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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents a set of equations of motion for remotely piloted vehicles. The equations are written in a form suitable for a real-time digital computer simulation. The simulation is intended to provide a test bed for evaluating al- ternative RPV control systems. A FORTRAN program for use on a Digital Equipment Corporation PDP-12 Computer is presented. Airframe parameter values are given for several flight conditions		

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Contrails

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of an air-to-ground RPV, an air-to air RPV and, a reconnaissance/EW RPV.

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PREFACE

This final technical report has been prepared for the United States Air Force by Adaptronics, Inc., McLean, Virginia, under the terms of Contract F33615-73-C-4055, "Development of Software Computer Programs to Simulate RPV Flight Characteristics for Specified RPV Missions and Airframe Configurations . The report covers work performed during the period 1 January to 29 September 1973.

Major Charles S. Lessard, Mathematics and Analysis Branch, Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, has been the project engineer for the Air Force in this work. The authors are grateful to Major Lessard, Dr. Hans L. Oestreicher, Captain Joseph W. Carl and Major Roger A. Gagnon for their technical contributions to the project and their encouragement and support of the work.

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INTRODUCTION

This final report presents the equations and PDP-12 computer program for dynamic real-time simulations of representative air-to-ground, air-to-air, and reconnaissance/EW remotely piloted vehicle (RPV) configurations. These simulations emphasize retention of the primary linear and nonlinear characteristics of RPV airframes in a form suitable for use with integration intervals (equivalent to flight control system data sampling intervals) of 100 millisecc or less, with the simulations running in real time on a PDP-12 computer having floating-point hardware.

This project has been a partial continuation of work reported in Refs 1 and 2. In the preceding work, a preliminary RPV simulation was prepared. The preceding project also involved derivation of refined self-organizing controller (SOC) techniques, embodiment of these techniques in a breadboard SOC, and fabrication of a RPV/SOC demonstration system that includes a laboratory pilot's console with control stick and displays.

The present objective has been to aid development and employment of RPV's for high-threat environments by furthering the man-machine technology required to optimize RPV operation. An important aspect of this work has been to create means for conducting investigations regarding the comparative abilities of the SOC and other controllers to match remote pilots to RPV's in specific phases of their missions.

Six simulations have been prepared for specific RPV missions and airframe characteristics supplied by the Air Force. These simulations are suitable for investigations of the following SOC applications to RPV control:

- (1) terminal air-to-ground attacks, including evasive maneuvers,
- (2) terminal air-to-air engagements; and
- (3) maneuvers of reconnaissance/EW vehicles.

Additionally, work has been performed to interface and install altitude and airspeed indicators in the pilot's console; to furnish test equipment for maintenance of the SOC hardware; and to provide maintenance, repair, and technical services related to the demonstration system.

The second section of this report presents the simulation equations derived in the course of this and antecedent projects, with the principal assumptions made in formulation of these equations being presented in Appendix A. The second section also contains numerical characteristics of representative RPV configurations. These characteristics, extracted from Refs. 3 and 4, have been put into a format suitable for the present simulations. The third section details the computer simulations. Appendix C presents information on the altitude and airspeed indicators and the interface circuits used for these displays.

FORMULATION OF SIMULATION EQUATIONS

Background

Although a number of alternative approaches may be followed in formulating simulation equations for RPV flight, the conflicting requirements of real-time computing speed, exactness of solution, and ease of operator visualization must dominate consideration in the present instance.

Speed of computation is critically dependent on the number of trigonometric evaluations performed per solution interval during integration of the differential relationships. Additionally, the numbers of multiplications and additions are important factors, although the floating point processor used in this project facilitates greatly increased speed over a software-coded floating point routine.

In the present project, a number of formulations have been tried and discarded because they consumed too much computer time in meeting the need for a dynamically correct simulation. Other versions of the simulation that did meet the speed requirement have been set aside in favor of the development presented below because of the importance of employing coordinate systems that permit relatively easy visualization and interpretation by human operators.

Problem Statement

The simulation problem is to obtain faithful, real-time, man-in-the-loop simulations of the terminal phases of representative RPV strike missions and of air-to-air RPV engagements. These simulations are performed on the AMRL PDP-12 computer system in Building 441 at Wright-Patterson Air Force Base. The real-time

simulations require integration of the RPV equations of motion using intervals no greater than approximately 0.03 sec. for the rotational responses and 0.1 sec for the translational responses, inasmuch as greater intervals can cause loss of numerical accuracy in the integrations, excessively low display up-date rates for the RPV pilot and scientific observer, and/or excessively low data rates for the self-organizing controller.

Assumptions

The principal assumptions made in formulating the simulation equations are:[†]

- (1) The RPV angles of attack and sideslip, α and β , respectively, are sufficiently small that their cosines can be reasonably approximated by unity and their sines by the radian measures of these angles.
- (2) The body-axes angular-rate cross-product terms (PQ, QR, PR) and product-of-inertia terms are negligible in the equations of moment balance.
- (3) Atmospheric density (ρ) is essentially constant throughout the RPV maneuver and wind velocities are zero.
- (4) Aerodynamic coefficients (partial derivatives) of the RPV are essentially constant throughout its maneuvers.
- (5) The RPV mass and thrust are essentially constant throughout its maneuvers.

[†] See discussion of these assumptions in Appendix A.

Coordinate Systems

The coordinate systems used in the present formulation are:

(1) Geographic Coordinates -- The geographic coordinate axes (\vec{X}_G , \vec{Y}_G , \vec{Z}_G) belong to a right-handed system (centered at the target for air-to-ground missions against stationary objects) wherein:

$$X_G \equiv N = \text{RPV distance North}$$

$$Y_G \equiv E = \text{RPV distance East}$$

$$Z_G \equiv -h = \text{Negative of RPV Altitude}$$

(2) RPV Inertial Orientation -- The RPV inertial orientation is defined in terms of the angles relating RPV body axes to the geographic coordinate system. With \vec{x} , \vec{y} , \vec{z} denoting right-handed principal axes of the RPV body; such that rolling motions (roll rate = P) occur about \vec{x} , pitching motions (pitch rate = Q) occur about \vec{y} , and yawing motions (yaw rate = R) occur about \vec{z} ; the following sequence of right-handed rotations of the body is defined, assuming that the body axes are initially aligned with \vec{X}_G , \vec{Y}_G , \vec{Z}_G :

$$\theta_1 \equiv Az = \text{Rotation about } \vec{Z}_G = \text{Orientation Azimuth Angle}$$

$$\theta_2 \equiv El = \text{Rotation about } \vec{y} = \text{Orientation Elevation Angle}$$

$$\theta_3 \equiv Bank = \text{Rotation about } \vec{x} = \text{Orientation Bank Angle}$$

(3) RPV Velocity Vector Orientation -- The RPV velocity vector (\vec{V}), having components u , v , and w along the body axes \vec{x} , \vec{y} , and \vec{z} , respectively, has an orientation defined in terms of the angle of attack, α . This is the angle between the component of \vec{V} in the $\vec{x} - \vec{z}$ plane and the \vec{x} axis (positive if the projection of \vec{V} on \vec{z} is positive), and the angle of sideslip, β , which is the angle between the component of \vec{V} in the $\vec{x} - \vec{y}$ plane and the \vec{x} axis (positive if the projection of \vec{V} on \vec{y} is positive). Additionally, \vec{V} has a geographic heading ψ_V , which is the angle between the component of \vec{V} in the $\vec{X}_G - \vec{Y}_G$ plane and the \vec{X}_G axis (positive if the projection of \vec{V} on \vec{Y}_G is positive), and a geographic flight-path inclination (climb angle), γ , which is the angle between \vec{V} and the $\vec{X}_G - \vec{Y}_G$ plane (positive if the projection on \vec{Z}_G is negative).

(4) Target LOS Relative to RPV Body Axes -- The target line-of-sight (LOS), expressed relative to the RPV rotating body axes (\vec{x} , \vec{y} , \vec{z}), forms the angles A_T and E_T within the $\vec{x} - \vec{y}$ plane and $\vec{x} - \vec{z}$ plane, respectively. A_T is positive when the projection of the LOS on \vec{y} is positive and E_T is positive when the projection of the LOS on \vec{z} is negative.

Sequence of Calculations in Simulation

Figure 1 presents the basic flow chart for the RPV dynamic simulations, showing the sequence of calculations followed within these programs. Data input and output are discussed in the third Section.

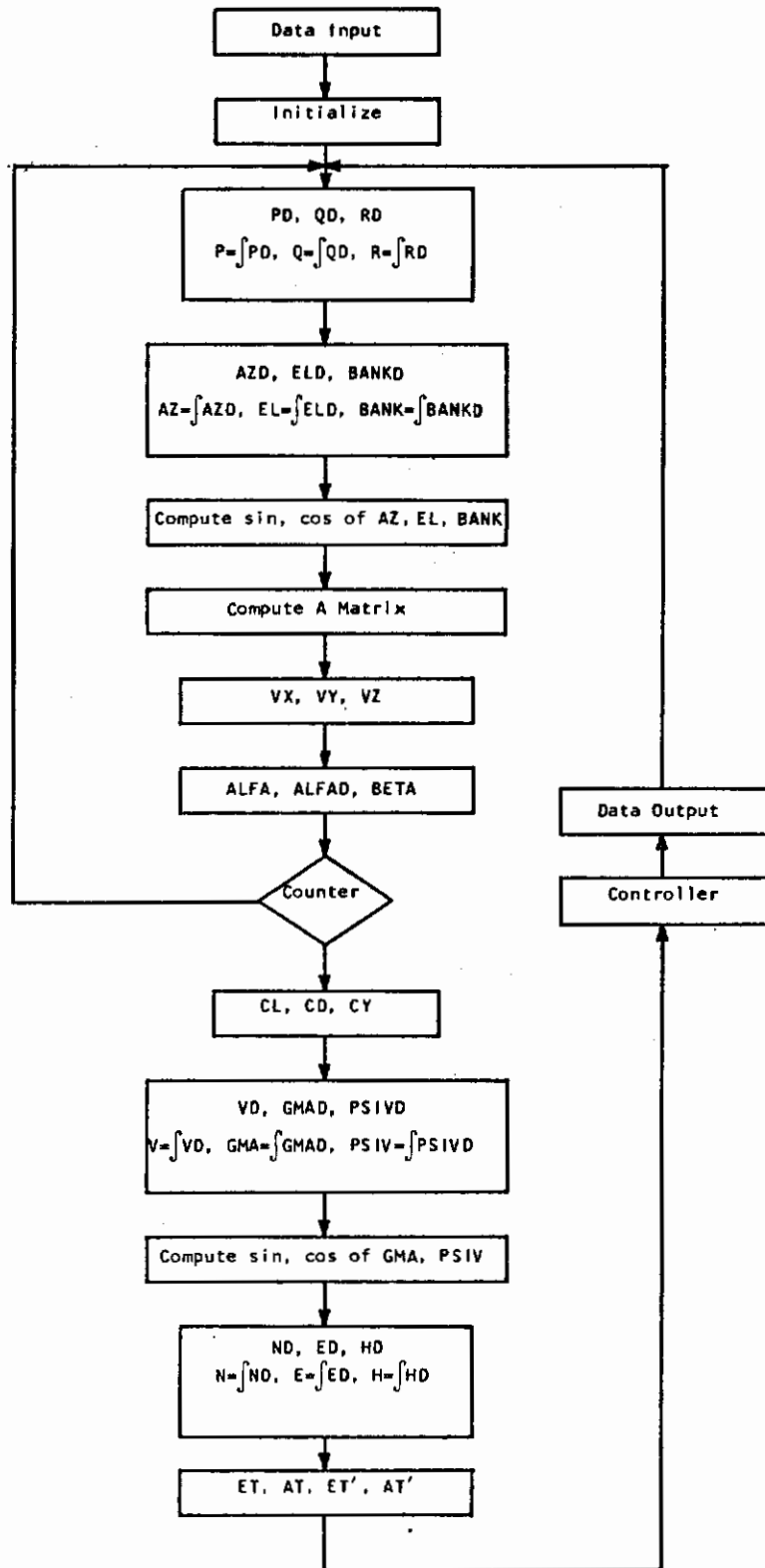


Figure 1: GENERAL FLOW CHART FOR RPV SIMULATIONS

Equations of Moment Balance

The equations of RPV moment balance are:

$$\dot{P} = (q/\bar{q}) (L_{\delta_a} \delta_a + L_{\delta_r} \delta_r + L_{\beta} \beta + L_P P + L_R R) \quad (1)$$

$$\dot{Q} = (q/\bar{q}) (M_{\delta_e} \delta_e + M_{\alpha} \alpha + M_{\dot{\alpha}} \dot{\alpha} + M_Q Q) \quad (2)$$

$$\dot{R} = (q/\bar{q}) (N_{\delta_r} \delta_r + N_{\beta} \beta + N_R R + N_P P) \quad (3)$$

In these equations:

$$q = \frac{1}{2} \bar{\rho} V^2 \quad (4)$$

$$q/\bar{q} = V^2/V_{nom}^2 \quad (5)$$

in which q represents dynamic pressure, ρ denotes atmospheric density, and V is the airspeed. The bar, $(\bar{\quad})$, over a variable denotes a mean value and the subscript nom , $(\quad)_{nom}$, signifies a nominal value. In the absence of wind gusts, the airspeed is given by

$$V = (\dot{N}^2 + \dot{E}^2 + \dot{h}^2)^{\frac{1}{2}} \quad (6)$$

where \dot{N} , \dot{E} , \dot{h} represent translation velocity components along the respective geographic axes.

δ_a , δ_e , and δ_r denote aerodynamic control-surface deflections, as follows:

δ_a = Aileron deflection, positive with right surface "up",
left surface "down"

δ_e = Elevator deflection, positive with surface "down"

δ_r = Rudder deflection, positive with surface "left"

The dimensional coefficients, L_{δ_a} , L_{δ_r} , L_{δ} , etc., are defined in Table 1.

All angles and angular rates are expressed in radian measure.

T denotes thrust. The coefficient M_T is zero for the air-to-ground RPV's simulated.

Advanced rectangular integrations of Eqs 1 - 3 are obtained as follows:

$$P_n = P_{n-1} + \delta t \dot{P}_n \quad (7)$$

$$Q_n = Q_{n-1} + \delta t \dot{Q}_n \quad (8)$$

$$R_n = R_{n-1} + \delta t \dot{R}_n \quad (9)$$

where δt ($\Delta t \leq 0.02$ sec.) is the small integration interval, a constant, and n is an index associated with δt .

Inertial Orientation

The inertial orientation rates are:

$$\dot{\theta}_1 = Q \frac{\sin \theta_3}{\cos \theta_2} + R \frac{\cos \theta_3}{\cos \theta_2} \quad (10)$$

$$\dot{\theta}_2 = Q \cos \theta_3 - R \sin \theta_3 \quad (11)$$

$$\dot{\theta}_3 = P + Q \frac{\sin \theta_3 \sin \theta_2}{\cos \theta_2} + R \frac{\cos \theta_3 \sin \theta_2}{\cos \theta_2} \quad (12)$$

Table 1:

PARAMETER VALUES FOR RPV SIMULATIONS

Parameter	Units	Values.					
		A	B	C	D	E	F
$L_{\delta_a} = \frac{\bar{q} S b^2}{J_x} C_{L_{\delta_a}}$	sec. ⁻²	14.25	59.25	101.3	69.75	17.52	119.3
$L_{\delta_r} = \frac{\bar{q} S b^2}{J_x} C_{L_{\delta_r}}$	sec. ⁻²	5.02	21.10	14.86	35.64	3.305	60.03
$L_{\delta_\beta} = \frac{\bar{q} S b^2}{J_x} C_{L_{\delta_\beta}}$	sec. ⁻²	-17.79	-175.6	-218.2	-88.78	-75.79	-165.3
$L_P = \frac{\bar{q} S b^2}{2 J_x V_o} C_{L_P}$	sec. ⁻¹	-1.28	-2.687	-7.837	-3.010	-2.436	-6.549
$L_R = \frac{\bar{q} S b^2}{2 J_x V_o} C_{L_R}$	sec. ⁻¹	.656	1.868	1.929	.8840	2.510	2.096
$M_{\delta_e} = \frac{\bar{q} S C}{J_y} C_{m_{\delta_e}}$	sec. ⁻²	-22.79	-18.91	-8.183	-121.0	-5.545	-44.98
$M_a = \frac{\bar{q} S C}{J_y} C_{m_a}$	sec. ⁻²	-23.84	-6.429	-28.00	-71.52	-4.541	-21.34
$M_a' = \frac{\bar{q} S C}{2 J_y V_o} C_{m_a'}$	sec. ⁻¹	-.3979	-.2261	-.3599	-1.304	-.1865	-.5509
$M_Q = \frac{\bar{q} S C}{2 J_y V_o} C_{m_Q}$	sec. ⁻¹	-.7958	-.4426	-.7583	-2.090	-.3667	-.9641
$M_T = M_T(x_{CG}, z_{CG}) \frac{\text{rad.}}{\text{sec}^2 \text{ lb.}}$		0	0	.0005875	0	0	0
$N_{\delta_r} = \frac{\bar{q} S b^2}{J_z} C_{n_{\delta_r}}$	sec. ⁻²	-9.233	-7.298	-5.220	-46.74	-2.150	-23.17
$N_{\delta_\beta} = \frac{\bar{q} S b^2}{J_z} C_{n_{\delta_\beta}}$	sec. ⁻²	7.549	8.545	28.18	45.88	2.110	25.40
$N_R = \frac{\bar{q} S b^2}{2 J_z V_o} C_{n_R}$	sec. ⁻¹	-.2974	-.2827	-.5167	-.7550	-.2364	-.4615
$N_P = \frac{\bar{q} S b^2}{2 J_z V_o} C_{n_P}$	sec. ⁻¹	-.02388	-.007362	0	-.006195	-.01619	-.007566

Table 1 (Concluded)

Parameter	Units	Values					
		A	B	C	D	E	F
C_{L_0}	1/1	.06816	.01739	.377	-.007477	.0639	-.009185
C_{L_α}	rad. ⁻¹	6.25	5.34	5.134	7.54	4.70	6.80
$C_{L_{\delta_e}}$	rad. ⁻¹	.685	.655	.1902	.83	.585	.77
$\left(\frac{\bar{c}}{2V_0} C_{L_\alpha}\right)$	$\frac{\text{sec.}}{\text{rad.}}$	.01180	.007765	0	.008984	.01968	.009731
$\left(\frac{\bar{c}}{2V_0} C_{L_Q}\right)$	$\frac{\text{sec.}}{\text{rad.}}$	.02406	.01533	.01902	.01444	.03852	.01670
$C_{L_{\min}}$	1/1	-.5(est.)	-.5(est.)	-.5(est.)	-.5(est.)	-.5(est.)	-.5(est.)
$C_{L_{\max}}$	1/1	.7877	.7424	1.56	.7330	.9550	.7323
C_{D_e}	1/1	.0403	.0287	.0228	.0403	.0281	.0347
K	1/1	.060	.091	.068	.060	.091	.060
$C_{D_{\text{RAM}}}$	1/1	0	0	UNK.	0	0	0
C_{Y_β}	rad. ⁻¹	-1.36	-1.178	-.6875	-1.505	-1.102	-1.193
$\left(\frac{b}{2V_0} C_{Y_R}\right)$	$\frac{\text{sec.}}{\text{rad.}}$	0	0	.00980	0	0	0
$C_{Y_{\delta_r}}$	rad. ⁻¹	.38	.259	.1031	.454	.232	.428
i_T	rad.	0	0	.2618	0	0	0
$\left(\frac{l}{m}\right)$	$\frac{\text{ft.}}{\text{sec.}^2}$	12.27	3.537	30.03	11.08	3.375	6.398
g	$\frac{\text{ft.}}{\text{sec.}^2}$	32.2	32.2	32.2	32.2	32.2	32.2
$\left(\frac{gS}{m}\right)$	$\frac{\text{ft.}}{\text{sec.}^2}$	54.78	84.42	188.5	269.0	44.30	183.8
m	slugs	184.4	155.3	79.92	151.0	99.14	77.76

Advanced rectangular integration is again used, as follows, to obtain the RPV inertial orientation coordinates:

$$(\theta_1)_n = (\theta_1)_{n-1} + \delta t (\dot{\theta}_1)_n \quad (13)$$

$$(\theta_2)_n = (\theta_2)_{n-1} + \delta t (\dot{\theta}_2)_n \quad (14)$$

$$(\theta_3)_n = (\theta_3)_{n-1} + \delta t (\dot{\theta}_3)_n \quad (15)$$

Aerodynamic Angles

Defining:

$$m_{11} \equiv \cos \theta_2 \cos \theta_1 \quad (16)$$

$$m_{12} \equiv \cos \theta_2 \sin \theta_1 \quad (17)$$

$$m_{13} \equiv -\sin \theta_2 \quad (18)$$

$$m_{21} \equiv -\cos \theta_3 \sin \theta_1 + \sin \theta_3 \sin \theta_2 \cos \theta_1 \quad (19)$$

$$m_{22} \equiv \cos \theta_3 \cos \theta_1 + \sin \theta_3 \sin \theta_2 \sin \theta_1 \quad (20)$$

$$m_{23} \equiv \sin \theta_3 \cos \theta_2 \quad (21)$$

$$m_{31} \equiv \sin \theta_3 \sin \theta_1 + \cos \theta_3 \sin \theta_2 \cos \theta_1 \quad (22)$$

$$m_{32} \equiv -\sin \theta_3 \cos \theta_1 + \cos \theta_3 \sin \theta_2 \sin \theta_1 \quad (23)$$

$$m_{33} \equiv \cos \theta_3 \cos \theta_2 \quad (24)$$

the components of \vec{V} in the RPV body axes (\vec{x} , \vec{y} , \vec{z}) are given by the following ratios of u , v , and w to the magnitude of \vec{V} :

$$u/V = m_{11} \cos \gamma \cos \psi_V + m_{12} \cos \gamma \sin \psi_V - m_{13} \sin \gamma \quad (25)$$

$$v/V = m_{21} \cos \gamma \cos \psi_V + m_{22} \cos \gamma \sin \psi_V - m_{23} \sin \gamma \quad (26)$$

$$w/V = m_{31} \cos \gamma \cos \psi_V + m_{32} \cos \gamma \sin \psi_V - m_{33} \sin \gamma \quad (27)$$

Accordingly, the aerodynamic angles become:

$$\alpha = w/u \quad (28)$$

$$\beta = v/u \quad (29)$$

and the rate of change of α is computed as

$$\dot{\alpha} = \frac{\alpha_n - \alpha_{n-1}}{\delta t} \quad (30)$$

Coefficients of Lift, Drag, and Side Force

The RPV total lift coefficient, C_L , is

$$C_L = C_{L_{\alpha=0}} + C_{L_{\alpha}} \alpha + C_{L_{\delta_e}} \delta_e + \left(\frac{\bar{c}}{2V_0} C_{L_{\dot{\alpha}}} \right) \dot{\alpha} + \left(\frac{\bar{c}}{2V_0} C_{L_Q} \right) Q \quad (31)$$

in which $C_{L_{\alpha=0}}$ (denoted C_{L_0}) and the partial derivatives C_{L_α} , C_{L_δ} , etc. have the values listed in Table 1. (Note: \bar{c} denotes mean aerodynamic chord.) C_L is limited by the stall boundaries

$$C_{L_{\min}} \leq C_L \leq C_{L_{\max}} \quad (32)$$

The RPV total drag coefficient, C_D , is

$$C_D = C_{D_e} + KC_L^2 + C_{D_{RAM}} \quad (33)$$

The values of C_{D_e} , K , and $C_{D_{RAM}}$ are listed in Table 2. $C_{D_{RAM}}$ is zero for the air-to-ground RPV configurations simulated.

The RPV total side-force coefficient, C_Y , is

$$C_Y = C_{Y_\beta} \beta + C_{Y_{\delta_r}} \delta_r + \left(\frac{b}{2V_0} C_{Y_R} \right) R \quad (34)$$

where C_{Y_β} , etc. have the values listed in Table 1. C_{Y_R} is negligible for the air-to-ground RPV configurations simulated. (Note: b denotes wingspan.)

Equations of Force Balance

The equations of RPV force balance are:

$$\dot{V} = \left(\frac{I}{m} \right) \cos(\alpha + i_T) - g \sin \gamma - (q/\bar{q}) \left(\frac{\bar{q} S}{m} \right) C_D \quad (35)$$

Table 2:
RPV CONFIGURATIONS AND
FLIGHT CONDITIONS SIMULATED

<u>Flight Condition</u>	<u>Type of RPV</u>	<u>Initial Mach Number</u>	<u>Initial Altitude, h, ft.</u>
A	Air-to-Ground, External Stores On	0.40	1,000
B	Recce/EW	0.80	30,000
C*	Air-to-Air	0.60	20,000
D*†	Air-to-Ground, External Stores on	0.80	500
E*	Recce/Ew	0.25	500
F*	Air-to-Ground, External Stores Off	0.70	20,000

*Conditions of primary interest

†Air-to-Ground and Recce/EW RPV's have similar characteristics at M=0.80, h=500.

#Similar to condition simulated in work under Contract F33615-72-C-1816 ("Refinements in SOC Logic").

$$\dot{\gamma} = \frac{1}{V} \left[\left(\frac{T}{m} \right) \sin (\alpha + i_T) - g \cos \gamma + \right. \\ \left. (q/\bar{q}) \left(\frac{\bar{q} S}{m} \right) (C_L \cos \theta_3 - C_Y \sin \theta_3) \right] \quad (36)$$

$$\dot{\psi}_V = \frac{1}{V \cos \gamma} \left[\left(\frac{T}{m} \right) \sin (\alpha + i_T) + \right. \\ \left. (q/\bar{q}) \left(\frac{\bar{q} S}{m} \right) (C_L \sin \theta_3 + C_Y \cos \theta_3) \right] \quad (37)$$

In these equations, i_T is the thrust incidence angle relative to \vec{x} and is constant. For the air-to-ground RPV's simulated, $i_T = 0$, and thus $\cos (\alpha + i_T) \approx 1$ and $\sin (\alpha + i_T) \approx \alpha$ for these aircraft. g , the acceleration of gravity, is treated as a constant, as is thrust, T , and the RPV mass, m . (Note: S denotes wing area.)

Again, using advanced rectangular integrations:

$$V_N = V_{N-1} + \Delta t \dot{V}_N \quad (38)$$

$$\gamma_N = \gamma_{N-1} + \Delta t \dot{\gamma}_N \quad (39)$$

$$\psi_{V_N} = \psi_{V_{N-1}} + \Delta t \dot{\psi}_{V_N} \quad (40)$$

where Δt ($\Delta t \approx 0.1$ sec.) is the large integration interval, a constant, and N is an index associated with Δt .

Eq 38 is used in preference to Eq 6 for computation of airspeed.

Geographic Coordinates

The geographic position of the RPV is obtained by integration of the following translation rates:

$$\dot{X}_G = \dot{N} = V \cos \gamma \cos \psi_V \quad (41)$$

$$\dot{Y}_G = \dot{E} = V \cos \gamma \sin \psi_V \quad (42)$$

$$-\dot{Z}_G = \dot{h} = V \sin \gamma \quad (43)$$

whence:

$$N_N = N_{N-1} + \Delta t \dot{N}_N \quad (44)$$

$$E_N = E_{N-1} + \Delta t \dot{E}_N \quad (45)$$

$$h_N = h_{N-1} + \Delta t \dot{h}_N \quad (46)$$

Target Line of Sight

With the target position (N_T , E_T , h_T) given in geographic coordinates, one has the following components of the LOS vector:

$$\Delta X_T = N_T - N \quad (47)$$

$$\Delta Y_T = E_T - E \quad (48)$$

$$\Delta Z_T = h - h_T \quad (49)$$

Therefore:

$$\Delta x_T = m_{11} \Delta X_T + m_{12} \Delta Y_T + m_{13} \Delta Z_T \quad (50)$$

$$\Delta y_T = m_{21} \Delta X_T + m_{22} \Delta Y_T + m_{23} \Delta Z_T \quad (51)$$

$$\Delta z_T = m_{31} \Delta X_T + m_{32} \Delta Y_T + m_{33} \Delta Z_T \quad (52)$$

The target LOS angles relative to the RPV body axes are thus:

$$A_T = \frac{\Delta y_T}{\Delta x_T} \quad (53)$$

$$E_T = \frac{-\Delta z_T}{\Delta x_T} \quad (54)$$

in which it is assumed that A_T and E_T are small angles.

RPV Configurations and Parameter Values

Table 2 presents a summary of RPV configurations and flight conditions simulated. The air-to-ground RPV (conditions A, D, and F) is the Northrop air-to-ground (recoverable) RPV described in Ref. 3. The recce/EW RPV (conditions B and E) is the Northrop recce/EW aircraft described in the same reference. The air-to-air RPV is the FDL-23 vehicle, Ref. 4. These RPV configurations and flight conditions have been approved by the Air Force Project Monitor for the present project.

Table 1 lists the parameters appearing in the above simulation equations, giving their physical units and numerical values for the six flight conditions defined in Table 2.

Initialization Equations and Initial Conditions

Initialization of the simulation requires computation of the $\alpha(0)$, $\delta_e(0)$, $T(0)$, and $\theta_z(0)$ values that produce aerodynamic

trim of the RPV at a given flight condition.[†] Thus, given the values of $\dot{V}(0)$ and:

$$V(0), \gamma(0), \psi_V(0), \theta_1(0), \theta_3(0), N(0), E(0), h(0)$$

and setting the following quantities to zero:

$$\delta_a(0), \delta_r(0), \beta(0), \dot{\alpha}(0), P(0), Q(0), R(0)$$

one has:

$$\alpha(0) \approx \left[\frac{mg \cos \gamma(0)}{\bar{q}(0) S} - C_{L_0} \right] \left(C_{L_\alpha} - \frac{C_{L_{\delta_e}} C_{m_\alpha}}{C_{m_{\delta_e}}} \right) \quad (55)$$

$$\delta_e(0) = - \frac{C_{m_\alpha} \alpha(0)}{C_{m_{\delta_e}}} \quad (56)$$

$$\begin{aligned} T(0) = \frac{1}{\cos \alpha(0)} \{ m \dot{V}(0) + mg \sin \gamma(0) + \\ \bar{q}(0) S [C_{D_e} + K (C_{L_0} + C_{L_\alpha} \alpha(0) + \\ C_{L_{\delta_e}} \delta_e(0))^2] \} \end{aligned} \quad (57)$$

[†]The zero in parentheses denotes an initial value of the associated variable. In Table 3 the subscript zero, $()_0$, is used for the same purpose. However, $C_{L_0} = C_{L_{\alpha=0}} \neq C_L(0)$.

Table 3:

INITIAL CONDITIONS FOR RPV SIMULATIONS

Parameter	Units	Values					
		A	B	C	D	E	F
V_o	$\frac{ft}{sec}$	446	795	622	894	281.4	726
h_o	ft	1,000	30,000	20,000	500	500	20,000
γ_o	rad	-.5236	0	0	0	0	0
α_o	rad	.0925	.07086	-.04589	.01592	.1571	.0258
$(\theta_a)_o$	rad	-.4311	.07086	-.04589	.01592	.1571	.0258
δ_{a_o}	rad	0	0	0	0	0	0
δ_{r_o}	rad	0	0	0	0	0	0
β_o	rad	0	0	0	0	0	0
P_o	$\frac{rad}{sec}$	0	0	0	0	0	0
R_o	$\frac{rad}{sec}$	0	0	0	0	0	0
$\delta_{e_o} = -\left(\frac{C_{m\alpha}}{C_{m\delta e}}\right)\alpha_o$	rad	-.09677	-.024089	.1570	-.009414	-.1287	-.01224
$\dot{\alpha}_o$	$\frac{rad}{sec}$	0	0	0	0	0	0
Q_o	$\frac{rad}{sec}$	0	0	0	0	0	0
T_o	lb	2,263	549.3	2,400	1,673	334.6	497.5
$(\theta_s)_o$	rad	0	0	0	0	0	0
$(\theta_1)_o$	rad	0	0	0	0	0	0
ψ_{V_o}	rad	0	0	0	0	0	0
N_o, E_o	ft	TBD	TBD	TBD	TBD	TBD	TBD

The approximation in $\alpha(0)$ consists of an assumption that $|T \sin \alpha| \ll |W \cos \gamma|$.

$\theta_2(0)$ is obtained as the sum of $\gamma(0)$ and $\alpha(0)$.

Table 3 presents numerical values of variables for initialization of the simulations.

THE RPV SIMULATIONS

Background

Design and analysis of high-performance aircraft flight control systems requires the use of accurate, real-time simulations of aircraft dynamic and kinematic relationships. This is especially true in creating an RPV strike capability because of the importance of developing an effective man-machine interface and of subsequently providing pilot flying experience without the benefit of flying the real aircraft. In simulations, attributes of the airframe, on-board control system, communications links, and the remotely located pilot's console can be evaluated qualitatively and quantitatively. Simulations thus provide an effective means for human engineering of the system, for specifying piloting requirements, and for establishing procedures for pilot training and maintenance of pilot proficiency.

Computer Program

The RPV simulations have been written in a single Fortran IV program specifically for the AMRL PDP-12 computer system located in Building 441 at Wright-Patterson Air Force Base. A special (Adaptronics-provided) interface is used to communicate with the Adaptronics Mark VI Self-Organizing Controller (SOC) and the Adaptronics demonstration pilot's console. The requisite software used to handle communications between the PDP-12 and the SOC and pilot's console exists as a machine-language routine resident in the PDP-12. It is coded as a Fortran subroutine.

The simulation program is separated into two parts consisting of an executive called "MAINA" and a subroutine called "MAINB". In addition to these major components, three other subroutines serve to handle input/output and to communicate with the SOC and the pilot's console.

A list of program symbols and their meanings is provided in Table 4. A general flow chart of the program and the complete Fortran source listing is shown in Figures 1, and 2 through 5, respectively. A discussion of "MAINA", "MAINB", and the supporting subroutines is provided in the following paragraphs.

MAINA

MAINA serves as the executive for the RPV simulation. All input and output is done in MAINA excluding communications with the SOC and the pilot's console. In addition, all program variables are initialized to their proper values in MAINA before the simulation begins.

MAINB

MAINB is the subroutine that performs the RPV simulations. This subroutine utilizes the simulation equations presented in the second section of this report. The sequence of computations may be seen by referring to the flow chart shown in Figure 1.

The dynamic and kinematic relationships are programmed in a form similar to the mathematical equations with the following exceptions:

Table 4:

LIST OF PROGRAM SYMBOLS

DT	integration interval for translational dynamics
CTRL	controls number of inner loop iterations
NO, EO, HO	initial geographic coordinates of the RPV
GMAO, PSIVO	initial value of the angles GMA and PSIV
VO	initial airspeed
HT	height of the target in geographic coordinates
WGHT, M	weight and mass of the RPV, respectively
JX, JY, JX; JXZ	moments of inertia; product of inertia
B, L	characteristic lengths of the RPV
S	reference area of the RPV
VNOM	nominal air speed of (constant for a given flight condition)
LDA, LDR, LB, LP, LR MDE, MA, MAD, MQ, MT, NDR, NB, NR, NP, CLO, CLA, CLAD, CLDE, CLQ, CDE, CDCL, CDRAM, CYB, CYDR, CYR	parameter values for the RPV (constant for a given flight condition)
AMAX	maximum magnitude allowed for ALFA
CLMIN, CLMAX	upper and lower limit for C_L
HMIN	minimum altitude allowed for RPV
ETC	pitch command
CAPA	roll command gain
G1, G2, G3	proportional, derivative, and integral gain, respectively, for the PID pitch loop controller
G4, G5, G6	proportional, derivative, and integral gain, respectively, for the PID yaw and roll loop controller
GDE, GDA, GDR	elevator, aileron, and rudder gain, respectively.
GA, TA	proportional and derivative gain, respectively, for roll command

Table 4 (Continued):
LIST OF PROGRAM SYMBOLS

DEMAX, DAMAX, DRMAX	maximum magnitude allowed for elevator, aileron, and rudder deflections, respectively
BCMAX	maximum bank (roll) command allowed
ANGSF, SFT, SFB, AIDXT, AIDXB, XMAX, TMAX	scale factors and indices used to format and control data displayed on the MKVI console oscilloscopes
ANPRNT	controls the printout interval when printing RPV variables during a run
DTI	integration interval for the rotational dynamics
VNSQ	the nominal airspeed squared
RHO	air density
RHOSM2	$\text{RHO} \cdot \text{S} / 2 \cdot \text{M}$
QBAR	$\text{RHO} \cdot \text{V}_0^2 / 2$
THRST	thrust
TM	THRST / M
DEO, DAO, DRO	trim values for elevator, aileron, and rudder, respectively
T	time
VSQ	airspeed squared
VV	VSQ / VNOM
QSM	$\text{RHOSM2} \cdot \text{VSQ}$
PD, QD, RD	time derivatives of P, Q, and R, respectively
P, Q, R	pitch, bank, and yaw rates, respectively, in RPV coordinates.
AZD, ELD, BANKD	time derivatives of AZ, EL, and BANK, respectively
AZ, EL, BANK	azimuth, elevation and bank, respectively, in geographic coordinates
SAZ, CAZ, SEL, CEL, SBANK, CBANK	sine and cosine of AZ, EL, and BANK, respectively
A11, A12, A13, A21 A22, A23, A31, A32, A33	matrix elements to transform from RPV to geographic coordinates
VX, VY, VZ	components of airspeed in RPV coordinates
ALFA0	past value of ALFA

Table 4 (Concluded):
LIST OF PROGRAM SYMBOLS

ALFA, ALFAD	angle of attack and its time derivative, respectively
BETA	sideslip angle
CL, CD, CY	coefficients of lift, drag, and side-force, respectively
VD, GMAD, PSIVD	time derivatives of V, GMA, and PSIV, respectively
V, GMA, PSIV	airspeed, flight path inclination angle, and yaw angle with respect to V, respectively.
CGMA, SGMA, SPSIV, CPSIV	cosine and sine of GMA, and PSIV, respectively
ND, ED, HD	time derivatives of N, E, H, respectively
N, E, H,	geographic coordinates of the RPV
DXT, DYT, DZT	components of the LOS vector in terms of target position given in geographic coordinates
DXA, DYA, DZA	components of target LOS bearing relative to RPV body axes
AT, ET	target line-of-sight azimuth and elevation, respectively, in RPV body axes
RANGE, RANGP	present and past value of line-of-sight distance to the target, respectively
ATPRMO	past value of ATPRIM.
ATPRIM, ETPRIM	AT and ET measured in geographic coordinates
BANKC	bank command
X1, X2	feedbacks from the RPV representing ETPRIM and roll rate, respectively
XC1, XC2	computed command inputs to the controller representing pitch and roll rates, respectively
U1, U2	the control signals representing pitch, (roll and yaw), respectively
EPI, EP2, ED1, ED2, EI1, EI2	proportional, derivative, and integral error signals used by the PID controller
DELE, DELA, DELR	elevator, aileron, and rudder control surface deflections
SF1 - SF16	scale factors used in conjunction with the pilot's console oscilloscopes


```

C      MAINA
C
      REAL M,L,JX,JY,JZ,JXZ,
      *LDA,LDR,LB,LP,LR
      *MDE,MA,MAD,MQ,MT,
      *NDR,NB,NR,NP,
      *ND,N,NC,NT,
      *KEPSL,KEPSQ,KUMAX
C
      LOGICAL SENSW
      DIMENSION SENSW(18)
C
      COMMON/TDATA/DATA(6,73)
C
      COMMON/CONST/DT,CTRL
      COMMON/CONST/NC,EC,HC,GMAC,PSIVC,VC,HT
      COMMON/CONST/WGHT,JX,JY,JZ,JXZ,S,B,L,VNOM
      COMMON/CONST/LDA,LDR,LB,LP,LR
      COMMON/CONST/MDE,MA,MAD,MQ,MT
      COMMON/CONST/NDR,NB,NR,NP,AMAX
      COMMON/CONST/CLC,CLA,CLAD,CLDE,CLQ,CLMIN,CLMAX
      COMMON/CONST/CDE,CDCL,CDRAM
      COMMON/CONST/CYB,CYDR,CYR,HMIN
      COMMON/CONST/ETC,CAPA,G1,G2,G3,G4,G5,G6,
      COMMON/CONST/GDE,GDA,GDR,GA,TA
      COMMON/CONST/DEMAX,DAMAX,DRMAX,BCMAX
      COMMON/CONST/ANGSF,SFT,SFB,AIDXT
      COMMON/CONST/AIDXB,XMAX,TMAX
      COMMON/CONST/AILIM,ANPRNT
C
      COMMON/WORK/DTI,VNSQ,RHC,RHCSM2,QBAR,THRST,TM
      COMMON/WORK/DEC,DAC,DRC
      COMMON/WORK/T,VSQ,VV,QSM
      COMMON/WORK/PD,QD,RD,P,P,R
      COMMON/WORK/AZD,ELD,BANKD,AZ,EL,BANK
      COMMON/WORK/SAZ,CAZ,SEL,CEL,SBANK,CBANK
      COMMON/WORK/A11,A12,A13,A21,A22,A23,A31,A32,A33
      COMMON/WORK/VX,VY,VZ,ALFAC,ALFA,ALFAD,BETA
      COMMON/WORK/CL,CD,CY
      COMMON/WORK/VD,GMAD,PSIVD,V,GMA,PSIV
      COMMON/WORK/CGMA,SGMA,SPSIV,CPSIV
      COMMON/WORK/ND,ED,HD,N,E,H
      COMMON/WORK/DXT,DYT,DZT,DXA,DYA,DZA
      COMMON/WORK/AT,ET,RANGE,RANGP
      COMMON/WORK/ATPRMC,ATPRIM,ETPRIM,BANKC
      COMMON/WORK/X1,X2,XC1,XC2,U1,U2
      COMMON/WORK/EP1,EP2,E1,E2,EI1,EI2,ED1,ED2
      COMMON/WORK/DELE,DELA,DELR
      COMMON/WORK/SF1,SF2,SF3,RF4,SF5,SF6,SF7
      COMMON/WORK/SF8,SF9,SF10,SF11,SF12,SF13,SF14,SF15,SF16
C
      COMMON/WORK/GERCR(2),GRATE(2),GINTG(2),UMAX(2),KEPSL(2),EPSMN(2),
      * EPSMX(2),KUMAX,DICNT,RNCNT,TCRL,GBIAS,DMIN,RX,WGHTX(16),
      * WGHTU(16),X(2),XC(2),U(2),ERRCR(2),EPAST(2),ERINT(2),TED(2),
      * FE(2),DXDD(2),DELTU(2),DD(7),GSQ(2),TCNT(2),TINT(2),EPSQ(2),

```

Figure 2:

PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINA

Contrails

```

* EPMAG(2),SGN(2),BIAS(2),EPSLN(2),UPRIM(2),UMAX1(2)
COMMON/WORK/GSQMN(2),GSQMX(2),KEPSQ(2),S11,S12,S21,S22,R11,R12,P22
* DETRM,G11,G12,G21,G22,TCRL1,TCRL2,XTRA,WSQ,XSTCR(2,16),
* USTCR(2,16),EPMGS,MCNT,MCNT,KCUNT

C
COMMON/ICDD/ICD1,ICD2,ICD3,ICD4,ICD5,ICD6,
*ICD7,ICD8,ICD9,ICD10,ICD11,ICD12,ICD13,ICD14,ICD15,ICD16
DIMENSION CONSTD(73),WORKD(302),ICD(14),DUM(73)
EQUIVALENCE (CONSTD(1),DT),(WORKD(1),DT1),(ICD(1),ICD1)

C
1  FORMAT(16H SELECT FLT COND//)
2  FORMAT(F15.7)
3  FORMAT(17H CHANGE CONSTANTS)
4  FORMAT(5F13.4)
5  FORMAT(4H SCC)
6  FORMAT( 5H HMIN,F10.2)
7  FORMAT(5H RMIN,F10.2)
8  FORMAT(2F10.2/7F10.4,F10.2/7F10.4,
*F10.2/10X,3F10.4,10X,2F10.4,F10.2/)
9  FORMAT(7E10.3/7E10.3/7E10.3/7E10.3//)
10 FORMAT( 5H ALFA,F10.2)
11 FORMAT(3H CL,F10.2)
12 FORMAT(5HIRHC ,F6.5,6H QBAR ,F6.2,6H ALFA ,F6.5,6H DELE ,F6.5,
*7H THRST ,F6.1/)

C
C  READ DATA BLOCK FROM DEC TAPE
C
C  READ(5)DATA,WORKD

C
C  SELECT FLIGHT CONDITION
C
100 WRITE (1,1)
    READ(2,2) AIFLT
    IFLT=AIFLT+1

C
C  CHANGE RPV FLIGHT DATA
C
    WRITE(1,3)
    DO 50 I=1,73
50   DUM(I)= DATA(IFLT,I)
    CALL INPUT( DUM )
    DO 51 I=1,73
51   DATA(IFLT,I)= DUM(I)
    CALL RSW(3,SENSW(3))
    IF(.NOT.SENSW(3)) GO TO 102
    WRITE(1,4) (DATA(IFLT,J),J= 1,73)

C
C  CHANGE SCC DATA
C
102  WRITE(1,5)
    CALL INPUT(WORKD)
    CALL RSW(3,SENSW(3))
    IF(.NOT.SENSW(3)) GO TO 103
    WRITE(1,4) (WORKD(J),J= 110,299)

C

```

Figure 2 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINA

```

C      WRITE DATA BLOCK ON DEC TAPE
C
103    PAUSE 4
122    CALL RSW(2,SENSW(2))
      SFI= 1023./ TMAX
      WRITE(6) DATA,WCRKD
      STOP
C
C      TRANSFER DATA BLOCK TO COMMON
C
104    DO 106 I=1,73
106    CONSTD(I)= DATA(IFLT,I)
C
C      INITIALIZATIONS
C
      IFLAG=0
      ILIMIT=AILIM
      ABCDE= RANDUM(0,1,ILIMIT)
      NPRINT= ANPRNT
      INPRINT= NPRINT-1
      T=-DT
      DTI=DT/CTRL
      KTRL = CTRL +.1
      RANGP = 1. E12
      H=HC
      N=NC
      E=EC
      V=VC
      M=WGHT/32.2
      VSQ=V**2
      VNSQ= VNCM**2
      VV=VSQ/VNSQ
      RHC= .00238*EXP(-(HT+500.)/23111. )
      RHCSM2= RHC* S/(M* 2.)
      QSM=RHCSM2*VSQ
      QBAR=(RHC*VC**2)/2.
      ALFA= (WGHT* (CCS(GMAC)/(QBAR*S)- CLC)/
      *(CLA- CLDE* MA/MDE)
      ALFAD=0.
      BETA = 0.
      DEC= -MA* ALFA/ MDE
      DRC = 0.
      DAC = 0.
      DELE = DEC
      THRST = (WGHT*SIN(GMAC)+QBAR*S
      ***(CDE+CDCL*(CLC+CLA*ALFA+
      *CLDE*DELE)**2))/CCS(ALFA)
      TM=THRST/M
      P=0.
      Q=0.
      R=0.
      AZ=PSIVC
      EL=GMAC+ALFA
      BANK=0.
      SAZ=SIN(AZ)

```

Figure 2 (Continued):
 PROGRAM SOURCE LISTING
 FOR RPV SIMULATIONS--MAINA

Contrails

```
CAZ=CCS(AZ)
SEL=SIN(EL)
CEL=CCS(EL)
SBANK=0.
CBANK = 1.
A11 = CAZ*CEL
A12=SAZ*CEL
A13=-SEL
A21=CAZ*SEL*SBANK- $\dot{S}$ AZ*CBANK
A22=SAZ*SEL*SBANK+CAZ*CBANK
A23=CEL*SBANK
A31=CAZ*SEL*CBANK+ $\dot{S}$ AZ*SBANK
A32=SAZ*SEL*CBANK-CAZ*SBANK
A33=CEL*CBANK
GMA=GMA0
PSIV=PSIV0
CGMA=CCS(GMA)
SGMA=SIN(GMA)
CPSIV=CCS(PSIV)
SPSIV=SIN(PSIV)
ICD8=0
SF1= 1023./ TMAX
SF3=511./(SFT*2.)
SF4=511./(SFB*2. )
SF5=2047./ANGSF
SF6=2047.
SF7=2047./ANGSF
SF9=2047.
SF10=2047./ANGSF
SF11= 2047./ 50000.
SF12= 2047./ VNOM
SF13= 32726./ XMAX
SF14= 32726./ XMAX
SF15= 32726./ XMAX
SF16= 32726./ XMAX
CALL MKINIT
DMIN= 1.E-12

C
C PRINTOUT INITIAL CONDITIONS
C
WRITE(1,12) RHC,QBAR,ALFA,DELE,THRST
PAUSE 5

C
C START AERODYNAMIC SIMULATION
C
109 CALL MAINB(ITEST,ILIMIT,IFLAG,KTRL)
GC TO (114,116,112,113,100,120),ITEST

C
C HALT CONDITIONS
C
112 WRITE(1,6)H
GC TO 110
113 WRITE(1,7) RANGP
110 WRITE(1,8)T,RANGE,ETPRIM,DELE,Q,
*EL,ALFA,GAM,CL,H,ATPRIM,
```

Figure 2 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINA

```
*DELR,R,AZ,BETA,PSIV,CD,E,DELA,P,  
*BANK,V,CY,N  
GC TC 100  
114 WRITE(1,10) ALFA  
GC TC 110  
116 WRITE(1,11) CL  
GC TC 110  
C  
C NORMAL DATA PRINTOUT  
IPRINT=IPRINT+1  
IF(IPRINT.NE.NPRINT) GC TC 109  
CALL RSW(4,SENSW(4))  
120 IF (.NOT.SENSW(4)) GC TC 122  
WRITE(1,8)T,RANGE,ETPRIM,DELE,Q,EL,ALFA.GAM,CL,H,  
*ATPRIM,DELR,R,AZ,BETA,PSIV,CD,E,DELA,P,BANK,V,CY,N  
655 ' ' H 5 ↑ 5  
IF(SENSW(2)) WRITE(1,9)G11,DD(1),DD(5),  
*S11,R11,DELTU,G12,DD(2),DD(6),S12,EPSLN,  
*DXDD,G21,DD(3),DD(7),P21,R12,EPSLN,  
*G22,DD(4),WSC,S22,DETRM,U  
IPRINT=0  
GC TC 109  
END
```

Figure 2 (Concluded):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINA

```

C  SUBROUTINE (MAINB) TO PERFORM AERODYNAMIC SIMULATION OF RPV
C
C      SUBROUTINE MAINB(ITEST,ILIMIT,IFLAG,KTRL)
C      REAL M,L,JX,JY,JZ,JXZ,
C      *LDA,LDR,LB,LP,LR,
C      *MDE,MA,MAD,MQ,MT,
C      *NDR,NB,NR,NP,
C      *ND,N,NC,NT,
C      *KEPSL,KEPSQ,KUMAX
C
C      LOGICAL SENSW
C      DIMENSION SENSW(18)
C
C      COMMON/TDATA/DATA(6,73)
C
C      COMMON/CONST/DT,CTRL
C      COMMON/CONST/NC,EC,HC,GMAC,PSIVC,VC,HT
C      COMMON/CONST/WGHT,JX,JY,JZ,JXZ,S,B,L,VNOM
C      COMMON/CONST/LDA,LDR,LB,LP,LR
C      COMMON/CONST/MDE,MA,MAD,MQ,MT
C      COMMON/CONST/NDR,NB,NR,NP,AMAX
C      COMMON/CONST/CLC,CLA,CLAD,CLDE,CLQ,CLMIN,CLMAX
C      COMMON/CONST/CDE,CDCL,CDRAM
C      COMMON/CONST/CYB,CYDR,CYR,HMIN
C      COMMON/CONST/ETC,CAPA,G1,G2,G3,G4,G5,G6,
C      COMMON/CONST/GDE,GDA,GDR,GA,TA
C      COMMON/CONST/DEMAX,DAMAX,DRMAX,BCMAX
C      COMMON/CONST/ANGSF,SFT,SFB,AIDXT
C      COMMON/CONST/AILIM,ANPRNT
C
C      COMMON/WORK/DTI,VNSQ,RHC,RHCSM2,QBAR,THRST,TM
C      COMMON/WORK/DEC,DAC,DRC
C      COMMON/WORK/T,VSQ,VV,QSM
C      COMMON/WORK/PD,QD,RD,P,Q,R
C      COMMON/WORK/AZD,ELD,BANKD,AZ,EL,BANK
C      COMMON/WORK/SAZ,CAZ,SEL,CEL,SBANK,CBANK
C      COMMON/WORK/A11,A12,A13,A21,A22,A23,A31,A32,A33
C      COMMON/WORK/VX,VY,VZ,ALFAC,ALFA,ALFAD,BETA
C      COMMON/WORK/CL,CD,CY
C      COMMON/WORK/VD,GMA,PSIVD,V,GMA,PSIV
C      COMMON/WORK/CGMA,SGMA,SPSIV,CPSIV
C      COMMON/WORK/ND,ED,HD,N,E,H
C      COMMON/WORK/DXT,DYT,DZT,DXA,DYA,DZA
C      COMMON/WORK/AT,ET,RANGE,RANGP
C      COMMON/WORK/ATPRMC,ATPRIM,ETPRIM,BANKC
C      COMMON/WORK/X1,X2,XC1,XC2,U1,U2
C      COMMON/WORK/EP1,EP2,E1,E2,EI1,EI2,ED1,ED2
C      COMMON/WORK/DELE,DELA,DELR
C      COMMON/WORK/SF1,SF2,SF3,SF4,SF5,SF6,SF7
C      COMMON/WORK/SF8,SF9,SF10,SF11,SF12,SF13,SF14,SF15,SF16
C
C      COMMON/WORK/GERCR(2),GRATE(2),GINIG(2),UMAX(2),KEPSL(2),EPSMN(2),
C      * EPSMX(2),KUMAX,DTCNT,RNCNT,TCORL,GBIAS,DMIN,RX,WGHTX(16),
C      * WGHTU(16),X(2),XC(2),U(2),ERRCR(2),EPAST(2),ERINT(2),TED(2),
C      * FE(2),DXDD(2),DELTU(2),DD(7),GSQ(2),TCNT(2),TINT(2),EPSQ(2),

```

Figure 3:
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB
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```

*   EPMAG(2),SGN(2),BIAS(2),EPSLN(2),UPRIM(2),UMAX1(2)
COMMON/WORK/GSQMN(2),GSQMX(2),KEPSQ(2),S11,S12,S21,S22,R11,R12,R22
*   DETRM,G11,G12,G21,G22,TCRL1,TCRL2,XTRA,WSQ,XSTCR(2,16),
*   USTCR(2,16),EPMGS,NCNT,MCNT,KCUNT
C
COMMON/ICDD/ICD1,ICD2,ICD3,ICD4,ICD5,ICD6,
*ICD7,ICD8,ICD9,ICD10,ICD11,ICD12,ICD13,ICD14,ICD15,ICD16
C
DIMENSION CCNSTD(73),WORKD(302),ICD(16)
EQUIVALENCE (CCNSTD(1),DT),(WORKD(1),DTI),(ICD(1),ICD1)
C
C   INCREMENT TIME
C
100   T=T+DT
C
C   ROTATIONAL EQUATIONS
C
      VSQ=V**2
      VV=VSQ/VNSQ
      QSM=RHCOSM2*VSQ
C
C   BEGIN INNER LOOP
C
      KTR=0
150   PD=VV*(LDA*DELA+LDR*DELR+LB*BETA+LP*P+LR*R)
      QD=VV*(MDE*DELE+MA*ALFA+MAD*ALFAD+MQ*Q+MT*THRST)
      RD=VV*(NDR*DELR+NB*BETA+NR*R+NP*P)
C
C   INTEGRATE TO OBTAIN P,Q,R
C
      P=P+PD*DTI
      Q=Q+QD*DTI
      R=R+RD*DTI
C
C   TRANSFORM P,Q,R INTO INERTIAL
C   ORIENTATION RATES AZD,ELD,BANKD
C
      TEMP1=SBANK/CEL
      TEMP2=CBANK/CEL
      AZD=TEMP1*Q + TEMP2*R
      ELD= CBANK*Q - SBANK*R
      BANKD= P +(TEMP1*Q+TEMP2*R)*SEL
C
C   INTEGRATE TO OBTAIN AZ,EL,BANK
C
      AZ=AZ+AZD*DTI
      EL=EL+ELD*DTI
      BANK=BANK+BANKD*DTI
C
C   COMPUTE SIN, COS OF AZ,EL,BANK
C
      SAZ=SIN(AZ)
      CAZ=COS(AZ)
      SEL=SIN(EL)
      CEL=COS(EL)

```

Figure 3 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB


```

SBANK=SIN(BANK)
CBANK=CCS(BANK)
C
C  COMPUTE 'A' MATRIX
C
A11=CAZ*CEL
A12=SAZ*CEL
A13=-SEL
TEMP1=SEL*SBANK
TEMP2=SEL*CBANK
A21=CAZ*TEMP1-SAZ*CBANK
A22=SAZ*TEMP1+CAZ*CBANK
A23=CEL*SBANK
A31=CAZ*TEMP2+SAZ*SBANK
A32=SAZ*TEMP2-CAZ*SBANK
A33=CEL*CBANK
C
C  COMPUTE COMPONENTS OF V IN
C  RPV BODY AXES
C
TEMP1=CGMA*CPSIV
TEMP2=CGMA*SPSIV
VX=A11*TEMP1+A12*TEMP2-A13*SGMA
VY=A21*TEMP1+A22*TEMP2-A23*SGMA
VZ=A31*TEMP1+A32*TEMP2-A33*SGMA
C
C  COMPUTE AERODYNAMIC ANGLES AND
C  ALFA-DOT
C
ALFAC=ALFA
ALFA=VZ/VX
ALFAD = (ALFA-ALFAC)/DTI
C
C  END INNER LOOP
C
KTR= KTR + 1
IF( KTR.LT. KTRL ) GO TO 150
C
C  TEST FOR OUT-OF-BOUNDS ALFA
C
IF(ABS(ALFA).LE.AMAX)GOTO200
ITEST=1
RETURN
C
C  COMPUTE LIFT, DRAG, AND SIDEFORCE
C  COEFFICIENTS
C
200 CL=CLC+CLA*ALFA+CLAD*ALFAD
  *+CLDE*DELE+CLQ*Q
C
C  TEST FOR OUT-OF-BOUNDS CL
C
IF((CL.LE.CLMAX).AND.(CL.GE.CLMIN))GO TO 201
ITEST=2
RETURN

```

Figure 3 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB


```

C
201  CD=CDE+CDCL*CL**2+CDAM
    CY=CYB*BEYA+CYDR*DELX+CYR*R
C
C    COMPUTE AIRSPEED, GAMMA, PSIV RATES
C
    VD=TM-32.2*SGMA-QSM*CD
    TEMP1= 1./V
    TEMP2=TM*ALFA
    GMAD=TEMP1*(TEMP2-32.2*CGMA
    *QSM*(CL*CBANK-CY*SBANK))
    PSIVD=(TEMP1/CGMA)*(TEMP2+
    *QSM*(CL*SBANK+CY*CBANK))
C
C    INTEGRATE TO OBTAIN V, GAMMA, PSIV
C
    V=V+VD*DT
    GMA=GMA+GMAD*DT
    PSIV=PSIV+PSIVD*DT
C
C    COMPUTE SIN, COS OF GAMMA, PSIV
C
    CGMA=COS(GMA)
    SGMA=SIN(GMA)
    CPSIV=COS(PSIV)
    SPSIV=SIN(PSIV)
C
C    COMPUTE GEOGRAPHIC TRANSLATIONAL
C    RATES
C
    ND=V*CGMA*CPSIV
    ED=V*CGMA*SPSIV
    HD=V*SGMA
C
C    INTEGRATE TO OBTAIN N,E,H
C
    N=N+ND*DT
    E=E+ED*DT
    H=H+HD*DT
C
C    TEST RPV ALTITUDE
C
    IF(H.GT.HMIN)GO TO 202
    ITEST=3
    RETURN
C
C    COMPUTE COMPONENTS OF LOS VECTOR
C    IN TERMS OF TARGET POSITION GIVEN
C    IN GEOGRAPHIC COORDINATES(NT,ET,HT)
C
202  DXT=-N
    DYT=-E
    DZT=H-HT
C
C    COMPUTE TARGET LOS BEARING RELATIVE

```

Figure 3 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB

Contrails

```
C      TC RPV BODY AXES(SMALL ANGLES ASSUMED)
C
RANGE=SQRT(DXT**2+DYT**2+DZT**2)
DXA= A11*DXT + A21*DYT + A31*DZT
DYA= A12*DXT + A22*DYT + A32*DZT
DZA= A13*DXT + A23*DYT + A33*DZT
ET= - DZA/DXA
AT=  DYA/DXA

C
C      CHECK FOR FLY-BY AND PUSH DOWN
C      PRESENT RANGE
C
      IF(RANGE.LT.RANGP) GC TC 203
      ITEST=4
      RETURN
203    RANGP=RANGE
C
C      GUIDANCE AND CONTROL COMPUTATIONS
C
      ATPRMG=ATPRIM
      ATPRIM=AT*CBANK-ET*SBANK
      ETPRIM=ET*CBANK+AT*SBANK

C
C      FILTER ATPRIM(PD COMPENSATION)
C      AND LIMIT
C
      BANKC = GA*ATPRIM+(ATPRIM-ATPRMG)*TA/DT
      IF(ABS(BANKC).GT.BCMAX)BANKC=SIGN(BCMAX,BANKC)

C
C      COMPUTE COMMAND INPUTS TO CONTROLLER
C
      XC1 = ETC
      XC2 = CAPA*(BANKC-BANK)

C
C      ASSIGN RPV SENSOR OUTPUTS TO
C      CONTROLLER FOR ERROR SIGNAL GENERATION
C
      X1=ETPRIM
      X2=P

C
C      SELECT CONTROLLER
C
      CALL SSW(6,SENSW(18))
      IF(SENSW(18)) GC TC 204

C
C      CALL SUBROUTINE TO COMMUNICATE
C      WITH CONSOLE MKVI SCC AND DISPLAY SCOPES
C
      CALL DATIC
204    CALL RSW(6,SWNSW(6))
      IF(SENSW(6)) GC TC 205
      CALL RSW(7,SENSW(7))
      IF(SENSW(7)) GC TC 206
      CALL RSW(8,SENSW(8))
      IF(SENSW(8)) GC TC 208
```

Figure 3 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB

```

      GC TC 209
C
C   OPEN LOOP TESTS
C
205  CALL SSW(1,SENSW(13))
      CALL SSW(2,SENSW(14))
      CALL SSW(3,SENSW(15))
      DELE=DEC
      DELA=0.
      DELR=0.
      IF(SENSW(13))DELE=DEC+.02
      IF(SENSW(14))DELA=.02
      IF(SENSW(15))DELR=.02
      GC TC 210
C
C   PID CONTROLLER
206  IF(IFLAG.EQ.1) GC TC 207
      EP1=XC1-X1
      EP2=XC2-X2
      EI1=0.
      EI2=0.
      IFLAG=1
C
207  E1=XC1-X1
      E2=XC2-X2
      ED1=(E1-EP1)/DT
      ED2=(E2-EP2)/DT
      EI1=EI1+E1*DT
      EI2=EI2+E2*DT
      EP1=E1
      EP2=E2
      U1 = G1*E1 + G2*ED1 + G3*EI1
      U2 = G4*E2 + G5*ED2 + G6*EI2
      GC TC 209
C
C   SOFTWARE SCC
C
208  CALL MKVI(ILIMIT)
C
C   COMPUTE CONTROL SURFACE DEFLECTIONS
C
209  DELE=DEC+GDE*U1
      DELA=DAC+GDA*U2
      DELR=DRC+GDR*U2
C
C   LIMIT CONTROL SURFACE DEFLECTIONS
C
      IF(ABS(DELE).GT.DEMAX)DELE=SIGN(DEMAX,DELE)
      IF(ABS(DELA).GT.DAMAX)DELA=SIGN(DAMAX,DELA)
      IF(ABS(DELR).GT.DRMAY)DELR=SIGN(DRMAY,DELR)
C
C   PROGRAM STOP AND PRINT OPTIONS
C
210  CALL RSW(5,SENSW(5))
      IF(.NCT. SENSW(5)) GC TC 211

```

Figure 3 (Continued):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB

```
      ITEST=5  
      RETURN  
211   CALL RSW(5,SENSW(5))  
      CALL RSW(2,SENSW(2))  
      IF((.NOT.SENSW(2)).AND.(.NOT.SENSW(4)))GO TO 100  
      ITEST=6  
      RETURN  
      END
```

Figure 3 (Concluded):
PROGRAM SOURCE LISTING
FOR RPV SIMULATIONS--MAINB

```

C      SUBROUTINE FOR PDP12-SOC DATA COMMUNICATIONS
C
C      SUBROUTINE DATIG
C
C      REAL M,L,JX,JY,JZ,JXZ,
*      LDA,LDR,LB,LP,LR,
*      MDE,MA,MAD,MQ,MT,
*      NDR,NB,NR,NP,
*      ND,N,NC,NT,
*      KEPSL,KEPSQ,KUMAX
C
C      LOGICAL SENSW
C      DIMENSION SENSW(18)
C
C      COMMON/TDATA/DATA(6,73)
C
C      COMMON/CONST/DT,CTRL
COMMON/CONST/NC,EC,HC,GMAC,PSIVC,VC,HT
COMMON/CONST/WGHT,JX,JY,JZ,JXZ,S,B,L,VNOM
COMMON/CONST/LDA,LDR,LB,LP,LR
COMMON/CONST/MDE,MA,MAD,MQ,MT
COMMON/CONST/NDR,NB,NR,NP,AMAX
COMMON/CONST/CLC,CLA,CLAD,CLDE,CLQ,CLMIN,CLMAX
COMMON/CONST/CDE,CDCL,CDRAM
COMMON/CONST/CYB,CYDR,CYR,HMIN
COMMON/CONST/ETC,CAPA,G1,G2,G3,G4,G5,G6,
COMMON/CONST/GDE,GDA,GDR,GA,TA.
COMMON/CONST/DEMAX,DAMAX,DRMAX,BCMAX
COMMON/CONST/ANGSF,SFT,SFB,AIDXT
COMMON/CONST/AIDXB,XMAX,IMAX
COMMON/CONST/AILIM,ANPRNT
C
COMMON/WORK/DII,VNSQ,RHC,RHCSM2,QBAR,THRST,IM
COMMON/WORK/DEG,DAG,DRG
COMMON/WORK/T,VSQ,VV,QSM
COMMON/WORK/PD,QD,RD,P,Q,R
COMMON/WORK/AZD,ELD,BANKD,AZ,EL,BANK
COMMON/WORK/SAZ,CAZ,SEL,CEL,SBANK,CBANK
COMMON/WORK/A11,A12,A13,A21,A22,A23,A31,A32,A33
COMMON/WORK/VX,VY,VZ,ALFAC,ALFA,ALFAD,BETA
COMMON/WORK/CL,CD,CY
COMMON/WORK/VD,GMAD,PSIVD,V,GMA,PSIV
COMMON/WORK/CGMA,SGMA,SPSIV,CPSIV
COMMON/WORK/CGMA,SGMA,SPSIV,CPSIV
COMMON/WORK/ND,ED,HD,N,E,H
COMMON/WORK/DXT,DYT,DZT,DXA,DYA,DZA
COMMON/WORK/AT,ET,RANGE,RANGP
COMMON/WORK/ATPRMC,ATPRIM,ETPRIM,BANKC
COMMON/WORK/X1,X2,XC1,XC2,U1,U2
COMMON/WORK/EP1,EP2,E1,E2,EI1,EI2,ED1,ED2
COMMON/WORK/DELE,DELA,DELR
COMMON/WORK/SF1,SF2,SF3,SF4,SF5,SF6,SF7
COMMON/WORK/SF8,SF9,SF10,SF11,SF12,SF13,SF14,SF15,SF16
C
COMMON/WORK/GERGR(2),GRATE(2),GINTG(2),UMAX(2),KEPSL(2),EPSMN(2),

```

Figure 4:
SUBROUTINE FOR PDP-12 COMMUNICATIONS
WITH SOC
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```
* EPSMX(2),KUMAX,DTCNT,RNCNT,TCRL,GBIAS,DMIN,RX,WGHTX(16),
* WGHTU(16),X(2),XC(2),U(2),ERROR(2),EPAST(2),ERINT(2),TED(2),
* FE(2),DXDD(2),DELTU(2),DD(7),GSQ(2),TCNT(2),TINT(2),EPSQ(2),
* EPMAG(2),SGN(2),BIAS(2),EPSLN(2),UPRIM(2),UMAX(2)
COMMON/WORK/GSQMN(2),GSQMX(2),KEPSQ(2),S11,S12,S21,S22,R11,R12,R22
* DETRM,G11,G12,G21,G22,TCRL1,TCRL2,XTRA,WSQ,XSTCR(2,16),
* USTCR(2,16),EPMGS,NCNT,MCNT,KCUNT
```

```

DIMENSIONED CCNSTD(73), WORKD(302), ICD(16)
EQUIVALENCE (CCNSTD(1), DT), (WORKD(1), DT1), (ICD(1), ICD1)
IDXT=AIDCT
IDXB=AIDXB

```

```

C      STORAGE SCOPE
      ICD1=T*SF1-511.
      ICD2=ICD1
      ICD3=WCRKD(IDXT)*SF3+255.
      ICD4=WCRKD(IDXB)*SF4-255.

```

ICD5=-EL*SF5
ICD6=SBANK*SF6
ICD7=ET*SF7
ICD9=CBANK*SF9
ICD10=AT*SF10
GG TC 200

C
C ALTITUDE AND AIRSPEED

C
C
C

FORMAT RECEIVE DATA

```
U1=ICD1
U2=ICG2
RETURN
END
```

Approved for Public Release

```
C  SUBROUTINE TO ACCEPT REAL INPUTS FROM THE KEYBOARD
C
      SUBROUTINE INPUT(VAR)
      DIMENSION VAR(1)
6      FORMAT (4HN = /)
7      FORMAT (15,3H = /)
8      FORMAT (16. 8)
100     WRITE(1,6)
      READ(2,8) AN
      N = AN + .1
      IF(N.EQ.0) RETURN
      IF(N. LT.0) GO TO 130
      WRITE(1,7) N
      READ (2,8) VAR(N)
      GO TO 100
130     N=-N
      WRITE(1,8) VAR(N)
      GO TO 100
      END
```

Figure 5:
SUBROUTINE TO ACCEPT
INPUTS FROM KEYBOARD

- (1) temporary variables are defined to reduce repetitive computations;
- (2) tests are made on lift coefficient, alpha, altitude, and fly-by so as to abort the run in the event of out-of-bound conditions; and
- (3) an inner loop is used to integrate the rotational dynamics with a smaller integration interval than is used for translational dynamics.

Provisions are made to select either direct-manual control of the RPV, control via the Mark VI SOC in the pilot's console, or control via a conventional controller (simulated in the PDP-12). The operator will be able to make comparisons between the SOC and conventional controllers when parameter values for the latter have been determined in future work. An option is also provided for open-loop flight. This enables the operator to evaluate RPV responses to step-function surface displacements.

A software simulation of the Mark VI SOC was included in the original version of the program and was addressed from MAINB. However, this routine was used for diagnostic purposes only and is not provided as a user option.

DAT10

DAT10 is a subroutine used to set up variables that are transmitted to the SOC and the pilot's console. It also formats the control signals generated by the SOC and places them in the proper core locations for use by MAINB.

DAT10 makes a call to a special subroutine, PDP10, to perform the actual variable transfers to and from the SOC and pilot's console.

PDP10

PDP10 is a machine language subroutine used to communicate directly with the SOC and pilot's console. It takes the variables set up by DAT10, converts them to 12-bit integers, and transmits them to the SOC and other hardware registers in the console. In addition, it receives the control signals generated by the SOC on the control stick and makes them available to DAT10 for subsequent use in MAINB.

Data Input and Output

The RPV program is designed to perform a real-time simulation that operates with any one of six airframes and flight conditions. When the RPV program is loaded into core and started, the Decwriter will automatically print "Select Flight Condition". The operator then types a single digit (1 through 6) corresponding to the flight condition of interest. The corresponding airframe constants will be read from Dec-tape into the PDP-12 memory. These constants may be left as they are, or they may be changed with the INPUT subroutine to any value desired.

In addition to the variables displayed on the oscilloscopes and pilot's console indicators, important variables can also be printed on the Decwriter during a simulation run for documentation purposes.

At the end of each run a printout is provided to indicate the RPV status and its relationship to the target. A list of the actual variables printed out may be seen by referring to the presentation of operating procedures in Appendix B.

Appendix C contains the circuit schematics for the instrument indicators installed in the pilot's console during this project.

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3. Study of Multi-Mission Remotely Piloted Vehicle Systems, Volume III, Northrop Corporation, Newbury Park, California, NVR-72-10.
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Appendix A

DISCUSSION OF ASSUMPTIONS USED IN SIMULATION EQUATIONS

The assumptions used in formulating the simulation equations presented in Section II are discussed below.

(1) The RPV angles of attack and sideslip, α and β , respectively, are sufficiently small that their cosines can be reasonable approximated by unity and their sines by the radian measures of these angles.

The RPV equations of motion are founded on the usual Taylor-series expansions of the form

$$G = G(0) + \alpha \frac{\partial G}{\partial \alpha} + \beta \frac{\partial G}{\partial \beta} + \alpha \beta \frac{\partial^2 G}{\partial \alpha \partial \beta} + \frac{1}{2} \alpha^2 \frac{\partial^2 G}{\partial \alpha^2} + \frac{1}{2} \beta^2 \frac{\partial^2 G}{\partial \beta^2} + \dots \quad (\text{A:1})$$

where G is an aerodynamic force or torque and the partial derivatives of G are evaluated at $\alpha = 0$, $\beta = 0$. In the RPV simulations, most of the second- and higher-order stability derivatives of Eq. (A:1) are ignored because of the lack of aerodynamic data and/or theoretical estimates suitable for their determination. The only partial derivative higher than first order that is retained is $\partial^2 C_D / \partial \alpha^2$; i.e., the simulation uses

$$K \equiv \frac{\partial^2 C_D}{\partial C_L^2} = \frac{\partial^2 C_D}{\partial \alpha^2} \left(\frac{\partial \alpha}{\partial C_L} \right)^2 \quad (\text{A:2})$$

which is the drag-due-to-lift (induced-drag) factor.

Because the force and moment equations (particularly the moment equations) are linearized, α and β must be small so that the Taylor series remain valid representations of aerodynamic effects on the RPV. Generally speaking, this means that the magnitudes of α and β must be less than approximately 0.2 radian. It is emphasized that this restriction is imposed by the lack of more complete aerodynamic data.

For angles within the range $-0.2 + 0.2$ radian, the approximation $\cos () = 1$ produces an error of about 2 percent and the approximation $\sin () = ()$ produces an error of less than 1 percent. These errors are less than the uncertainties in the stability derivatives.

(2) It is assumed that the body-axes angular-rate cross-product terms (PQ, QR, PR) and product-of-inertia terms (J_{xz} , J_{xy} , J_{yz}) are negligible in the moment-balance equations.

The complete equations of moment balance (conservation of angular momentum) are as follows:

Angular momentum components

$$H_x = J_x P - J_{xy} Q - J_{xz} R \quad (A:3)$$

$$H_y = J_y Q - J_{xy} P - J_{yz} R \quad (A:4)$$

$$H_z = J_z R - J_{xz} P - J_{yz} Q \quad (A:5)$$

Angular momentum component derivatives

$$\dot{H}_x = \Sigma M_x + H_y R - H_z Q \quad (A:6)$$

$$\dot{H}_y = \Sigma M_y - H_x R + H_z P \quad (A:7)$$

$$\dot{H}_z = \Sigma M_z + H_x Q - H_y P \quad (A:8)$$

in which ΣM_x , ΣM_y , ΣM_z denote summations of aerodynamic moments about the RPV body axes.

Substituting Eqs. (A:3) - (A:5) into (A:6) - (A:8), one obtains, for constant inertia properties of the vehicle:

$$\begin{aligned} \dot{H}_x &= \Sigma M_x + (J_y - J_z) QR + \\ &\quad J_{xz} PQ - J_{xy} PR + J_{yz} (Q^2 - R^2) \end{aligned} \quad (A:9)$$

$$\begin{aligned} \dot{H}_y &= \Sigma M_y + (J_z - J_x) PR + \\ &\quad J_{xy} QR - J_{yz} PQ - J_{xz} (P^2 - R^2) \end{aligned} \quad (A:10)$$

$$\begin{aligned} \dot{H}_z &= \Sigma M_z + (J_x - J_y) PQ - \\ &\quad J_{xz} QR + J_{yz} PR + J_{xy} (P^2 - Q^2) \end{aligned} \quad (A:11)$$

Generally, the vehicle axes are chosen in such a way that $J_{xy} = J_{yz} = 0$. Additionally, yaw stabilization via both passive and active means is employed so as to maintain very small magnitudes of the yaw rate, R . Accordingly, Eqs. (A:9) - (A:11) reduce to:

$$\dot{H}_x = \Sigma M_x + J_{xz} PQ \quad (A:12)$$

$$\dot{H}_y = \Sigma M_y - J_{xz} P^2 \quad (A:13)$$

$$\dot{H}_z = \Sigma M_z + (J_x - J_y) PQ \quad (A:14)$$

Advanced rectangular integration of these relationships may be performed as follows:

$$H_{x_n} = H_{x_{n-1}} + \delta t \dot{H}_{x_n} \quad (\text{A:15})$$

$$H_{y_n} = H_{y_{n-1}} + \delta t \dot{H}_{y_n}$$

$$H_{z_n} = H_{z_{n-1}} + \delta t \dot{H}_{z_n} \quad (\text{A:17})$$

whence:

$$P = (J_z \dot{H}_x + J_{xz} \dot{H}_z) / (J_x J_z - J_{xz}^2) \quad (\text{A:18})$$

$$Q = \dot{H}_y / J_y \quad (\text{A:19})$$

$$R = (J_{xz} \dot{H}_x + J_x \dot{H}_z) / (J_x J_z - J_{xz}^2) \quad (\text{A:20})$$

Typical values of the inertial parameters are (for flight condition D):

$$J_x = 973.5 \text{ slug-ft.}^2$$

$$J_y = 2,139.3 \text{ slug-ft.}^2$$

$$J_z = 3,002.9 \text{ slug-ft.}^2$$

$$J_{xz} = 61.1 \text{ slug-ft.}^2$$

$$J_{xy} = J_{yz} = 0$$

Consider, as an extreme case, that $P = 7.85$ rad./sec. (45° of roll attitude change in 0.1 sec.), $Q = 1.75$ rad./sec. (10° of pitch attitude change in 0.1 sec.), and $R = 0.0175$ rad./sec. (0.1° of yaw attitude change in 0.1 sec.). Then Eqs. (A:9) - (A:11) give:

$$\dot{H}_x = \Sigma M_x + 812.9$$

$$\dot{H}_y = \Sigma M_y - 3,486.3$$

$$\dot{H}_z = \Sigma M_z - 16,017.1$$

But (also for flight condition D):

$$L_{\delta_a} = 69.75 \text{ sec.}^{-2}$$

$$M_{\delta_e} = - 121.0 \text{ sec.}^{-2}$$

$$N_{\delta_r} = - 46.74 \text{ sec.}^{-2}$$

and, therefore, the control surface deflections required to balance the cross-coupled torques resulting from PQ, PR, QR, and J_{xz} are:

$$\delta_a = - \frac{812.9}{J_x L_{\delta_a}} = - 0.011,97 \text{ rad.} = - 0.686^\circ$$

$$\delta_e = \frac{3,486.3}{J_y M_{\delta_e}} = - 0.013,47 \text{ rad.} = - 0.772^\circ$$

$$\delta_r = \frac{16,017.1}{J_z N_{\delta_r}} = - 0.114,12 \text{ rad.} = - 6.538^\circ$$

The SOC introduces small experimental motions of the aileron and elevator surfaces as a means of acquiring information about RPV characteristics. As is seen, these motions will ideally have a magnitude in excess of approximately 0.7 deg. so that J_{xz} -induced torques do not overemphasize the cross-axes responses to SOC experiments. Provided the SOC experiments have at least this magnitude, the J_{xz} effects will be of secondary significance in most RPV simulations.

However, the PQ cross coupling can be very important. As seen in the above example, 6.5 deg. of rudder deflection are required in an extreme case to balance the PQ-induced torque about \vec{z} . The assumption that this torque is negligible in the moment-balance equations can thus be invalid if extreme angular rates are involved. Nevertheless, since it is usually the practice to incorporate active yaw damping in high-performance aircraft, largely for the purpose of compensating for PQ coupling, it follows that -- to a first approximation -- RPV simulations that omit this coupling and also omit simulation of means for active yaw damping will produce results comparable to simulations that include both.

The SOC generally does not need δ_r authority, provided a yaw damper is used, because the SOC functions in a roll-pitch rather than pitch-yaw mode (Ref. 1).

In summary, the PQ and, to a lesser extent, the J_{xz} contributions cannot be ignored for accurate simulations under conditions of extremely high angular rates of the RPV. Accordingly, Eqs. (A:12) - (A:20) should be used for simulation when P and Q are very large.

(3) Atmospheric density (ρ) is assumed to be essentially constant throughout the RPV maneuver and wind velocities are zero.

The following short table of standard density vs. geometric altitude is taken from Ref. 5 :

<u>h, ft</u>	<u>ρ, slug/ft.³†</u>
0	0.002,375
500	0.002,340
1,000	0.002,306
1,500	0.002,272
2,000	0.002,239
10,000	0.001,754
15,000	0.001,495
20,000	0.001,266
25,000	0.001,065
30,000	0.000,890

Consider an air-to-ground strike having a mean altitude of 500 ft. If the RPV maneuvers between 1,000 and 0 ft., ρ varies a maximum of $\pm 0.000,035$ slug/ft.³ (± 1.5 percent) relative to the mean density ($\bar{\rho} = 0.002,340$ slug/ft.³). This is less than the density variation expected in going from a hot day to a cold day. However, if the RPV engages in air-to-air combat or otherwise maneuvers over a range of altitudes about a mean altitude of 20,000 ft., the following maximum variations in density can be expected relative to the mean density ($\bar{\rho} = 0.001,266$ slug/ft.³):

- (a) Changes of $\pm 5,000$ ft. about the mean h result in
- 0.000,202 slug/ft.³ (- 15.9 percent) and + 0.000,229
slug/ft.³ (+ 18.1 percent) changes in ρ ;

†Assuming $g = 32.2$ ft./sec.² independently of h .

- (b) Changes of $\pm 10,000$ ft. about the mean h result in
- $0.000,376$ slug/ft.³ (- 29.7 percent) and + $0.000,488$
slug/ft.³ (+ 38.5 percent) changes in ρ .

The assumption of constant density is thus entirely appropriate for terminal ground-strike maneuvers but not for typical air-to-air engagements.

The assumption of zero wind velocities is usually not realistic but is defensible on the basis of the substantial computing load that would arise were one to give exact treatment to wind effects. These effects are discussed in Ref. 5 and elsewhere in the literature. For investigations of man-machine performance, it is often sufficient to simulate wind effects by introducing small random fluctuations in α , β , and V . Although using this simplified approach substantially reduces the computational burden, it still requires the generation of random $\Delta\alpha$, $\Delta\beta$, and ΔV variables having appropriate frequency distributions, a task causing the PDP-12 to exceed its available solution time unless special external equipment is used.

Wind effects in an operational RPV system would tend to cause degradation of (a) manual control accuracy (due to display jitter) and (b) automatic control accuracy (due to noise on line-of-sight (A_T , E_T) input signals for the SOC or other controller). In extreme cases, winds could induce loss of control due to wing or control surface stall or engine flameout, particularly if the RPV is being flown by a very "tight" inertial or sight-line control loop (either manual or automatic).

(4) The aerodynamic coefficients (partial derivatives) of the RPV are essentially constant throughout its maneuvers.

In general, the aerodynamic coefficients are functions of dynamic pressure, Mach number, and the angles α , β , δ_a , δ_e , and δ_r . Dynamic pressure and Mach number are the most important sources of variation in the coefficients. The dynamic pressure influence is taken fully into account (subject to the assumption that ρ is constant) by the factor (q/\bar{q}) in Eqs. (1) - (3) and (35) - (37) of Section II.

The Mach number dependence has been considered to the extent that aerodynamic coefficients are given the numerical values pertaining to initial Mach conditions (see Tables 1-3 in Section II). This is a good assumption in the mid-subsonic range ($M = 0.2$ to 0.9), where the coefficients depend only weakly on Mach number, but is generally not acceptable in other regimes, particularly in transonic flight ($M = 0.9$ to 1.1). None of the flight conditions simulated is outside of the mid-subsonic range, and for these vehicles only the air-to-air intercept case is likely to involve RPV acceleration into the transonic regime.

Provided the RPV is flying at a Mach number below transonic, dependence of aerodynamic coefficients on small α , β , and control-surface deflection angles is not important. In any event, little or no data are available by which such dependence could be characterized for the subject airframes.

Another source of variation in aerodynamic coefficients is the release of external stores. This has been considered in selecting vehicle configurations and flight conditions to be simulated (some cases with stores, some without), but no provisions have been made for altering coefficients during the simulated maneuvers, as to do so would require more computing speed than is offered by the PDP-12 system.

(5) Mass and thrust of the RPV are essentially constant throughout its maneuvers.

Mass variations arise from consumption of fuel and may also occur due to ordnance release. For probable thrust specific fuel consumption rates of approximately one pound of fuel per pound of thrust per hour, a 30 sec. maneuver at a thrust of 1,673 lb. requires about 14 lb. of fuel, and a two-minute maneuver at a thrust of 2,400 requires about 80 lb., or about 0.3 percent and 3.1 percent, respectively, of the air-to-ground and air-to-air RPV initial mass values (for flight conditions D and C, respectively). Comparable variations in the moments of inertia can be expected. Thus, because of the small percentage variations that occur in mass and moments of inertia, neglecting effects of fuel consumption on RPV dynamics is entirely justified for brief maneuvers.

The effects of ordnance and other stores releases during RPV maneuvers can be profound, altering the total mass and mass distribution markedly. But, because the release of stores also changes the aerodynamic characteristics of the RPV, no provisions have been made for this purpose in the simulation, due to limitations of computer speed.

Thrust variations, if the throttle setting is constant, result primarily from varying airspeed and varying ambient temperature and pressure conditions. Additionally, the effects of wind gusts and of large angles of attack and sideslip may be important, and, in some instances, the ingestion of smoke or jet engine or rocket engine exhaust gases can produce significant drops in thrust. The effects of changes in airspeed, temperature, and pressure could be modeled (given sufficient engine and inlet data) at considerable cost in solution time, but it is believed that these effects are not large for the narrow speed-altitude envelopes of interest here (the air-to-air RPV may be an exception).

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However, simulation of the other thrust variations would completely over-tax the capabilities of the PDP-12 computer system.

Appendix B

RPV SIMULATION OPERATING PROCEDURES

This appendix presents the start-up and operating procedures for the RPV/SOC Demonstration System. All the flight conditions, system parameters, and controls which may be varied by the operator are listed in check-list form to permit ease of experiment design, execution, and documentation.

EQUIPMENT STARTUP PROCEDURES

Starting up the RPV/SOC Demonstration System involves the connection of the Demonstrator Console to the PDP-12 computer and the startup of the Console and computer. Always make certain all systems are powered off before connecting or disconnecting console/computer cables.

Console/Computer Connection

The console is connected to the computer as follows:

- (1) Remove the PDP-12 data base termination card from socket N14. (This socket is located at the bottom of the PDP-12 chassis containing the TU-10 magnetic tape system.)
- (2) Plug the Console connectors, on the cables coming out of the lower rear portion of the Console, into PDP-12 sockets N14, N15, and N16. The connectors are appropriately labeled and are keyed such that they cannot be inserted backward.

Reversing the above sequence disconnects the Console/computer interface.

Console Startup

The main power switch on the rear panel of the SOC Console applies power to all subsystems in the Console. By depressing the initialize switch next to the power switch, all subsystems are automatically initialized. (The display oscilloscopes have power switches on the front panel. These must be on for the scopes to work; however, these switches may be left on at all times, since power is cut off when the Console main power switch is turned off.) After allowing 15-20 seconds for the oscilloscopes to warm-up, adjust the focus on each one so as not to produce a sharply focused beam. This will preclude the possibility of burning the phosphors with pin-point beams.

Computer Startup

The PDP-12 computer program is stored on the magnetic tape reel labeled "RPV/SOC Simulation." The computer is started and the program loaded as follows: (Note: ↵ indicates a carriage return on the Decwriter. Spaces are indicated by an underscore (_).)

1. Turn on power. The power key is located on the black vertical panel to the left of the console.
2. Clean the heads on each tape unit. Put the RPV/SOC System tape on tape drive unit "0" and the RPV/SOC Work tape on tape drive unit "1." Place both tape units in "local mode" and fast forward each tape for 2 or 3 seconds. Switch both units to the "remote" and "write enable" positions.
3. Set all switches on the computer console to the "up" or "logical zero" condition, except left switches 3, 4, and 5 are depressed for a "logical one" condition.

4. Load the System Monitor by pressing the following switches in sequence:

- (a) I/O Preset
- (b) D0 (Note: Allow tapes to stop spinning, 2-3 seconds, before proceeding to (c))
- (c) START 20 (Note: A dot (.) will automatically be typed on the Decwriter.

5. Type the date:

DA_X/XX/XX ↵

6. Load the program loader routine by typing:

R_LOAD ↵

7. After an asterisk (*) is typed, load the RPV program by typing:

LTA0: RPV/D ↵

8. After the asterisk is again typed, the flight condition data block "CONST" is initialized with the "nominal" flight condition data. Type:

LTA1: DATA/5 ↵

The RPV program will be loaded into core and will begin execution by typing "SELECT FLT COND" on the Decwriter.

The system is now ready for operation.

OPERATING PROCEDURES

Once the system has been started, it is operated as follows:

- (1) Type in the desired flight condition number (1., 2., ..., 6.) in floating point notation. (Typing in a zero (0.) will leave the flight condition the same as the prior run.)
- (2) "CHANGE CONSTANTS" is automatically typed. Set the desired initial simulation conditions in accordance with "RPV Parameters." Table B1 presents data which may be altered. Since the "nominal" sets of initial conditions, for all flight conditions, are placed into the constant blocks at load time, only variations from these conditions need be typed in.
- (3) The RPV/SOC run is automatically initialized upon exit from the Change Constants Routine. The values for ρ , \bar{q} , α_0 , δ_{e_0} , and Thrust_0 are typed out, and the program pauses at Pause 0.
- (4) Set sense switches in accordance with "Sense Switch Options."
- (5) Select the SOC controller mode in accordance with "SOC Control Mode Options."
- (6) Select the SOC controller parameters in accordance with "SOC Controller Parameters." Table B2 presents the data which may be altered.
- (7) Depress the PDP-12 console "Continue" switch to begin the simulation run from $t = 0$.

Table B1: INDICES RPV FLIGHT CONDITION PARAMETERS
AND INITIAL CONDITIONS

<u>N</u>	<u>Variable</u>			<u>N</u>	<u>Variable</u>		
1.	DT	.....	_____	41.	CDE	.....	_____
2.	CTRL	.....	_____	42.	CDCL	.....	_____
3.	NO	.....	_____	43.	CDRAM	.....	_____
4.	EO	.....	_____	44.	CYB	.....	_____
5.	HO	.....	_____	45.	CYDR	.....	_____
6.	GMAO	.....	_____	46.	CYR	.....	_____
7.	PSIVO	.....	_____	47.	HMIN	.....	_____
8.	VO	.....	_____	48.	AIT	.....	_____
9.	HT	.....	_____	49.	ETC	.....	_____
10.	WGHT	.....	_____	50.	CAPB	.....	_____
11.	JX	.....	_____	51.	GA	.....	_____
12.	JY	.....	_____	52.	TA	.....	_____
13.	JZ	.....	_____	53.	BCMAX	.....	_____
14.	JXZ	.....	_____	54.	CAPA	.....	_____
15.	S	.....	_____	55.	GP1	.....	_____
16.	B	.....	_____	56.	GP2	.....	_____
17.	L	.....	_____	57.	GP3	.....	_____
18.	VNOM	.....	_____	58.	GP4	.....	_____
19.	LDA	.....	_____	59.	GP5	.....	_____
20.	LDR	.....	_____	60.	GP6	.....	_____
21.	LB	.....	_____	61.	GR1	.....	_____
22.	LP	.....	_____	62.	GR2	.....	_____
23.	LR	.....	_____	63.	GR3	.....	_____
24.	MDE	.....	_____	64.	GR4	.....	_____
25.	MA	.....	_____	65.	GR5	.....	_____
26.	MAD	.....	_____	66.	GR6	.....	_____
27.	MQ	.....	_____	67.	GDE	.....	_____
28.	MT	.....	_____	68.	GDA	.....	_____
29.	NDR	.....	_____	69.	GDR	.....	_____
30.	NB	.....	_____	70.	DEMAX	.....	_____
31.	NR	.....	_____	71.	DAMAX	.....	_____
32.	NP	.....	_____	72.	DRMAX	.....	_____
33.	AMAX	.....	_____	73.	ANGSF	.....	_____
34.	CLO	.....	_____	74.	SFT	.....	_____
35.	CLA	.....	_____	75.	SFB	.....	_____
36.	CLAD	.....	_____	76.	AIDXT	.....	_____
37.	CLDE	.....	_____	77.	AIDXB	.....	_____
38.	CLQ	.....	_____	78.	XMAX	.....	_____
39.	CLMIN	.....	_____	79.	TMAX	.....	_____
40.	CLMAX	.....	_____	80.	ANDPRNT	.....	_____
				101.	TYPE OUT	.....	_____

- Notes: 1) Both the indices and the variables must be typed using floating point format.
- 2) Explanations of the variables are presented in Table 4, page 27.

Table B2: SOC CONTROLLER PARAMETERS

Thumbwheel Settings

<u>Parameter</u>	<u>Units</u>	<u>Explanation</u>
GE1	---	Pitch error gain
GR1	sec	Pitch error rate gain
GI1	sec ⁻¹	Pitch error integral gain
GE2	---	Roll error gain
GR2	sec	Roll error rate gain
GI2	sec ⁻¹	Roll error integral gain
TCORL	sec	SOC correlation time constant

Note: The decimal point is between the second and third digits.

Pin Matrix Panel Settings

TCOMP	sec	SOC sampling interval
NCNT	---	SOC perturbation rate
WX(1-16)	---	Coefficients for $\Delta x^{(r)}$ filter
WU(1-16)	---	Coefficients for Δu filter
GEPS1	---	Gain on δ_e perturbation
GEPS2	---	Gain on δ_a perturbation
EPSMN	---	Minimum perturbation level

Sense Switches (on condition)

SSW0: $\delta_e = \delta_{e_0} + .02$ with RPV flying open loop (RSW3 on)

SSW1: $\delta_a = .02$ with RPV flying open loop (RSW3 on)

SSW2: $\delta_r = .02$ with RPV flying open loop (RSW3 on)

SOC Control Mode Options

Block diagrams of the RPV control loops are shown in Figures B1 and B2. To use the SOC in the pitch and roll rate loops, RSW4 is set to the on position. Figure B1 shows the corresponding RPV/SOC control block diagram. To use the SOC in the pitch and roll position loops, RSW4 is set to the off position. Figure B2 shows the corresponding RPV/SOC control system. There are three RPV control modes which are selected by the two sets of switches shown in the SOC hardware:

Full Manual Mode -- The pilot controls the actuator surfaces directly. The commanded control surface deflections δ_{e_c} , δ_{a_c} , and δ_{r_c} come directly from the control stick. The right switches, in Figure B1, are put in their up position by inserting a pin in Row 39, Bit 14, and having no pin in Row 39, Bit 15, on the matrix panel. (1,0)

SOC-Aided Manual Mode -- The pilot, via the control stick, provides the RPV control system with elevation and roll-rate commands and the SOC generates the actuator control signals based on elevation and roll-rate errors. The stick inputs are the commands E'_T and P_c . The right set of switches, Figure B1, is put in the down position by having no pin in Row 39, Bit 15, on the matrix panel and the left set of switches is put in the up position by having no pin in Row 39, But 14. (0,0)

- (8) Simulation proceeds; data are printed and/or displayed on the scopes.

At the end of each run the RPV simulator and Mark VI SOC hardware return to the starting points of their initialization routines. A new simulation may be performed by repeating the above procedure.

RPV Parameters

The RPV simulation program contains a COMMON block CONST which stores all constants and initial conditions for the RPV simulation. Any constant or initial condition may be examined or modified. Table B1 presents all the variables and their indices. The procedure for changing parameter values is as follows:

- (1) "N=" is automatically typed. N indicates the index of the variable.
- (2) To examine a variable; type a negative index -N (e.g., -4.↵). The Decwriter will print the current value of the parameter.
- (3) To change a variable; type a positive index N (e.g., 4.↵). The Decwriter will print "(index) =". Proceed by typing the desired value for the parameter.
- (4) Typing a value of N equal to "0." causes an exit from the change data routine and a return to the main program.

Contrails

- (5) Typing a value of N greater than "100." causes a complete printout of the data for the flight condition under consideration. The data are printed sequentially from N=1. to N=80..

Note: Use floating point format to enter both the indices and the values of the variables.

Sense Switch Options

The PDP-12 console "right switches" and "sense switches" serve as option select switches for the RPV simulation. The switches are considered "off" when in the "logical zero" position. The function of each switch is as follows:

Right switches (on condition)

- RSW1: SOC Controller is used.
- RSW2: PID controller is used.
- RSW3: RPV flies open loop with δ_e , δ_a , and δ_r , set at nominal trim conditions or .02 based upon sense switches 0, 1, and 2.
- RSW4: Rate controller is used. (Position controller is used if RSW4 is off.)
- RSW5: Bar-dot display presents "outside-looking-in" perspective. (SSW4 off: "inside-looking-out").
- RSW6: RPV runtime data is printed out on the Decwriter.[†]
- RSW10: Pause simulation run. Run continues upon depressing continue switch on the PDP-12 console.
- RSW11: Terminate simulation run. Simulation returns to initialization routines.

[†]The runtime print format is:

Time	Range						
E_T'	δ_e	Q	E_L	α	γ	C_L	H
A_T'	δ_a	R	Az	β	ψ_V	C_D	N
	δ_r	P	Bank		V	C_Y	E

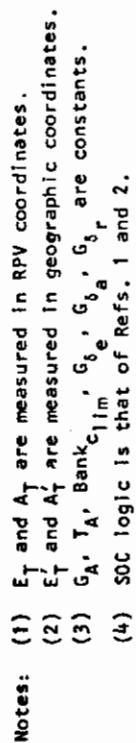
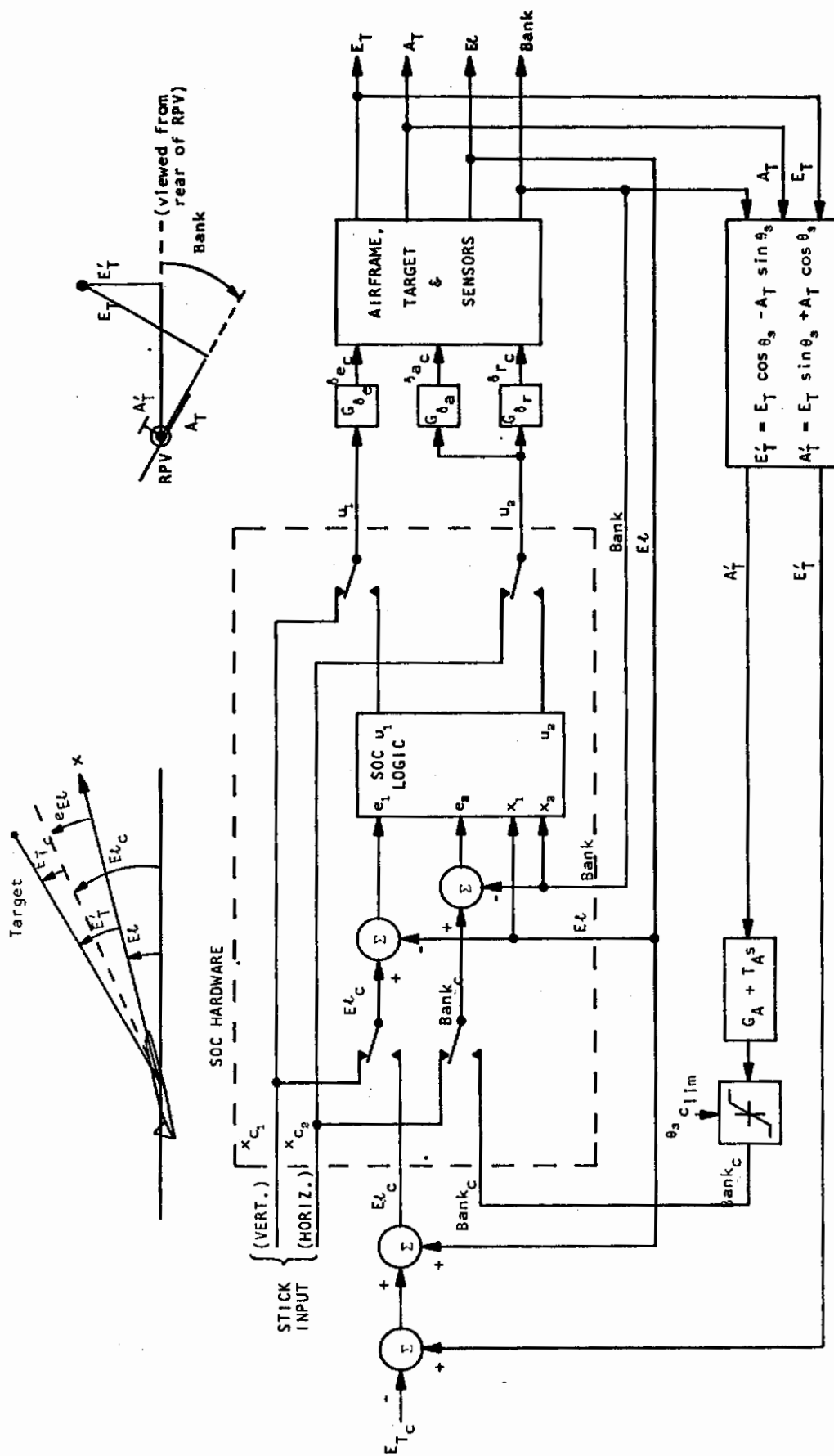


Figure B1: RPV Control Loops, SOC in Rate Loops (RSW 4 ON)



- Notes:
- (1) E_T and A_T are measured in RPV coordinates.
 - (2) E_T and A_T are measured in geographic coordinates.
 - (3) G_A , T_A , $Bank_{clim}$, $G_{\delta e}$, $G_{\delta a}$, $G_{\delta r}$ are constants.
 - (4) SOC logic is that of Refs. 1 and 2.

Figure B2: RPV Control Loops, SOC in Position Loops (RSW 4 OFF)

Full SOC Automatic Mode -- Elevation and roll commands are generated automatically and the SOC generates the actuator control signals based on elevation and azimuth errors.

The elevation command E'_{T_c} is a constant bias which insures that the RPV flies a downward turning arc toward the target rather than a drooping arc which would bring the RPV too close to the ground. The roll command is based on azimuth error A'_T . The RPV banks toward the target by an amount proportional to the predicted A'_T , but the bank command is limited to a half radian to assure continued RPV lift.

The Full Automatic Mode is selected by setting both the right and left sets of switches in Figure B1 down. No pin is inserted in bit 14 and a pin is inserted in bit 15 of Row 39. (0,1)

SOC Parameters

The SOC parameters which must be set are listed in Table B1. The implied decimal point in the thumbwheel settings is between the second and third digits. Figure B3 shows the pin matrix panel. The pin settings are all binary. For TCOMP, GEPS1, GEPS2, and EPSMN, the binary number is multiplied by 0.01 (decimal) within the MKVI computer, so this scale factor must be accounted for when setting the parameters. The binary point for the weights WX and WU are indicated in Figure B3.

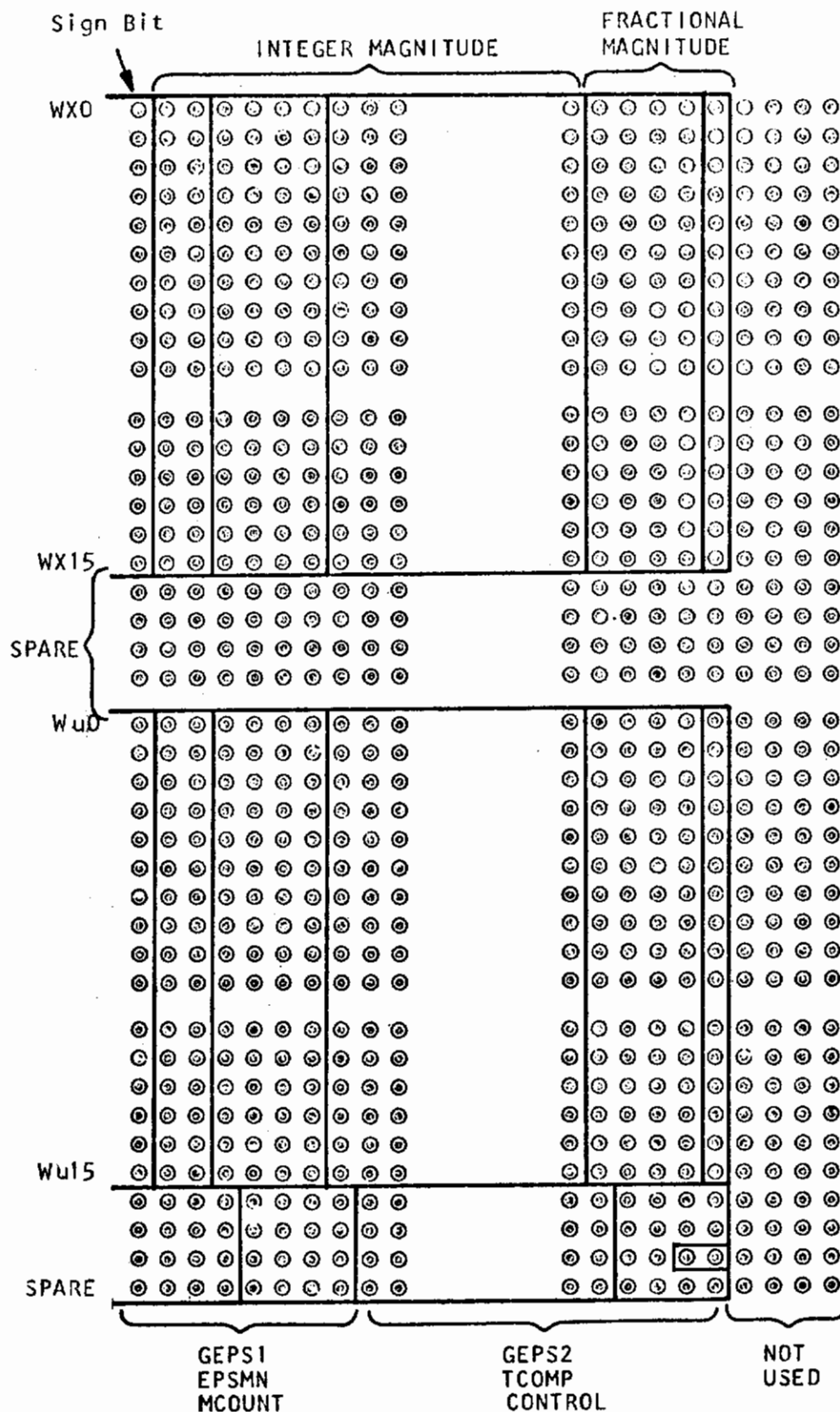


Figure B3: MATRIX DATA FIELDS
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Appendix C

ALTITUDE AND AIRSPEED METER INTERFACE DESCRIPTION

Background

Two conventional aircraft instruments have been added to the pilot's console of the RPV/Mark VI SOC demonstrator. These instruments (meters), located on the front panel directly above the oscilloscopes, are used to display the altitude and airspeed of the RPV as simulated in the PDP-12 computer. They are slaved to the RPV simulation and operate whenever the simulation is running on the PDP-12.

The altimeter displays altitude from 0 to 100,000 directly in feet. The airspeed indicator is set up to display $(V - V_N)/V_N \times 100$,

where: V is true airspeed

V_N is nominal airspeed (constant for a given flight condition)

Thus, it indicates the percentage increase or decrease in airspeed relative to nominal.

Circuit Description

Information is transmitted to the pilot's console via the PDP-12 output interface (Ref. 2). The demultiplexer (Ref. 2) in the demonstrator routes the received 12-bit word to a data register corresponding to the address contained in the demultiplexor address register. This address is set prior to the data transfer. The altitude and airspeed indicators have addresses of 12 and 13, respectively.

Figure C1 shows the data register, digital-to-analog



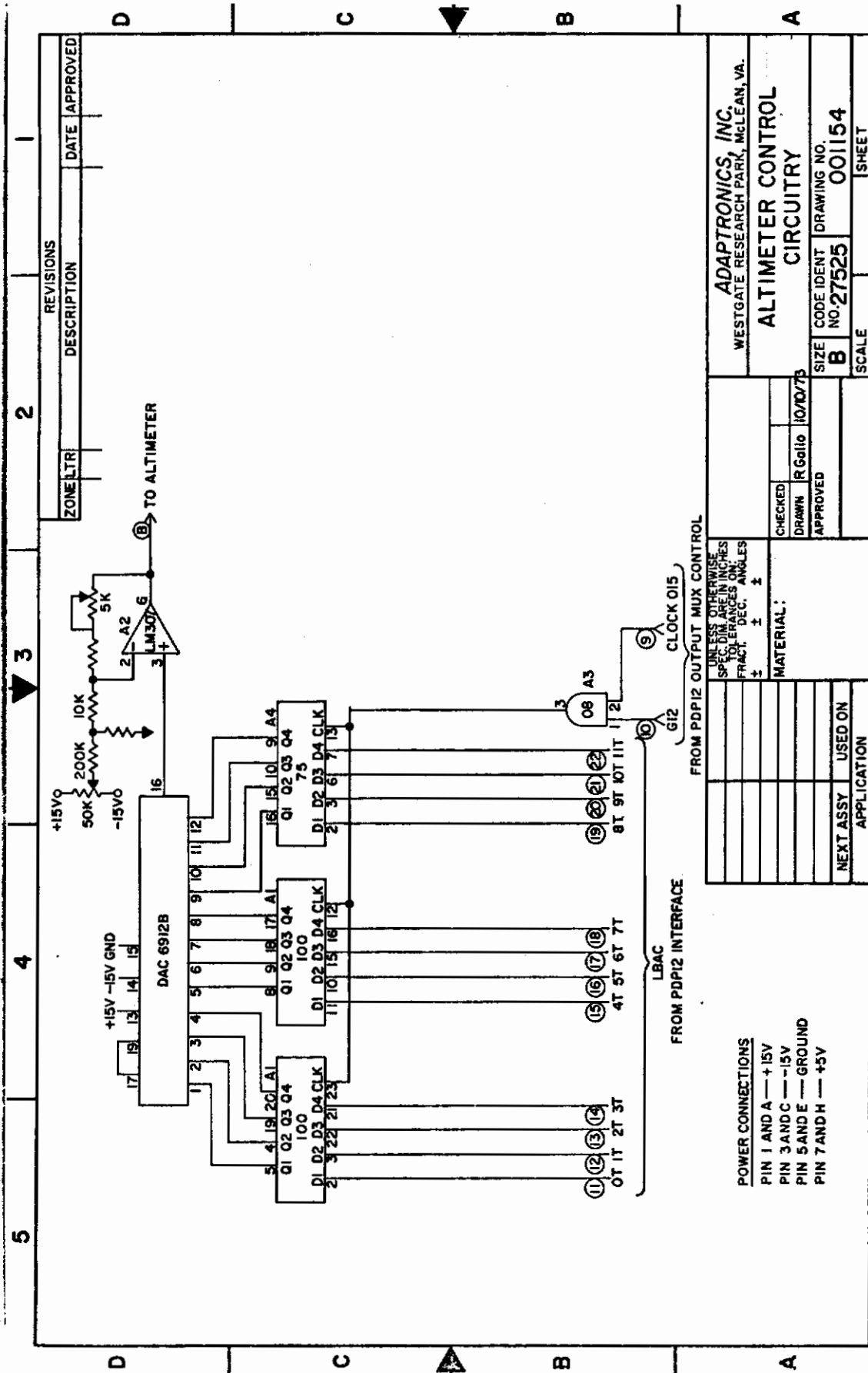
converter (DAC), and buffer amplifier associated with the airspeed indicator. Data are presented to a 12-bit latch (A1 and A2) from buffered accumulator bits (LBAC) 0 through 11. Since the DAC is a 10-bit converter, we are only interested in the most significant LBAC bits, 0 through 9. If the airspeed indicator has been addressed, input G13 of AND gate A3 will be at a logical one level. The LBAC bits will be loaded into A1 and A2 when clock 015 becomes true. The DAC will sense the new contents of A1 and A2 and convert the data into a corresponding analog voltage between plus and minus 15 volts. The DAC output is buffered and attenuated by operational amplifier A4. The gain of A4 is set equal to 0.66 in order to provide a range of plus or minus 10 volts for input to the airspeed indicator. Potentiometers are provided to adjust zero offset, R1, and gain, R6.

The circuitry used to drive the altimeter is shown in Figure C2. Its operation is identical to that described above except that AND gate A3 uses demultiplexor control line G12, and a 12 bit DAC is used.

Figures C3 and C4 show the manufacturer's specifications and a schematic diagram, respectively, for the airspeed indicator. Figures C5 and C6 show the corresponding information for the altimeter.

Software Control

Numbers corresponding to altitude and airspeed are scaled and set up in the DAT10 subroutine. The PDPI0 machine language subroutine performs the actual data transfer to the demonstrator.



DC Servo Indicator

Series 207 A



MODEL 207A DC SERVO INDICATOR

DESCRIPTION

The Model 207A DC Servo Indicator is a single pointer aircraft instrument in a 3 inch MS 33639 case configuration. The pointer is driven by a DC position servo, scaled such that ± 1 V DC produces $\pm 180^\circ$ displacement of the pointer.

Features of the Model 207A are replaceable dial scale, zero adjustable from -90° to $+90^\circ$, fast response, and adjustable damping.

OPERATION

Connect the power and input leads as shown in Drawing No. 207A--S. Pins G and B must be connected together for proper operation. However, to preclude the chance of a ground loop, (should the signal source already be referenced to the low side of the 28 V supply) no connection is made inside the indicator.

To calibrate the Model 207A, apply a 1V DC voltage between pins A and B. The indicator should deflect 180° . If readjustment is desired, remove the cover, sliding it forward. Adjust the GAIN control, G, to obtain desired scaling. To rezero the indicator to a new position, adjust the BIAS control, B. Desired speed of response can be obtained by adjusting the DAMPING control, D.

SPECIFICATIONS

Input Impedance: Greater than 4k.

Input Gain: 0.8 to 1.2V for 180° (Adjustable).

Deflection: -180° to $+270^\circ$ ($\pm 225^\circ$ Total)

Zero Adjust: -20° to $+110^\circ$

Response Time Constant: 0.1 to 1.0 sec. (Adj.)

Slew Rate: Response to a step input of 180° settles in less than 1 second.

Repeatability: Less than 1.8° .

Accuracy: Less than 3.6° .

Dial Scale: 0 to ± 100 for 0 to $\pm 180^\circ$ (1 extra blank dial provided).

Power: ± 15 V. @ 40 ma., $\pm 0.5\%$ regulation

$+28$ V. @ 0.8 A., Max., $\pm 10\%$ regulation

(No damage from 70V. spikes, operate with 3kc ripple.)

Temperature: $+40^\circ$ F to $+120^\circ$ F.

Vibration:

0.05 in. double amplitude 10–37 Hz

± 3.5 G 37–117 Hz

0.005 in. double amplitude 117–140 Hz

± 5 G 140–500 Hz

Size: MS 33639

3 in. diam., $5\frac{1}{2}$ " long.

Connector: Bendix PT02 or MS 3122

FEATURES

- Replaceable Dial Scales
- Fast, Adjustable Response
- Design Proven in Airborne Application
- Smooth Motion
- Standard 3 inch MS 33639 Case
- Scale 180° /V; Zero Adjustable $\pm 45^\circ$

APPLICATIONS

- Aircraft Flight Testing
- Flight Simulators



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Figure C3: Manufacturer's Specifications for the Airspeed Indicator 79

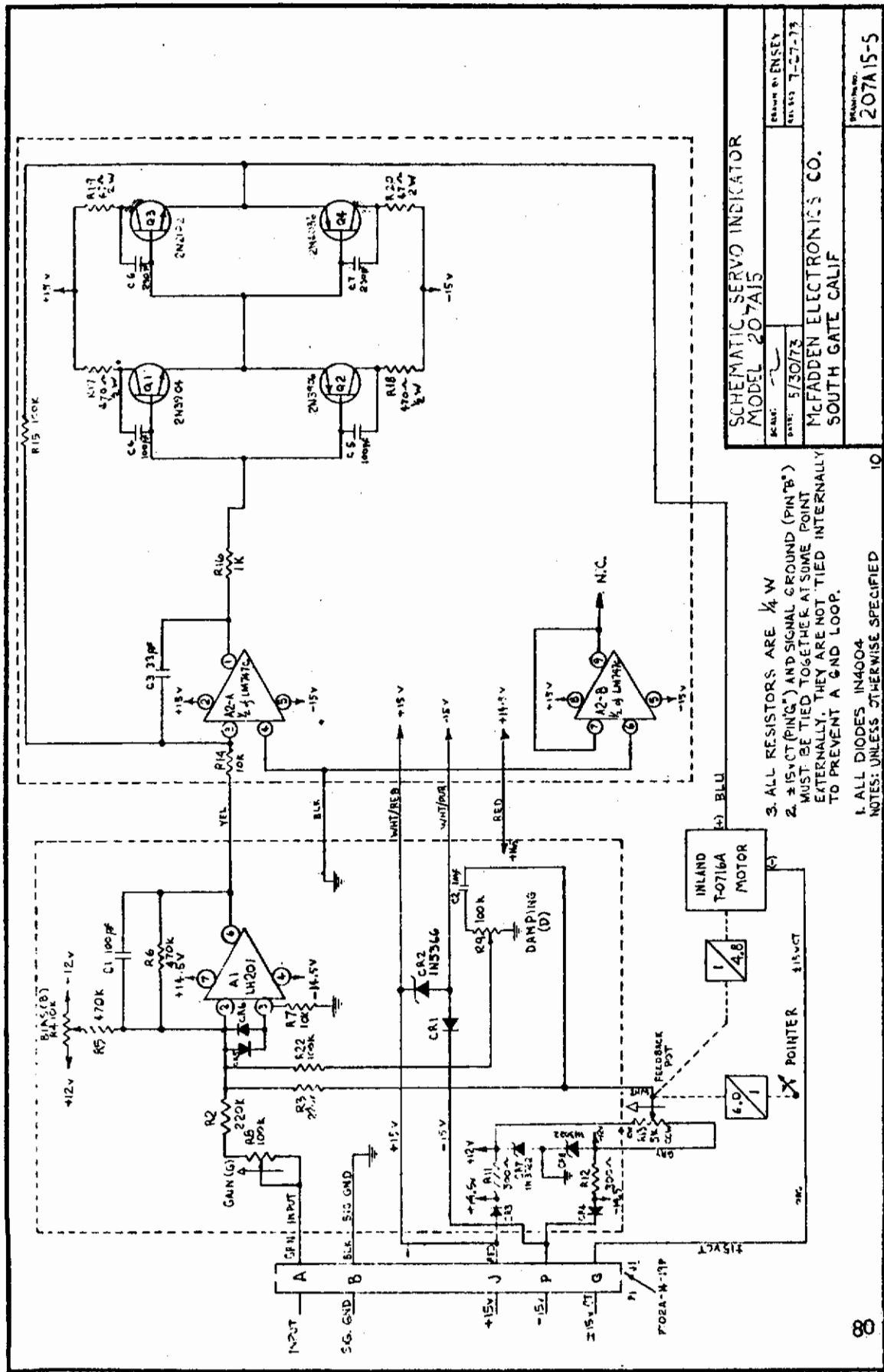


Figure C4: Schematic Diagram of the Airspeed Indicator

DC Simulator Altimeter

Series 206A



MODEL 206A DC SERVO ALTIMETER

DESCRIPTION

The Model 206A DC Simulator Altimeter is a high performance multi-turn, closed loop position servo which direct drives the hands of a conventional altimeter. The normal barometric sensor has been removed and the case has been elongated to accommodate the servo components. Standard panel mounting is retained.

Very smooth motion of the 1,000 ft/rev hand is featured with full scale being 100 turns.

The servo can be adapted to drive other types of altimeters as well as other types of multi-turn instruments.

SPECIFICATIONS

Range: 0 to 100,000 ft.
 Input: ~~100 to +100 V.~~ **-10 to +10V.**
 Accuracy: $\pm 0.33\%$ of altitude or 50 ft.
 (whichever is greater)
 Resolution: Less than 10 ft.
 Input: Impedance: Greater than 20k
 Signal: 2V/1000 ft. (nominal)
 Power: ~~$\pm 15\%$~~ , 0.6A. maximum
 (1% or better regulation)
~~+100V., 10ma~~
~~(0.001% regulation)~~
 Max. Rate: Greater than ~~30,000~~ **200,000** ft./min.

FEATURES

- -100 to +100 VDC commands 0 to 100,000 ft.
- Low resolution
- Low threshold
- Smooth motion over wide dynamic range



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Figure C5: Manufacturer's Specifications for the Altimeter

