CR-151489

INSTANTANEOUS RELATIONSHIP BETWEEN SOLAR INERTIAL AND LOCAL VERTICAL LOCAL HORIZONTAL ATTITUDES

Job Order 81-397

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Lockheed Electronics Company, Inc.
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Houston, Texas

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For

MISSION PLANNING AND ANALYSIS DIVISION

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LYNDON B. JOHNSON SPACE CENTER

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TECHNICAL REPORT INDEX/ABSTRACT

(See instructions on reverse side.)

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13. ABSTRACT

The instantaneous relationship between the Solar Inertial (SI) and Local Vertical Local Horizontal (LVLH) coordinate systems is derived. A method is presented for computation of the LVLH-to-SI rotational transformation matrix as a function of an input LVLH attitude and the corresponding look angles to the sun. Logic is provided for conversion between LVLH and SI attitudes expressed in terms of a pitch, yaw, roll Euler sequence.

Documentation is included for a program which implements the logic on the Hewlett-Packard 97 programmable calculator.

14. SUBJECT TERMS

INSTANTANEOUS RELATIONSHIP BETWEEN SOLAR INERTIAL AND LOCAL VERTICAL LOCAL HORIZONTAL ATTITUDES

The Solar Inertial (SI) coordinate system is centered at the orbiter center of mass and is defined such that the negative z-axis is directed toward the sun, the x-axis is in the orbit plane and positive in the direction of motion at orbital noon, and the y-axis completes the orthogonal, right-handed coordinate system. Thus, the SI frame is related to an arbitrary reference frame (REF) through the rotational transformation matrix

$$[R]^{SI}_{REF} = \begin{bmatrix} \hat{u}_1^T \\ \hat{u}_2^T \\ \hat{u}_3^T \end{bmatrix} \qquad (1)$$

where

$$\hat{u}_3 = -\hat{S}_{REF} \qquad (2)$$

$$\hat{u}_1 = \text{unit}\left[\bar{h}_{REF} \times \hat{S}_{REF}\right] \qquad (3)$$

$$\hat{u}_2 = \hat{u}_3 \times \hat{u}_1 \qquad (4)$$

and

$\hat{S}_{REF}$ = unit vector in the reference frame from orbiter to sun

$\bar{h}_{REF}$ = orbital angular momentum vector in the reference frame ($= \bar{r}_{REF} \times \bar{v}_{REF}$)

$\bar{r}_{REF}$ = orbiter position vector in reference frame

$\bar{v}_{REF}$ = orbiter velocity vector in reference frame

The Local Vertical Local Horizontal (LVLH) frame is centered at the orbiter center of mass and is defined such that the y-axis is along the negative orbital angular momentum vector, the z-axis is along the negative position vector, and the x-axis completes the right-handed, orthogonal coordinate system.

Then the relationship between the SI frame and the LVLH frame is given as

$$[R]^{SI}_{LVLH} = \begin{bmatrix} \hat{u}_1^T \\ \hat{u}_2^T \\ \hat{u}_3^T \end{bmatrix} \qquad (5)$$

where

$$\hat{u}_3 = -\hat{S}_{LVLH} \qquad (6)$$

$$\hat{u}_1 = \text{unit}\left[\bar{h}_{LVLH} \times \hat{S}_{LVLH}\right] \qquad (7)$$

$$\hat{u}_2 = \hat{u}_3 \times \hat{u}_1 \qquad (8)$$

From the definition of the LVLH frame,

$$\hat{h}_{LVLH} = \begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix} \qquad (9)$$

Thus from eq. (7)

$$\hat{u}_1 = \begin{pmatrix} -S_3/D \\ 0 \\ S_1/D \end{pmatrix} \qquad (10)$$

where

$$S_i = \hat{S}_{LVLH}(i) , \qquad i=1,2,3$$
$$D = \sqrt{S_1^2 + S_3^2} \qquad (11)$$

Carrying out the cross product indicated by eq. (8) gives

$$\hat{u}_2 = \begin{pmatrix} -S_1 S_2/D \\ D \\ -S_2 S_3/D \end{pmatrix} \qquad (12)$$

The relationship between the SI system and the LVLH system is given by the matrix

$$[R]^{SI}_{LVLH} = \begin{bmatrix} -S_3/D & 0 & S_1/D \\ -S_1 S_2/D & D & -S_2 S_3/D \\ -S_1 & -S_2 & -S_3 \end{bmatrix} \qquad (13)$$

where S_i and D are defined in eq. (11). All that remains is to define the orbiter-to-sun line-of-sight vector in the LVLH system, $\hat{S}_{LVLH}$.

Suppose that the orbiter attitude is given in terms of pitch, yaw, roll Euler angles with respect to LVLH and the pitch, yaw look angles to the sun are given. Both types of data are given by the Shuttle Attitude and Pointing Timeline (SAPT) Program and by the HP9825A Super Sighter (SS) Program and are usually published in Reference Flight Profile documentation.

From the pitch, yaw look angles to the sun $\left(P_{sun}, Y_{sun}\right)$ the orbiter-to-sun line-of-sight unit vector is computed in the orbiter body (BY) system as

$$\hat{S}_{BY} = \begin{bmatrix} \cos\left(P_{sun}\right)\cos\left(Y_{sun}\right) \\ \sin\left(Y_{sun}\right) \\ -\sin\left(P_{sun}\right)\cos\left(Y_{sun}\right) \end{bmatrix} \tag{14}$$

The pitch, yaw, roll Euler angles which define the orbiter attitude with respect to LVLH are used to construct the LVLH-to-BY matrix

$$[A]_{LVLH}^{BY} = \left[R_X(\text{roll})\right]\left[R_Z(\text{yaw})\right]\left[R_Y(\text{pitch})\right] \tag{15}$$

where

$$R_X(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix} \tag{16}$$

$$R_Y(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix} \tag{17}$$

$$R_Z(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{18}$$

The unit vector in the LVLH frame along the orbiter-to-sun line of sight is given by

$$\hat{S}_{LVLH} = \left[A^T\right]_{BY}^{LVLH} \hat{S}_{BY} \tag{19}$$

Given the LVLH attitude and the look angles to the sun, the equivalent SI attitude is computed by extracting the pitch, yaw, roll Euler angles from

$$[M]_{SI}^{BY} = [A]_{LVLH}^{BY} \left[R^T\right]_{SI}^{LVLH} \tag{20}$$

Once the SI-LVLH relationship has been established, an equivalent LVLH attitude may be computed for any given SI attitude by constructing the SI-to-BY matrix $[M]_{SI}^{BY}$ from the pitch, yaw, roll Euler angles with respect to SI as

$$[M]_{SI}^{BY} = \left[R_X(\text{roll})\right]\left[R_Z(\text{yaw})\right]\left[R_Y(\text{pitch})\right] \tag{21}$$

and extracting the pitch, yaw, roll Euler angles with respect to LVLH from the matrix

$$[A]_{LVLH}^{BY} = [M]_{SI}^{BY} \left[R^T\right]_{LVLH}^{SI} \tag{22}$$

A summary of the SI $\leftrightarrow$ LVLH attitude computations is given in the flow diagrams.

A program was written for the Hewlett-Packard 97 programmable calculator to perform the SI $\leftrightarrow$ LVLH computations. Documentation and sample output of the HP-97 program are included.

LVLH TO SI ATTITUDE CONVERSION

ENTER

$$\hat{S}_{BY} = \begin{pmatrix} \cos(P_{sun}) \cos(Y_{sun}) \\ \sin(Y_{sun}) \\ -\sin(P_{sun}) \cos(Y_{sun}) \end{pmatrix}$$

$$[A]^{BY}_{LVLH} = [R_X(\text{roll})]\,[R_Z(\text{yaw})]\,[R_Y(\text{pitch})]$$

$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix} = \hat{S}_{LVLH} = [A^T]^{LVLH}_{BY}\ \hat{S}_{BY}$$

$$D = \sqrt{S_1^2 + S_3^2}$$

$$[R]^{SI}_{LVLH} = \begin{bmatrix} -S_3/D & 0 & S_1/D \\ -S_1S_2/D & D & -S_2S_3/D \\ -S_1 & -S_2 & -S_3 \end{bmatrix}$$

$$[M]^{BY}_{SI} = [A]^{BY}_{LVLH}[R^T]^{LVLH}_{SI}$$

EXTRACT PYR WRT LVLH FROM $[M]^{BY}_{SI}$

EXIT

INPUT

PITCH, YAW LOOK ANGLES TO SUN
PITCH, YAW, ROLL ATTITUDE
WITH RESPECT TO LVLH

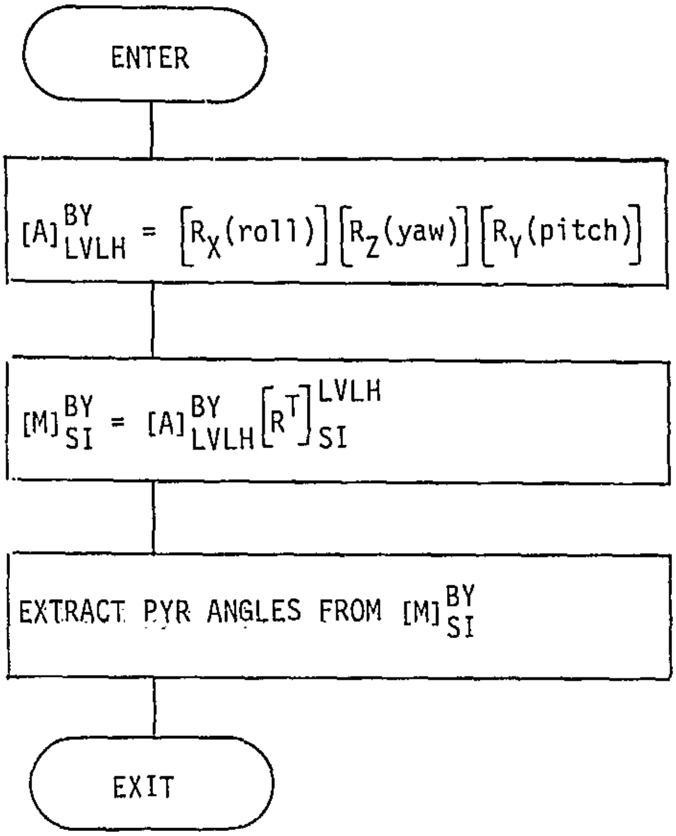
OUTPUT

LVLH-TO-SI MATRIX

SI-TO-BY MATRIX

PITCH, YAW, ROLL ATTITUDE
WITH RESPECT TO SI

EQUIVALENT SI, LVLH ATTITUDES



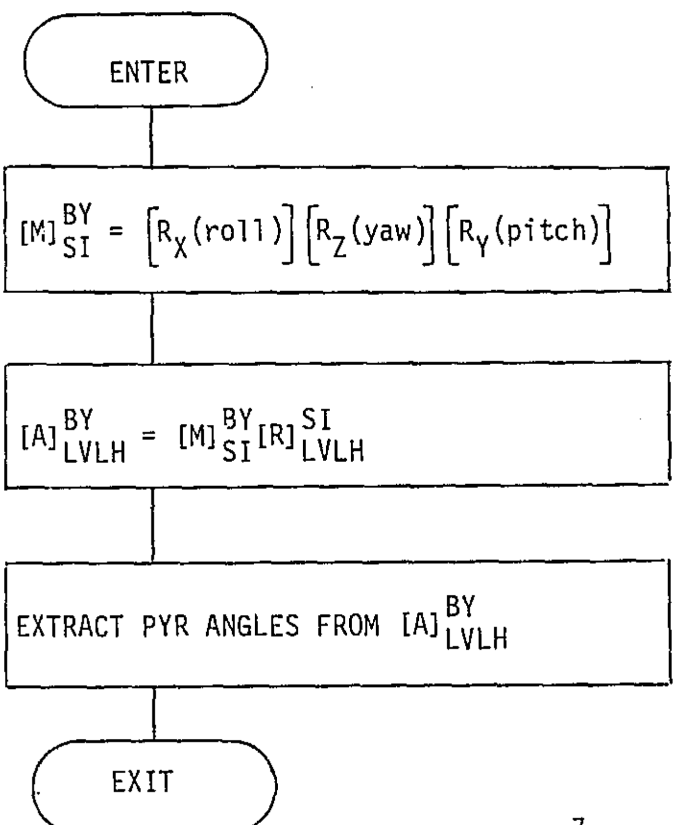
INPUT

PITCH, YAW, ROLL ATTITUDE WITH RESPECT TO LVLH

LVLH-to-SI MATRIX $[R]^{SI}_{LVLH}$

OUTPUT

PITCH, YAW, ROLL ATTITUDE WITH RESPECT TO SI



INPUT

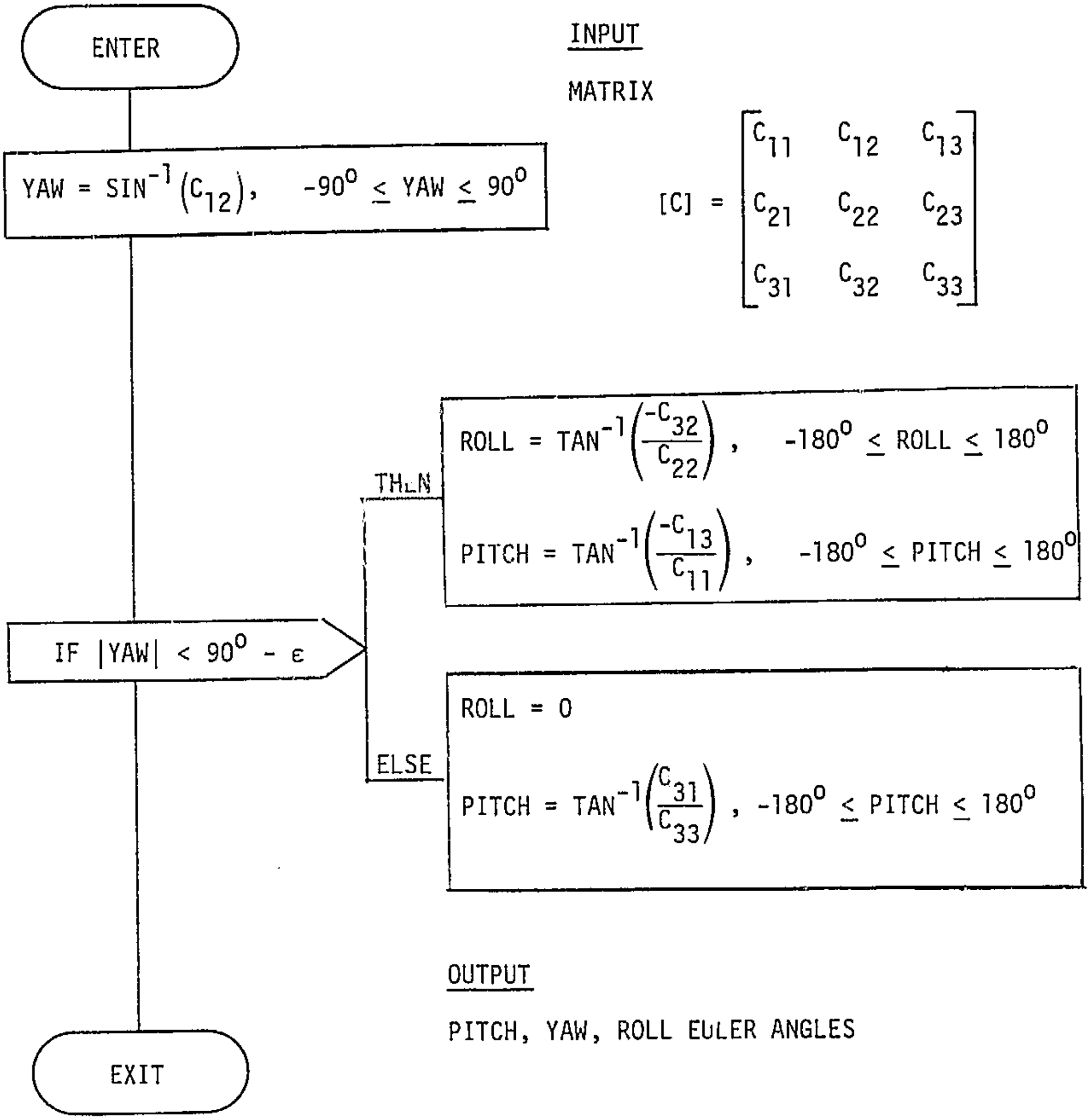
PITCH, YAW, ROLL ATTITUDE WITH RESPECT TO SI

LVLH-to-SI MATRIX $[R]^{SI}_{LVLH}$

OUTPUT

PITCH, YAW, ROLL ATTITUDE WITH RESPECT TO LVLH

PITCH, YAW, ROLL EULER ANGLE EXTRACTION



INPUT

MATRIX

$$[C] = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$

OUTPUT

PITCH, YAW, ROLL EULER ANGLES

Program Description

Program Title LVLH ←→ SI ATTITUDE CONVERSION

Name STEPHANIE A. VICKERY Date 4/18/1977

Address

City State Zip Code

Program Description, Equations, Variables, etc. This program converts from LVLH (Local Vertical Local Horizontal) to SI (Solar Inertial) attitudes given look angles to the sun (pitch, yaw sequence). Once the LVLH-to-SI relationship has been established, conversion may be made from SI to LVLH. A pitch, yaw, roll Euler sequence is used for the input and output attitudes

- take p,y look angles to sun and construct unit line-of-sight vector to sun in body coordinates $\hat{S}_{BY} = \begin{pmatrix} \cos(p)\cos(y) \\ \sin(p) \\ -\sin(p)\cos(y) \end{pmatrix}$
- take p,y,r Euler angles of the body attitude with respect to LVLH and construct

$$[A]^{BY}_{LVLH} = \text{product of } [R_x(\text{roll})][R_z(\text{yaw})][R_y(\text{pitch})]$$

- Compute line-of-sight to sun in LVLH

$$\begin{pmatrix} s_1 \\ s_2 \\ s_3 \end{pmatrix} = \hat{S}_{LVLH} = [A^T]^{LVLH}_{BY} \hat{S}_{BY}$$

- Construct the SI-to-LVLH matrix

$$D = \sqrt{s_1^2 + s_3^2} \qquad [R^T]^{LVLH}_{SI} = \begin{bmatrix} -s_3/D & -s_1 s_2/D & -s_1 \\ 0 & D & -s_2 \\ s_1/D & -s_2 s_3/D & -s_3 \end{bmatrix}$$

- Then extract pitch, yaw, roll sequence Euler angles of BY wrt SI from the matrix

$$[M]^{BY}_{SI} = [A]^{BY}_{LVLH} [R^T]^{LVLH}_{SI}$$

p,y,r Euler angles will be printed. The matrix $[R]^{SI}_{LVLH}$ will be in secondary S_1-S_9. Matrix $[M]^{BY}_{SI}$ will be in primary R_1-R_9.

- Given any p,y,r wrt SI, then the p,y,r attitude wrt LVLH is computed as

$$[M]^{BY}_{LVLH} = [A]^{BY}_{SI} [R]^{SI}_{LVLH}$$

Operating Limits and Warnings

Euler extraction logic fails at yaw = ±90°

$$\text{pitch} = \tan^{-1}\left(\frac{-m_{13}}{m_{11}}\right), \quad -180° \le \text{pitch} \le 180°$$

$$\text{yaw} = \sin^{-1}(m_{12}), \quad -90° < \text{yaw} < 90°$$

$$\text{roll} = \tan^{-1}\left(\frac{-m_{32}}{m_{22}}\right), \quad -180° < \text{roll} < 180°$$

User Instructions

LVLH ⟷ SI

pty → $\hat{S}_{BY}$		Extract pyr		Transpose M_P
ptyr → $[A]^{BY}_{ref}$	ptyr wrt LVLH → pyr wrt SI	ptyr wrt SI → pyr wrt LVLH	$M_S = M_P M_S$	

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STEP	INSTRUCTIONS	INPUT DATA/UNITS*	KEYS		OUTPUT DATA/UNITS*
1	Load Side 1 and Side 2				
2	Input pitch, yaw look angles to sun	pitch	ENT↑		
		yaw	f	A	
3	Input pitch, yaw, roll attitude with respect to	pitch	ENT↑		
	LVLH. Output angles are pitch, yaw,	yaw	ENT↑		
	roll with respect to SI	roll	B		pitch
	A^{BY}_{SI} will be in primary registers $R_1 - R_9$	wrt LVLH			yaw
	R^{SI}_{LVLH} will be in secondary registers $S_1 - S_9$				roll
					wrt SI
4	Input another pitch, yaw, roll with respect to	pitch	ENT↑		
	SI. Output angles are pitch, yaw, roll	yaw	ENT↑		
	with respect to LVLH.	roll	C		pitch
	A^{BY}_{LVLH} will be in primary registers $R_1 - R_9$	wrt SI			yaw
	R^{SI}_{LVLH} will be in primary registers $S_1 - S_9$				roll
					wrt LVLH
*	Angles are in degrees				
	Matrices are stored by columns				
	OTHER USEFUL SUBROUTINES				
•	Input pitch, yaw, roll sequence Euler angles.	pitch	ENT↑		
	The pyr matrix will be constructed and	yaw	ENT↑		
	stored by columns in $R_1 - R_9$.	roll	A		pyr Matrix
	The angles will be stored into B, C, A registers.				in $R_1 - R_9$
•	If a rotational transformation matrix is in		f	C	
	primary registers $R_1 - R_9$, Extract pitch, yaw, roll				pitch
	Euler angles				yaw
					roll
•	Transpose the matrix stored in primary $R_1 - R_9$		f	E	
	M_P				M_P^T in $R_1 - R_9$
•	Matrix Product: Multiply matrix in primary				
	storage times matrix in secondary storage.				
	Put product in secondary storage. $M_S = M_P M_S$		D		$M_P M_S \rightarrow M_S$
•	After step 3 or 4, to convert an arbitrary LVLH attitude				
	to SI, input p, y, r wrt LVLH as below				
	ptyr A f E R↔S D R↔S f E f C	pyr wrt LVLH	(SEE	LEFT)	pyr wrt SI

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
001		*LBLA	Construct pitch,
002	$p \uparrow y \uparrow r$	STOA	yaw, roll rotational
003		R↓	transformation matrix
004	$\rightarrow [A]^{BY}_{ref}$	STOC	and store by
005		R↓	columns in
006		STOB	Primary registers
007		COS	$R_1 - R_9$
008		STO1	Store pitch(y),
009		STO2	yaw(z), roll(x)
010		STO3	angles into B, C, A
011		STO8	
012		STO9	
013		RCLC	
014		COS	
015		ST×1	
016		STO5	
017		STO6	
018		STO7	$R_1 = a_{11} = \cos(y)\cos(z)$
019		RCLC	
020		SIN	$R_2 = a_{21} = \sin(y)\sin(x) - \cos(y)\sin(z)\cos(x)$
021		STO4	
022		ST×2	
023		ST×3	$R_3 = a_{31} = \sin(y)\cos(x) + \cos(y)\sin(z)\sin(x)$
024		RCLA	
025		COS	
026		ST×9	$R_4 = a_{12} = \sin(z)$
027		ST×5	
028		CHS	$R_5 = a_{22} = \cos(z)\cos(x)$
029		ST×2	
030		RCLA	$R_6 = a_{32} = -\cos(z)\sin(x)$
031		SIN	
032		ST×3	$R_7 = a_{13} = -\sin(y)\cos(z)$
033		ST×8	
034		CHS	$R_8 = a_{23} = \cos(y)\sin(x) + \sin(y)\sin(z)\cos(x)$
035		ST×6	
036		RCL4	
037		×	$R_9 = a_{33} = \cos(y)\cos(x) - \sin(y)\sin(z)\sin(x)$
038		RCLB	
039		SIN	
040		STO0	
041		×	
042		ST+9	
043		RCL0	
044		CHS	
045		ST×7	
046		RCL0	
047		RCLA	
048		COS	
049		×	
050		ST+3	
051		RCL0	
052		RCLA	
053		SIN	
054		×	
055		ST+2	
056		RCL0	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057		RCLC	
058		SIN	
059		×	
060		RCLA	
061		COS	
062		×	
063		ST+6	
064		RTN	
065		*LBLa	Given pitch, yaw
066	$p \uparrow y \rightarrow \hat{s}$	P⇄S	look angles
067		1	referenced to the
068		→R	BY +x axis, compute
069		STO1	unit line-of-sight
070		STO3	
071		R↓	$\hat{s}_{BY} = \begin{pmatrix} \cos(p)\cos(y) \\ \sin(y) \\ -\sin(p)\cos(y) \end{pmatrix}$
072		STO2	
073		R↓	
074		1	
075		→R	
076		ST×1	
077		R↓	
078		CHS	and store into
079		ST×3	secondary registers
080		P⇄S	$S_1 - S_3$
081		RTN	
082		*LBLD	Matrix Multiplication
083		GSB5	
084		GSB0	$M_S = M_P M_S$
085		GSB0	
086		*LBL0	
087		ISZI	
088		ISZI	Replace matrix
089		ISZI	in secondary
090		RCLi	storage (M_S)
091		STOC	with the product
092		DSZI	of the primary
093		RCLi	matrix (M_P) and
094		STOB	the secondary
095		DSZI	matrix (M_S)
096		RCLi	
097		STOA	
098		RCL1	
099		ST×i	
100		RCL4	
101		RCLB	
102		×	Matrices are
103		ST+i	stored by columns
104		RCL7	in the primary
105		RCLC	and secondary
106		×	registers 1-9
107		ST+i	
108		ISZI	
109		RCL5	
110		ST×i	
111		RCL2	
112		RCLA	

LABELS

A $pyr \rightarrow A^{BY}_{ref}$	B $pyr_{LVLH} \rightarrow pyr_{SI}$	C $pyr_{SI} \rightarrow pyr_{LVLH}$	D Matrix Multiply	E
a $py \rightarrow \hat{s}$	b	c Extract pyr	d	e Matrix Transpose
0 Matrix x vector	1	2	3	4
5 store 10 into I	6	7	8	9

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☒	FIX	☒
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n	6

STEP	KEY ENTRY	KEY CODE	COMMENTS
113		x	
114		ST+i	
115		RCL5	
116		RCLC	
117		x	
118		ST+i	
119		ISZI	
120		RCL9	
121		STxi	
122		RCL6	
123		RCL8	
124		x	
125		ST+i	
126		RCL3	
127		RCLA	
128		x	
129		ST+i	
130		RTN	
131		*LBLe	Transpose the matrix in primary registers $R_1 - R_9$
132		RCL2	
133		RCL4	
134		STO2	
135		R↓	
136		STO4	
137		RCL3	$M_p^T \rightarrow M_p$
138		RCL7	
139		STO3	
140		R↓	
141		STO7	
142		RCL6	
143		RCL8	
144		STO6	
145		R↓	
146		STO8	
147		RTN	
148		*LBLc	Extract pitch, yaw, roll Euler angles from the matrix in primary storage
149		RCL7	
150		CHS	
151		RCL1	
152		→P	
153		X⇄Y	
154		PRTX	pitch = $\tan^{-1}\left(\frac{-m_{13}}{m_{11}}\right)$
155		RCL4	
156		SIN⁻¹	
157		PRTX	yaw = $\sin^{-1}(m_{12})$
158		RCL6	
159		CHS	
160		RCL5	roll = $\tan^{-1}\left(\frac{-m_{32}}{m_{22}}\right)$
161		→P	
162		X⇄Y	
163		PRTX	fails for yaw = ±90°
164		RTN	
165		*LBL5	Store 10 into register I
166		1	
167		0	
168		STOI	

STEP	KEY ENTRY	KEY CODE	COMMENTS
169		RTN	
170		*LBLB	Given pitch, yaw, roll attitude with respect to LVLH and pitch, yaw look angles to sun
171	p↑y↑r LVLH	GSBA	
172		GSBe	
173		GSB5	
174	→ pyr SI	GSB0	
175		P⇄S	
176		RCL1	
177		X²	
178		RCL3	
179		X²	
180		+	
181		√X	compute pitch, yaw, roll attitude with respect to SI
182		STO5	
183		RCL1	
184		CHS	
185		STO7	
186		RCL2	
187		CHS	
188		STO8	
189		RCL3	
190		CHS	
191		STO9	Store input p, y, r wrt LVLH into B, C, A
192		STO1	
193		STO6	
194		RCL7	
195		STO3	
196		STO4	Store output $[A]_{SI}^{BY}$ into $R_1 - R_9$
197		RCL8	
198		STx4	
199		STx6	
200		RCL5	
201		ST÷1	Store output $[R]_{LVLH}^{SI}$ into $S_1 - S_9$
202		CHS	
203		ST÷3	
204		ST÷4	
205		ST÷6	
206		0	
207		STO2	
208		GSBe	
209		GSBD	
210		P⇄S	
211		GSBe	
212		GSBc	
213		RTN	
214		*LBLC	Given p, y, r attitude wrt SI and $[R]_{LVLH}^{SI}$ in $S_1 - S_9$,
215		GSBA	
216	p↑y↑r SI	GSBe	
217		P⇄S	
218	→ pyr LVLH	GSBe	Compute p, y, r attitude wrt LVLH
219		GSBD	
220		GSBe	
221		P⇄S	
222		GSBe	
223		GSBc	
224		RTN	

REGISTERS

0	1	2	3	4	5	6	7	8	9
Scratch	A_{11}	A_{21}	A_{31}	A_{12}	A_{22}	A_{32}	A_{13}	A_{23}	A_{33}
S0	S1 R_{11}, $\hat{S}_1$	S2 R_{21}, $\hat{S}_2$	S3 R_{31}, $\hat{S}_3$	S4 R_{12}	S5 R_{22}	S6 R_{32}	S7 R_{13}	S8 R_{23}	S9 R_{33}

A	B	C	D	E	I
roll, scratch	pitch, scratch	yaw, scratch			Indexing

TYPICAL USAGE OF THE SI ↔ LVLH CONVERSION PROGRAM

Given LVLH attitude { 356.8 pitch, 12.2 yaw, 201.8 roll }
Look angles to sun { 346.5 pitch, 319.2 yaw }

from Reference Flight Profile for OFT-1, JSC Internal Note 77-FM-15 at MECO

Input pitch, yaw look angles to sun	346.500000 ENT↑ 348.200000 GSBa
Input LVLH pitch, yaw, roll attitude	{ 356.800000 ENT↑ 12.200000 ENT↑ 201.800000 GSBB
Compute equivalent SI attitude and construct $[R]^{SI}_{LVLH}$	{ 80.996082 *** -15.485894 *** -162.512851 ***
Input computed SI attitude	{ 80.996082 ENT↑ -15.485894 ENT↑ -162.512891 GSBC
and compare output LVLH attitude with the original input LVLH attitude	{ -3.200000 *** 12.200000 *** -158.200000 ***
Input 0,0,0 Solar Inertial Attitude	{ 0.000000 ENT↑ 0.000000 ENT↑ 0.000000 GSBC
and compute Equivalent LVLH Attitude	{ -84.323495 *** 0.000000 *** 26.013041 ***
Input 0,0,0 LVLH Attitude	{ 0.000000 ENT↑ 0.000000 ENT↑ 0.000000 GSBA GSBe P⇄S GSBD P⇄S GSBe GSBc
and compute equivalent SI Attitude	{ 83.576115 *** -27.863670 *** -3.012192 ***
Input the computed SI Attitude	{ 83.576115 ENT↑ -27.863670 ENT↑ -3.012192 GSBC
and compare the output LVLH Attitude to the 0.0.0 LVLH Attitude (Note computational error of 10^{-6} deg.)	{ -1.485690267-07 *** 1.661577606-07 *** 0.000001 ***

Angles are input and output in pitch, yaw, roll order in degrees.

For in input pitch, yaw look angles to the sun	346.500000 ENT↑
	348.200000 GSBa
	P⇄S
	RCL1
Display the computed unit line-of-sight vector $\hat{S}_{BY}$	0.951821 ***
	RCL2
	-0.204496 ***
	RCL3
	0.228512 ***
	P⇄S
For input LVLH attitude	356.800000 ENT↑
	12.200000 ENT↑
	201.800000 GSBE
Compute the SI attitude and display the stored matrices*	88.996082 ***
	-15.485894 ***
	-162.512891 ***
	GSBE
Columns of the SI-to-BY matrix $[M]^{BY}_{SI}$	0.150328 ***
	-0.336643 ***
	-0.929475 ***
	-0.267001 ***
	-0.919159 ***
	0.289582 ***
	-0.951821 ***
	0.204496 ***
	-0.228512 ***
	P⇄S

*Matrices are printed from primary storage registers 1-9 by columns

	GSBE
Columns of the LVLH-to-SI matrix $[R]^{SI}_{LVLH}$	0.098912 ***
	-0.467369 ***
	-0.878511 ***
	0.000000 ***
	0.882841 ***
	-0.469673 ***
	0.995096 ***
	0.046456 ***
	0.087323 ***
	GSBa
	GSBE
Columns of the SI-to-LVLH matrix $\left[R^T\right]^{LVLH}_{SI}$	0.098912 ***
	0.000000 ***
	0.995096 ***
	-0.467369 ***
	0.882841 ***
	0.046456 ***
	-0.878511 ***
	-0.469673 ***
	0.087323 ***
For the input LVLH attitude	356.800000 ENT↑
	12.200000 ENT↑
	201.800000 GSBA
	DSP6
	GSBE
Display the columns of the LVLH-to-BY matrix $[A]^{BY}_{LVLH}$	0.975892 ***
	0.216636 ***
	-0.026527 ***
	0.211325 ***
	-0.907517 ***
	0.362961 ***
	0.054561 ***
	-0.359836 ***
	-0.931419 ***
	GSBc
Extract the pitch, yaw, roll angles back out	-3.800000 ***
	12.200000 ***
	-158.200000 ***