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JOHN C. HERTHER
1st Lt., USAF

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WS 117L ADVANCED RECONNAISSANCE SYSTEM

DEVELOPMENT PLAN

VOLUME II SUBSYSTEM PLANS

D. Guidance and Control

DOWNGRADED AT 12 YEAR INTERVALS; NOT AUTOMATICALLY DECLASSIFIED. DOD DIR 5200.10

LOCKHEED AIRCRAFT CORPORATION
MISSILE SYSTEMS DIVISION
PALO ALTO, CALIFORNIA

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FOREWORD TO VOLUME II

The Advanced Reconnaissance System (Weapon System 117L) consists of a satellite vehicle which can perform visual, electronic, and infrared reconnaissance, together with the necessary system of ground stations, data processing centers, and training facilities.

In accordance with the instructions of CCN No. 1 to Contract AF 33(616)-3105, the Missile Systems Division, Lockheed Aircraft Corporation, has revised its Subsystem Development Plan (MSD 1536, Volume II) to be consonant with the WDD Development Plan, dated 2 April 1956, as modified and published in Volume I of this report.

It should be noted the outline of subsystems as given in MSD 1536 has been changed to agree with the WDD Plan. Subsystems H and J of MSD 1536 have been combined to give a new Subsystem H - Ground-Space Communications.

In accordance with oral instructions from WDD, the Flight Test Subsystem I of MSD 1536 has not been documented at this time. The information pertaining to flight testing is presented in the other subsystem volumes as appropriate. The titles of old Subsystems K and L (now I and J, respectively) have been changed.

OUTLINE

OF

WS 117L DEVELOPMENT PLAN

Volume I	SYSTEM PLAN
	Supplement (Top Secret)
Volume II	SUBSYSTEM PLANS
A	Vehicle
B	Propulsion
C	Auxiliary Power
D	Guidance and Control
E	Visual Reconnaissance
F	Electronic Reconnaissance
G	Infrared Reconnaissance
H	Ground-Space Communications
I	Data Processing and Intelligence Dissemination
J	Ground Support and Training

CONTENTS

MSD 2011

RDB PROJECT CARD

LOCKHEED AIRCRAFT CORPORATION
MISSILE SYSTEMS DIVISION

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MSD-2011

RDB PROJECT CARD | TYPE OF REPORT | REPORTS CONTROL SYMBOL DD-RDB(A)48

1. PROJECT TITLE
GUIDANCE AND CONTROL SUBSYSTEM FOR
ADVANCED RECONNAISSANCE SYSTEM
(UNCLASSIFIED)
WEAPON SYSTEM 117L

2. SECURITY S

3. PROJECT NUMBER WS 117L-P1758

4. INDEX NUMBER

5. REPORT DATE [redacted]

6. BASIC FIELD OR SUBJECT
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7. SUBFIELD OR SUBJECT SUBGROUP

7A. TECH. OBJ.

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Development Command

9. DIRECTING AGENCY
Hq ARDC
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OFFICE SYMBOL WDTR

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Hq USAF

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12. CONTRACTOR AND/OR LABORATORY
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~~Lockheed Aircraft Corp.,~~
~~Missile Systems~~ Division
MASS. INST. OF TECH.

CONTRACT/W.O. NO.

13. RELATED PROJECTS
WS 107A
WS 315A

14. DATE APPROVED

15. PRIORITY 1A

16.

17. EST. COMPL. DATES

RES.	
DEV.	
TEST	
OP. EVAL.	

18. FY	FISCAL ESTS. (M $)

19.

20. REQUIREMENT AND/OR JUSTIFICATION

20 a. The guidance and control subsystem is required to provide the following functions:

1. Inertial guidance for the satellite from takeoff to a DESIRED ~~circular~~ orbit, ~~at the prescribed altitude~~ [illegible]

~~2. Correction signals to the attitude control system and to the orbital boost phase to obtain accurate speed and direction for a prescribed circular orbit.~~ DESIRED

~~3. Attitude control during non-powered flight and control during orbital boost phase by use of autopilot and control motors.~~

2. Attitude control of vehicle orientation in orbit for maximum ~~visual~~ reconnaissance ~~resolution~~.

3. ATTITUDE INDICATION TO PROVIDE FOR GEOGRAPHIC ~~LOCATION~~ CORRELATION OF RECONNAISSANCE DATA.

22. RDB	SN	CN	IC & P	X.	I.	C.

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R&D PROJECT CARD
CONTINUATION SHEET

SECURITY CLASSIFICATION

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NUMBER
GUIDANCE AND CONTROL SUBSYSTEM FOR ADVANCED RECONNAISSANCE SYSTEM (UNCLASSIFIED) WEAPON SYSTEM 117 L	S	MSD-2011 WS 117 L
	4.	5. REPORT DATE 1 November 1956

21 a. Brief and Operational Characteristics

This subsystem will provide the means for guidance and control of the orbiting vehicle so as to place it in a ~~circular~~ DESIRED orbit ~~at approximately 300 n. miles~~ above the surface of the earth. In addition, the subsystem will operate in an orbit attitude control mode to stabilize the vehicle and to provide a platform suitable for mounting reconnaissance elements.

The attitude will be stabilized in order to prevent image motion from degrading resolution of visual data. AND DISTORTION OR LOSS OF DATA. The attitude must also be known with sufficient accuracy to permit the application of navigation location techniques to the data gathered.

b. Approach

Ascent guidance will be accomplished by self-contained inertial guidance equipment similar to that being developed for the WS 107 A and WS 315 A programs. Autopilot control will be that furnished with the booster vehicle used.

Attitude stabilization during the orbiting phase is derived from the differential gravity torques acting on the mass distribution of the vehicle with damping provided by means of rate SENSING gyros and motor driven inertia wheels.

The effects of the environment on the sensing instruments will constitute one of the major problems in this development program. Every effort will be made to take advantage of the information, EQUIPMENT, and test results from the WS 107 A and WS 315 A programs.

c. Tasks of the Subsystem

1. TASK# a. Ascent Guidance ~~Package~~

[redacted]

c. During the period from launch to cut-off of the boost engines, the vehicle will be guided by a self-contained inertial guidance system, which consists of a gyro stabilized platform, singly integrating accelerometers, and a guidance computer. The design of the platform gimbals,

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gyros, and accelerometers and the computer programming will be similar to those under development for the WS 107 A and WS 315 A programs.

At the end of boost the ascent guidance ~~package~~ [subsystem] will furnish information on the missile's position and velocity to the transition computer.

During the coast phase after termination of boost the gyro platform will sense the attitude of the vehicle and furnish control signals to the transition control system.

[2. WS 107A-1 AUTOPILOT]

~~2~~ [3]. a. Transition Computer

b. ~~Subcontract and/LAC MSD~~ [or]

c. During the coast phase the transition computer will compute the time to fire the ~~final stage~~ [vernier stage] propulsion and the velocity to be gained both in magnitude and direction. This information will be used to orient the vehicle in the desired attitude for final boost and to furnish initial conditions for the ~~orbital~~ [vernier] boost guidance.

[4]. a. Transition Control System

b. Contractor: LAC MSD

c. During the coast period a control system is required to reorient and stabilize the combined booster-~~ARS stage~~ [OSV] [(orbit stage vehicle)] ~~vehicle~~ in the correct attitude for ~~orbital~~ [vernier] boost. Commands to this unit ~~come~~ [are derived] from the ascent guidance unit.

[5]. a. ~~Orbital~~ [Vernier] Boost Guidance

b. ~~Subcontract~~

c. This unit provides guidance signals to the OSV autopilot, measures the velocity gained during orbital boost, and provides a signal to cut off the engine. Some components of this sytem may be common to the ascent guidance unit or the orbital attitude control system.

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6 a. OSV Autopilot

b. ~~Contractor: LAC MSD~~

c. The orbit stage autopilot provides for dynamic control of thrust direction in order to maintain the vehicle in a controlled attitude during the final stage thrust acceleration. This unit derives its commands from the orbital boost guidance unit.

7 a. ~~Orbital~~ Attitude Control

A

b. ~~Subcontract and/or LAC MSD~~

c. The orbital attitude control unit is designed to align and maintain the alignment of the vehicle to the local vertical of the earth's gravitational field during the orbital life of the vehicle.

Attitude control on orbit will be achieved by a mass distribution of the vehicle which will make the desired orientation a naturally stable one about three orthogonal axes. Since this constitutes an essentially undamped dynamic system, damping will be provided by means of angular rate sensing devices and motor-driven inertia wheels. Rough initial alignment to the local vertical will be accomplished after orbital boost. BY [illegible] JET REACTION

8 a. Attitude Indication and Image Motion Compensation

b. ~~Subcontract and/or LAC MSD~~

c. An indication of the instantaneous vehicle attitude may be necessary in order to correlate reconnaissance data with geographical location. This may be accomplished by a combination of internal measurements and an external reference. The indication outputs are presented to the data transmission system.

Body rotations of the vehicle will cause blurring of the image of ground objects if the attitude control is insufficient to permit maximum use of system resolution. It may be necessary to compensate for these rotations by attitude sensing and control of the optical pickup system.

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21 d. Other Information

The environment in which the guidance and control equipment must operate is of paramount importance and influences the accuracy and operability of the systems and components. Advantage will be taken wherever possible of the environmental test facilities that have been established for the WS 107 A and WS 315 A programs. Tests of components and subsystems under those programs will be followed closely wherever applicable.

21 e. Background History

Work on guidance and control for a satellite vehicle has been conducted at MIT, North American Aviation Inc., and the RAND Corp. These studies have indicated the feasibility of ascent guidance and orbital attitude control of a satellite.

Work on the inertial guidance systems for WS 107 A and WS 315 A is of direct interest to the ARS project for the fields of ascent guidance, environmental effects, and component development and testing.

21 f. Future Plans

NOTE: See System Development Plan GUIDANCE + CONTROL MILESTONES

The establishment of subcontracts for the various tasks in guidance and control with qualified contractors will be initiated in the near future.

Investigation of the feasibility and accuracy of autopilot guidance for early test flights will be initiated.

Procurement of some components in preproduction quantities and testing of them will be initiated.

Investigations of various methods of control actuation during coast and immediately after orbital boost will be continued.

21 g. References

1. Monthly and Quarterly Reports of Project Pied Piper. (S)
2. Progress Reports Nos. 1 through 5 AND FINAL REPORT on Air Force Contract AF 33(616)-2039 "Guidance and Attitude Control Study" MIT Instrumentation Laboratory. (S)

[redacted]

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	4.	5. REPORT DATE 1 November 1956

3. Progress AND FINAL Reports on Air Force Contract AF 33(616)-2137 "Guidance and Attitude Control Study" North American Aviation Inc. Autonetics Division. ~~(S)~~

DD FORM FEB 53 613-1 PREVIOUS EDITIONS OF THIS FORM MAY BE USED.

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TABS

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~~SUBSYSTEM D~~ - GUIDANCE AND CONTROL SUBSYSTEM FOR ADVANCED RECONNAISSANCE SYSTEM, WS117L

~~Tab 1~~ - General Design Specification

~~I. GENERAL~~

A. Statement of Problem

The objective of the Guidance and Control Subsystem is to ensure the thrust is applied in such a way that the vehicle is placed in a circular orbit at an altitude of 300 n. miles. At this altitude the vehicle velocity must be in a horizontal plane and its magnitude must be approximately 25,500 ft/sec ($v = \sqrt{gR}$). When the vehicle enters the orbit the error in velocity must not exceed 30 feet per second in magnitude and 1 milliradian in direction. If these conditions are met, a 300-n. mile orbit will have maximum and minimum altitudes of 320 and 280 n. miles, respectively. After the orbiting condition has been obtained and the engines have been shut down, the guidance and control subsystem converts to an attitude control mode of operation. The vehicle attitude must be controlled so as to stabilize the line of sight with respect to a known reference frame to permit reconnaissance read-in and read-out.

B. Approach

The operation of the ARS guidance and attitude control systems can be divided into four phases:

1. The booster-powered phase beginning at launch and continuing to the cutoff of the booster and sustainer engines.
2. The unpowered coast to apogee on an elliptical ascent trajectory.
3. The application of the orbital powered boast to provide the necessary increment of velocity to place the vehicle on the desired orbit.
4. Attitude stabilization and indication after the orbit stage vehicle has been established on the desired orbit.

C. <u>Solution</u>

1. <u>Booster-Powered Phase</u>

The initial booster-powered phase is very similar to that of the intercontinental and intermediate range ballistic missiles. Hence advantage can be taken of the development of booster vehicles including propulsion, airframe, autopilot and control system, and guidance, for the ballistic missile projects, WS 107A and WS315A.

An inertial guidance system consisting of a gyro-stabilized platform, singly integrating accelerometers, and a guidance computer will provide steering signals to the booster autopilot and propulsion cutoff signals for the rocket engines.

2. <u>Coast Phase</u>

After termination of the main boost propulsion, the vehicle the required attitude. In addition, the orbital boost guidance system will measure the velocity gained by means of an integrating accelerometer and will furnish the propulsion cutoff signal when the required velocity is attained.

4. <u>Attitude Stabilization</u>

After termination of the orbital boost, the ~~OSV~~ SATELLITE must be reoriented roughly to the local vertical so that the vehicle will stabilize in attitude through the action of the earth's gravitational field on the mass distribution of the vehicle. THIS WILL REQUIRE THAT THE MOMENTS OF INERTIA OF THE ORBITING MASS TO BE UNEQUAL [illegible] 10:9.6:1 FOR THE PITCH, ROLL AND YAW AXES. Through the operation of rate gyros sensing the vehicle's angular motion and the action of motor-powered flywheels, the oscillations of the vehicle's angular motion will be damped to a stable orientation with respect to the local gravitational vertical (including orientation about the vertical as the yaw axis).

Torques disturbing the stable orientation of the OSV to the vertical may arise during orbiting because of the oblateness of the earth, elliptical orbiting, non-compensated torques from rotating machinery, radiation torques from the APU, etc. Since damping is provided in the orbital attitude control, the angular motion resulting from these disturbances will always be damped out (provided the disturbing torques are not too large). THIS DICTATES THAT ALL TORQUES FROM INTERNAL MACHINERY BE COUNTERBALANCED AND THAT THE NET TORQUE RESULTING FROM IMPERFECT COUNTERBALANCE BE SMALL.

Because the attitude control system time constant is large, a~~n~~ CONTINUOUS indication of the instantaneous attitude may be necessary to PROVIDE A REFERENCE IN THE VEHICLE FROM WHICH TO COMMAND OFFSET ANGLES OF SENSING ELEMENTS IN THE ADVANCED PROGRAMS.

co~~rrelate reconnaissance data with geographical location~~ and to ~~compensate for image motion in the optical pickup system~~. This could be accomplished by means of an external reference (e.g., horizon sensor or sun tracker) or internally by gyro means, or by a combination of both.

II. DESCRIPTION

A. Tasks

1. Ascent Guidance

This task requires the provision of an inertial guidance package to guide the vehicle during boost and to furnish attitude stabilization information during the coast phase. Because of the latter requirement, a ground-linked radio guidance system such as that being developed for the Atlas ballistic missile is not sufficient, although its use may be of some benefit during boost.

It is anticipated that the inertial guidance package will consist of a three-axis platform stabilized by three single-axis gyros, three single-axis integrating accelerometers mounted on the platform, and a guidance computer. The outputs from the guidance equipment during boost will be steering signals to the boost autopilot which is assumed to be furnished with the booster vehicle, a propulsion cutoff signal to the rocket engines, and information to the transition computer on the measured position and velocity at the end of boost.

During coast the stable platform furnishes attitude information to the transition control system.

Ground equipment for initial alignment of the inertial system and for monitoring the operation of the guidance equipment will be required.

It is anticipated that significant advantage can be taken of the guidance development work on the WS 107A and WS 315A programs in the utilization of developed components and environmental test facilities and test results.

2. Transition Computer

During the transition coast period a computer is required which accepts data from the ascent guidance equipment and computes the velocity magnitude to be gained during the orbital boost stage, the time to initiate the orbital boost, and the proper attitude for the OSV during orbital boost.

It is anticipated that the transition computer can operate on the basis of deviations from a preset program. Hence its accuracy is not critical, and it can be a relatively simple analogue type computer.

3. Transition Control System

Attitude control must be exercised whenever the rocket engines are not operating. During the coast or transition phase of the trajectory, the residual angular impulse during and after termination of the booster propulsion and that due to booster separation must be removed, and the attitude must be stabilized for proper thrust orientation prior to initiation of the orbital boost.

Attitude sensing information inputs to the transition control system are derived from the gyro-stabilized platform and from the transition computer. The torques necessary to control and stabilize the attitude can be obtained by means of small auxiliary gas jets or by means of motor-controlled inertia flywheels.

4. <u>Orbital Boost Guidance</u>

During the orbital boost phase it is necessary to provide steering signals to the OSV autopilot and a propulsion cutoff signal to the rocket engine. The orbital boost guidance system must sense the attitude of the vehicle and provide steering signals to the OSV autopilot control system to maintain the proper thrust attitude. In addition, it must measure the velocity gained during orbital thrust, compare this with the velocity-to-be gained computed by the transition computer, and provide a cutoff signal to the rocket engine when the two are equal.

The attitude sensing function can best be provided by means of gyroscopes, and the velocity gained can be measured by means of an integrating accelerometer oriented along the thrust axis of the vehicle.

Some of the components of the orbital boost guidance system may be common to the ascent guidance system or the orbital attitude control system.

5. <u>OSV Autopilot</u>

Thrust will be applied to the OSV in a direction parallel to the horizontal plane at the apogee. This thrust will be applied for about 30 seconds prior to apogee so that a measured increase is made to the vehicle horizontal velocity while no vertical velocity component is added. The vehicle heading is established to provide the proper value of the maximum latitude for the orbit.

The OSV autopilot provides the dynamic control of thrust direction through deflections of two gimballed 150-pound thrust control engines. This control is required to maintain a stable vehicle attitude during the OSV boost stage. Since this unit functions at very high altitude and after the OSV has already gained a high velocity, the primary requirement on it is that it be capable of providing stable flight control. Through reference to the attitude reference unit, the autopilot receives error signals required to correct initial errors in a short time and to ensure that thrust is applied in the proper direction to avoid large residual vertical velocity components at the end of the boost stage.

6. Orbital Attitude Control

During orbiting flight the vehicle attitude must be controlled so that payload elements will be aligned properly for reconnaissance purposes. The directions of lines-of-sight, antenna axes, etc., must be controllable, and, in some cases, they must be known within accurate limits.

The reference direction for alignment is the local vertical of the earth's gravitational field. By proper distribution of the mass of the vehicle, the desired orientation can be made a naturally stable one about three orthogonal axes through the action of the gravitational field gradient in producing restoring torques on the vehicle. Oscillations of the vehicle about the stable orientation are undamped. In order to provide damping so that the oscillations will die out with time, a means of sensing the rates of angular motion, such as rate gyros, will provide signals to control electric motors driving inertia wheels.

After the orbital boost stage, the vehicle must be aligned roughly to the local vertical before the orbital attitude control becomes effective. This can be accomplished by means of small auxiliary air jets controlled by the stabilization elements of the orbital boost guidance system.

Some components of the orbital attitude control system may be shared with the orbital boost guidance system.

7. Attitude Indication and Image Motion Compensation

Disturbing torques on the orbiting vehicle due to the oblateness of the earth, the effect of an elliptical orbit, residual unbalance in rotating machinery, etc., will cause transitory and steady-state oscillations despite the presence of damping. An indication of the instantaneous attitude of the vehicle may be necessary in order to correlate reconnaissance information with geographical location. Changes in attitude will be available from the rate gyros of the orbital attitude control equipment, but drifts in the gyros will limit the long-term accuracy. Use of an external reference, such as the earth's horizon or astronomical bodies, e.g., the sun, can provide an absolute reference for attitude indication.