DELFT UNIVERSITY OF TECHNOLOGY

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Report LR-248

THE GENERATION OF MOTION CUES ON A SIX-DEGREES-OF-FREEDOM MOTION SYSTEM

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M. Baarspul

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"Experiencing the motions of a six-degrees-of-freedom motion system is like listening to an orchestra. If you concentrate on one degree of freedom, you only hear the clarinet."

Jaap Veldhuijzen van Zanten

Foreword

The motion simulation described in this report has been performed at the Flight Crew Training Center of KLM, Royal Dutch Airlines at Schiphol Airport in 1975.

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Summary

The mathematical formulation of motion cue generation on a six-degree-of-freedom motion base is described. From the mathematical model of the simulated aircraft, the specific forces and rotational accelerations at the aircraft c.g. are determined as primary control inputs to the motion drive laws. Because the specific forces are acting on the pilot inside the simulator cockpit, they should be transformed to the centroid location of the motion system.

As the motion possibilities of the moving platform are constrained, filtering of the specific forces and rotational accelerations is necessary. As far as possible, tilt angles are used to reproduce sustained specific forces, providing the motion system with "co-ordinated washout".

The scaled equations as programmed in the digital computer, including values for the time constants and damping ratio of the motion filters as applied to the KSS B-747 flight simulator, are represented in Appendix A. The listing of the main motion program for the SDS Sigma 2 computer of this flight simulator is represented in Appendix B.

Table of Contents | Page

Symbols

A_{x_b}	body-axes longitudinal specific force at aircraft c.g.
$A_{x_b,c}$	body-axes longitudinal specific force at centroid location.
A_{y_b}	body-axes lateral specific force at aircraft c.g.
$A_{y_b,c}$	body-axes lateral specific force at centroid location.
A_{z_b}	body-axes vertical specific force at aircraft c.g.
$A_{z_b,c}$	body-axes vertical specific force at centroid location.
c.g.	center of gravity
F_x	total force along the X-axis, the subscript indicates the axes-system concerned.
F_y	total force along the Y-axis, the subscript indicates the axes-system concerned.
F_z	total force along the Z-axis, the subscript indicates the axes-system concerned.
g	acceleration due to gravity, m/sec^2.
H(P)	transfer function.
m	aircraft mass.
p_b	roll-rate in body axes, rad/sec.
p_{b,l_p}	simulator roll-rate in body-axes to simulate lateral specific force, rad/sec.
p_{b,h_p}	simulator roll-rate in body-axes to simulate roll acceleration, rad/sec.
p_s	$= p_{b,l_p} + p_{b,h_p}$
P	Laplace operator.
q_b	pitch-rate in body-axes, rad/sec.
q_{b,h_p}	simulator pitch-rate in body-axes to simulate pitch acceleration, rad/sec.
q_{b,l_p}	simulator pitch-rate in body-axes to simulate longitudinal specific force, rad/sec.
q_s	$= q_{b,l_p} + q_{b,h_p}$

Symbols cont'd

r_b yaw-rate in body-axes, rad/sec.

r_{b,h_p} simulator yaw-rate in body axes to simulate yaw acceleration, rad/sec.

R_x $= x_p - x_{p,c}$

R_y $= y_p - y_{p,c}$

R_z $= z_p - z_{p,c}$

S scale factor, the index indicates the variable concerned.

u_b body-axis longitudinal velocity component, m/sec.

v_b body-axis lateral velocity component, m/sec.

w_b body-axis vertical velocity component, m/sec.

W aircraft weight, kgf.

W_{x_b} component of the aircraft weight along the X_b-axis.

W_{y_b} component of the aircraft weight along the Y_b-axis.

W_{z_b} component of the aircraft weight along the Z_b-axis.

$x_{b,1}$ longitudinal motion base position to simulate longitudinal specific force.

$x_{b,2}$ longitudinal motion base position to compensate for longitudinal specific force error.

x_c lead compensated longitudinal position command input to the motion system.

x_m inertial longitudinal position command input to the motion system.

x_p x co-ordinate of pilot's station relative to the aircraft c.g. in body-axes.

$x_{p,c}$ x co-ordinate of centroid location relative to the pilot's station in body axes.

x_s $= x_{b,1} + x_{b,2}$.

$y_{b,1}$ lateral motion base position to simulate lateral specific force.

$y_{b,2}$ lateral motion base position to compensate for lateral specific force error.

Symbols cont'd

y_c	lead compensated lateral position command input to the motion system.
y_m	inertial lateral position command input to the motion system.
y_p	y co-ordinate of pilot's station relative to the aircraft c.g. in body-axes.
$y_{p,c}$	y co-ordinate of centroid location relative to the pilot's station in body-axes.
y_s	$= y_{b,1} + y_{b,2}$.
z_b	body-axes vertical motion base position.
z_c	lead compensated vertical position command input to the motion system.
z_m	inertial vertical position command input to the motion system.
z_p	z co-ordinate of pilot's station relative to the aircraft c.g. in body-axes.
$z_{p,c}$	z co-ordinate of centroid location relative to the pilot's station in body-axes.
α_b	aircraft body angle of attack, rad.
β	angle of sideslip, rad.
θ	aircraft body pitch attitude, rad.
θ_c	lead compensated pitch-input to the motion system, rad.
θ_{h_p}	body-axes simulator pitch angle, as a consequence of the simulation of pitch acceleration, rad.
θ_{l_p}	body-axes simulator pitch angle to simulate longitudinal specific force, rad.
θ_m	inertial pitch-input to the motion system, rad.
τ	time constant, the index indicating the variable concerned.
ϕ	roll angle, rad.
ϕ_c	lead compensated roll-input to the motion system, rad.
ϕ_{h_p}	body-axes simulator roll angle, as a consequence of the simulation of roll acceleration, rad.
ϕ_{l_r}	body-axes simulator roll angle to simulate lateral specific force.
ϕ_m	inertial roll-input to the motion system, rad.

Symbols cont'd

Ψ	yaw angle, rad.
Ψ_{h_p}	body-axes simulator yaw angle, as a consequence of the simulation of yaw acceleration, rad.
Ψ_c	lead compensated yaw-input to the motion system, rad.
Ψ_m	inertial yaw-input to the motion system, rad.
ζ	damping ratio, the index indicating the variable concerned.

Subscripts

b	body-axes
c	centroid location
h_p	high-pass filtered
i	intertial axes
l_p	low-pass filtered
w	flightpath - (wind) axes
x	along x-axis
y	along y-axis
z	along z-axis.

A dot over a variable indicates the time derivative of that variable.

Systems of axes

In this report three systems of axes are used:

1. The aircraft "body-axes": an aircraft-fixed right-handed reference-frame $O_bX_bY_bZ_b$. The origin O_b lies in the aircraft's center of gravity, the positive X_b-axis lies in the plane of symmetry $O_bX_bZ_b$ and points forward along the fuselage reference-line. The positive Y_b-axis is perpendicular to the $O_bX_bZ_b$-plane and points to starboard. The positive Z_b-axis is perpendicular to the $O_bX_bY_b$-plane and points downward.

2. The flightpath-(wind) axes: a right-handed reference-frame $O_wX_wY_wZ_w$. The origin O_w coincides with the aircraft c.g. the positive X_w-axis lies along the velocity-vector of the aircraft c.g. The positive Y_w-axis is perpendicular to the $O_wX_wZ_w$-plane and points in the direction of the positive lateral force. The positive Z_w-axis is perpendicular to the velocity-vector, opposite to the direction of the lift and lies in the aircraft plane of symmetry, see Fig. 3.

3. An earth-fixed reference-frame $O_eX_eY_eZ_e$. This reference-frame is identical to the $O_bX_bY_bZ_b$ reference-frame with the exception of the orientation of the origin O_e and the direction of the X_e-axis. The origin O_e coincides with the centroid location of the motion system, see Fig. 4.
   The X_e-axis lies in the plane of symmetry $O_eX_eZ_e$ of the flight simulator and in the horizontal plane.

1. Introduction

The addition of six-degree-of-freedom motion to a flight simulator cockpit provides realism and gives a greater consistency of training results between simulator- and flight training. Ideally, the simulator cockpit would be commanded to move about in accordance with the states that the real aircraft would possess. Generally, it is impossible to do this since the cockpit is mounted in a mechanical structure with limited possibilities of movement. In each degree of freedom the motion system cannot exceed physical limits on position, velocity and/or acceleration. These limits are given in Table 1 for motion in single degree of freedom operation, of the KLM 747 motion base.

Now the following dilemma arises. The pilot manipulates the controls of the simulator. The computer determines the resultant motion of the aircraft being simulated and sets the flight instruments and visual display to show this motion.

The computer also commands the simulator cockpit to move, preferably just as the aircraft would. However, since only limited motion of the cockpit is possible, some modifications of the computed motion is necessary before it can be used to command cockpit motion. Otherwise, the motion system might be driven into its structural limits and hence give totally erroneous motion impressions to the pilot.

The way in which the motion variables of the aircraft must be modified is closely related to the properties of the human vestibular system. The exact quantities "sensed" by a pilot's motion perceptive organisms are not yet completely understood. However, emperical knowledge combined with theoretical and practical considerations leads to the assumption that a pilot can "sense" the same quantities as can be measured by three linear- and three rotational accelerometers mounted along three perpendicular axes, see Refs. 1, 2 and 3.

A linear accelerometer does not measure acceleration but rather the difference between acceleration and gravitation. This difference is called specific force, e.g. in inertial navigation literature, see Ref. 4.

Three linear accelerometers are assumed to be appropriately mounted to measure the specific forces, denoted as A_{x_b}, A_{y_b} and A_{z_b} along the aircraft's X_b, Y_b and Z_b-axis respectively. The sum of these specific forces is the specific force vector, which is defined here as the positive sum of all non-gravitational forces per unit mass. According to the foregoing a pilot's motion perceptive organisms sense the specific force vector.

Three rotational accelerometers are assumed to be mounted along the aircraft's X_b, Y_b and Z_b-axis respectively, to measure the rotational accelerations along these axes. For sufficiently small rotations the rotational accelerations can be approximated by $\ddot{\Psi}$, $\ddot{\Theta}$ and $\ddot{\phi}$ respectively. During the simulation of aircraft motion the three components of specific force A_{x_b}, A_{y_b} and A_{z_b} and the rotational accelerations $\ddot{\Psi}$, $\ddot{\Theta}$ and $\ddot{\phi}$ acting on the pilot in the simulator cockpit should as much as possible agree with the magnitudes of the same variables in the aircraft cockpit during flight. As an example, the rolling response of an aircraft and the simulator are compared in a somewhat simplified form in Fig. 1. In the case considered here Fig. 1a shows that the bank angle ϕ of the real aircraft increases continuously. In about 1 sec. the aircraft roll rate $\dot{\phi}$ becomes constant, see Fig. 1b. The flight simulator cockpit however can only follow this motion partially, see Fig. 1a and has to return asymptotically to its neutral position, avoiding the generation of a false specific force, see section 9.2.
In spite of the great differences of the bank angle ϕ and the roll rate $\dot{\phi}$ between the aircraft and the simulator, Fig. 1c shows that the rotational accelerations agree very well.
The block diagram of Fig. 2 shows in great detail the modification of the specific forces and rotational accelerations of the simulated aircraft necessary to drive the motion system of the flight simulator.
In the subsequent Sections the motion drive signals for each degree of freedom of the motion system will be described. The motion limitations and restrictions mentioned in Table 1 are a major factor in the task suitability of the particular motion base as well as in the selection of the parameters in the motion simulation program, as further described in Appendix A.

The majority of the report is devoted to the mathematical formulation of motion generation, which aside from the physical characteristics of the hardware, see Ref. 5, is the major factor affecting the quality of a motion simulation.

2. General survey of the motion simulation concept

The emphasized parts of the motion simulation are illustrated in detailed form in Fig. 2. Frequent reference to Fig. 2 will be necessary in as much as the description of the motion cue generation consists of a block-by-block discussion.

From the equations of motion, describing the aircraft dynamics in flight and on the ground, the three total forces F_x, F_y and F_z and the three rotational accelerations $\dot{r}_b$, $\dot{q}_b$ and $\dot{p}_b$ are determined as primary control inputs of the motion drive laws. For the calculation of the body-axes specific forces, the total forces are required in body-axes. In the off-ground condition however, the total forces in the KSS B-747 flight simulation program are computed in flightpath- (wind) axes. They are transformed to body-axes before being used to compute the body-axes specific forces at the c.g. of the simulated aircraft, see Fig. 2, block 3.
The centroid transformation converts the specific forces at the aircraft c.g. into specific forces, which, when applied at the centroid of the motion system, see Fig. 4, would produce the actual specific forces at the pilot's seat of the aircraft on the pilot inside the simulator cockpit.
As the motion possibilities of the base are constrained, filtering of the specific forces at centroid location and the rotational accelerations is necessary. Sustained longitudinal and lateral specific forces can only be represented on a motion simulator by tilting the cockpit and utilizing the gravity-vector to generate the cue. However, the tilt angle must be obtained without pilot knowledge. Therefore the rotational acceleration of the cab, necessary to obtain the tilt angle should be below the threshold level of the pilot's perception. The initial part of the specific force, the onset, can only be generated by translational motion until the tilt angle is obtained. In this way translational and rotational motion of the flight simulator cockpit are co-ordinated to generate longitudinal and lateral specific forces.
In the case of the simulation of a rotational acceleration about the longitudinal or lateral axis by means of rotation alone, a false specific force may be otained because of temporary misalinement of the gravity-vector relative to the simulator cockpit. Translational motion of the base is required to compensate for this specific force error.
This has been indicated in Fig. 2, see the boxes labeled "specific force error". The motion system operates in an earth-fixed, or inertial reference frame, so the filtered specific forces and rotational rates are transformed to inertial axes whereafter a second attenuation is applied.
Lead compensation of the six position and attitude command signals to the motion system is required to compensate for motion system lag. The actuator extension transformation routine transforms the six compensated position commands into the length of the servo-actuators of the motion system, see Fig. 2, block 13.

3. Flightpath to body-axes transformation of the total forces F_{x_w}, F_{y_w} and F_{z_w}.

For the calculation of the body-axes specific forces from the total forces F_x, F_y and F_z, see Fig. 2, the total forces are required in body-axes. However, in the off-ground condition, the total forces are computed in flightpath- (wind) axes. Therefore in the off-ground condition, the total forces F_{x_w}, F_{y_w} and F_{z_w} have to be transformed to body-axes, see Fig. 3.
The transformation equations read:

$$
\begin{aligned}
F_{x_b} &= + \cos\alpha_b \cdot \cos\beta \cdot F_{x_w} - \cos\alpha_b \cdot \sin\beta \cdot F_{y_w} - \sin\alpha_b \cdot F_{z_w} \\
F_{y_b} &= + \sin\beta \cdot F_{x_w} + \cos\beta \cdot F_{y_w} \\
F_{z_b} &= + \sin\alpha_b \cdot \cos\beta \cdot F_{x_w} - \sin\alpha_b \cdot \sin\beta \cdot F_{y_w} + \cos\alpha_b \cdot F_{z_w}
\end{aligned}
\qquad (3.1.)
$$

where: α_b is the aircraft body angle of attack and β is the side-slip angle.

When the aircraft is on the ground, the total forces F_x, F_y and F_z are computed in body-axes. As a consequence in the on-ground condition, transformation (3.1.) is not required, see Fig. 2, blocks 1, 2 and 3.

4. Calculation of the body-axes specific forces A_{x_b}, A_{y_b} and A_{z_b}.

For the total forces F_{x_b}, F_{y_b} and F_{z_b} in body-axes can be written, see Ref. 6:

$$
\begin{aligned}
F_{x_b} &= m\,(\dot{u}_b - r_b \cdot v_b) \qquad *) \\
F_{y_b} &= m\,(\dot{v}_b + r_b \cdot u_b - p_b \cdot w_b) \\
F_{z_b} &= m\,(\dot{w}_b - q_b \cdot u_b + p_b \cdot v_b)
\end{aligned}
\qquad (4.1.)
$$

where: $m = \frac{W}{g}$ is the aircraft mass.

$\dot{u}_b$ is the aircraft body-axes longitudinal acceleration, denoted as $\dot{V}'_{x_b}$ in Ref. 6.

u_b is the body-axes longitudinal velocity component, denoted as V'_{x_b} in Ref. 6.

$\dot{v}_b$ is the aircraft body-axes lateral acceleration, denoted as $\dot{V}'_{y_b}$ in Ref. 6.

v_b is the body-axes lateral velocity component, denoted as V'_{y_b} in Ref. 6.

$\dot{w}_b$ is the aircraft body-axes vertical acceleration, denoted as $\dot{V}'_{z_b}$ in Ref. 6.

w_b is the body-axes vertical velocity component, denoted as V'_{z_b} in Ref. 6.

*) In Ref. 6 the term $q_b w_b$ in the equation for F_{x_b} is neglected, because its magnitude is small.

From the total forces, the specific forces in body-axes can be easily derived by subtraction of the component of the aircraft weight and deviding the result by the aircraft mass, see Fig. 2, block 4:

$$A_{x_b} = (F_{x_b} - W_{x_b}) \cdot g/_W$$

where: $W_{x_b} \cdot g/_W = - g \cdot \sin\theta$

$$A_{y_b} = (F_{y_b} - W_{y_b}) \cdot g/_W$$

where: $W_{y_b} \cdot g/_W = +g \cdot \cos\theta \cdot \sin\phi$ (4.2.)

$$A_{z_b} = (F_{z_b} - W_{z_b}) \cdot g/_W$$

where: $W_{z_b} \cdot g/_W = +g \cdot \cos\theta \cdot \cos\phi$

According to (4.1.):

$$F_{x_b} \cdot g/_W = \dot{u}_b - r_b \cdot v_b$$

$$F_{y_b} \cdot g/_W = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b$$

$$F_{z_b} \cdot g/_W = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b \qquad (4.3.)$$

Combination of (4.2.) and (4.3.) results in the specific forces in body-axes at the c.g. of the simulated aircraft:

$$A_{x_b} = \dot{u}_b - r_b \cdot v_b + g \cdot \sin\theta$$

$$A_{y_b} = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b - g \cdot \cos\theta \cdot \sin\phi \qquad (4.4.)$$

$$A_{z_b} = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b - g \cdot \cos\theta \cdot \cos\phi$$

5. Centroid transformation of A_{x_b}, A_{y_b} and A_{z_b}.

The purpose of the centroid transformation is to provide the motion filters with the unconstrained motions of the base that would be necessary to produce all the cues to which a pilot would be subjected at the pilot's station, see Fig. 2 block 5. Thus it is necessary to locate hypothetically the centroid of the motion base, see Fig. 4, in the simulated aircraft with respect to the pilot's station, and then transform the motion, derived for the center of gravity of the simulated aircraft, to this hypothetical location. This location with respect to the aircraft c.g. is defined as:

$$R_x = x_p - x_{p,c}$$

$$R_y = y_p - y_{p,c}$$

$$R_z = z_p - z_{p,c}$$

where x_p, y_p and z_p locate the pilot's station with respect to the aircraft c.g. and $x_{p,c}$, $y_{p,c}$ and $z_{p,c}$ locate the centroid with respect to the pilot's station.

Now the specific forces A_{x_b}, A_{y_b} and A_{z_b} (4.4.) can be computed at centroid location:

$$A_{x_b,c} = A_{x_b} - (q_b^2 + r_b^2) \cdot R_x + (q_b \cdot p_b - \dot{r}_b) \cdot R_y + (r_b \cdot p_b + \dot{q}_b) \cdot R_z$$
$$A_{y_b,c} = A_{y_b} + (p_b \cdot q_b + \dot{r}_b) \cdot R_x - (p_b^2 + r_b^2) \cdot R_y + (r_b \cdot q_b - \dot{p}_b) \cdot R_z$$
$$A_{z_b,c} = A_{z_b} + (p_b \cdot r_b - \dot{q}_b) \cdot R_x + (q_b \cdot r_b + \dot{p}_b) \cdot R_y - (p_b^2 + q_b^2) \cdot R_z$$

For the KSS B-747 flight simulator:

$y_p = y_{p,c}$, therefore: $R_y = 0$
$z_p = z_{p,c}$, therefore: $R_z = 0$

Introducing these simplifications and substitution of (4.4.) for A_{x_b}, A_{y_b} and A_{z_b} results in:

$$A_{x_b,c} = \dot{u}_b - r_b \cdot v_b + g \cdot \sin\theta - (q_b^2 + r_b^2) \cdot R_x$$
$$A_{y_b,c} = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b - g \cdot \cos\theta \cdot \sin\phi + (p_b \cdot q_b + \dot{r}_b) \cdot R_x \quad (5$$
$$A_{z_b,c} = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b - g \cdot \cos\theta \cdot \cos\phi + (p_b \cdot r_b - \dot{q}_b) \cdot R_x$$

Now the following notations are introduced:

$$\dot{u}_{b,c} = \dot{u}_b - r_b \cdot v_b - (q_b^2 + r_b^2) \cdot R_x$$
$$\dot{v}_{b,c} = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b + (p_b \cdot q_b + \dot{r}_b) \cdot R_x$$
$$\dot{w}_{b,c} = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b + (p_b \cdot r_b - \dot{q}_b) \cdot R_x$$

Substituting $\dot{u}_{b,c}$, $\dot{v}_{b,c}$ and $\dot{w}_{b,c}$ in the expressions (5.1.) results in the specific forces at the centroid location in the simulated aircraft:

$$A_{x_b,c} = \dot{u}_{b,c} + g \cdot \sin\theta \quad (5.2.)$$
$$A_{y_b,c} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi \quad (5.3.)$$
$$A_{z_b,c} = \dot{w}_{b,c} - g \cdot \cos\theta \cdot \cos\phi \quad (5.4.)$$

6. Motion filters for the translational degrees of freedom

6.1. Longitudinal motion

The simulation of longitudinal specific forces is performed by means of the co-ordinated longitudinal and pitch motion of the simulator cockpit. The longitudinal motion is used to reproduce the high-frequency onset cue of the longitudinal specific force until the pitch motion has had time to aline the simulator cockpit relative to the gravity vector to present the sustained, or low frequency portion of the longitudinal specific force.

High-pass filtering of $A_{x_b, c}$ removes the low-frequency portion of the longitudinal specific force, likely to exceed the motion platform position limits in X-direction, see Fig. 2, block 6.1.

The longitudinal specific force at the centroid position inside the simulator cockpit can be written as:

$$(A_{x_b,c})_{sim} = A_{x_{b,1},c} + g \cdot \theta_{1_p} \qquad (6.1.)$$

where $A_{x_{b,1},c}$ is the high-frequency portion of the longitudinal specific force, reproduced by means of the simulator longitudinal translational motion and θ_{1_p} is the simulator pitch angle needed to reproduce sustained longitudinal specific force, see Section 9.1.

Combining the two expressions for the longitudinal specific force at the centroid location, (5.2.) and (6.1.), gives:

$$A_{x_{b,1},c} = \dot{u}_{b,c} + g \cdot \sin\theta - g \cdot \theta_{1_p}$$

The low frequency gravity component $g \cdot \sin\theta$ of $A_{x_b,c}$ will be simulated separately by means of θ_{1_p}, as discussed in section 9.1.

So, for the simulator, the high-frequency longitudinal specific force becomes:

$$A_{x_{b,1},c} = \dot{u}_{b,c} - g \cdot \theta_{1_p} \qquad (6.2.)$$

The transfer function of the applied high-pass second order filter reads:

$$\frac{\ddot{x}_{b,1}(P)}{(\dot{u}_{b,c} - g \cdot \theta_{1_p})(P)} = H(P) \ ^{*)} = \frac{\tau_x^2 \cdot P^2}{1 + 2 \cdot \tau_x \cdot \zeta_x \cdot P + \tau_x^2 \cdot P^2}$$

Substituting (6.2.) and applying the inverse Laplace transform results in:

$$x_{b,1} + 2 \cdot \tau_x \cdot \zeta_x \cdot \dot{x}_{b,1} + \tau_x^2 \cdot \ddot{x}_{b,1} - \tau_x^2 \cdot (\dot{u}_{b,c} - g \cdot \theta_{1_p}) = 0$$

*) Note: In order to stay with the existing notation of the KSS B-747 motion simulation program, time constants τ (sec) have been used, rather than the more usual natural frequencies ω_o (sec^{-1}), where $\tau = \frac{1}{\omega_o}$.

The resulting longitudinal acceleration of the motion base now can be written as:

$$\ddot{x}_{b,1} = \dot{u}_{b,c} - g \cdot \theta_{1_p} - \frac{2\zeta_x}{\tau_x} \cdot \dot{x}_{b,1} - \frac{1}{\tau_x^2} \cdot x_{b,1} \qquad (6.3.)$$

If the computer sample time for the sequential calculations is 50 msec (20 times/sec) rectangular integration of $\ddot{x}_{b,1}$ gives at time t_n:

$$\dot{x}_{b,1_n} = \dot{x}_{b,1_{n-1}} + 0{,}05 \cdot \ddot{x}_{b,1_{n-1}}$$

$$x_{b,1_n} = x_{b,1_{n-1}} + 0{,}05 \cdot \dot{x}_{b,1_n}$$

The correction for specific force error as a consequence of the simulation of aircraft pitch acceleration, see section 9.1., reads:

$$\ddot{x}_{b,2} = -g \cdot \theta_{h_p}$$

where θ_{h_p} is the simulator pitch angle resulting as a consequence of the simulation of pitch acceleration, see Fig. 2, block 9.1.2.

The resulting body-axes longitudinal translational acceleration of the motion base now becomes:

$$\ddot{x}_s = \ddot{x}_{b,1} + \ddot{x}_{b,2} \qquad (6.4.)$$

6.2. <u>Lateral motion</u>

The simulation of lateral specific forces is performed in a way similar to the longitudinal case by means of the co-ordinated lateral and roll motions of the motion base, see Fig. 2, block 6.2.
The lateral specific force at the centroid location inside the simulator cockpit is:

$$(A_{y_{b,c}})_{sim} = A_{y_{b,1},c} - g \cdot \phi_{1_p} \qquad (6.5.)$$

where $A_{y_{b,1},c}$ is the high-frequency part of the lateral specific force, reproduced by the simulator lateral translational motion and ϕ_{1_p} is the simulator roll angle needed to reproduce sustained lateral specific force, see section 9.2.
Equating the lateral specific force at centroid location (5.3.) and (6.5.) gives:

$$A_{y_{b,1},c} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p} \qquad (6.6.)$$

The transfer function of the applied high-pass second order filter reads:

$$\frac{\ddot{y}_{b,1}(P)}{(\dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p})(P)} = H\,(P)^{*)} = \frac{\tau_y^2 . P^2}{1 + 2\tau_y\zeta_y . P + \tau_y^2 . P^2}$$

*) See note on page 7.

Substituting (6.6.) and applying the inverse Laplace transform results in:

$$y_{b,1} + 2\,\tau_y\zeta_y \cdot \dot{y}_{b,1} + \tau_y^2 \cdot \ddot{y}_{b,1} - \tau_y^2 \cdot (\dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p}) = 0$$

The resulting lateral acceleration of the motion base now can be written as:

$$\ddot{y}_{b,1} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p} - \frac{2\zeta_y}{\tau_y} \cdot \dot{y}_{b,1} - \frac{1}{\tau_y^2} \cdot y_{b,1} \quad (6.7.)$$

Rectangular integration at a rate of 20 times/sec results at time t_n:

$$\dot{y}_{b,1_n} = \dot{y}_{b,1_{n-1}} + 0{,}05\,\ddot{y}_{b,1_{n-1}}$$

$$y_{b,1_n} = y_{b,1_{n-1}} + 0{,}05\,\dot{y}_{b,1_n}$$

The correction for specific force error as a consequence of the simulation of aircraft roll acceleration, see section 9.2., reads:

$$\ddot{y}_{b,2} = +g \cdot \phi_{h_p}$$

where ϕ_{h_p} is the simulator roll angle resulting as a consequence of the simulation of roll acceleration, see Fig. 2, block 9.2.2.

The total body-axes lateral translational acceleration of the motion base now becomes:

$$\ddot{y}_s = \ddot{y}_{b,1} + \ddot{y}_{b,2} \quad (6.8.)$$

6.3. Heave motion

The simulation of vertical specific forces is, because of the restricted stroke of the servo-actuators, see Table 1, only possible in a very limited way. No tilt angle is available to reproduce the low-frequency part of the vertical specific force and thus the low-frequency part cannot be simulated. This results in the limitation of simulating only relatively small normal accelerations during a short time. Specific forces or normal accelerations as a result of atmospheric turbulence or touch down can therefore be simulated very well, but the longer lasting specific forces occuring in a steep turn or during a pull up from a dive can only be simulated approximately. That is why also in this degree of freedom a high-pass filter is applied, see Fig. 2, block 6.3., to suppress the low frequency changes of the vertical specific force.

The vertical specific force at the centroid location inside the simulator cockpit is:

$$(A_{z_b,c})_{sim} = \ddot{z}_b - g \quad (6.9.)$$

Combining the two expressions for the vertical specific force at the centroid location, (5.4.) and (6.9.), gives:

$$\dot{w}_{b,c} - g \cdot \cos\theta \cdot \cos\phi = \ddot{z}_b^{*} - g \qquad (6.10.)$$

where $\ddot{z}_b^{*}$ is the not yet filtered vertical acceleration of the simulator cockpit in body-axes.

The transfer function of the applied high-pass filter reads:

$$H(P)^{*)} = \frac{z_b(P)}{z_b^{*}(P)} = \frac{\tau_z^{2}.P^2}{1 + 2\,\tau_z\zeta_z.P + \tau_z^{2}.P^2}$$

Substituting (6.10.) for $\ddot{z}_b^{*}$ and applying the inverse Laplace transform results in:

$$z_b + 2\,\tau_z.\zeta_z.\dot{z}_b + \tau_z^{2}.\ddot{z}_b - \tau_z^{2}\,\dot{w}_{b,c} - \tau_z^{2}.g(1 - \cos\theta \cdot \cos\phi) = 0$$

The term $\tau_z^{2}.\ g\ (1 - \cos\theta \cdot \cos\phi)$ in this equation will be neglected, because of its low mangitude and its relatively low frequency.

The resulting vertical acceleration of the simulator cockpit can now be written as:

$$\ddot{z}_b = \dot{w}_{b,c} - \frac{2\zeta_z}{\tau_z} \cdot \dot{z}_b - \frac{1}{\tau_z^{2}} \cdot z_b \qquad (6.11.)$$

Rectangular integration of $\ddot{z}_b$ at a rate of 20 times/sec gives at time t_n:

$$\dot{z}_{b_n} = \dot{z}_{b_{n-1}} + 0{,}05\ \ddot{z}_{b_{n-1}}$$

$$z_{b_n} = z_{b_{n-1}} + 0{,}05\ \dot{z}_{b_n}$$

7. Body to inertial transformation of the motion platform translational accelerations.

The translational degrees of freedom of the motion base operate in an earth-fixed inertial reference frame. Therefore the body-axes translational accelerations $\ddot{x}_s$ (6.4.), $\ddot{y}_s$ (6.8.) and $\ddot{z}_b$ (6.11.) are transformed to inertial co-ordinates.

According to Table 14 of Ref. 7, for the inertial translational accelerations can be written successively:

$$\ddot{x}_i = \cos\theta_m \cdot \cos\psi_m \cdot \ddot{x}_s + (\sin\phi_m \cdot \sin\theta_m \cdot \cos\psi_m - \cos\phi_m \cdot \sin\psi_m).\ddot{y}_s + (\cos\phi_m \cdot \sin\theta_m \cdot \cos\psi_m + \sin\phi_m \cdot \sin\psi_m).\ddot{z}_b \qquad (7.1.)$$

$$\ddot{y}_i = \cos\theta_m \cdot \sin\psi_m \cdot \ddot{x}_s + (\sin\phi_m \cdot \sin\theta_m \cdot \sin\psi_m + \cos\phi_m \cdot \cos\psi_m).\ddot{y}_s + (\cos\phi_m \cdot \sin\theta_m \cdot \sin\psi_m - \sin\phi_m \cdot \cos\psi_m).\ddot{z}_b \qquad (7.2.)$$

*) See note on page 7.

$$\ddot{z}_i = -\sin\theta_m \cdot \ddot{x}_s + \sin\phi_m \cdot \cos\theta_m \cdot \ddot{y}_s + \cos\phi_m \cdot \cos\theta_m \cdot \ddot{z}_b \qquad (7.3.)$$

where ψ_m, θ_m and ϕ_m are the simulator yaw, pitch and roll angles respectively, see Section 11.

8. Translational wash-out.

To prevent the motion platform from running into its limits, translational wash-out is carried out on the inertial accelerations $\ddot{x}_i$, $\ddot{y}_i$ and $\ddot{z}_i$ by means of second-order high-pass filters of the form:

$$\begin{aligned}
\ddot{x}_m &= \ddot{x}_i - \frac{2\zeta_{x_T}}{\tau_{x_T}} \cdot \dot{x}_m - \frac{1}{\tau_{x_T}^2} \cdot x_m \\
\ddot{y}_m &= \ddot{y}_i - \frac{2\zeta_{y_T}}{\tau_{y_T}} \cdot \dot{y}_m - \frac{1}{\tau_{y_T}^2} \cdot y_m \\
\ddot{z}_m &= \ddot{z}_i - \frac{2\zeta_{z_T}}{\tau_{z_T}} \cdot \dot{z}_m - \frac{1}{\tau_{z_T}^2} \cdot z_m
\end{aligned} \qquad (8.1.)$$

The inertial motion platform positions x_m, y_m and z_m, not yet compensated for the motion system's dynamic lag, see section 12, and velocities $\dot{x}_m$, $\dot{y}_m$ and $\dot{z}_m$ are obtained by rectangular integration of $\ddot{x}_m$, $\ddot{y}_m$ and $\ddot{z}_m$ respectively at a rate of 20 times/sec.

9. Motion filters for the rotational degrees of freedom.

9.1. Pitch motion

The pitch motion of the flight simulator is used for the simulation of the sustained portion of the longitudinal specific force, see Section 6.1., and for the simulation of aircraft pitch acceleration, see Fig. 2, blocks 9.1.1. and 9.1.2.

The sustained portion of the longitudinal specific force $A_{x_b,c}$ is created in the simulator by means of a component of gravity:

$$A_{x_b,c} = g \cdot \sin\theta_{1_p} \qquad (9.1.)$$

The generation of the simulator pitch angle θ_{1_p} necessary for this purpose is inevitably associated with pitch acceleration. As the pilot should not notice this acceleration, it should be kept below the threshold level of the pilot's perception. That is why a low-pass filter is used in the computation of θ_{1_p}, see Fig. 2, block 9.1.1.

The computation of θ_{1_p} occurs in the following way.

Equating the longitudinal specific force at the centroid location (5.2.) and the longitudinal specific force at the centroid positon inside the simulator cockpit (9.1.) gives:

$\dot{u}_{b,c} + g \cdot \sin\theta = g \cdot \sin\theta_{1_p}^{*}$

where $\theta_{1_p}^{*}$ is the not yet filtered pitch angle of the simulator cockpit to simulate the sustained portion of longitudinal specific forces.
As the longitudinal specific force acting inside a B-747 cockpit is normally less than 0,3g, resulting in $\theta_{1_p}^{*} < 16^{0}$, $\sin\theta_{1_p}^{*}$ is approximated by $\theta_{1_p}^{*}$:

$\sin\theta_{1_p}^{*} = \theta_{1_p}^{*}$

For $\theta_{1_p}^{*}$ now can be written:

$$\theta_{1_p}^{*} = \frac{\dot{u}_{b,c}}{g} + \sin\theta \qquad (9.2.)$$

$\theta_{1_p}^{*}$ is fed through a low-pass filter, see Fig. 2, block 9.1.1., the transfer function of which reads:

$$H(P) = \frac{\theta_{1_p}(P)^{*)}}{\theta_{1_p}^{*}(P)} = \frac{1}{1 + 2 \cdot \tau_{\theta_{1_p}} \cdot \zeta_{\theta_{1_p}} \cdot P + \tau_{\theta_{1_p}}^{2} \cdot P^{2}}$$

Substituting (9.2.) for $\theta_{1_p}^{*}$ and applying the inverse Laplace transform gives:

$$\theta_{1_p} + 2\tau_{\theta_{1_p}} \cdot \zeta_{\theta_{1_p}} \cdot q_{b,1_p} + \tau_{\theta_{1_p}}^{2} \cdot \dot{q}_{b,1_p} - \frac{\dot{u}_{b,c}}{g} - \sin\theta = 0$$

The resulting pitch acceleration reads:

$$\dot{q}_{b,1_p} = \frac{\dot{u}_{b,c}}{\tau_{\theta_{1_p}}^{2} \cdot g} + \frac{\sin\theta}{\tau_{\theta_{1_p}}^{2}} - \frac{2\zeta_{\theta_{1_p}}}{\tau_{\theta_{1_p}}} \cdot q_{b,1_p} - \frac{1}{\tau_{\theta_{1_p}}^{2}} \cdot \theta_{1_p} \qquad (9.3.)$$

Rectangular integration at a rate of 20 times/sec gives at time t_n:

$$q_{b,1_{p_n}} = q_{b,1_{p_{n-1}}} + 0{,}05\ \dot{q}_{b,1_{p_{n-1}}} \qquad (9.4.)$$

$$\theta_{1_{p_n}} = \theta_{1_{p_{n-1}}} + 0{,}05\ q_{b,1_{p_n}}$$

*) See note on page 7.

The simulation of the aircraft pitch acceleration $\dot{q}_b$ on the simulator gives also rise to a simulator pitch angle θ_{h_p}.
According to the foregoing θ_{h_p}, is sensed by the pilot as an erroneous specific force.
Therefore, the pitch angle θ_{h_p} of the simulator as a result of the simulation of the pitch acceleration $\dot{q}_b$ should remain as small as possible.
This can be achieved by applying a high-pass filter in the computation of the pitch acceleration $\dot{q}_{b,h_p}$ of the simulator.
The computation of the simulator pitch angle θ_{h_p} for the simulation of pitch acceleration occurs in the following way. The transfer function of the applied high-pass second order filter reads:

$$\frac{\theta_{h_p}(P)^{*)}}{\theta(P)} = \frac{\tau^2_{\theta_{h_p}} \cdot P^2}{1 + 2\tau_{\theta_{h_p}} \cdot \zeta_{\theta_{h_p}} \cdot P + \tau^2_{\theta_{h_p}} \cdot P^2}$$

Applying the inverse Laplace transform results in:

$$\theta_{h_p} + 2\tau_{\theta_{h_p}} \cdot \zeta_{\theta_{h_p}} \cdot q_{b,h_p} + \tau^2_{\theta_{h_p}} \cdot \dot{q}_{b,h_p} - \tau^2_{\theta_{h_p}} \cdot \dot{q}_b = 0$$

The simulator pitch acceleration now can be written as:

$$\dot{q}_{b,h_p} = \dot{q}_b - \frac{2\zeta_{\theta_{h_p}}}{\tau_{\theta_{h_p}}} \cdot q_{b,h_p} - \frac{1}{\tau^2_{\theta_{h_p}}} \cdot \theta_{h_p}$$

Rectangular integration at a rate of 20 times/sec gives at time t_n:

$$q_{b,h_{p_n}} = q_{b,h_{p_{n-1}}} + 0,05 \cdot \dot{q}_{b,h_{p_{n-1}}}$$

$$\theta_{h_{p_n}} = \theta_{h_{p_{n-1}}} + 0,05 \cdot q_{b,h_{p_n}}$$

The flight simulator pitch angle θ_{h_p} as a consequence of the simulation of pitch acceleration $\dot{q}_b$ results in a specific force error:

$$(A_{x_{b,c}})_{error} = -g \cdot \theta_{h_p}$$

This longitudinal specific force error can be compensated by means of the longitudinal translational motion of the base:

$\ddot{x}_{b,2} = -g \cdot \theta_{h_p}$, see Section 6.1.

*) See note on page 7.

The total body-axes pitch acceleration, used for lead-compensation of the motion system, see section 12, reads:

$$\dot{q}_s = \dot{q}_{b,l_p} + \dot{q}_{b,h_p} \qquad (9.5.)$$

The total body-axes pitch rate, to be transformed into inertial axes, see section 10, reads:

$$q_s = q_{b,l_p} + q_{b,h_p} \qquad (9.6.)$$

9.2. Roll motion

The roll motion of the flight simulator is used for the simulation of the sustained portion of the lateral specific force, see Section 6.2. and for the simulation of aircraft roll acceleration, see Fig. 2, blocks 9.2.1. and 9.2.2. respectively.

The simulation of the lateral specific force $A_{y_{b,c}}$ occurs in just the same manner as the simulation of the longitudinal specific force $A_{x_{b,c}}$, described in the previous section:

$$A_{y_{b,c}} = -g \cdot \sin \phi_{1_p} \qquad (9.7.)$$

where $g \cdot \sin \phi_{1_p}$ is the lateral component of gravity inside the simulator cockpit. Note, that for the simulation of a positive lateral specific force ϕ_{1_p} is negative.

Equating the lateral specific force at the centroid location (5.3.) and the lateral specific force at the centroid position inside the simulator cockpit (9.7.) results in:

$$\dot{v}_{b,c} - g \cdot \cos \theta \cdot \sin \phi = - g \cdot \sin \phi_{1_p}^{*}$$

where $\phi_{1_p}^{*}$ is the not yet filtered roll angle of the simulator to generate lateral specific forces.

Also here the approximation is made:

$$\sin \phi_{1_p}^{*} \approx \phi_{1_p}^{*}$$

as $A_{y_{b,c}}$ normally $<$ 0,3g.

For $\phi_{1_p}^{*}$ now can be written:

$$\phi_{1_p}^{*} = -\frac{\dot{v}_{b,c}}{g} + \cos \theta \cdot \sin \phi \qquad (9.8.)$$

*) See note on page 7.

$\phi_{1_p}^{*}$ is fed through a low-pass filter to keep the roll acceleration of the cab below the threshold level of the pilot's perception. The transfer function of this filter reads:

$$\frac{\phi_{1_p}(P)^{*)}}{\phi_{1_p}^{*}(P)} = \frac{1}{1 + 2\tau_{\phi_{1_p}} \cdot \zeta_{\phi_{1_p}} \cdot P + \tau^2_{\phi_{1_p}} \cdot P^2}$$

Substituting (9.8.) for $\phi_{1_p}^{*}$ and applying the inverse Laplace transform gives:

$$\phi_{1_p} + 2\tau_{\phi_{1_p}} \cdot \zeta_{\phi_{1_p}} \cdot p_{b,1_p} + \tau^2_{\phi_{1_p}} \cdot \dot{p}_{b,1_p} + \frac{\dot{v}_{b,c}}{g} - \cos\theta \cdot \sin\phi = 0$$

The resulting roll acceleration $\dot{p}_{b,1_p}$ reads:

$$\dot{p}_{b,1_p} = -\frac{\dot{v}_{b,c}}{\tau^2_{\phi_{1_p}} \cdot g} + \frac{\cos\theta \cdot \sin\phi}{\tau^2_{\phi_{1_p}}} - \frac{2\zeta_{\phi 1_p}}{\tau_{\phi_{1_p}}} \cdot p_{b,1_p} - \frac{1}{\tau^2_{\phi_{1_p}}} \cdot \phi_{1_p} \qquad (9.9.)$$

Rectangular integration at a rate of 20 times/sec gives at time t_n:

$$p_{b,1_{p_n}} = p_{b,1_{p_{n-1}}} + 0{,}05 \cdot \dot{p}_{b,1_{p_{n-1}}}$$

$$\phi_{1_{p_n}} = \phi_{1_{p_{n-1}}} + 0{,}05 \cdot p_{b,1_{p_n}}$$

The computation of the simulator roll angle ϕ_{h_p} to simulate aircraft roll accelerations occurs in the same manner as the computation of θ_{h_p}.

The transfer function of the applied high-pass second order filter reads:

$$\frac{\phi_{h_p}(P)^{*)}}{\phi(P)} = \frac{\tau^2_{\phi_{h_p}} \cdot P^2}{1 + 2\tau_{\phi_{h_p}} \cdot \zeta_{\phi_{h_p}} \cdot P + \tau^2_{\phi_{h_p}} \cdot P^2}$$

The resulting simulator roll acceleration $\dot{p}_{b,h_p}$ can be written as:

$$\dot{p}_{b,h_p} = \dot{p}_b - \frac{2\zeta_{\phi_{h_p}}}{\tau_{\phi_{h_p}}} \cdot p_{b,h_p} - \frac{1}{\tau^2_{\phi_{h_p}}} \cdot \phi_{h_p}$$

Rectangular integration of $\dot{p}_{b,h_p}$ gives at time t_n:

$$p_{b,h_{p_n}} = p_{b,h_{p_{n-1}}} + 0{,}05 \cdot \dot{p}_{b,h_{p_{n-1}}}$$

*) See note on page 7.

$$\phi_{h_{p_n}} = \phi_{h_{p_{n-1}}} + 0{,}05 \cdot p_{b,h_{p_n}}$$

The specific force error as a result of ϕ_{h_p} reads:

$$(A_{y_{b,c}})_{error} = + g \cdot \phi_{h_p}$$

This lateral specific force error is compensated by means of the lateral translational motion of the base:

$\ddot{y}_{b,2} = + g \cdot \phi_{h_p}$, see Section 6.2.

The total body-axes roll acceleration, used for lead-compensation of the motion system, see Section 12, reads:

$$\dot{p}_s = \dot{p}_{b,1_p} + \dot{p}_{b,h_p} \qquad (9.10.)$$

The total body-axes roll rate, to be transformed into inertial axes, see Section 10, reads:

$$p_s = p_{b,1_p} + p_{b,h_p} \qquad (9.11.)$$

9.3. Yaw motion

Because of the restricted freedom in yaw of the motion base, see Table 1, also here a high-pass filter is applied to suppress the low-frequency changes of aircraft yaw acceleration $\dot{r}_b$.
The transfer function of the applied high-pass second order filter reads:

$$\frac{\dot{r}_{b,h_p}}{\dot{r}_b} = H(P)^{*)} = \frac{\tau_\psi^2 \cdot P^2}{1 + 2\tau_\psi \cdot \zeta_\psi \cdot P + \tau_\psi^2 \cdot P^2}$$

The resulting body-axes yaw acceleration $\dot{r}_{b,h_p}$ can be written as:

$$\dot{r}_{b,h_p} = \dot{r}_b - \frac{2\zeta_\psi}{\tau_\psi} \cdot r_{b,h_p} - \frac{1}{\tau_\psi^2} \cdot \psi_{h_p} \qquad (9.12.)$$

Rectangular integration gives at time t_n:

$$r_{b,h_{p_n}} = r_{b,h_{p_{n-1}}} + 0{,}05 \cdot \dot{r}_{b,h_{p_{n-1}}} \qquad (9.13.)$$

$$\psi_{h_{p_n}} = \psi_{h_{p_{n-1}}} + 0{,}05 \cdot r_{b,h_{p_n}} \qquad (9.14.)$$

*) See note on page 7.

10. Body to inertial transformation of the motion system rotational rates.

Just as the translational degrees of freedom, the rotational degrees of freedom of the motion base operate in an inertial axes system. Therefore, the rotational rates (9.6.), (9.11.) and (9.13.) are transformed to Euler rates. According to Table 33 of Ref. 7, the Euler rates $\dot{\psi}_i$, $\dot{\theta}_i$ and $\dot{\phi}_i$ can be written as:

$$\dot{\psi}_i = \frac{\sin \phi_m}{\cos \theta_m} \cdot q_s + \frac{\cos \phi_m}{\cos \theta_m} \cdot r_{b,h_p}$$

$$\dot{\theta}_i = \cos \phi_m \cdot q_s - \sin \phi_m \cdot r_{b,h_p} \qquad (10.1.)$$

$$\dot{\phi}_i = p_s + \sin \phi_m \cdot \tan \theta_m \cdot q_s + \cos \phi_m \cdot \tan \theta_m \cdot r_{b,h_p}$$

where θ_m and ϕ_m are the simulator pitch and roll angles respectively, see also section 11.

11. Rotational washout.

In accordance with section 8, an attennuation is applied also to the Euler rates $\dot{\psi}_i$, $\dot{\theta}_i$ and $\dot{\phi}_i$ of the motion platform, see Fig. 2, block 11, to prevent the platform from running into its limits.
Use is made here of first order high-pass washout filters.

$$\dot{\psi}_m = \dot{\psi}_i - \frac{1}{\tau_{\psi_R}} \cdot \psi_m$$

$$\dot{\theta}_m = \dot{\theta}_i - \frac{1}{\tau_{\theta_R}} \cdot \theta_m \qquad (11.1.)$$

$$\dot{\phi}_m = \dot{\phi}_i - \frac{1}{\tau_{\phi_R}} \cdot \phi_m$$

The yaw angle ψ_m, pitch angle θ_m and roll angle ϕ_m of the motion platform, not yet compensated for the platform's dynamic lag, are obtained by rectangular integration of $\dot{\psi}_m$, $\dot{\theta}_m$ and $\dot{\phi}_m$ respectively at a rate of 20 times/ sec.

12. Lead compensation for dynamic lag in the motion system's translational and rotational degrees of freedom.

An analysis of the motion system's response characteristics revealed that the hardware had dominant second-order phase lag characteristics, see Ref. 5.

Compensation for these lags could be achieved by introducing in the software program of the motion simulation appropriate second-order lead terms. Both the first and second deratives are required of the signal to be compensated. For the translational degrees of freedom, both the transformed first and second deratives $\dot{x}_m$, $\dot{y}_m$, $\dot{z}_m$, $\ddot{x}_m$, $\ddot{y}_m$, and $\ddot{z}_m$ are available for this purpose, see section 8. For the rotational degrees of freedom, however, the second deratives (9.5.), (9.10.) and (9.12.) are available only in body-axes and thus they will be used for the compensation.
The six compensated position and attitude command signals, to be sent to the actuator extension transformation, see Fig. 2, block 13, read:

$$\begin{aligned} x_c &= x_m + B_1 \cdot \dot{x}_m + A_1 \cdot \ddot{x}_m \\ y_c &= y_m + B_2 \cdot \dot{y}_m + A_2 \cdot \ddot{y}_m \\ z_c &= z_m + B_3 \cdot \dot{z}_m + A_3 \cdot \ddot{z}_m \\ \theta_c &= \theta_m + B_4 \cdot \dot{\theta}_m + A_4 \cdot \dot{q}_s \\ \phi_c &= \phi_m + B_5 \cdot \dot{\phi}_m + A_5 \cdot \dot{p}_s \\ \psi_c &= \psi_m + B_6 \cdot \dot{\psi}_m + A_6 \cdot \dot{r}_{b,h_p} \end{aligned} \qquad (12.1.)$$

Numerical values for the "time-constants"*), damping ratio and other parameters as applied to the KSS B-747 motion simulation are presented in Appendices A and B.

13. Summary of the equations as applied in the motion simulation.

Flightpath to body-axes transformation of the total forces F_{x_w}, F_{y_w} and F_{z_w} in the off-ground condition:

$$\begin{aligned} F_{x_b} &= + \cos\alpha_b \cdot \cos\beta \cdot F_{x_w} - \cos\alpha_b \cdot \sin\beta \cdot F_{y_w} - \sin\alpha_b \cdot F_{z_w} \\ F_{y_b} &= + \sin\beta \cdot F_{x_w} + \cos\beta \cdot F_{y_w} \\ F_{z_b} &= + \sin\alpha_b \cdot \cos\beta \cdot F_{x_w} - \sin\alpha_b \cdot \sin\beta \cdot F_{y_w} + \cos\alpha_b \cdot F_{z_w} \end{aligned} \qquad (3.1.)$$

The body-axes specific forces:

$$\begin{aligned} A_{x_b} &= \dot{u}_b - r_b \cdot v_b + g \cdot \sin\theta \\ A_{y_b} &= \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b - g \cdot \cos\theta \cdot \sin\phi \\ A_{z_b} &= \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b - g \cdot \cos\theta \cdot \cos\phi \end{aligned} \qquad (4.4.)$$

*) See note on page 7.

Centroid transformation:

$$A_{x_b,c} = \dot{u}_{b,c} + g \cdot \sin\theta \qquad (5.2.)$$

where:

$$\dot{u}_{b,c} = \dot{u}_b - r_b \cdot v_b - (q_b^2 + r_b^2) \cdot R_x$$

$$A_{y_b,c} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi \qquad (5.3.)$$

where:

$$\dot{v}_{b,c} = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b + (p_b \cdot q_b + \dot{r}_b) \cdot R_x$$

$$A_{z_b,c} = \dot{w}_{b,c} - g \cdot \cos\theta \cdot \cos\phi \qquad (5.4.)$$

where:

$$\dot{w}_{b,c} = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b + (p_b \cdot r_b - \dot{q}_b) \cdot R_x$$

Longitudinal motion:

$$\ddot{x}_{b,1} = \dot{u}_{b,c} - g \cdot \theta_{1_p} - \frac{2\zeta_x}{\tau_x} \cdot \dot{x}_{b,1} - \frac{1}{\tau_x^2} \cdot x_{b,1} \qquad (6.3.)$$

$$\ddot{x}_{b,2} = - g \cdot \theta_{h_p} \qquad \text{(specific force error)}$$

$$\ddot{x}_s = \ddot{x}_{b,1} + \ddot{x}_{b,2} \qquad (6.4.)$$

Lateral motion:

$$\ddot{y}_{b,1} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p} - \frac{2\zeta_y}{\tau_y} \cdot \dot{y}_{b,1} - \frac{1}{\tau_y^2} \cdot y_{b,1} \qquad (6.7.)$$

$$\ddot{y}_{b,2} = + g \cdot \phi_{h_p} \qquad \text{(specific force error)}$$

$$\ddot{y}_s = \ddot{y}_{b,1} + \ddot{y}_{b,2} \qquad (6.8.)$$

Heave motion:

$$\ddot{z}_b = \dot{w}_{b,c} - \frac{2\zeta_z}{\tau_z} \cdot \dot{z}_b - \frac{1}{\tau_z^2} \cdot z_b \qquad (6.11.)$$

Body to inertial transformation of the motion platform translational accelerations:

$$\ddot{x}_i = \cos\theta_m \cdot \cos\psi_m \cdot \ddot{x}_s + (\sin\phi_m \cdot \sin\theta_m \cdot \cos\psi_m - \cos\phi_m \cdot \sin\psi_m) \cdot \ddot{y}_s$$
$$+ (\cos\phi_m \cdot \sin\theta_m \cdot \cos\psi_m + \sin\phi_m \cdot \sin\psi_m) \cdot \ddot{z}_b \qquad (7.1.)$$

$$\ddot{y}_i = \cos\theta_m \cdot \sin\psi_m \cdot \ddot{x}_s + (\sin\phi_m \cdot \sin\theta_m \cdot \sin\psi_m + \cos\phi_m \cdot \cos\psi_m) \cdot \ddot{y}_s$$
$$+ (\cos\phi_m \cdot \sin\theta_m \cdot \sin\psi_m - \sin\phi_m \cdot \cos\psi_m) \cdot \ddot{z}_b \qquad (7.2.)$$

$$\ddot{z}_i = -\sin\theta_m \cdot \ddot{x}_s + \sin\phi_m \cdot \cos\theta_m \cdot \ddot{y}_s + \cos\phi_m \cdot \cos\theta_m \cdot \ddot{z}_b \qquad (7.3.)$$

Translational washout:

$$\ddot{x}_m = \ddot{x}_i - \frac{2\zeta_{x_T}}{\tau_{x_T}} \cdot \dot{x}_m - \frac{1}{\tau_{x_T}^2} \cdot x_m$$

$$\ddot{y}_m = \ddot{y}_i - \frac{2\zeta_{y_T}}{\tau_{y_T}} \cdot \dot{y}_m - \frac{1}{\tau_{y_T}^2} \cdot y_m \qquad (8.1.)$$

$$\ddot{z}_m = \ddot{z}_i - \frac{2\zeta_{z_T}}{\tau_{z_T}} \cdot \dot{z}_m - \frac{1}{\tau_{z_T}^2} \cdot z_m$$

Pitch motion:

$$\dot{q}_{b,l_p} = \frac{\dot{u}_{b,c}}{\tau_{\theta_{l_p}}^2 \cdot g} + \frac{\sin\theta}{\tau_{\theta_{l_p}}^2} - \frac{2\zeta_{\theta_{l_p}}}{\tau_{\theta_{l_p}}} \cdot q_{b,l_p} - \frac{1}{\tau_{\theta_{l_p}}^2} \cdot \theta_{l_p} \qquad (9.3.)$$

$$\dot{q}_{b,h_p} = \dot{q}_b - \frac{2\zeta_{\theta_{h_p}}}{\tau_{\theta_{h_p}}} \cdot q_{b,h_p} - \frac{1}{\tau_{\theta_{h_p}}^2} \cdot \theta_{h_p}$$

$$\dot{q}_s = \dot{q}_{b,l_p} + \dot{q}_{b,h_p} \qquad (9.5.)$$

$$q_s = q_{b,l_p} + q_{b,h_p} \qquad (9.6.)$$

Roll motion:

$$\dot{p}_{b,l_p} = -\frac{\dot{v}_{b,c}}{\tau_{\phi_{l_p}}^2 \cdot g} + \frac{\cos\theta \cdot \sin\phi}{\tau_{\phi_{l_p}}^2} - \frac{2\zeta_{\phi_{l_p}}}{\tau_{\phi_{l_p}}} \cdot p_{b,l_p} - \frac{1}{\tau_{\phi_{l_p}}^2} \cdot \phi_{l_p} \qquad (9.9.)$$

$$\dot{p}_{b,h_p} = \dot{p}_b - \frac{2\zeta_{\phi_{h_p}}}{\tau_{\phi_{h_p}}} \cdot p_{b,h_p} - \frac{1}{\tau_{\phi_{h_p}}^2} \cdot \phi_{h_p}$$

$$\dot{p}_s = \dot{p}_{b,l_p} + \dot{p}_{b,h_p} \qquad (9.10.)$$

$$p_s = p_{b,l_p} + p_{b,h_p} \qquad (9.11.)$$

Yaw motion:

$$\dot{r}_{b,h_p} = \dot{r}_b - \frac{2\zeta_\psi}{\tau_\psi} \cdot r_{b,h_p} - \frac{1}{\tau_\psi^2} \cdot \psi_{h_p} \tag{9.12.}$$

Euler rates:

$$\dot{\psi}_i = \frac{\sin \phi_m}{\cos \theta_m} \cdot q_s + \frac{\cos \phi_m}{\cos \theta_m} \cdot r_{b,h_p}$$

$$\dot{\theta}_i = \cos \phi_m \cdot q_s - \sin \phi_m \cdot r_{b,h_p} \tag{10.1.}$$

$$\dot{\phi}_i = p_s + \sin \phi_m \cdot \tan \theta_m \cdot q_s + \cos \phi_m \cdot \tan \theta_m \cdot r_{b,h_p}$$

Rotational washout:

$$\dot{\psi}_m = \dot{\psi}_i - \frac{1}{\tau_{\psi_R}} \cdot \psi_m$$

$$\dot{\theta}_m = \dot{\theta}_i - \frac{1}{\tau_{\theta_R}} \cdot \theta_m \tag{11.1.}$$

$$\dot{\phi}_m = \dot{\phi}_i - \frac{1}{\tau_{\phi_R}} \cdot \phi_m$$

Motion system lead compensation:

$$x_c = x_m + B_1 \cdot \dot{x}_m + A_1 \cdot \ddot{x}_m$$

$$y_c = y_m + B_2 \cdot \dot{y}_m + A_2 \cdot \ddot{y}_m$$

$$z_c = z_m + B_3 \cdot \dot{z}_m + A_3 \cdot \ddot{z}_m$$

$$\theta_c = \theta_m + B_4 \cdot \dot{\theta}_m + A_4 \cdot \dot{q}_s \tag{12.1.}$$

$$\phi_c = \phi_m + B_5 \cdot \dot{\phi}_m + A_5 \cdot \dot{p}_s$$

$$\psi_c = \psi_m + B_6 \cdot \dot{\psi}_m + A_6 \cdot \dot{r}_{b,h_p}$$

14. Concluding remarks

In this report the mathematical formulation of the generation of motion cues is described. From the mathematical model of the simulated aircraft, the specific forces and rotational accelerations at the aircraft c.g. are determined as primary control inputs of the motion drive laws. Because the specific forces are acting on the pilot inside the simulator cockpit, they should be transformed to the so called centroid location of the motion system.

As the motion possibilities of the base are constrained, filtering of the specific forces and rotational accelerations is necessary and as far as possible, tilt angles are used to reproduce sustained specific forces, providing the motion system with so called "co-ordinated wash-out".

The dynamic characteristics of the motion system should be such, that for the reproduction of the high frequencies, the high frequency-response of the base is of sufficient quality. On the other hand the smoothness of the base is important to keep the low-frequence "wash-out" below the threshold level of the pilot's perception.

Experience obtained from the development of the motion simulation software, presented in Appendix B, has shown that realistic motion cues are obtained, especially in the approach, landing and take-off phases of flight. Among other difficulties, problems such as lateral pilot-induced-oscillations in the final part of the visual approach were solved.

15. References

1. S.F. Schmidt, B. Conrad — "Motion Drive Signals For Piloted Flight Simulators", Analytical Mechanics Associates, Inc. Palo Alto, California, 1970.

2. R.L. Stapleford, R.A. Peters, F.K. Alex — "Experiments and a Model for Pilot Dynamics with Visual on Motion Inputs", NASA CR 1325, May 1969.

3. D.T. McRuer et al. — "New Approaches to Human Pilot/Vehicle Dynamic Analysis", Systems Technology Inc., Techn. Report AFFDL-TR-76-150, 1968.

4. C. Broxmeyer — "Inertial Navigation Systems", Electronic Services Series, McGraw-Hill, 1964.

5. M. Baarspul — "Hardware Modifications to improve the frequency response and smoothness of a synergistic six-degree-of-freedom motion system", (KLM report to be published).

6. J. Schlien — CAE Program Specification Flight part 1 and 4, CAE Electronics Ltd., Canada, November 1971.

7. W.G. Vermeulen — "Overzicht van in de vliegmechanica veel gebruikte assenstelsels en de daarmee samenhangende transformatie formules", Memo VH-69-035, National Aerospace Laboratory NLR, The Netherlands.

16. Acknowledgements

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Degree of freedom	Performance limits			
	Position	Velocity	Acceleration	Rate of change accelerations
Horizontal x	forward 1,24 m aft 1,24 m	$\pm$ 0,610 m/sec	$\pm$ 0,5 g	$\pm$ 30g/sec
Lateral y	left 1,21 m right 1,21 m	$\pm$ 0,610 m/sec	$\pm$ 0,5 g	$\pm$ 30g/sec
Vertical z	up 0,85 m down 0,85 m	$\pm$ 0,91 m/sec	$\pm$ 0,75 g	$\pm$ 50g/sec
Yaw ψ	$\pm 36^{o}$	$\pm 20^{o}$/sec	$\pm 20^{o}/sec^{2}$	
Pitch θ	$+ 34^{o}$ $- 32^{o}$	$\pm 20^{o}$/sec	$\pm 30^{o}/sec^{2}$	
Roll ϕ	$\pm 28^{o}$	$\pm 16^{o}$/sec	$\pm 20^{o}/sec^{2}$	

Table 1: Performance limits for single degree of freedom operation.

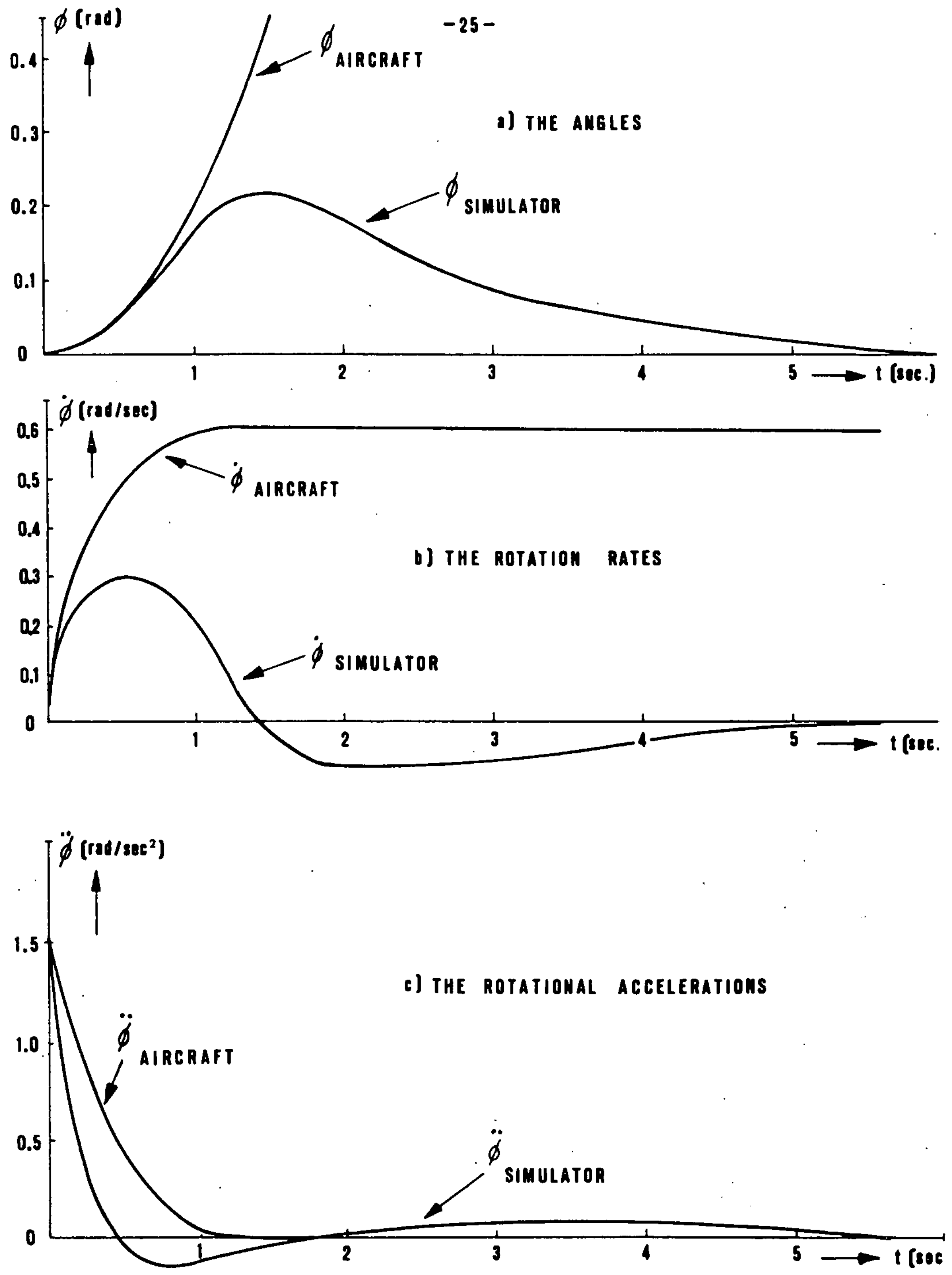

FIG. 1 THE RESPONSES OF THE BANK ANGLE (ϕ) THE ROLLRATE ($\dot{\phi}$) AND THE ROLL ACCELERATION ($\ddot{\phi}$) OF AN AIRCRAFT AND THE FLIGHT SIMULATOR TO AN AILERON STEP INPUT

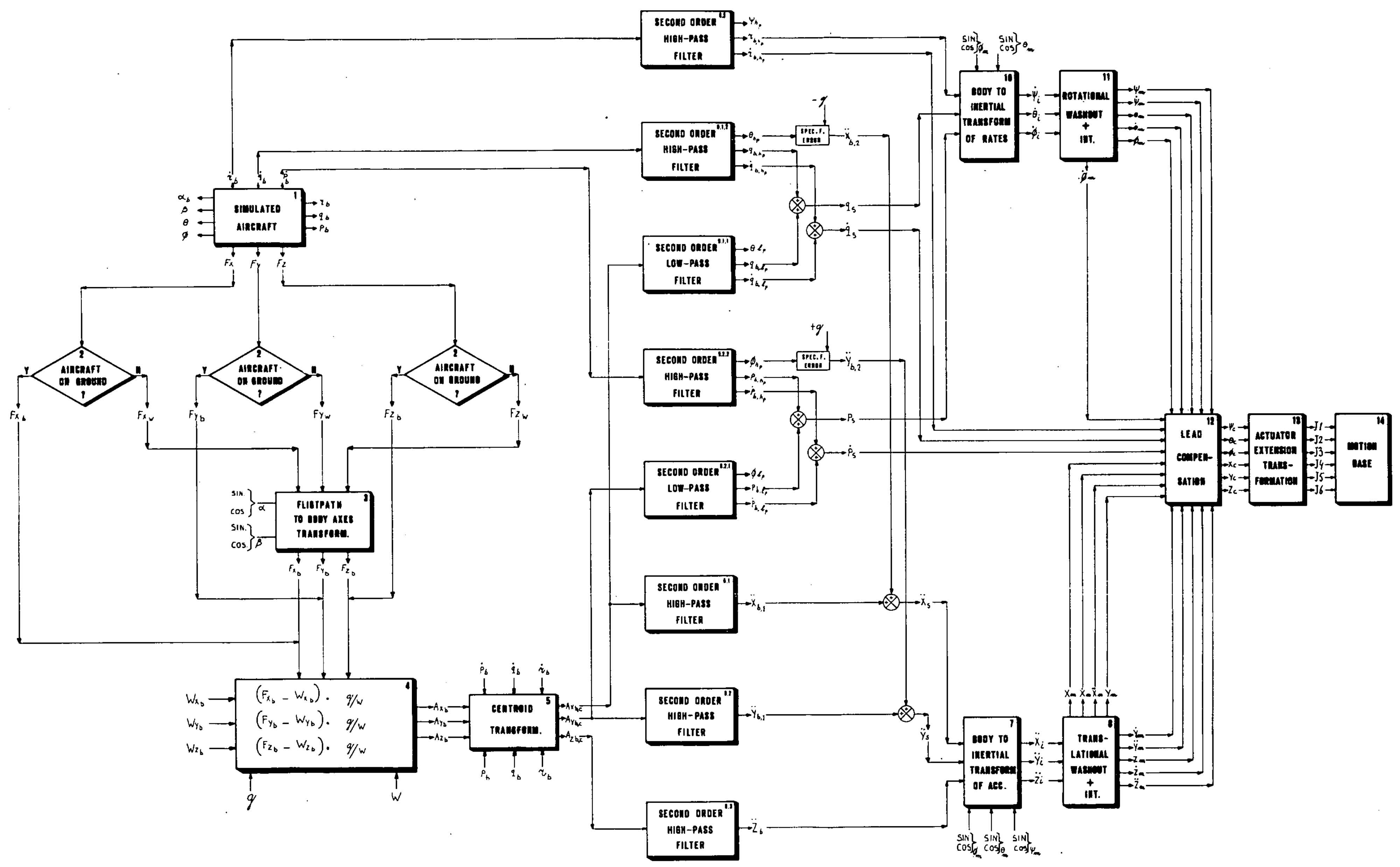

FIG. 2: KSS BOEING 747 MOTION SIMULATION

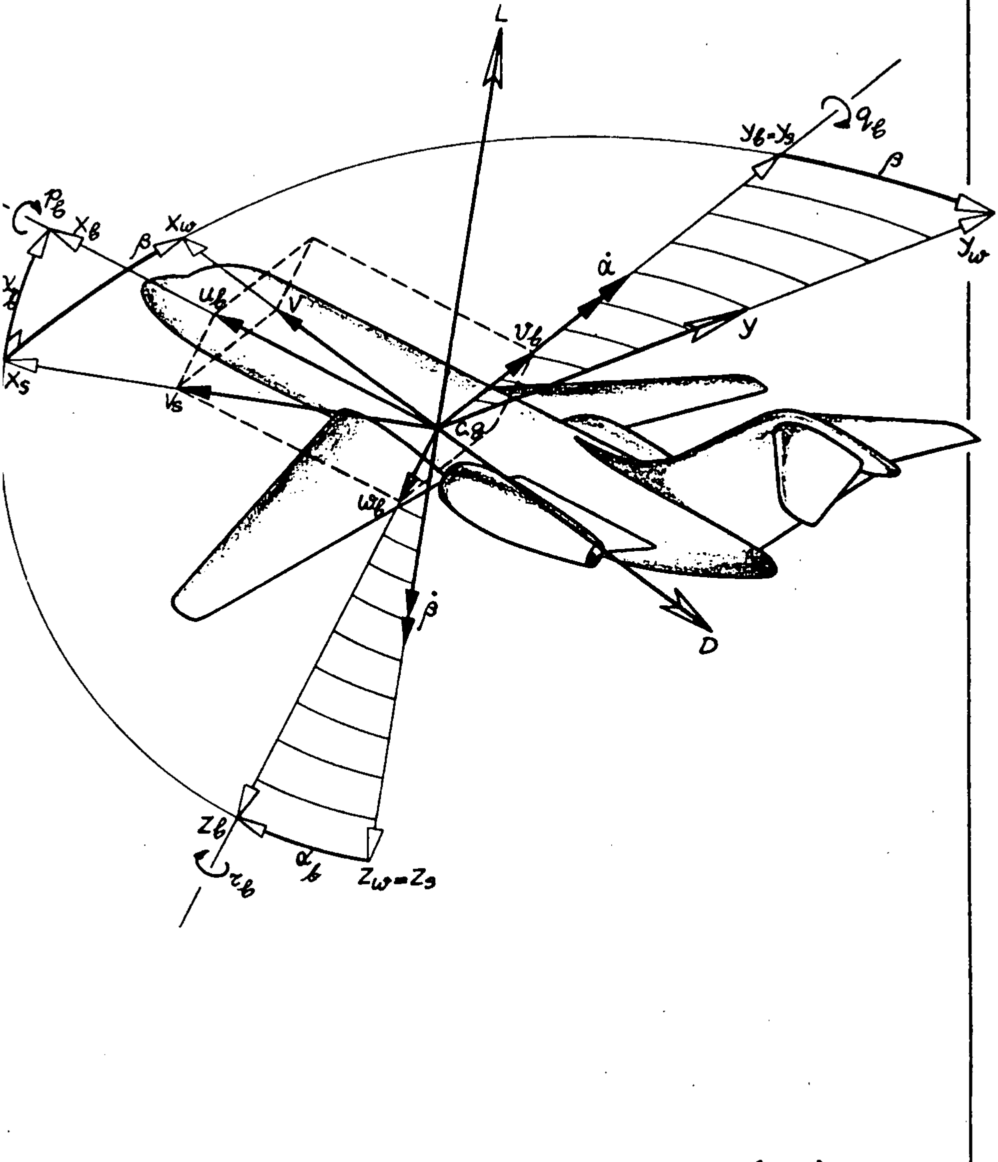

FIG 3 THE RELATION BETWEEN BODY AXES AND FLIGHTPATH- (WIND) AXES

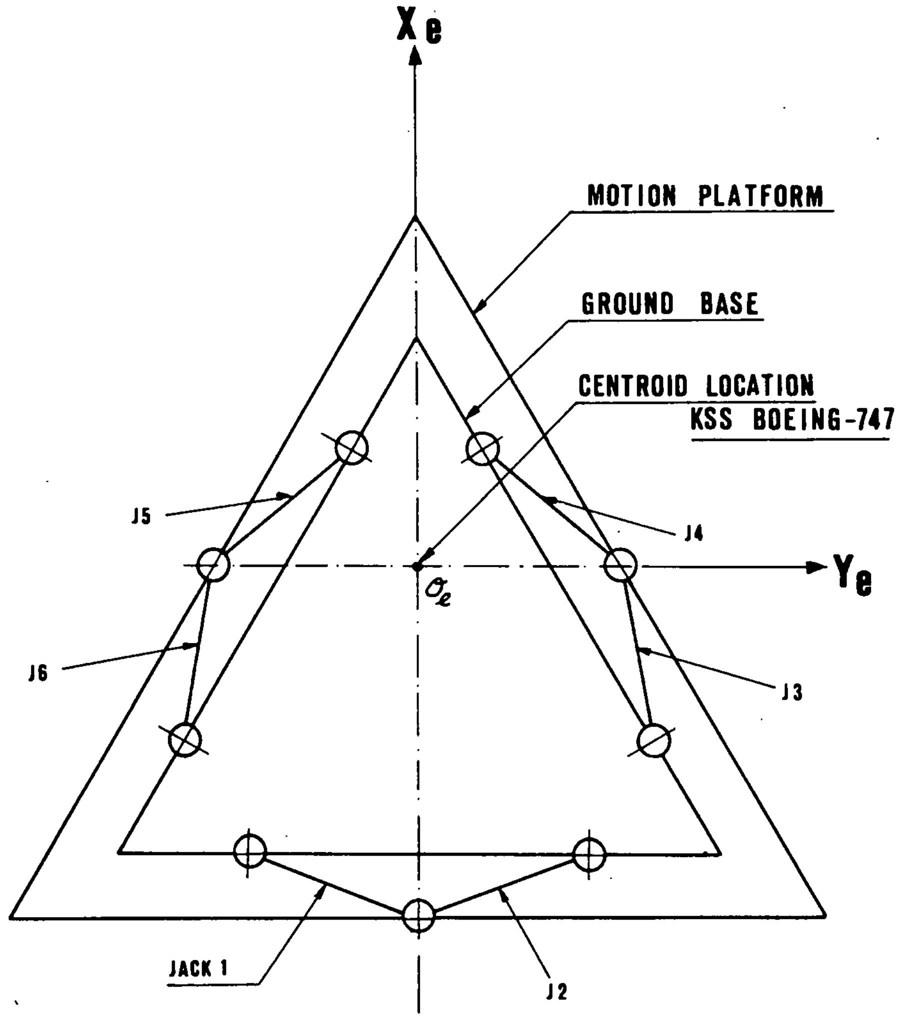

FIG. 4: ARRANGEMENT OF THE KSS BOEING-747 MOTION SYSTEM,

DEFINING THE $O_e X_e Y_e Z_e$ - REFERENCE FRAME AND THE CENTROID LOCATION

Appendix A. Scaled equations as used in the KSS Boeing 747 Main Motion Simulation Program.

The scaled equations of the KSS Boeing 747 Main Motion Simulation Program in the sequence as followed by the digital computer are given below. The parameters used in the software are summarized in Table 2.

Computations in behalf of the specific forces, see section 4; on ground:

$$\dot{u}_b - r_b \cdot v_b = \frac{F_{x_b}}{W} \cdot g$$

$$\frac{\dot{u}_b - r_b \cdot v_b}{10} = \left(\frac{F_{x_b}}{W \cdot 1{,}748}\right) \cdot \frac{1{,}748}{10} \cdot 9{,}81$$

UBD = MFXWB . KXU1

Off ground:

UWD = MFXWB . KXU1

$$KXU1 = K\ SCALE = \frac{1{,}748}{10} \cdot 9{,}81 = 1{,}71479 = 0{,}428697\ SALD\ 3.^{*)}$$

On ground:

$$\dot{v}_b + r_b \cdot u_b - p_b \cdot w_b = \frac{F_{y_b}}{W} \cdot g$$

$$\frac{\dot{v}_b + r_b \cdot u_b - p_b \cdot w_b}{8} = \frac{F_{y_b}}{W.2} \cdot \frac{2}{8} \cdot 9{,}81$$

VBDM = MFYWB . KYV1

Off ground:

VWD = MFYWB . KYV1

$$KYV1 = K\ SCALE = \frac{2}{8} \cdot 9{,}81 = 2{,}4525 = 0{,}613124\ SALD\ 3.$$

On ground:

$$\dot{w}_b - q_b \cdot u_b + p_b \cdot v_b = \frac{F_{z_b}}{W} \cdot g$$

$$\frac{\dot{w}_b - q_b \cdot u_b + p_b \cdot v_b}{40} = \left(\frac{F_{z_b}}{W.6}\right) \cdot \frac{6}{40} \cdot 9{,}81$$

WBD = MFZWB . KZW1

Off ground:

WWD = MFZWB . KZW1

*) Note: SALD 3 means arithm. left shift double ($3 = 2^2$ effectively).

$KZW1 = K\ SCALE = \frac{6}{40} \cdot 9{,}81 = 1{,}4715 = 0{,}367875$ SALD 3.

The above computations are performed by means of LOOP 1 and 2 in part 1 of KSS Boeing 747 Main Motion Simulation, see line 41 of Appendix B, part

Wind- to body-axes transformation of UWD, VWD and WWD, when the aircraft is off-ground, see section 3:

$$UBD = UWD \cdot \cos\alpha_b \cdot \cos\beta - VWD \cdot \cos\alpha_b \cdot \sin\beta - WWD \cdot \sin\alpha_b$$

$$\frac{UBD}{10} = \frac{UWD}{10} \cdot \frac{\cos\alpha_b}{1} \cdot \frac{\cos\beta}{1} - \frac{1}{10} \cdot \left(\frac{VWD}{8}\right) \cdot 8 \cdot \frac{\cos\alpha_b}{1} \cdot \frac{\sin\beta}{1} - \frac{1}{10} \cdot \left(\frac{WWD}{40}\right) \cdot 40 \cdot \frac{\sin\alpha_b}{1}$$

$$\overline{UBD} = \overline{UWD} \cdot VCSAB \cdot VCSB - \overline{VWD} \cdot VCSAB \cdot VSNB \cdot KUBBD - \overline{WWD} \cdot VSNAB \cdot 4$$

$KUBBD = \frac{8}{10} = 0{,}8$, see line 81 of Appendix B.

$$VBDM = UWD \cdot \sin\beta + VWD \cdot \cos\beta$$

$$\frac{VBDM}{8} = \frac{1}{8} \cdot \left(\frac{UWD}{10}\right) \cdot 10 \cdot \frac{\sin\beta}{1} + \frac{VWD}{8} \cdot \frac{\cos\beta}{1}$$

$$\overline{VBDM} = \overline{UWD} \cdot VSNB \cdot KVBBD + \overline{VWD} \cdot VCSB$$

$KVBBD = \frac{10}{8} = 1{,}25 = 0{,}625$ SALD 2, see line 98 and 99 of Appendix B, part 1

$$WBD = UWD \cdot \sin\alpha_b \cdot \cos\beta - VWD \cdot \sin\alpha_b \cdot \sin\beta + WWD \cdot \cos\alpha_b$$

$$\frac{WBD}{40} = \frac{1}{40} \cdot \left(\frac{UWD}{10}\right) \cdot 10 \cdot \frac{\sin\alpha_b}{1} \cdot \frac{\cos\beta}{1} - \frac{1}{40} \cdot \left(\frac{VWD}{8}\right) \cdot 8 \cdot \frac{\sin\alpha_b}{1} \cdot \frac{\sin\beta}{1} + \frac{WWD}{40} \cdot \frac{\cos\alpha_b}{1}$$

$$\overline{WBD} = \overline{UWD} \cdot VSNAB \cdot VCSB \cdot KWBBD1 - \overline{VWD} \cdot VSNAB \cdot VSNB \cdot KWBBD2 + \overline{WWD} \cdot VS$$

$KWBBD1 = \frac{10}{40} = 0{,}25$, see line 120 of Appendix B, part 1.

$KWBBD2 = \frac{8}{40} = 0{,}2$, see line 129 of Appendix B, part 1.

To avoid discontinuity problems during the transition from on- to off-ground, the calculation is stopped for 1 sec in case of a condition change see line 141 of Appendix B, part 1.

Pitch acceleration, see section 9.1:

$\zeta_{\theta_{h_p}} = 0{,}7$

$\tau_{\theta_{h_p}} = 6$ sec.

$S_{\dot{q}_{b,h_p}} = 2$ rad/sec^2

$S_{q_{b,h_p}} = 1$ rad/sec

$S_{\theta_{h_p}} = 1$ rad

$S_{\dot{q}_b} = 2$ rad/sec^2

$$\dot{q}_{b,h_p} = \dot{q}_b - \frac{2\zeta_{\theta_{h_p}}}{\tau_{\theta_{h_p}}} \cdot q_{b,h_p} - \frac{1}{\tau_{\theta_{h_p}}^{\ 2}} \cdot \theta_{h_p}$$

$$\frac{\dot{q}_{b,h_p}}{2} = \frac{\dot{q}_b}{2} - \frac{2\zeta_{\theta_{h_p}}}{2\tau_{\theta_{h_p}}} \cdot \frac{q_{b,h_p}}{1} - \frac{1}{2\tau^2_{\theta_{h_p}}} \cdot \frac{\theta_{h_p}}{1}$$

MPITCHDD = VPRD - (KP1 . MPITCHDM + KP2 . MPITCHM)

$$KP1 = \frac{2\zeta_{\theta_{h_p}}}{2\tau_{\theta_{h_p}}} = \frac{2 \cdot 0{,}7}{2 \cdot 6} = 0{,}11666 \text{ (line 359)}$$

$$KP2 = \frac{1}{2\tau^2_{\theta_{h_p}}} = \frac{1}{2 \cdot 36} = 0{,}01388 \text{ (line 360)}$$

Rectangular integration:

$$q_{b,h_p} = q_{b,h_p} + 0{,}05 \cdot \dot{q}_{b,h_p}$$

$$\frac{q_{b,h_p}}{1} = \frac{q_{b,h_p}}{1} + \frac{0{,}05}{1} \cdot \left(\frac{\dot{q}_{b,h_p}}{2}\right) \cdot 2$$

MPITCHDM = MPITCHDM + KP3 . MPITCHDD

$$KP3 = \frac{0{,}05}{1} \cdot 2 = 0{,}1$$

$$\theta_{h_p} = \theta_{h_p} + 0{,}05 \cdot q_{b,h_p}$$

$$\frac{\theta_{h_p}}{1} = \frac{\theta_{h_p}}{1} + \frac{0{,}05}{1} \cdot \frac{q_{b,h_p}}{1}$$

MPITCHM = MPITCHM + KP4 . MPITCHDM

$$KP4 = \frac{0{,}05}{1} = 0{,}05$$

Roll acceleration, see section 9.2:

$$\zeta_{\phi_{h_p}} = 0{,}7$$

$$\tau_{\phi_{h_p}} = 6 \text{ sec}$$

$$S_{\dot{p}_{b,h_p}} = 4 \text{ rad/sec}^2$$

$$S_{p_{b,h_p}} = 2 \text{ rad/sec}$$

$$S_{\phi_{h_p}} = 2 \text{ rad}$$

$$S_{\dot{p}_b} = 4 \text{ rad/sec}^2$$

$$\dot{p}_{b,h_p} = \dot{p}_b - \frac{2\zeta_{\phi_{h_p}}}{\tau_{\phi_{h_p}}} \cdot p_{b,h_p} - \frac{1}{\tau^2_{\phi_{h_p}}} \cdot \phi_{h_p}$$

$$\frac{\dot{p}_{b,h_p}}{4} = \frac{\dot{p}_b}{4} - \frac{2\zeta_{\phi_{h_p}}}{4\tau_{\phi_{h_p}}} \cdot \left(\frac{p_{b,h_p}}{2}\right) \cdot 2 - \frac{1}{4\tau^2_{\phi_{h_p}}} \cdot \left(\frac{\phi_{h_p}}{2}\right) \cdot 2$$

MROLLDD = VRRD - (KR1 . MROLLDM + KR2 . MROLLM)

$$KR1 = \frac{2\zeta_{\phi_{h_p}}}{4\tau_{\phi_{h_p}}} \cdot 2 = \frac{2.0{,}7.2}{4.6} = 0{,}11666$$

$$KR2 = \frac{1}{4\tau^2_{\phi_{h_p}}} \cdot 2 = \frac{2}{4.36} = 0{,}01388$$

Rectangular integration:

$$p_{b,h_p} = p_{b,h_p} + 0{,}05\ \dot{p}_{b,h_p}$$

$$\frac{p_{b,h_p}}{2} = \frac{p_{b,h_p}}{2} + \frac{0{,}05}{2} \cdot \left(\frac{\dot{p}_{b,h_p}}{4}\right) \cdot 4$$

MROLLDM = MROLLDM + KR3 . MROLLDD

$$KR3 = \frac{0{,}05}{2} \cdot 4 = 0{,}1$$

$$\phi_{h_p} = \phi_{h_p} + 0{,}05\ p_{b,h_p}$$

$$\frac{\phi_{h_p}}{2} = \frac{\phi_{h_p}}{2} + \frac{0{,}05}{2} \cdot \left(\frac{p_{b,h_p}}{2}\right) \cdot 2$$

MROLLM = MROLLM + KR4 . MROLLDM

$$KR4 = \frac{0{,}05}{2} \cdot 2 = 0{,}05$$

Yaw acceleration, see section 9.3:

ζ_ψ = 0,7

τ_ψ = 1,5 sec

$S_{\dot{r}_{b,h_p}}$ = 2 rad/sec²

$S_{r_{b,h_p}}$ = 1 rad/sec

$S_{\psi_{h_p}}$ = 1 rad

$S_{\dot{r}_b}$ = 2 rad/sec²

$$\dot{r}_{b,h_p} = \dot{r}_b - \frac{2\zeta_\psi}{\tau_\psi} \cdot r_{b,h_p} - \frac{1}{\tau_\psi^2} \cdot \psi_{h_p}$$

$$\frac{\dot{r}_{b,h_p}}{2} = \frac{\dot{r}_b}{2} - \frac{2\zeta_\psi}{2\tau_\psi} \cdot \frac{r_{b,h_p}}{1} - \frac{1}{2\tau_\psi^2} \cdot \frac{\psi_{h_p}}{1}$$

MYAWDD = VHRD - (KJ1 . MYAWDM + KJ2 . MYAWM)

$$KJ1 = \frac{2\zeta_\psi}{2\tau_\psi} = \frac{2 \cdot 0{,}7}{2 \cdot 1{,}5} = 0{,}233332 \cdot 2 \text{ (line 377)}$$

$$KJ2 = \frac{1}{2\tau_\psi^2} = \frac{1}{2 \cdot 2{,}25} = 0{,}05552 \cdot 4 \text{ (line 378)}$$

Rectangular integration:

$$r_{b,h_p} = r_{b,h_p} + 0,05\ \dot{r}_{b,h_p}$$

$$\frac{r_{b,h_p}}{1} = \frac{r_{b,h_p}}{1} + \frac{0,05}{1} \cdot \left(\frac{\dot{r}_{b,h_p}}{2}\right) \cdot 2$$

MYAWDM = MYAWDM + KJ3 . MYAWDD

$$KJ3 = \frac{0,05}{1} \cdot 2 = 0,1$$

$$\psi_{h_p} = \psi_{h_p} + 0,05 \cdot r_{b,h_p}$$

$$\frac{\psi_{h_p}}{1} = \frac{\psi_{h_p}}{1} + \frac{0,05}{1} \cdot \frac{r_{b,h_p}}{1}$$

MYAWM = MYAWM + KJ4 . MYAWDM

$$KJ4 = \frac{0,05}{1} = 0,05$$

Specific force errors, see section 9.1. and 9.2.:

$$\ddot{x}_{b,2} = -g \cdot \theta_{h_p}$$

$$\frac{\ddot{x}_{b,2}}{10} = \frac{-g}{10} \cdot \frac{\theta_{h_p}}{1}$$

MXDD = KX1 . MPITCHM

The program value of KX1 has been adjusted to:

KX1 = -0,12 (see line 380 of Appendix B, part 1)

to prevent the motion platform from running into its longitudinal position limits.

$$\ddot{y}_{b,2} = +g \cdot \phi_{h_p}$$

$$\frac{\ddot{y}_{b,2}}{8} = \frac{+g}{8} \cdot \left(\frac{\phi_{h_p}}{2}\right) \cdot 2$$

MYDD = KY1 . MROLLM

For the same reason, KY1 has been adjusted to:

KY1 = 0,3 (see line 381).

Centroid transformation, see section 5:

$$\dot{u}_{b,c} = \dot{u}_b - r_b \cdot v_b - (q_b^2 + r_b^2) \cdot R_x$$

$$\frac{\dot{u}_{b,c}}{10} = \frac{\dot{u}_b - r_b \cdot v_b}{10} - (\frac{q_b^2}{1} + \frac{r_b^2}{1}) \cdot \frac{R_x}{10}$$

UBCD = UBD - (VPR . VPR + VHR . VHR) . KUBC

KUBC = $\frac{25,9}{10}$ = 2,59 = 0,6475 SALD 3 (line 353)

$$\dot{v}_{b,c} = \dot{v}_b + r_b \cdot u_b - p_b \cdot w_b + (p_b \cdot q_b + \dot{r}_b) \cdot R_x$$

$$\frac{\dot{v}_{b,c}}{8} = \frac{\dot{v}_b + r_b \cdot u_b - p_b \cdot w_b}{8} + (\frac{p_b}{2}.2 \cdot \frac{q_b}{1} + \frac{\dot{r}_b}{2}.2) \cdot \frac{R_x}{8}$$

VBCD = VBDM + (VRR . VPR + VHRD) . KVBC

KVBC = $\frac{25,9 \cdot 2}{8}$ = 6,475 = 0,8094 SALD 4 (line 354)

$$\dot{w}_{b,c} = \dot{w}_b - q_b \cdot u_b + p_b \cdot v_b + (p_b \cdot r_b - \dot{q}_b) \cdot R_x$$

$$\frac{\dot{w}_{b,c}}{40} = \frac{\dot{w}_b - q_b \cdot u_b + p_b \cdot v_b}{40} + (\frac{p_b}{2}.2 \cdot \frac{r_b}{1} - \frac{\dot{q}_b}{2}.2) \cdot \frac{R_x}{40}$$

WBCD = WBD + (VRR . VHR - VPRD) . KWBC

KWBC = $\frac{2 \cdot 25,9}{40}$ = 1,295 = 0,6475 SALD 2 (line 355)

LONGITUDINAL SPECIFIC FORCE.

Longitudinal highpass filter, see section 6.1.:

ζ_x = 0,7

τ_x = 0,7

$S_{\ddot{x}}$ = 10 m/sec^2

$S_{\dot{x}}$ = 10 m/sec

S_x = 11,3952 m

$S_{\dot{u}_{b,c}}$ = 10 m/sec^2

$$\ddot{x}_{b,1} = \dot{u}_{b,c} - g \cdot \theta_{1_p} - \frac{2\zeta_x}{\tau_x} \cdot \dot{x}_{b,1} - \frac{1}{\tau_x^2} \cdot x_{b,1} \qquad (6.3.)$$

$$\frac{\ddot{x}_{b,1}}{10} = \frac{\dot{u}_{b,c}}{10} - \frac{g}{10} \cdot \frac{\theta_{1_p}}{1} - \frac{2}{10} \cdot \frac{\zeta_x}{\tau_x} \cdot (\frac{\dot{x}_{b,1}}{10}) \cdot 10 - \frac{1}{10\tau_x^2} \cdot (\frac{x_{b,1}}{11,3952}) \cdot 11,3952$$

BXDD = UBCD - BPITCHM - KX10 . BXDM - KX11 . BXM

$KX10 = \frac{2}{10} \cdot \frac{0,7}{0,7} \cdot 10 = 2 = 0,9999$ SALD 2 (line 482)

$KX11 = \frac{11,3952}{10 \cdot 0,49} = 2,3255 = 0,581377$ SALD 3 (line 358)

Rectangular integration:

$$\dot{x}_{b,1} = \dot{x}_{b,1} + 0,05\ \ddot{x}_{b,1}$$

$$\frac{\dot{x}_{b,1}}{10} = \frac{\dot{x}_{b,1}}{10} + \frac{0,05}{10} \cdot \left(\frac{\ddot{x}_{b,1}}{10}\right) \cdot 10$$

BXDM = BXDM + KX12 . BXDD

$$KX12 = \frac{0,05}{10} \cdot 10 = 0,05$$

$$x_{b,1} = x_{b,1} + 0,05\ \dot{x}_{b,1}$$

$$\frac{x_{b,1}}{11,3852} = \frac{x_{b,1}}{11,3952} + \frac{0,05}{11,3952} \cdot \left(\frac{\dot{x}_{b,1}}{10}\right) \cdot 10$$

BXM = BXM + KX13 . BXDM

$$KX13 = \frac{0,05 \cdot 10}{11,3952} = 0,043877$$

Longitudinal low-pass filter, see séction 9.1.

$\zeta_{\theta_{1_p}} = 0,7$

$\tau_{\theta_{1_p}} = 2$ sec

$S_{\dot{q}_{b,1_p}} = 1$ rad/sec^2

$S_{q_{b,1_p}} = 1$ rad/sec

$S_{\theta_{1_p}} = 1$ rad

$S_{\dot{u}_{b,c}} = 10$ m/sec^2

$$\dot{q}_{b,1_p} = \frac{\dot{u}_{b,c}}{\tau^2_{\theta_{1_p}} \cdot g} + \frac{\sin\theta}{\tau^2_{\theta_{1_p}}} - \frac{2\zeta_{\theta_{1_p}}}{\tau_{\theta_{1_p}}} \cdot q_{b,1_p} - \frac{1}{\tau^2_{\theta_{1_p}}} \cdot \theta_{1_p} \qquad (9.3.)$$

$$\frac{\dot{q}_{b,1_p}}{1} = \frac{1}{\tau^2_{\theta_{1_p}} \cdot g} \cdot \left(\frac{\dot{u}_{b,c}}{10}\right) \cdot 10 + \frac{\sin\theta}{1 \cdot \tau^2_{\theta_{1_p}}} - \frac{2\zeta_{\theta_{1_p}}}{\tau_{\theta_{1_p}}} \cdot \frac{q_{b,1_p}}{1} - \frac{1}{\tau^2_{\theta_{1_p}}} \cdot \frac{\theta_{1_p}}{1}$$

BPITCHDD = KP13 . UBCD + KP14 . VSNPB - KP15 . BPITCHDM - KP16 . BPITCHM

$KP13 = \frac{10}{4 \cdot 10} = 0,25$ (line 361)

$KP14 = \frac{1}{4} = 0,25$ (line 362)

$KP15 = \frac{2 \cdot 0,7}{2} = 0,7$ (line 363)

$KP16 = \frac{1}{4} = 0,25$ (line 364)

Rectangular integration of $\dot{q}_{b,1_p}$:

$$q_{b,1_p} = q_{b,1_p} + 0,05\ \dot{q}_{b,1_p}$$

$$\frac{q_{b,1_p}}{1} = \frac{q_{b,1_p}}{1} + \frac{0,05}{1} \cdot \frac{\dot{q}_{b,1_p}}{1}$$

BPITCHDM = BPITCHDM + KP17 . BPITCHDD

KP17 = 0,05

$$\theta_{1_p} = \theta_{1_p} + 0,05\ q_{b,1_p}$$

$$\frac{\theta_{1_p}}{1} = \frac{\theta_{1_p}}{1} + \frac{0,05}{1} \cdot \frac{q_{b,1_p}}{1}$$

BPITCHM = BPITCHM + KP18 . BPITCHDM

KP18 = 0,05

Remark: BXDD and BPITCHDD are forced to hold their momentary values for 1 sec, when the aircraft condition changes from on- to off ground and from off- to on ground, see page A-2.

LATERAL SPECIFIC FORCE

Lateral high-pass filter, see section 6.2.:

$\zeta_y = 0,7$

$\tau_y = 1$ sec

$S_{\ddot{y}_{b,1}} = 8\ m/sec^2$

$S_{\dot{y}_{b,1}} = 10\ m/sec$

$S_y = 11,3952\ m$

$S_{\dot{v}_{b,c}} = 8\ m/sec^2$

$$\ddot{y}_{b,1} = \dot{v}_{b,c} - g \cdot \cos\theta \cdot \sin\phi + g \cdot \phi_{1_p} - \frac{2\zeta_y}{\tau_y} \cdot \dot{y}_{b,1} - \frac{1}{\tau_y^{\,2}} \cdot y_{b,1} \qquad (6.7$$

$$\frac{\ddot{y}_{b,1}}{8} = \frac{\dot{v}_{b,c}}{8} - \frac{g}{8} \cdot \frac{\cos\theta}{1} \cdot \frac{\sin\phi}{1} + \frac{g}{8} \cdot \frac{\phi_{1_p}}{1} - \frac{2}{8} \cdot \frac{\zeta_y}{\tau_y} \cdot \left(\frac{\dot{y}_{b,1}}{10}\right) \cdot 10 +$$

$$- \frac{1}{8\tau_y^{\,2}} \cdot \left(\frac{y_{b,1}}{11,3952}\right) \cdot 11,3952$$

BYDD = VBCD - KR28 . VCSPB . VSNRB + KR12 . BROLLM - KY10 . BYDM +
- KY11 . BYM

KR28 = $\frac{g}{8} \cdot \frac{1}{1}$ = 1,25 = 0,625 SALD 2 (line 371)

KR12 = $\frac{g}{8} \cdot \frac{1}{1}$ = 1,25. In Appendix B: KR12 has been experimentally reduced to $\frac{1,25}{2}$ = 0,625 (line 367)

KY10 = $\frac{2 \cdot 07}{8 \cdot 1} \cdot 10$ = 1,750 = 0,875 SALD 2 (line 365)

KY11 = $\frac{1}{8 \cdot 1} \cdot 11,3952$ = 1,4244 = 0,7122 SALD 2 (line 366)

Rectangular integration:

$$\dot{y}_{b,1} = \dot{y}_{b,1} + 0,05\ \ddot{y}_{b,1}$$

$$\frac{\dot{y}_{b,1}}{10} = \frac{\dot{y}_{b,1}}{10} + \frac{0,05}{10} \cdot \left(\frac{\ddot{y}_{b,1}}{8}\right) \cdot 8$$

BYDM = BYDM + KY12 . BYDD

KY12 = $\frac{0,05}{10} \cdot 8 = 0,04$

$$y_{b,1} = y_{b,1} + 0,05\ \dot{y}_{b,1}$$

$$\frac{y_{b,1}}{11,3952} = \frac{y_{b,1}}{11,3952} + \frac{0,05}{11,3952} \cdot \left(\frac{\dot{y}_{b,1}}{10}\right) \cdot 10$$

BYM = BYM + KY13 . BYDM

KY13 = $\frac{0,05 \cdot 10}{11,3952}$ = 0,043878

Lateral low-pass filter, see section 9.2.:

$\zeta_{\phi_{1_p}}$ = 0,7

$\tau_{\phi_{1_p}}$ = 2 sec

$S_{\dot{p}_{b,1_p}}$ = 2 rad/sec^2

$S_{p_{b,1_p}}$ = 1 rad/sec

$S_{\phi_{1_p}}$ = 1 rad

$S_{\dot{v}_{b,c}}$ = 8 m/sec^2

$$\dot{p}_{b,1_p} = -\frac{\dot{v}_{b,c}}{\tau^2_{\phi_{1_p}} \cdot g} + \frac{\cos\theta \, . \, \sin\phi}{\tau^2_{\phi_{1_p}}} - \frac{2\zeta_{\phi_{1_p}}}{\tau_{\phi_{1_p}}} \cdot p_{b,1_p} - \frac{1}{\tau^2_{\phi_{1_p}}} \cdot \phi_{1_p} \qquad (9.9.)$$

$$\frac{\dot{p}_{b,1_p}}{2} = -\frac{1}{2\tau^2_{\phi_{1_p}} \cdot g} \cdot \left(\frac{\dot{v}_{b,c}}{8}\right) . 8 + \frac{1}{2\tau^2_{\phi_{1_p}}} \cdot \frac{\cos\theta}{1} \cdot \frac{\sin\phi}{1} - \frac{2\zeta_{\phi_{1_p}}}{2\tau_{\phi_{1_p}}} \cdot$$

$$\cdot \frac{p_{b,1_p}}{1} - \frac{1}{2\tau^2_{\phi_{1_p}}} \cdot \frac{\phi_{1_p}}{1}$$

BROLLDD = - (KR13 . VBCD + KR14 . VCSPB . VSNRB + KR15 . BROLLDM +
+ KR16 . BROLLM).

KR13 = $\frac{1}{2.4.10} \cdot 8 = 0{,}1$

KR14 = $-\frac{1}{2.4} = -0{,}125$ (line 368)

KR15 = $\frac{2 \, . \, 0{,}7}{2.2} = 0{,}35$ (line 369)

KR16 = $\frac{1}{2.4} = 0{,}125$ (line 370)

Rectangular integration:

$$p_{b,1_p} = p_{b,1_p} + 0{,}05 \, \dot{p}_{b,1_p}$$

$$\frac{p_{b,1_p}}{1} = \frac{p_{b,1_p}}{1} + \frac{0{,}05}{1} \cdot \left(\frac{\dot{p}_{b,1_p}}{2}\right) . 2$$

BROLLDM = BROLLDM + KR17 . BROLLDD.

KR17 = $\frac{0{,}05}{1} \cdot 2 = 0{,}1$

$$\phi_{1_p} = \phi_{1_p} + 0{,}05 \, p_{b,1_p}$$

$$\frac{\phi_{1_p}}{1} = \frac{\phi_{1_p}}{1} + \frac{0{,}05}{1} \cdot \frac{p_{b,1_p}}{1}$$

BROLLM = BROLLM + KR18 . BROLLDM

KR18 = 0,05

Vertical high-pass filter, see section 6.3.:

ζ_z = 0,7

τ_z = 0,7

$S_{\ddot{z}_b}$ = 40 m/sec^2

$S_{\dot{z}_b}$ = 10 m/sec

S_{z_b} = 49,854 m

$S_{\dot{w}_{b,c}}$ = 40 m/sec^2

$$\ddot{z}_b = \dot{w}_{b,c} - \frac{2\zeta_z}{\tau_z} \cdot \dot{z}_b - \frac{1}{\tau_z{}^2} \cdot z_b \qquad (6.11.)$$

$$\frac{\ddot{z}_b}{40} = \frac{\dot{w}_{b,c}}{40} - \frac{2}{40} \cdot \frac{\zeta_z}{\tau_z} \cdot (\frac{\dot{z}_b}{10}) \cdot 10 - \frac{1}{40\tau_z{}^2} \cdot (\frac{z_b}{49,854}) \cdot 49,854$$

BZDD = WBCD - KZ1 . BZDM - KZ2 . BZM

KZ1 = $\frac{2}{40} \cdot \frac{0,7}{0,7} \cdot 10 = 0,5$ (line 694)

KZ2 = $\frac{49,854}{40 \cdot 0,7^2} = 2,54356 = 0,63589$ SALD 3 (line 382)

Rectangular integration:

$$\dot{z}_b = \dot{z}_b + 0,05 \cdot \ddot{z}_b$$

$$\frac{\dot{z}_b}{10} = \frac{\dot{z}_b}{10} + \frac{0,05}{10} \cdot (\frac{\ddot{z}_b}{40}) \cdot 40$$

BZDM = BZDM + KZ3 . BZDD

KZ3 = $\frac{0,05}{10} \cdot 40 = 0,2$

$$z_b = z_b + 0,05\ \dot{z}_b$$

$$\frac{z_b}{49,854} = \frac{z_b}{49,854} + \frac{0,05}{49,854} \cdot (\frac{\dot{z}_b}{10}) \cdot 10$$

BZM = BZM + KZ4 . BZDM

KZ4 = $\frac{0,05 \cdot 10}{49,854} = 0,0100294$

KSS Boeing 747 Main motion simulation, part 2:
Sum of body-axes rotational accelerations, see sections 9.1., 9.2. and 12.

$$\dot{q}_s = \dot{q}_{b,l_p} + \dot{q}_{b,h_p} \qquad (9.5.)$$

$$\frac{\dot{q}_s}{1} = \frac{\dot{q}_{b,l_p}}{1} + \left(\frac{\dot{q}_{b,h_p}}{2}\right) . 2$$

SPITCHDD = BPITCHDD + KP26 . MPITCHDD

KP26 = 2 (see line 41 of Appendix B, part 2)

$$\dot{p}_s = \dot{p}_{b,l_p} + \dot{p}_{b,h_p} \qquad (9.10.)$$

$$\frac{\dot{p}_s}{2} = \frac{\dot{p}_{b,l_p}}{2} + \frac{\dot{p}_{b,h_p}}{2}$$

SROLLDD = BROLLDD + MROLLDD

Sum of body-axes rotational rates, see sections 9.1., 9.2. and 10.

$$q_s = q_{b,l_p} + q_{b,h_p} \qquad (9.6.)$$

$$\frac{q_s}{1} = \frac{q_{b,l_p}}{1} + \frac{q_{b,h_p}}{1}$$

SPITCHDM = BPITCHDM + MPITCHDM

$$p_s = p_{b,l_p} + p_{b,h_p} \qquad (9.11.)$$

$$\frac{p_s}{1} = \frac{p_{b,l_p}}{1} + \frac{p_{b,h_p}}{1}$$

SROLLDM = BROLLDM + MROLLDM

Euler rates, see section 10:

$$\dot{\theta}_i = q_s . \cos\phi_m - r_{b,h_p} . \sin\phi_m$$

$$\frac{\dot{\theta}_i}{1} = \frac{q_s}{1} . \frac{\cos\phi_m}{1} - \frac{r_{b,h_p}}{1} . \frac{\sin\phi_m}{1}$$

MPITCHSD = SPITCHDM . cos(MROLLSM) - MYAWDM . sin(MROLLSM)

$$\dot{\phi}_i = p_s + q_s . \sin\phi_m . \frac{\sin\theta_m}{\cos\theta_m} + r_{b,h_p} . \cos\phi_m . \frac{\sin\theta_m}{\cos\theta_m}$$

$$\frac{\dot{\phi}_i}{1} = \frac{p_s}{1} + \frac{q_s}{1} . \frac{\sin\phi_m}{1} . \frac{\sin\theta_m}{\cos\theta_m} + \frac{r_{b,h_p}}{1} . \frac{\cos\phi_m}{1} . \frac{\sin\theta_m}{\cos\theta_m}$$

MROLLSD = SROLLDM + SPITCHDM . sin(MROLLSM) . sin(MPITCHSM)
/cos(MPITCHSM) + MYAWDM . cos(MROLLSM) . sin(MPITCHSM)
/cos(MPITCHSM).

$$\dot{\psi}_i = q_s \cdot \frac{\sin \phi_m}{\cos \theta_m} + r_{b,h_p} \cdot \frac{\cos \phi_m}{\cos \theta_m}$$

$$\frac{\dot{\psi}_i}{1} = \frac{q_s}{1} \cdot \frac{\sin \phi_m}{\cos \theta_m} + \frac{r_{b,h_p}}{1} \cdot \frac{\cos \phi_m}{\cos \theta_m}$$

MYAWSD = SPITCHDM . sin(MROLLSM)/cos MPITCHSM + MYAWDM . cos(MROLLSM)
/cos MPITCHSM.

Return to ground check: When the simulated aircraft is returned to ground by means of the "return to ground button" on the instructor's console, the following variables in the motion program are set to zero:

$\dot{\theta}_i$, $\dot{\theta}_m$ and θ_m

$\dot{\phi}_i$, $\dot{\phi}_m$ and ϕ_m

$\dot{\psi}_i$, $\dot{\psi}_m$ and ψ_m,

see Appendix B, part 2, line 142 - 157.

Rotational washout, see section 11:

Pitch: $\tau_{\theta_R} = 200$ sec

$S_{\theta_m} = 1$ rad.

$$\dot{\theta}_m = \dot{\theta}_i - \frac{1}{\tau_{\theta_R}} \cdot \theta_m$$

$$\frac{\dot{\theta}_m}{1} = \frac{\dot{\theta}_i}{1} - \frac{1}{\tau_{\theta_R}} \cdot \frac{\theta_m}{1}$$

MPITCHMD = MPITCHSD - KP24 . MPITCHSM

$$KP24 = \frac{1}{200} = 0{,}005$$

Rectangular integration:

$$\theta_m = \theta_m + 0{,}05\ \dot{\theta}_m$$

$$\frac{\theta_m}{1} = \frac{\theta_m}{1} + \frac{0{,}05}{1} \cdot \frac{\dot{\theta}_m}{1}$$

MPITCHSM = MPITCHSM + KP18 . MPITCHMD

KP18 = 0,05

Motion system lead compensation, see section 12:

$$\theta_c = \theta_m + B_4 \cdot \dot{\theta}_m + A_4 \cdot \dot{q}_s$$

$$\frac{\theta_c}{1} = \frac{\theta_m}{1} + B_4 \cdot \frac{\dot{\theta}_m}{1} + A_4 \cdot \frac{\dot{q}_s}{1}$$

MPITCHC = MPITCHSM + KP19 . MPITCHMD + KP20 . SPITCHDD

KP19 = 0,28
KP20 = 0,044

Roll:

$$\tau_{\phi_R} = 200 \text{ sec}$$

$$S_{\phi_m} = 1 \text{ rad.}$$

$$\dot{\phi}_m = \dot{\phi}_i - \frac{1}{\tau_{\phi_R}} \cdot \phi_m$$

$$\frac{\dot{\phi}_m}{1} = \frac{\dot{\phi}_i}{1} - \frac{1}{\tau_{\phi_R}} \cdot \frac{\phi_m}{1}$$

MROLLMD = MROLLSD - KR23 . MROLLSM

$$KR23 = \frac{1}{200} = 0{,}005$$

Rectangular integration:

$$\phi_m = \phi_m + 0{,}05 \cdot \dot{\phi}_m$$

$$\frac{\phi_m}{1} = \frac{\phi_m}{1} + \frac{0{,}05}{1} \cdot \frac{\dot{\phi}_m}{1}$$

MROLLSM = MROLLSM + KR18 . MROLLMD

KR18 = 0,05

Motion system lead compensation:

$$\phi_c = \phi_m + B_5 \cdot \dot{\phi}_m + A_5 \cdot \dot{p}_s$$

$$\frac{\phi_c}{1} = \frac{\phi_m}{1} + B_5 \cdot \frac{\dot{\phi}_m}{1} + A_5 \cdot \left(\frac{\dot{p}_s}{2}\right) \cdot 2$$

MROLLC = MROLLSM + KR19 . MROLLMD + KR20 . SROLLDD

KR19 = 0,28

KR20 = 0,044 . 2 = 0,088

Yaw:

$$\tau_{\psi_R} = 20 \text{ sec}$$

$$S_{\psi_m} = 1 \text{ rad}$$

$$\dot{\psi}_m = \dot{\psi}_i - \frac{1}{\tau_{\psi_R}} \cdot \psi_m$$

$$\frac{\dot{\psi}_m}{1} = \frac{\dot{\psi}_i}{1} - \frac{1}{\tau_{\psi_R}} \cdot \frac{\psi_m}{1}$$

MYAWMD = MYAWSD - KJ11 . MYAWSM

$$KJ11 = \frac{1}{20} = 0,05$$

Rectangular integration:

$$\psi_m = \psi_m + 0,05\ \dot{\psi}_m$$

$$\frac{\psi_m}{1} = \frac{\psi_m}{1} + \frac{0,05}{1} \cdot \frac{\dot{\psi}_m}{1}$$

MYAWSM = MYAWSM + KJ4 . MYAWMD

KJ4 = 0,05

Motion system lead compensation:

$$\psi_c = \psi_m + B_6 \cdot \dot{\psi}_m + A_6 \cdot \dot{r}_{b,h_p}$$

$$\frac{\psi_c}{1} = \frac{\psi_m}{1} + B_6 \cdot \frac{\dot{\psi}_m}{1} + A_6 \cdot \left(\frac{\dot{r}_{b,h_p}}{2}\right) \cdot 2$$

MYAWC = MYAWSM + KJ5 . MYAWMD + KJ6 . MYAWDD

KJ5 = 0,28

KJ6 = 0,044 . 2 = 0,088.

Sum of body-axes translational accelerations, see section 6:

$$\ddot{x}_s = \ddot{x}_{b,1} + \ddot{x}_{b,2} \qquad (6.4.)$$

$$\frac{\ddot{x}_s}{10} = \frac{\ddot{x}_{b,1}}{10} + \frac{\ddot{x}_{b,2}}{10}$$

SXDD = BXDD + MXDD

$$\ddot{y}_s = \ddot{y}_{b,1} + \ddot{y}_{b,2}$$

$$\frac{\ddot{y}_s}{8} = \frac{\ddot{y}_{b,1}}{8} + \frac{\ddot{y}_{b,2}}{8}$$

SYDD = BYDD + MYDD (see line 351 - 357 of Appendix B, part 2)

Body to inertial transformation of the motion platform translational accelerations, see section 7:

$$\ddot{x}_i = \ddot{x}_s \cdot \cos\theta_m \cdot \cos\psi_m + \ddot{y}_s (\sin\phi_m \cdot \sin\theta_m \cdot \cos\psi_m + - \cos\phi_m \cdot \sin\psi_m) \quad ^{*)} \qquad (7.1.)$$

$$\frac{\ddot{x}_i}{10} = \frac{\ddot{x}_s}{10} \cdot \frac{\cos\theta_m}{1} \cdot \frac{\cos\psi_m}{1} + \frac{1}{10} \cdot (\frac{\ddot{y}_s}{8}) \cdot 8 \cdot (\frac{\sin\phi_m}{1} \cdot \frac{\sin\theta_m}{1} \cdot \frac{\cos\psi_m}{1} + - \frac{\cos\phi_m}{1} \cdot \frac{\sin\psi_m}{1})$$

MXSDD = SXDD . cos(MPITCHSM) . cos(MYAWSM) + KY16 . SYDD .
{ sin(MROLLSM) . sin(MPITCHSM) . cos(MYAWSM) - cos(MROLLSM) .
. sin(MYAWSM) }

KY16 = $\frac{8}{10}$ = 0,8

$$\ddot{y}_i = \ddot{x}_s \cdot \cos\theta_m \cdot \sin\psi_m + \ddot{y}_s \cdot (\sin\phi_m \cdot \sin\theta_m \cdot \sin\psi_m + + \cos\phi_m \cdot \cos\psi_m) \quad ^{*)} \qquad (7.2.)$$

$$\frac{\ddot{y}_i}{8} = \frac{1}{8} \cdot (\frac{\ddot{x}_s}{10}) \cdot 10 \cdot \frac{\cos\theta_m}{1} \cdot \frac{\sin\psi_m}{1} + \frac{\ddot{y}_s}{8} \cdot (\frac{\sin\phi_m}{1} \cdot \frac{\sin\theta_m}{1} \cdot \frac{\sin\psi_m}{1} + + (\frac{\cos\phi_m}{1} \cdot \frac{\cos\psi_m}{1})$$

MYSDD = KX16 . SXDD . cos(MPITCHSM) . sin(MYAWSM) + SYDD .
{ sin(MROLLSM) . sin(MPITCHSM) . sin(MYAWSM) + cos(MROLLSM) .
. cos(MYAWSM) }

KX16 = $\frac{10}{8}$ = 1,25 = 0,625 SALD 2

*) Note: The contribution of $\ddot{z}_b$ to $\ddot{x}_i$ and $\ddot{y}_i$ is neglected in the KSS Boeing 747 Motion Simulation Program, because this contribution is small and the computation-time required for the transformation is less.

$$\ddot{z}_i = -\ddot{x}_s \cdot \sin\theta_m + \ddot{y}_s \cdot \sin\phi_m \cdot \cos\theta_m + \ddot{z}_b \cdot \cos\phi_m \cdot \cos\theta_m$$

$$\frac{\ddot{z}_i}{40} = -\frac{1}{40} \cdot (\frac{\ddot{x}_s}{10}) \cdot 10 \cdot \frac{\sin\theta_m}{1} + \frac{1}{40} \cdot (\frac{\ddot{y}_s}{8}) \cdot 8 \cdot \frac{\sin\phi_m}{1} \cdot \frac{\cos\theta_m}{1} + \frac{\ddot{z}_b}{40} \cdot$$

$$\cdot \frac{\cos\phi_m}{1} \cdot \frac{\cos\theta_m}{1}$$

MZSDD = KX17 . SXDD . sin(MPITCHSM) + KY17 . SYDD . sin(MROLLSM) .

. cos(MPITCHSM) + BZDD . cos(MROLLSM) . cos(MPITCHSM).

$KX17 = -\frac{10}{40} = -0{,}25$

$KY17 = \frac{8}{40} = 0{,}2$

Translational washout, see section 8:

$\zeta_{x_T} = 0{,}7$

$\tau_{x_T} = 2$ sec

$$\ddot{x}_m = \ddot{x}_i - \frac{2\zeta_{x_T}}{\tau_{x_T}} \cdot \dot{x}_m - \frac{1}{\tau_{x_T}^2} \cdot x_m$$

$$\frac{\ddot{x}_m}{10} = \frac{\ddot{x}_i}{10} - \frac{2\zeta_{x_T}}{10\tau_{x_T}} \cdot (\frac{\dot{x}_m}{10}) \cdot 10 - \frac{1}{10\tau_{x_T}^2} \cdot (\frac{x_m}{11{,}3952}) \cdot 11{,}3952$$

MXMDD = MXSDD - KX18 . MXDM - KX19 . MXM

$KX18 = \frac{2 \cdot 0{,}7}{10 \cdot 2} \cdot 10 = 0{,}7$

$KX19 = \frac{11{,}3952}{10 \cdot 4} = 0{,}28488$

Rectangular integration:

$$\dot{x}_m = \dot{x}_m + 0{,}05\,\ddot{x}_m$$

$$\frac{\dot{x}_m}{10} = \frac{\dot{x}_m}{10} + \frac{0{,}05}{10} \cdot (\frac{\ddot{x}_m}{10}) \cdot 10$$

MXDM = MXDM + KX12 . MXMDD

$KX12 = \frac{0{,}05}{10} \cdot 10 = 0{,}05$

$$x_m = x_m + 0{,}05\,\dot{x}_m$$

$$\frac{x_m}{11{,}3952} = \frac{x_m}{11{,}3952} + \frac{0{,}05}{11{,}3952} \cdot (\frac{\dot{x}_m}{10}) \cdot 10$$

MXM = MXM + KX13 . MXDM

$$KX13 = \frac{0,05 \ . \ 10}{11,3952} = 0,043878$$

Motion system lead compensation, see section 12:

$$x_c = \ddot{x}_m + B_1 \cdot \dot{x}_m + A_1 \cdot \dddot{x}_m$$

$$\frac{x_c}{11,3952} = \frac{x_m}{11,3952} + \frac{B_1}{11,3952} \cdot (\frac{\dot{x}_m}{10}) \cdot 10 + \frac{A_1}{11,3952} \cdot (\frac{\ddot{x}_m}{10}) \cdot 10$$

MXC = MXM + KX14 . MXDM + KX15 . MXMDD

$$KX14 = \frac{0,28 \ . \ 10}{11,3952} = 0,24572$$

$$KX15 = \frac{0,044 \ . \ 10}{11,3952} = 0,038613$$

$$\zeta_{y_T} = 0,7$$

$$\tau_{y_T} = 2 \text{ sec}$$

$$\ddot{y}_m = \ddot{y}_i - \frac{2\zeta_{y_T}}{\tau_{y_T}} \cdot \dot{y}_m - \frac{1}{\tau_{y_T}^{\,2}} \cdot y_m$$

$$\frac{\ddot{y}_m}{8} = \frac{\ddot{y}_i}{8} - \frac{2\zeta_{y_T}}{\tau_{y_T} . 8} \cdot (\frac{\dot{y}_m}{10}) \cdot 10 - \frac{1}{8\tau_{y_T}^{\,2}} \cdot (\frac{y_m}{11,3952}) \cdot 11,3952$$

MYMDD = MYSDD - (KY18 . MYDM) - (KY19 . MYM)

$$KY18 = \frac{2 \ . \ 0,7}{8 \ . \ 2} \ . \ 10 = 0,875$$

$$KY19 = \frac{11,3952}{8 \ . \ 4} = 0,3561$$

Rectangular integration:

$$\dot{y}_m = \dot{y}_m + 0,05 \ \ddot{y}_m$$

$$\frac{\dot{y}_m}{10} = \frac{\dot{y}_m}{10} + \frac{0,05}{10} \cdot (\frac{\ddot{y}_m}{8}) \cdot 8$$

MYDM = MYDM + KY12 . MYMDD

$$KY12 = \frac{0,05}{10} \ . \ 8 = 0,04$$

$$y_m = y_m + 0,05 \ \dot{y}_m$$

$$\frac{y_m}{11,3952} = \frac{y_m}{11,3952} + \frac{0,05}{11,3952} \cdot (\frac{\dot{y}_m}{10}) \cdot 10$$

MYM = MYM + KY13 . MYDM

$$KY13 = \frac{0,05}{11,3952} \cdot 10 = 0,043878$$

Motion system lead compensation:

$$y_c = y_m + B_2 \cdot \dot{y}_m + A_2 \cdot \ddot{y}_m$$

$$\frac{y_c}{11,3952} = \frac{y_m}{11,3952} + \frac{B_2}{11,3952} \cdot (\frac{\dot{y}_m}{10}) \cdot 10 + \frac{A_2}{11,3952} \cdot (\frac{\ddot{y}_m}{8}) \cdot 8$$

MYC = MYM + KY14 . MYDM + KY15 . MYMDD

$$KY14 = \frac{0,28 \cdot 10}{11,3952} = 0,245718$$

$$KY15 = \frac{0,044 \cdot 8}{11,3952} = 0,03089$$

$$\zeta_{z_T} = 0,7$$

$$\tau_{z_T} = 2 \text{ sec.}$$

$$\ddot{z}_m = \ddot{z}_i - \frac{2\zeta_{z_T}}{\tau_{z_T}} \cdot \dot{z}_m - \frac{1}{\tau_{z_T}^2} \cdot z_m$$

$$\frac{\ddot{z}_m}{40} = \frac{\ddot{z}_i}{40} - \frac{2\zeta_{z_T}}{40\tau_{z_T}} \cdot (\frac{\dot{z}_m}{10}) \cdot 10 - \frac{1}{40\tau_{z_T}^2} \cdot (\frac{z_m}{49,854}) \cdot 49,854$$

MZMDD = MZSDD - (KZ8 . MZDM) - (KZ9 . MZM)

$$KZ8 = \frac{2 \cdot 0,7}{40 \cdot 2} \cdot 10 = 0,175$$

$$KZ9 = \frac{49,854}{40 \cdot 4} = 0,311587$$

Rectangular integration:

$$\dot{z}_m = \dot{z}_m + 0,05 \cdot \ddot{z}_m$$

$$\frac{\dot{z}_m}{10} = \frac{\dot{z}_m}{10} + \frac{0,05}{10} \cdot (\frac{\ddot{z}_m}{40}) \cdot 40$$

MZDM = MZDM + KZ3 . MZMDD

$$KZ3 = \frac{0,05 \cdot 40}{10} = 0,2$$

$$z_m = z_m + 0,05 \cdot \dot{z}_m$$

$$\frac{z_m}{49,854} = \frac{z_m}{49,854} + \frac{0,05}{49,854} \cdot \left(\frac{\dot{z}_m}{10} \right) \cdot 10$$

MZM = MZM + KZ4 . MZDM

$$KZ4 = \frac{0,05}{49,854} \cdot 10 = 0,0100294$$

Motion system lead compensation:

$$z_c = z_m + B_3 \cdot \dot{z}_m + A_3 \cdot \ddot{z}_m$$

$$\frac{z_c}{49,854} = \frac{z_m}{49,854} + \frac{B_3}{49,854} \cdot \left(\frac{\dot{z}_m}{10} \right) 10 + \frac{A_3}{49,854} \cdot \left(\frac{\ddot{z}_m}{40} \right) \cdot 40$$

MZC = MZM + KZ5 . MZDM + KZ6 . MZMDD

$$KZ5 = \frac{0,28}{49,854} \cdot 10 = 0,056164$$

$$KZ6 = \frac{0,044 \cdot 40}{49,854} = 0,035302$$

The KSS Boeing 747 main motion simulation program, represented in Appendix B, is executed each 50 msec on a SDS Sigma 2 computer. Timing runs of this program show, that the average computation time required for execution amounts to 7 msec, see Table 3.

Table 4 shows a timing-run of the complete KSS Boeing 747 flight simulation program, including motion simulation, with the aircraft in the on-ground condition. The average time required for the computation remains within 50 msec.

Parameter	Value in SI units	Program value	Parameter	Value in SI units	Program value
KXU1	1,71479	0,428697	KJ3	0,1	0,1
KYV1	2,4525	0,613125	KJ4	0,05	0,05
KZW1	1,4715	0,367875	KX1	-0,12	-0,12
KUBBD	0,8	0,8	KY1	0,3	0,3
KVBBD	1,25	0,625	KUBC	2,59	0,6475
KWBBD1	0,25	0,25	KVBC	6,475	0,8094
KWBBD2	0,2	0,2	KWBC	1,295	0,6475
$\zeta_{\theta_{h_p}}$	0,7	0,7	KX10	2,0	0,9999
$\tau_{\theta_{h_p}}$, sec	6	6	KX11	2,3255	0,581377
KP1	0,11666	0,11666	ζ_x	0,7	0,7
KP2	0,01388	0,01388	τ_x	0,7	0,7
KP3	0,1	0,1	$\zeta_{\theta_{1_p}}$	0,7	0,7
KP4	0,05	0,05	$\tau_{\theta_{1_p}}$, sec	2	2
$\zeta_{\phi_{h_p}}$	0,7	0,7	KP13	0,25	0,25
$\tau_{\phi_{h_p}}$, sec	6	6	KP14	0,25	0,25
KR1	0,11666	0,11666	KP15	0,7	0,7
KR2	0,01388	0,01388	KP16	0,25	0,25
KR3	0,1	0,1	KX12	0,05	0,05
KR4	0,05	0,05	KX13	0,043878	0,043878
ζ_ψ	0,7	0,7	KP17	0,05	0,05
τ_ψ, sec	1,5	1,5	KP18	0,05	0,05
KJ1	0,466664	0,233332	ζ_y	0,7	0,7
KJ2	0,22228	0,055552	τ_y, sec	1	1

Table 2: Parameter values as used in the KSS B-747 Motion simulation.

Parameter	Value in SI units	Program value
KR28	1,25	0,625
KR12	0,625	0,625
KY10	1,750	0,875
KY11	1,4244	0,7122
KY12	0,04	0,04
KY13	0,043878	0,043878
$\zeta_{\phi_{1_p}}$	0,7	0,7
$\tau_{\phi_{1_p}}$, sec	2	2
KR13	0,1	0,1
KR14	-0,125	-0,125
KR15	0,35	0,35
KR16	0,125	0,125
KR17	0,1	0,1
KR18	0,05	0,05
ζ_z	0,7	0,7
τ_z, sec	0,7	0,7
KZ1	0,5	0,5 (shift)
KZ2	2,543572	0,635893
KZ3	0,2	0,2
KZ4	0,010029	0,010029
KP26	2,0	2,0 (shift)
KP24	0,005	0,005
KP19	0,28	0,28

Parameter	Value in SI units	Program value
KP20	0,044	0,044
KR23	0,005	0,005
KR19	0,28	0,28
KR20	0,088	0,088
KJ11	0,05	0,05
KJ5	0,28	0,28
KJ6	0,088	0,088
KJ9	0,31831	0,31831
KY16	0,8	0,8
KP25	0,31831	0,31831
KR24	0,31831	0,31831
KX16	1,25	0,625
KX17	-0,25	-0,25
KY17	0,2	0,2
KX18	0,7	0,7
KX19	0,28488	0,28488
KX14	0,24572	0,24572
KX15	0,038613	0,038613
KY18	0,875	0,875
KY19	0,3561	0,3561
KY14	0,24572	0,24572
KY15	0,03089	0,03089
KZ8	0,175	0,175
KZ9	0,311587	0,311587
KZ5	0,056164	0,056164
KZ6	0,035302	0,035302

Table 2: Parameter values as used in the KSS B-747 Motion simulation. (cont'd)

```
!SL
!XE
TIMING FOR SYSTEM  '4089'
-AVERAGE AFTER  01  MINUTES   26  SECONDS-
 BAND  MAX   MIN  AVG  (IN MSECS)
 #00  09.0  06.0  07.0
 #01  06.5  06.0  06.0
 #02  06.5  06.0  06.0
 #03  08.5  06.0  06.0
 #04  09.0  06.0  06.5
 #05  08.5  06.0  07.0
 #06  06.5  06.0  06.0
 #07  06.5  06.0  06.0
 #08  08.5  06.0  07.0
 #09  08.5  06.0  06.5
 #10  09.0  06.0  07.0
 #11  08.0  06.0  06.0
 #12  08.5  06.0  06.5
 #13  08.5  06.0  07.0
 #14  06.5  06.0  06.0
 #15  06.5  06.0  06.0
```

Table 3: Timing-run of KSS Boeing 747 main motion simulation program.

```
TIMING FOR SYSTEM  '408F'
-AVERAGE AFTER  00  MINUTES   42  SECONDS-
 BAND  MAX   MIN  AVG  (IN MSECS)
 #00  50.0  45.5  47.5
 #01  50.5  43.5  46.5
 #02  52.0  45.0  47.5
 #03  50.5  42.5  46.0
 #04  49.5  44.0  46.5
 #05  47.0  40.5  43.5
 #06  55.0  46.5  49.5
 #07  50.0  45.0  47.0
 #08  49.5  45.0  46.5
 #09  48.5  41.0  44.0
 #10  48.5  42.5  44.5
 #11  50.0  42.0  46.0
 #12  48.5  42.0  45.5
 #13  47.0  40.5  43.5
 #14  52.5  46.5  49.5
 #15  52.5  47.5  49.5
```

Table 4: Timing-run of total system; aircraft on ground.

APPENDIX B, PART 1

```
                   *        KSS B-747 MAIN MOTION SIMULATION. PART 1
                   *
                   *        MAINMN1         FILE NO :  K-817-1
                   *        MAINMN2         FILE NO :  K-817-2
                   *
                   *
                   *        TEST PILOT  : CAPTAIN J.L. VELDHUYZEN VAN ZANTEN
                   *
                   *        DESIGN      : IR. M.BAARSPUL
                   *
                   *        SOFTWARE    : B.BAARSCHERS
                   *
                   *        ASSEMBLE THIS PROGRAM WITH :
                   *        EXT. X-REF
                   *        SLV SP
                   *        MOTION X-REF
                   *        FLIGHT INT. X-REF.
                   *
                   *        ISSUE    3
                   *        AUG.     1975
                   *
                            DEF      MAINMN1
                   *
                            CSECT
                            ORG      X'0000'
                   *
0000 8CC9 A MAINMN1 LDA      ACTFLG04          FLIGHT OR TOTAL FREEZE ?
0001 98C9 A         AND      BIT4&8
0002 6402 A         BAZ      NOFRZE            NO
0003 44FD A         B        *PROGRETN         YES
                   *
                            BASE     X'1000'
                   *
0004 80BD A NOFRZE  LDA      BASE10
0005 7407 A         RCPY     A,B
                   *
```

```
                          PAGE
                  *
                  *       RESCALING FOR TRANSFORMATION FROM WIND TO BODY
                  *
   0006 C0D8 A            LDX      M3
   0007 83AB A LOOP1      LDA      MFZWB+1,1        W/B-AXIS FORCES / GROSS WEIGHT
   0008 3AAE A            MUL      KSCALE,1         RESCALE
   0009 20A3 A            SALD     3
   000A 74F6 A            RCPY     E,A
   000B E3AE A            STA      WWD+1,1          W/B AXIS ACCEL'S
   000C 67FB A            BIX      LOOP1
                  *
                  *       DECIDE FOR ON OR OFF GROUND.
                  *
   000D 8CBB A            LDA      VBOG             ON GROUND ?
   000E 6E02 A            BAN      ONGROUND         YES
   000F 4808 A            B        TRANSFORM        NO
   0010 C0D8 A ONGROUND   LDX      M3
   0011 8CB0 A LOOP2      LDA      VVXBP            GROUNG SPEED ZERO ?
   0012 6402 A            BAZ      ZERO             YES
   0013 83AE A            LDA      WWD+1,1          NO,LOAD ACCEL'S
   0014 E3B1 A ZERO       STA      WBD+1,1          BODY AXIS ACCEL'S
   0015 67FC A            BIX      LOOP2
   0016 483D A            B        TIMEX
```

```
                         PAGE
                  *
                  *      TRANSFORMATION OF  X  WIND TO BODY-AXIS ACCEL'S.
                  *      UBD = (UWD*VCSAB*VCSB)-(VWD*VCSAB*VSNB*KUBBD)
                  *            -(WWD*VSNAB*4)        (=SALD 3)
                  *
0017 81AB A TRANSFOR LDA      UWD                W-AXIS  X  ACCEL.
0018 3CA2 A          MUL      VCSAB              COS.ALPHA BODY
0019 20A1 A          SALD     1
001A 74F6 A          RCPY     E,A
001B 3CA0 A          MUL      VCSB               COS.BETA
001C 20A1 A          SALD     1
001D 74B6 A          RCPY     E,T                SAVE IT
001E 81AC A          LDA      VWD                W-AXIS  Y  ACCEL.
001F 3C9B A          MUL      VCSAB              COS.ALPHA BODY
0020 20A1 A          SALD     1
0021 74F6 A          RCPY     E,A
0022 3C9A A          MUL      VSNB               SINE BETA
0023 20A1 A          SALD     1
0024 74F6 A          RCPY     E,A
0025 3891 A          MUL      KUBBD              .8
0026 20A1 A          SALD     1
0027 7D3E A          RADDI    *E,T               SUBTRACT IN  T  REG.
0028 81AD A          LDA      WWD                W-AXIS  Z  ACCEL.
0029 3C94 A          MUL      VSNAB              SINE ALPHA BODY
002A 20A3 A          SALD     3                  *4
002B 7D3E A          RADDI    *E,T               SUBTRACT IN  T  REG.
002C 74F3 A          RCPY     T,A
002D E1AE A          STA      UBD
                  *
                  *      TRANSFORMATION OF  Y  WIND TO BODY-AXIS ACCEL.
                  *      VBDM = (UWD*VSNB) * KVBBD) + (VWD*VCSB)
                  *
002E 81AB A          LDA      UWD                W-AXIS LONGITUDINAL ACCEL.
002F 3C8D A          MUL      VSNB               SINE BETA
0030 20A1 A          SALD     1
0031 74F6 A          RCPY     E,A
0032 3885 A          MUL      KVBBD              .625
0033 20A2 A          SALD     2                  *2 = 1.25
0034 74B6 A          RCPY     E,T                SAVE IT
0035 81AC A          LDA      VWD                W-AXIS LATERAL ACCEL.
0036 3C85 A          MUL      VCSB               COS.BETA
0037 20A1 A          SALD     1
0038 7C36 A          RADD     E,T                SUM IT
0039 74F3 A          RCPY     T,A
003A E1AF A          STA      VBDM
```

```
                        PAGE
                *
                *       TRANSFORMATION OF  Z  WIND TO BODY AXIS ACCEL.
                *       WBD = (UWD*VSNAB*VCSB*KWBBD1)-(VWD*VSNAB*VSNB*KWBBD2)
                *             +(WWD*VCSAB)
                *
0038 81AB A             LDA     UWD             W-AXIS  X  ACCEL.
003C 3C81 A             MUL     VSNAB           SINE ALPHA BODY
003D 20A1 A             SALD    1
003E 74F6 A             RCPY    E,A
003F 3C7C A             MUL     VCSB            COS.BETA
0040 20A1 A             SALD    1
0041 74F6 A             RCPY    E,A
0042 3876 A             MUL     KWBBD1          .25
0043 74B6 A             RCPY    E,T             SAVE IT
0044 81AC A             LDA     VWD             W-AXIS  Y  ACCEL.
0045 3C78 A             MUL     VSNAB           SINE ALPHA BODY
0046 20A1 A             SALD    1
0047 74F6 A             RCPY    E,A
0048 3C74 A             MUL     VSNB            SINE BETA
0049 20A1 A             SALD    1
004A 74F6 A             RCPY    E,A
004B 386E A             MUL     KWBBD2          .2
004C 7D3E A             RADDI   *E,T            SUBTRACT IN  T  REG.
004D 81AD A             LDA     WWD             W-AXIS  Z  ACCEL.
004E 3C6C A             MUL     VCSAB           COS.ALPHA BODY
004F 20A1 A             SALD    1
0050 7C36 A             RADD    E,T             SUM IT
0051 74F3 A             RCPY    T,A
0052 E1B0 A             STA     WBD             Z-BODY AXIS ACCEL.
```

```
                        PAGE
                   *
                   *    TIMER TO STOP THE CALCULATIONS DURING ON/OFF GRD TRANSITION
                   *
0053 888A A TIMEX       LDA     TIMER
0054 6403 A             BAZ     TIMEUP
0055 F888 A             IM      TIMER
0056 480C A             B       G01                 TIME WAS NOT YET UP
0057 8C71 A TIMEUP      LDA     VBOG
0058 D886 A             CP      LTCONDT             CONDITION CHANGED ?
0059 6203 A             BNC     $+3                 YES
005A 74F0 A             RCPY    Z,A                 NO
005B 4804 A             B       $+4                 RESET STOPFLAG
005C 8883 A             LDA     20ITERS             1 SECOND
005D E880 A             STA     TIMER
005E 74F8 A             RCPY    *Z,A                SET STOPFLAG
005F E881 A             STA     STOPFLAG
0060 8C68 A             LDA     VBOG                STORE PRESENT CONDITION
0061 E870 A             STA     LTCONDT             IN LAST TIME CONDITION
```

```
                          PAGE
                 *
                 *        PITCH BODY ACCELERATIONS
                 *
                 *        TAU      THETA  HI-PASS     =  6 SEC
                 *        ZETA     THETA  HI-PASS     =  .7
                 *        S        THETA  HP DD       =  2 RAD/SEC 2
                 *        S        THETA  HP D        =  1 RAD/SEC
                 *        S        THETA  HP          =  1 RAD
                 *
                 *        VPRD                        =  2 RAD/SEC 2
                 *
                 *        MPITCHDD = VPRD - ((KP1*MPITCHDM) + (KP2*MPITCHM))
                 *
0062 81B7 A G01           LDA      MPITCHDM
0063 386F A               MUL      KP1
0064 74B6 A               RCPY     E,T                SAVE
0065 81BA A               LDA      MPITCHM
0066 386D A               MUL      KP2
0067 7C36 A               RADD     E,T
0068 10C0 A               RD       X'C0'              RESET COF
0069 8C5D A               LDA      VPRD
006A 7D7B A               RADDI    *T,A               ADD 2TH COMPLEMENT = SUBTRACT
006B E1B4 A               STA      MPITCHDD
                 *
                 *        PITCH RATE
                 *
                 *        MPITCHDM = MPITCHDM + (KP3*MPITCHDD)
                 *
006C 31CE A               MUL      KP3
006D A879 A               ADD      MPITCHDL           L/S PART
006E E878 A               STA      MPITCHDL           NEW L/S PART
006F 10C0 A               RD       X'C0'              RESET COF
0070 81B7 A               LDA      MPITCHDM           M/S PART
0071 7E76 A               RADDC    E,A
0072 E1B7 A               STA      MPITCHDM           M/S PART
                 *
                 *        MPITCHM = MPITCHM + (KP4*MPITCHDM)
                 *
0073 31CF A               MUL      KP4
0074 A875 A               ADD      MPITCHL             L/S PART
0075 E874 A               STA      MPITCHL            NEW L/S PART
0076 10C0 A               RD       X'C0'              RESET COF
0077 81BA A               LDA      MPITCHM
0078 7E76 A               RADDC    E,A
0079 E1BA A               STA      MPITCHM            M/S PART
```

```
                        PAGE
                 *
                 *      ROLL BODY ACCELERATIONS
                 *
                 *      TAU     PHI    HI-PASS     =  6 SEC
                 *      ZETA    PHI    HI-PASS     =  .7
                 *      S       PHI    HP DD       =  4 RAD/SEC 2
                 *      S       PHI    HP D        =  2 RAD/SEC
                 *      S       PHI    HP          =  2 RAD
                 *
                 *      VRRD                       =  4 RAD/SEC 2
                 *
                 *      MROLLDD = VRRD - ((KR1*MROLLDM) + (KR2*MROLLM))
                 *
007A 81B8 A ROLLCHAN LDA        MROLLDM
007B 3857 A          MUL        KR1
007C 74B6 A          RCPY       E,T
007D 81B8 A          LDA        MROLLM
007E 3855 A          MUL        KR2
007F 7C36 A          RADD       E,T
0080 10C0 A          RD         X'CO'               RESET COF
0081 8C46 A          LDA        VRRD                ROLL ACCEL.
0082 7D78 A          RADDI      *T,A                ADD 2TH COMPLEMENT = SUBTRACT
0083 E1B5 A          STA        MROLLDD
                 *
                 *      ROLL RATE
                 *
                 *      MROLLDM = MROLLDM + (KR3*MROLLDD)
                 *
0084 31CE A          MUL        KR3
0085 A862 A          ADD        MROLLDL             L/S PART
0086 E861 A          STA        MROLLDL             NEW L/S PART
0087 10C0 A          RD         X'CO'               RESET COF
0088 81B8 A          LDA        MROLLDM             M/S PART
0089 7E76 A          RADDC      E,A
008A E1B8 A          STA        MROLLDM             NEW M/S PART
                 *
                 *      MROLLM = MROLLM + (KR4*MROLLDM)
                 *
008B 31CF A          MUL        KR4
008C A85E A          ADD        MROLLL              L/S PART
008D E85D A          STA        MROLLL              NEW L/S PART
008E 10C0 A          RD         X'CO'               RESET COF
008F 81B8 A          LDA        MROLLM
0090 7E76 A          RADDC      E,A
0091 E1B8 A          STA        MROLLM              M/S PART
```

```
                                PAGE
                       *
                       *        YAW BODY ACCELERATIONS
                       *
                       *        TAU      PSI     HI-PASS        =  1.5 SEC
                       *        ZETA     PSI     HI-PASS        =  .7
                       *        S        PSI     HP DD          =  2 RAD/SEC 2
                       *        S        PSI     HP D           =  1 RAD/SEC
                       *        S        PSI     HP             =  1 RAD
                       *
                       *        VHRD                            =  2 RAD/SEC 2
                       *
                       *        MYAWDD = VHRD - ((KJ1*MYAWDM) + (KJ2*MYAWM))
                       *
0092 81B9 A YAWCHAN     LDA      MYAWDM
0093 384E A             MUL      KJ1
0094 74B6 A             RCPY     E,T
0095 81BC A             LDA      MYAWM
0096 384C A             MUL      KJ2
0097 7C36 A             RADD     E,T
0098 10C0 A             RD       X'C0'                  RESET COF
0099 8C2C A             LDA      VHRD
009A 7D7B A             RADDI    *T,A                   ADD 2TH COMPLEMENT = SUBTRACT
009B E1B6 A             STA      MYAWDD
                       *
                       *        YAW RATE
                       *
                       *        MYAWDM = MYAWDM + (KJ3*MYAWDD)
                       *
009C 31CE A             MUL      KJ3
009D A84B A             ADD      MYAWDL                 L/S PART
009E E84A A             STA      MYAWDL                 NEW L/S PART
009F 10C0 A             RD       X'C0'                  RESET COF
00A0 81B9 A             LDA      MYAWDM                 M/S PART
00A1 7E76 A             RADDC    E,A
00A2 E1B9 A             STA      MYAWDM                 NEW M/S PART
                       *
                       *        MYAWM  = MYAWM + (KJ4*MYAWDM)
                       *
00A3 31CF A             MUL      KJ4
00A4 A847 A             ADD      MYAWL                  L/S PART
00A5 E846 A             STA      MYAWL                  NEW L/S PART
00A6 10C0 A             RD       X'C0'                  RESET COF
00A7 81BC A             LDA      MYAWM
00A8 7E76 A             RADDC    E,A
00A9 E1BC A             STA      MYAWM                  NEW M/S PART
```

```
                  PAGE
               *
               *  SPECIFIC FORCE ERRORS
               *
               *  MXDD = KX1*MPITCHM
               *
00AA 81BA A       LDA     MPITCHM
00AB 3838 A       MUL     KX1
00AC 74F6 A       RCPY    E,A
00AD E1C1 A       STA     MXDD
               *
               *  MYDD = KY1*MROLLM
               *
00AE 81BB A       LDA     MROLLM
00AF 3835 A       MUL     KY1
00B0 74F6 A       RCPY    E,A
00B1 E1C2 A       STA     MYDD
               *
               *
00B2 484C A       B       G02
```

```
                             PAGE
                     *
                     *       DATA AND ADRL'S. WHEN SCALED OTHER THAN  BO
                     *       THIS IS DONE TO AVOID NECESSARY SHIFTS
                     *
                     *       WIND TO BODY RESCALING USED WITH SALD 3
                     *
00B3 36E0 A KXU1             DEC       428697E-6
00B4 4E7B A KYV1             DEC       613125E-6
00B5 2F17 A KZW1             DEC       367875E-6
00B6        KSCALE           RES       0
                     *
00B6 6666 A KUBBD            DEC       8E-1
00B7 5000 A KVBBD            DEC       625E-3             SALD 2
00B8 4000 A KWBBD1           DEC       25E-2B1
00B9 3333 A KWBBD2           DEC       2E-1B1
                     *
00BA 0851 A                  ADRL      VCSAB              COSINE ALPHA BODY
00BB 0853 A                  ADRL      VCSB               COSINE BETA
00BC 0885 A                  ADRL      VSNB               SINE BETA
00BD 0883 A                  ADRL      VSNAB              SINE ALPHA BODY
00BE 0888 A                  ADRL      VSNRB              SINE ROLL  BODY
00BF 0887 A                  ADRL      VSNPB              SINE PITCH BODY
00C0 0855 A                  ADRL      VCSPB              COS. PITCH BODY
00C1 08E0 A                  ADRL      VVXBP              GROUND SPEED
00C2 08D1 A                  ADRL      VPR                PITCH RATE
00C3 08C5 A                  ADRL      VHR                YAW   RATE
00C4 08D5 A                  ADRL      VRR                ROLL  RATE
00C5 08C6 A                  ADRL      VHRD               YAW   ACCEL.  2B1
00C6 08D2 A                  ADRL      VPRD               PITCH ACCEL.  2B1
00C7 08D6 A                  ADRL      VRRD               ROLL ACCEL.  2B2
00C8 08B3 A                  ADRL      VBOG               ON/OFF GRD FLAG
00C9 0FE0 A                  ADRL      ACTFLG04           FOR FREEZE
00CA 0880 A BIT4&8           DATA      X'0880'            FLT & TOTAL FRZE
                     *
00CB 0000 A UBCD             DATA      0       BODY-CENTROID ACCEL.10M/SEC 2.LONGITUDIN
00CC 0000 A VBCD             DATA      0                               8M/SEC 2.LATERAL
00CD 0000 A WBCD             DATA      0                              40M/SEC 2.VERTICAL
                     *
00CE 52E1 A KUBC             DEC       6475E-4            SALD  3
00CF 679A A KVBC             DEC       8094E-4            SALD  4
00D0 52E1 A KWBC             DEC       6475E-4            SALD  2
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                          PAGE
                 *
0001 4A6B A KX11         DEC       581377E-6          SALD 3
0002 1D00 A KP1          DEC       11666E-5B1
0003 038E A KP2          DEC       01388E-5B1
0004 4000 A KP13         DEC       25E-2B1
     00D4 R KP14         EQU       KP13
0005 599A A KP15         DEC       7E-1               SALD 1
     00D4 R KP16         EQU       KP13
0006 7000 A KY10         DEC       875E-3             SALD  2
0007 5B29 A KY11         DEC       7122E-4            SALD  2
0008 5000 A KR12         DEC       625E-3
0009 E000 A KR14         DEC       -125E-3B1
000A 599A A KR15         DEC       35E-2B1
000B 2000 A KR16         DEC       125E-3B1
000C 5000 A KR28         DEC       625E-3             SALD 2
000D 0000 A TIMER        DATA      0
000E 0000 A LTCONDT      DATA      0                  LAST TIME CONDITION
000F FFEC A 20ITERS      DATA      -20                FOR 20  *  50 M/SEC
00E0 0000 A STOPFLAG     DATA      0                  -1 IMPLIES : STOP CALCULATION
                 *
00E1 7777 A KJ1          DEC       233332E-6B2
00E2 38E3 A KJ2          DEC       055552E-6B3
                 *
00E3 E148 A KX1          DEC       -03E-2B3
00E4 4CCD A KY1          DEC       3E-1B1
00E5 5165 A KZ2          DEC       635893E-6          SALD 3
```

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                        PAGE
                  *
00E6 0000 A MPITCHDL DATA      0              PITCH L/S RATE INTEGRATION
00E7 0000 A MROLLDL  DATA      0              ROLL
00E8 0000 A MYAWDL   DATA      0              YAW
                  *
00E9 0000 A MPITCHL  DATA      0              PITCH
00EA 0000 A MROLLL   DATA      0              ROLL
00EB 0000 A MYAWL    DATA      0              YAW
                  *
00EC 0000 A BPITCHDL DATA      0              PITCH BODY DOT L/S INTEGRATION
00ED 0000 A BROLLDL  DATA      0
                  *
00EE 0000 A BXM      DATA      0              X BODY MOST INTEGRATION
00EF 0000 A BYM      DATA      0              Y
00F0 0000 A BZM      DATA      0              Z
                  *
00F1 0000 A BXL      DATA      0              X BODY L/S INTEGRATION
00F2 0000 A BYL      DATA      0              Y
00F3 0000 A BZL      DATA      0              Z
                  *
00F4 0000 A BXDM     DATA      0              X BODY DOT MOST INTEGRATION
00F5 0000 A BYDM     DATA      0              Y
00F6 0000 A BZDM     DATA      0              Z
                  *
00F7 0000 A BXDL     DATA      0              X BODY DOT L/S INTEGRATION
00F8 0000 A BYDL     DATA      0              Y
00F9 0000 A BZDL     DATA      0              Z
                  *
00FA 0000 A BPITCHL  DATA      0              PITCH BODY L/S INTEGRATION
00FB 0000 A BROLLL   DATA      0              ROLL
                  *
00FC 0000 A BPITCHM  DATA      0              PITCH BODY MOST INTEGRATION
00FD 0000 A BROLLM   DATA      0              ROLL
```

```
                          PAGE
                   *
                   *      SPECIFIC FORCES
                   *
                   *      CENTROID TRANSFORMATION
                   *
                   *      UBCD = UBD - (((VPR*VPR)+(VHR*VHR))*KUBC)
                   *
00FE 8DC4 A G02           LDA      VPR
00FF 3DC3 A               MUL      VPR              PITCH RATE MOST
0100 20A1 A               SALD     1
0101 74B6 A               RCPY     E,T              SAVE
0102 8DC1 A               LDA      VHR
0103 3DC0 A               MUL      VHR              YAW RATE
0104 20A1 A               SALD     1
0105 7C36 A               RADD     E,T
0106 74F3 A               RCPY     T,A
0107 39C7 A               MUL      KUBC
0108 20A3 A               SALD     3                SAVE IN  E  REG.
0109 81AE A               LDA      UBD              MOT.B-AXIS LONGITUDINAL ACC.
010A 7D7E A               RADDI    *E,A             SUBTRACT
010B E9C0 A               STA      UBCD             MOT.B-AXIS LONG.ACC.AT CENTROID
                   *
                   *      VBCD = VBDM + (((VRR*VPR) + VHRD) * KVBC)
                   *
010C 8DB8 A               LDA      VRR              ROLL RATE
010D 3DB5 A               MUL      VPR
010E 20A1 A               SALD     1
010F 74F6 A               RCPY     E,A
0110 ADB5 A               ADD      VHRD
0111 39BE A               MUL      KVBC
0112 20A4 A               SALD     4
0113 74F6 A               RCPY     E,A
0114 A1AF A               ADD      VBDM             MOT.B-AXIS LATERAL ACC.
0115 E9B7 A               STA      VBCD             MOT.B-AXIS LAT.ACC. AT CENTROID
                   *
                   *      WBCD = WBD + (((VRR*VHR)-VPRD)*KWBC)
                   *
0116 8DAE A               LDA      VRR
0117 3DAC A               MUL      VHR
0118 20A1 A               SALD     1
0119 74F6 A               RCPY     E,A
011A BDAC A               SUB      VPRD
011B 39B5 A               MUL      KWBC
011C 20A2 A               SALD     2
011D 74F6 A               RCPY     E,A
011E A1B0 A               ADD      WBD              MOT.B-AXIS VERTICAL ACC.
011F E9AE A               STA      WBCD             MOT.B-AXIS VERT.ACC. AT CENTROID
```

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                          PAGE
                    *
                    *     LONGITUDINAL SPECIFIC FORCE.
                    *
                    *     LONGITUDINAL HI-PASS FILTER
                    *
                    *     TAU     X     HI-PASS     =  .7 SEC
                    *     ZETA    X     HI-PASS     =  .7
                    *     S       X     HI DD       =  10M/SEC 2
                    *     S       X     HI D        =  10M/SEC
                    *     S       X     HI          =  11.3952 M
                    *
                    *     BXDD = UBCD - (BPITCHM)-(KX10*BXDM)-(KX11*BXM)
                    *
0120 89C0 A               LDA     STOPFLAG          CALC.TO BE STOPPED ?
0121 6E3A A               BAN     G03               YES
0122 89D2 A               LDA     BXDM              NO
0123 7C77 A               RADD    A,A               FOR KX10 = 2.0
0124 A9D8 A               ADD     BPITCHM
0125 74B7 A               RCPY    A,T               SAVE IT
0126 89C8 A               LDA     BXM
0127 39AA A               MUL     KX11
0128 20A3 A               SALD    3
0129 7C36 A               RADD    E,T               SUM IT
012A 89A1 A               LDA     UBCD
012B 707B A               RADDI   *T,A              SUBTRACT
012C E1B1 A               STA     BXDD
                    *
                    *     INTEGRATION
                    *
                    *     BXDM = BXDM + (KX12*BXDD)
                    *
012D 81B1 A               LDA     BXDD
012E 31CF A               MUL     KX12
012F A9C8 A               ADD     BXDL              L/S PART
0130 E9C7 A               STA     BXDL              NEW L/S PART
0131 10C0 A               RD      X'C0'
0132 89C2 A               LDA     BXDM              M/S PART
0133 7E76 A               RADDC   E,A
0134 E9C0 A               STA     BXDM              NEW M/S PART
                    *
                    *     BXM = BXM + (KX13*BXDM)
                    *
0135 31D0 A               MUL     KX13
0136 A9BB A               ADD     BXL                L/S PART
0137 E98A A               STA     BXL               NEW L/S PART
0138 10C0 A               RD      X'C0'             RST COF
0139 89B5 A               LDA     BXM               M/S PART
013A 7E76 A               RADDC   E,A
013B E9B3 A               STA     BXM               NEW M/S PART
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                *       LONGTITUDNAL LOW-PASS FILTER
                *
                *       TAU     THETA  LOW-PASS    =  2 SEC
                *       ZETA    THETA  LOW-PASS    =  .7
                *       S       THETA  LP DD       =  1 RAD/SEC 2
                *       S       THETA  LP D        =  1 RAD/SEC
                *       S       THETA  LP          =  1 RAD
                *
                *       BPITCHDD = (KP13*UBCD) + (KP14*VSNPB) - (KP16*BPITCHM)
                *                 -(KP15*BPITCHDM)
                *
013C 81BF A             LDA     BPITCHDM
013D 3998 A             MUL     KP15
013E 20A1 A             SALD    1
013F 74B6 A             RCPY    E,T                 SAVE
0140 898B A             LDA     UBCD                LONGITUDINAL CENTROID ACCEL.
0141 3993 A             MUL     KP13
0142 74A6 A             RCPY    E,L
0143 8D7C A             LDA     VSNPB               SINE PITCH BODY
0144 3990 A             MUL     KP14
0145 7C26 A             RADD    E,L                 SUM IN  L  REG.
0146 89B6 A             LDA     BPITCHM
0147 398D A             MUL     KP16
0148 7D2E A             RADDI   *E,L                SUBTRACT IN  L  REG.
0149 74F2 A             RCPY    L,A
014A 7D7B A             RADDI   *T,A                SUBTRACT
014B E1BD A             STA     BPITCHDD
                *
                *       INTEGRATION
                *
                *       BPITCHDM = BPITCHDM + (KP17*BPITCHDD)
                *
014C 81BD A             LDA     BPITCHDD
014D 31CF A             MUL     KP17
014E A99E A             ADD     BPITCHDL            L/S PART
014F E99D A             STA     BPITCHDL            NEW L/S PART
0150 10C0 A             RD      X'C0'               RST COF
0151 81BF A             LDA     BPITCHDM            M/S PART
0152 7E76 A             RADDC   E,A
0153 E1BF A             STA     BPITCHDM            NEW M/S PART
                *
                *       BPITCHM = BPITCHM + (KP18*BPITCHDM)
                *
0154 31CF A             MUL     KP18
0155 A9A5 A             ADD     BPITCHL             L/S PART
0156 E9A4 A             STA     BPITCHL             NEW L/S PART
0157 10C0 A             RD      X'C0'               RST COF
0158 89A4 A             LDA     BPITCHM             M/S PART
0159 7E76 A             RADDC   E,A
015A E9A2 A             STA     BPITCHM             NEW M/S PART
```

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                              PAGE
                      *
                      *       LATERAL SPECIFIC FORCE
                      *
                      *       LATERAL HI-PASS FILTER
                      *
                      *       TAU      Y       HI-PASS     =  1 SEC
                      *       ZETA     Y       HI-PASS     =  .7
                      *       S        Y       HI DD       =  8M/SEC 2
                      *       S        Y       HI D        =  10M/SEC
                      *       S        Y       HI          =  11.3952 M
                      *
                      *       BYDD = VBCD +(KR12*BROLLM)-(KY10*BYDM)-(KY11*BYM)
                      *                -(KR28*VSNRB*VCSPB)
                      *
0158 899A A G03               LDA      BYDM
015C 397A A                   MUL      KY10
015D 20A2 A                   SALD     2                   = KY10*2
015E 74B6 A                   RCPY     E,T                 SAVE
015F 8990 A                   LDA      BYM
0160 3977 A                   MUL      KY11
0161 20A2 A                   SALD     2                   = KY11*2
0162 7C36 A                   RADD     E,T                 SAVE SUM
0163 8D5B A                   LDA      VSNRB               SINE ROLL BODY
0164 3D5C A                   MUL      VCSPB               COS.PITCH BODY
0165 20A1 A                   SALD     1
0166 74F6 A                   RCPY     E,A
0167 3975 A                   MUL      KR28
0168 20A2 A                   SALD     2
0169 7C36 A                   RADD     E,T
016A 8993 A                   LDA      BROLLM
016B 396D A                   MUL      KR12
016C 20A1 A                   SALD     1                   AND SAVE IN E REG.
016D 895F A                   LDA      VBCD
016E 7C76 A                   RADD     E,A
016F 7D7B A                   RADDI    *T,A                SUBTRACT T REG. CONTENTS
0170 E1B2 A                   STA      BYDD
```

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                        PAGE
                 *
                 *      INTEGRATION
                 *
                 *      BYDM = BYDM + (KY12*BYDD)
                 *
0171 31D4 A             MUL     KY12
0172 A986 A             ADD     BYDL          L/S PART
0173 E985 A             STA     BYDL          NEW L/S PART
0174 10C0 A             RD      X'C0'         RST COF
0175 8980 A             LDA     BYDM          M/S PART
0176 7E76 A             RADDC   E,A
0177 E97E A             STA     BYDM          NEW M/S PART
                 *
                 *      BYM = BYM + (KY13*BYDM)
                 *
0178 31D0 A             MUL     KY13
0179 A979 A             ADD     BYL           L/S PART
017A E978 A             STA     BYL           NEW L/S PART
017B 10C0 A             RD      X'C0'         RST COF
017C 8973 A             LDA     BYM           M/S PART
017D 7E76 A             RADDC   E,A
017E E971 A             STA     BYM           NEW M/S PART
```

```
                        PAGE
                *
                *       LATERAL LOW-PASS FILTER
                *
                *       TAU     PHI   LOW-PASS   =  2 SEC
                *       ZETA    PHI   LOW-PASS   =  .7
                *       S       PHI   LP DD      =  2 RAD/SEC 2
                *       S       PHI   LP D       =  1 RAD/SEC
                *       S       PHI   LP         =  1 RAD
                *
                *       BROLLDD = -((KR13*VBCD)+(KR14*VSNRB*VCSPB)+(KR15*BROLLDM
                *                    (KR16*BROLLM))
                *
017F 894D A             LDA     VBCD
0180 31CE A             MUL     KR13
0181 7486 A             RCPY    E,T                  SAVE
0182 8D3C A             LDA     VSNRB                SINE ROLL BODY
0183 3956 A             MUL     KR14
0184 74F6 A             RCPY    E,A
0185 3D3B A             MUL     VCSPB
0186 20A1 A             SALD    1
0187 7C36 A             RADD    E,T                  SAVE SUM
0188 81C0 A             LDA     BROLLDM
0189 3951 A             MUL     KR15
018A 7C36 A             RADD    E,T                  SAVE SUM
018B 8972 A             LDA     BROLLM
018C 394F A             MUL     KR16
018D 7C36 A             RADD    E,T                  SAVE SUM
018E 75FB A             RCPYI   *T,A                 FOR - SIGN
018F E1BE A             STA     BROLLDD
```

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                        PAGE
                 *
                 *      INTEGRATION
                 *
                 *      BROLLDM = BROLLDM + (KR17*BROLLDD)
                 *
0190 31CE A             MUL       KR17
0191 A95C A             ADD       BROLLDL            L/S PART
0192 E95B A             STA       BROLLDL            NEW L/S PART
0193 10C0 A             RD        X'CO'              RST COF
0194 81C0 A             LDA       BROLLDM            M/S PART
0195 7E76 A             RADDC     E,A
0196 E1C0 A             STA       BROLLDM            NEW M/S PART
                 *
                 *      BROLLM = BROLLM + (KR18*BROLLDM)
                 *
0197 31CF A             MUL       KR18
0198 A963 A             ADD       BROLLL             L/S PART
0199 E962 A             STA       BROLLL             NEW L/S PART
019A 10C0 A             RD        X'CO'              RST COF
019B 8962 A             LDA       BROLLM             M/S PART
019C 7E76 A             RADDC     E,A
019D E960 A             STA       BROLLM             NEW M/S PART
```

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                           PAGE
                   *
                   *       VERTICAL HI-PASS FILTER
                   *
                   *       TAU       Z      HI-PASS     =  .7 SEC
                   *       ZETA      Z      HI-PASS     =  .7
                   *       S         Z      HP DD       =  40 M/SEC 2
                   *       S         Z      HP D        =  10 M/SEC
                   *       S         Z      HP          =  49.854 M
                   *       BZDD = WBCD - (.5*BZDM) - (KZ2*BZM)
                   *
     019E 8952 A           LDA       BZM
     019F 3946 A           MUL       KZ2
     01A0 20A3 A           SALD      3
     01A1 74B6 A           RCPY      E,T                SAVE
     01A2 8954 A           LDA       BZDM
     01A3 2001 A           SARS      1                  *.5
     01A4 7C37 A           RADD      A,T                SAVE SUM
     01A5 8928 A           LDA       WBCD
     01A6 707B A           RADDI     *T,A               SUBTRACT
     01A7 E1B3 A           STA       BZDD
                   *
                   *       INTEGRATION
                   *
                   *       BZDM = BZDM + (KZ3*BZDD)
                   *
     01A8 31D5 A           MUL       KZ3
     01A9 A950 A           ADD       BZDL               L/S PART
     01AA E94F A           STA       BZDL               NEW L/S PART
     01AB 10C0 A           RD        X'CO'              RST COF
     01AC 894A A           LDA       BZDM               M/S PART
     01AD 7E76 A           RADDC     E,A
     01AE E948 A           STA       BZDM               NEW M/S PART
                   *
                   *       BZM = BZM + (KZ4*BZDM)
                   *
     01AF 31D6 A           MUL       KZ4
     01B0 A943 A           ADD       BZL                L/S PART
     01B1 E942 A           STA       BZL                NEW L/S PART
     01B2 10C0 A           RD        X'CO'              RST COF
     01B3 893D A           LDA       BZM                M/S PART
     01B4 7E76 A           RADDC     E,A
     01B5 E93B A           STA       BZM                NEW M/S PART
     01B6 44FD A           B         *PROGRETN
```

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                           PAGE
                *
                *          EQUALS   TABLE AT END OF PROGRAM
                *
     10CE A KP3            EQU      KPRJ3
     10CE A KR3            EQU      KPRJ3
     10CE A KJ3            EQU      KPRJ3
                *
     10CE A KR17           EQU      KPRJ3
     10CE A KR13           EQU      KPRJ3
                *
     10CF A KP4            EQU      KPRJ4
     10CF A KR4            EQU      KPRJ4
     10CF A KJ4            EQU      KPRJ4
                *
     10CF A KJ11           EQU      KPRJ4
     10CF A KX12           EQU      KPRJ4
                *
     10CF A KR18           EQU      KPRJ4
     10CF A KP17           EQU      KPRJ4
     10CF A KP18           EQU      KPRJ4
                *
                *
     10D0 A KX13           EQU      KXY13
     10D0 A KY13           EQU      KXY13
                *
                *
     10D1 A KP19           EQU      KR19
     10D1 A KJ5            EQU      KR19
                *
                *
     10D3 A KP24           EQU      KPR2423
     10D3 A KR23           EQU      KPR2423
                *
                *
     10D2 A KR20           EQU      KPRJ206
     10D2 A KJ6            EQU      KPRJ206
                *
     0002 R KR1            EQU      KP1
     0003 R KR2            EQU      KP2
                *
                *
     0000 A                END

      0  ERRORS
EQUALS ERROR   MAINMN1
```

A	0007	X	ACTFLG04	0FE0	X	B	0005	X	BASE10	0080	X
BIT4&8	00CA	R	BPITCHDD	10BD	X	BPITCHDL	00EC	R	BPITCHDM	10BF	X
BPITCHL	00FA	R	BPITCHM	00FC	R	BROLLDD	10BE	X	BROLLDL	00ED	R
BROLLDM	10C0	X	BROLLL	00FB	R	BROLLM	00FD	R	BXDD	10B1	X
BXDL	00F7	R	BXDM	00F4	R	BXL	00F1	R	BXM	00EE	R
BYDD	10B2	X	BYDL	00F8	R	BYDM	00F5	R	BYL	00F2	R
BYM	00EF	R	BZDD	10B3	X	BZDL	00F9	R	BZDM	00F6	R
BZL	00F3	R	BZM	00F0	R	E	0006	X	G01	0062	R
G02	00FE	R	G03	015B	R	KJ1	00E1	R	KJ11	10CF	A
KJ2	00E2	R	KJ3	10CE	A	KJ4	10CF	A	KJ5	10D1	A
KJ6	10D2	A	KPRJ206	10D2	X	KPRJ3	10CE	X	KPRJ4	10CF	X
KPR2423	10D3	X	KP1	00D2	R	KP13	00D4	R	KP14	00D4	R
KP15	00D5	R	KP16	00D4	R	KP17	10CF	A	KP18	10CF	A
KP19	10D1	A	KP2	00D3	R	KP24	10D3	A	KP3	10CE	A
KP4	10CF	A	KR1	00D2	R	KR12	00D8	R	KR13	10CE	A
KR14	00D9	R	KR15	00DA	R	KR16	00DB	R	KR17	10CE	A
KR18	10CF	A	KR19	10D1	X	KR2	00D3	R	KR20	10D2	A
KR23	10D3	A	KR28	00DC	R	KR3	10CE	A	KR4	10CF	A
KSCALE	00B6	R	KUBBD	00B6	R	KUBC	00CE	R	KVBBD	00B7	R
KVBC	00CF	R	KWBBD1	00B8	R	KWBBD2	00B9	R	KWBC	00D0	R
KXU1	00B3	R	KXY13	10D0	X	KX1	00E3	R	KX11	00D1	R
KX12	10CF	A	KX13	10D0	A	KYV1	00B4	R	KY1	00E4	R
KY10	00D6	R	KY11	00D7	R	KY12	10D4	X	KY13	10D0	A
KZW1	00B5	R	KZ2	00E5	R	KZ3	10D5	X	KZ4	10D6	X
L	0002	X	LOOP1	0007	R	LOOP2	0011	R	LTCONDT	00DE	R
MAINMN1	0000	R	MFZWB	10AA	X	MPITCHDD	10B4	X	MPITCHDL	00E6	R
MPITCHDM	10B7	X	MPITCHL	00E9	R	MPITCHM	10BA	X	MROLLDD	10B5	X
MROLLDL	00E7	R	MROLLDM	10B8	X	MROLLL	00EA	R	MROLLM	10BB	X
MXDD	10C1	X	MYAWDD	10B6	X	MYAWDL	00E8	R	MYAWDM	10B9	X
MYAWL	00EB	R	MYAWM	10BC	X	MYDD	10C2	X	M3	00D8	X
NOFRZE	0004	R	ONGROUND	0010	R	PROGRETN	00FD	X	ROLLCHAN	007A	R
STOPFLAG	00E0	R	T	0003	X	TIMER	00DD	R	TIMEUP	0057	R
TIMEX	0053	R	TRANSFOR	0017	R	UBCD	00CB	R	UBD	10AE	X
UWD	10AB	X	VBCD	00CC	R	VBDM	10AF	X	VBOG	08B3	X
VCSAB	0851	X	VCSB	0853	X	VCSPB	0855	X	VHR	08C5	X
VHRD	08C6	X	VPR	08D1	X	VPRD	08D2	X	VRR	08D5	X
VRRD	08D6	X	VSNAB	0883	X	VSNB	0885	X	VSNPB	0887	X
VSNRB	0888	X	VVXBP	08E0	X	VWD	10AC	X	WBCD	00CD	R
WBD	10B0	X	WWD	10AD	X	YAWCHAN	0092	R	Z	0000	X
ZERO	0014	R	20ITERS	00DF	R						

APPENDIX B, PART 2

```
                    *        KSS B-747 MAIN MOTION SIMULATION.  PART 2.
                    *
                    *        TEST PILOT  : CAPTAIN J.L. VELDHUYZEN VAN ZANTEN
                    *
                    *        DESIGN      : IR. M. BAARSPUL
                    *
                    *        SOFTWARE    : B.BAARSCHERS
                    *
                    *        ASSEMBLE THIS PROGRAM WITH :
                    *        EXT. X-REF
                    *        SLV SP
                    *        MOTION X-REF
                    *        FLIGHT INT. X-REF
                    *
                    *        ISSUE    3
                    *        AUG.     1975
                    *
                             DEF      MAINMN2
                    *
                             SREF     MOTION,MZ
                    *
                             CSECT
                             ORG      X'0000'
                    *
0000 8C61 A MAINMN2          LDA      ACTFLG04          FLIGHT OR TOTAL FREEZE ?
0001 9861 A                  AND      BIT4&8
0002 6404 A                  BAZ      NOFREEZE
0003 808E A                  LDA      BASE8
0004 74D7 A                  RCPY     A,B               RESTORE BASE REG.
0005 44FD A                  B        *PROGRETN         EXIT
                    *
                             BASE     X'1000'
                    *
```

```
                         PAGE
                *
                *        SUM OF BODY ROTATIONAL ACCELERATIONS
                *
                *        SPITCHDD = BPITCHDD + ( 2.0 * MPITCHDD )
                *
0006 81B4 A NOFREEZE LDA      MPITCHDD
0007 2021 A          SALS     1                2.0 *
0008 A1BD A          ADD      BPITCHDD
0009 E86C A          STA      SPITCHDD
                *
                *        SROLLDD = BROLLDD + MROLLDD
                *
000A 81B5 A          LDA      MROLLDD
000B A1BE A          ADD      BROLLDD
000C E86A A          STA      SROLLDD
                *
                *        SUM OF BODY ROTATIONAL RATES
                *
                *        SPITCHDM = BPITCHDM + MPITCHDM
                *
000D 81B7 A          LDA      MPITCHDM
000E A1BF A          ADD      BPITCHDM
000F E868 A          STA      SPITCHDM
                *
                *        SROLLDM = BROLLDM + MROLLDM
                *
0010 81B8 A          LDA      MROLLDM
0011 A1C0 A          ADD      BROLLDM
0012 E866 A          STA      SROLLDM
```

```
                      PAGE
              *
              *       EULER RATE  :  PITCH
              *
              *       MPITCHSD = (SPITCHDM*COS(MROLLSM))-(MYAWDM*SIN(MROLLSM))
              *
0013 8857 A            LDA     MROLLSM
0014 3848 A           MUL     KR24               SCALING FOR SINE/COS
0015 74F6 A           RCPY    E,A
0016 75A1 A           RCPYI   P,L
0017 44E9 A           B       *LOOKYCOS
0018 E85B A           STA     CMROLLSM           COSINE ROLLSM
0019 385E A           MUL     SPITCHDM
001A 20A1 A           SALD    1
001B 74B6 A           RCPY    E,T                SAVE
001C 884E A           LDA     MROLLSM
001D 383F A           MUL     KR24               SCALING FOR SINE/COS
001E 74F6 A           RCPY    E,A
001F 75A1 A           RCPYI   P,L
0020 44E8 A           B       *LOOKYSIN
0021 E84F A           STA     SMROLLSM           SINE ROLLSM
0022 31B9 A           MUL     MYAWDM
0023 20A1 A           SALD    1
0024 7D3E A           RADDI   *E,T               ADD 2TH COMPL.TO T REG. = SUB.
0025 74F3 A           RCPY    T,A
0026 E840 A           STA     MPITCHSD
```

```
                     PAGE
                *    EULER RATE  :  ROLL
                *
                *    MROLLSD = SROLLDM
                *    +(SPITCHDM*SIN(MROLLSM)*SIN(MPITCHSM) / COS(MPITCHSM)
                *    +(MYAWDM*COS(MROLLSM)*SIN(MPITCHSM)  /  COS(MPITCHSM))
0027 8842 A          LDA      MPITCHSM
0028 3834 A          MUL      KP25             SCALE FOR SINE/COS
0029 74F6 A          RCPY     E,A
002A 75A1 A          RCPYI    P,L
002B 44E8 A          B        *LOOKYSIN
002C E843 A          STA      SPITCHSM         SINE MPITCHSM = SIN SIM.CAB.PI
002D 883C A          LDA      MPITCHSM
002E 382E A          MUL      KP25             SCALE FOR SINE/COS
002F 74F6 A          RCPY     E,A
0030 75A1 A          RCPYI    P,L
0031 44E9 A          B        *LOOKYCOS
0032 E840 A          STA      CPITCHSM         COS.MPITCHSM = COS.SIM.CAB.PIT
0033 8844 A          LDA      SPITCHDM         SUM OF PITCH ROT.RATES
0034 383C A          MUL      SMROLLSM         SINE MROLLSM
0035 20A1 A          SALD     1
0036 74F6 A          RCPY     E,A
0037 3838 A          MUL      SPITCHSM         SINE MPITCHSM
0038 583A A          DIV      CPITCHSM         COS.MPITCHSM
0039 74B7 A          RCPY     A,T              SAVE
003A 81B9 A          LDA      MYAWDM
003B 3838 A          MUL      CMROLLSM         COSINE MROLLSM
003C 20A1 A          SALD     1
003D 74F6 A          RCPY     E,A
003E 3831 A          MUL      SPITCHSM         SINE OF MPITCHSM
003F 5833 A          DIV      CPITCHSM         COS  MPITCHSM
0040 7C73 A          RADD     T,A
0041 A837 A          ADD      SROLLDM          SUM OF ROLL ROT.RATES
0042 E825 A          STA      MROLLSD
                *
                *
                *    EULER RATE : YAW
                *
                *    MYAWSD = (SPITCHDM*SIN(MROLLSM) / COS(MPITCHSM)
                *             +(MYAWDM*COS(MROLLSM) / COS(MPITCHSM))
                *
0043 8834 A          LDA      SPITCHDM
0044 382C A          MUL      SMROLLSM         SINE MROLLSM
0045 582D A          DIV      CPITCHSM
0046 74B7 A          RCPY     A,T              SAVE
0047 81B9 A          LDA      MYAWDM
0048 382B A          MUL      CMROLLSM         COSINE MROLLSM
0049 5829 A          DIV      CPITCHSM         COSINE MPITCHSM
004A 7C73 A          RADD     T,A
004B E81D A          STA      MYAWSD
```

```
                          PAGE
                  *
                  *       RETURN TO GROUND CHECK
                  *
004C 8C13 A               LDA     DISOPO75          RETURN TO GRD ?
004D 90C6 A               AND     BIT12
004E 6402 A               BAZ     RETNGRD           YES
004F 482A A               B       GO5               NO
0050 COD8 A RETNGRD       LDX     M3
0051 74F0 A               RCPY    Z,A               CLEAR
0052 EA14 A               STA     MPITCHMD+3,1      CLEAR EULER RATE WASHOUT
0053 EA16 A               STA     MPITCHSD+3,1      CLEAR EULER RATE
0054 EA18 A               STA     MPITCHSM+3,1      CLEAR EULER ANGLE MOST
0055 EA1A A               STA     MPITCHSL+3,1      CLEAR EULER ANGLE LEAST
0056 67FB A               BIX     RETNGRD+1         LOOP
0057 EC09 A               STA     VVXBP             TO ZERO THE GROUND SPEED
0058 4821 A               B       GO5
                  *
```

```
                        PAGE
                   *   ALL CONSTANTS SCALED OTHER THAN  B0  ,THIS SCALING
                   *   IS TO AVOID SHIFTING AFTER A MULTIPLY
                   *
0059 5000 A KX16       DEC       625E-3            SALD  2
005A C000 A KX17       DEC       -25E-2B1
005B 0B44 A KP20       DEC       044E-3B1
005C 517D A KP25       DEC       31831E-5B1        SCALE FOR SINE/COSINE
                   *
005D 6666 A KY16       DEC       8E-1
     10D5 A KY17       EQU       KZ3               IN BASE
                   *
     005C R KR24       EQU       KP25             SCALE FOR SINE/COS
                   *
005E 0888 A            ADRL      VSNRB             SINE ROLL BODY  AT  2B0
005F 01B9 A            ADRL      DISOP075
0060 08E0 A            ADRL      VVXBP
0061 0FE0 A            ADRL      ACTFLG04
                   *
0062 0880 A BIT4&8     DATA      X'0880'           FOR FLIGHT & TOTAL FREEZE
                   *
     005C R KJ9        EQU       KP25              SCALE FOR SINE / COS
                   *
0063 0000 A MPITCHMD DATA        0                 EULER RATE WASHOUT
0064 0000 A MROLLMD  DATA        0
0065 0000 A MYAWMD   DATA        0
                   *
0066 0000 A MPITCHSD DATA        0                 EULER RATE
0067 0000 A MROLLSD  DATA        0
0068 0000 A MYAWSD   DATA        0
                   *
0069 0000 A MPITCHSM DATA        0                 EULER ANGLE M/S PART
006A 0000 A MROLLSM  DATA        0
006B 0000 A MYAWSM   DATA        0
                   *
006C 0000 A MPITCHSL DATA        0                 EULER ANGLE L/S PART
006D 0000 A MROLLSL  DATA        0
006E 0000 A MYAWSL   DATA        0
                   *
006F 0000 A SPITCHSM DATA        0                 SINE MPICHTSM (EULER ANGLE M/S
0070 0000 A SMROLLSM DATA        0                      MROLLSM
0071 0000 A SMYAWSM  DATA        0                      MYAWSM
                   *
0072 7FFF A CPITCHSM DATA        X'7FFF'           COSINE MPITCHSM (EULER ANGLE M
0073 7FFF A CMROLLSM DATA        X'7FFF'                  MROLLSM
0074 7FFF A CMYAWSM  DATA        X'7FFF'                  MYAWSM
```

```
                        PAGE
              *
              *         SUM OF ROTATIONAL ACCEL'  &  RATES
              *
0075 0000 A SPITCHDD DATA     0                   PITCH ACC. SUM
0076 0000 A SROLLDD  DATA     0                   ROLL  ACC. SUM
0077 0000 A SPITCHDM DATA     0                   PITCH RATE SUM
0078 0000 A SROLLDM  DATA     0                   ROLL  RATE SUM
              *
```

```
                         PAGE
                   *
                   *     ROTATIONAL WASHOUT.
                   *
                   *     TAU      THETA  ROTATIONAL =  200 SEC
                   *     S        THETA (MOTION)    =  1   RAD
                   *
                   *     MPITCHMD = MPITCHSD - (KP24*MPITCHSM)
                   *
0079 89F0 A G05          LDA      MPITCHSM
007A 31D3 A              MUL      KP24
007B 89EB A              LDA      MPITCHSD
007C 7D7E A              RADDI    *E,A              ADD 2TH COMPLEMENT
007D E9E6 A              STA      MPITCHMD
                   *
                   *     INTEGRATION
                   *
                   *     MPITCHSM = MPITCHSM + (KP18*MPITCHMD)
                   *
007E 31CF A              MUL      KP18
007F A9ED A              ADD      MPITCHSL          L/S PART
0080 E9EC A              STA      MPITCHSL          NEW L/S PART
0081 10C0 A              RO       X'C0'             RESET OVERFLOW
0082 89E7 A              LDA      MPITCHSM          M/S PART
0083 7E76 A              RADDC    E,A
0084 E9E5 A              STA      MPITCHSM          NEW M/S PART
                   *
                   *     COMPENSATION
                   *
                   *     MPITCHC = MPITCHSM + (KP19*MPITCHMD) + (KP20*SPITCHDD)
                   *
0085 89DE A              LDA      MPITCHMD
0086 31D1 A              MUL      KP19
0087 74B6 A              RCPY     E,T
0088 89ED A              LDA      SPITCHDD          SUM OF PITCH ACCELERATIONS
0089 39D2 A              MUL      KP20
008A 7C36 A              RADD     E,T
008B 89DE A              LDA      MPITCHSM
008C 7C73 A              RADD     T,A
008D E1C7 A              STA      MPITCHC
```

```
                      PAGE
                *
                *     ROTATIONAL WASHOUT.
                *
                *     TAU       PHI  ROTATIONAL     =  200 SEC
                *     S         PHI  (MOTION)       =  1   RAD
                *
                *     MROLLMD  = MROLLSD - (KR23*MROLLSM)
                *
008E 89DC A           LDA       MROLLSM
008F 31D3 A           MUL       KR23
0090 89D7 A           LDA       MROLLSD
0091 7D7E A           RADDI     *E,A               ADD 2TH COMPLEMENT
0092 E9D2 A           STA       MROLLMD
                *
                *     INTEGRATION
                *
                *     MROLLSM = MROLLSM + (KR18*MROLLMD)
                *
0093 31CF A           MUL       KR18
0094 A9D9 A           ADD       MROLLSL            L/S PART
0095 E9D8 A           STA       MROLLSL            NW L/S PART
0096 10C0 A           RD        X'C0'              RESET COF
0097 89D3 A           LDA       MROLLSM            M/S PART
0098 7E76 A           RADDC     E,A
0099 E9D1 A           STA       MROLLSM            NEW M/S PART
                *
                *     COMPENSATION
                *
                *     MROLLC = MROLLSM + (KR19*MROLLMD) + (KR20*SROLLDD)
                *
009A 89CA A           LDA       MROLLMD
009B 31D1 A           MUL       KR19
009C 74B6 A           RCPY      E,T
009D 89D9 A           LDA       SROLLDD            SUM OF ROLL ACCELERATIONS
009E 31D2 A           MUL       KR20
009F 7C36 A           RADD      E,T
00A0 89CA A           LDA       MROLLSM
00A1 7C73 A           RADD      T,A
00A2 E1C8 A           STA       MROLLC
```

```
                        PAGE
                *
                *       ROTATIONAL WASHOUT
                *
                *       TAU     PSI  ROTATIONAL    =  20 SEC
                *       S       PSI  (MOTION)      =  1  RAD
                *
                *       MYAWMD = MYAWSD -(KJ11*MYAWSM)
                *
00A3 89C8 A             LDA     MYAWSM
00A4 31CF A             MUL     KJ11
00A5 89C3 A             LDA     MYAWSD
00A6 7D7E A             RADDI   *E,A                ADD 2TH COMPLEMENT
00A7 E9BE A             STA     MYAWMD
                *
                *       MYAWSM = MYAWSM + (KJ4*MYAWMD)
                *
00A8 31CF A             MUL     KJ4
00A9 A9C5 A             ADD     MYAWSL              L/S PART
00AA E9C4 A             STA     MYAWSL              NEW L/S PART
00AB 10C0 A             RD      X'CO'               RESET COF
00AC 89BF A             LDA     MYAWSM              M/S PART
00AD 7E76 A             RADDC   E,A
00AE E9BD A             STA     MYAWSM              NEW M/S PART
                *
                *       MYAWC = MYAWSM + (KJ5*MYAWMD) + (KJ6*MYAWDD)
                *
00AF 89B6 A             LDA     MYAWMD
00B0 31D1 A             MUL     KJ5
00B1 74B6 A             RCPY    E,T                 SAVE
00B2 81B6 A             LDA     MYAWDD
00B3 31D2 A             MUL     KJ6
00B4 7C36 A             RADD    E,T
00B5 89B6 A             LDA     MYAWSM
00B6 7C73 A             RADD    T,A
00B7 E1C6 A             STA     MYAWC
```

```
                       PAGE
                 *
                 *     GENERATE SINE AND COSINE OF MYAWSM
                 *     FOR BODY TO INERTIAL TRANSFORMATION.
                 *
                 *
00B8 89B3 A            LDA      MYAWSM
00B9 39A3 A            MUL      KJ9              SCALING FOR SIN/COS
00BA 74F6 A            RCPY     E,A
00BB 75A1 A            RCPYI    P,L
00BC 44E8 A            B        *LOOKYSIN
00BD E9B4 A            STA      SMYAWSM          SINE OF MYAWSM
                 *
00BE 89AD A            LDA      MYAWSM
00BF 399D A            MUL      KJ9              SCALING FOR SIN/COS
00C0 74F6 A            RCPY     E,A
00C1 75A1 A            RCPYI    P,L
00C2 44E9 A            B        *LOOKYCOS
00C3 E9B1 A            STA      CMYAWSM          COSINE OF MYAWSM
                 *
                 *     SUMMATION OF TRANSLATIONAL ACCELERATIONS
                 *
00C4 81B1 A            LDA      BXDD
00C5 A1C1 A            ADD      MXDD
00C6 E1CC A            STA      SXDD
                 *
00C7 81B2 A            LDA      BYDD
00C8 A1C2 A            ADD      MYDD
00C9 E1CD A            STA      SYDD
                 *
```

```
                        PAGE
                 *
                 *      BODY TO INERTIAL TRANSFORMATION OFTRANSL.ACCEL'S  :  X CH
                 *
                 *      MXSDD = (SXDD*COS(MPITCHSM)*COS(MYAWSM))
                 *            + (KY16*SYDD)*((SIN(MROLLSM)*SIN(MPITCHSM)*COS(MYAW
                 *                                 - (COS(MROLLSM)*SIN(MYAWSM)))
                 *
 00CA 89AA A            LDA      CMYAWSM            COS.MYAWSM
 00CB 39A4 A            MUL      SPITCHSM
 00CC 20A1 A            SALD     1
 00CD 74F6 A            RCPY     E,A
 00CE 39A2 A            MUL      SMROLLSM
 00CF 20A1 A            SALD     1
 00D0 74B6 A            RCPY     E,T                SAVE
 00D1 89A2 A            LDA      CMROLLSM
 00D2 399F A            MUL      SMYAWSM            SINE OF MYAWSM
 00D3 20A1 A            SALD     1
 00D4 74F3 A            RCPY     T,A
 00D5 7D7E A            RADDI    *E,A
 00D6 31CD A            MUL      SYDD
 00D7 20A1 A            SALD     1
 00D8 74F6 A            RCPY     E,A
 00D9 3984 A            MUL      KY16
 00DA 20A1 A            SALD     1
 00DB 74B6 A            RCPY     E,T                SAVE
 00DC 8998 A            LDA      CMYAWSM
 00DD 3995 A            MUL      CPITCHSM
 00DE 20A1 A            SALD     1
 00DF 74F6 A            RCPY     E,A
 00E0 31CC A            MUL      SXDD
 00E1 20A1 A            SALD     1
 00E2 7C36 A            RADD     E,T                SUM IT
 00E3 74F3 A            RCPY     T,A
 00E4 E1C9 A            STA      MXSDD
```

```
                           PAGE
                   *       BODY TO INERTIAL TRANSFORMATION FOR :  Y
                   *
                   *       MYSDD = (KX16*SXDD*COS(MPITCHSM)*SIN(MYAWSM))
                   *             + (SYDD*SIN(MROLLSM)*SIN(MPITCHSM)*SIN(MYAWSM))
                   *                  +(COS(MROLLSM)*COS(MYAWSM)))
                   *
00E5 898E A                LDA      CMROLLSM
00E6 398E A                MUL      CMYAWSM
00E7 20A1 A                SALD     1
00E8 74B6 A                RCPY     E,T                SAVE
00E9 8987 A                LDA      SMROLLSM
00EA 3985 A                MUL      SPITCHSM
00EB 20A1 A                SALD     1
00EC 74F6 A                RCPY     E,A
00ED 3984 A                MUL      SMYAWSM
00EE 20A1 A                SALD     1
00EF 7C36 A                RADD     E,T
00F0 74F3 A                RCPY     T,A
00F1 31CD A                MUL      SYDD
00F2 20A1 A                SALD     1
00F3 74B6 A                RCPY     E,T                SAVE
00F4 81CC A                LDA      SXDD
00F5 3964 A                MUL      KX16
00F6 20A2 A                SALD     2                  = KX16*2
00F7 74F6 A                RCPY     E,A
00F8 397A A                MUL      CPITCHSM
00F9 20A1 A                SALD     1
00FA 74F6 A                RCPY     E,A
00FB 3976 A                MUL      SMYAWSM
00FC 20A1 A                SALD     1
00FD 7C36 A                RADD     E,T                SUM IT
00FE 74F3 A                RCPY     T,A
00FF E1CA A                STA      MYSDD
```

```
                        PAGE
                 *
                 *      BODY TO INERTIAL TRANSFORMATION OF TRANSL.ACCEL'S :  Z  C
                 *
                 *      MZSDD = (KX17*SXDD*SIN(MPITCHSM))
                 *             +(KY17*SYDD*SIN(MROLLSM)*COS(MPITCHSM))
                 *             +(BZDD*COS(MROLLSM)*COS(MPITCHSM)))
                 *
0100 896F A             LDA     SPITCHSM        SINE  MPITCHSM
0101 31CC A             MUL     SXDD
0102 20A1 A             SALD    1
0103 74F6 A             RCPY    E,A
0104 3956 A             MUL     KX17
0105 74B6 A             RCPY    E,T             SAVE IT
0106 896C A             LDA     CPITCHSM        COSINE  MPITCHSM
0107 3969 A             MUL     SMROLLSM
0108 20A1 A             SALD    1
0109 74F6 A             RCPY    E,A
010A 31CD A             MUL     SYDD
010B 20A1 A             SALD    1
010C 74F6 A             RCPY    E,A
010D 31D5 A             MUL     KY17
010E 7C36 A             RADD    E,T             SUM IT IN  T  REG
010F 8963 A             LDA     CPITCHSM
0110 3963 A             MUL     CMROLLSM
0111 20A1 A             SALD    1
0112 74F6 A             RCPY    E,A
0113 31B3 A             MUL     BZDD
0114 20A1 A             SALD    1
0115 7C36 A             RADD    E,T             SUM IT IN  T  REG
0116 74F3 A             RCPY    T,A
0117 E1CB A             STA     MZSDD
```

```
                     PAGE
               *
               *     TRANSLATIONAL WASHOUT FOR :  X
               *
               *     TAU       X  TRANSLATIONAL  =  2 SEC
               *     ZETA      X  TRANSLATIONAL  =  .7
               *
               *     MXMDD = MXSDD - (KX18*MXDM) - (KX19*MXM)
               *
0118 886F A          LDA       MXDM
0119 3874 A          MUL       KX18
011A 20A1 A          SALD      1
011B 74B6 A          RCPY      E,T
011C 886D A          LDA       MXM
011D 3871 A          MUL       KX19
011E 7C36 A          RADD      E,T
011F 81C9 A          LDA       MXSDD
0120 7D7B A          RADDI     *T,A            ADD 2TH COMPLEMENT OF SUM
0121 E869 A          STA       MXMDD
               *
               *     INTEGRATION
               *
               *     MXDM = MXDM + (KX12*MXMDD)
               *
0122 31CF A          MUL       KX12
0123 A863 A          ADD       MXDL            L/S PART
0124 E862 A          STA       MXDL            NEW L/S PART
0125 10C0 A          RD        X'C0'           RESET COF
0126 8861 A          LDA       MXDM
0127 7E76 A          RADDC     E,A
0128 E85F A          STA       MXDM            M/S PART
               *
               *     MXM = MXM + (KX13*MXDM)
               *
0129 31D0 A          MUL       KX13
012A A85E A          ADD       MXL             L/S PART
012B E85D A          STA       MXL             NEW L/S PART
012C 10C0 A          RD        X'C0'           RESET COF
012D 885C A          LDA       MXM
012E 7E76 A          RADDC     E,A
012F E85A A          STA       MXM             NEW M/S PART
```

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                         PAGE
                 *
                 *       COMPENSATION
                 *
                 *       MXC = MXM + (KX14*MXDM) + (KX15*MXMDD)
                 *
                 *
0130 8857 A              LDA      MXDM
0131 385A A              MUL      KX14
0132 74B6 A              RCPY     E,T
0133 8857 A              LDA      MXMDD
0134 3858 A              MUL      KX15
0135 7C36 A              RADD     E,T
0136 8853 A              LDA      MXM
0137 7C73 A              RADD     T,A
0138 E1C3 A              STA      MXC
```

```
                           PAGE
                    *
                    *      TRANSLATIONAL WASHOUT FOR :  Y
                    *
                    *      TAU       Y  TRANSLATIONAL  =  2 SEC
                    *      ZETA      Y  TRANSLATIONAL  =  .7
                    *
                    *      MYMDD = MYSDD - (KY18*MYDM) - (KY19*MYM)
                    *
0139 8857 A                LDA      MYDM
013A 385B A                MUL      KY18
013B 20A1 A                SALD     1
013C 74B6 A                RCPY     E,T
013D 8855 A                LDA      MYM
013E 3858 A                MUL      KY19
013F 7C36 A                RADD     E,T
0140 81CA A                LDA      MYSDD
0141 7D7B A                RADDI    *T,A              ADD 2TH COMPLEMENT OF SUM
0142 E851 A                STA      MYMDD
                    *
                    *      INTEGRATION
                    *
                    *      MYDM = MYDM + (KY12*MYMDD)
                    *
0143 31D4 A                MUL      KY12
0144 A84B A                ADD      MYDL              L/S
0145 E84A A                STA      MYDL              NEW L/S PART
0146 10C0 A                RD       X'C0'             RESET COF
0147 8849 A                LDA      MYDM
0148 7E76 A                RADDC    E,A
0149 E847 A                STA      MYDM              M/S PART
                    *
                    *      MYM =MYM + (KY13*MYDM)
                    *
014A 31D0 A                MUL      KY13
014B A846 A                ADD      MYL               L/S PART
014C E845 A                STA      MYL               NEW L/S PART
014D 10C0 A                RD       X'C0'             RESET COF
014E 8844 A                LDA      MYM
014F 7E76 A                RADDC    E,A
0150 E842 A                STA      MYM               M/S PART
```

```
                         PAGE
                  *
                  *      COMPENSATION
                  *
                  *      MYC = MYM + (KY14*MYOM) + (KY15* MYMDD)
                  *
0151 883F A              LDA      MYOM
0152 3839 A              MUL      KY14
0153 74B6 A              RCPY     E,T
0154 883F A              LDA      MYMDD
0155 383F A              MUL      KY15
0156 7C36 A              RADD     E,T
0157 883B A              LDA      MYM
0158 7C73 A              RADD     T,A
0159 E1C4 A              STA      MYC
```

```
                    PAGE
               *
               *    TRANSLATIONAL WASHOUT FOR :  Z
               *
               *    TAU      Z  TRANSLATIONAL  =  2 SEC
               *    ZETA     Z  TRANSLATIONAL  =  .7
               *
               *    MZMDD = MZSDD - (KZ8*MZDM) - (KZ9*MZM)
               *
015A 883E A         LDA      MZDM
015B 3843 A         MUL      KZ8
015C 74B6 A         RCPY     E,T                SAVE IT
015D 883D A         LDA      MZM
015E 3841 A         MUL      KZ9
015F 7C36 A         RADD     E,T                SUM IT IN  T  REG
0160 81CB A         LDA      MZSDD
0161 7D78 A         RADDI    *T,A               SUBTRACT  T  IN  A  REG
0162 E839 A         STA      MZMDD
               *
               *    INTEGRATION
               *
               *    MZDM = MZDM + (KZ3*MZMDD)
               *
0163 31D5 A         MUL      KZ3
0164 A833 A         ADD      MZDL               L/S PART
0165 E832 A         STA      MZDL               NEW L/S PART
0166 10C0 A         RD       X'C0'              RESET COF
0167 8831 A         LDA      MZDM               M/S PART
0168 7E76 A         RADDC    E,A
0169 E82F A         STA      MZDM               NEW M/S PART
               *
               *    MZM =MZM + (KZ4*MZDM)
               *
016A 31D6 A         MUL      KZ4
016B A82E A         ADD      MZL                L/S PART
016C E82D A         STA      MZL                NEW L/S PART
016D 10C0 A         RD       X'C0'              RESET
016E 882C A         LDA      MZM                M/S PART
016F 7E76 A         RADDC    E,A
0170 E82A A         STA      MZM                NEW M/S PART
```

```
                        PAGE
               *
               *        COMPENSATION
               *        MZC = (MZM + (KZ5*MZDM) + (KZ6*MZMOD))
               *
0171 8827 A             LDA      MZDM
0172 382A A             MUL      KZ5
0173 74B6 A             RCPY     E,T               SAVE IT
0174 8827 A             LDA      MZMOD
0175 3828 A             MUL      KZ6
0176 7C36 A             RADD     E,T               SUM IT IN  T  REG
0177 8823 A             LDA      MZM
0178 7C73 A             RADD     T,A
0179 E1C5 A             STA      MZC
```

```
                      PAGE
               *
               *      SUMMATION OF OUTPUTS TO MOTION OUTPUT PROGRAM.
               *
017A COEO A           LDX     M6
017B 83C9 A           LDA     MXC+6,1          COMPENSATED SIGNALS
017C EE08 A           STA     MOTION,1         INTO OUTPUT PROGRAM
017D 67FE A           BIX     $-2              LOOP
               *
               *      RESTORE BASE FOR OUTPUT PROGRAM
               *
017E 808E A           LDA     BASE8
017F 74D7 A           RCPY    A,B              RESTORE BASE REG.
               *
                      BASE    $BASE8
               *
               *      RUNWAY BUMPS
               *
0180 8C05 A           LDA     MZ
0181 A120 A           ADD     BUMPS            COMPUTED BUMPS FROM RNWYBMPS
0182 EC03 A           STA     MZ               HEAVE MOTION
               *
               *
               *
0183 44FD A           B       *PROGRETN        EXIT
```

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                         PAGE
               *    ALL CONSTANTS SCALED OTHER THAN  B0  THIS SCALING
               *    IS TO AVOID SHIFTING AFTER A MULTIPLY
               *
    0184 0000 E          ADRL     MOTION              FOR OUTPUT PROGRAM
    0185 0000 E          ADRL     MZ                  HEAVE MOTION
               *
    0186 0000 A MXDL     DATA     0
    0187 0000 A MXDM     DATA     0
    0188 0000 A MXL      DATA     0
    0189 0000 A MXM      DATA     0
    018A 0000 A MXMDD    DATA     0
    018B 3EE8 A KX14     DEC      24572E-5B1
    018C 09E3 A KX15     DEC      038613E-6B1
    018D 599A A KX18     DEC      7E-1
    018E 48EE A KX19     DEC      28488E-5B1
               *
    018F 0000 A MYDL     DATA     0
    0190 0000 A MYDM     DATA     0
    0191 0000 A MYL      DATA     0
    0192 0000 A MYM      DATA     0
    0193 0000 A MYMDD    DATA     0
         018B R KY14     EQU      KX14
    0194 07E8 A KY15     DEC      03089E-5B1
    0195 7000 A KY18     DEC      875E-3
    0196 5B29 A KY19     DEC      3561E-4B1
               *
    0197 0000 A MZDL     DATA     0
    0198 0000 A MZDM     DATA     0
    0199 0000 A MZL      DATA     0
    019A 0000 A MZM      DATA     0
    019B 0000 A MZMDD    DATA     0
    019C 0E61 A KZ5      DEC      056164E-6B1
    019D 090A A KZ6      DEC      035302E-6B1
    019E 2CCD A KZ8      DEC      175E-3B1
    019F 4FC4 A KZ9      DEC      311587E-6B1
```

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                        PAGE
                *
                *       EQUALS    TABLE AT END OF PROGRAM
                *
     10CE A KP3         EQU       KPRJ3
     10CE A KR3         EQU       KPRJ3
     10CE A KJ3         EQU       KPRJ3
                *
     10CE A KR17        EQU       KPRJ3
     10CE A KR13        EQU       KPRJ3
                *
     10CF A KP4         EQU       KPRJ4
     10CF A KR4         EQU       KPRJ4
     10CF A KJ4         EQU       KPRJ4
                *
     10CF A KJ11        EQU       KPRJ4
     10CF A KX12        EQU       KPRJ4
                *
     10CF A KR18        EQU       KPRJ4
     10CF A KP17        EQU       KPRJ4
     10CF A KP18        EQU       KPRJ4
                *
                *
     10D0 A KX13        EQU       KXY13
     10D0 A KY13        EQU       KXY13
                *
                *
     10D1 A KP19        EQU       KR19
     10D1 A KJ5         EQU       KR19
                *
                *
     10D3 A KP24        EQU       KPR2423
     10D3 A KR23        EQU       KPR2423
                *
                *
     10D2 A KR20        EQU       KPRJ206
     10D2 A KJ6         EQU       KPRJ206
                *
                *
                *
     0000 A             END

       0  ERRORS
EQUALS ERROR    MAINMN2
```

$BASE8	0800	X	A	0007	X	ACTFLGO4	0FE0	X	B	0005	X
BASE8	00BE	X	BIT12	00C6	X	BIT4&8	0062	R	BPITCHDD	10BD	X
BPITCHDM	10BF	X	BROLLDD	10BE	X	BROLLDM	10C0	X	BUMPS	0820	X
BXDD	10B1	X	BYDD	10B2	X	BZDD	10B3	X	CMROLLSM	0073	R
CMYAWSM	0074	R	CPITCHSM	0072	R	DISOPO75	01B9	X	E	0006	X
GO5	0079	R	KJ11	10CF	A	KJ3	10CE	A	KJ4	10CF	A
KJ5	10D1	A	KJ6	10D2	A	KJ9	005C	R	KPRJ206	10D2	X
KPRJ3	10CE	X	KPRJ4	10CF	X	KPR2423	10D3	X	KP17	10CF	A
KP18	10CF	A	KP19	10D1	A	KP20	005B	R	KP24	10D3	A
KP25	005C	R	KP3	10CE	A	KP4	10CF	A	KR13	10CE	A
KR17	10CE	A	KR18	10CF	A	KR19	10D1	X	KR20	10D2	A
KR23	10D3	A	KR24	005C	R	KR3	10CE	A	KR4	10CF	A
KXY13	10D0	X	KX12	10CF	A	KX13	10D0	A	KX14	018B	R
KX15	018C	R	KX16	0059	R	KX17	005A	R	KX18	018D	R
KX19	018E	R	KY12	10D4	X	KY13	10D0	A	KY14	018B	R
KY15	0194	R	KY16	005D	R	KY17	10D5	A	KY18	0195	R
KY19	0196	R	KZ3	10D5	X	KZ4	10D6	X	KZ5	019C	R
KZ6	019D	R	KZ8	019E	R	KZ9	019F	R	L	0002	X
LOOKYCOS	00E9	X	LOOKYSIN	00E8	X	MAINMN2	0000	R	MOTION	0184	E
MPITCHC	10C7	X	MPITCHDD	10B4	X	MPITCHDM	10B7	X	MPITCHMD	0063	R
MPITCHSD	0066	R	MPITCHSL	006C	R	MPITCHSM	0069	R	MROLLC	10C8	X
MROLLDD	10B5	X	MROLLDM	10B8	X	MROLLMD	0064	R	MROLLSD	0067	R
MROLLSL	006D	R	MROLLSM	006A	R	MXC	10C3	X	MXDD	10C1	X
MXDL	0186	R	MXDM	0187	R	MXL	0188	R	MXM	0189	R
MXMDD	018A	R	MXSDD	10C9	X	MYAWC	10C6	X	MYAWDD	10B6	X
MYAWDM	10B9	X	MYAWMD	0065	R	MYAWSD	0068	R	MYAWSL	006E	R
MYAWSM	006B	R	MYC	10C4	X	MYDD	10C2	X	MYDL	018F	R
MYDM	0190	R	MYL	0191	R	MYM	0192	R	MYMDD	0193	R
MYSDD	10CA	X	MZ	0185	E	MZC	10C5	X	MZDL	0197	R
MZDM	0198	R	MZL	0199	R	MZM	019A	R	MZMDD	019B	R
MZSDD	10CB	X	M3	00D8	X	M6	00E0	X	NOFREEZE	0006	R
P	0001	X	PROGRETN	00FD	X	RETNGRD	0050	R	SMROLLSM	0070	R
SMYAWSM	0071	R	SPITCHDD	0075	R	SPITCHDM	0077	R	SPITCHSM	006F	R
SROLLDD	0076	R	SROLLDM	0078	R	SXDD	10CC	X	SYDD	10CD	X
T	0003	X	VSNRB	0888	X	VVXBP	08E0	X	Z	0000	X

APPENDIX B, PART 3

```
                *       X-REF  PART FOR MOTION SYSTEM.
                *
                *       B-747     FILE NO: K 820
                *       JULY      1975
                *       B. BAARSCHERS.
                *       ISSUE     1
                *
                        ASECT
                        ORG       X'10A8'
                *
                *
10A8 0000 A MFXWB       DATA      0                 WIND/BODY AXIS LONG.FORCE/GW
10A9 0000 A MFYWB       DATA      0                 WIND/BODY-AXIS LAT. FORCE/GW
10AA 0000 A MFZWB       DATA      0                 WIND/BODY-AXIS VERT.FORCE/GW
                *
                *       ON/OFF GROUND FUNCTIONS AFTER RESCALING.
                *
10AB 0000 A UWD         DATA      0                 W/B-AXIS LONGITUDINAL ACCEL.
10AC 0000 A VWD         DATA      0                 W/B-AXIS LATERAL      ACCEL.
10AD 0000 A WWD         DATA      0                 W/B-AXIS VERTICAL     ACCEL
                *
                *       ON/OFF GROUND FUNCTIONS.
                *
10AE 0000 A UBD         DATA      0                 MOTION BODY-AXIS LONGITUD.ACCEL
10AF 0000 A VBDM        DATA      0                 MOTION BODY AXIS LATERAL ACCEL
10B0 0000 A WBD         DATA      0                 MOTION BODY-AXIS VERTICAL ACCEL
                *
                *       BODY - AXIS FUNCTIONS
                *
10B1 0000 A BXDD        DATA      0                 X  BODY DOUBLE DOT
10B2 0000 A BYDD        DATA      0                 Y  BODY DOUBLE DOT
10B3 0000 A BZDD        DATA      0                 Z  BODY DOUBLE DOT
                *
10B4 0000 A MPITCHDD    DATA      0                 PITCH ACCEL
10B5 0000 A MROLLDD     DATA      0                 ROLL
10B6 0000 A MYAWDD      DATA      0                 YAW
                *
10B7 0000 A MPITCHDM    DATA      0                 PITCH RATE
10B8 0000 A MROLLDM     DATA      0                 ROLL
10B9 0000 A MYAWDM      DATA      0                 YAW
                *
10BA 0000 A MPITCHM     DATA      0
10BB 0000 A MROLLM      DATA      0
10BC 0000 A MYAWM       DATA      0
                *
10BD 0000 A BPITCHDD    DATA      0                 PITCH ACCEL BODY
10BE 0000 A BROLLDD     DATA      0                 ROLL
```

```
                                PAGE
   10BF  0000 A BPITCHDM  DATA      0              PITCH RATE BODY
   10C0  0000 A BROLLDM   DATA      0              ROLL
                *
   10C1  0000 A MXDD      DATA      0              X SPEC. FORCE ERROR
   10C2  0000 A MYDD      DATA      0              Y
                *
                *         COMPENSATED SIGNALS TO MOTION OUTPUT
                *
                *
   10C3  0000 A MXC       DATA      0              X-AXIS
   10C4  0000 A MYC       DATA      0              Y-AXIS
   10C5  0000 A MZC       DATA      0              Z-AXIS
                *
   10C6  0000 A MYAWC     DATA      0              YAW
   10C7  0000 A MPITCHC   DATA      0              PITCH
   10C8  0000 A MROLLC    DATA      0              ROLL
                *
                *
                *
   10C9  0000 A MXSDD     DATA      0              X INERTIAL ACCEL
   10CA  0000 A MYSDD     DATA      0              Y
   10CB  0000 A MZSDD     DATA      0              Z
                *
                *         SUM OF TRANSLATIONAL ACCEL'S
                *
   10CC  0000 A SXDD      DATA      0
   10CD  0000 A SYDD      DATA      0
                *
                *         THIS DATA IS SCALED AT B1 TO AVOID ALL THE SALD 1 INSTR'
                *
   10CE  199A A KPRJ3     DEC       1E-1B1
   10CF  0CCD A KPRJ4     DEC       05E-2B1
   10D0  0B3C A KXY13     DEC       043878E-6B1
   10D1  47AE A KR19      DEC       28E-2B1
   10D2  1687 A KPRJ206   DEC       088E-3B1
   10D3  0148 A KPR2423   DEC       005E-3B1
   10D4  0A3D A KY12      DEC       04E-2B1
   10D5  3333 A KZ3       DEC       2E-1B1
   10D6  0291 A KZ4       DEC       010029E-6B1
                *
                          TAPE
TAPE

!KEY-IN
!GO
                *
         0000 A           END
```

771308