in fig. (22), along with explanatory wave shapes for various sections of the circuits.

Analysis of the computer problem has continued with the result that preliminary steering equations, based on geometrical relations that must exist between velocity and line of sight vectors for collision, have been set up. These equations are expressed in terms of slant range, elevation angle, and azimuth angle, and rates of change of these quantities, the same information that is received from conventional tracking radars.

Although a number of simplifying assumptions have been made (i.e., the ignoring of atmospheric effects, variation of gravity, evasive action of target, inability to wipe out undesired components of momentum instantaneously, and exact time and place of interception), it is possible to gain from

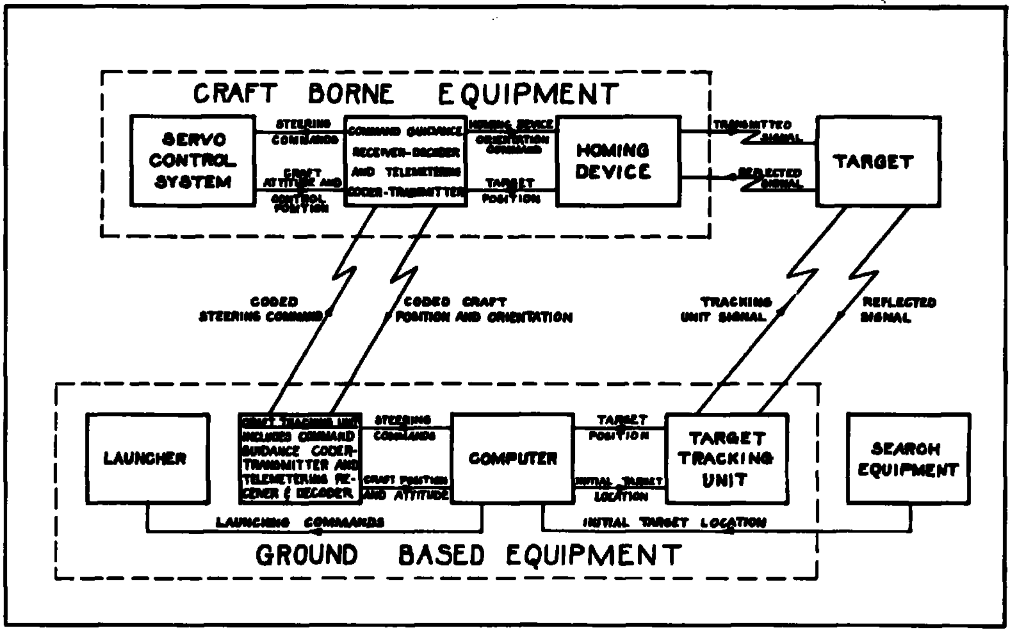

Fig. (20)

BLOCK DIAGRAM OF GUIDANCE SYSTEM

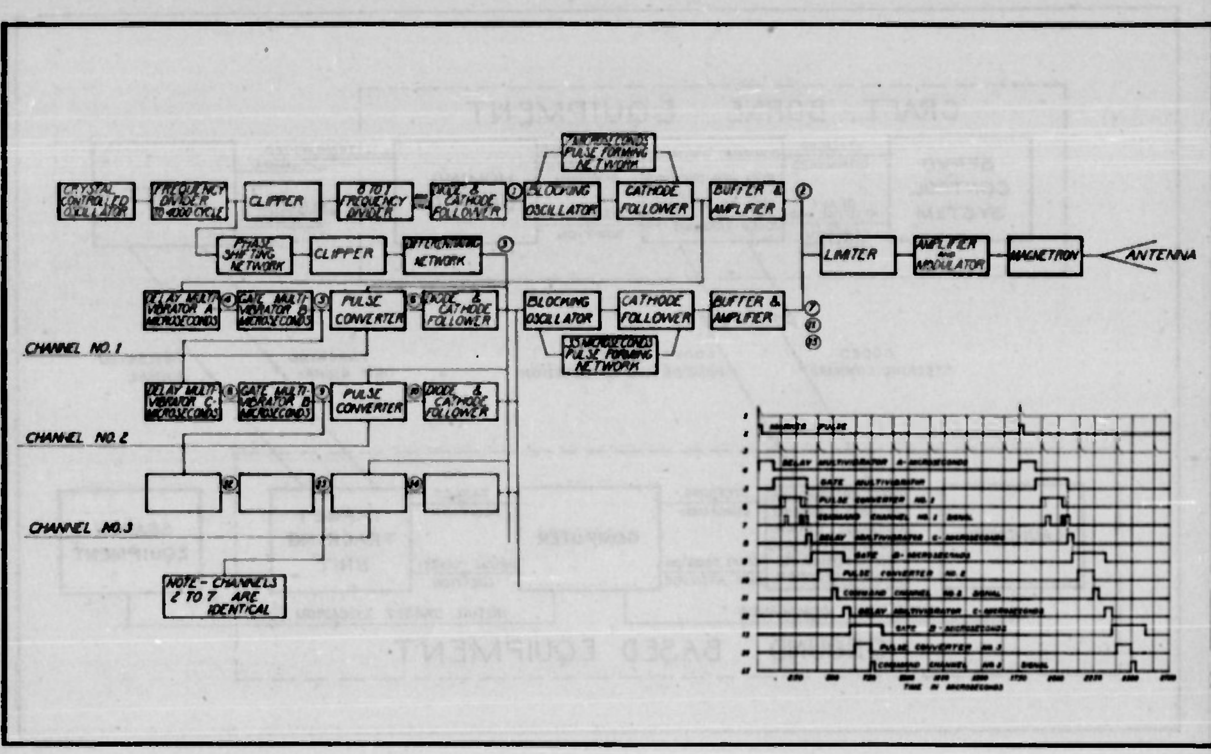

Fig. (21)

BLOCK DIAGRAM OF COMMAND CODED TRANSMITTER

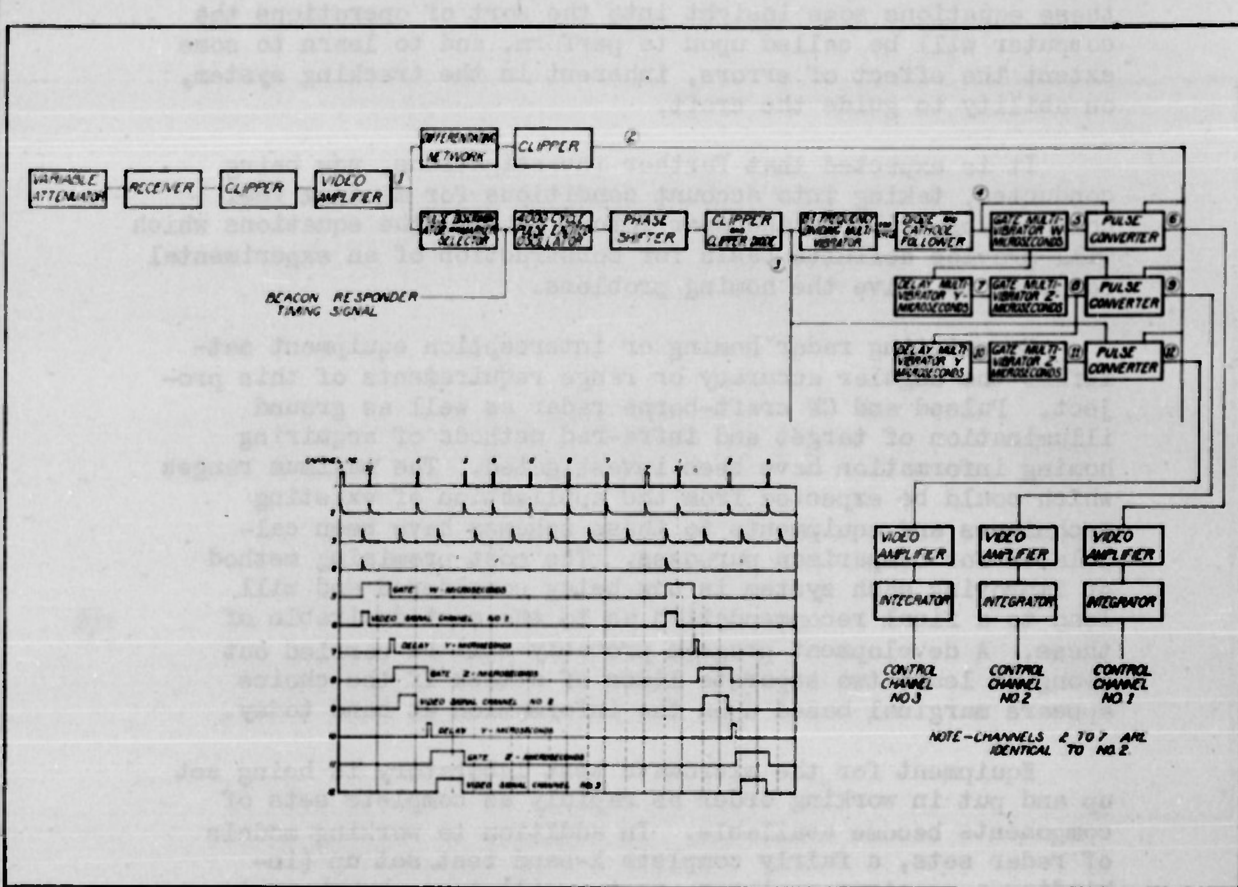

Fig. (22)

BLOCK DIAGRAM OF RECEIVER DECODER

these equations some insight into the sort of operations the computer will be called upon to perform, and to learn to some extent the effect of errors, inherent in the tracking system, on ability to guide the craft.

It is expected that further investigations, now being conducted, taking into account conditions for minimum fuel consumption, will in the near future lead to the equations which will provide definite basis for construction of an experimental computer to solve the homing problems.

No existing radar homing or interception equipment satisfies the angular accuracy or range requirements of this project. Pulsed and CW craft-borne radar as well as ground illumination of target and infra-red methods of acquiring homing information have been investigated. The maximum ranges which could be expected from the application of existing techniques and equipments to these schemes have been calculated for comparison purposes. The most promising method of improving each system is now being considered and will lead to a final recommendation as to the most desirable of these. A development program probably will be carried out along at least two separate lines of attack if the choice appears marginal based upon the information at hand today.

Equipment for the microwave test laboratory is being set up and put in working order as rapidly as complete sets of components become available. In addition to working models of radar sets, a fairly complete X-band test set up (including a spectrum analyser, test oscillators, bench equipment for making standing wave ratio and power measurements, and a bell jar with electrical connections for testing microwave components at low pressures) is already in service.

VI LAUNCHING

A survey of launching systems has been completed which included gun launching, catapult launching, rocket launching, and a detailed analysis of the electric launcher. From this it appears that rocket launching is probably the simplest and least expensive type, and is well adapted to the design of portable launchers, if such are desired. The analysis of the electric launcher included studies of the DC linear motor, the Northrup inductive launcher, and the Westinghouse electric catapult, which is essentially a linear induction motor of the squirrel cage type. It appears that any electrical launching device will be large, immobile, and very expensive. It will be justified economically only if frequent launchings are to be made. Studies based on the acceleration of a 28,000 lb projectile to 1000 ft per sec with a constant acceleration of 30 g indicate that the total input to the launcher, for both the DC and induction launchers, will be of the order of 2,000,000 kw in approximately one second. In the case of the DC launcher, this will require the transfer, by high velocity sliding contacts, of currents of the order of 3,000,000 amperes, with considerably smaller currents in the case of the induction launchers.

Preliminary design studies were completed of an aluminum casing for solid fuel rockets, assuming an internal pressure of 1000 lb per sq in., a burning temperature of 5000 °F, and a burning time of 4 sec, and of a solid fuel booster unit with a toroidal shape. This shape was investigated as it appears to offer the possibility of equalizing the thrust from a number of nozzles.

Preliminary design studies have been started of a launching ramp for a finless type of craft. Structural drawings have been started of a launching ramp for a finned missile. Both launchers will be capable of adjustment in both elevation and azimuth.

VII MATHEMATICS

A method has been developed for solving the point mass homing problem under the following assumptions:

(a) Drag is negligible.
(b) Specific impulse is constant.
(c) Time delays due to rotation of the craft and failure of the burner to develop full thrust immediately are negligible.
(d) Relative velocity and relative position are known.
(e) The optimum path is followed corresponding to the homing time chosen.

The method determines:

(a) At what times homing is possible.
(b) The fuel consumption which corresponds to any chosen homing time.
(c) The path of minimum fuel consumption (if such a path exists).

For any chosen homing time, the optimum path can be specified in terms of thrust.

The method seems particularly well adapted to use in a computer in the field, as the parameters of the craft need not be specified beforehand. All of the parameters of the craft and of the initial conditions are included in a single equation. The method is basically graphic, as it seems that any method will be, because of the logarithmic relation between velocity and fuel consumption. It consists of a single grid, as shown on fig. (23), which can be prepared in advance, and which represents the distance from an origin, as a function of time, for all possible craft trajectories, which may involve operating the thrust unit all the way to the interception point or cutting off the thrust unit at any point and coasting the rest of the way. Thrust is considered constant during operation of the thrust unit. The heavy curved line represents the trajectory as long as the craft is under thrust. After thrust has been cut off, the distance of the craft from the origin is given by points on the tangent to the curve at the point of cut off.

By a simple graphical method, the target trajectory can be plotted on the grid, and an example is given by the dashed curve on fig. (23). These trajectories are represented by hyperbolas, whose shape and location depend on the relative velocities and coordinates, and on the specific impulse of the craft. Possible points of interception of the target by the craft are given by intersections of target and craft paths on the grid. For example, points A, B, and C on fig. (23) represent possible inter-

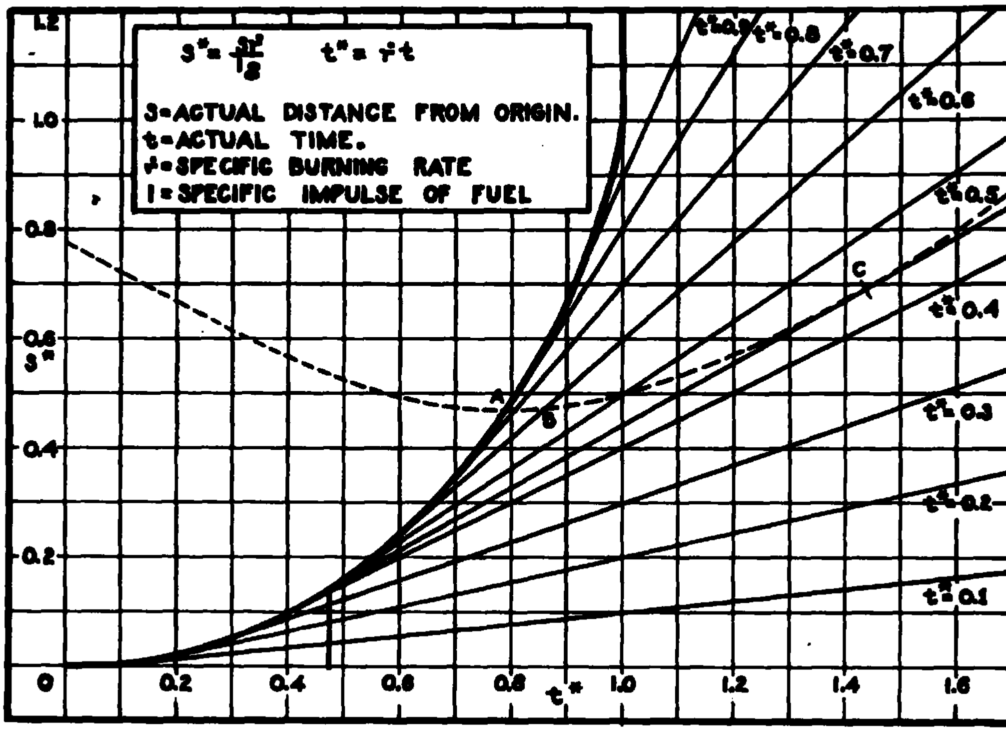

Fig. (23)

DISTANCE OF CRAFT FROM A CHOSEN ORIGIN

AS A FUNCTION OF TIME

ception points. Point A represents an interception where the craft thrust unit is operating all the way. The interception shown by point B requires that the craft burn 0.6 of its initial gross weight as fuel, and then coast to interception. Point C, the point of common tangency between the target curve and the craft curve, represents the interception corresponding to minimum fuel consumption (in the case shown, 43.5% of initial gross weight). The angle at which thrust must be applied is given by a separate equation after a particular path of interception has been determined.

The method is being extended to include the problem of proceeding to a fixed point in space. In this case, drag is considered negligible and change in gravity and rotation of the earth have been ignored.

Preliminary analyses have been made of the connection of errors arising during the homing stage, the problems of infrared homing, and of approximate methods of solving homing problems.

Studies have been initiated of paths of minimum fuel consumption in the atmosphere.

VIII PROPULSION

A performance study has been completed of the ram-jet engine burning both lean and rich fuel-air mixtures at altitudes up to 60,000 feet and at flight velocities up to a Mach number of 6. This study is in addition to the study previously completed for the ram-jet burning the stoichiometric fuel-air mixture. The next step in these ram-jet studies will be the comparison of flight paths of ram-jet engines burning lean, stoichiometric, and rich fuel-air mixtures. Curves of ram-jet gross thrust and specific impulse as functions of fuel-air ratio are shown on figures (24) and (25). From these it may be seen that gross thrust usually is a maximum at approximately the stoichiometric fuel-air ratio (.0665), whereas the specific impulse is improved by the use of leaner mixtures.

An initial study of the turbo-jet engine operating at flight velocities up to a Mach number of 3.5 at altitudes up to 60,000 feet and at various compression ratios is being completed.

Apparatus for investigating the factors affecting the speed of flame propagation in combustible mixtures has been completed and placed in operation, and is shown on fig. (26). Initial tests indicated certain deficiencies in the apparatus which have been remedied, and a series of tests is now underway to determine the effect of moisture on flame propagation. Typical curves of flame speed as a function of mixture ratio for two values of water vapor partial pressure are shown on fig. (27). The fuel used was propane.

Apparatus for the investigation of heat transfer problems has been designed, and fabrication of the burner and frame are underway. Procurement has been initiated of various items necessary for the test apparatus, and space for the set-up has been allotted.

In the theoretical investigation of ram-jet cooling requirements calculations have been made of equilibrium temperature, velocity, and density of the gases being burned in a burner of uniform section, for a Mach number of the craft equal to 2 at 40,000 feet, assuming a divergent diffuser with normal shock at the entrance and ideal conditions thereafter to a characteristic velocity of the unburned gases at the beginning of combustion.

Analytic studies of the energy and thermochemistry of fuels have been initiated, and red fuming nitric acid-aniline with a mixture ratio of 3:1 by weight is currently being investigated. The necessary calculations for the construction of an enthalpy-entropy diagram for the products of combustion of this system are nearly complete. The proposed diagram will have lines of con-

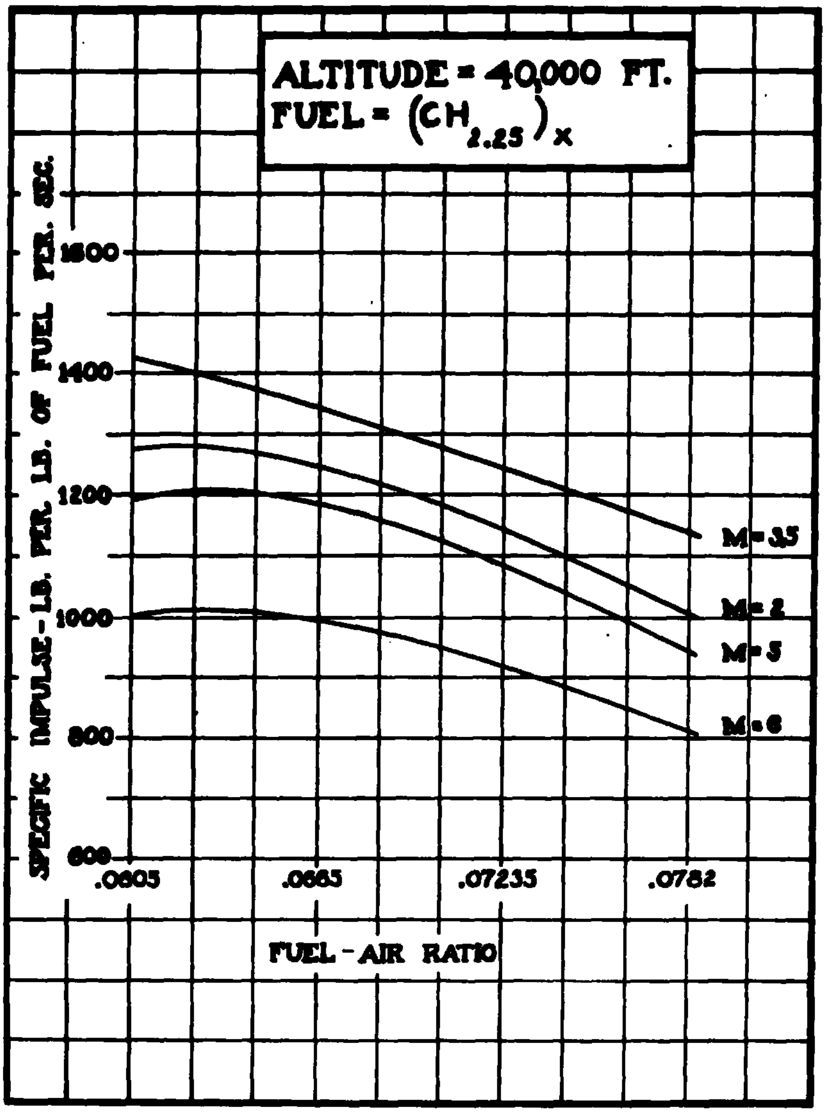

Fig. (24)

RAM JET GROSS THRUST AS A FUNCTION

OF FUEL-AIR RATIO

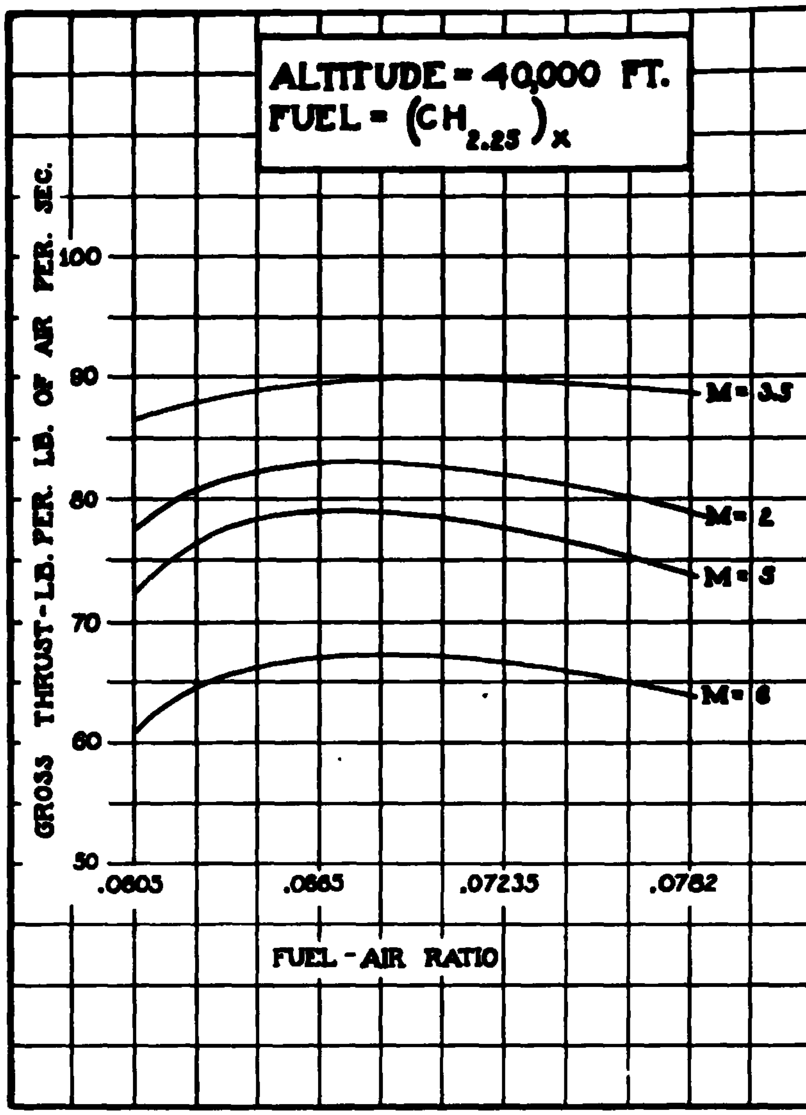

Fig. (25)

RAM JET SPECIFIC IMPULSE AS A

FUNCTION OF FUEL-AIR RATIO

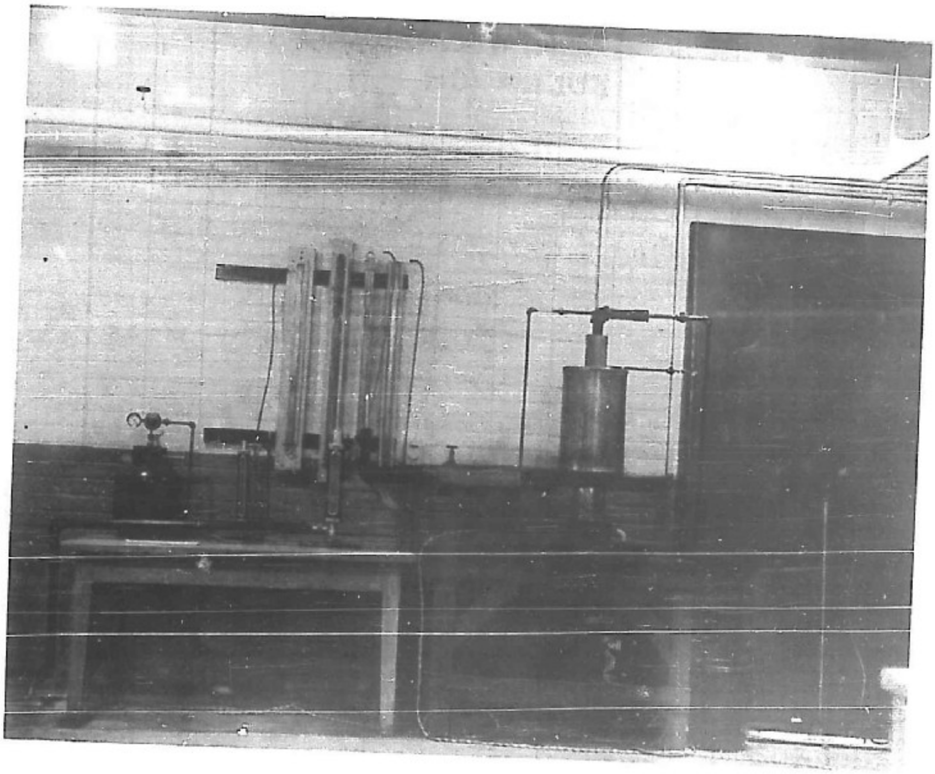

Fig. (26)

FLAME SPEED APPARATUS

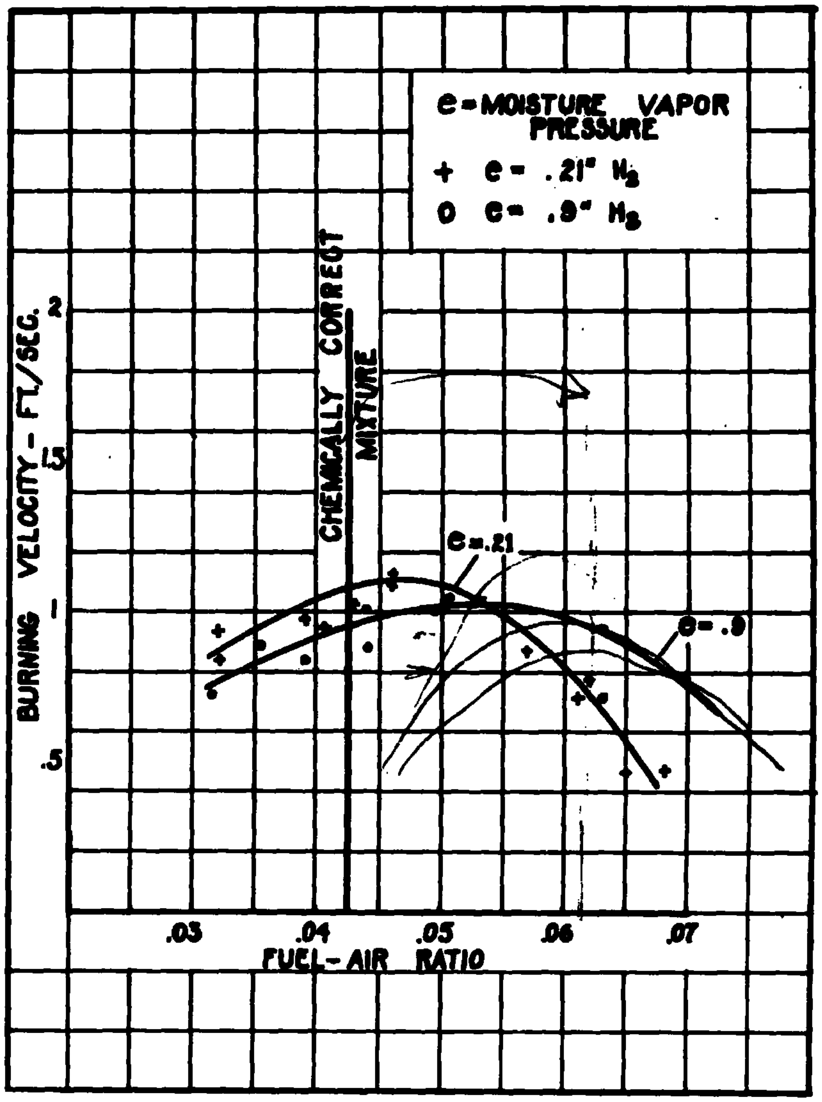

Fig. (27)

BURNING VELOCITY OF PROPANE AS A FUNCTION OF FUEL-AIR RATIO AT CONSTANT MOISTURE VAPOR PRESSURE stant temperature and pressure, and, for a chosen combustion chamber pressure, will permit the evaluation of energy available for any expansion ratio.

At the request of the Air Materiel Command, a study has been made of measurement techniques for the determination of jet velocities. The direct spectrographic method based on the Doppler effect is considered to be the most promising.

IX RESEARCH TECHNIQUES

The design and construction of most auxiliary schlieren components for the supersonic wind tunnel have been completed. These components include the schlieren camera, which was of special design, the shadowgraph screen with frame, the flash unit, and other auxiliary units of the light source. The camera uses a 40 inch aerial camera lens and a synchronized shutter. The schlieren images are recorded on a 4 x 5 film. The flash unit, which was constructed in the electronics shop, is used for flashing the type B-H6 mercury lamp at very high intensities. A ground glass surface is used for the shadowgraph or for nearly full size schlieren observation. The schlieren system was made very flexible to cover a large range of conditions and uses.

Studies were continued of the absorption method of density measurement in supersonic wind tunnels. This method depends on the introduction of a foreign gas into the circulating air of the tunnel. This foreign gas will absorb a certain spectrum band of ultra violet light. By using a monochromatic light source of this wavelength, the absorption of light in the test section will depend on the density distribution of air in the test section. A photographic plate exposed to this light will record the density distribution, which can then be evaluated quantitatively by photometric methods. At low densities the accuracy of this method may exceed that of the interferometer. A schematic diagram of the proposed system is shown on fig. (28).

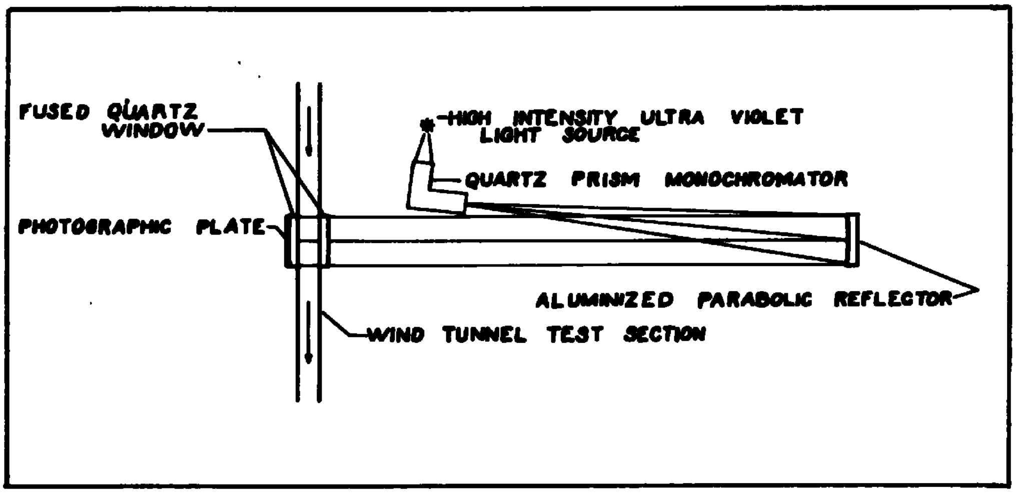

Fig. (28)

SCHEMATIC DIAGRAM OF APPARATUS FOR MEASUREMENT OF DENSITY DISTRIBUTION IN SUPERSONIC WIND TUNNEL TEST SECTION

X PROGRAM PLANNED FOR NEXT PERIOD (1 FEBRUARY - 1 APRIL, 1947)

(a) Aerodynamics

1. Trajectory studies, and stability and controllability studies will be continued.

2. The supersonic wind tunnel will be completed, preliminary calibration runs and tests on the balance system will be carried out, and a preliminary report will be completed on the design, construction, and operation.

(b) Design

1. Design studies of a possible guidance test vehicle will be continued, and further preliminary design studies of multi-stage missiles utilizing ram-jets will be carried out.

2. One or more of the most promising configurations developed during the series of preliminary design studies will be selected, and the studies necessary for the completion of Phase I will be initiated.

(c) Guidance

1. The design of an intelligence coder and decoder will be continued. Preliminary schematic diagrams will be completed and the construction of breadboard models will be started.

2. Preliminary studies leading to the design of computers for this project will be completed, and the design of an actual computer will be carried through the block diagram stage.

3. A theoretical study of various types of homing devices will be completed. Design work will be started on a homing system, or two separate systems, such as ground illumination and infra-red.

4. The assembly of radar sets to be used for test work in the micro-wave laboratory will be completed.

5. Additional K and S band test equipment will be obtained and placed in service in the micro-wave laboratory.

6. Guidance equipment for the guidance flight test vehicle will be designed.

(d) Launching

1. Design studies of rocket launchers will be continued.

2. Further studies of solid fuel rocket units will be conducted.

(e) Mathematics

1. Studies of paths of minimum fuel consumption within the atmosphere will be continued.

2. The analysis of the correction of errors which arise during homing will be continued, and the analysis of the problem of rotating the craft during homing will be started.

3. If time permits, development of the theory of infra-red homing will be continued, and the study of the probability of hits under different kinds of fragmentation will be started.

(f) Propulsion

1. Apparatus for the investigation of the burning of gasoline or other hydro-carbons under conditions which will be encountered in a ram-jet at high altitudes and supersonic speeds will be designed.

2. An investigation of the gas velocities at the exit from a ram-jet combustion chamber for various heat additions as related to high Mach number will be made.

3. Investigations of the effect of moisture on flame propagation will be completed and investigations of the effect of turbulence will be initiated.

4. Apparatus for the investigation of heat transfer problems will be constructed.

5. Studies of the propulsion properties of rocket fuels will be continued with the investigation of additional mixture ratios for the nitric acid-aniline system.

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ORIGINATING AGENCY: University of Michigan, Ann Arbor, Mich.

PUBLISHED BY: (Same)

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Feb '47	[redacted]	U.S.	Eng.	63	photos, diagrs, graphs

(OVER)

ABSTRACT:

Various design problems are analyzed for ground-to-air missile capable of intercepting and destroying aircraft operating at altitudes up to 500,000 ft and at speeds up to 4000 mph. Supersonic wind tunnel for aerodynamic tests is nearing completion. The command guidance system is in the design stage, while other guidance problems are still in experimental stage. General survey of launching methods was conducted. Ramjet and turbojet engines, as well as rocket engines, have been considered as means of propulsion.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

DIVISION: Guided Missiles (1)
SECTION: Design and Description (12)

12/1

ATI SHEET NO.: S-1-12-70

SUBJECT HEADINGS: Missiles, Guided - Development (62920); Missiles, Guided - Propulsion (63450); Missiles, Guided - Design (62909); Missiles - Guidance and control (62030); Missiles, Guided - Launching (63075); MX-794 (62920)

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DEPARTMENT OF THE AIR FORCE
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12 May 2016

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Defense Technical Information Center
Attn: Mr. Robert Stokes (DTIC-R)
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Dear Mr. Stokes

This concerns the following Technical Reports:

The following records have been cleared for public release by HQ AFMC/PAX on 13 June 2007. The reviews were performed by the following Air Force organization: HQ AFMC/PAX. Therefore, the following records are now fully releasable to the public. See attachment 1.

Technical Report number: ADB816663
Technical Report Title: Project "Wizard" Progress Report No. 1
Technical Report Date: June 1, 1946
Previous classification/distribution code: Unclassified

Technical Report number: ADB816741
Technical Report Title: Project "Wizard" Progress Report No. 5
Technical Report Date: 1 December 1946 – 1 February 1947
Previous classification/distribution code: Unclassified

Subsequent to WPAFB FOIA Control Number 2016-02428-F, AFMC-2016-0019, the following record has been cleared for public release by HQ AFMC/PA on 4 April 2016. The review was performed by the following Air Force organization: HQ AFMC/HO. Therefore, the following record is now fully releasable to the public. See attachment 2.

Technical Report number: ADB817886
Technical Report Title: Project "Wizard" Progress Report No. 4
Technical Report Date: October 1 – December 1, 1946
Previous classification/distribution code: Unclassified

The following record is publicly available at the University of Michigan Library at the following link: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/4989/bad5904.0001.001.txt?sequence=4&IsAllowed=y.

Technical Report number: ADB804022
Technical Report Title: External Memorandum Report No. 7, A Simplified Method of Calculating Ram-Jet Performance Applicable To High Mach Numbers
Technical Report Date: July 23, 1947
Previous classification/distribution code: Unclassified

Please let my point of contact know when the record is available to the public. Ms. Janet M. Caddell is the point of contact for this request and she can be reached at (937) 904-0884, e-mail Janet.Caddell@us.af.mil or the FOIA Office Main Line (937) 522-3095, e-mail wpafb.foia@us.af.mil.

Sincerely

DARRIN BOOHER, Civ, DAF
Freedom of Information Act Manager
Base Information Management Section
Knowledge Operations

Attachements:
1. AFMC/HO Memorandum, dated 11 June 2007
2. SAFPAOSP E-mail, dated 4 April 2016