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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2385 Irving Hill Rd.—Campus West Lawrence, Kansas 66044

NINTH PROGRESS REPORT ON NASA/KU
SSSA DEVELOPMENT PROGRAM

AN INVESTIGATION OF SEPARATE SURFACE STABILITY AUGMENTATION SYSTEMS FOR GENERAL AVIATION AIRCRAFT

Prepared By:

Members of the Flight Research Laboratory
of the Department of Aerospace Engineering
of The University of Kansas

April 1974

I

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ABBREVIATIONS

DG	Directional Gyro
FRL	Flight Research Lab
S	Switch
SSSA	Separate Surface Stability Augmentation
$V_{\Delta\Psi}$	Voltage Due to Heading Error
$V_{\dot{\Psi}}$	Voltage Due to Yaw Rate
$\Delta\Psi$	Heading Error

1.0 INTRODUCTION

1.1 DISCUSSION

This Progress Report discusses the activities that have taken place at the K.U. FRL since the publication of the status report in November, 1973. There are no schedule problems associated with the current K.U. efforts. However, due to the fact that the K.U./NASA contract has not been finalized at this time, Beech has not begun small parts manufacturing as scheduled. This may result in some schedule modifications (see Fig.1). As can be noted from the schedule, all of the Task II items have been completed with the exception of aircraft and instrument wiring drawings to Beech. Completion dates on these items are 1 May 1974 and 7 July 1974, respectively. These items are progressing on schedule.

Section 2.0 of this report covers the pending organizational changes at K.U. FRL. The fault analysis, Task III on the schedule, (see Fig.1) is described in Section 3.0. The current status and future plans are discussed in detail. The latest electrical design, roll heading hold, is described extensively in Section 4.0. Schematics and an operational description is included. Section 5.0 describes the detailed flight test plan being developed by K.U. and Beech followed by the electrical build-up status in Section 6.0. Drawings and descriptions of the operator's console and rack design are found in

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Section 7.0. The environmental test plan status is found in Section 8.0 followed by the control and management panel description in Section 9.0.

2.0 K.U. ORGANIZATIONAL CHANGES

2.1 DISCUSSION

At the end of the spring, 1974 classes, Mr. D. Collins and Mr. W. Bolton will complete the Doctor of Engineering requirements and leave K.U. Mr. M. Ashburn and Mr. G. Jenks will take over their positions. To retain as much continuity as possible, Mr. Jenks has been working on the program since 21 Jan. 1974; Mr. Ashburn will arrive on 1 April 1974. A detailed organizational chart will be included in the next progress report which will describe program responsibilities.

3.0 FAULT ANALYSIS

3.1 FUNCTIONAL BLOCK FAULT ANALYSIS

The SSSA system has been subdivided into functional blocks and analyzed to determine the type of failures that are possible (see Table 1).The fault analysis indicates that there is no single failure that will result in all surfaces going hardover. (See Tables 2, 3, 4 and 5).

3.2 SIMULATION OF FUNCTIONAL BLOCK FAULT ANALYSIS

A program is currently in progress that will simulate the hypothesized failures as described in Section 3.1. The basic intent of the simulation program is to determine three things: 1) does the system respond to the failure as predicted, 2) does the aircraft present any controllability problems, and 3) what is the pilot corrective action to the failure. In addition an investigation will be conducted to define critical system states that would render the aircraft uncontrollable. For example, if the rudder failed "hardover" to the right and the right aileron failed "hardover" up would the aircraft be controllable. This is the opposite approach that was taken on the "functional block fault analysis" and will tend to serve as a check on the validity of the analysis. A preliminary investigation of one such failure has been accomplished and is described below.

TABLE 1. FUNCTIONAL BLOCKS OF THE SSSA SYSTEM

Power Supplies

- 28 VDC
- 115 VAC, 400 ~
- +15 VDC (2)
- -15 VDC (2)

Primary Position Sensors (4)

Separate Surface Position Sensors (4)

Rate Gyros

- Roll
- Pitch
- Yaw

Vertical Gyros

- Roll
- Pitch

Directional Gyro

Mode Select Card (1)

Control & Management Panel

- Power Relays

Computer Cards (5)

Drive Cards (4)

Actuators (4)

- Diode Bridge

Auto-Trim

- (Command mode only)

Secondary Trim Motor

Secondary Trim Switch

Modes

- OFF
- SLAVE
- COMMAND
  - Heading Hold Rudder
  - Heading Hold Aileron
  - Heading Hold Both

TABLE 2. THEORETICAL BLOCK ANALYSIS & RESULTS

COMPONENT	FAILURES	EFFECTS
Power Supplies 28 VDC	1) No Power	1) System Inop - Surfaces trail
	2) Spikes - Noise	2) Surface Impulse - chatter
	3) Under Voltage	3) System Inop - Actuator response degraded
	4) Over Voltage	4) Surface impulse
115 VAC, 400 ~	1) No Power	1) Positioned to trail - No Response DG Inop
	2) Under Voltage	2) Actuator response degraded
	3) Noise	3) Surfaces chatter
	4) Over Voltage	4) Possible surface impulse
	5) Oscillation	5) Possible surface oscillation
+15 VDC	*1) No Power	1) Nothing
	2) Spikes - Noise	2) Surfaces impulse - chatter
	3) Under Voltage	3) Nothing
	4) Over Voltage	4) Nothing
	5) Oscillation	5) Nothing
-15 VDC	*1) No Power	1) Nothing
	2) Spikes - Noise	2) Surfaces impulse - chatter
	3) Under Voltage	3) Nothing
	4) Over Voltage	4) Nothing
	5) Oscillation	5) Nothing
Both +15 VDC or Both -15 VDC or 3±15 VDC	No Power	All surfaces hardover
All 4 15 VDC	No Power	System Inop - Surfaces trail
Primary Surface Position Sensors (4 ea) LA, RA, ELEV, RUDDER	1) No Output	Slave - Trail 1) Att Command - hold at last attitude
	2) Spikes - Noise	2) Surfaces chatter,
	3) Pot Sticks	3) Slave - Holds last value Att Command - maintains last attitude
	4) Change in null pt.	4) Slave - assymetric deflection, reduced control authority Att Command - assymetric deflection, reduced control authority

*Assumed ±15 VDC power supplies connected in parallel

TABLE 3. THEORETICAL COMPONENT ANALYSIS & RESULTS

COMPONENT	FAILURES	EFFECTS
Rate Gyros-Pot Output		
ROLL	1) No Output	*1) No roll damping
	2) Output does not change	2) No damping & offset
	3) Noise	3) Surface chatter
	4) Oscillation	4) Surface chatter or oscillation
PITCH	1) No Output	*1) No pitch damping
	2) Stuck	2) No damping & surface offset
	3) Noise	3) Surface chatter
	4) Oscillation	4) Surface chatter or oscillation
YAW	1) No Output	*1) No yaw damping
	2) Stuck	2) No damping & surface offset
	3) Noise	3) Surface chatter
	4) Oscillation	4) Surface chatter or oscillation
Sep. Surface Position Sensors (4 ea) LA, RA, ELEV, RUDDER	1) No Output	1) Hardover
	2) Noise	2) Surface chatter
	3) Pot sticks	3) Small deflection to hardover
	4) Changes in null pt.	4) Assymetric deflections & reduced control authority
Vertical Gyro-Pot Output		
ROLL	1) No Output	*1) Command - roll hardover
	2) Stuck	2) Surface offset
	3) Precession	3) Plane would drift to undesirable attitude
	4) Tumbling gyro - Oscillation	4) Alternating full travel deflections
	5) Noise -(Pot)	5) Aileron separate surface chatter
	6) Varying Offset	6) Assymetric deflection and reduced control authority

*No effect in Slave mode

TABLE 4. THEORETICAL COMPONENT ANALYSIS & RESULTS

COMPONENT	FAILURES	EFFECTS
Vertical Gyro-Pot Output PITCH	1) No Output	*1) Command - pitch hardover
	2) Stuck	2) Surface offset
	3) Precession	3) Surface drift
	4) Tumbling Gyro - Oscillation	4) Alternating full travel deflections
	5) Noise -(Pot)	5) Elevator separate surface chatter
	6) Varying Offset	6) Assymetric deflection and reduced control authority
BOTH - Combination not single failure	1) No Output	*1) Command - pitch & roll hardovers
	2) Stuck	2) Surfaces offset
	3) Precession	3) Surfaces drift
	4) Tumbling Gyro - Oscillation	4) Alternating full travel deflections
	5) Noise -(Pot)	5) Aileron & elevator separate surfaces chatter
	6) Varying Offset	6) Assymetric deflection and reduced control authority
Directional Gyro	1) No Output	*1) No heading hold, possible hardover rudder.
	2) Precession - Erratic	2) Gradual movement to hardover
	3) Stuck	3) Surface offset to hold heading
	4) Oscillation	4) Heading drift
Mode Select Card	1) Selects No Mode (includes engage switch failure)	1) Surface trail
	2) Selects Both Modes (SL & COMM)	2) Assymetric deflections
	3) Pilot Improper Switching	3) Selected function
	4) Heading Hold Switching, Ailerons & Rudder Failure	4) No heading hold

*No effect in Slave mode.

TABLE 5. THEORETICAL COMPONENT ANALYSIS & RESULTS

COMPONENT	FAILURE	EFFECTS
Control & Management Panel	1) Selects No Mode	1) Surface Trail
	2) Selects Both SL & COMM Modes	2) Assymetric deflections -(?)
	3) Disable Switch Failure	3) No change - no cut out
	4) Warning Light, Meter Failure	4) Nothing
Power Relays	1) Fail to close (supply power)	1) Surface Trail
	2) Fail to open (off power)	2) System engaged, may kill by circuit breaker or panel switches
	3) Chatter	3) Possible surface chatter
Computer Cards LA, RA, ELEV, RUDDER	1) No Output	1) Trail
	2) Noise - Spikes	2) Surface chatter
	3) Constant Output	3) Surface offset, nothing to hardover
	4) Oscillation	
Drive Cards	1) No Output	1) Surfaces trail
	2) Noise	2) Surface chatter
	3) Constant Output	3) Surface offset, from nothing to hardover
Actuators	1) Freeze, Stuck	1) Surface frozen in place
	2) Broken Shaft	2) Trail
Diode Bridge	1) Short Circuit	1) Surface trail
	2) Open Circuit	2) Surface drive in one direction only
Auto Trim (COMM only)		
Secondary Trim Motor	1) Fail to Operate	
	2) "Run Away"	
	3) Intermittent	
Secondary Trim Switch	1) Stuck ON	
	2) Stuck OFF	
	3) Intermittent	

3.2.1 Preliminary Combined Hardover Failure Simulation

The design philosophy of the SSSA flight hardware is that no single failure will produce simultaneous hardover failures of more than one SSSA actuator. However, the controllability of the aircraft in the event of combined hardover failures has been evaluated using piloted simulation. The pilot was aware that a failure was going to occur but did not know the nature of the failure or exactly when it was to occur. Following recognition of a failure, the pilot waited 1 second before initiating corrective action. All failures were encountered in level flight in the approach flight condition, with all axes of the attitude command operating prior to the failure. The worst-case failure resulted in the following attitude upset:

Hardover Failures	Maximum Bank Angle	Maximum Pitch Angle	Altitude Loss
Both ailerons elevator (T.E.U) 30% rudder	51°	6°	To be determined

It should be emphasized that the attitude upsets mentioned above are for a particular pilot; actual upsets would be dependent upon pilot technique used during recovery. In all cases, the pilot was able to trim the hardover failures using the remaining pilot surface control power. As a result of these investigations it is concluded that combined hardover failures will be controllable in the approach flight condition.

3.3 ELECTRICAL COMPONENT FAULT ANALYSIS

The electrical component fault analysis will be an integral part of the simulation program as defined in Section 3.2. If critical system states* are discovered either from the "simulation of the functional block faults" or the additional simulation of compound failures, then a component search will be conducted to determine if any components can fail and result in this critical state.

3.4 FAULT ANALYSIS SUMMARY AND STATUS

Presently, the "functional block fault analysis" is complete (see Tables 2-5). This analysis revealed that there is no single failure that will result in hardover failure of ALL the control surfaces. The most serious failures discovered were single surface hardovers and surface chatter or oscillation. These failures are currently being simulated. The outcome of this simulation will be:

1) Confirmation of system response to hypothesized failure.
2) Required pilot corrective actions.
3) Definition of critical system states.*
4) Component analysis of critical system states.

The fault analysis is on schedule with no foreseeable problems to meet the 1 July milestone.

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*Critical system state defines an uncommanded control combination, with the system engaged, that renders the aircraft uncontrollable.

4.0 ROLL AXIS HEADING HOLD DESIGN AND DEVELOPMENT

4.1 DESIGN DESCRIPTION AND PHILOSOPHY

Recently, it was reported that the rate gyro output exhibited a dead-band which made it unsuitable for integration to develop $V_{\Delta\psi}$, the heading error signal. Accordingly, other methods for developing $V_{\Delta\psi}$ from a directional gyro were studied.

The two basic approaches identified were:

1) Use a new DG with a clutched pot; this would provide $V_{\Delta\psi}$ directly but at considerable expense.

2) Use the synchro output of the existing DG along with suitable demodulation and track/store circuitry to provide $V_{\Delta\psi}$.
   Two possible demodulators were identified:
   a) A commercial synchro/DC converter, together with appropriate circuitry for avoiding discontinuities at 0, 360° or ±180°.
   b) A custom made synchro demodulator to be designed and produced by the project staff.

Cost, reliability and lead time considerations dictated that approach #2 should be taken. The commercial unit has been delivered and the custom-made unit is under development.

The roll heading hold system block diagram is shown in Fig. 2. The heading hold decision unit is what has previously been called yaw axis card 3, (see Nov. 1973 Status Report, pg. 73). When the decision unit commands heading-hold "off" the following occur:

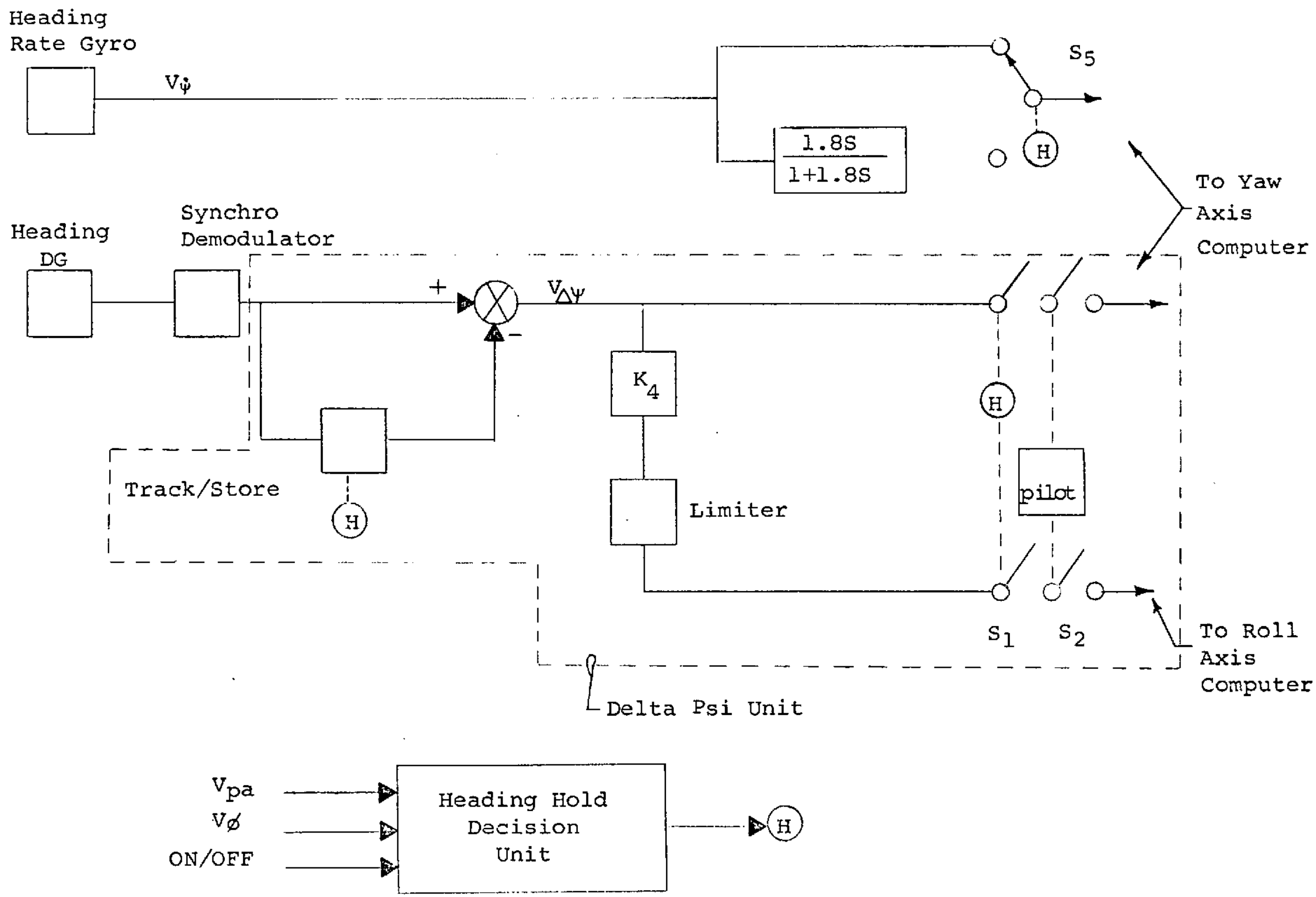


FIGURE 2. Roll Heading Hold System Block Diagram

1) switches S_1 and S_2 open so that no $\Delta\Psi$ information is sent to the yaw and roll axis computer, 2) switch S_5 moves to the lower position so that a "washed-out" version of $V_{\dot{\psi}}$ is sent to the yaw axis computer, and 3) the track/store unit tracks the output of the synchro demodulator.

When the decision unit commands heading-hold "on" a contrasting set of events occurs: 1) switch S_1 and S_2 close so that $V_{\Delta\Psi}$ is made available to the roll and/or yaw axis computers according to the status of pilot-controlled switches S_3 and S_4, (Note: physically S_1 and S_3 are one analog switch controlled by a logic gate having inputs from the pilot and the decision unit. This also applies to S_2 and S_4), 2) switch S_5 moves to the upper position so that the true V signal is sent to the yaw axis computer, and 3) the track/store unit stores the value of the synchro demodulator output at the instant that heading-hold "on" was commanded. The signal $V_{\Delta\Psi}$ thus is a measure of any change in heading from the selected heading.

The circuitry used in the synchro demodulator (using commercial converter), delta psi unit, $\Delta\Psi$, and decision unit are shown in Figures 3, 4, and 5.

4.2 HEADING HOLD SUMMARY AND STATUS

The original design of the heading hold circuitry integrated the output of the yaw rate gyro to generate $\Delta\Psi$. However, it was learned that the rate gyro had an operational deadband which made it unsuitable

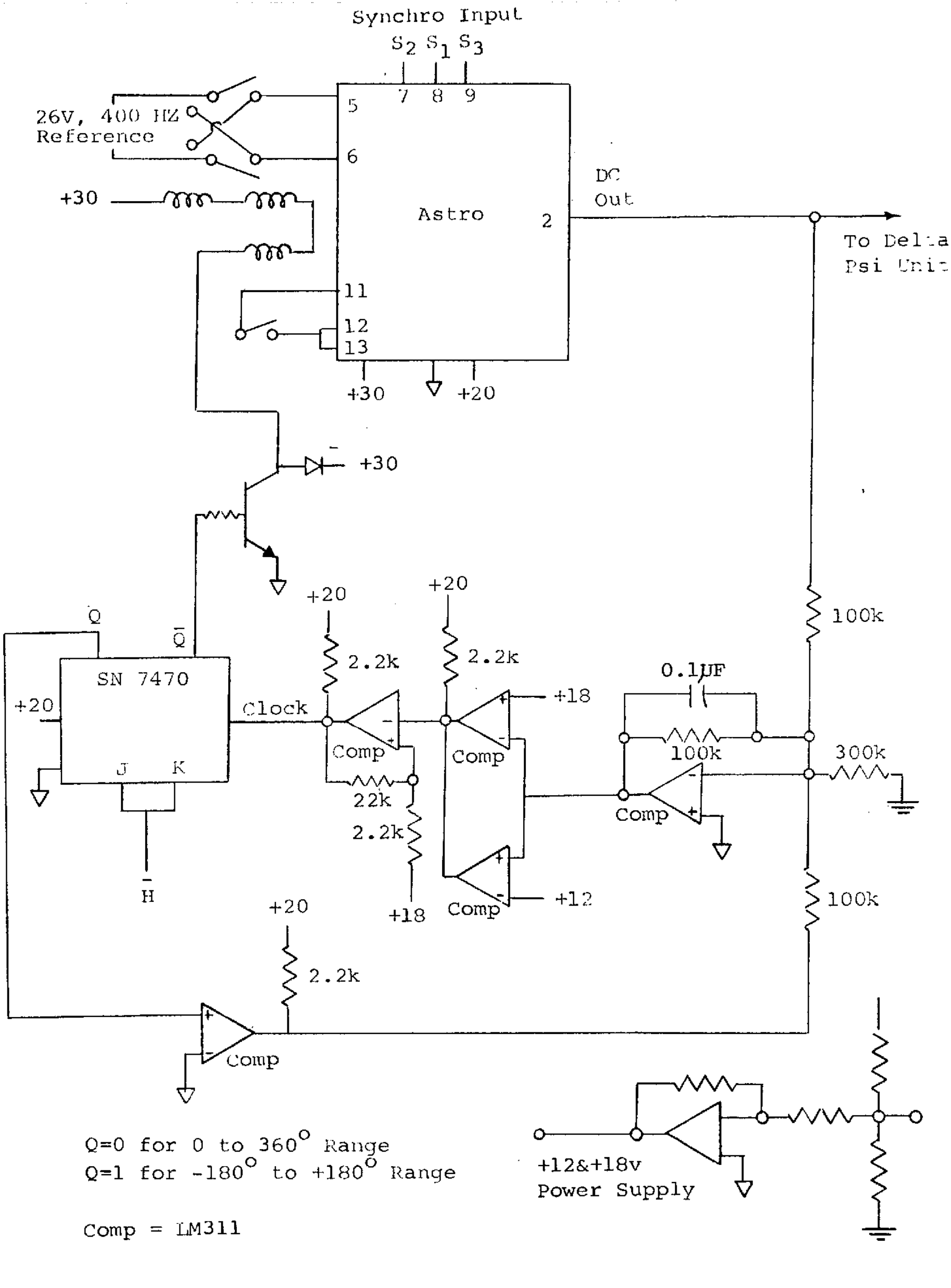


Figure 3. Heading Hold Synchro Demodulator

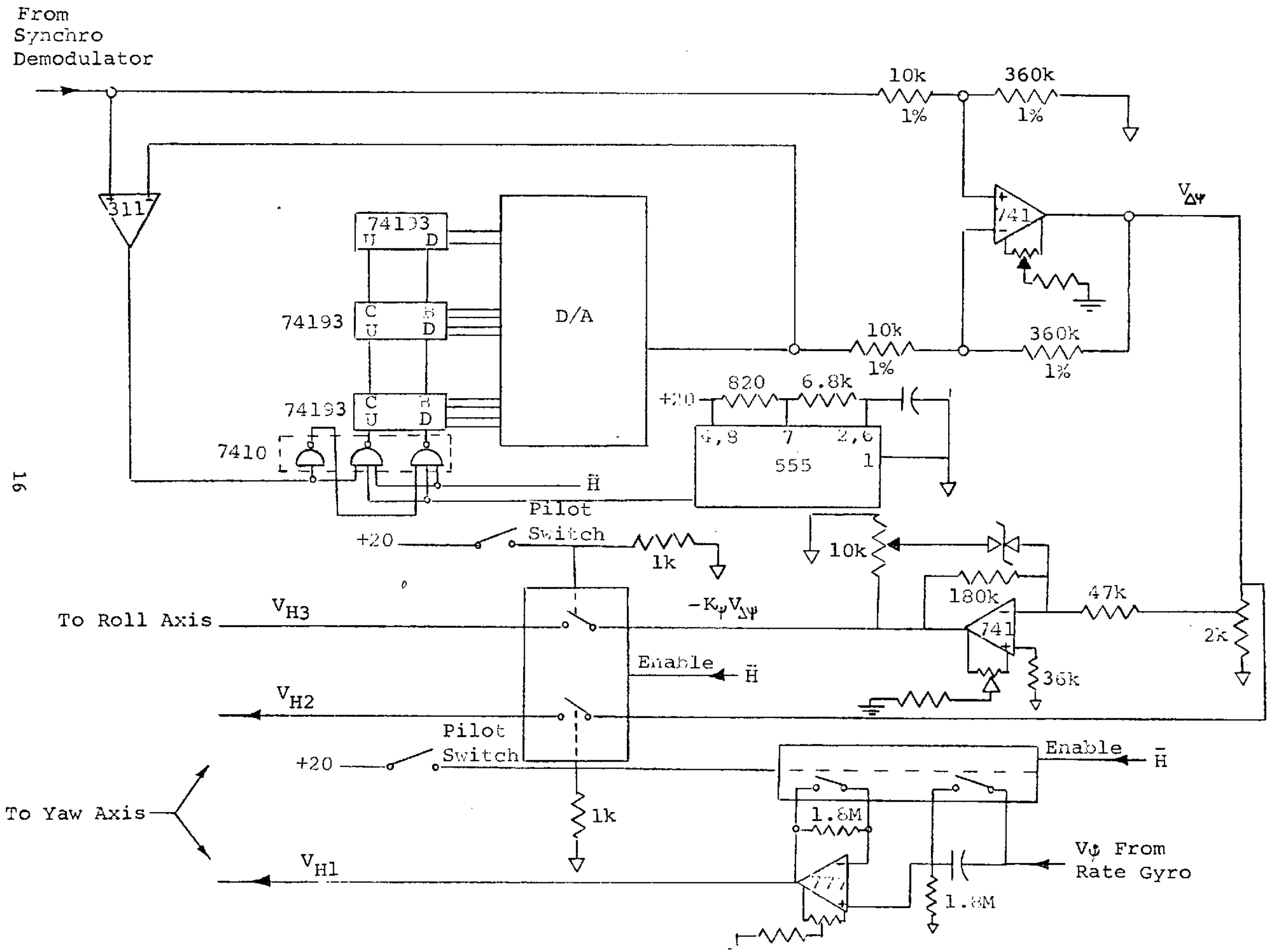


Figure [illegible]. Heading Hold Delta Psi Unit

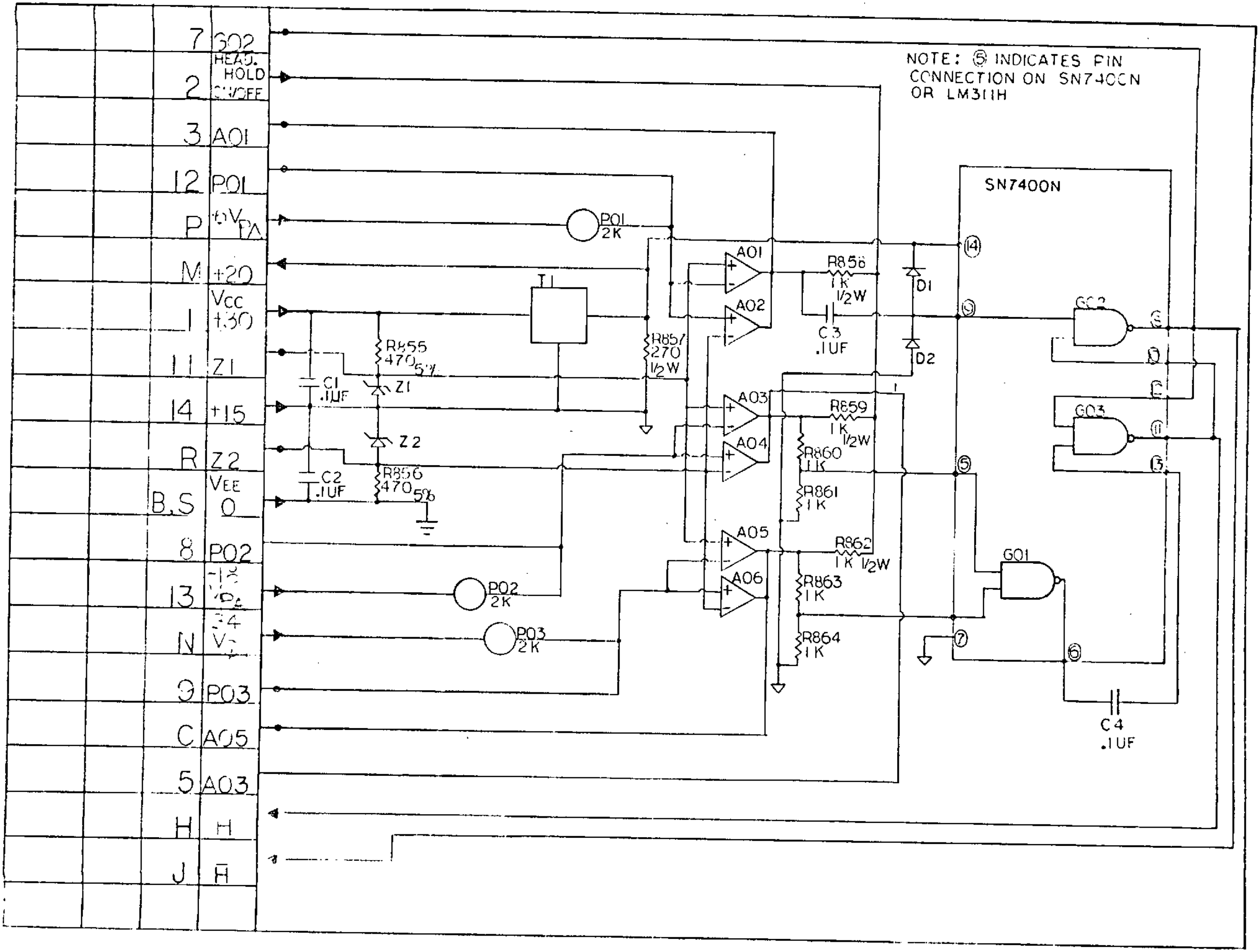


Figure 5. Heading Hold Decision Unit

for this application. Another design has been developed which utilizes the existing synchro output from the DG.

All of the components required for this system have been ordered and some have been received. Construction of the circuits has already begun.

5.0 DETAILED FLIGHT TEST PLAN DEVELOPMENT

5.1 FLIGHT TEST PLAN DESCRIPTION AND STATUS

The detailed flight test plan is still in the preliminary stages of development. The plan has been divided into three sections:

1) SSSA system operational check procedure,

2) Quantitative flight analysis and development,

3) Qualitative flight analysis.

K.U. developed items 1 and 3, Beech developed item 2. A rough draft of items 1 and 3 has been submitted to Beech for review and Beech has submitted item 2 to K.U. A copy of items 1 and 3 is found in Appendices A and B, respectively.

When K.U. and Beech agree on the contents of these 3 sections, they will be combined and submitted to NASA as a detailed flight test plan. At that time it would be desirable to have a meeting with K.U., Beech and NASA representatives to discuss the details of the flight test program.

6.0 ELECTRICAL BUILD-UP

6.1 CIRCUIT CARD MODULE AND CAGE DESIGN

Some concern was originally expressed about housing the electrical circuitry of the SSSA system. Such factors as access, vibration, and heat were considered as possible problem areas. After a catalog search, it was decided that "Vector-Pak" card, module and equipment cages would be utilized. (See Figure 6).

Each of the modules will hold one circuit card. Access to the card is obtained by removing the side plates from the module. Electrical connections are through the back with a hard-wired cannon connector.

6.2 CIRCUIT CARD CONNECTOR DESIGN CHANGE

Recently, a problem was encountered on the Iron Bird that resulted in changing from the edge type connectors to the hard-wired ribbon connectors.

The problem was analyzed extensively and it was discovered that the circuit cards could be installed improperly. This resulted in short circuits that failed several components. This prompted a change from the card edge connectors (see Fig. 7) to the series 57 micro ribbon connectors (see Fig. 8). These new connectors have been ordered for all circuit cards and the first group will be delivered by the middle of April. Modification will begin immediately upon receiving the connectors.

EASY TO ORDER AND READY TO USE

• • • VECTOR-PAK ASSEMBLED MODULE CAGES

Now!

CAGE SUPPLIED COMPLETELY ASSEMBLED

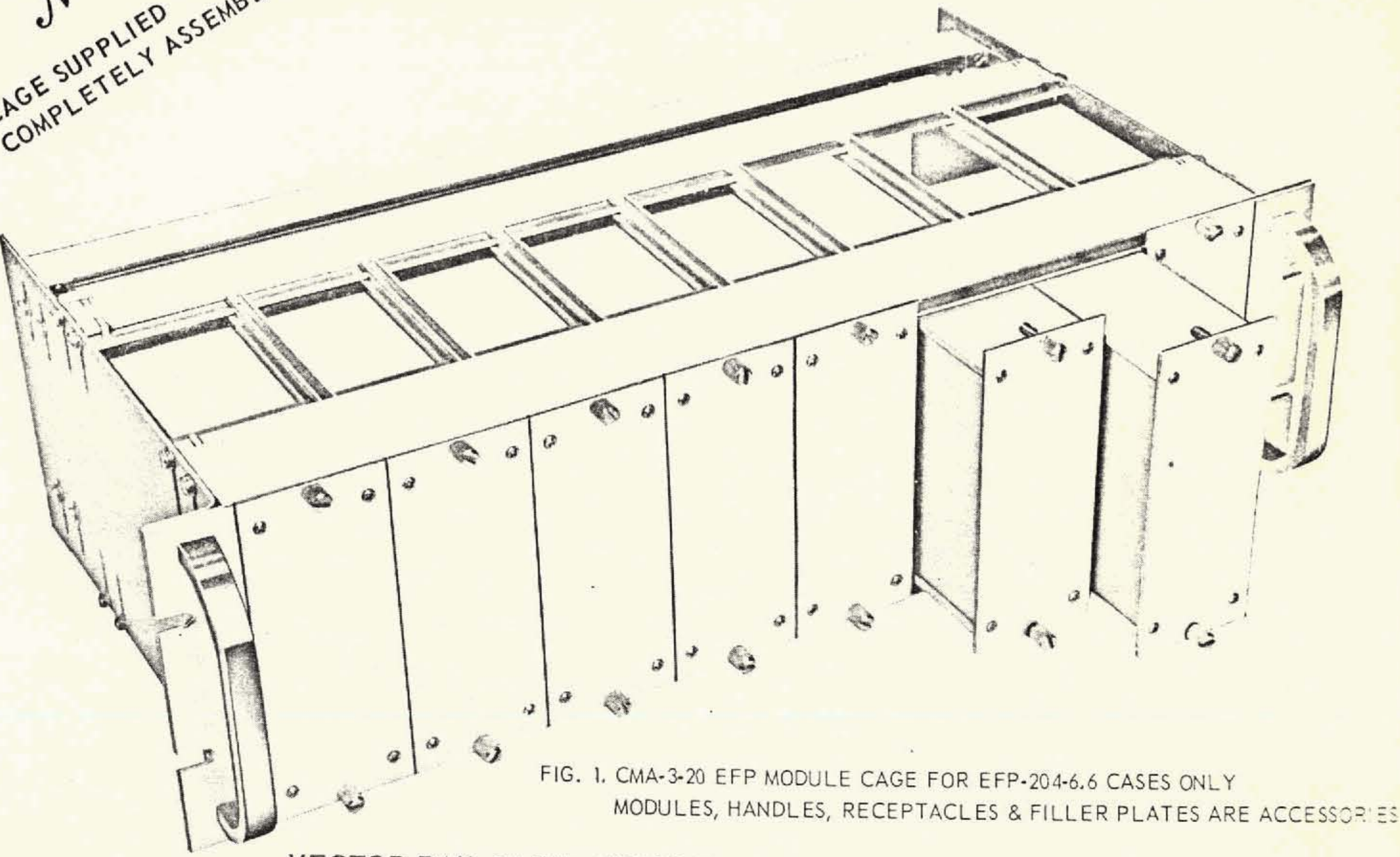


FIG. 1. CMA-3-20 EFP MODULE CAGE FOR EFP-204-6.6 CASES ONLY
MODULES, HANDLES, RECEPTACLES & FILLER PLATES ARE ACCESSORIES

VECTOR-PAK CARD, MODULE AND EQUIPMENT CAGES

These cages provide attractive, sturdy and mechanically excellent housings with which to enclose electronic assemblies; either those which evolved through use of the Totally Flexible "Vector-Pak System" or of other arrangements. The units have most of the benefits of much more expensive custom made enclosures.

The strut members which join the two side walls are of unique design, which provides for convenient assembly of related parts, and can accommodate numerous special assembly requirements. A pair of struts at top and bottom support the guides for cards or modules. A pair of struts at the rear are fully adjustable for mounting receptacles. A more detailed description of the struts is given on Page 8. For description of side walls see pp. 4D & 5.

Cages are obtainable for use in standard electronic enclosures with sizes for widths of 10", 19" and 24", heights of 3 1/2", 5 1/4" and 8 3/4" and depths of 9", 12" and 15". Cage sizes stocked are indicated in the ordering information which covers only cages 19" wide. All other widths are to special order.

The inside net width of cage available for mounting components is 16.85" when 19" cage is used.

As described later, numerous accessory parts are available for special applications and assembly conditions. However, the most common cages for modules or cards are covered by catalog numbers in tabular presentation which simplifies ordering and will provide either a complete parts kit or a completely assembled cage as indicated.

The standard units regularly furnished are intended to mount in larger equipment racks or cabinets. However, if a "unit case" is desired for bench use this can be supplied (see Page 20).

GENERAL SPECIFICATIONS

MATERIAL: Side Walls: .080" aluminum alloy.
Struts: Extruded aluminum alloy.
Card & Case Guides: Extruded aluminum alloy.
Miscellaneous Small Hardware: Steel, cadmium plate and iridite.

FINISH: Side Walls and Struts: Satin finish and clear anodize. Conductive iridite to special order.

SIZE: Standard sizes to industry standards as shown herein.

VECTOR-PAK MODULE CAGES

These cages are available in three categories: EFP Module Cages (Fig. 1), Convertible EFP Module Cages (Fig. 2), and Multi-Use Equipment Cages (Fig. 3). See also NIM (Nuclear Instruments Modules) Bins shown on Page 15.

VECTOR-PAK EFP MODULE CAGES

These are excellent and simplified cages for either ten 1.6" or eight 2.0" wide modules 5 1/4" high (see Fig. 3). Other sizes are available to special order.

A single part number orders all necessary parts except modules and optional accessories. The cage comes completely assembled (see Table 1, p. 3, for ordering information).

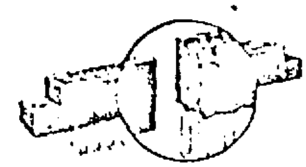
Figure 6. "Vector Pak", Card, Module and Equipment Cage

225 Series Printed Circuit Receptacles

BIFURCATED BELLOWS CONTACT PRINTED CIRCUIT CONNECTORS QUALIFIED TO MIL-C-21097C/21

LOW MILLIVOLT DROP • NEGLIGIBLE PC CIRCUITRY WEAR

Amphenol gold-plated RIBBON contacts — with their smooth glide mating action — incur practically no wear on fragile printed circuitry. Ribbon contacts are bifurcated (slit), to guarantee at least two points of electrical contact, even with an irregular shaped printed circuit board. The double spring tension of the ribbon contact, and large mating surface, provides consistent low contact resistance, with corresponding low millivolt drop.



.156" CENTERS

Bifurcated ribbon contacts are on .156" centers and will accept PC boards of .054" to .071" thickness.

DIALLYL PHTHALATE

One piece, flame resistant, glass filled diallyl phthalate. Chamfered throat opening assists in guiding PC boards to a perfect engagement.

MIL-C-21097C/21

Amphenol 225 Series PC Connectors represent the most comprehensive connector line designed and qualified to MIL-C-21097C.

POLARIZATION

Molded keying slots between contacts accept polarizing key without loss of contact positioning. One key is supplied with each commercial connector.

CONTACT ROWS

225 Series PC Connectors are available with two rows of separate independent contacts, or one row of contacts with back-up springs provided for proper mating tension. The 43 position size connector is therefore available with either 43 or 86 contacts. Double sided contacts with single tails are also available in 6 through 36 sizes. See configuration 5 on next page.

TERMINATION

A wide variety of contact tails permit 225 Series Printed Circuit Connectors to be terminated by soldering, or by crimping, of either Poke-Home or taper pin contacts. Wire wrappable terminations are also available.

SPECIFICATIONS

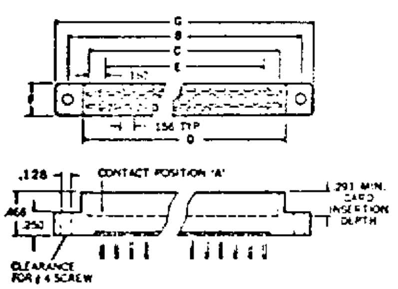
Operating voltage: 600 VAC (RMS) at sea level — 150 VAC (RMS) at 70,000 feet
Current rating: 5 amperes continuous
Test Voltage Between Adjacent Contacts: 1800 VAC (RMS) at sea level — 450 VAC (RMS) at 70,000 feet
Insulation Resistance: 5,000 megohms minimum
Contact Resistance
- Crimp and taper pin terminated — 35 millivolts max. at rated current
- Solder terminated — 30 millivolts max. at rated current

Contact Retention
- Solder terminated — 5 pounds axial load min.
- Crimp terminated — 10 pounds axial load min.
- Taper pin — 15 pounds axial load min.

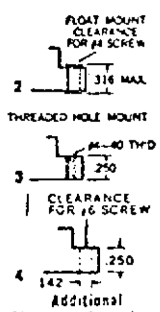
Dielectric material: Glass fiber reinforced diallyl phthalate — Type SGDF per MIL-M-14
Contact material: Beryllium copper, or phosphor bronze (see below)
Contact plating — .00003" min. gold over copper, or .00005" min. gold over copper.

Solder Termination — Standard

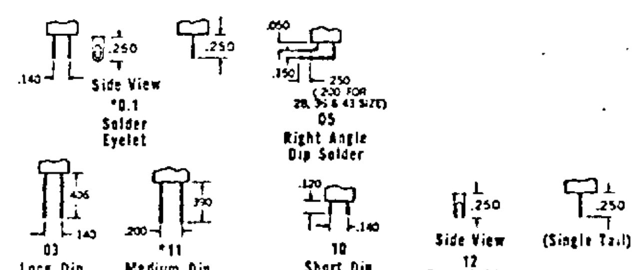
AMPHENOL 225 Series Printed Circuit Connectors with solder terminations provide full flexibility of termination with six different tail styles — three straight plug-in terminations (.140" and .200" grid), one right angle plug-in termination, and two eyelet terminations.



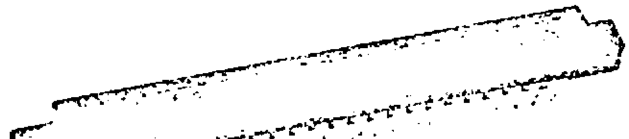
Mounting Provision 1



Additional Mounting Provisions

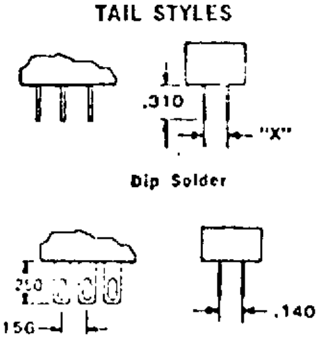


Economy Solder Terminations - (117 Deviation)



These low cost connectors are similar to the standard 225 Series but with an economical phenolic dielectric and .00002" min. gold plating on the contacts. They are available in 6 through 43 positions with either solder eyelet or dip solder tails. Contacts are .156" on center, with .140" or .200" row spacing, and may be arranged in two rows for two-sided circuit boards or in a single row with back-up springs for single-sided boards.

TAIL STYLES



Style	Dim. "X"
04	.140
07	.200

SPECIFICATIONS

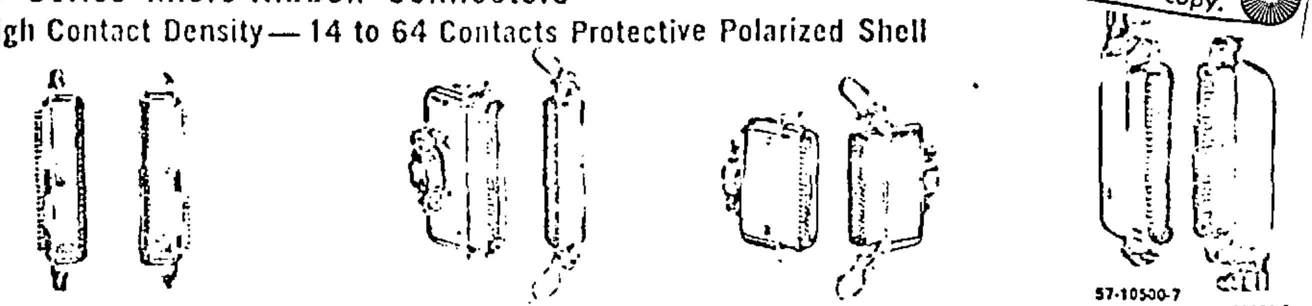
Operating Voltage: 600VAC (RMS) at sea level — 150VAC (RMS) at 70,000 ft.
Current Rating: 5 amps
Dielectric Material: Electrical Grade Phenolic, Black, Mineral filled
Insulation Resistance: 5,000 megohms minimum
Contact Material: Spring bronze with .000020" gold over copper
Contact Resistance: 30 millivolts maximum at rated current
Board Thickness: .054 to .071"

Figure 7. Edge Connectors

Reproduced from best available copy.

57 Series Micro-Ribbon Connectors

High Contact Density — 14 to 64 Contacts Protective Polarized Shell



57-10500 57-20500
RACK & PANEL

57-50500 57-40500
SIDE CABLE ENTRY

57-30360 57-60360
TOP CABLE ENTRY

57-10500-7 57-20500-7
LOW PROFILE HOOD

All of the advantages of ribbon contacts apply to Micro Ribbon Connectors. This includes the self-cleaning, self-wiping action of the contacts and extremely low insertion and withdrawal forces. Dielectric is improved diallyl phthalate with high impact strength and low moisture absorbency characteristics. Trapezoidal shells provide polarization, and are made of zinc plated brass with a clear chromate conversion seal. Small size makes the Amphenol Micro Ribbon Connector ideal for high density miniature modules as well as rack and panel applications. Connectors may be top or bottom mounted. Rated 700V DC at sea level; 200 VDC at 70,000 feet.

Rack and Panel and Module Applications. Receptacle mounting plate includes float bushings to allow a float of .020 in each direction. This facilitates blind mating and minimizes the need for critical mounting dimensions.

Cable-To-Panel Application. Panel receptacles are equipped with sturdy spring latches which are guided and retained by cutouts in the plug's flanges. Receptacles must be top mounted. Cable entry at top side, as desired.

SPECIFICATIONS

(Meets requirements of SCL-6020A)

Current Capacity — 5 amps per contact.

Voltage Rating — 700 volts D.C. at sea level.
200 volts D.C. at 70,000 ft.

Operating Temperature — −55°C to +105°C
−67°F to +221°F

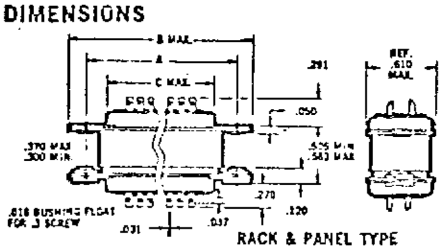
Wire Sizes — Solid — 22 gauge max.
Stranded — 24 gauge max.

Contacts — .000030" gold plated over copper flash on cadmium copper base.

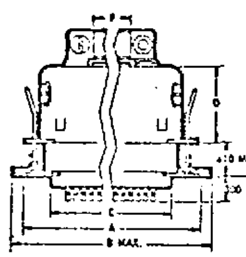
Dielectric — Diallyl phthalate per Mil-M-14F Type MDG

Shells — Zinc plated brass with clear chromate coating, trapezoidal shape for polarization. Gold iridescent chromate finish also available.

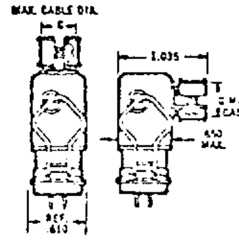
DIMENSIONS



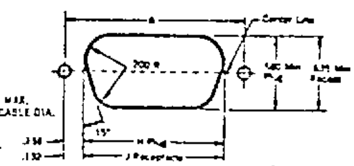
RACK & PANEL TYPE



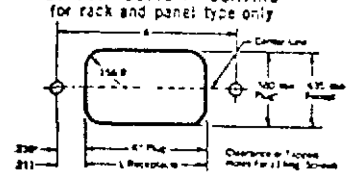
CABLE-TO-PANEL TYPE



TOP CABLE ENTRY   SIDE CABLE ENTRY

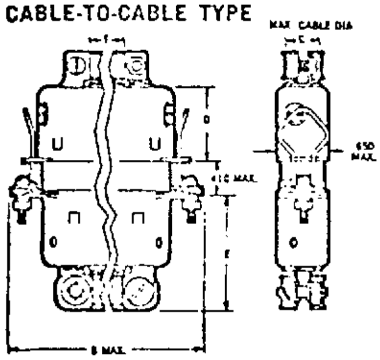


CUTOUT—BOTTOM MOUNTING
for rack and panel type only



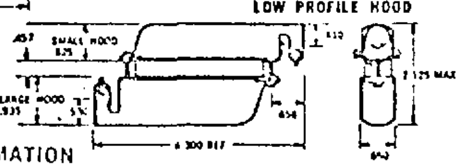
CUTOUT—TOP MOUNTING
for both types

CABLE-TO-CABLE TYPE



TOP CABLE ENTRY

LOW PROFILE HOOD



DIMENSIONS

		14 Contacts	24 Contacts	36 Contacts	50 Contacts	64 Contacts
BOTH TYPES	A	1.417	1.812	2.352	2.947	3.542
	MAX. B	1.750	2.175	2.655	3.270	3.875
	MAX. C	.910	1.335	1.845	2.440	3.035
CABLE TO CHASSIS TYPE ONLY	D	.843	.825	.905	.935	—
	E	1.243	1.225	1.305	1.335	—
	F	.301	.468	.629	.756	—
	G	.412	.468	.468	.468	—
BOTTOM MOUNTING FOR RACK & PANEL TYPE ONLY	H	1.098	1.523	2.033	2.628	3.224
	J	1.153	1.578	2.088	2.683	3.278
TOP MOUNTING FOR BOTH TYPES	K	.940	1.365	1.875	2.470	3.055
	L	.955	1.420	1.930	2.525	[illegible]

ORDERING INFORMATION

Contacts	Rack and Panel Module Applications: Stand. Solder Cup Tails Plugs	Stand. Solder Cup Tails Receptacles	Tapered P.C. Tails Plugs	Tapered P.C. Tails Receptacles	Cable to Panel Applications: Top Entry Cable Plugs	Side Entry Cable Plugs	Receptacles	Cable-To-Cable Application: Plugs	Receptacles	Low Profile
14	57-10140	57-20140	57-10140-3	57-20140-8	[illegible]	57-51140	57-40140	See	57-60140	50 contacts only.
24	57-10240	57-20240	57-10240-3	57-20240-8	[illegible]	57-50240	57-40240	Cable	[illegible]	Receptacle — 57-20500-7
36	57-10360	57-20360	57-10360-13	57-20360-9	[illegible]	57-50360	57-40360	to	[illegible]	Plug — 57-10500-7
50	[illegible]	57-20500	57-10500-27	57-20500-31	[illegible]	57-50500	57-40500	Panel	57-60500	
64	57-10640	57-20640	—	—	—	—	—	Listing	—	

Figure 8. New Micro Ribbon Connector

6.3 ELECTRICAL BUILD-UP STATUS

All required electrical components for the system build-up are on order. Many of these components have already been received and no delivery problems are anticipated on the others. Build-up is continuing on the power amplifiers and circuit cards.

7.0 OPERATOR'S CONSOLE/RACK DESIGN AND DEVELOPMENT

7.1 DESCRIPTION AND STATUS

The purpose for the operator's console/rack is

1) To provide easy access to system gains so they can be adjusted in flight,

2) To house the module cage as described in Section 6.1, two 15 volt power supplies, and four power amplifier/heat sink combinations.

The rack chosen was a "BUD" electronic cabinet. However, it has been modified. The cabinet has been reduced to its basic frame to allow for maximum heat dissipation. Also, it has been reduced in height for installation in the Model 99, (see Fig. 9). The rack will be shock mounted to an existing Beechcraft loading pallet which mounts to the standard Model 99 seat rails. This type of mounting will provide a great amount of flexibility for optimum location in the aircraft. This will also provide easy access to the pilot and co-pilot's seats. There is a full 28" clearance for the passageway.

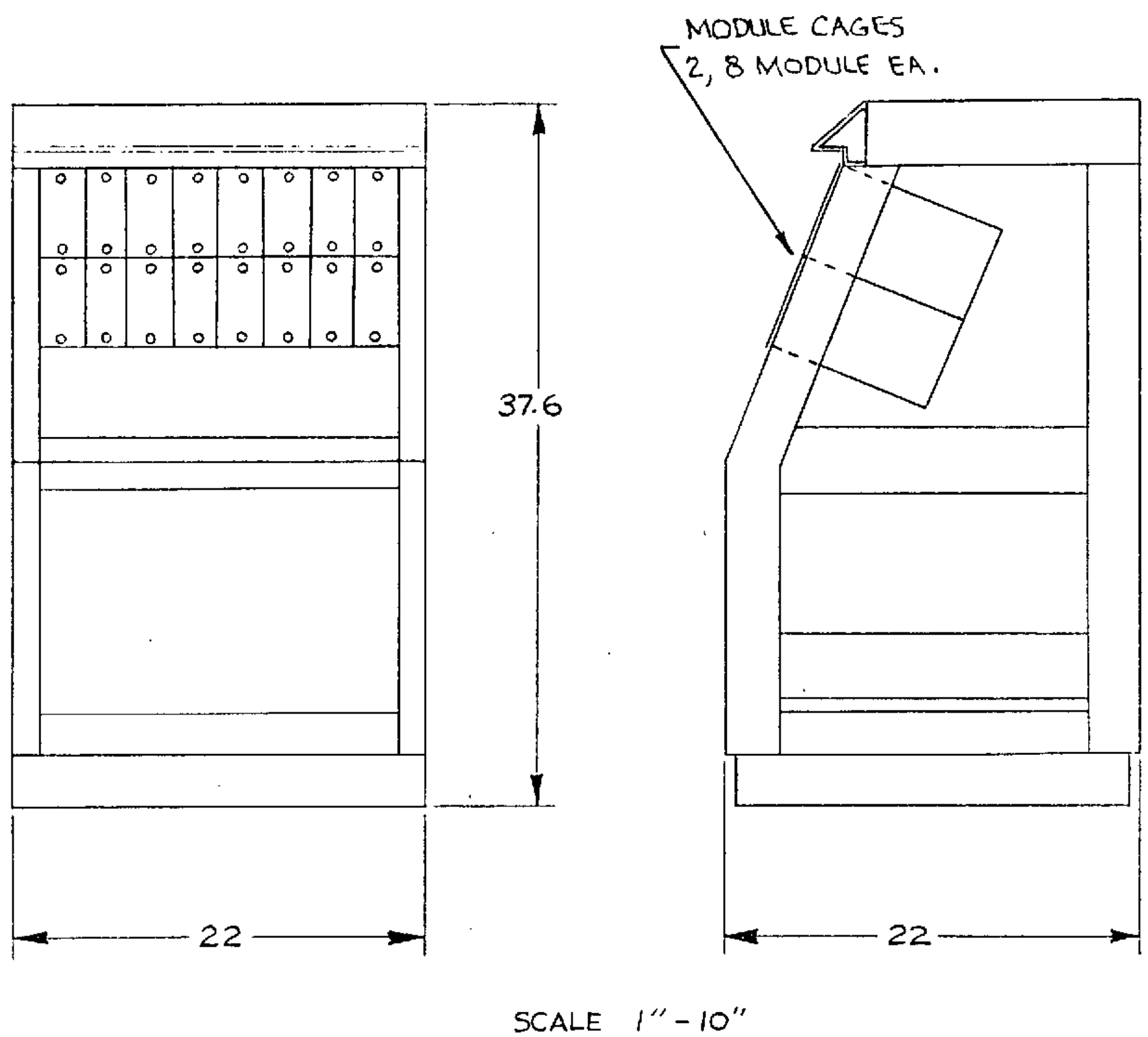


Figure 9. SSSA Module Rack

8.0 ENVIRONMENTAL TEST

8.1 DESCRIPTION AND STATUS

The environmental test plan is described in detail in "Revised Statement of Work" dated 3-13-74, a continuation of NASA grant NGR-17-002-095. A copy is also included as Appendix C.

Work has already begun on the test set-up. The test box will be constructed of styrofoam and will be large enough to place the module cage and rack inside. The temperature ranges desired will be obtained by using electric space heaters and either dry ice or refrigeration coils. The vibrational phases of this test will be separate from the temperature phase.

There are no foreseeable problems in meeting the set-up milestone.

9.0 CONTROL AND MANAGEMENT PANEL DESIGN

9.1 DESCRIPTION AND STATUS

Comments from Beech and NASA representatives resulted in modifying the original management and control panel. Incorporation of those comments produced the panel depicted in Fig. 10. The primary changes are 1) use of one switch for aileron actuator control, 2) amber colored fault lights, and 3) labels added to the mode select switch and the fault lights.

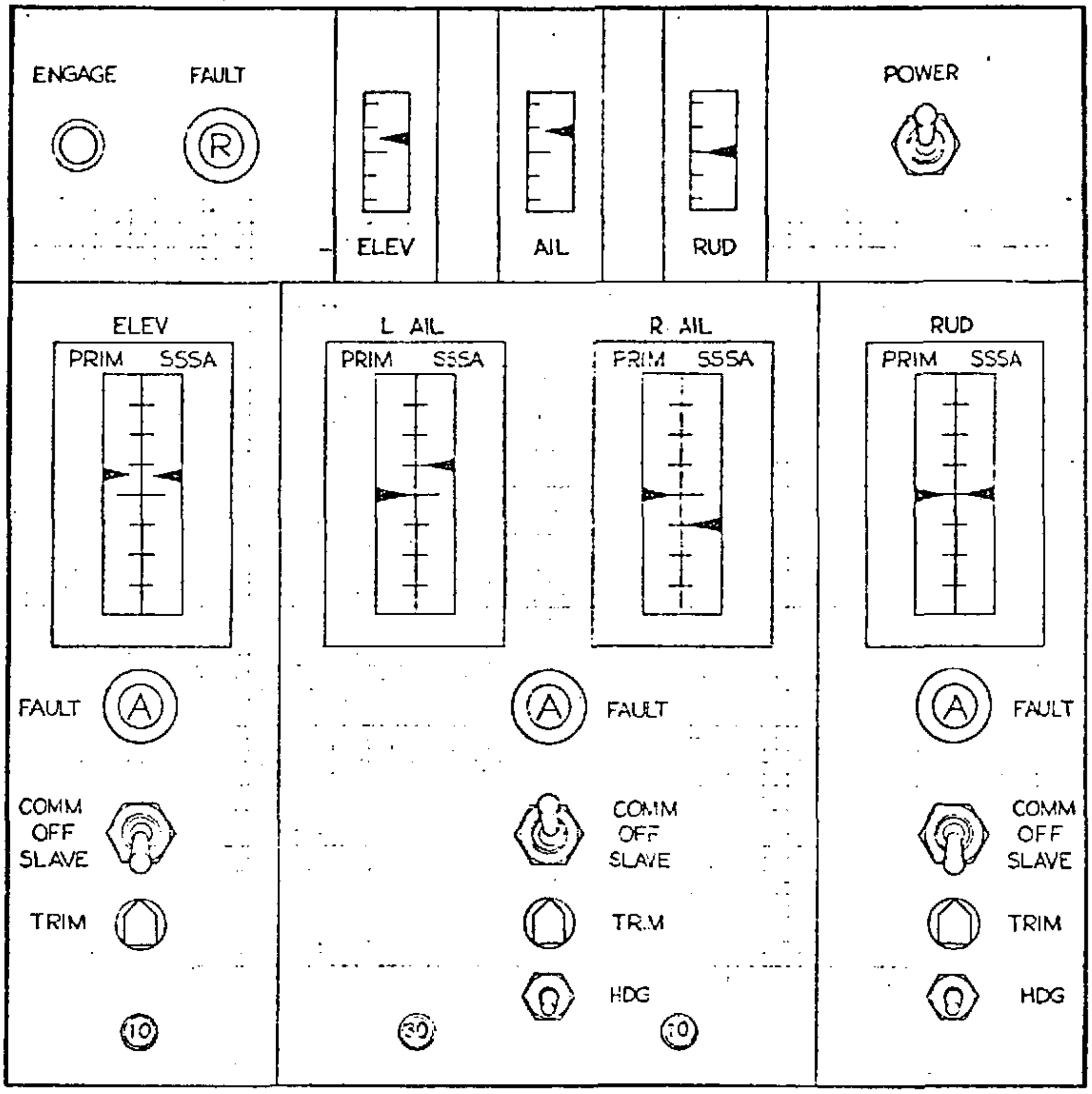


Figure 10. SSSA Management and Control Panel

The vertical instruments have also been selected for the new panels. Phaostron is the manufacturer, however, Beech will supply K.U. with those instruments. Coordination is continuing.

APPENDIX A

SSSA SYSTEM CHECK OUT

SYSTEM FUNCTIONAL CHECK PROCEDURES

To obtain meaningful data during flight testing, it is mandatory that the SSSA system operate in a proper and consistent manner. While circuit check procedures outlined in the System Operation Manual (Ref. 20) provide adequate checks of certain components, this section describes functional checks that may be used to exercise the entire SSSA system. These checks are divided into two subsections: ground checks and flight checks. Ground checks confirm correct system setup and operation of the slave and command modes using test signals introduced into the system. Flight checks confirm proper operation of the command mode by observing aircraft response to control inputs. These checks may be used on a routine basis to confirm consistent system operation.

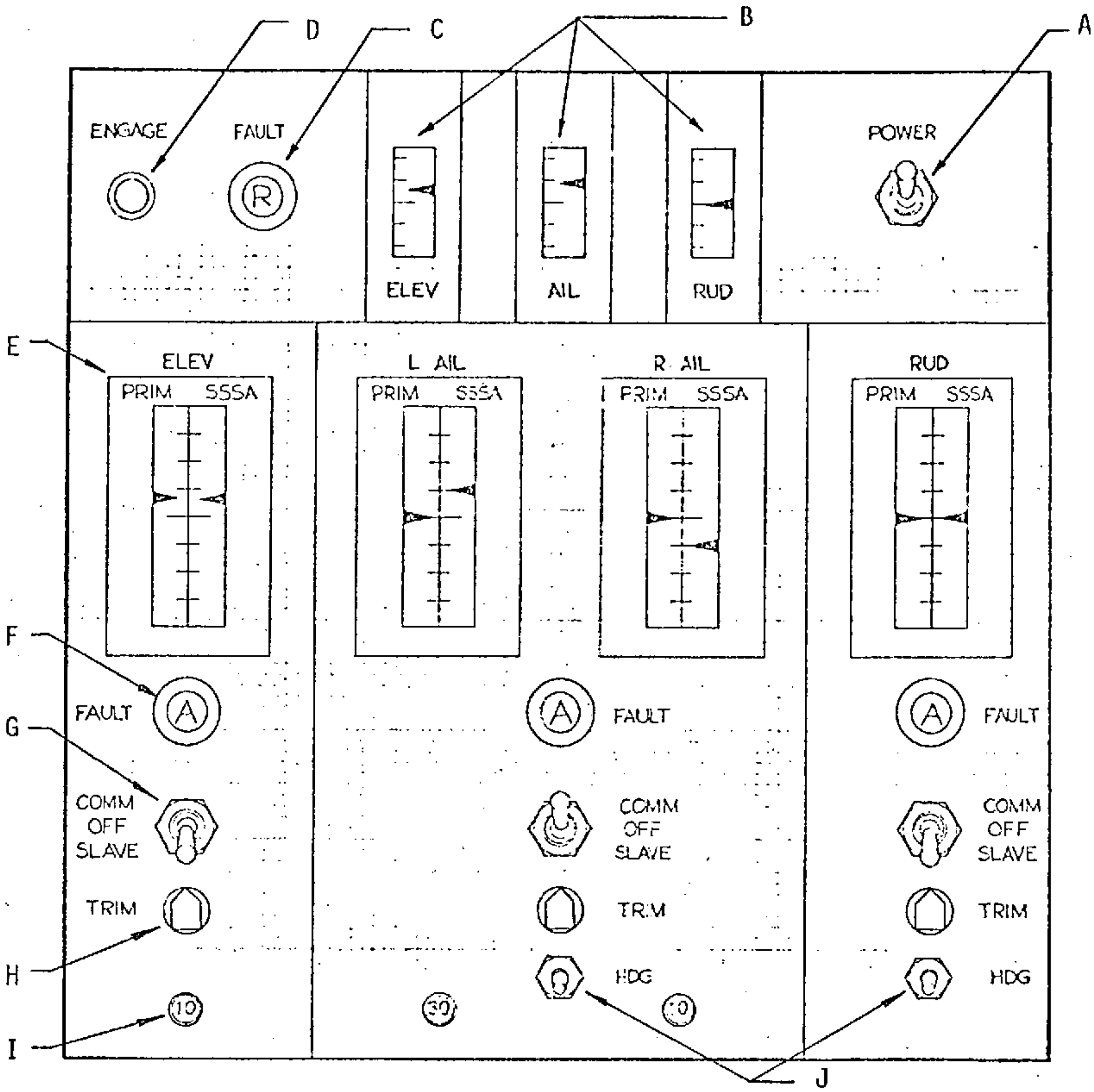
Ground Checks

The system ground checks emphasize the SSSA control position resulting from a known input signal. Therefore, these checks are specified in terms of angular surface position, which may be measured with the aid of a surface position template or monitored electrically from the calibrated output of the corresponding surface position potentiometer. In preparation for ground checks, the SSSA computer cards should be adjusted for nominal gains and functionally tested as described in the System Operation Manual (Ref. 20). Next, the system should be adjusted for zero position both in slave and command mode. This is accomplished by centering the pilot controls (zero deflection position), engaging the SSSA system, and centering the SSSA control surfaces by adjusting the "zero" or "bias" potentiometers on the appropriate drive card. The location of these potentiometers on the drive cards is specified in Reference 20. Figure 9.1 shows the SSSA Control and Management panel and points out major controls.

Slave Mode Gains

In all axes, the nominal values of slave gains are $K_{SLAVE} = 1.0$. Slave gains may be easily adjusted by potentiometers mounted on the system operator's console. Slave gains may be confirmed with the following procedure:

1. Engage and zero SSSA system.
2. Introduce pilot control surface deflection of known magnitude.
3. Observe corresponding SSSA surface position (For example: with the elevator slave gain = 1, a pilot elevator deflection of +5° will result in a SSSA elevator deflection of +5°.)



A. System Power Switch
B. Servo Error Indicators
C. System Disengage Light
D. Engage Button
E. Surface Position Indicators
F. Actuator Disengage Light
G. Actuator Mode Select Switch
H. Trim Potentiometers
I. Circuit Breaker
J. Heading Hold Mode Select Switch

Figure 9.1 SSSA Control and Management Panel

It should be emphasized that under a no-load condition the surface position will match the commanded surface position. However, under load (as in flight) there will be an offset between the commanded and actual surface position that is a function of the actuator feedback gain. The nature of this functional relationship is shown in Figure 9.2. Notice that for a given loading condition the magnitude of the offset is reduced by increasing the actuator feedback gain. However, increasing this gain tends to destabilize the actuator servo loop. Therefore, the actuator feedback

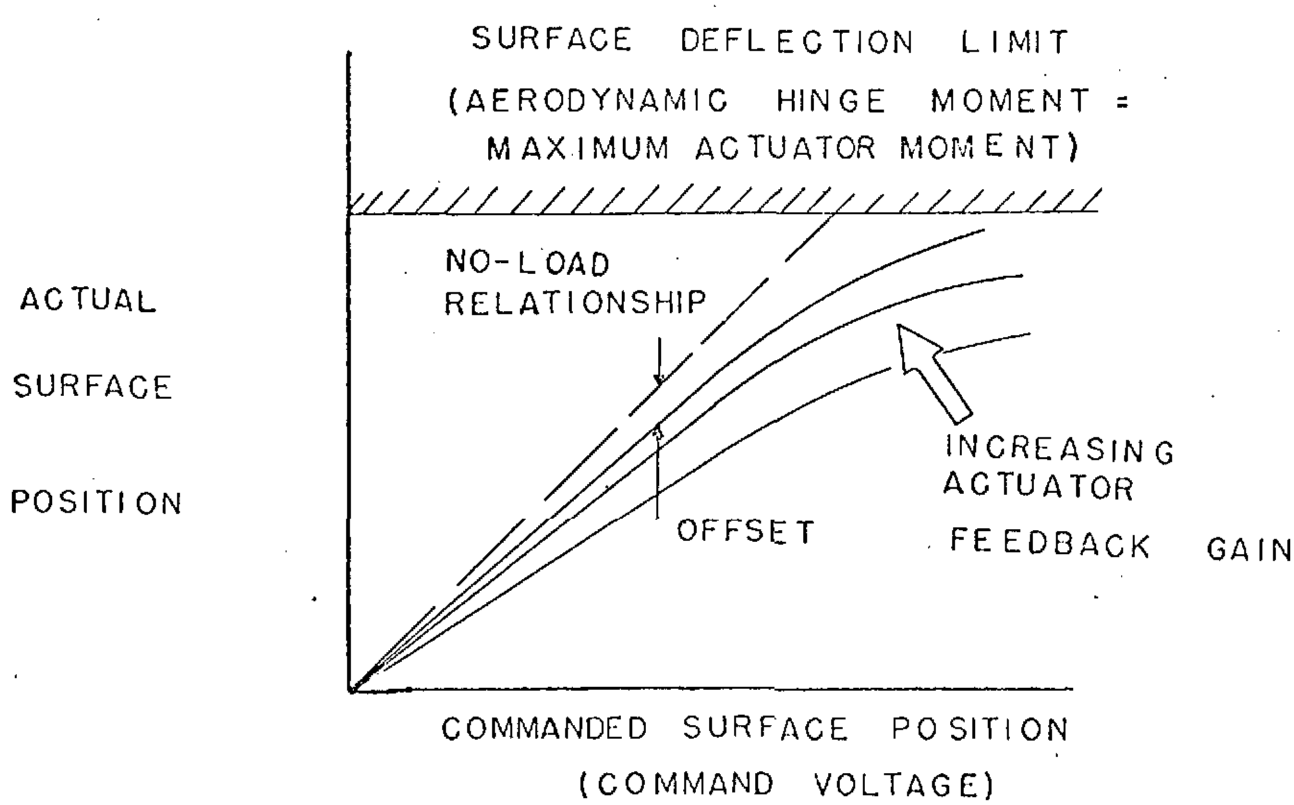


Figure 9.2 Effect of Actuator Feedback Gain

gain should be adjusted to the highest value that does not result in surface oscillations. The simulator actuator feedback gains are approximately 8 volts/degree of offset. These values may be readjusted for the flight test hardware. To obtain the desired slave gain under flight loads it may be necessary to increase the slave gains slightly. For example, to obtain a slave gain of 1.0 it may require setting $K_{SLAVE} = 1.1$ to compensate for offset at the maximum achievable value of actuator gain.

Pilot Disengage

The pilot may disengage the SSSA system by turning the system power off (computer and all actuators disengage), depressing the control wheel mounted "kill" switch (actuators disengage), or by placing the SSSA axis "off-slave-command" switches in the "off" position (individual actuators disengage). These features should be checked by engaging the SSSA system and exercising each disengage method.

SSSA Surface Limit Disconnect Switches

The SSSA control system includes surface position limit switches to minimize the consequences of hard-over failures. In the event a SSSA control surface exceeds its normal deflection range, as in hard-over failure, the limit switch will disengage power from the affected actuator. Aerodynamic hinge moments will then tend to return the surface to the trail position against the friction of the unpowered actuator. Power is not reapplied to the actuator unless the pilot elects to do so from the Control and Management panel.

Proper operation of each SSSA surface limit switch should be checked using the following procedure:

1. Engage the SSSA system in slave mode.
2. Position the SSSA surface at its deflection limit using the corresponding pilot control.
3. Manually trip the switch or force the surface to trip the limit switch. The power relay should open, removing power from the actuator.
4. Note the surface deflection at which the limit switch actuates. This should occur ahead of the surface hard stop and slightly beyond the pilot surface deflection limit.

SSSA Surface Position Limit

The SSSA drive circuits include provision to limit the maximum surface deflection command. This feature is intended to prevent the SSSA surfaces from reaching the limit switches in normal operation and, therefore, minimize nuisance actuator disengagements. The proper operation of the position limit may be observed by injecting any command voltage that would drive the SSSA surface past its deflection limit. The following procedure is based on a slave mode input:

1. Set $K_{SLAVE} = 2.0$.

2. Engage and zero SSSA system in slave mode.

3. Position pilot surface at each deflection limit.

4. SSSA surface position should approximately agree with pilot surface position without tripping the limit disengage switch.

5. Return K_{SLAVE} to nominal value.

Control Surface Position Indicator Calibration

Control surface position indicators are installed on the Control and Management panel to allow the pilot to continuously monitor SSSA and pilot control positions. Correct operation and calibration of these indicators may be observed by engaging the system in slave mode and comparing the actual surface position with the position indicators throughout the surface deflection range.

Auto-Trim Threshold

The auto-trim feature of the longitudinal axis senses SSSA elevator position and drives the stabilizer through the secondary stabilizer motor to return SSSA elevator deflection to zero. To avoid activating auto-trim with short term SSSA elevator deflections, a one second lag is incorporated in the surface position sensing circuit. The following procedure may be used to exercise the auto-trim system:

1. Engage the SSSA pitch axis in command mode with the elevator actuator circuit breaker open.
2. With power applied to the stabilizer motor, manually deflect the SSSA elevator beyond the 10° threshold. After approximately 1 second, the secondary stabilizer motor should begin to run in the following direction:

SSSA Elevator Deflection	Stabilizer Motion
Trailing edge up	Leading edge down
Trailing edge down	Leading edge up

3. Return the SSSA elevator to zero deflection, that is, trail position with respect to the stabilizer. The stabilizer should immediately stop running.

Command Mode Static Checks

The feedback gains of the SSSA command mode may be checked with the entire system installed in the aircraft. To make the static check as inclusive as possible, the gains are checked from the gyro output to the SSSA position. The pilot control input is introduced by positioning the pilot surface. Gyro inputs are simulated by disconnecting the gyro and injecting an appropriately scaled signal at the gyro mating electrical connector. The command mode gains are checked using the following procedure:

1. Engage and zero the SSSA system in command mode.
2. Introduce scaled inputs one at a time.

3. Measure the resulting steady state SSSA surface deflection. The command mode gain is the ratio of surface deflection to scaled input.

The nominal values of command mode gains are shown in Table 9.1.

Command Mode Dynamic Checks

The purpose of the dynamic checks is to confirm that the required compensating transfer functions are correctly mechanized on the SSSA computer cards. This is accomplished by observing the transfer function response to a step input. The dynamic check may be performed with the circuit cards in a test box or installed in the SSSA system. The output to be monitored is the command voltage output of each axis computer card. Figures 9.3, 9.4, and 9.5 show the inputs and important characteristics of the computer card outputs.

Ground Test Equipment

Table 9.2 summarizes test equipment that will be required for ground test and setup of the SSSA system. Those ground checks that take place in the aircraft will require the entire SSSA system to be supplied with the necessary electric power (26VDC and 115V 400 HZ AC). In addition, provision must be made to supply electric power for test equipment used in the aircraft only during ground tests (115V 60 HZ AC). It is not anticipated that any SSSA system diagnostic equipment will be used in flight.

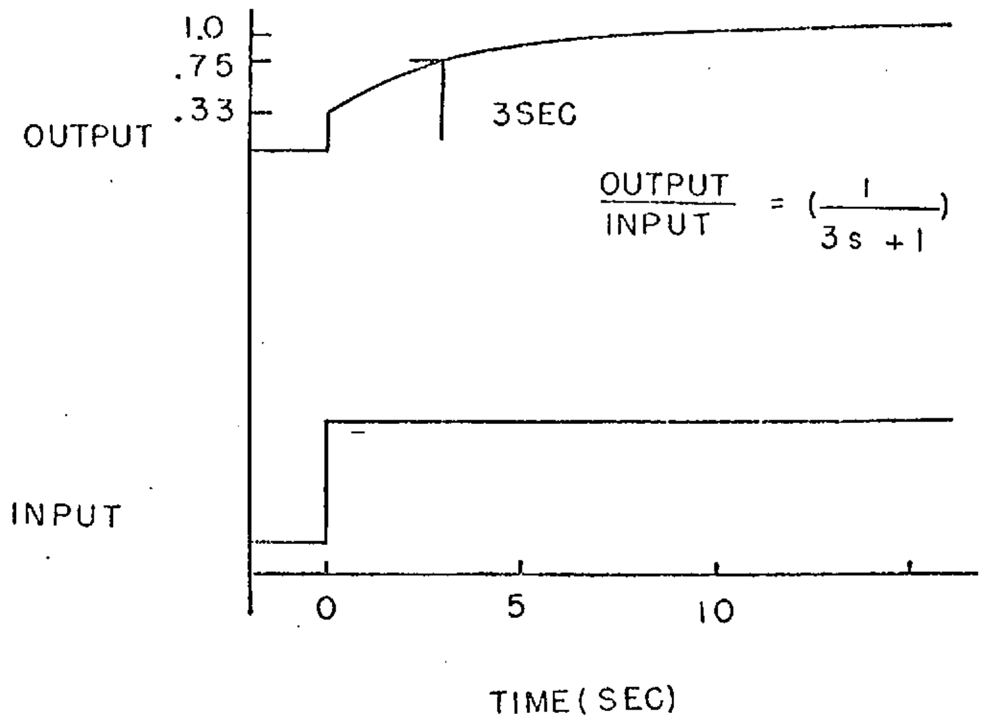


Figure 9.3 Roll Transfer Function Step Response

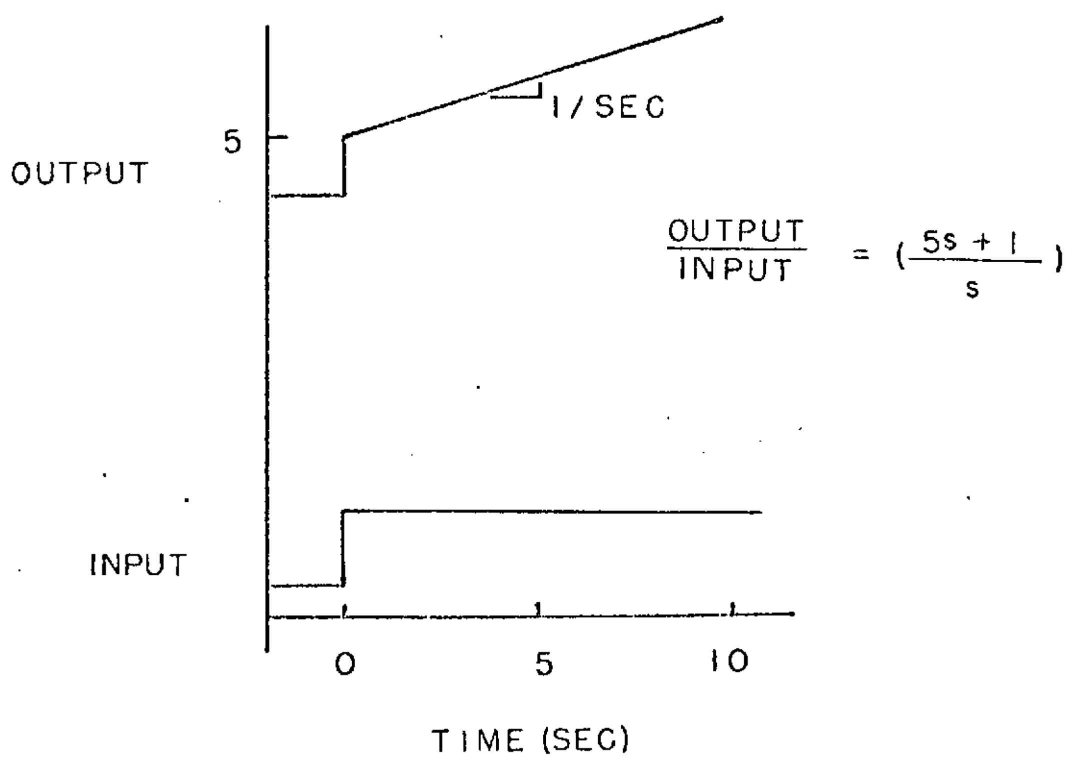


Figure 9.4 Pitch Transfer Function Step Response

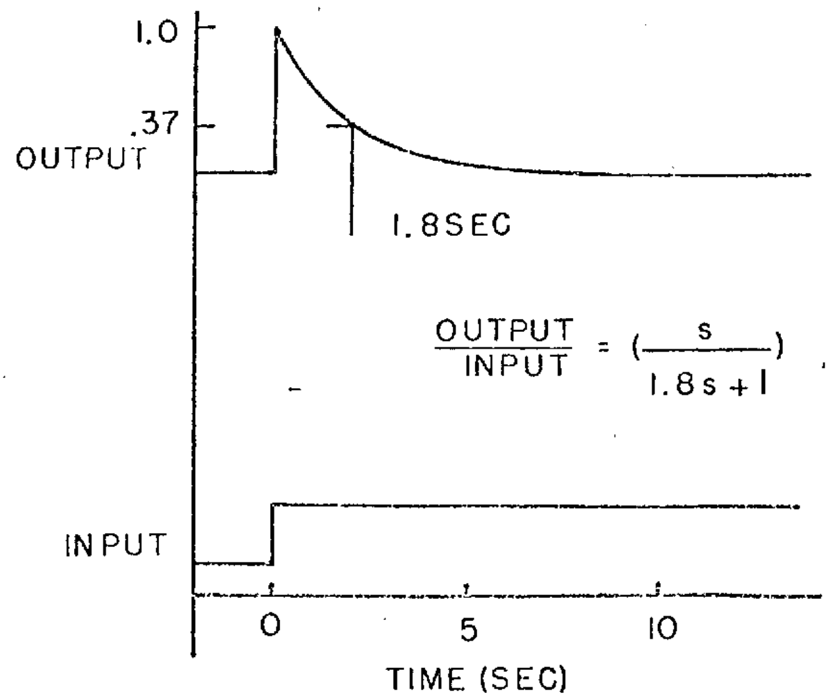


Figure 9.5 Yaw Transfer Function Step Response

Flight Checks

The flight checks were developed to permit rapid in-flight evaluation of the SSSA attitude command function. Proper system operation is determined by observation of aircraft response to various pilot inputs with the SSSA system engaged. It should be emphasized that due to the nature of the inputs and observations, these evaluations are somewhat imprecise and subjective. The flight checks are based on an understanding of the SSSA system capabilities developed during flight simulation. Therefore, these checks should represent the best SSSA system operation to be expected during flight test. In all cases, the flight

TABLE 9.1

COMMAND MODE GAINS

Input	Magnitude	Input Voltage	Resulting SSSA Surface Position	Command Mode Gain
Roll Axis:				
δ_{A_p}	+0.5°	--	+7.5°	15
ϕ	+1°	0.167 v[1]	+6	6
ϕ	+1°/sec	0.3 v[2]	+12	12
Pitch Axis:[4]				
δ_{E_p}	+1°	--	+10°	10
θ	+0.5°	0.125 v[3]	+10°	20
θ	+2°/sec	0.6 v[2]	+8°	4
Yaw Axis:				
δ_{R_p}	+5°	--	+5°	1
ψ[5]	+1/sec	0.3 v[2]	+10°	10

NOTE:

1. Assuming vertical gyro roll scaling of ±90° = ±15v or 0.167 v/deg.
2. Assuming rate gyro scaling of ±50°/sec = ±15v or 0.3 v/deg/sec.
3. Assuming vertical gyro pitch scaling of ±60° = ±15v or or 0.25 v/deg.
4. To observe the steady state SSSA elevator deflection the error integration in the pitch axis computer card must be disabled. Refer to System Operation Manual (Ref. 20).
5. To observe $\dot{\psi}$ gain, the 1.8 second washout must be disabled. Refer to System Operation Manual (Ref.20).

TABLE 9.2

GROUND TEST EQUIPMENT

Description	Purpose or Use	Where Used
1. Oscilloscope, Dual Trace (H.P. 140A or Equiv.)	Functional Check and Gain Set or SSSA Computer Cards	Test Bench
2. Digital Multimeter (Fluke 8000A or Equiv.)	SSSA Computer Card and System Checkout	Test Bench and Aircraft (Ground)
3. Sine Wave Signal Generator (H.P. 209A or Equiv.)	SSSA Computer Card Test Input	Test Bench
4. DC Power Supplies, ±15VDC, +26VDC	SSSA Computer Card Test Power Supply	Test Bench
5. Test Box with Mating Connector for SSSA Computer Cards	Setup and Check of SSSA Computer Cards	Test Bench
6. Duplicate Electrical Connector for Each Type of SSSA Gyro	Inject Simulated Gyro Signals Into SSSA System to Check and Set Command Mode Gains	Aircraft (Ground)
7. DC Step Input Source (Precisely Adjustable in the Range 0-1VDC)	Input for SSSA Computer Card Transfer Function Dynamic Check	Test Bench
8. Strip Chart Recorder	Record SSSA Computer Card Transfer Function Step Response	Test Bench
9. Aircraft Control Surface Deflection Indicators	Measure Surface Deflections During Ground Checks	Aircraft (Ground)

checks are based on the nominal feedback gains established during static checks.

As part of the preflight checks, the following disengagement checks should be accomplished:

1. Turn on system power and engage all axes of the system in either command or slave mode.
2. In sequence, place each axis mode select switch in the "off" position. The switched axis should disengage while the other axes remain engaged.
3. With all axes engaged, depress the pilot control wheel mounted disengage switch. All axes should disengage simultaneously.
4. With all axes engaged, turn off system power. All actuators should become unpowered.

Yaw Axis

The SSSA yaw axis consists of a dutch roll damper and an optional heading hold feature mechanized through the SSSA rudder. Correct operation of the yaw damper is confirmed by exciting the aircraft dutch roll and observing the damping of the resulting oscillation. Due to the relatively large ratio of bank angle to sideslip, the SSSA roll axis is also effective in damping dutch roll. The following procedure may be used to check the yaw damper.

1. Trim the aircraft at the desired flight condition.

2. With the SSSA system engaged in the desired configuration, disturb the aircraft using a pilot rudder pulse of approximately 5° magnitude and 1 second duration. Dutch roll damping will be degraded if the pilot rudder input is of sufficient magnitude to result in SSSA rudder saturation.
3. With pilot controls fixed, observe the resulting aircraft oscillation. The expected aircraft response is summarized in Table 9.3.

The level of dutch roll damping is primarily affected by the yaw rate feedback gain $K_{\dot{\psi}}$.

The yaw axis heading hold feature attempts to maintain the aircraft on the commanded heading by deflecting the SSSA rudder in proportion to error from the desired heading, $\Delta\Psi$. Either "Heading Hold" or "Yaw Damper Only" mode of the yaw axis is selected by a switch on the Control and Management panel. This switching function is checked by observing that the SSSA rudder activity corresponds to the switch position. When selected by the control switch, heading hold operates either in "track" or "engage" mode as controlled by logic circuitry. Heading hold reverts to the track mode when the pilot wheel deflection exceeds a preset threshold. The nominal threshold corresponds to a pilot aileron deflection of $\pm 3°$. However, this threshold may be adjusted as required. The heading hold remains in the track mode while the pilot

TABLE 9.3

SSSA YAW DAMPER FLIGHT CHECK

	Approach Flight Condition		Cruise Flight Condition	
SSSA Roll Axis Status	Dutch Roll Damping Ratio	Number of Heading Overshoots	Dutch Roll Damping Ratio	Number of Heading Overshoots
Off	0.3	4	0.25	4
On	0.65	1	0.6	1

turns the aircraft to a new heading. While in the track mode, the SSSA rudder acts as a dutch roll damper with a 1.8 second washout. To engage the heading hold, two conditions must be satisfied: first, the pilot must command wings level flight by centering his control wheel; second, the aircraft must reach level flight, defined as the condition of bank angle less than a preset threshold. The nominal value of bank angle threshold is $\pm 2°$. As soon as both engagement conditions are satisfied, heading hold will accept the current aircraft heading as the reference heading.

The following procedure may be used to check for correct operation of the heading hold feature:

1. With the wheel centered and aircraft wings level on the desired heading, select the yaw axis heading hold mode.
2. Generate a heading error by "skidding" the aircraft with the pilot rudder. With the pilot rudder centered, the SSSA rudder should return the aircraft to within 1 degree of the preselected heading.
3. Create a steady state yawing moment with an asymmetric power setting. At the nominal value of $K_{\Delta\Psi} = 2$, the SSSA rudder will reach its deflection limit for a heading error of approximately 7°. Less than 30% of the total rudder area is devoted to the SSSA rudder.

Therefore, the SSSA rudder alone, driven by heading hold, is not capable of trimming a severe asymmetric thrust condition.

4. Using a conventional banked turn, select a new reference heading. Provided the turn was initiated without a large heading error, reversion to track mode should create no noticeable transient aircraft motions. Confirm that heading hold has accepted a new reference heading by repeating step #2.

Roll Axis

The SSSA roll axis provides bank angle command and an optional roll axis heading hold function. Attitude command is achieved by displacing the SSSA ailerons in proportion to the error between bank angle command (pilot aileron position) and aircraft bank angle. When a disturbance rolling moment is present, as might result from asymmetric fuel loading, the aircraft attains an equilibrium attitude where the SSSA aileron moment, resulting from the bank angle error, balances the disturbance moment. The relationship between the disturbance and resulting bank angle error is termed the "stiffness" of the roll axis. The following procedure may be used to evaluate the roll stiffness:

1. Trim the aircraft for straight and level flight with the roll axis command mode engaged and the yaw axis slave mode engaged.
2. Create a steady state rolling moment through the aircraft roll-due-to-sideslip characteristic by displacing the pilot rudder with the pilot wheel centered.
3. Observe the resulting aircraft roll attitude. Table 9.4 summarizes the rudder input and expected bank angle.
4. Center the pilot rudder. The aircraft should return to level flight.

Bank angle stiffness is primarily determined by the bank angle feedback gain, K_{ϕ}.

TABLE 9.4

ROLL AXIS STIFFNESS CHARACTERISTICS

Flight Condition	Pilot Rudder Deflection	Resulting Bank Angle Deviation From Level Flight
Approach	Approx. 10°	$\leq$ 4°
Cruise	Approx. 5°	$\leq$ 1°

The range of bank angle over which attitude command is available is determined by the bank angle at which the SSSA ailerons reach their deflection limit. At bank angles beyond SSSA saturation the aircraft responds as a rate control rather than attitude command system. Saturation and the gearing between bank angle and pilot aileron input is primarily determined by the ratio of pilot input gain to bank angle feedback gain, $K_{\delta_{A_P}}/K_{\phi}$. At nominal gains, each degree of pilot aileron input should result in approximately 1.6° of bank angle and saturation should occur at a bank angle of ±30°.

The damping of the roll axis response depends, to some extent, on the magnitude of the command input. For small inputs the roll axis remains a linear system, that is, the SSSA ailerons do not reach their deflection limits during the response. The linear step response of the roll axis resembles a first order system (no overshoot) with a time constant of approximately 0.7 seconds. For step commands large enough to send the SSSA ailerons to their deflection limits but smaller than 30°, the aircraft will overshoot then return to the commanded bank angle. For commands in excess of 30°, the aircraft responds as a rate controlled system. Damping of the roll axis is primarily determined by the roll rate feedback gain, $K_{\dot{\phi}}$.

The roll axis heading hold feature is mechanized using the same logic and heading error circuitry as used in the yaw axis heading hold. Roll heading hold enters track mode when the pilot aileron exceeds a preset threshold and enters the engage mode when pilot aileron is centered and bank angle equals zero. The nominal values of threshold are the same as the yaw axis values: aileron threshold = $\pm 3°$ and bank angle threshold = $\pm 2°$.

NOTE: To fly the roll axis heading hold it will be necessary to insure that the yaw axis heading hold has been disabled.

The operation of the roll heading hold is similar to the analogous yaw axis system. A bank angle reference signal proportional to heading angle error, $\Delta\Psi$, drives the SSSA ailerons. The aircraft then banks to turn the aircraft toward the desired heading. A limiter is provided to prevent heading hold from commanding a bank angle in excess of 15° regardless of the magnitude of $\Delta\Psi$. The heading hold check procedure outlined in the yaw axis section is repeated in a form that applies to the roll axis mechanization:

1. With the wheel centered and aircraft wings level on the desired heading, select the roll axis heading hold mode.
2. Generate a heading error by "skidding" the aircraft with the pilot rudder. With the pilot rudder centered, the SSSA ailerons should turn the aircraft to within 1 degree of the preselected heading. For the nominal value of K_ψ = 0.55 deg ail./deg $\Delta\Psi$ the aircraft should return to the commanded heading with no more than 1 overshoot.

3. Create a steady state yawing moment with an asymmetric power setting. The aircraft will bank toward the desired heading and stabilize at a steady state bank angle. At no time should the roll axis heading hold command a bank angle in excess of 15°.
4. Using a conventional banked turn, select a new aircraft reference heading. The reversion to track mode should not create any noticeable transient motion. Confirm that heading hold has accepted a new reference heading by repeating step #2.

Pitch Axis

The SSSA pitch axis provides attitude command by driving the SSSA elevator to maintain the aircraft pitch angle in fixed proportion to the pilot elevator (control column) position. An "auto-trim" or "stabilizer follow up" minimizes the effects of an SSSA elevator disconnect and increases pitch authority by maintaining its deflection near zero. In addition, the SSSA pitch axis includes a forward loop integration that drives long term errors in pitch attitude to zero. The Model 99 longitudinal electric trim has been incorporated into the pitch attitude command system to allow pitch attitude command through the pilot column, trim button, or combination of the two. The following procedures may be used to evaluate each function of the pitch axis:

SSSA PITCH AXIS

1. With the aircraft trimmed for straight and level flight, engage the SSSA pitch axis in command mode.

2. Command a new pitch attitude using the pilot elevator (column). The relationship between pitch attitude change and pilot elevator input should be 0.6 deg $\Delta\theta$/deg δ_{E_P}. This gearing is a function of the ratio of pilot input gain to pitch attitude feedback gain, $K_{\delta_{E_P}}/K_\theta$.

3. In response to a step pilot elevator input the aircraft should stabilize at the commanded attitude with no more than one overshoot of less than 10%. The damping of the pitch response is primarily determined by the ratio of pitch rate to pitch angle feedback gains, $K_{\dot{\theta}}/K_\theta$.

4. Induce a change in aircraft pitching moment by deflecting the flaps and maintain constant airspeed with power setting. The forward loop integration should return the aircraft to the commanded attitude with no noticeable offset or error within 3 seconds.

5. Command a change in attitude using the pilot elevator, and then by using the pilot trim. Finally, establish an attitude with the elevator and trim the stick force to zero using the pilot trim. It should be possible to establish a desired attitude using any of these methods.

AUTO-TRIM

1. With pitch command mode engaged and the aircraft trimmed for level flight, make speed changes with throttle setting. Pitch angle should never vary from commanded attitude more than 2°.
2. As airspeed changes, the SSSA elevator should deflect to maintain attitude. When elevator deflection exceeds the auto-trim threshold (nominal value of 10°) the stabilizer should drive in the appropriate direction to reduce SSSA elevator deflection to zero. Check in both aircraft nose up (speed decreasing) and aircraft nose down (speed increasing) directions.
3. Make configuration changes with landing gear and flaps. The pitch axis with auto-trim should maintain the aircraft within $\pm 2°$ of the commanded attitude. Simulator evaluations indicate that the auto-trim rate may be marginal for the landing wave-off case.

4. With auto-trim running, oppose with the pilot trim button. The pilot trim should over-ride the auto-trim in both directions.
5. With auto-trim running, depress the pilot disengage button. Auto-trim should stop running.
6. When auto-trim runs the aircraft attitude should not change unless commanded through the pilot trim or elevator.

Throughout these flight checks reference has been made to the expected performance of the system based on nominal gains and adjustments. These adjustments and gains should be suitable for flight testing; therefore, there should be no need of an extensive gain tailoring program during flight test. It will be left to the judgment of the flight test project pilot and engineer to determine if the actual system performance is significantly degraded from the expected performance. In the event that it is necessary to modify some gains based on flight test experience, Chapter 7 of this document explains the interrelationship of the gains and should prove helpful.

APPENDIX B

QUALITATIVE FLIGHT TEST PLAN

This appendix represents a "first cut" at the problem of defining the qualitative flight test plan. It will be further managed and coordinated with Beech and with NASA.

A detailed quantitative flight test plan will be developed in the near future. This will contain data processing flow charts.

SSSA QUALITATIVE FLIGHT ANALYSIS

General Discussion of Principles

An integral part of the SSSA program is the analysis of the flight hardware or the flight evaluation. At the present time this program is broken down into two phases, the 1) quantitative analysis, 2) qualitative analysis.

The quantitative analysis will be the comparison of absolute performance maneuvers between the standard model 99 and the SSSA modified model 99. The qualitative analysis, however, isn't quite as definitative as the quantitative analysis due to the fact that the data generated are pilot opinions. This type of an analysis isn't as "cut-and-dried" as a plot of stick force versus speed or stick force versus g or roll response, etc. However, it is one of the most important ingredients in developing a viable system. Therefore, considerable attention must be given to establishing the evaluation criterion and relating this criterion to some known standard.

The standard used in most instances is the "Cooper-Harper" score of pilot rating, (see Fig. 1 and 2). This scale is an attempt to standardize the basis upon which pilots would rate airplane handling qualities. For example, if an aircraft was rated an overall 3.0, then everyone would know, whether they had flown the aircraft or not, that for the mission defined it had relatively good handling qualities. It has some "mildly unpleasant" characteristics but it is still in the upper portion of the rating scale. The important point to remember is

COMPENSATION

The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

HANDLING QUALITIES

Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

MISSION

The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

PERFORMANCE

The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot-vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

ROLE

The function or purpose that defines the primary use of an aircraft.

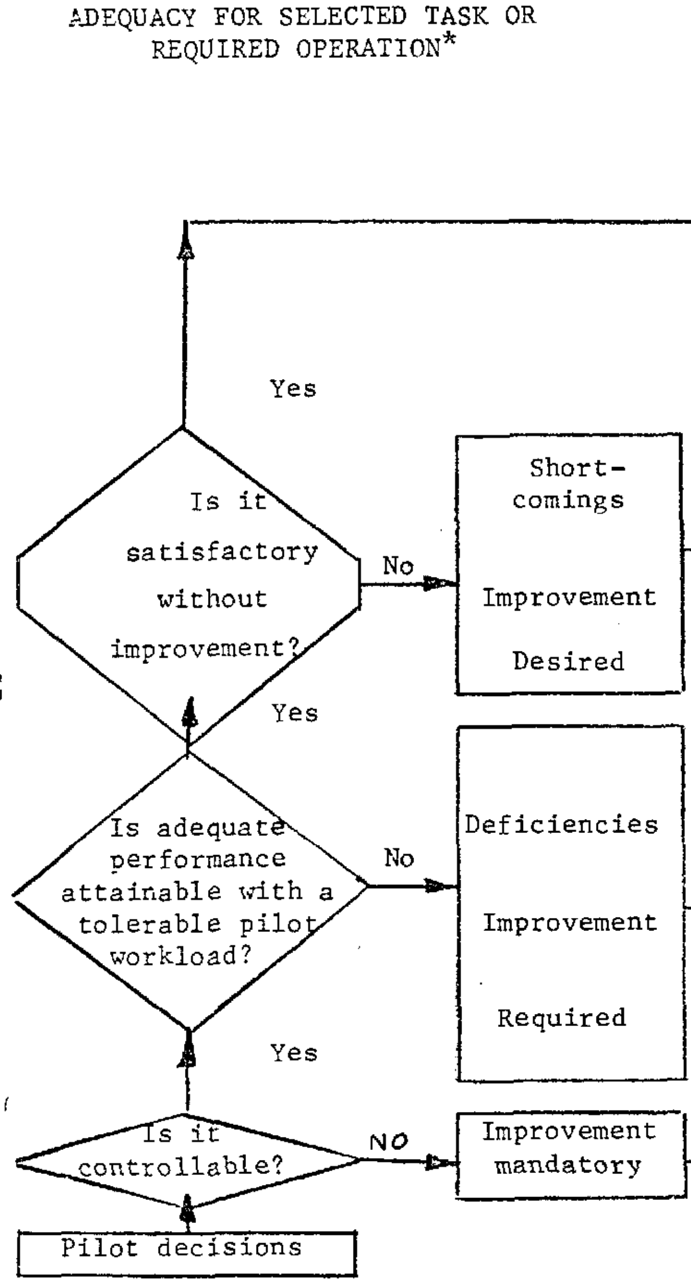
TASK

The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

WORKLOAD

The integrated physical and mental effort required to perform a specified piloting task.

Figure 1. Definitions From TN-D-5153



AIRCRAFT CHARACTERISTICS	DEMANDS ON THE PILOT IN SELECTED TASK OR REQUIRED OPERATION*	PILOT RATING
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible	Pilot compensation not a factor for desired performance	2
Fair--Some mildly unpleasant	Minimal pilot compensation required for desired performance	3
Minor but annoying shortcomings	Desired performance requires moderate pilot compensation	4
Moderately objectionable shortcomings	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable shortcomings	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question.	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

Figure 2. Handling Qualities Rating Scale

Based upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TN-D-5153) that this scale attempts to alleviate the personal preferences of the pilots and that when a rating is generated it will apply to a general cross section of pilots. This standardization is accomplished by two methods, 1) impressing on the evaluation pilot to report exactly what he sees and not try to analyze the situation too deeply, 2) by having an engineer who can very systematically apply all of the logical steps of the "Cooper-Harper" scale in generating an absolute number for a pilot rating. This will require the engineer to be knowledgeable of the flight task and mission such that pertinent questions can be asked that will stimulate the pilot to justify or defend his evaluation comments.

Application of these principles to the SSSA flight program should follow three logical steps:

1. Define the mission of the aircraft.
2. Define the task involved in that mission.
3. Define the field of pilots that is applicable to the mission.

Evaluation Criterion

1. Define the mission of the aircraft.

The general mission of the basic aircraft is transporting people from point A to point B. However, the primary goal of this program is to determine whether or not the AACCS system improves the handling characteristics of this class of airplane. Therefore, it will be necessary to define the pilot rating of the standard model 99 such that any improvements or degradations in the pilot ratings can be detected on the modified aircraft. These data will be generated within the confines of the general mission of the basic airplane. This type of analysis will also establish the feasibility of the SSSA system when mechanized as an attitude command control system.

2. Define the task involved in that mission.

The basic task involved in the general mission is an IFR profile consisting of a relatively low altitude cruise, descent or penetration to a final approach course, approach to landing and a missed approach or go-around. Therefore, to evaluate all phases of this profile several maneuvers have been developed which tend to represent the task of heading control, constant rate climbs and descents, steady rate turns, course and glideslope interceptions.

A. Vertical S Maneuver -- This maneuver is designed to develop the pilot's instrument cross check and aircraft control under instrument flight conditions. The maneuver consists of a constant rate climb, 500 fpm, for 500 ft, while maintaining a constant airspeed, 100 kias, and a standard rate turn. At the end of the 500 ft climb the turn is reversed and a 500 ft descent is started at a constant rate of 500 fpm and constant airspeed, 100 kias, (see Fig. 3). This type of Vertical S can be repeated for as many cycles as desired. This maneuver will tend to utilize many of the design features of the SSSA system; elimination of trim changes with power, undesirable spiral instabilities and precise climb and descent control.

The data required for this maneuver and the evaluation criteria for those parameters are as follows:

Parameter	Evaluation Criteria
1. Altitude	All of these parameters will be evaluated by looking at excursions from the defined constants, R/C, A/S, transition altitudes, etc.
2. Pitch Angle, θ	
3. A/S	
4. ϕ	
5. Control Travels, (Pilot & SSSA)	
6.* TIM	
7. Pilot Comments	

Configuration -- gear dn, flaps approach, A/S = 100 kias, R/C=R/D=500 fpm, ϕ = Std. Rate Turn, Alt.=500 ft.

*The data taken for comparison purposes must be compared at approximately the same level of turbulence. Therefore, these data will be required for definition of the test conditions.

B. ILS Approach -- To emphasize the performance characteristics of the evaluation aircraft the ILS approaches will not be flown as conventional ILS approaches. Instead it will be flown with two variations, 1) the modified localizer interception and 2) the modified glideslope interception.

The modified localizer interception will consist of configuring the aircraft, gear down, flaps approach, A/S = 100 kias at the glideslope interception altitude, with a 90° localizer intercept angle, within 1 mile outbound of the outer marker. As soon as the localizer needle begins to move,the pilot will attempt to maneuver the aircraft onto the localizer such that he is established on the localizer and glidepath when he reaches the outer marker, (see Fig. 3).

This exaggerated intercept will force the pilot to overshoot the localizer and result in rapid maneuvering which will readily tax the operational capabilities of the lateral control. Therefore, any improvement or degradation of the flight controls should be readily observed.

The modified glideslope interception has the same intent as the modified localizer interception; exaggerating the maneuvering requirements for the approach. However, this is aimed at the longitudinal trim characteristics of the aircraft. This maneuver is begun by establishing the aircraft on the localizer outbound of the outer marker at an altitude 500 ft* above the glideslope interception altitude. The aircraft configuration will be clean, gear and flaps up, airspeed 120 kias. When the aircraft reaches the outer marker the pilot will attempt, as quickly as possible, to configure the aircraft into the approach configuration, descend and intercept the ILS glideslope.

This maneuver will tend to exaggerate the trim requirements with gear and flap extensions and power applications. In addition it will also emphasize the importance of good descent and heading control.

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*This altitude may vary depending upon degree of pilot work load.

The data required for the localizer and glideslope task are as follows:

LOCALIZER TASK

Parameter	Evaluation Criteria
1. A/S	Looking for mean deviations from the known values such as glideslope and localizer. Also variation of control forces and travels.
2. ALT	
3. Bank Angle, ϕ	
4. Pitch Angle, θ	
5. Heading Angle, Ψ	
6. Control Travel (SSSA & Pilot)	
7. Localizer Position	
8. Glideslope Position	
9. Control Forces	
10. TIM	
11. Pilot Comments	

Configuration -- gear down, flaps approach, A/S = 100 kias, Alt.= glideslope interception altitude.

GLIDESLOPE TASK

Parameters	Evaluation Criteria
1. A/S	Looking for mean deviations from the known values such as glideslope and localizer. Also variation of control forces and travels.
2. ALT	
3. Bank Angle, ϕ	
4. Pitch Angle, θ	
5. Heading Angle, Ψ	
6. Control Travels (SSSA & Pilot)	
7. Localizer Position	
8. Glideslope Position	
9. Control Forces	
10. Glide Position	
11. Flap Position	
12. Throttle Position	
13. TIM	
14. Pilot Comments	

Configuration -- prior to OM: gear up, flaps up, altitude 500 ft above as intercept altitude airspeed, 120 kias.

inbound from OM: gear down, flaps approach, established on glideslope & localizer, airspeed = 100 kias.

C. Go-Around -- This maneuver is merely to demonstrate the effects of the SSSA system on the balked landing or go-around conditions. The maneuver should be flown from the ILS missed approach point with the aircraft configured for landing, gear down, flaps landing, A/S = 100 kias. When the aircraft reaches the missed approach altitude the pilot will apply full power, begin a climb and raise the gear and flaps as prescribed in the flight manual.

The data required for this maneuver will be as follows:

	Parameter	Evaluation Criteria
1.	A/S	Variation
2.	Alt.	Variation after execution of go-around
3.	Bank Angle, ϕ	Variation & max.
4.	Pitch Angle, θ	Variation & max.
5.	Heading Angle, Ψ	Variation
6.	Control Travels (SSSA & Pilot)	Frequency & max.
7.	Control Forces	Direction & max.
8.	Gear, Flap & Throttle Position	Position
9.	TIM	Max. & mean
10.	Pilot Comments	

Configuration -- prior to missed approach point: gear down, flaps landing, A/S = 100 kias, power as required.

-- after missed approach point: gear up, flaps up, A/S = best rate of climb A/S, power = max. continuous.

D. Precision Heading Control -- This task doesn't tend to exaggerate the maneuvering requirements of the aircraft but it should point out any serious deficiencies that may exist. The maneuver will be accomplished by merely giving 1° and 2° heading changes to the pilot by means of a ground controller or by on-board commands. This maneuver could probably be coordinated with the ILS approach task.

The data required for this task is as follows:

Parameter	Evaluation Criteria
1. A/S	
2. Alt.	Looking for variation in A/S,
3. Bank Angle, ϕ	Alt, Heading Angle, Control Activity
4. Heading Angle, Ψ	and Turbulence Level.
5. Control Travels (SSSA & Pilot)	
6. TIM	
7. Pilot Comments	
8. Heading Commands	

Configuration -- clean & dirty, A/S = 100 kias - 150 kias, alt. constant from 2,000 ft - 5,000 ft AGL, power as required.

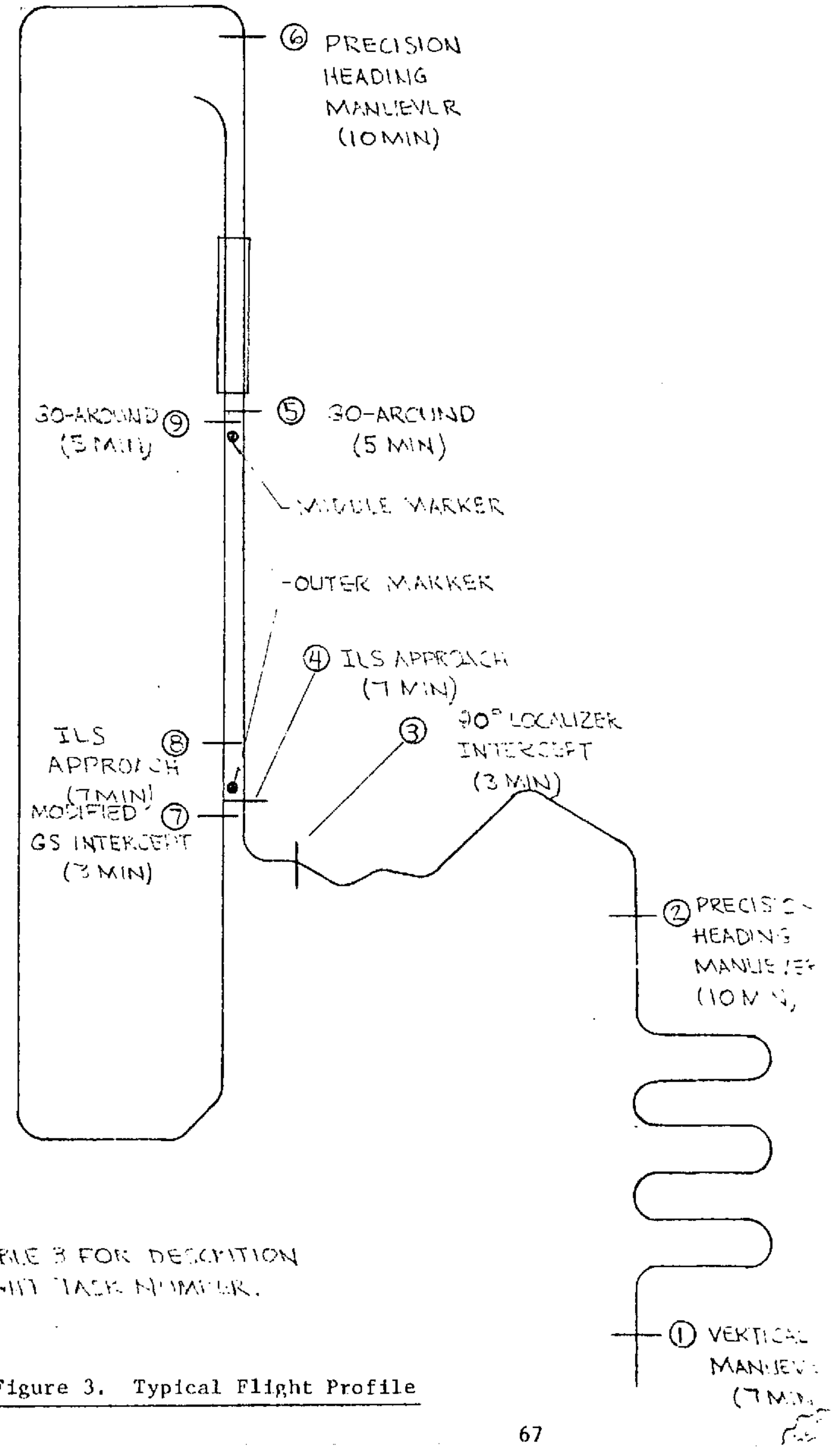
3. Define the field of pilots that is applicable to the mission.

The field of pilots that could apply to this mission could become so large that hundreds of hours of flying time could be expended in gathering data. However, the main concern would be the changes in the handling qualities from the unmodified to the modified model 99, and this would narrow the field down to a minimum number of pilots. For this evaluation the program pilot, some K.U. pilots and one professional model 99 operator would probably provide enough data to generate a reasonable evaluation. However, any additional pilots would tend to add to the credibility of the evaluation.

<u>Program Organization</u>

This program will be using the standard model 99 as the base line data. Therefore, as soon as the aircraft returns from NASA-FRC the unmodified model 99 will be simulated by mechanically interconnecting the SSSA and pilot controls. The evaluation will be conducted by building a flight plan utilizing the task or maneuvers described above. One such scheme could be as follows: 1) 2 to 3 cycles of the vertical S maneuvers followed by a descent to the ILS altitude, 2) precision heading vectors to a 90° ILS intercept, 3) ILS flown to a missed approach point, 4) go-around from landing configuration, 5) precision heading vectors back to the ILS localizer at an altitude 500 ft above the localizer course, 6) modified glideslope intercept flown to missed approach, 7) go-around. (See Figure 3.)

TYPICAL QUALITATIVE EVALUATION PROFILE



NOTE: SEE TABLE 3 FOR DESCRIPTION OF FLIGHT TASK NUMBER.

Figure 3. Typical Flight Profile

Flight Task Number	Flight Time (Min.)	Altitude (Ft.) or As Noted	Airspeed (Kias)	Configuration
1	7	4000→5000	120	Clean
2	10	ILS intercept altitude	120	Clean
3	3	ILS intercept altitude	100	Gear dn, Flaps appr.
4	7	Glideslope altitude	100	Gear dn, Glaps dn.
5	5	ILS decision height.	Best R/C airspeed	Clean, max. cont. pwr.
6	10	4000→5000	120	Clean
7	3	ILS intercept alt. + 500 ft.	120	Clean
8	7	Glideslope altitude	100	Gear dn, Flaps dn.
9	5	ILS decision height	Best R/C airspeed	Clean, max. cont. pwr.

Figure 4. Typical Flight Profile Configurations

This scheme of task would define the overall mission that the pilot rating would define. While each task is being accomplished and after the task the pilot comments would need to be recorded and analyzed. After the whole mission is accomplished then the "Cooper-Harper" scale would be utilized to generate the absolute pilot rating. Each of the designated pilots would perform a similar mission and generate a pilot rating. The quantitative data, airspeed, attitude control forces, etc., would then be correlated with the pilot rating and become an integral part of the evalauation.

After the SSSA system is fully developed, an analogous evaluation will be conducted on that aircraft and compared with the base line data. This data will define the degradations or improvements in the handling qualities.

Flight Time Estimation

The flying time is going to be a function of the number of evaluation pilots. However, assuming that four pilots are used (project pilot, two K.U. pilots and one civilian operator) a reasonable amount of flying would be utilized. A typical profile or mission and time estimate is shown in Fig. 3. This scheme shows a total task time of approximately one hour, however, this does not include the time for take-off, landing and maneuvering into the test area. This will normally require approximately 0.3 hr. which makes a typical mission 1.3 hrs. It is necessary to fly only one evaluation pilot on each profile so that the second pilot doesn't become fatigued and influenced by the first pilot. Therefore, four pilots have a total time of 5.3 hours. If the same time is utilized for the evaluation of the modified aircraft then the time would be 10.6 hours. This estimate is probably accurate within +100%. Such factors as pilot performance, aircraft sequencing, pilot debriefing, etc. can very likely increase the time substantially.

APPENDIX C

ENVIRONMENTAL TEST PLAN

1.0 PURPOSE

To provide an environmental test specification for the electronic components of the SSSA system. The equipment to be tested will include the computer cards, drive cards, card mounting rack and any associated wiring and switches within the rack.

2.0 TEST REQUIREMENTS

2.1 ALTITUDE

Altitude testing will not be required. The aircraft this equipment will be used in is unpressurized and normally will not be flown above 10,000 feet. The cruise altitude for flight testing of the SSSA system is 5,000 feet and is considered by engineering to be low enough not to warrant altitude testing.

2.2 TEMPERATURE

Subject test unit to a cold soak temperature of 0°F and a hot soak of 160°F. The test unit will be functionally checked for operation before beginning temperature test. The temperature will be lowered to the cold soak temperature and held within 10°F for three hours. At the end of the soak period the test unit will be functionally checked and then allowed to return to ambient temperature. When the test unit temperature has returned to ambient an additional functional test will be required. Cycle will be repeated for the hot soak with the same type of checking procedures.

2.3 VIBRATION

The vibration shall be applied in separate tests to each of three mutually perpendicular axes of the test unit.

Vibration applied shall be sinusoidal and the frequency shall be cycled at a logarithmic rate between the frequency limits, and at the acceleration levels prescribed by Figure 1. One complete sweep up and down between the prescribed frequency limits shall be made for each axis and shall span approximately 15 minutes (7 1/2 minutes up and 7 1/2 minutes down). Test interruptions are permitted, but the clock shall be stopped during any such interruptions. During the frequency sweep any resonant frequencies shall be recorded. A resonance dwell test shall then be made at each of the recorded resonance frequencies, the dwell time being a maximum of two minutes at each frequency.

The test unit will be given operational functional checks before and after vibration in any axis.

3.0 GENERAL NOTES

3.1 Adequate records of all tests performed shall be maintained.

3.2 At the completion of any portion of this testing (i.e. at the functional test) a "covers off" inspection shall be performed and noted before the next phase of the test is started. Any discrepancies discovered shall be remedied and the appropriate portion of the environmental test (as determined by the Project Manager) will be repeated.

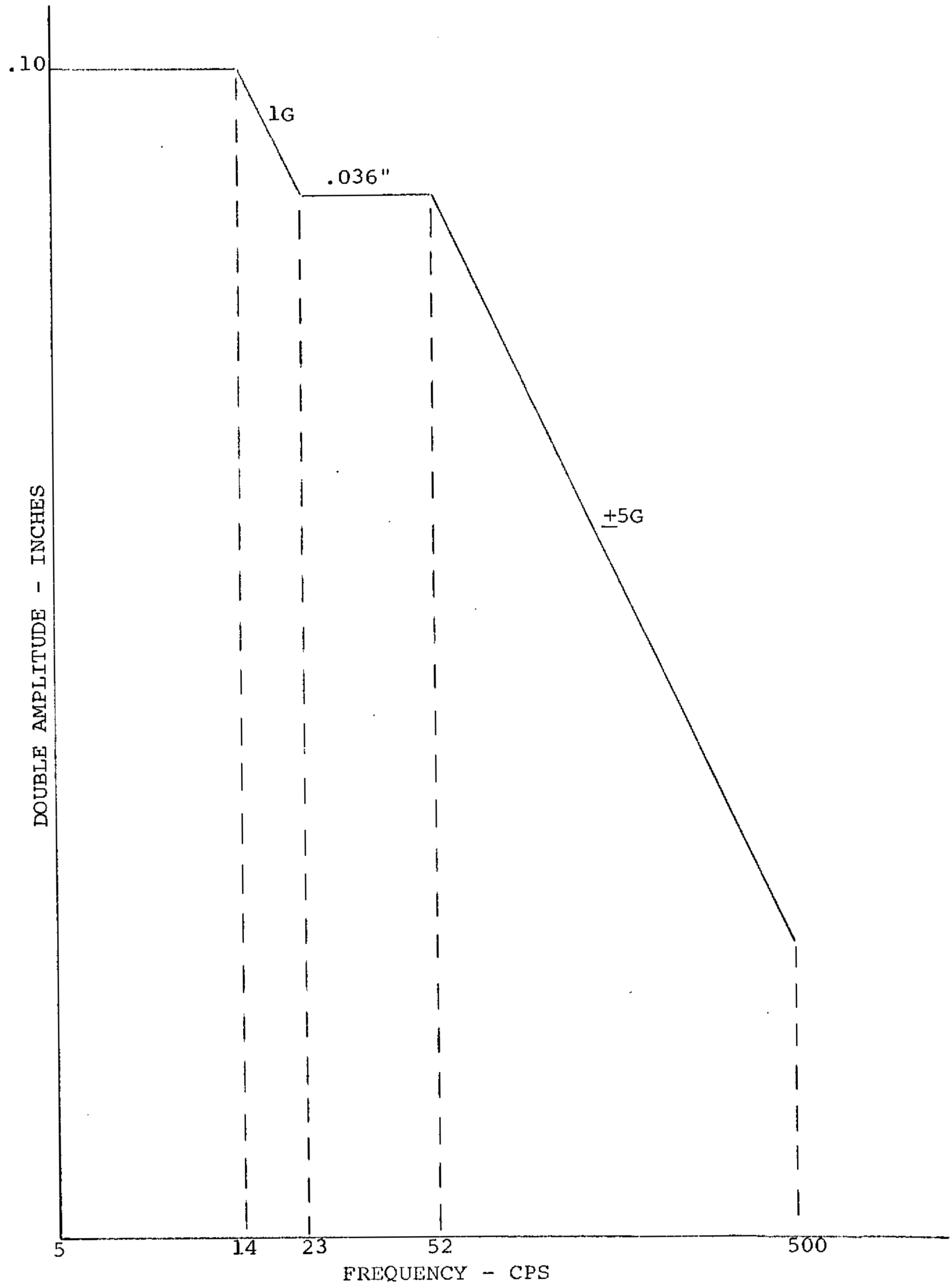


FIGURE I. TEST SCHEDULE

4.0 REFERENCES

1. Anon., "Flight Assurance Testing (Environmental) Electronic and Electromechanical Equipment," Process Specification No. 21-2, NASA Flight Research Center, March 5, 1969.

CRINC LABORATORIES

Chemical Engineering Low Temperature Laboratory

Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

Technology Transfer Laboratory