INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HMIT RPRV

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INVESTIGATION OF THE CROSS-SHIP COMPARISON MONITORING METHOD OF FAILURE DETECTION IN THE HiMAT RPRV

James A. Wolf

INTRODUCTION

The highly maneuverable aircraft technology (HiMAT) program will provide researchers in the military, industry, and the National Aeronautics and Space Administration (NASA) a developmental tool with which to test new concepts for the next generation fighter aircraft. The HiMAT remotely piloted research vehicle (RPRV) is a subscale prototype which will have enhanced maneuverability (sustained 8G turn, 0.9 M, at 7,900 m) using state-of-the-art technology (ref. 1).

The HiMAT RPRV has a basic design requirement that no single failure shall result in the loss of the vehicle (ref. 2). The method by which this requirement is met, with respect to failure detection in the canard, aileron, and elevator servosystems, is of some concern. The on-board primary microcomputer compares the surface position of corresponding right and left surfaces. This cross-ship comparison monitoring (CSCM) should detect a servosystem failure in time for a safe recovery. However, a failure indication for any other reason other than a failed servosystem (nuisance trip) would greatly hamper the research mission. By using a computer model of the HiMAT CSCM technique, the sensitivity to servosystem differences was evaluated. It is important that the
CSCM be evaluated to improve confidence in the performance and to define potential problems. This report gives a brief background of the HiMAT RPRV, describes the modeling of the servosystems and failure detection scheme, and discusses the possible effects of variations between servosystems.

SYMBOLS

ACT  actuator  
A/D  analog-to-digital converter  
AGE  auxiliary ground equipment  
AMP  command amplifier  
C  hydraulic control pressure, psi  
CMDS  commands  
COMP  computer  
CSCM  cross-ship comparison monitoring  
cm  centimeters  
DEMOD  demodulator  
DISCR  discrete  
dB  decibel  
deg  degree  
EHSV  electrohydraulic servovalve  
FB  feedback amplifier  
FDBKS  feedbacks  
F.S.  full stroke  
f  frequency, Hz  
G  acceleration of gravity, m/sec²  
Gₐ  actuator gain, in⁻²  
G₄  command gain, mA/V₇dc
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G\textsubscript{5}</td>
<td>ram LVDT gain Vac/in</td>
</tr>
<tr>
<td>G\textsubscript{6}</td>
<td>ram demodulator gain, Vdc/Vac</td>
</tr>
<tr>
<td>G\textsubscript{7}</td>
<td>feedback gain, mA/Vdc</td>
</tr>
<tr>
<td>G\textsubscript{11}</td>
<td>linkage gain, deg/in</td>
</tr>
<tr>
<td>G\textsubscript{V}</td>
<td>servovalve gain, in\textsuperscript{3}/sec-mA</td>
</tr>
<tr>
<td>HiMAT</td>
<td>highly maneuverable aircraft technology</td>
</tr>
<tr>
<td>Hz</td>
<td>hertz</td>
</tr>
<tr>
<td>I\textsubscript{L}</td>
<td>current limit, mA</td>
</tr>
<tr>
<td>I/O</td>
<td>input-output</td>
</tr>
<tr>
<td>IPCS</td>
<td>integrated propulsion control system</td>
</tr>
<tr>
<td>I\textsubscript{T}</td>
<td>current threshold, mA</td>
</tr>
<tr>
<td>k</td>
<td>kth iteration</td>
</tr>
<tr>
<td>LOOP 1</td>
<td>first servosystem model</td>
</tr>
<tr>
<td>LOOP 2</td>
<td>second servosystem model</td>
</tr>
<tr>
<td>LT</td>
<td>left</td>
</tr>
<tr>
<td>LVDT</td>
<td>linear variable-differential-transformer</td>
</tr>
<tr>
<td>M</td>
<td>Mach number</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>mA</td>
<td>millampere</td>
</tr>
<tr>
<td>ms</td>
<td>millisecond</td>
</tr>
<tr>
<td>N</td>
<td>noise source</td>
</tr>
<tr>
<td>n</td>
<td>number of bits</td>
</tr>
<tr>
<td>P\textsubscript{1}</td>
<td>hydraulic source pressure, psi</td>
</tr>
<tr>
<td>POS</td>
<td>position</td>
</tr>
<tr>
<td>PROP</td>
<td>propulsion</td>
</tr>
<tr>
<td>R\textsubscript{1}</td>
<td>hydraulic return pressure, psi</td>
</tr>
<tr>
<td>R\textsubscript{L}</td>
<td>rate limit, in/sec</td>
</tr>
</tbody>
</table>
RPRV  remotely piloted research vehicle
RPV   remotely piloted vehicle
R_s   sample rate, samples/sec
RT    right
SOL   solenoid
s     Laplace variable
sps   samples/sec
T     iteration period
t     time, sec
t_t   transfer time delay
V_ac  volts, ac
V_c   command voltage
V_dc  volts, dc
V_DL  left demodulator output signal
V_DR  right demodulator output signal
V_m   demodulator monitor signal
V_o   dc component of demodulator output
V_R   amplitude of demodulator ripple signal
X_L   ram stroke limit, in
\delta_s surface deflection, deg
\dot{\delta} error rate, deg/sec
\dot{\delta}_c commanded surface rate, deg/sec
\dot{\theta}_d transfer delay error, deg
\dot{\theta}_f failed surface rate, deg/sec
\theta_{fs} full stroke deflection range, deg
\theta_q quantization error, deg
\theta_{iL} initiation point of lock-up, deg
$\theta_s$ safe limit
$\theta_{sr}$ sample rate error, deg
$\theta_t$ computer threshold limit

Subscripts:
i input
o output
k-1 previous iteration
HiMAT RPRV

A brief description of the HiMAT RPRV is given in the first section. The focus of the following sections is on the method of failure detection for the simplex servosystems which actuate the canard, aileron, and elevator control surfaces. Pertinent background information is given and some of the potential problems discussed.

Description

The HiMAT RPRV is a scaled version (.44) of an advanced technology fighter aircraft. There are numerous state-of-the-art concepts implemented in the design, such as the composite structure, close-coupled canards, and wingtip fins. Figure 1 illustrates the dimensions of the vehicle and the five types of control surfaces. The following subsections give an overview of the HiMAT RPRV and program, and because the subject of this report is the failure detection in the simplex servosystems, these systems are discussed in depth.

Overview. - In the primary flight mode the vehicle is controlled by the ground-based pilot in the cockpit of the Remotely Piloted Vehicle (RPV) facility (see figure 2). This facility provides the pilot with conventional displays using downlinked data from the HiMAT RPRV. Pilot commands are processed in the ground-based computer, then uplinked to the on-board microcomputer which outputs the command signals to the respective control surface actuators.

There are two on-board microcomputers in operation during the primary flight mode. This is the normal mode for maneuver and cruise research. The major functions are distributed be-
Figure 1.- Three-view drawing of HiMAT RPRV. Dimensions are in meters.
Figure 2.- Conceptual layout of RPRV operation with ground facility.
between the two computers. One computer is termed the primary computer and one is termed the back-up computer. Although the back-up computer has a major function in the primary flight mode, the term "back-up" arises because, should a failure occur, there would be a transfer of some functions from the primary computer to the back-up computer. Functions that are not taken over by the back-up computer are halted. Table 1 shows the division of tasks between computers. Figure 3 is a block diagram of the on-board computer system (ref. 1).

If a function or element has an importance to the RPRV such that its failure would result in loss of the vehicle, it is defined to be a flight critical function or element. Flight critical functions or elements are dual redundant (i.e., on-board microcomputers, electrical power system, and rudder and elevon hydraulic systems).

Mission critical functions or elements are not essential to keeping the vehicle in flight (i.e., canards, ailerons, and elevators). However, a failure of one of these functions or elements, would constitute an immediate end to the research mission and a return to base. Effective failure detection of the mission critical functions or elements should prevent loss of the vehicle. As an example, take the case of a failure in a canard servosystem, the failure detection routine would:

1. Detect the failure
2. Begin the actuator locking sequence
3. Transfer control to the back-up computer

The back-up system would provide emergency return home capability using an on-board autopilot. The flight critical
<table>
<thead>
<tr>
<th>MODE</th>
<th>PRIMARY COMPUTER PROCESSING TASKS</th>
<th>BACK-UP COMPUTER PROCESSING TASKS</th>
</tr>
</thead>
</table>
| Primary Flight Mode | - primary flight sensor data  
- control surfaces  
- uplink information  
- downlink information  
- failure detection | - integrated propulsion control system                  |
| Back-up Flight Mode |                                                                                 | - back-up control surfaces  
- back-up autopilot  
- reduced IPCS  
- sensor data |
Figure 3. - Functional block diagram of the on-board computer system.
control surfaces (elevons and rudders) would be used to control the HiMAT RPRV back to a lakebed landing. The pilot can control the altitude variations, directions, and speed using discrete commands. The canards, ailerons, and elevators are hydraulically locked at a predetermined position.

**Simplex servosystems.** - The ten control surfaces of the HiMAT RPRV are positioned using hydraulic servoactuators. The mission critical surfaces (canards, ailerons, and elevators) have a single hydraulic supply and input. This is defined to be a simplex servosystem. Except for the elevator, which has a higher force output requirement (tandem actuator), they have a single actuator. This is shown in figure 4 which is a schematic of the simplex servoactuator. The control surface characteristics are shown in table 2. Notice that the canards can move symmetrically or antisymmetrically, but not combined.

Uplinked pilot commands are converted from a digital signal to an analog signal and fed to the commanded surfaces. The simplex servosystem is illustrated in figure 5 with a block diagram (ref. 3). Table 3 gives the corresponding gain values. The servoamplifier sums the command and feedback inputs and supplies a proportional output current to the electro-hydraulic servovalve (EHSV). The EHSV controls the fluid flow rate to the actuator (ref. 4). The actuator provides the force output to move the control surface to the commanded position. The surface deflection rate is determined by the characteristics of the EHSV and actuator. Position feedback is derived from the output of the linear variable-differential transformer (LVDT) (ref. 5). The iron core of the transformer is attached to the actuator ram (see figure 4). The LVDT pri-
Figure 4.- Schematic of the simplex servoactuator.
<table>
<thead>
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<th>AILERONS</th>
<th>CANARDS</th>
<th>ELEVATORS</th>
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<tr>
<td>Servo-Actuator type</td>
<td>single input single actuator</td>
<td>single input single actuator</td>
<td>single input tandem actuator</td>
</tr>
<tr>
<td>Surface deflection</td>
<td>antisymmetric</td>
<td>antisymmetric or symmetric</td>
<td>symmetric</td>
</tr>
<tr>
<td>Maximum surface rate</td>
<td>90°/sec</td>
<td>90°/sec</td>
<td>90°/sec</td>
</tr>
<tr>
<td>Location on the vehicle</td>
<td>outboard wing surface</td>
<td>forward control surface</td>
<td>inboard wing surface</td>
</tr>
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**TABLE 2**

CONTROL SURFACE CHARACTERISTICS

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Figure 5.- Block diagram of the simplex servosystem and failure detection scheme.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Canard</th>
<th>Aileron</th>
<th>Elevator</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>$G_V$</td>
<td>0.636</td>
<td>0.636</td>
<td>1.503</td>
<td>in³/sec-mA</td>
</tr>
<tr>
<td>$G_A$</td>
<td>0.909</td>
<td>0.909</td>
<td>0.455</td>
<td>in⁻²</td>
</tr>
<tr>
<td>$G_b$</td>
<td>6.969</td>
<td>6.969</td>
<td>8.621</td>
<td>mA/VDC</td>
</tr>
<tr>
<td>$G_5$</td>
<td>2.919</td>
<td>2.919</td>
<td>2.919</td>
<td>V_AC/in</td>
</tr>
<tr>
<td>$G_b$</td>
<td>3.824</td>
<td>3.824</td>
<td>3.824</td>
<td>V_DC/V_AC</td>
</tr>
<tr>
<td>$G_7$</td>
<td>12.346</td>
<td>12.346</td>
<td>10.471</td>
<td>mA/V_DC</td>
</tr>
<tr>
<td>$G_{11}$</td>
<td>39.72</td>
<td>39.72</td>
<td>34.13</td>
<td>Deg/in</td>
</tr>
<tr>
<td>$I_L$</td>
<td>+4.0</td>
<td>+4.0</td>
<td>+4.0</td>
<td>mA</td>
</tr>
<tr>
<td>$X_L$</td>
<td>+0.503</td>
<td>+0.503</td>
<td>+0.870</td>
<td>-0.595</td>
</tr>
<tr>
<td>$R_L$</td>
<td>2.312</td>
<td>2.312</td>
<td>2.733</td>
<td>in/sec</td>
</tr>
<tr>
<td>$V_C$</td>
<td>±10</td>
<td>±10</td>
<td>±10</td>
<td>V_DC</td>
</tr>
<tr>
<td>$\delta_S$</td>
<td>±20</td>
<td>±20</td>
<td>+30</td>
<td>-20</td>
</tr>
<tr>
<td>$V_m$</td>
<td>±5.60</td>
<td>±5.60</td>
<td>±8.176</td>
<td>V_DC</td>
</tr>
</tbody>
</table>

$G_V$ - EHSV Gain  
$G_A$ - Actuator Gain  
$G_b$ - Command Gain  
$G_5$ - Ram LVDT Gain  
$G_7$ - Ram Demond Gain  
$G_{11}$ - Linkage Gain  
$I_L$ - Command Current Limit  
$X_L$ - Ram Stroke Limit  
$R_L$ - Ram Rate Limit  
$V_C$ - Actuator Command  
$\delta_S$ - Surface Position  
$V_m$ - Ram LVDT Monitor

TABLE 3

SIMPLEX SERVOSYSTEM GAINS AND SPECIFICATIONS
mary winding is excited by an oscillator as the actuator ram changes position (causing an accompanying change in the surface deflection). The iron core movement causes a change in the amplitude of the induced voltage in the secondary windings. This signal is demodulated and fed back to the servoamplifier. The demodulated signal is also picked off and converted to a digital signal for use in the CSCM failure detection scheme. Command signals sent from the primary microcomputer and monitoring of the LVDT output occur at a rate of 53.33 hertz (18.75 millisecond cycle time). The command input will be a series of steps. The output of the LVDT demodulator will also appear to the computer as a series of steps, due to the sampling effect.

The simplex servosystem frequency response should be flat out to about 13 hertz under no-load conditions for movements up to thirty percent of full actuator ram stroke. The load frequency response specifications for displacements of up to ten percent full-stroke and thirty percent of maximum rate are listed below (ref. 3)

Attenuation - Less than +2 or -3 dB out to 3 hertz
Phase Shift - Less than 30 degrees out to 3 hertz

The servosystems will be operating under loaded conditions a majority of the time. The potential for a problem in the CSCM exists during flight due to aerodynamic loading of the control surfaces. This is because there are conditions in the flight envelope where the loading on one surface may be different from the loading on the opposite surface. This would mean a difference in response characteristics and thus, a chance for an error between corresponding surface position
indications. The failure detection system design must take this into account.

Failure Detection

The following subsections describe the design approach for the CSCM failure detection scheme. A general description of how it works, design constraints, and possible sources of error are given.

Design approach. - With the requirement that a single failure shall not result in loss of the vehicle, flight critical elements or functions must have a failure detection technique and back-up system. Mission critical elements or functions must have a failure detection technique that not only detects the failure but provides a return to stable flight (ref. 2). This is why the canards, elevators and ailerons are designed to move to a locked position after a first failure.

The failure detection and corrective action must be designed to respond quickly because of the fast response of the actuators and the vehicle. The actuators can move the control surfaces at a maximum rate of 90 degrees per second. Likewise, a failed servosystem could move the control surface at the maximum rate. It is possible, however, that a control surface could fail at the maximum rate while the surfaces are responding to a command signal. The resulting error rate between corresponding surface positions would exceed 90 degrees per second.

Functional description of the cross-ship comparison monitoring. - The failure detection method for the canards, ailerons, and elevators uses the fact that these surfaces move
either symmetrically or antisymmetrically. A comparison is made between respective right and left surface deflections. The on-board microcomputer monitors the comparison to determine the integrity of the aileron, canard, and elevator control surfaces.

The dc voltage output, from the actuator ram LVDT demodulator, proportional to the control surface position, is converted to a digital value (ref. 6). The microcomputer sums the values of each side, as in the case of the ailerons, to determine an error value. Because the canards move either antisymmetrically or symmetrically, depending on which mode they are in, the difference or sum of the surface positions is used. The error value is compared to the predetermined threshold value stored as a constant in the computer. Should the error value exceed the computer limit, a failure would be declared and an immediate switch to the back-up mode initiated.

The on-board microprocessor samples and processes the surface position information of the ailerons, elevators, and canards 53.33 times a second. The LVDT demodulator output voltage is converted to a 12 bit digital word. Since the demodulator voltage range is plus or minus 5.62 volts and the A/D converter is a plus or minus 10 volt type, the full A/D converter is not used (ref. 4).

A digital word representing a control surface position on one side is updated by the computer. Twenty-five microseconds later the opposite side is updated. This is done just prior to the output of a command signal so that any servosystem transients from the previous cycle will have died down. The
two double precision words representing corresponding surfaces are added or subtracted. The resulting quantity represents the error value between surfaces. The most significant eight bits are compared to the threshold constant stored in the computer. If the error value exceeds the threshold value, the resulting switch to back-up is initiated and the control surface lock-up sequence begins. The lock-up sequence and respective time delays are as follows:

1. Switch relay to de-energize solenoid - 15ms
2. De-energize locking solenoid - 20 ms
3. Hydraulic lag before check valves seat and ram begins to move to the lock-up position - 15ms

Thus, the total transfer delay before a failed actuator begins moving to the lock-up position is 50 milliseconds. For the case where one surface is fixed and the other is failing at the maximum rate of 90 degrees per second, the total transfer delay translates into an error between surfaces of 4.5 degrees. Therefore, the threshold value should be selected such that an additional error of 4.5 degrees would not exceed the safe limit.

Design Constraints on the cross-ship comparison monitoring technique. - The error between ailerons, canards, or elevators allowed before an unrecoverable flight condition occurs is seven degrees, ten degrees, and seven degrees, respectively. These values were determined based on simulation studies and on analysis of the effects for the case of one control surface fixed and the other failing hardover (90 degrees per second). However, it is possible for a failure to occur during positioning of the surfaces. This could result in an error rate of greater than 90 degrees per second.
There is a design compromise between the allowance of false failure indications, and the risk of losing the vehicle in the event a failure goes undetected. False failure indications, termed "nuisance trips", are very detrimental to the research mission because of considerable overhead involved in a single mission and the delays involved in troubleshooting the cause of the nuisance trip. Determination of a computer threshold value involves design trade-offs.

Two cases will be considered and the computer threshold values that are appropriate determined. The first case assumes the good control surface is fixed at some position when the opposite surface fails. The maximum error allowed before initiation of the lock-up sequence ($\theta_L$) is the difference between the safe limit allowance ($\theta_s$) and the error accumulated due to the total transfer delay ($\theta_d$).

$$\theta_d = t_t \times \theta$$

$$\theta_L = \theta_s - \theta_d$$

To assure that the lock-up sequence begins some time before the error reaches $\theta_L$, the worst case should be assumed. This means that the quantization error due to the analog-to-digital conversion is at the maximum and the sampling instant is the one least desirable. The quantization error is equal to the amount of control surface deflection represented by the least significant bit. For the CSCM technique, the comparison error value is represented by an eight bit digital word. The quantization error in degrees is therefore,

$$\theta_q = \theta_s / 2^n$$
where, \( \theta_{fs} \) = full surface deflection range

\[ n = \text{number of bits used in the comparison to the threshold value} \]

The least desirable sampling instant is at a point immediately before the error value reaches the computer threshold limit. The computer will not detect a failure until the next sample period. Therefore, the error accumulation in one sample period \((1/R_s)\) where \(R_s\) is the sample rate) at the specified error rate \((\dot{\theta})\) is

\[ \dot{\theta}_{sr} = \dot{\theta}/R_s \]

Thus, the computer threshold limit \((\theta_t)\) together with the quantization \((\theta_q)\) and sample rate error \((\dot{\theta}_{sr})\) should be less than the maximum error allowed before initiation of the lock-up sequence \((\theta_{t\text{max}})\) or:

\[ \theta_t = \theta_{t\text{max}} - \theta_{sr} - \theta_q \]

Figure 6 illustrates the error rate between surfaces, the worst-case quantization and sample rate error, and the required threshold limit.

The second case is that in which the good control surface is not fixed, but moving in such a way so as to produce a greater error rate than 90 degrees per second. The error rate \((\dot{\theta})\) is now equal to the sum of the failed surface rate \((\dot{\theta}_f)\) and the commanded surface rate \((\dot{\theta}_c)\),

\[ \dot{\theta} = \dot{\theta}_f = \dot{\theta}_c \]

The computer threshold limit is calculated as described in the first case. Table 4 gives the computer threshold limit values for the canards, ailerons, and elevators for the 90 degrees
Figure 6.- Determination of the computer threshold limit.
<table>
<thead>
<tr>
<th></th>
<th>CANARDS</th>
<th>ELEVATORS</th>
<th>AILERONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ERROR RATE (DEGREES/SEC)</strong></td>
<td>90</td>
<td>95</td>
<td>90</td>
</tr>
<tr>
<td>$\theta$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>INITIATION POINT OF LOCK-UP</strong></td>
<td>5.5</td>
<td>5.25</td>
<td>2.5</td>
</tr>
<tr>
<td>$\theta_I$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRANSFER DELAY ERROR (DEGREES)</strong></td>
<td>4.50</td>
<td>4.75</td>
<td>4.50</td>
</tr>
<tr>
<td>$\theta_d$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SAMPLE RATE ERROR (DEGREES)</strong></td>
<td>1.69</td>
<td>1.78</td>
<td>1.69</td>
</tr>
<tr>
<td>$\theta_{sr}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QUANTIZATION ERROR (DEGREES)</strong></td>
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<td>.16</td>
<td>.20</td>
</tr>
<tr>
<td>$\theta_q$</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>SAFE LIMIT (DEGREES)</strong></td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>$\theta_s$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COMPUTER THRESHOLD LIMIT (DEGREES)</strong></td>
<td>3.65</td>
<td>3.31</td>
<td>0.69</td>
</tr>
<tr>
<td>$\theta_t$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4**  
SUMMARY OF PARAMETERS USED IN DETERMINING COMPUTER THRESHOLD LIMITS
per second error rate case and for a 95 degrees per second error rate, illustrating the second case. It is evident that the calculated computer threshold limit for the elevators and ailerons is cause for concern. The total transfer delay accounts for a considerable amount of error. A reduction in this delay would allow the computer threshold limit to be increased. This might be accomplished by using a different switching relay to de-energize the locking solenoid. A reduction in the 20 millisecond de-energizing time to 4 milliseconds may be possible with a resulting increase in the necessary computer threshold limit ($\theta_T$) of 1.44 degrees. The availability of the faster switching relay is not likely to be a problem.

The sample rate error ($\theta_{sr}$) is fixed because of constraints on the on-board computer loading. Since the computational load is near the maximum, any additional increase in sampling is not feasible. The quantization error ($\theta_Q$) could be reduced if the full range of the analog-to-digital converter were used and the full 12 bits instead of the most significant 8 bits were used. This would increase the computational loading to some degree, however, and the elimination of this error may not justify the additional loading. The advantage of increasing the threshold limit is the buffering effect created. Errors due to nonidentical unfailed servosystems are less likely to be a source of nuisance trips if there is a sufficient buffer band.

Possible sources of comparison errors in unfailed servosystems. – Any characteristic which is not identical between
corresponding servosystems is a source of comparison error. For example, the gains of each component in one servosystem may differ from those of the other servosystem due to manufacturing tolerances. In flight, the servosystem differences might be caused by aerodynamic loading. Electrical properties in corresponding components will be different. These types of differences give rise to error sources such as ENVS threshold error, servosystem hysteresis error and rate limit error.

**LVDT demodulator ripple error.** - Each servosystem LVDT demodulator has a ripple signal superimposed on it. These signals are from a single 1800 hertz oscillator and therefore, they will be in phase. As described earlier, the demodulator output sampling for corresponding surfaces occurs twenty-five microseconds apart.

Each right and left demodulator output is equal to the sum of the dc voltage, $V_o$, and the approximately sinusoidal ripple voltage, $V_R \sin(360ft)$. The frequency, $f$, is the oscillator frequency and the ripple amplitude, $V_R$, is equal to $0.071|V_o|$ (ref. 3). The sampling time difference, with respect to the error between demodulator outputs, can be thought of as a phase difference between corresponding right and left demodulator output signals, $V_{DR}$ and $V_{DL}$. Therefore, the right and left demodulator outputs are,

\[ V_{DL} = V_o + V_R \sin(360ft) \]  \hspace{1cm} (1)
\[ V_{DR} = V_o + V_R \sin(360f(t + 2.5 \times 10^{-5})) \]  \hspace{1cm} (2a)

or,

\[ V_{DR} = V_o + V_R \sin(360ft + 16.2) \]  \hspace{1cm} (2b)

Two types of errors due to the ripple signal could occur.
One type would be characteristic of the symmetrically moving surfaces and the other would be characteristic of the antisymmetrically moving surfaces.

Taking the case of the symmetrically moving surfaces, the difference of the right and left demodulator outputs would be determined in the on-board microcomputer. All other things being equal (neglecting the analog-to-digital conversion effects), the error value determined would be the difference in the two ripple signal equations, 1 and 2b.

\[
\text{ripple error} = V_R \left[ \sin(360ft) - \sin(360ft + 16.2) \right]
\]

(3)

Figure 7a illustrates the error value for a plus 10 degree surface deflection.

For the case of the antisymmetrically moving surfaces, the right and left outputs have opposite polarity and so they would be added to produce an error signal. The error value would be the sum of equations 1 and 2b.

\[
\text{ripple error} = V_R \left[ \sin(360ft) + \sin(360ft + 16.2) \right]
\]

(4)

Figure 7b illustrates the error value for a plus and minus 10 degree surface deflection.

The worst-case ripple error for symmetrically deflected surfaces, deflected 20 degrees, would be significant. The worst-case sampling instant would occur at a point in time when the argument of the sine wave is at minus 8.1 degrees. After a 25 microsecond delay, when the argument of the sine wave is plus 8.1 degrees, the opposite position output would be sampled. According to equation 3, the ripple error magnitude
(a) Symmetric 10 degrees deflection.

Figure 7.- Left and right ripple signals shifted 25 microseconds
(b) Antisymmetric 10 degrees deflection.

Figure 7.-Concluded.
would be approximately 0.11 volts which corresponds to a false error between surface positions of approximately 0.4 degrees. This would be a potential source of nuisance trips because of the comparable value to the computer threshold limit for symmetrically moving surfaces. A possible solution to this condition would be to filter the LVDT demodulator output with a low-pass filter to attenuate the ripple signal.

The worst-case ripple error for antisymmetrically moving surfaces, deflected 20 degrees, would be more severe. The worst-case sampling is at a point in time when the first sample is taken just before the ripple signal reaches a peak value. The first position output would be sampled when the sine wave argument is 81.8 degrees. After the cycle delay, the opposite position output would be sampled, and again the argument would be 81.8 degrees. Using equation 4 the ripple error magnitude would be approximately 0.78 volts. This corresponds to a false indication of approximately 2.8 degrees, an excessive error. Again, a possible solution might be to filter the LVDT demodulator with a low-pass filter to attenuate the ripple signal, and thus, the error. Filtering, however, would involve additional hardware and analysis. This presents a problem because of an already compacted hardware arrangement.

For small surface deflections (less than one degree) the quantization error masks the ripple error for both symmetric and antisymmetric surfaces. Increasing deflections cause the ripple error for antisymmetric surfaces to dominate. The ripple error for symmetric surfaces is not a factor for a deflec-
tion under 8.0 degrees, due to the quantization error.

The effect of the ripple error in both cases would be to increase the probability of nuisance trips. For large surface deflections and computer threshold values as calculated, it is almost certain that a nuisance trip would occur. Filtering the demodulator output appears to be the most effective solution to this problem.

COMPUTER MODEL

The advantages of using a computer program to model the CSCM technique are listed below:

- Straightforward implementation of nonlinear as well as linear characteristics
- Amount of error that each component variation contributes is readily identified
- Servosystem changes can be made quickly and easily
- Data can be easily formatted for automatic plotting

The formulation of the FORTRAN program used for evaluating the CSCM technique is discussed. The initial linear model is described after which the non-linear affects are added and the resulting model described.

Linear Model

A linear model was formulated to which other elements were included to more closely represent the actual servosystem. Once the servosystem was modeled the CSCM technique was represented using two servosystem models. Ease of including non-linear blocks was a design goal for the linear model. A brief description of the servosystem and the characteristics of the components are given. Simplifying assumptions and
verification of the model performance is described.

**Description.** - The objective, when modeling the servosystem and subsequently the CSCM technique for failure detection, was to match the model behavior as closely as possible to the physical system behavior, within the anticipated operating range. For the physical system with command signal frequencies of up to 13 hertz, the unloaded servosystem response was very near that of an ideal low-pass filter (ref. 3). The servosystem actuator dynamics contribute a closed-loop pole at 13 hertz. The other servosystem elements have dynamic response characteristics as follows (ref. 3):

\[
\text{Servoamplifier} \quad G \left( \frac{628}{s + 628} \right)
\]
(for signals up to 20% of rated output current)

\[
\text{EHHSV} \quad G \left( \frac{580}{s + 580} \right) \left( \frac{5406}{s + 5406} \right)
\]

\[
\text{LVDT Demodulator} \quad G \left( \frac{628}{s + 628} \right)
\]

The model of the servosystem was structured such that each mathematical expression in the code corresponded to a component of the actual servosystem. Initially the inputs and outputs were zero. One iteration of the code corresponded to one time increment and generated one set of output values. A flowchart of the model is shown in figure 8. For the first iteration the feedback value was assumed to be zero. The input to the EHHSV block was then equal to just the command amplifier output. As outputs were calculated, the input to the next block was set equal to the output of the preceding block. The loop was closed after the first iteration because the
Figure 8.- Flowchart of the servosystem computer model and CSCM scheme.
error signal value (the input to the EHSV for the next iteration) was the difference between the command amplifier output and the feedback amplifier output (see figure 5). In the physical system the LVDT demodulator is reverse polarity with respect to the command signal. The FORTRAN model of the LVDT demodulator output had the same polarity as the command signal for convenient analysis.

The modeling of the CSCM technique was made up of two servosystem models to represent the canard control surfaces. This was designed to allow one servosystem model to have nominal gains according to table 3 and the other to be varied, for sensitivity test purposes. The resulting error between the two models was of interest in determining the effects of disproportionate servosystems. The same command value was applied to each servosystem. The output values of each LVDT demodulator block were converted to the equivalent control surface deflection. The first servosystem model corresponded to the right control surface. The error value between surfaces was the difference of the left surface from the right surface, where the left surface corresponded to the second model. The appendix contains a computer listing of the FORTRAN program. Figure 5 shows a block diagram of the servosystem and CSCM method.

Simplifying assumptions. - A reasonable assumption concerning the frequency of the command input signal was that it would not be higher than 15 hertz. It follows that the EHSV, the LVDT and LVDT demodulator, and servoamplifier dynamics would cause negligible attenuation and phase shift. These
elements were modeled as pure gain elements. The actuator was conveniently modeled as an integrator and implemented in the digital program using the bilinear transformation expression (ref. 7,8). For the Kth iteration,

\[ \text{output}_K = \text{output}_{K-1} + \frac{T}{2} (\text{input}_K + \text{input}_{K-1}) \]

where \( T \) is the sample period, that is, the time between iterations and was nominally 0.2 milliseconds, 5000 hertz iteration rate. To obtain sufficient accuracy using the bilinear transformation expression for the integrator, the sample frequency was set much higher than the first-order pole of the model (greater by a factor of ten or more). The past input and output values were updated with each iteration.

**Verification.** — The CONTROL digital computer program (ref. 9), a program for analyzing linear continuous systems, was used to verify that the discrete model was an accurate representation of the linear first-order model of the simplex servosystem. Time history responses, of the control model and the discrete model, were compared. There was no detectable difference. The CSCM model was also verified by using two servosystem models in each program to simulate the CSCM. In both programs the difference of one servosystem monitor output from the other was computed to give an error value. The models corresponding to the right servosystem in each program had equal gains and the models corresponding to the left servosystems had equal gains but the right and left sides were unequal. As can be seen in figures 9a and 9b, for a step input and a sine wave input, the discrete model compares very close-
Figure 9. - Response of linear continuous models 1 and 2 and discrete models 1 and 2.
LINEAR CONTINUOUS MODEL

DISCRETE MODEL

(b) Sine wave input.

Figure 9. Concluded.
ly to the linear continuous model.

Non-linear Model

The following subsection describes the non-linearities that were added to the linear model. The origin of these non-linearities and the likelihood of any contribution to the error between unfailed actuators is discussed. The assumptions that were made in implementing these characteristics and the verification procedures are given.

Description. - The non-linearities that were added to the model are among the more common ones associated with servo-systems. The non-linear characteristics added were:

- EHSV current limiting
- EHSV threshold current
- Actuator ram position limit
- Total servosystem hysteresis

The EHSV provides the electrical-to-hydraulic interface which controls the source of fluid power to the hydraulic actuator. The EHSV rated current range changes the fluid flow, to the actuator, from maximum extension control flow to maximum retraction control flow. The servoamplifier supplies current to the EHSV within the specified range, plus or minus 4 milliamperes (ref. 3)

The EHSV threshold current non-linearity is essentially a characteristic produced by the static friction of the sliding valve. The specified threshold value was determined by the manufacturer during quality assurance tests. The current increment required to reverse the EHSV from a condition of increasing output was measured. The current was changed at a
a rate below that at which dynamic effects were important.

The actuator ram position limit is the maximum extension or retraction distance from the null position. For the CSCM model the full stroke (F.S.) of the actuator ram was approximately 2.56 cm (ref. 3). The position limits were plus and minus one half of this amount.

The actuator ram rate limit is the rate at which the ram can extend or retract under no-load conditions with maximum control flow from the EHSV. The rate limit is dependent on the properties of the other components in the loop. A change in loop gain may affect the rate limit as will a change in the maximum control flow from the EHSV. The current limit implementation was in effect a rate limit since a decrease in the current maximum output would decrease the control flow maximum output. The actuator ram rate limit used was 5.87 cm per second (ref. 3).

The total servosystem hysteresis is defined as the maximum difference in command voltages required to produce the same actuator ram position during a single cycling of the command voltage. This cycling is done below the rate at which dynamic effects are important. The hysteresis non-linear characteristic is produced by the combined effects of the EHSV threshold and electromagnetic characteristics, and the static friction of the actuator ram.

Simplifying assumptions. - There were some general assumptions made to simplify the implementation of the non-linear discrete model. Although a non-linearity in the physical system may be a function of several variables, in the
discrete model each non-linearity was assumed to be only a function of the input to that non-linear block. The linear representation of each servosystem element was retained. For example, in implementing the EHSV current limit characteristic, the EHSV input value was tested to determine if it was greater than or less than the limit values. If so, it was set equal to the appropriate limit value. The expression for EHSV behavior was not affected, it remained a pure gain element.

It was assumed that the non-linearities would be closely approximated as ideal non-linearities. For example, the total hysteresis value, as measured, might not be uniform for the full stroke of the actuator ram in the physical system. It was assumed to be uniform for the non-linear implementation in the discrete model.

It was also assumed, for the discrete model, that because the EHSV threshold produces a hysteresis non-linearity in the closed-loop response, the total hysteresis could be modeled by adjusting the threshold value. The position limits were included in the model. A difference in the position limits would produce an error between surfaces only at the maximum deflections. This effect was not investigated. A difference in the current limits of the EHSV would amount to a difference in the rate limit, which was investigated.

Verification. - The current limiter, and position and rate limiters are shown in figures 10a and 10b, respectively. The 10 degree command sine wave is shown in figure 10a along with the resulting input current waveform of the EHSV which
Figure 10a. Output of the current limiter block for a 10-degree sine wave command.

Figure 10b. Actuator response to a 25 degree step command illustrating rate and position limits.
was limited to plus or minus 4 milliamperes. Figure 10b shows the ram position and the maximum positive ram extension of 1.28 centimeters and also the maximum extension rate of 5.87 centimeters per second for a 25 degree step command. The threshold non-linearity is shown in figure 11 and hysteresis non-linearity, resulting from the closed loop response, is shown in figure 12. The horizontal axis is the input and the vertical axis is the output of the non-linear block. The non-linear block diagram is shown in figure 13. The inputs labeled N1 and N2 are points where noise was introduced into the model.

COMPUTER ANALYSIS

The objectives and procedures for the parameter sensitivity test of the CSCM technique are given. This test uses the non-linear digital model described in the preceding section.

Objectives

There were five main objectives in testing the sensitivity of various parameters in the CSCM technique

1. Determine the sensitivity of the error between servosystem LVDT demodulator outputs to variations in the values of the threshold and rate limit non-linearities.

2. Determine the effect of loop gain differences on the error between servosystems.

3. Investigate the effect typical system noise may have on the error between servosystems.

4. Investigate the demodulator ripple, sampling time difference, and digital-to-analog and analog-to-digital conversion errors.
Figure 11.- Threshold nonlinear block characteristics.
Figure 12.- Hysteresis nonlinear block characteristics.
Figure 13.- Block diagram of the servosystem model and CSCM scheme including nonlinear blocks.
5. Determine the total effect on the error value for two servosystems with reasonable differences in characteristics.

Using the data from the tests a judgement was made as to the impact of nonidentical servosystems on the performance of the CSCM failure detection technique. Potential solutions to problems that were evident were then formulated.

Test Procedure

The test objectives were met by varying the parameters of interest and collecting data on the response of the CSCM error value. The input command for each case was a six degree step command, a somewhat severe command but appropriate for the test.

**Loop gain variations.** - In order to study the effect of loop gain differences the gains of the left servosystem elements were set to the nominal values (see table 3). The right servosystem loop gain was then changed for each case by changing the dc gain of the actuator. The difference between the two servosystem gains would most likely be less than six percent. This is because the design specifications cite an overall system gain accuracy of plus or minus three percent for the test. The right servosystem loop gain was varied from 80 percent to 120 percent of the nominal value in five percent increments. The error magnitude, in degrees, for a step input is shown in figure 14. Notice that for the higher than nominal loop gains the error was zero for a time. This is due to the fact that the rate limiter was holding both actuator rates equal. Only when the actuators came off the rate limit was
Figure 14.- Error curves resulting from loop gain differences.
an error seen. For cases where the loop gain of the right
servo system is less than the nominal value, the rate limit is
less than nominal. Therefore, the error varies according to
the difference between rate limits.

Rate limit variations. - The rate limit of the left
servo system model was held at the nominal specification while
the right servo system model had a rate limit variation from
90 percent to 110 percent in two percent increments. For one
case, the left servo system was set at 110 percent while the
right servo system was set at 90 percent of the nominal spec-
ifications. The eleven cases are shown in figure 15a. The
current limiter was excluded to allow excursions of the rate
limit beyond that fixed by the current limiter. When the cur-
rent limiter was included there was no error. The right
servo system rate limit was set higher because the EHSV cur-
rent limit was already limiting the rate to the nominal value
in both servo systems. Figure 15b illustrates the result of
the same test cases with the current limits included.

EHSV threshold and total hysteresis. - The design spec-
ications for the simplex servo systems give an EHSV thres-
hold value and a total servo system hysteresis value, 0.7 per-
cent and 0.15 percent of full stroke (F.S.), respectively. In
the servo system model, the EHSV threshold non-linearity im-
plementation gives the hysteresis characteristic in the
closed-loop response. One set of cases was run using the
EHSV threshold specification for the left servo system and vary-
ing the threshold value of the right servo system in integral
amounts up to ten times the nominal value. This set of cases
Figure 15.— Error curves resulting from rate limit differences.

(a) Current limit block excluded.
Figure 15.- Concluded.

(b) Current limit block included.

Figure 15.- Concluded.
is shown in figure 16a. Again, there was no error until both servosystem models came off the rate limiters.

In order to model the total hysteresis, the threshold value of the EHSV was set to give the nominal hysteresis value for the left servosystem while the right servosystem was varied in integral amounts up to ten times the nominal value. Figure 16b shows the test results for a six degree step input.

Servosystem noise. - The effect of various types of noise on the error between servosystem models was investigated using a software pseudo-random noise generator. The noise signal was introduced at the EHSV input and at the demodulator output. Two cases using a different level of noise in each case were run for both noise input points. For the EHSV input, the noise level in each case was 0.1 percent of the maximum signal input (4.0 mA) and 3.0 percent of the maximum signal input. This is shown in figure 17a and 17b, respectively. For the demodulator output, the noise level in each case was 0.1 percent and 3.0 percent of the maximum demodulator output (5.61 Vdc) as shown in figure 17c, and 17d, respectively. The sampled values of the output were shown in these cases illustrating the values the on-board computer would be operating on.

Combined effects. - The combined effects of the previous sources of differences between servosystems were investigated. The left servosystem was set to the nominal specifications and the right servosystem characteristics were as shown in table 5. The resulting test plots are shown in Figure 18a-d.

Ripple error and sampling time differences. - For these test cases the demodulator ripple is added to the dc voltage
Figure 16a. Error curves resulting from EHSV threshold differences.
Figure 16b. Error curve resulting from total servosystem hysteresis difference.
(a) Noise signal of 0.1% introduced at the EHSV input.

Figure 17. - Surface responses and monitor error for a step command.

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(b) Noise signals of 3.0% introduced at the EHSV input.

Figure 17.- Continued.
(c) Noise signal of 0.1% introduced at the demodulator input.

Figure 17.—Continued.
(d) Noise signal of 3.0% introduced at the demodulator output.

Figure 17.- Concluded.
### Table 5

**Summary of Servosystem Conditions for Investigation of Combined Servosystem Differences**

<table>
<thead>
<tr>
<th>Right Servosystem</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
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</thead>
<tbody>
<tr>
<td>Loop gain</td>
<td>97%</td>
<td>99%</td>
<td>97%</td>
<td>99%</td>
</tr>
<tr>
<td>Rate limit</td>
<td>95%</td>
<td>99%</td>
<td>95%</td>
<td>99%</td>
</tr>
<tr>
<td>Threshold</td>
<td>95%</td>
<td>99%</td>
<td>95%</td>
<td>99%</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>95%</td>
<td>99%</td>
<td>95%</td>
<td>99%</td>
</tr>
<tr>
<td>EHSV Input Noise</td>
<td>2%</td>
<td>1%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Demodulator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Noise</td>
<td>2%</td>
<td>1%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### Left Servosystem

<table>
<thead>
<tr>
<th>Case 1-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop gain</td>
</tr>
<tr>
<td>Rate limit</td>
</tr>
<tr>
<td>Threshold</td>
</tr>
<tr>
<td>Hysteresis</td>
</tr>
<tr>
<td>EHSV Input Noise</td>
</tr>
<tr>
<td>Demodulator Output Noise</td>
</tr>
</tbody>
</table>

---

58
(a) Servosystem conditions as specified in case 1 of table 5.

Figure 18.- Surface responses and monitor error for a step command.
(b) Servosystem conditions as specified in case 2 of table 5.

Figure 18.—Continued.
(c) Servosystem conditions as specified in case 3 of table 5.

Figure 18. - Continued.
(d) Servosystem conditions as specified in case 4 of table 5.

Figure 18.- Concluded.
output according to equations 1. To simulate this sampling
time difference in the CSCM model, the ripple signals for each
side are set out of phase by 16.2 degrees. The input command
signal is a series of step inputs held to the command input
rate limit of 100 degrees per second and with a final value of
six degrees. The demodulator output samples are shown along
with the actual waveform. The symmetric case is shown in fig­
ure 19a and the antisymmetric case is shown in figure 19b.
The ripple waveform shown has a much lower frequency (ninth
harmonic) because of the iteration rate (1000 sps). It serves
to illustrate the amplitude, however.

COMPUTER ANALYSIS RESULTS AND DISCUSSION

The computer analysis provided information as to the rela­
tive contribution of the possible error sources (loop gain,
rate limit, threshold and hysteresis, system noise, and demod­
ulator ripple) to the amount of detected error between servosystem position monitors. The error magnitudes, for test cases
with varying differences between right and left servosystems
(as shown in table 5), provides an estimate of the integrity of
the CSCM failure detection method. That is, the likelihood of
nuisance trips, for the computer threshold limits of table 4,
may be hypothesized.

The loop gain variations shown in figure 14 indicate that
the worst-case difference of six percent would contribute a
peak value of approximately 0.3 degrees to the error. For the
canard threshold limit of 3.65 degrees (assuming a maximum of
90 degrees per second error rate), this error would not contri­
bute significantly to the likelihood of a nuisance trip. For
(a) Ripple signal added to the demodulator output of symmetrically moving surfaces.

Figure 19.- Surface responses and monitor error for a step command.
(b) Ripple signal added to the demodulator output of antisymmetrically moving surfaces.

Figure 19.- Concluded.
the aileron and elevator threshold limits of 0.65 and 0.69 degrees, respectively, a 0.3 degree contribution to the error value would increase the likelihood of a nuisance trip considerably. The loop gains should be matched as closely as possible to minimize this error contribution.

A difference between servosystem rate limits has the same effect, on the error value, as does differences in loop gains. Figure 15a and 15b illustrate the type of error response for a six degree step command. The maximum rate is dependent on the loading of the hydraulic actuator, in the physical system. For asymmetric aerodynamic loading on the control surfaces, the computer analysis indicates that the error rate varies according to the difference between right and left surface deflection rates. Thus, for a difference in surface rates of twenty-five percent and a six degree step command, the maximum error would be approximately 1.25 degrees. This would cause a nuisance trip in the aileron or elevator servosystems. Such an asymmetric load would be likely only for antisymmetrically moving surfaces.

The loop gain and rate limit analysis results may be summarized as follows. For each percent difference in loop gain (representing a static error) or rate limit (representing an error due to asymmetric loading), an error of approximately 0.9 degrees will be contributed with each second the surfaces are commanded at the maximum rate. Whichever factor is larger should determine the error contribution.

The error contribution due to differences in the threshold non-linearity (shown in figure 16a) is insignificant for dif-
ferences of as much as 500 percent. Hysteresis differences of as much as 300 percent were also shown to have a negligible contribution to the error (shown in figure 16b).

The effect of noise in the system due to the EHSV is shown in figures 17a and 17b. This noise could be from the environment or it could be thought of as state noise resulting from the unmodeled characteristics of the servovalve. The effects were attenuated by the actuator. The curve resembles the curves for differences in rate limit because in the model the noise was added to the EHSV input. This resulted in a larger than 4 milliampere input current and thus, a larger control flow. Looking at just the amplitude of the error curve gives a more realistic view of the effect of noise sources in the EHSV. The effect on the error for a three percent addition of random white noise appears to be negligible.

The error contribution from noise introduced at the demodulator output is shown in figures 18a and 18b. This is a significant problem for the CSCM method because any nonidentical signals introduced at this point directly affects the error magnitude. This has already been illustrated by the problem associated with the demodulator ripple. An average difference in the demodulator outputs of 3.0 percent due to system noise results in an error that approaches 2.0 degrees. Filtering of the demodulator output will attenuate the high frequency noise but a compromise would have to be made in choosing the cut-off frequency. The actual position information could not be attenuated which would result in selection of a filter cut-off frequency that would not attenuate low frequencies. The extent of the noise problem would most effectively be determined by
actual measurements on the vehicle servosystems.

The combined effects are shown in figures 18a-18d. The demodulator noise overshadowed the error contributions from other sources. The error contributions in the physical system will not always be additive as was the case in these tests. This set of tests was a worst-case situation which used a range of differences that could be expected in the servosystems. The elevator and aileron servosystems with nominal computer threshold limits of 0.69 and 0.65 degrees, respectively, would be likely to cause a nuisance trip under the conditions of test case 1 or 2. The two canard servosystems could be very unlikely to cause a nuisance trip in any of the cases because of the wide buffer band created by a computer threshold limit of approximately 3.65 degrees.

The effect of the demodulator ripple voltage was analyzed previously for the symmetrically and antisymmetrically deflected surfaces. The two test cases are shown in figures 19a and 19b, respectively, for a sampled, rate-limited command of six degrees. The sampled command input does not appear to have a significant effect on the servosystem or the error value. The error magnitude for symmetrically moving surfaces, approximately 0.1 degrees, would be of some concern in the case of the elevators because of the small threshold limit and the resulting small buffer band. In the case of the antisymmetrically moving surfaces, the error magnitude of approximately 1.0 degrees would be critical for the ailerons since it exceeds the computer threshold limit. The nearly 25 percent decrease in the width of the canard buffer band would be undesirable
although it would be unlikely to cause a nuisance trip in itself. As mentioned earlier, filtering the demodulator output will reduce the ripple voltage error.

The modeling of the CSCM method might have been more precise had the higher-order dynamics and other possible non-linearities been included. The most probable servosystem variations in characteristics were not known which resulted in somewhat arbitrary choices for the ranges used in the computer analysis. The trends of the sensitivities to various differences, however, were clear. The probable effect of system noise was demonstrated but the choice of the magnitude was arbitrary. The amount of noise in the servosystems would best be determined by measurement of the physical system. The computer analysis results could then be used to approximate the error magnitude. The expected error contribution from each error source is summarized in table 6.

CONCLUDING REMARKS

The investigation of the cross-ship comparison monitoring (CSCM) method of failure detection revealed several problems associated with the technique. The selection of the appropriate computer threshold limit involves a trade-off between the possibility of a nuisance trip and the assurance that an actual failure will be detected in time.

There are several error sources which, if decreased or eliminated, would lessen the likelihood of a nuisance trip. These possible errors, due to differences between corresponding right and left servosystems for the canard, aileron, and elevator control surfaces, are as listed:
### ERROR SOURCES

<table>
<thead>
<tr>
<th>ERROR SOURCES</th>
<th>APPROXIMATE ERROR CONTRIBUTION</th>
<th>AMOUNTS OF DIFFERENCE BETWEEN SERVOSYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop gain or rate limit</td>
<td>0.9 deg/second at maximum surface rate</td>
<td>1%</td>
</tr>
<tr>
<td>Threshold</td>
<td>7 x 10^{-5} deg</td>
<td>1%</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>2.6 x 10^{-4} deg</td>
<td>1%</td>
</tr>
<tr>
<td>EHSV input noise</td>
<td>2 x 10^{-3} deg</td>
<td>1%</td>
</tr>
<tr>
<td>Ripple voltage for symmetrically deflected surfaces</td>
<td>0.02 deg/deg of deflection</td>
<td>0%</td>
</tr>
<tr>
<td>Ripple voltage for anti-symmetrically deflected surfaces</td>
<td>0.14 deg/deg of deflection</td>
<td>0%</td>
</tr>
</tbody>
</table>

**TABLE 6**

SUMMARY OF ERROR SOURCES AND THE RELATIVE CONTRIBUTIONS FOR A 1% DIFFERENCE BETWEEN SERVOSYSTEMS
Ripple voltage on the demodulator output.

Electrical noise on the demodulator output.

Asymmetric loading of the antisymmetrically moving control surfaces.

Nonidentical loop gains.

The ripple voltage and electrical noise on the demodulator output signal could be attenuated by filtering the demodulator output. The low-frequency noise would still be present, however.

The problem due to asymmetric loading of the antisymmetrically moving surfaces could be a severe problem and should be analyzed further.

Nonidentical loop gains may be adjusted by changing the gain of the feedback amplifiers. Sufficient differences in the hydraulic components may require replacing the EHSV and servoactuator in one servosystem.

The likelihood of a nuisance trip may also be decreased by increasing the computer threshold limit. Decreasing the transfer delay time by using a faster switching relay for the lock up solenoid would allow a larger computer threshold limit to be selected. The selection of the computer threshold limit depends on the anticipated error rate. The error rate could be greater than or less than the maximum surface rate. The error rate, to some extent, depends on the commanded surface rate at the time of the failure. Therefore, the threshold limit should be chosen with the recognition that the error rate is dependent on the flight condition at the time of failure.
References


APPENDIX

CSCM COMPUTER MODEL

PROGRAM LISTING
CROSSHIP COMPARE REDUNDANCY MANAGEMENT MODEL OF A TYPE "B" SERVO-
SYSTEM LOOP: GAINS ARE TAKEN FROM UPDATED OR INFORMATION.
A BILINEAR TRANSFORM IS USED FOR THE IMPLEMENTATION OF THE INTE-
GRATOR WITH ADDITIONAL NONLINEARITIES CALLED AS SUPPORTS. THE
OUTPUTS TAKEN FROM THE DEMONSTRATIONS ARE DIFFERENTED AND THE ERROR
IS GIVEN IN TERMS OF THE DIFFERENCE IN SURFACE POSITION (DEGREES).
J. WOLF 10/77

THIS IS THE INITIALIZATION PORTION. THE GAIN
VALUES WILL BE READ, INITIAL CONDITIONS SET
AND MESSAGES PRINTED.

PROGRAM JKCC(input, output, tape1=input, tape3=output, tape4, tape6)
REAL LVOT
REAL LVOUT2, LVOUT(2), AGT(2)
DIMENSION AMP(2), ESV(2), AGT(2), LVOUT2, DEMOD(2), FEED(2)
DIMENSION AMP(2), ESV(2), LVOUT2, ACT(2), AGOUT2
*1, ACTIN(2), FEEDIN(2), FOOUT(2), DEMOD(2), DEMOD(2), YVOUT(2)
COMMON TIME, NFTS, THSPEC(2), TLSPEC(2), NYSPEC(2), NCASES
WRITE(3, 20)
20 FORMAT(1X, *CROSSHIP COMPARE REDUNDANCY MANAGEMENT OF THE
"TYPE "B" SERVO SYSTEM", /4X, "J. WOLF 10/77")

IF THE NO. OF POINTS IS GREATER THAN 400
THE COMMAND IS A 6.0 DEGREE STEP INPUT. IF
THE NO. OF POINTS IS EQUAL TO 400 THE INPUT
IS A SINE WAVE OF AMPLITUDE EQUALING 5.0
DEGREES AND FREQUENCY OF 5.0 Hertz. IF THE
NO. OF POINTS IS LESS THAN 400 THE COMMAND
IS A WHITE NOISE SIGNAL OF ZERO MEAN AND
STANDARD DEVIATION OF 1.0 DEGREE.

FIRST DATA CARD GIVES THE NO. OF CASES (IS)
90 FORMAT(1X, "NO. OF CASES")
99 FORMAT(1X, "THE NO. OF CASES IS", IS/)
DO 112 K=1, NCASES
PROGRAM JCC 73/74 01=1

C

C WRITE(1,21)
28 FORMAT(120X,*CASE NO.,*12,)//
C
C THE SAMPLE RATE OF THE SERVOSYSTEM IS READ
AND ALSO THE NO. OF DATA POINTS.
C
C READ(I,111)SSRATE,NPTS
11 FORMAT(*,13X,2X,2X,15X)
C
C WRITE(1,24)SSRATE,NPTS
24 FORMAT(120X,*THE SAMPLE RATE IS*,F9.3,* 12X,*THE NO. OF SAMPL
*ES EQUALS*,12,)//
C
C SERVOSYSTEM GAINS ARE READ FROM THE THIRD
DATA CARD IN A CASE. F10.4 FORMAT
C
C DO 100 I=1,2
C
C WRITE(1,21)
21 FORMAT(120X,*SERVOSYSTEM *,IL,*---- GAINS*,//)
C
C WRITE(1,22)
22 FORMAT(10X,*AMPLIFICATION*,12X,*ENLARGE*,15X,*ACTUATOR*,11X,*LVOT*,15X,
**DECOUPLATION*,12X,*FEEDBACK*)
C
C WRITE(1,222)
222 FORMAT(10X,*VAC/VAC "*,12X,*IN/SEC-M/M",9X," IN-2 "*,12X,"VAC/VAC"
*,13X," VDC/VAC",9X," VAC/VDC"//)
C
C READ(I,10)AMP(I),HYSV(I),ACT(I),LVOT(I),DEMOH(I),FEO(I)
10 FORMAT(6(F8.4))
C
C WRITE(3,23)AMP(I),HYSV(I),ACT(I),LVOT(I),DEMOH(I),FEO(I)
23 FORMAT(10X,6(F8.4)//)

C DEADBAND, RATE LIMIT, AND HYSTERESIS VALUES
ARE INPUT AS PERCENTAGES OF ACTUATOR FULL
STROKE SPECIFICATIONS. WITH THE DEADBAND
SPECIFICATION IT IS WITH RESPECT TO MAXIMUM
SERVOVALVE INPUT SPECIFICATIONS(*= 4MA).
C
C READ(I,710)T+SPEC(II),ALSPEC(II),HYSPEC(II)
710 FORMAT(3(F10.7))
T+SPEC(II) = HYSPEC(II) / 1.0*RANGE.*20.
C
C WRITE(I,713)
713 FORMAT(10X,*HYSTERESIS AND DEADBAND ARE GIVEN AS PERCENT OF FULL
*STROKE. RATE LIMIT IS GIVEN AS PERCENT OF 90 DEG/SEC.*//)
C
C WRITE(I,711,T+SPEC(II),ALSPEC(II),HYSPEC(II)
711 FORMAT(10X,*REVOLUTE VALUE =*,L4,F10.7,10X,*
*RATE LIMIT =*,9X,F10.7,10X,*HYSTERESIS VALUE =*,3Y,F10.7,10X,*
100 CONTINUE
C
LINES 4, 5 CHOOSE T) DESCRIPTIVE THE VARIABLE.
INITIALIZATION OF VARIABLES AND INITIAL
CONDITIONS ARE SET UP.

ERROR = 1.0
ICNT = 0
YYIN = 9.0
TIME = 0.0

DO 10 I = 1, 2
APPIN(I) = 0.0
AMPOUT(I) = 0.0
CMVIN(I) = 0.0
CMVOUT(I) = 0.0
ACTINH(I) = 0.0
ACTOUT(I) = 0.0
LVOUT(I) = 0.0
LVOUT(I) = 0.0
FEEDIN(I) = 0.0
FOOIT(I) = 0.0
DEMOD(I) = 0.0
DEMOD(I) = 0.0
YYOUT(I) = 0.0

ACTINF(I) = 0.0
ACT(I) = 0.0
101 CONTINUE

ACTINF IS THE PREVIOUS ACTUATOR INPUT AND
ACT I IS THE PREVIOUS ACTUATOR OUTPUT. THIS
SET OF VARIABLES IS FOR THE BILINEAR TRANS-
FORM OF THE INTEGRATOR.

ACTINP(I) = 0.0
ACT(I) = 0.0
101 CONTINUE

there are two servosystem loops in this
model. LOOP 1 REPRESENTS A RIGHT AILERON
OR CONTROL; LOOP 2 REPRESENTS THE LEFT. ALL
CHANGES IN THE SERVOSYSTEM CHARACTERISTICS
ARE DEPENDENT ON THE RIGHT "SURFACE WITH THE
LEFT ACTING AS A REFERENCE "CONTROL.

ALTHOUGH THE SIGNAL IN THE PHYSICAL SYSTEM
IS INVERTED AT THE LVDT DEMODULATOR THE
MODEL DOES NOT INVERT THE SIGNAL UNL THE
SHIPPING JUNCTION TO PROVIDE A CLEAR PLOT
PRESENTATION.

WRITE(3, 26)

CALL INPLT(YYIN)
C 111 WRITE(3,261)TIME,YIN,EROP,YVOUT(1),YVOUT(2)
C 120 FORMAT(1X,F10.4,5X,E10.6,5X,E10.6,5X,E10.6)
C 125 WRITE(14,TIME,YIN,EROP,YVOUT(1),YVOUT(2))
C 130 ICHT = ICHT + 1
C 135 IF(ICH,T. EQ. NPTF)GO TO 112
C 140 TIME = TIME + PERIOD
C 145 CALL INPIT(YVIN)
C 146 C 150 I = 1
C 155 CALL INPIT(YVIN)
C 160 C 170 AMPIN(I) = YVIN/2.
C 175 AMPOUT(I) = AMP(I) * AMPIN(I)
C 180 EHSVIN(I) = AMPD(I) - FPOUT(I)
C 185 TIME IS THE SHUTOFF TIME FOR MODELING A DEADMAN OR THRESHOLD NONLINEARITY. IN THE CLOSING LOOP RESPONSE DEADMAN GIVES THE Hysteresis NONLINEARITY.
C 190 CALL THRESH(I,EHSVIN)
C 195 THESE TWO LINES LIMIT THE FSV INPUT CURRENT
C 200 IF(EHSVIN(I).LE.-4.0)EHSVIN(I) = -4.0
C 205 IF(EHSVIN(I).GE.4.0)EHSVIN(I) = 4.0
C 210 EHSVOUT(I) = EHSVIN(I) * EHSVIN(I)
C 215 ACTIN(I) = FHSVOUT(I)
C 220 ACTOUT(I) = ACTI(I) + ACTII(I) * ACTI(I) * PFRIGHT / 2.0
C 225 THE RATE LIMIT SUBROUTINE LIMITS THE PAM MOVEMENT TO 7,112 IN/SEC. AS SPECIFIED.
C 230 CALL RLIMIT(I,ACTOUT,ACTI,PFRIGHT)
THESE TWO LINES ARE THE POSITION LIMITS FOR
THE ACTUATOR.

IF(ACOUT(I) .GE. .50)ACOUT(I) = .50
IF(ACOUT(I) .LE. -.50)ACOUT(I) = -.50

LVOUT(I) = ACOUT(I)
LVOUT(I) = LVOUT(I) * LVOUT(I)

DEMOO(I) = DEMO(I) * DEMO(I)

THE SURFACE POSITION ACCORDING TO THE DEMODULATOR OUTPUT IS GIVEN IN OLGSPELS FOR PLOT
CLARTY BUT ALSO TO SIMULATE WHAT THE ON-BOARD COMPUTER MIGHT BE SEEING WITH RESPECT
TO NOISE.

YYOUT(I) = (DEMO(I) * 39.77) / (DEMO(I) * LVOUT(I))

FEEDIN(I) = DEMO(I)
FCOUT(I) = FEED(I) * FEED(I)

ACTINP(I) = ACTIN(I)
ACTI(I) = ACTOUT(I)

THIS IS LOOP 2 OR THE LEFT CONTROL SURFACE

I = 2
AMFIN(I) = YYIN/2
AMOUT(I) = AMP(I) * AMFIN(I)

EHSVIN(I) = AMOUT(I) - FDOUT(I)
GALL TPSHI(I,EHSVIN)

IF(EHSVIN(I) .LE. 4.0)EHSVIN(I) = -4.0
IF(EHSVIN(I) .GE. 4.0)EHSVIN(I) = 4.0

EHSOUT(I) = EHSVIN(I) * EHSVIN(I)
ACTIN(I) = EHSOUT(I)

ACTIATOP IS MODELED AS AN INTEGRATOR

ACTOUT(I) = ACTOUT(I) + ACTIN(I) * ACT(I) * PERIOD / 2.0

CALL RLIMIT(I,ACTOUT,ACTI,PFITM)

IF(ACOUT(I) .GE. .50)ACOUT(I) = .50
IF(ACOUT(I) .LE. -.50)ACOUT(I) = -.50

LVOUT(I) = ACOUT(I)
LVOUT(I) = LVOUT(I) * LVOUT(I)

DEMOO(I) = DEMO(I) * DEMO(I)

YYOUT(I) = (DEMO(I) * 39.77) / (DEMO(I) * LVOUT(I))
C

FEEDIN(I) = ORENAC(I)
FOUT(I) = FEER(I) * FEEDIN(I)

ACTINP(I) = ACTIN(I)
ACT1(I) = ACTOUT(I)

THE DIFFERENCE IN THE TWO MONITOR OUTPUTS
IS CALCULATED AND PRINTED A "ERROR."

ERROR = YOUT(1) - YOUT(2)
GO TO 111

300 CALL TO PLOT ROUTINE

112 CONTINUE
REWIND 4
DO 723 KF = 1,NOCASES
CALL SCRIBL(KM)

723 CONTINUE
REWIND 4
CALL FLOT(0.,0.,999)
REWIND 6
STOP
END
SUBROUTINE THRESH(J, VALUE)
DIMENSION VALUE(2)
COMMON TIME,NPTS,THSPEC(2),RLSPEC(2),HYSPEC(2),NCASTS

C STOP THE SIGN
C
IF(VALUE(J).LT.0.0)Z = -1.0
IF(VALUE(J).GE.0.0)Z = +1.0
DEAD = ABS(VALUE(J))

C EIGHT HA IS THE FULL STROKE FING OF THE EHSV INPUT.
C
SPEC = 4.0 * THSPEC(J)

C THE DEADPAND IS ADDED OR SUBTRACTED FROM THE EHSV INPUT.
C
IF(DEAD. GE. SPEC) VALUE(J) = VALUE(J) - 12 * SPEC
IF(DEAD. LT. SPEC) VALUE(J) = 0.0

RETURN
END
SUBROUTINE RLIMIT, 73/74 OPT=1

DIMENSION CUT(2),OUT(I)
COMMON TIME,NITS,THSPEC(2),FLSPEC(2)

C

BY COMPARING THE SPECIFIED RATE LIMIT OF 2.312 IN./SEC, TO THE DELTA POSITION IN ONE PERIOD A LARGER VALUE IS DECREASED TO THE SPECIFIED

C

SPECIFS = 2.312 * FLSPEC(2)
GG = (OUT(I) - OUL(I))/PEP
ZZ = 1.
IF(GG.LT.-0.1) ZZ = -1.0

C

IF(AES(GG).GT.SPECIFS)OUT(I) = SPECIFS*ZZ*PEP+OUT(I)
RETURN
END
SUBROUTINE INPLT(VALUE)

   THIS IS THE SUBROUTINE FOR 'H' COMMAND INPUT

   COMMON TIME,NPTS

   IF(NPTS.GT.400) VALUE = 6.

   IF(NPTS.LT.400) VALUE = 0.0 AND 01

   IF(NPTS.EQ.400) GO TO 2

   GO TO 3

   SINE WAVE OF 5.0 DEGREES, 5.0 Hz.

   2 THETA = TIME * 6.28318 * .25
   VALUE = SIN(THETA) * .06

   CONTINUE

RETURN
END
SUBROUTINE ANOISE 73/74 OPT=1

SUBROUTINE ANOISE(OP,N,MX)
REAL MX
DIMENSION BP(2),VALU(2)
COMMON TIME,NPTS,MAXSPEC(2),MAXVAL(2),MAXSFC(2),MCASES

GRAND IT A WHITE NOISE GENERATOR OF ZERO MEAN A UNITY STANDARD DEVIATION
VALUE(N) = GRAND(1)

THE NOISE LEVEL IS GIVEN AS A PERCENT OF MAXIMUM SIGNAL LEVEL AT THE POINT OF INTEREST. THIS MUST BE PROVIDED BY THE USER.

BP(N) = VALUE(N) * .001 * MX + BP(N)
RETURN
END

BP(N) = VALUE(N) * .001 * MX + BP(N)
RETURN
END
G = FUNCTION GRAND(N)

G = WRITTEN 9/28/75 A. MYERS, NASA/FRC
G = ADAPTED BY J. BROWNLOW FROM COMM OF THE ACM ALGOL 60 REV. 1974 DECEMBER 1974
G = VOL 17 NO. 12 PAGE 504

G = ROUTINE RETURNS PSEUDO RANDOM NUMBER WITH STANDARD NORMAL DISTRIBUTION WITH ZERO MEAN AND STANDARD DEVIATION OF UNITY
G = NOTE: USES RANF TO SUPPLY UNIFORM PSEUDO RANDOM NUMBER WITH DISTRIBUTION OVER THE RANGE 0 TO 1.0
G = NOTE: REQUIRES ONE INITIALIZATION CALL
G = NOTE: N IS A DUMMY ARGUMENT

G = DIMENSION C(49)
G = COMMON /GRANDS/ U DATA.

G = A = 0, 0
I = 0
1 CONTINUE
U = U + U
IF(U .LT. 1.0) GO TO 2
U = 1.0
I = I + 1
A = A(I)
GO TO 1

2 CONTINUE
W = D(I + 1) - U
V = W - (0.5 - W - A)
3 CONTINUE
U = RANF(1)
IF(U .LE. W) GO TO 4
V = RANF(1)
IF(W .LE. V) GO TO 3
U = (U - U) / (1.0 - U)
GO TO 2

4 CONTINUE
U = (U - V) / (1.0 - V)
U = U + U
IF (U.LT. 1.0) GO TO 5
U = U - 1.0
GRAND = 1 - A
RETURN
5 CONTINUE
GRAND = A - H
END

GRAND
GRAND
GRAND
GRAND
GRAND
GRAND
GRAND
GRAND
GRAND
GRAND
SUBROUTINE SCRIRL 73/74
COMMON TIIF,NPTS,TIMESPEC(2),PLSPEC(2),WY SPEC(2),NCA,F5
REAL BUF(2048),TI(1000),S(O(1000),LPI(1000),LP2(1000)
DIMENSION TITLE(I),STORE(1000),S(1000),SS(1000),TT(1000)

CALL PLOTS(BUF,2048,F)
CALL FACTOR(2.0/3.5,F)
CALL PLOT(2,2,F)
DATA TITLE/10/TITLE/HISTO/PREF,10/HY,FRC,A 10/HY CFN,10/H

**

C C C
C ENCODE(10,1,TITLE(I))K
1 FORMAT(2X,12,6X)
C C C
C SET VARIABLES FOR ILLUSTRATING THE SAMPLED DATA EFFECT
C
I J = 1
II = 1
S(IJ) = 0.
SS(IJ) = 0.
TT(IJ) = 0.
DO 777 J = 1,NPTS
READ(4)TT(J),Y(J),DDATA(J),LPI(J),LP2(J)
C C C
C A SAMPLE AROUND THE APPROPRIATE SAMPLE TIME
C IS TAKEN AND HELD TILL THE NEXT SAMPLE TIME
C
IF(T(J),LT,(1./53.3)*II)GO TO 777
II = II + 1
I J = I J + 2
S(IJ) = DDATA(I J)
S(IJ - 1) = S(I,J-2)
SS(IJ) = LPI(J)
SS(IJ - 1) = SS(I,J-2)
SSS(IJ) = LP2(J)
SSS(IJ - 1) = SSS(I,J-2)
TT(IJ) = T(J)
TII(IJ) = T(J - 1)
777 CONTINUE
C
C THE DATA IS SCALED. SINCE A SCALE FACTOR OF
C EIGHT IS UNFEASIBLE IF IT SHOULD APPEAR
C THE EIGHT SUBROUTINE CHANGES THE SCALE FACTOR TO TEN.
C
CALL SCALE(DDATA,2.0,NPTS,1)
CALL EIGHT(DDATA,NPTS)
CALL SCALE(T,T,NPTS,1)
CALL EIGHT(T,NPTS)
CALL SCALE(Y,2.0,NPTS,1)
CALL EIGHT(Y,NPTS)
SUBROUTINE SCRIRL 73/74 OPT2

CALL SCALE(LP1,2.0,NPTS,1)
CALL SCALE(LP2,2.0,NPTS,1)
CALL EIGHT(LP2,NPTS)

THE SCALE FACTORS AND STARTING VALUES FOR
THE SAMPLED POINTS ARE TRANSFERRED TO THE
RESPECTIVE ARRAYS.

T(I+1) = T(I+NPTS)
T(I+2) = T(I+NPTS)
S(I+1) = CDATA(NPTS)
S(I+2) = CDATA(NPTS)
SS(I+1) = LP1(NPTS)
SS(I+2) = LP1(NPTS)

TIME AXIS

CALL AXIS (0.,0.,NITLE,-4.,7.0,0.,T(I+NPTS),T(I+NPTS))
CALL PLOT (0.,7.5,-3)

ERROR AXIS

CALL AX90 (0.,0.,"ERROR",+12.2,0,99.,CDATA(NPTS),CDATA(NPTS))

ERROR PLOT

CALL LINE(T,CDATA,NPTS,1,0)
CALL LINE(T(I+1),S(I+1),0)
CALL PLOT (0.,-2.5,-3)

COMMAND AXIS

CALL AX90 (0.,0.,"COMMAND",+13.2,0,99.,Y(NPTS),Y(NPTS))

COMMAND PLOT

CALL LINE(T,Y,NPTS,1,0)
CALL PLOT (0.,-2.5,-3)

RIGHT SURFACE AXIS

CALL AX90 (0.,0.,"RTS",+6.2,0,99.,LP1(NPTS),LP1(NPTS))

RIGHT SURFACE PLOT

CALL LINE(T,LP1,NPTS,1,0)
CALL LINE(T,SS,I+1,0)
CALL PLOT (0.,-2.5,-3)

LEFT SURFACE AXIS

CALL AX90 (0.,0.,"LTSG",+6.2,0,99.,LP2(NPTS),LP2(NPTS))

CALL PLOT (0.,-2.5,-3)
SUBROUTINE SCRIP(73/74, OPT=1)
C
CALL LINE1(T,LP2,NPTS,1,0,0)
CALL LINE1(T,SSS,I=1,0,0)
CALL SCALE(DDATA,2,0,NPTS,1)

CODE TO ARRANGE SCALE FACTORS FOR A SUMMATIVE PLOT OF THE ERROR DATA OF ALL CASES
C
STORE(K) = DDATA(NPTS+1)
CALL SCALE(ODATA,2,0,NPTS-1)
STORE(K*) = DDATA(NPTS+1)
IF(K+5.E.NCASES+50 TO 5
CALL SCALE(STORE,*5,NCASES*2,1)
CALL RIGHT(STORE,(NCASES*2))
ODATA(NPTS+1) = STORE(NCASES*2+1)
ODATA(NPTS+2) = STORE(NCASES*2)
CALL PLOT(12+3,0,4,"SECONDS",-7.7,0,1.T(NPTS+1),T(NPTS+2))
CALL IP(0,0,"ERROR OUTPUT ALL CASES,DEG",+2,6,0,9,90,DDATA, )
TS+1,ODATA(NPTS+1))
REWIN(4

ALL CASES PLOT
DO 7 L = 1,NCASES
DO 6 N = 1,NPTS
READ(41)IT(N),Y(N),ODATA(IN),LP1(N),LP2(N)
6 CONTINUE
CALL LINE1(T,ODATA,NPTS,1,0,0)
7 CONTINUE
5 CALL FLOT(12+3,2,NPTS)
RETURN
END
SUBROUTINE EIGHT

DIMENSION CAT(1000)

THE SCALE FACTOR OF DAT ARRAY DIMENSIONED

NPTS POINTS IS CHECKED TO SEE IF IT IS A FACTOR OF EIGHT (MIGHT BE 8, 40, OR 800 ETC.)

THEN CHANGE IT TO 10, 100, 1000, etc.

Z = 1.

IF (DAT(NPTS+2) > 0.) Z = -1.

O = ALOG10 (ABS (DAT(NPTS+2)))

E = ALOG10 (10.)

CC = O - INT (O)

IF (ABS (CC - E) > 0.01 AND ABS (CC -(E-1.)) > 0.01) RETURN

IF (CC > 10.1) CC = INT (CC) + 1.

IF (CC < 10.0) CC = INT (CC) + 0.

DAT(NPTS+2) = (10.*O) * Z
RETURN
END
# Conversion Factors to SI Units

<table>
<thead>
<tr>
<th>To correct from-</th>
<th>To-</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>psi</td>
<td>N/m²</td>
<td>6894.76</td>
</tr>
<tr>
<td>in</td>
<td>m</td>
<td>0.0254</td>
</tr>
<tr>
<td>in²</td>
<td>m²</td>
<td>1550.15</td>
</tr>
<tr>
<td>Vac/in</td>
<td>Vac/m</td>
<td>39.37</td>
</tr>
<tr>
<td>deg/in</td>
<td>deg/m</td>
<td>39.37</td>
</tr>
<tr>
<td>in³/sec-mA</td>
<td>m³/sec-mA</td>
<td>1.639 x 10⁻⁵</td>
</tr>
<tr>
<td>in/sec</td>
<td>m/sec</td>
<td>0.0254</td>
</tr>
</tbody>
</table>
The HiMAT RPRV uses cross-ship comparison monitoring of the actuator RAM positions to detect a failure in the aileron, canard, and elevator control surface servosystems. Some possible sources of nuisance trips for this failure detection technique are analyzed. A FORTRAN model of the simplex servosystems and the failure detection technique were utilized to provide a convenient means of changing parameters and introducing system noise. The sensitivity of the technique to differences between servosystems and operating conditions was determined. The cross-ship comparison monitoring method presently appears to be marginal in its capability to detect an actual failure and to withstand nuisance trips. Several suggestions are given to alleviate potential problems. The LVDT demodulator outputs should be filtered to attenuate the ripple signal and system noise. Each set of servosystems should be set as closely as possible to the same loop gain. A higher sample rate along with a faster switching relay would allow a larger failure threshold value to be used.