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BY EXECUTIVE ORDER REVIEW TEAM
DATE 24 Jul 97 REVIEWER 45

Project RAND

(U) PROPOSED TYPE SPECIFICATION FOR AN EXPERIMENTAL SATELLITE

RA-15031

February 1, 1947

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DOUGLAS AIRCRAFT COMPANY, INC.

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*This initial external distribution list includes the distribution of all related technical reports on the satellite vehicle.

PROPOSED TYPE SPECIFICATION FOR AN EXPERIMENTAL SATELLITE

I. INTRODUCTION

A. Purpose of Specification

This specification is intended to set forth the requirements for an unmanned artificial satellite, including the basic rocket, the payload, and the necessary ground and launching equipment.

It is desired that a rocket craft be designed and constructed which will rise to an altitude at which the earth's atmosphere is extremely rarefied, enter a horizontal flight path and achieve a velocity such that stable coasting motion in a nearly circular orbit around the earth will be established. The unit intended to accomplish the above mission will be referred to in this specification as the "satellite", "craft", or "vehicle".

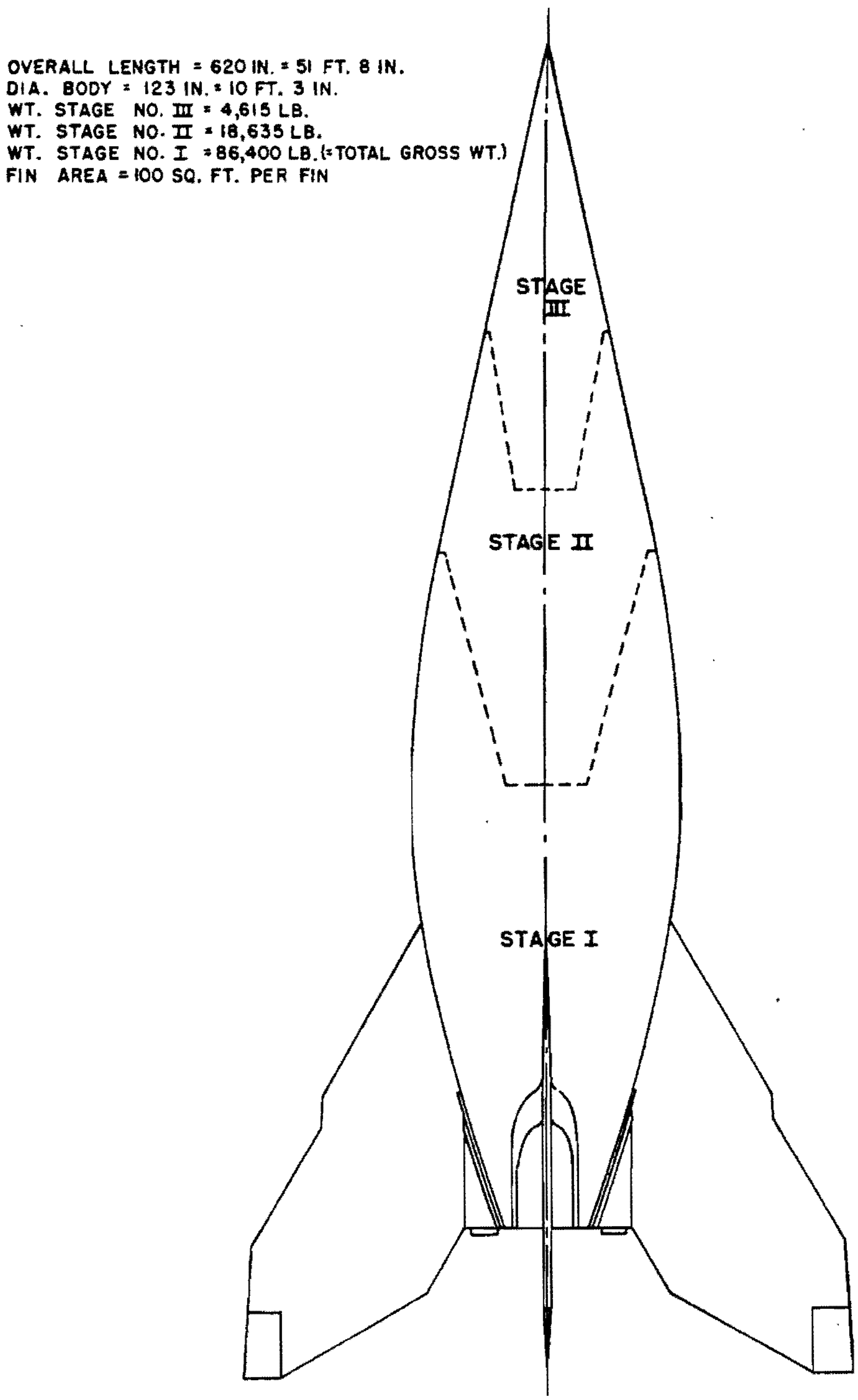
In addition to demonstrating the possibility of establishing an artificial satellite on an orbit the experimental unit or units should be equipped with instrumentation and a telemetering transmitter to send to ground stations information on properties and physical phenomena in the outer reaches of the atmosphere. Since several satellites may be sent aloft the design must be such that the instrumentation can be altered from one vehicle to the next without great difficulty.

A few command signals from the ground to the craft during the climbing trajectory will probably be necessary. Furthermore, tracking of the satellite to determine the gradual reduction in orbit altitude due to drag forces will furnish valuable information on properties of the outer atmosphere. Hence, adequate ground observing and communicating equipment will be required.

Finally, facilities for launching must be considered.

B. General Description

This specification is intended to set forth the characteristics of a satellite that can achieve an experimental mission with a minimum of research, development, and construction costs and a minimum of elapsed time. Such a policy involves seeking a design arrangement that uses existing techniques as far as possible and that at the same time results in a low gross weight. A detailed discussion of technical problems is given in the references listed in section I.C. below. An abbreviated summary of possible characteristics is given here to assist in orienting prospective contractors.



3-STAGE SATELLITE

FIG. 1

It is necessary that the craft have a duration of weeks or months on its orbit in order to be useful. Estimates of drag forces show the duration to be a sensitive function of altitude as noted in Table I (see ref. 1 for detailed study).

Table I
DURATION VS ALTITUDE

Altitude, miles	250	300	350
Duration, days	20	100	350

To allow for reasonable errors in control of velocity, direction and altitude at the time of burning cut off (as well as errors in the predicted atmospheric properties) the nominal orbit altitude should be somewhat greater than 250 miles. The corresponding orbital velocity for altitudes in this neighborhood will be around 25,000 feet per second (roughly 5 miles per second).

Even with any reasonable improvement in present design techniques, it is fairly well established that stepping, or staging of the rocket will be necessary. This means that the rocket is divided into segments, with the largest at the rear and smallest at the nose, as shown in Fig. 1. Each stage is discarded when its fuel is exhausted and the motor of the next stage then begins to operate. The reasons why staging is considered necessary are set forth in ref. 1. The suggested arrangement employs three stages, although it is possible that two stages will be desirable. A two stage rocket, for a given fuel, will have roughly twice to three times the gross weight of a three stage rocket; however, the smaller number of stages leads to a comparatively simple field testing program.

In order to keep the gross weight required to accomplish the mission within reasonable limits, (100,000 pounds or less) a high performance propellant combination is necessary. Anhydrous hydrazine and liquid oxygen are suggested as giving a good compromise of performance, availability and handling characteristics, however, various other fuels may be worthy of consideration. Ref. 4 gives information on characteristics of a few propellants.

Furthermore, to minimize the gross weight required, an optimum trajectory program should be chosen. The three stage hydrazine-oxygen rocket operates efficiently on a trajectory approximately as shown in Fig. 2. Tilting starts at a low altitude, the maximum load factor is about 4.5g to 5g and a long coasting period is inserted late in the third stage burning period. This trajectory results in rather high skin temperatures at about the time of starting third stage burning. See refs. 1 and 2 for further discussion.

During the climbing trajectory an automatic pilot, similar in function to that in the V-2 missile, but of slightly better accuracy, can be used for guidance. Some correcting signals (length of coasting period) may be sent up from the ground control stations. After the orbit is established, control of the vehicle attitude may be necessary (depending on the instruments carried), either to keep one face

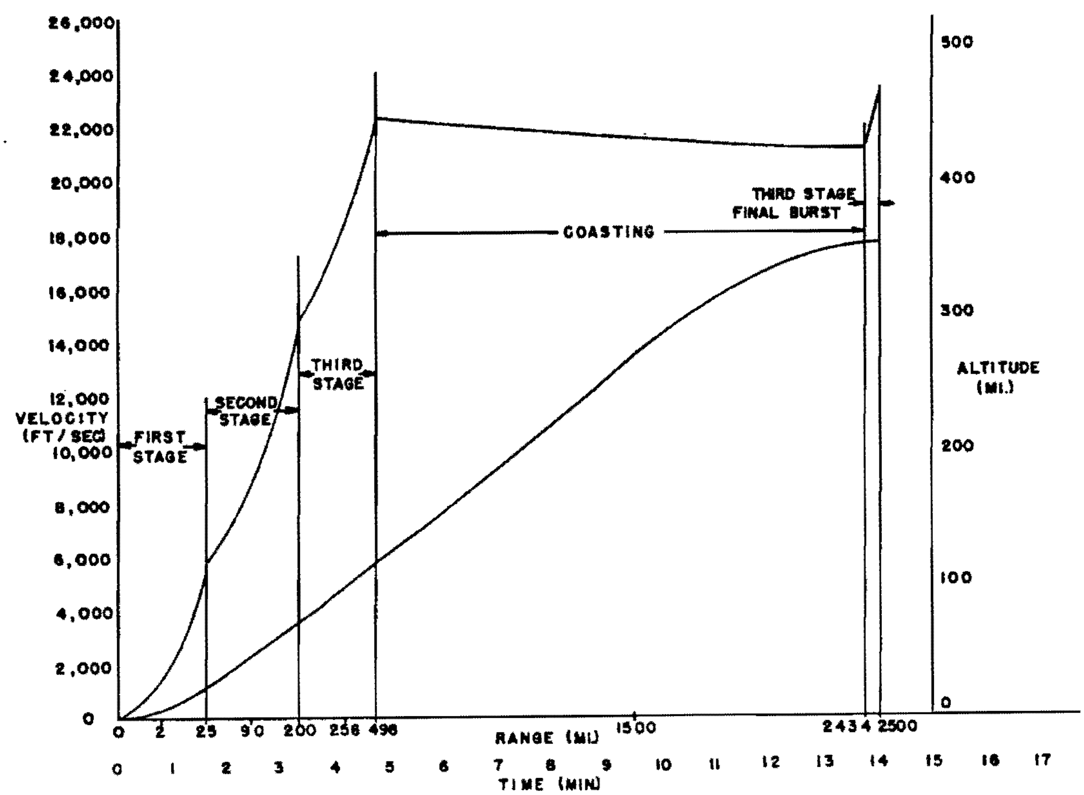
For references see page 5

toward the earth or to maintain a fixed orientation in space. Methods for achieving this are discussed in ref. 5.

Various design problems, such as power plant, mechanical separation of stages, fuel system, etc., are considered in refs. 6 and 7 and the drawings which accompany those reports.

A serious problem is involved in an auxiliary power supply for the electrical equipment that must operate after the orbit is established. The power drain probably will be much less than one horsepower, thus leading to a small engine. On the other hand, the duration required is long and the necessary weight of any chemical fuel is fairly large. Prospects for obtaining adequate auxiliary power by various methods are discussed in ref. 7.

No effort will be made to bring the experimental craft safely down to earth. The cost and effort consumed in doing so would be out of proportion to the benefit gained.



TYPICAL TRAJECTORY

FIG. 2

C. References

The following reports contain discussions and recommendations relative to methods of achieving a successful satellite development. Recommendations in the reports are not considered as requirements of this specification but are furnished as data to assist contractors in preparing their own preliminary designs and analyses.

1. Flight Mechanics of a Satellite Rocket, RA-15021, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947
2. Aerodynamic, Gas Dynamics and Heat Transfer Problems of a Satellite Rocket, RA-15022
3. Analysis of Temperature, Pressure and Density of the Atmosphere Extending to Extreme Altitudes, RA-15023
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D. Outline of Specification; Definitions

Separate sections of this specification are used to set forth requirements for (1) the rocket, (2) payload and (3) ground equipment. These terms are defined below.

1. The "rocket" consists of the entire flying vehicle except the items listed under "payload". The rocket includes structure, power plant, auxiliary power plant, servo-mechanisms, control systems, fuel and tanks, mechanical parts and miscellaneous accessories.

2. The "payload" consists of radio, radar and telemetering transmitters and receivers, all instrumentation from which information will be sent to the ground, and any intermediate circuits that prepare data for telemetering or transmission.

3. "Ground equipment", within the meaning of this specification, includes surface facilities for launching, tracking, command guidance (if any) and reception of telemetered information. It does not include such items as test stand facilities (which should be included in estimates for development and construction of the "rocket") or living provisions for personnel on overseas expeditions.

E. General Requirement

Contractors, in submitting proposals under this specification shall furnish supporting analyses and/or data, using methods equivalent to those set forth in the references of paragraph I.C. The goal of each contractor should be to achieve the performance set forth in paragraph II.A. with a minimum of total cost and elapsed time. Where characteristics greatly different from those of the reference reports are chosen, the reasons for the choice shall be stated.

II. SPECIFICATION OF ROCKET

A. Performance

1. Duration on Orbit

The orbit altitude shall be chosen so that the craft will continue in coasting flight for a period of at least 20 days before falling back to earth because of drag forces. According to ref. 1, the recommended altitude is 350 miles, held to such an accuracy that the craft will not approach nearer than 250 miles to the earth during the first complete orbital revolution.

2. *Velocity at End of Burning*

The final speed of the craft at cut-off shall be within +2%,-0% of a speed consistent with a stable circular orbit at the final operating altitude. At 350 miles altitude the minimum velocity thus defined is 24,880 feet per second.

B. Control

1. Horizontal Flight Path

The flight path, at the end of burning, shall be as nearly horizontal as practicable in order to reduce the orbit eccentricity to a minimum. The recommended orbit, as given in paragraph II.A.I. requires that the path angle at cut-off shall not be more than ± ½° from the horizontal.

2. *Attitude While on Orbit*

Adequate attitude control shall be provided so that one side of the craft will always face the earth within an error of ± 10° in pitch, yaw and roll after the orbit is established, unless some other attitude requirement can be shown to be preferable for a particular payload arrangement.

C. Payload Allowance

1. Provisions shall be made for payload of at least 500 pounds weight and 25 cubic feet volume. The possibility of larger payloads should be considered in alternate proposals.

D. Size

1. Gross Weight

The initial gross weight, including propellant and payload, shall not exceed 100,000 pounds for a three stage rocket or 200,000 pounds for a two stage rocket. Desired figures are 50,000 pounds (three stage) and 100,000 pounds (2 stage).

2. Linear Dimensions

Overall length and diameter of the rocket shall be kept to a minimum in order to facilitate shipping and handling at the launching site.

E. Structural and Mechanical Features

1. Temperature

The outer shell shall be made of a material that can withstand the high temperature that will be experienced due to drag heating during the climbing trajectory. A sample calculation is given in ref. 2.

Contents of the vehicle shall be protected from or made resistant to the effects of the skin heating mentioned above.

Likewise, the low temperatures to be experienced in the final orbit shall be considered in designing the structure and its contents.

2. Stage Separation

Separation of stages shall be analyzed carefully to insure reliability and minimum disturbance of the flight path.

3. Payload Compartment

A separate compartment shall be allotted to the payload so that the payload can be altered conveniently on successive vehicles. See paragraph II.C.1. for space requirement.

The payload compartment preferably should be located in the extreme forward end of the rocket, unless good reasons can be presented for placing it elsewhere.

F. Auxiliary Power Plant

1. Operating Life

It is desired that the auxiliary power plant shall furnish adequate electrical power, operating on the design duty cycle, to the payload during the entire nominal life of the craft as described in paragraph II.A.1. If such a duration is impractical because of large fuel requirements, then an auxiliary power duration of at least 7 days shall be provided.

A duty cycle which involves operation intermittently or only on interrogation from the ground may be used, depending on the payload configuration and its demands for satisfactory operation.

III. SPECIFICATION OF PAYLOAD

A. Limitations

1. *Size*

The various payloads proposed under this specification should not weigh more than 500 pounds nor occupy more than 25 cubic feet of space. However, consideration may be given to larger payloads if the rocket proposed under section II is adjusted accordingly.

2. *Power Requirement*

In order to keep the auxiliary power plant and its fuel within a reasonable weight allowance, it is imperative that the power drain by the payload shall be kept to a minimum. Studies in refs. 7 and 8 indicate that a few hundred watts should be sufficient. In terms of gross weight of the craft and overall cost of the program it is probably economical to make the ground equipment under section IV as powerful as necessary to keep the payload power small.

B. General Requirement

1. *Environment*

The payload shall be designed to withstand extremes of temperature, pressure, humidity and acceleration to which it will be subjected.

C. Communications

1. *Transmitters and Receivers*

The payload shall in all cases contain the radio and/or radar transmitters and receivers necessary for communicating to and from the ground.

2. *Telemetering*

At least 12 channels of telemetering shall be provided. Consideration may be given to bank switching if a larger number of records seems desirable.

D. Types of Payload Instrumentation

1. *Atmospheric Data*

It is essential that proposals should include at least one arrangement for measuring pressure, temperature, density and, if possible, ionization and chemical composition of the atmosphere in the range from 200 to 350 miles altitude.

2. *Optical Data*

A desired optional payload proposal consists of a means of observing the earth telescopically or photographically and transmitting the information to the ground. Consideration should be given to the possibility of retaining information (for example on a wire or tape) for delayed transmission.

3. *Scientific Data*

It is desired that consideration should be given to optional payloads which can take data on cosmic rays, solar and/or stellar spectra, and terrestrial magnetism.

IV. SPECIFICATION OF GROUND EQUIPMENT

A. General Requirements

1. *Weather Conditions*

The ground equipment associated with the first experimental craft must be designed to withstand tropical operation, since the initial launching is is expected to be on the equator. At a few points, observing stations may be situated on mountains, in which cases low temperature operation must be considered also.

2. *Portability*

Some stations will be situated in remote places, so that a high degree of convenience in handling, setup and operation must be given consideration.

B. Launching Requirements

1. *Platform*

A suitable launching platform shall be provided which can be leveled and aligned to the accuracy required by the rocket design.

2. *Servicing Equipment*

Suitable units shall be provided for fueling, electrical testing and other preparations for launching while the craft is on the launching platform. This will include any necessary plants for low temperature liquids that cannot be transported over long distance.

3. *Radio and Radar*

Equipment for tracking, velocity measurements, control signaling and telemetering during the ascending period shall be coordinated with the requirements of the rocket and payload design as proposed under sections II and III. Particular attention must be given to accuracy and power requirements.

4. *Optical Observations*

Consideration should be given to optical tracking by means of telescopes during the ascending period.

5. *Computers*

Necessary computing equipment for controlling the rocket during the ascending period shall be given consideration as a part of the ground equipment.

C. Ground Equipment Related to the Orbit

1. *Observing Stations*

Any proposal shall consider sufficient radio, radar and/or optical observing stations around equator so that the path of the craft can be determined at all times during the first few revolutions. If desirable, some of the stations may then be abandoned, leaving a few at widely spaced intervals for intermittent observation throughout the life of the satellite.

Where desirable, and if feasible from an accuracy standpoint, boats or ships may be used as observing stations.

2. *Determination of Orbit*

Ground equipment shall be considered in relation to the rocket and payload so that the altitude and distance north or south of the equator (as well as changes in these quantities) and the orbital period can be measured with an accuracy sufficient to determine the rate of descent on the orbit due to drag forces.

3. *Telemetering*

Adequate ground equipment shall be provided for the reception and recording of telemetered data. This equipment shall take account of the power restrictions imposed on the payload, and any special requirements such as transmission of interrogating signals to the satellite, etc.

4. *Computers and Miscellaneous*

Any equipment necessary for handling orbit and telemetered data in the field is considered a part of the ground equipment.

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Initial distribution of all related technical reports on the satellite vehicle are given below. The code is explained on pages 12 through 21.

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Federal Telephone and Radio Corp. 200 Mt. Pleasant Avenue Newark 4, New Jersey Attn: Mr. E. N. Wendell		AAF
Galvin Manufacturing Corp. 4545 Augusta Blvd. Chicago 5, Illinois Attn: Mr. G. R. MacDonald		AAF
G. M. Giannini and Co., Inc. 285 West Colorado St. Pasadena, California	Bureau of Aeronautics Rep. 15 South Raymond St. Pasadena, California	BUAER
Gilfillan Corp. 1815-1849 Venice Blvd. Los Angeles 6, California Attn: Mr. G. H. Miles		AAF
Hillyer Engineering Co. New York, New York Attn: Mr. Curtiss Hillyer	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Kearfott Engineering Co. New York, New York Attn: Mr. W. A. Reichel	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Lear Incorporated 110 Iona Avenue, N.W. Grand Rapids 2, Michigan Attn: Mr. R.M. Mock		AAF
Manufacturers Machine & Tool Co. 320 Washington Street Mt. Vernon, N.Y. Attn: Mr. L. Kenneth Mayer, Comptroller		AAF
Minneapolis-Honeywell Mfgr. Co. 2753 Fourth Avenue Minneapolis 8, Minnesota Attn: Mr. W. J. McGoldrick, Vice-President		AAF
Ohio State University Research Foundation Columbus, Ohio Attn: Mr. Thomas E. Davis, Staff Assistant		AAF

D. COMPONENT CONTHACTORS (Cont'd)

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Haller, Raymond & Brown P.O. Box 342 State College, Pennsylvania Attn: Dr. R. C. Raymond, Pres.		AAF
Office of Chief Signal Officer Engineering & Technical Services, Engineering Division Pentagon Washington 25, D.C.		ORD DEPT
Raytron, Inc. 209 E. Washington Avenue Jackson, Michigan Attn: Mr. John R. Gelzer, Vice-Pres.		AAF
L. N. Schwein Engineering Co. 5736 Washington Blvd. Los Angeles 16, California Attn: L.N. Schwein, General Partner		AAF
Senior Naval Liaison Officer U.S. Naval Electronic Liaison Office Signal Corps, Engineering Laboratory Fort Monmouth, New Jersey		NAVY
Servo Corporation of America Huntington, L.I., New York	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Square D Co. Kollsman Instrument Division Elmhurst, New York Attn: Mr. V. E. Carbonara	Bureau of Aeronautics Rep. 90 Church Street New York 7, New York	BUAER
Stromberg-Carlson Company Rochester, New York Attn: Mr. L.L. Spencer, Vice-Pres.		AAF
Submarine Signal Company Boston, Massachusetts Attn: Mr. Edgar Horton	Development Contract Officer Massachusetts Institute of Technology Cambridge 39, Massachusetts	BUORD
Summers Gyroscope Co. 1100 Colorado Avenue Santa Monica, California Attn: Mr. Tom Summers, Jr.		AAF
Sylvania Electric Products Inc. Flushing, Long Island, N.Y. Attn: Dr. Robert Bowie	Inspector of Naval Material 90 Church Street New York 7, New York	BUORD
University of Illinois Urbana, Illinois Attn: Mr. H. E. Cunningham, Sec.		AAF
University of Pennsylvania Moore School of Electrical Engr. Philadelphia, Pa.	Commanding Officer Naval Aircraft Modification Unit Johnsville, Pa.	BUAER
University of Pittsburgh Pittsburgh, Pennsylvania Attn: Mr. E. A. Holbrook, Dean		AAF
University of Virginia Physics Department Charlottesville, Virginia Attn: Dr. J. W. Beams	Development Contract Officer University of Virginia Charlottesville, Virginia	BUORD

D. COMPONENT CONTRACTORS (Cont'd)

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Washington University Research Foundation 8135 Forsythe Blvd., Clayton 5, Missouri Attn: Dr. R. C. Spencer		AAF
Westinghouse Electric Corp. Springfield, Massachusetts Attn: J.K.B. Hare, Vice-Pres. (Dayton Office)		AAF
Director of Specialty Products Development Whippany Radio Laboratory Whippany, N.J. Attn: Mr. M.H. Cook		ORD DEPT
Zenith Radio Corporation Chicago, Illinois Attn: Hugh Robertson, Executive Vice-Pres.		AAF

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Aerojet Engineering Corp. Azusa, California Attn: K.F. Mundt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	BUAER
Armour Research Foundation Technical Center, Chicago 16, Illinois Attn: Mr. W. A. Casler		ORD DEPT
Arthur D. Little, Inc. 30 Memorial Drive, Cambridge, Mass. Attn: Mr. Helge Holst		ORD DEPT
Battelle Memorial Institute 505 King Avenue Columbus 1, Ohio Attn: Dr. B. D. Thomas		AAF & BUAER
Bendix Aviation Corp. Pacific Division, SPD West N. Hollywood, Calif.	Development Contract Officer Bendix Aviation Corp. 11600 Sherman Way N. Hollywood, Calif.	BUORD
Bendix Products Division Bendix Aviation Corporation 401 Bendix Drive South Bend 20, Indiana Attn: Mr. Frank C. Mock		AAF BUORD
Commanding General Army Air Forces Pentagon Washington 25, D.C. Attn: AC/AS-4 DRE-2E		AAF
Commanding General Air Materiel Command Wright Field Dayton, Ohio Attn: TSEPP-4B(2) TSEPP-4A(1) TSEPP-5A(1) TSEPP-5C(1) TSORE-(1)		
Commanding Officer Picatinny Arsenal Dover, New Jersey Attn: Technical Division		ORD DEPT

D. COMPONENT CONTRACTORS (Cont'd)

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Commanding Officer Watertown Arsenal Watertown 72, Massachusetts. Attn: Laboratory.		ORD DEPT
Continental Aviation and Engr. Corp. Detroit, Michigan	Bureau of Aeronautics Rep. 11111 French Road Detroit 5, Michigan	BUAER & AAF
Curtiss-Wright Corporation Propeller Division Caldwell, New Jersey Attn: Mr. C. W. Chillson		AAF
Experiment, Incorporated Richmond, Virginia Attn: Dr. J. W. Mullen, II	Development Contract Officer P.O. Box 1-T Richmond 2, Virginia	BUORD
Fairchild Airplane & Engine Co. Ranger Aircraft Engines-Div. Farmingdale, L.I., New York	Bureau of Aeronautics Rep. Bethpage, L.I., N.Y.	BUAER
General Motors Corporation Allison Division Indianapolis, Indiana Attn: Mr. Ronald Hazen	Bureau of Aeronautics Rep. General Motors Corporation Allison Division Indianapolis, Indiana	BUAER
G. M. Giannini & Co., Inc. 285 W. Colorado St. Pasadena, California		AAF
Hercules Powder Co. Port Ewen, N.Y.	Inspector of Naval Material 90 Church Street New York 7, New York	BUORD
Marquardt Aircraft Company Venice, California Attn: Dr. R. E. Marquardt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	AAF BUAER
Menasco Manufacturing Co. 805 E. San Fernando Blvd. Burbank, California Attn: Robert R. Miller Exec. Vice-Pres.		AAF
New York University Applied Mathematics Center New York, New York Attn: Dr. Richard Courant	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Office of Chief of Ordnance Ordnance Research & Development Div. Rocket Branch Pentagon, Washington 25, D.C.		ORD DEPT
Polytechnic Institute of Brooklyn Brooklyn, New York Attn: Mr. R.P. Harrington	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Purdue University Lafayette, Indiana Attn: Mr. G. S. Meikel	Inspector of Naval Material 141 W. Jackson Blvd. Chicago 4, Illinois	
Reaction Motors, Inc. Lake Denmark Dover, New Jersey	Bureau of Aeronautics Resident Representative Reaction Motors, Inc. Naval Ammunition Depot Lake Denmark, Dover, N.J.	BUAER

D. COMPONENT CONTRACTORS (Cont'd)

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Rensselaer Polytechnic Institute Troy, New York Attn: Instructor of Naval Science		BUORD
Solar Aircraft Company San Diego 12, California Attn: Dr. M.A. Williamson		ORD DEPT
Standard Oil Company Esso Laboratories Elizabeth, New Jersey	Development Contract Officer Standard Oil Company Esso Laboratories, Box 243 Elizabeth, New Jersey	BUORD
University of Virginia Physics Department Charlottesville, Virginia Attn: Dr. J. W. Beams	Development Contract Officer University of Virginia Charlottesville, Virginia	BUORD
University of Wisconsin Madison, Wisconsin Attn: Dr. J.O. Hirschfelder	Inspector of Naval Material, 141 W. Jackson Blvd. Chicago 4, Illinois	BUORD
Westinghouse Electric Co. Essington, Pennsylvania	Bureau of Aeronautics Resident Representative Westinghouse Electric Corp. Essington, Pennsylvania	BUAER
Wright Aeronautical Corp. Woodridge, New Jersey	Bureau of Aeronautics Rep. Wright Aeronautical Corp. Woodridge, New Jersey	BUAER
Bethlehem Steel Corp. Shipbuilding Division Quincy 69, Mass. Attn: Mr. B. Fox	Supervisor of Shipbuilding, USN Quincy, Mass.	BUAER