THE SYSTEMS DYNAMICS RESEARCH AIRPLANE

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It is the purpose of the next two talks to acquaint you with a flight research airplane, which is now being equipped, and which will be used for flight research on airborne systems and for simulation studies of advanced airplanes. The airplane with its equipment is well suited to the study of adaptive control techniques and it is planned that one of the first uses of this vehicle will be in this field. In this talk the various pieces of equipment that go to make up this research airplane will be described and then the next talk will go into the research capabilities.

The first slide is a schematic which indicates the main pieces of equipment to be installed in an F-101 airplane. I' ll not attempt to go through this flow diagram. The main pieces of equipment are general purpose analog and digital computers, electrical input flight control systems - indicated by the series servo, a stable platform included with the sensors and instrumentation, a pilot' s display - which indicates computed rather than actual flight conditions, and an air data computer which is not indicated on this slide.

The equipment that makes this vehicle unique and which provides good versatility for systems and airplane dynamics studies is the on-board computers.

The usual procedure in conducting flight research on airborne systems is to design equipment to study a specific problem. This specific problem approach is time consuming and usually results in hardware that is not applicable to other studies without considerable modification. Using the airborne analog computer, airborne systems can be simulated and thus good versatility for in-flight systems studies is obtained. Let' s now get into some details on this airborne analog unit.

DESCRIPTION OF EQUIPMENT

Analog Computer

The analog computer which is now under development by the Autonetics Division of North American Aviation is a transistorized differential analyzer. To give you an idea of the computer capacity a list of the computing components is shown on the next slide. As you can see from the slide, the computer has a reasonably good capacity, including 100 operational amplifiers and a significant amount of non-linear equipment. Besides being transistorized, the computer has been miniaturized so as to meet the space limitations.

The miniaturization has caused the basic accuracy of this airborne unit to be reduced from that of general purpose ground based computers. The inherent accuracy of most of the individual components is about 0.1 percent.

The next slide lists some other pertinent features of the analog computer equipment.

Significant non-linear function generation can be accomplished since 20 tapped pots with 19 taps per pot and 4 diode function generators are available. In addition 10 diode bridge limiters and 24 free diodes are available for switching, limiting, and other types of function generation.

As in the ground based computer, the inputs to and outputs of the computer components are brought to a patching system so problems can be changed easily.

Two types of systems are available for generation of time varying parameters. A punch tape timer system for discrete problem changes and a magnetic tape playback system for continuous changes. In addition the magnetic tape makes possible the insertion of noise voltages into the problem by taping the noise signal on the ground and playing it back in the air.

A multi-recording system is also available. The majority of the recording will be done on a 50 channel oscillograph. In addition 7 channels of magnetic tape recordings are available. In order to determine problem malfunctions in flight, an events recorder shows when and where any amplifier overload occurred. The computer will weigh about 900 pounds, including recording and pilot display equipment, and occupies a volume of about 21 cubic feet.

While on the subject of analog computers, it should be mentioned that a ground based computer will be used to simulate the F-101 airplane on the ground. This will make possible the studying and checking out of test problems on the ground prior to the actual flight tests. Thus the flight test time can be used most efficiently.

Digital Computer

Next, let's go into the digital computer. The digital computer, being built by the Burroughs Corporation, is a completely independent computing system. However, it has features which allow it to be integrated with the analog computer system providing a combination which affords flexibility, high accuracy and rapid calculations.

A block diagram of the digital computer is shown on the next slide. The system consists of a magnetic drum for storage of programs and constants, a random access memory, a three register arithmetic unit, input and output systems which provide analog-to-digital and digital-to-analog conversion and a problem control unit.

The magnetic drum is used to store the computer programs, constants used in the computation, and initial conditions.

The arithmetic unit consists of three registers. Within these are performed the arithmetic operations. Addition and subtraction require about 25 microseconds to complete. Multiplication and division take about 75 microseconds. These times are about twice those of an IBM 704.

The random access memory is a ferrite core unit with 128 word storage. The input-output system is one of the unique features of the computer. There are available 32 input and 10 output channels. Both the analog-to-digital and digital-to-analog conversions can be completed in 75 microseconds. The digital computer program is formulated in the ground and loaded into the drum by a punch tape system through the control unit. The programming procedure is quite straightforward.

It is the combination of the digital and analog computers which give good flexibility and no-drift high accuracy computing capabilities to the system. It is expected that the analog will do the rapid summation, integration and solution of the basic differential equations since these type processes are quite slow on a digital machine. However, the digital machine can do the long term high accuracy calculations such as coordinate transformations and space position calculations. The combination of analog and digital computers should provide an excellent airborne computation and simulation system.

Electrical Input Flight Control System

Next, let's go into some of the details of the electrical input flight control system to be used in this research airplane. The control systems have been developed by the Sperry Gyroscope Company and the next slide lists some of the control system characteristics. The stabilizer, rudder, and the two aileron channles are electro-hydraulic in operation and are installed in series with the conventional controls through summing links. The input signals can come from the computers, the sensors or the pilot's side controller stick. Full authority has been designed into the system but the authority can be limited by ground adjustable stops.

As to the dynamic performance, the specifications call for the phase lag between input and output to be less than 3 degrees at one cycle per second and less than 45 degrees at 10 cycles per second. The amplitude ratio at any frequency is specified to be less than 1.3 times the static amplitude ratio.

The dynamic performance of the electrical input control systems is high as compared to the power actuators so they will not be a limiting factor.

For safety considerations, all of the electrical input control systems are dualed. The dualed systems operate from the same input signal. If for any reason the dualed servos do not operate together within preset limits the electrical input servos are shut off and the pilot assumes control through the conventional control systems. In addition to the dualed electrical input control systems, limit sensors are used to prevent structural overloading of the airplane.

A side located control stick is used by the pilot for generating control signals, and a torque servo is used to provide feel forces to the pilot's side controller. The torque servo accepts electrical signals from the various sensors or computers and its output is a force proportional to the sum of the input signals.

Stable Platform

Another important piece of equipment is the stable platform and its computer. It has also been built by the Sperry Gyroscope Company. The platform is of the 4 gimbal type and the inertial angle and velocity data it provides will be used in target simulation and navigation studies.

Sensor System and Flight Instrumentation

A complete set of sensors and flight instrumentation is installed to measure the linear and angular motions of the aircraft, the motions of the control surfaces, and the flight conditions. An air data computer developed by Bendix provides analog signals representing Mach number, true airspeed, altitude and dynamic pressure.

Pilot's Display

A portion of the instrument panel in the F-101 airplane has been made available for a pilot's display of test problems. It consists of various indicating instruments which depend on the program being run. These instruments will receive their information from the computers and will indicate computed flight conditions. In addition a 4 input channel oscilloscope is available for target and other displays.

RESEARCH CAPABILITIES

Now that the equipment has been described, I would like to tell you about the research capabilities of the vehicle. To do this, I will outline some of the research areas of interest today, where the research vehicle will be used. Then, to give you a better idea of how the equipment will be employed, I will outline how we might simulate a self-adaptive controller in conjunction with an advanced aircraft design.

The first slide lists some of the research areas of interest where this research vehicle has capabilities. The areas are divided into two categories; the first having to do with the studies of systems and system techniques and the second with the simulation of advanced aircraft and re-entry vehicles.

Under the first category is control systems. The most important development here has been self-adaptive control techniques. The research airplane is well suited to the study of adaptive control principles.

As examples, the relay amplifiers included with the analog equipment can be used in the study of non-linear switching techniques like those proposed by Mrs. Flugge-Lotz and by the Minneapolis-Honeywell Regulator Company.

The technique proposed by the Sperry Gyroscope Company employs a mechanism which senses damping ratio changes of the high frequency control system poles and modifies the system accordingly. These changes could be sensed using a digital amplitude comparitor logic system which would compare the amplitude peaks in the time interval after excitation.

A third system, the most difficult for the airborne simulator to handle, is a technique using cross correlation which has been proposed by Aeronutronics Systems, Inc. One method of instrumenting this technique uses a random flip-flop to produce binary white noise and a time delay on the input signal to obtain a comparison between input shifted in time and the output. This shift register may be accomplished in the digital computer by sampling the input and using a digital program to shift this sampled input. The delayed signals may be reproduced by using the digital-to-analog converter. With the equipment available, 10 such delayed signals could be reproduced since there are 10 digital-to-analog converter channels. It is possible to simulate other proposed adaptive techniques as well and also there are other methods for simulating the techniques outlined above. What I have tried to do by citing these examples is to give you an idea of the research vehicle' s versatility with the on board computing equipment.

The research vehicle has capabilities for studies of systems other than self-adaptive controllers. The stable platform-digital computer combination provides the essentials of a high performance navigation system and also provides the axis reference for target simulation. Thus studies can be conducted on digital autopilot and navigation systems, automatic weapons delivery including fire control systems, and automatic on-board landing systems. The target simulation in some cases allows for studies in speed ranges greater than that of the F-101 airplane because the target is not actual but is represented by simulation.

In the category on the right hand side of the slide, studies of advanced aircraft such as the B-70 or F-108 can be done in actual flight. Because of the on-board computers continuous flight operations can be accomplished where Mach number and altitude are changing. This is in contrast to the variable stability airplane where essentially only one flight condition at a time can be investigated.

For the last item in this category, a part of the re-entry of vehicles such as the X-15 or Dynasoar could be simulated. For example, during a portion of the re-entry a sustained normal acceleration greater than one g builds up. This could be simulated by having the airplane perform wind-up turns. At the same time the airplane would be made to have the same short period dynamics as associated with the re-entering vehicle. Thus, the dynamics research vehicle would represent the re-entry by simulating the most important forces and motions of the re-entering vehicle.

The problem could be handled in the following way. The analog and digital computers would be used to solve the re-entry vehicle equations of motion. The pilot's side stick and rudder pedal motions would serve as inputs to the computers and the pilot's instrument panel would display conditions about the re-entry vehicle. This is similar to the way in which a ground simulation of the problem would be conducted. In flight, however, the computed output quantities would be used as command inputs to the F-101 electrical input system and the airplane sensors would furnish feedback and stabilization signals.

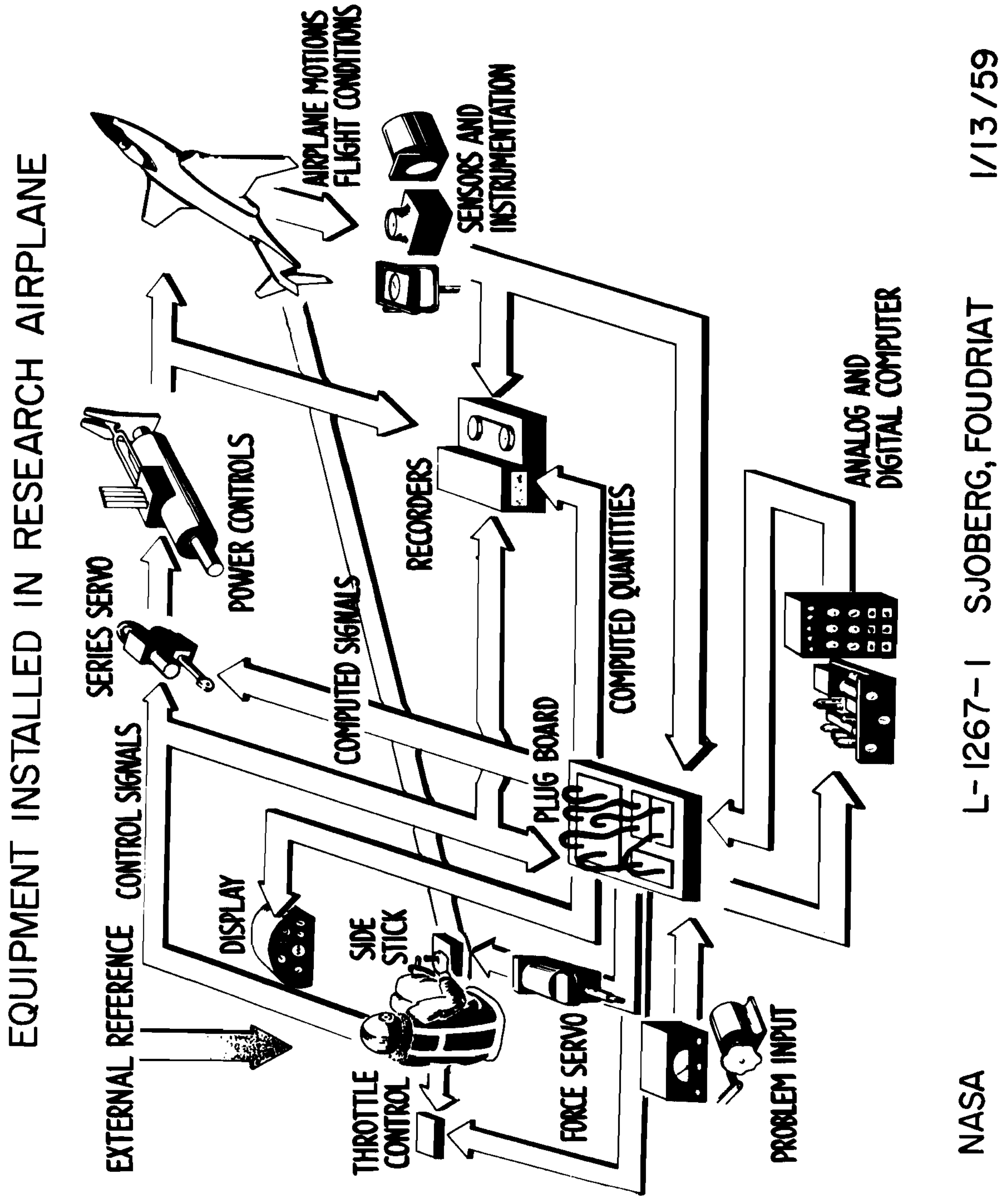
To give you a better idea of how this equipment is used in a simulation study, a program will be outlined. The problem is the simulation of a self-adaptive controller on an advanced aircraft. The next slide shows a block diagram of how this could be accomplished.

The problem may be divided into two parts, the simulation of the advanced airplane and the simulation of the adaptive controller. The first part can be accomplished in a manner shown on the right hand side of the slide, using a technique similar to that used in variable stability studies. That is, the feedback quantities are used to modify the stability characteristics of the F-101 so that they match those of the airplane being studied. For example, in the longitudinal case the angle of attack and pitch rate signals are fed-back through the control surface to modify the stability derivatives C_{m_a} and C_{m_q} respectively, so that the desired short period dynamics i.e. frequency and damping are obtained. With the computer equipment aboard, information about the desired stability characteristics would be programmed as a function of altitude and Mach number. By furnishing Mach number and altitude through the air data computer the F-101 could be made to fly like some other airplane over a wide range of flight conditions. Thus the right hand side of the slide, that is the series servos, sensors, air data computer and variable stability simulator, represents the dynamics of the aircraft being studied.

The other portion of the slide shows a representation of the simulation of the adaptive control technique under study and the input commands as shown by the block marked " pilot' s input" . Any of several techniques including those mentioned previously could be simulated in a study program. The sensed signals for feedback to the adaptive controller can be taken directly from the airplane sensors in most cases.

Thus flight problems related to adaptive controllers and pilot opinions about them can be obtained directly without resorting to hardware build up of each system.

In conclusion, the dynamics research vehicle should be a useful facility for system and airplane simulation studies. Because of its versatility it should be usable for many research programs. It should help to reduce system lead time since it provides the ability to flight test the proposed technique before the system equipment has been built. As to the status of the vehicle, all major pieces of equipment except the analog computer are to be delivered for installation within the next few months. The analog computer is scheduled for July 1 delivery. It is expected that the vehicle will be operational about the end of the year.


EQUIPMENT INSTALLED IN RESEARCH AIRPLANE
EXTERNAL REFERENCE
CONTROL SIGNALS
SERIES SERVO
POWER CONTROLS
AIRPLANE MOTIONS
FLIGHT CONDITIONS
SENSORS AND
INSTRUMENTATION
RECORDERS
COMPUTED SIGNALS
COMPUTED QUANTITIES
PLUG BOARD
ANALOG AND
DIGITAL COMPUTER
DISPLAY
SIDE
STICK
THROTTLE
CONTROL
FORCE SERVO
PROBLEM INPUT
NASA
L-1267-1
SJOBERG, FOUDRIAT
1/13/59

ANALOG COMPUTING EQUIPMENT

COMPONENT	QUANTITY
OPERATIONAL AMPLIFIERS	100
RELAY AMPLIFIERS	8
SERVO MULTIPLIERS AND FUNCTION GENERATORS	6
SERVO RESOLVERS	4
HIGH SPEED MULTIPLIERS	4
DIODE FUNCTION GENERATORS	4
DIODE LIMITERS	10
COEFFICIENT POTENTIOMETERS	80
PRECISION REFERENCE POWER SUPPLY	1

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FEATURES OF THE ANALOG COMPUTER EQUIPMENT

SIGNIFICANT NONLINEAR FUNCTION GENERATING EQUIPMENT

PATCHBOARD SYSTEM

TIME VARYING PARAMETER GENERATING EQUIPMENT

MULTI-RECORDING SYSTEM

OVERLOAD EVENTS RECORDING SYSTEM

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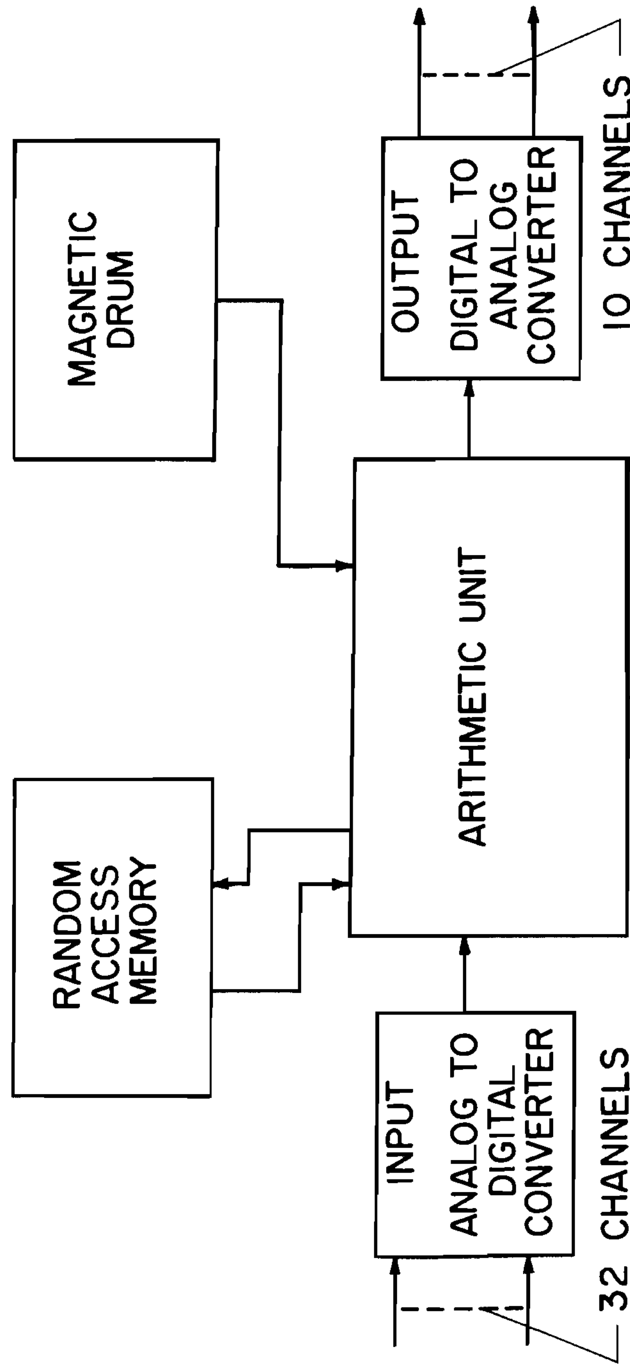
BLOCK DIAGRAM OF DIGITAL COMPUTER



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ELECTRICAL INPUT CONTROL SYSTEM CHARACTERISTICS

ELECTRO-HYDRAULIC

SERIES INSTALLATION

FULL AUTHORITY

DYNAMIC PERFORMANCE :

PHASE SHIFT	$< 3°$ AT 1 CPS
	$< 45°$ AT 10 CPS
AMPLITUDE RATIO	$< 1.3 \times$ STATIC AMPLITUDE RATIO

DUALED SYSTEMS

LIMIT SENSORS

SIDE LOCATED PILOTS CONTROLLER

TORQUE SERVO FOR PILOT FEEL FORCES

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CAPABILITIES OF DYNAMICS RESEARCH VEHICLE

STUDIES OF SYSTEMS	SIMULATION OF VEHICLES
CONTROL SYSTEMS	FUTURE AIRCRAFT
ADAPTIVE CONTROLLERS	B-70, F-108
NAVIGATION SYSTEMS	HANDLING QUALITIES
DIGITAL AUTOPILOTS	FLIGHT CONTROLS
AUTOMATIC WEAPONS DELIVERY	WEAPONS SYSTEMS
AUTOMATIC LANDINGS	RE-ENTRY VEHICLES
UNUSAL AERODYNAMICS	X-15, DYNASOAR
PILOTING PROBLEMS	RE-ENTRY PULLOUT
	LANDING

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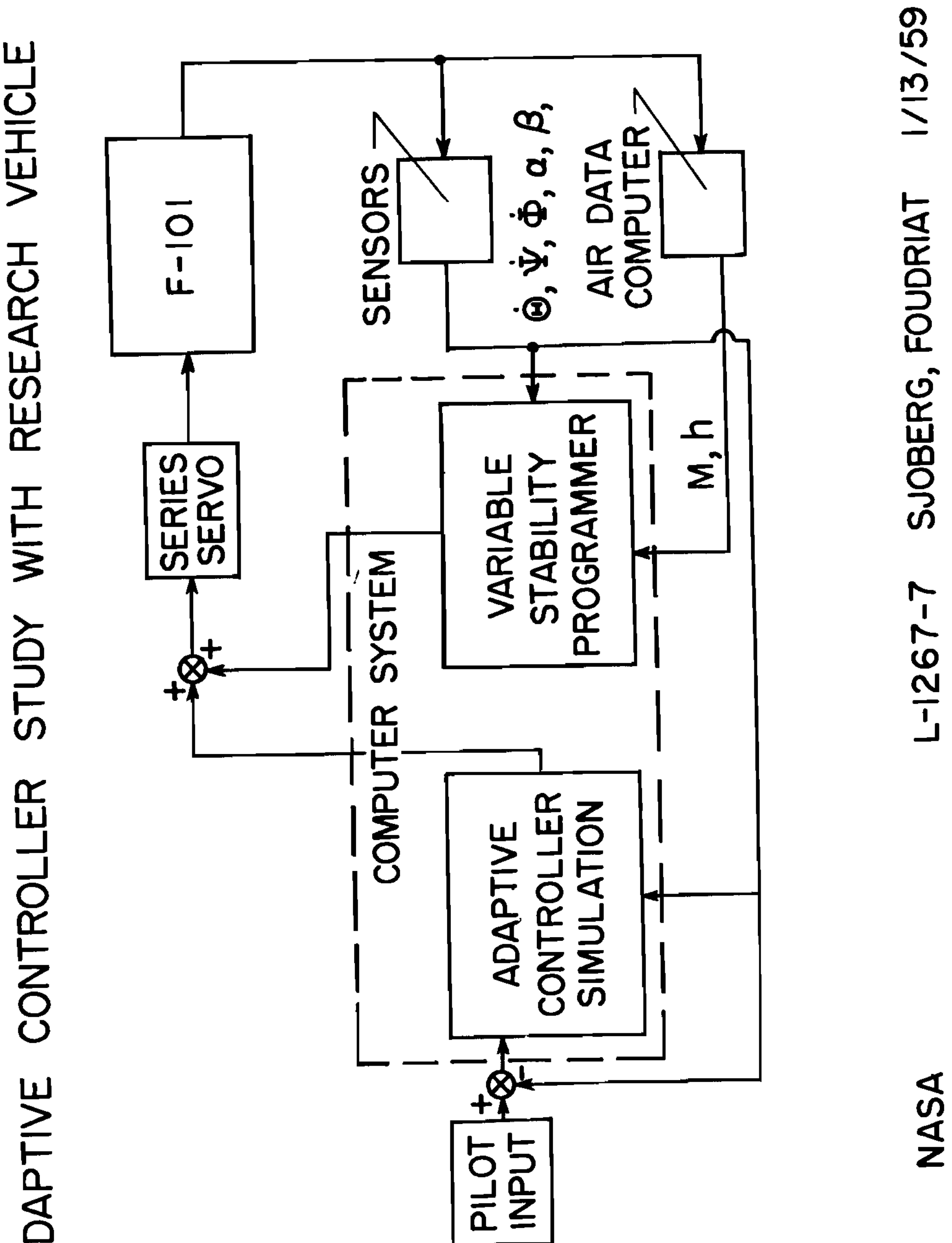
ADAPTIVE CONTROLLER STUDY WITH RESEARCH VEHICLE
F-101
SERIES SERVO
SENSORS
$\dot{\Theta}, \dot{\Psi}, \dot{\Phi}, \alpha, \beta,$
AIR DATA COMPUTER
VARIABLE STABILITY PROGRAMMER
M, h
COMPUTER SYSTEM
ADAPTIVE CONTROLLER SIMULATION
PILOT INPUT
NASA
L-1267-7 SJOBERG, FOUDRIAT 1/13/59