

AN ISOMETRIC BIOMECHANICAL MODEL OF WORKER STRENGTH-KINETIC DATA FOR HUMAN MOTION

— 作業者 體力の ISOMETRIC 모델 분석을 위한 BASIC 언어 프로그램 —

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요 약

人體의 運動은 많은 수의 自由度를 지닌 조인트(JOINT)와 링크(LINK)의 복잡한 運動으로 표현될 수 있다. 이들 링크(LINK)의 回轉 運動은 SINE, COSINE 自乘 形態의 비선형 運動으로 이루어져있으나, 最近 PERSONAL COMPUTER의 發達로 복잡한 人體 運動의 數學的 모델에 대한 人體 運動의 動力學的 DATA 計算이 可能해졌다.

본 研究에서는 5개의 링크(LINK)로 連結된 人體 움직임에 있어 링크(LINK)의 絕對 運動(ABSOLUTE MOTION) 및 相對運動(RELATIVE MOTION)을 고려한 PLAGENHOEF의 運動 모델을 PERSONAL COMPUTER를 利用하여 人體 움직임의 動力學的 DATA를 얻을 수 있도록 BASIC 언어로 프로그램을 제기 하였다.

NOMENCLATURE

- θ : Segment angle counterclockwise from the right horizontal
- ω : Angular velocity
- α : Angular acceleration
- V : Linear velocity
- a : Linear acceleration
- y : Vertical component
- x : Horizontal component
- W : Segment weight
- F : Force
- M : Moment of force
- r : Distance from appropriate joint to the segment center of gravity
- l : Segment length
- k : Radius of gyration
- $m_r \alpha$: Tangential force of the relative motion of the segment
- $m_r \omega^2$: Normal force of the relative motion of the segment
- $m_R \alpha$: Tangential force due to the movement of all other segments
- $m_R \omega^2$: Normal force due to the movement of all other segments
- $m_2 \omega_1 V_2$: Coriolis force
- F_m : The resultant of all muscle forces at unknown, resultant point of application
- F_u : Force of the upper arm on segment 4

1. Introduction

The analytical technique of biomechanical strength began at the time when scientist noticed that people

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had strengths and that various method of moving objects resulted in different levels of effort. It was natural development of biomechanical model to analyze and predict the volitional force capability(strength) of given strata of the workers when performing a designated manual task requiring a specific posture.

The concept of a biomechanical model is not new. Many scholars and researchers have contributed to such a concept. Computerized biomechanical models had been developed in 1960s to provide the ability to predict gross resultant moments and forces at major joint of the body while either moving or exerting static forces with hands on an object.

Pearson, McGinley, Butzel[1], developed a two-link model of the arm for planar motions. The model computed joint forces and torque due to inertial forces. Slote and Store[2] studied discrete unloaded voluntary forearm flexion in the sagittal plane. From curves of angular displacement, velocity and acceleration over time, elbow torque was computed and the analysis extended into zero-gravity environment. Plagenhoef [3] extended the Pearson's model which performed a kinetic two-dimensional analysis of the human body.

Dempster[4] began to apply the theory of free body diagrams and vector analysis to muscular exertions. William and Lissner[5] attempted to take the classical theories of two dimensional statics and directly apply to the human body. Chaffin[6] with Fisher[7] and Baker[8] extended the Plagenhoef's arm model of sagittal plane of a human arm to an entire sagittal plane model.

Havanan[9] developed a mathematical model for predicting the inertial properties of human body in various static positions. He approximated the center of gravity the body segments by a series of solid geometric object and was able to find the whole body center of gravity.

Recent computer technology enables researchers to model man's body position during doing tasks. Healy and Katz[10] developed a mathematical model-a non-linear optimization technique-applied to position and orient the joints.

Dempster[11], Slote and Stone[12], Ramsey[13], and Nandler[14] presented dynamic path of motion models. In this research, motion path were defined and complete displacement, velocity, and acceleration profiles were obtained.

In this study, basic language program using personal computer to obtain kinetic data(force and moment data) for motion based upon Plagenhoef's model is presented.

2. Plagenhoef model for obtaining kinetic data on human movement

The force and moment data on human movement were determined for various motions. Certain principles of motion were common to all the movements and should be understood to interpret and define body motion properly.

- ① Every motion is rotational or a result of a combination of rotating segments.
- ② The velocity of a given segment can be increased by decelerating the adjoining segment.
- ③ Each body segment has a normal and tangential acceleration that produce unpredictable force directions.
- ④ Muscle action at one joint can produce muscle action at one adjoining joint opposite to what the movement indicates.
- ⑤ The muscles that start a segment in motion and the muscles that produce the stopping action are equally important and are about the same magnitude.

(1) Plagenhoef's formulae[3]

The skeletal system is treated as a link system and the force and moments formulae are determined using both the absolute and relative motion method.

- ① The formulae for a five segment moment using absolute method(fig 1)

$$\vec{H} = \vec{l}_1 + \vec{l}_2 + \vec{l}_3 + \vec{l}_4$$

$$R_y = l_1 \sin \theta_1 + l_2 \sin \theta_2 + l_3 \sin \theta_3 + l_4 \sin \theta_4$$

$$R_x = l_1 \cos \theta_1 + l_2 \cos \theta_2 + l_3 \cos \theta_3 + l_4 \cos \theta_4$$

$$V_y = \frac{dy}{dt} = l_1 \cos \theta_1 \omega_1 + l_2 \cos \theta_2 \omega_2 + l_3 \cos \theta_3 \omega_3 + l_4 \cos \theta_4 \omega_4$$

$$V_x = \frac{dx}{dt} = -(l_1 \sin \theta_1 \omega_1) - (l_2 \sin \theta_2 \omega_2) - (l_3 \sin \theta_3 \omega_3) - (l_4 \sin \theta_4 \omega_4)$$

$$A_y = \frac{d^2y}{dt^2} = l_1 (\cos \theta_1 \alpha_1 - \sin \theta_1 \omega_1^2) + l_2 (\cos \theta_2 \alpha_2 - \sin \theta_2 \omega_2^2) + l_3 (\cos \theta_3 \alpha_3 - \sin \theta_3 \omega_3^2) + l_4 (\cos \theta_4 \alpha_4 - \sin \theta_4 \omega_4^2)$$

$$A_x = \frac{d^2x}{dt^2} = -l_1 (\sin \theta_1 \alpha_1 + \cos \theta_1 \omega_1^2) - l_2 (\sin \theta_2 \alpha_2 + \cos \theta_2 \omega_2^2) - l_3 (\sin \theta_3 \alpha_3 + \cos \theta_3 \omega_3^2) - l_4 (\sin \theta_4 \alpha_4 + \cos \theta_4 \omega_4^2)$$

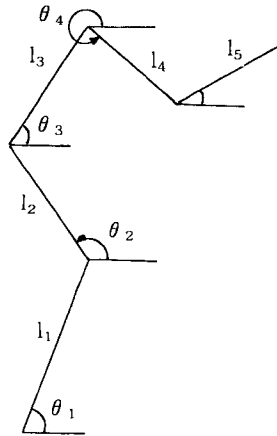


Fig 1 Absolute motion

Therefore, force formulae and moment formulae for segments are as follows.

For segment 5,

$$F_y + (-W_5) - ma_y - mr \alpha_5 \cos \theta_5 + mr \omega_5^2 \sin \theta_5 = 0$$

$$F_x - ma_x + mr \alpha_5 \sin \theta_5 + mr \omega_5^2 \cos \theta_5 = 0$$

$$M_5 + W_5 \cos \theta_5 - mk^2 \alpha_5 - mr (a_y \cos \theta_5 - a_x \sin \theta_5) = 0$$

where, $a_y \cos \theta_5 - a_x \sin \theta_5$

$$= l_4 \alpha_4 \cos(\theta_5 - \theta_4) + \omega_4^2 l_4 \sin(\theta_5 - \theta_4)$$

$$+ l_3 \alpha_3 \cos(\theta_5 - \theta_3) + \omega_3^2 l_3 \sin(\theta_5 - \theta_3)$$

$$+ l_2 \alpha_2 \cos(\theta_5 - \theta_2) + \omega_2^2 l_2 \sin(\theta_5 - \theta_2)$$

$$+ l_1 \alpha_1 \cos(\theta_5 - \theta_1) + \omega_1^2 l_1 \sin(\theta_5 - \theta_1)$$

For segment 4,

$$F_y + (-W_4) - ma_y - mr \alpha_4 \cos \theta_4 + mr \omega_4^2 \sin \theta_4 - F_{y5} = 0$$

$$F_x - ma_x + mr \alpha_4 \sin \theta_4 + mr \omega_4^2 \cos \theta_4 - F_{x5} = 0$$

$$M_4 + W_4 \cos \theta_4 - mk^2 \alpha_4 - mr (a_y \cos \theta_4 - a_x \sin \theta_4) - M_5 - F_{y5} l_4 \cos \theta_4 + F_{x5} l_4 \sin \theta_4 = 0$$

where, $a_y \cos \theta_4 - a_x \sin \theta_4$

$$= l_3 \alpha_3 \cos(\theta_4 - \theta_3) + \omega_3^2 l_3 \sin(\theta_4 - \theta_3)$$

$$+ l_2 \alpha_2 \cos(\theta_4 - \theta_2) + \omega_2^2 l_2 \sin(\theta_4 - \theta_2)$$

$$+ l_1 \alpha_1 \cos(\theta_4 - \theta_1) + \omega_1^2 l_1 \sin(\theta_4 - \theta_1)$$

② The formulae for a five segment movement using the relative motion method(fig 2)

The resultant inertial acceleration due to the movement of all segments other than the segment 5 are as follows(fig 2)

$$R_a = R_4 \alpha_4 + R_3 \alpha_3 + R_2 \alpha_2 + R_1 \alpha_1$$

$$R \omega^2 = R_4 \omega_4^2 + R_3 \omega_3^2 + R_2 \omega_2^2 + R_1 \omega_1^2$$

The inertial accelerations due to the movement of the segment 5 are,

$$r_5 \alpha_5 \text{ and } r_5 \omega_5^2$$

Coriolis acceleration for two segments in motion can be obtained by equating the relative and absolute accelerations.

$$F = \omega_2^2 r^2 + \omega_1^2 (l_1 + r_2) \text{ for relative motion.}$$

$$F = \omega_1^2 l_1 + (\omega_1 + \omega_2)^2 r_2 \text{ for absolute motion.}$$

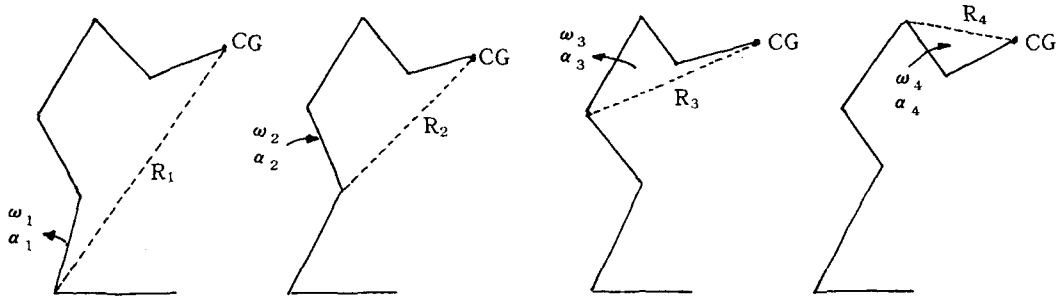


fig 2 relative motion

The force formulae for the relative motion method,

$$F_y = -\omega - mr \alpha \cos \theta + mr \omega \sin \theta - mr \alpha \sin \phi + mr \omega^2 \cos \phi + m2v \omega \sin \theta$$

$$F_x = mr \alpha \sin \theta + mr \omega^2 \cos \theta + mr \alpha \cos \phi + mr \omega^2 \sin \phi + m2v \omega \cos \theta$$

Therefore, the moment of force for the segment 5 in a five segment movement is,

$$M_5 + W_r \cos \theta_5 - mk^2 \alpha_5 - mR \alpha \sin \phi + mr \omega^2 r \cos \phi = 0$$

And the moment of force for the segment 4, is,

$$M_4 - W_L \cos \theta_4 - mk^2 \alpha_4 - mR \alpha \sin \phi + mr \omega^2 r \cos \phi - F_y s l_4 \cos \theta_4 + F_5 \alpha l_4 \sin \theta_4 - M_5 = 0$$

It is necessary to use the relative motion method in order to obtain the contribution of each segment to the whole motion.

3. Result of PC run

(1) Data used for the PC run.

	SEG # 1	SEG # 2
W _t	2800	2276
f	28.6	27.5
r	12.5	22.4
k	15.5	26.6

	SEG # 1			SEG # 2		
	θ	ω	α	θ	ω	α
1	288	323.7	4305.2	316	-39.1	42525.0
2	295	399.8	3288.9	323	637.1	25611.3
3	303	454.8	2191.2	340	1006.3	11832.4
4	313	486.9	1012.0	361	1131.3	1188.4
5	323	494.7	-248.7	384	1074.7	-6320.8
6	333	476.4	-1590.7	404	899.3	-10695.3
7	342	430.5	-3014.2	419	667.8	-11934.9
8	350	355.3	-4519.2	430	442.8	-10039.6
9	356	249.2	-6105.6	437	287.1	-5009.1
10	359	110.6	-7773.4	443	263.4	3155.3
11	360	-62.3	-9522.7	449	234.2	14445.5

(2) RESULTS

1 CGX= 13.318420000 CGY= -25.73090000

			FX	FY	F	PHI	MOMENT
1	1	1	-33095.8300	21952.9900	39714.8300	135.23	1369426.0000
1	2	1	-30895.8600	25007.8700	39748.5600	119.88	423383.2000
1	1	1	0.00	0.00	0.00		
1	1	2	-26.83	-214.72	173.89		
1	2	1	0.00	0.00	0.00		
1	2	2	-106.00	-109.10	-9.71		

2 CGX= 16.357580000 CGY= -23.91600000

			FX	FY	F	PHI	MOMENT
1	1	2	-12069.6000	7595.3250	14260.5800	138.29	422454.9000
1	2	2	-10946.5000	11104.9300	15593.1200	87.86	162554.0000
2	1	1	-63.53	-65.40	-69.15		
2	1	2	-64.57	-55.59	-61.61		
2	2	1	-63.53	-65.40	-69.15		
2	2	2	88.53	-309.47	357.27		

3 CGX= 20.181060000 CGY= -19.97293000

			FX	FY	F	PHI	MOMENT
1	1	3	11634.1800	-3738.7580	12220.1600	-19.07	-361776.2000
1	2	3	11554.9800	204.5974	11555.8900	1.01	5880.2580
3	1	1	-135.15	-117.03	-126.42		
3	1	2	-137.10	-99.18	-98.61		
3	2	1	-135.15	-117.03	-126.42		
3	2	2	-12.04	-246.66	154.83		

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4 CGX= 20.677210000 CGY= -21.39858000

			FX	FY	F	PHI	MOMENT
1	1	4	17550.8600	-22552.7300	28577.2300	-194.98	104793.0000
1	2	4	16253.2300	-18296.6700	24473.1600	-120.12	51825.6900
4	1	1	-153.03	-202.73	-92.35		
4	1	2	-152.61	-173.16	-87.76		
4	2	1	-153.03	-202.73	-92.35		
4	2	2	-78.67	-196.15	18.07		

5 CGX= 24.927840000 CGY= -7.78199600

			FX	FY	F	PHI	MOMENT
1	1	5	20734.0600	-7810.7480	22156.4700	-22.67	-139517.5000
1	2	5	18514.4500	-3284.6430	18803.5500	-10.27	183170.4000
5	1	1	-162.65	-135.58	-110.19		
5	1	2	-159.93	-113.13	-56.74		
5	2	1	-162.65	-135.58	-110.19		
5	2	2	-140.99	-119.86	-61.20		

6 CGX= 22.923110000 CGY= -3.08541900

			FX	FY	F	PHI	MOMENT
1	1	6	8835.9150	-8590.6410	12323.6600	-84.01	133868.3000
1	2	6	6185.7760	-3786.2250	7252.5390	-40.22	78828.5900
6	1	1	-126.70	-139.13	-90.22		
6	1	2	-120.02	-115.14	-81.38		
6	2	1	-126.70	-139.13	-90.22		
6	2	2	-126.19	-73.52	-109.77		

7 CGX= 22.420620000 CGY= 1.01162000

			FX	FY	F	PHI	MOMENT
1	1	7	2261.2380	-10750.4500	10985.6900	1368.54	246122.6000
1	2	7	-236.9197	-5540.5020	5545.5650	501.47	-13117.3300
7	1	1	-106.83	-148.97	-82.03		
7	1	2	-99.23	-122.16	-103.10		
7	2	1	-106.83	-148.97	-82.03		
7	2	2	-105.10	-56.46	-134.91		

8 CGX= 21.667180000 CGY= 4.27680400

			FX	FY	F	PHI	MOMENT
1	1	8	-871.8726	-12845.1600	12874.7200	95.47	295305.5000
1	2	8	-2713.5380	-7032.5120	7537.8720	144.88	-57332.7900
8	1	1	-97.37	-158.51	-78.44		
8	1	2	-91.22	-128.12	-113.54		
8	2	1	-97.37	-158.51	-78.44		
8	2	2	-90.27	-62.10	-140.82		

9 CGX= 20.963910000 CGY= 6.55071600

			FX	FY	F	PHI	MOMENT
1	1	9	-680.8272	-14685.8600	14701.6300	154.38	368116.0000
1	2	9	-1620.2660	-8042.1830	8203.7780	-43.36	-22707.2000
9	1	1	-97.94	-166.90	-73.12		
9	1	2	-94.76	-132.16	-105.36		
9	2	1	-97.94	-166.90	-73.12		
9	2	2	-89.75	-81.90	-125.33		

10 CGX= 18.927540000 CGY= 7.72305600

			FX	FY	F	PHI	MOMENT
1	1	10	2798.1370	-15587.6500	15836.8000	49.49	449689.2000
1	2	10	2580.5140	-7940.6540	8349.4340	3.70	85948.0100
10	1	1	-108.45	-171.00	-67.16		
10	1	2	-108.35	-131.75	-79.70		
10	2	1	-108.45	-171.00	-67.16		
10	2	2	-102.46	-112.22	-90.77		

11 CGX= 19.330050000 CGY= 8.09525300

			FX	FY	F	PHI	MOMENT
1	1	11	10128.7200	-17920.8300	20585.1200	284.83	725082.8000
1	2	11	10086.4900	-9185.0240	13641.9200	-73.80	278269.5000
11	1	1	-130.60	-181.63	-47.05		
11	1	2	-132.65	-136.73	-34.27		
11	2	1	-130.60	-181.63	-47.05		
11	2	2	-125.77	-151.60	-43.76		

CGX : CENTER OF GRAVITY IN HORIZONTAL PLANE

CGY : CENTER OF GRAVITY IN VERTICAL PLANE

Fx : HORIZONTAL FORCE IN GRAMS

Fy : VERTICAL FORCE IN GRAMS

F : RESULTANT FORCE IN GRAMS

PHI : DIRECTION OF RESULTANT FORCE

MOMENT : JOINT MOMENT IN G-CM

4. Summary

Body movement may be more fully interpreted by obtaining joint moments of force of whole body action. The information obtained can be used to predict the volitional force capability(strength), to assist the development of job design to improve the work environment, and to analyze individual performance. It also can be used in sports, rehabilitation, and other fields where body motion analysis is required.

(PROGRAM LIST)

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10 DIM W(30),XL(30),R(30),S(30),C(30),XMASS(30),CG(30,2),Z(30,2),FXA(30),
    FYA(30),AMOUNT(30)
20 DIM XK(30),OMEGA(30),ALPHA(30),OMEG(30),ALPH(30),FX(60),FY(60),XMOMT(30),
    F(60),OM(30),ALP(30),THETA(30)
30 INPUT "NSEG=":NSEG
40 Q=0
50 Z(1,1)=0
60 Z(1,2)=0
70 PI=3.1415927#
80 CONST=.017453293#
90 N1=NSEG-1
100 IT=1
110 INPUT "NPOINT=":NPOINT
120 SAMSON=SAMSON+1
130 IF SAMSON=12 THEN GOTO 780
140 CGY=0
150 SW=0
170 FOR I=1 TO NSEG
220 READ W(I)
230 READ THETA(I)
240 READ XL(I)
250 READ R(I)
260 READ XK(I)
270 READ OM(I)
280 READ ALP(I)
290 XMASS(I)=W(I)/980
300 THETA(I)=THETA(I)*CONST
310 OMEGA(I)=OM(I)*CONST
320 ALPHA(I)=ALP(I)*CONST
330 S(I)=SIN(THETA(I))
340 C(I)=COS(THETA(I))
350 Z(I+1,1)=Z(I,1)+XL(I)*C(I)
360 Z(I+1,2)=Z(I,2)+XL(I)*S(I)
370 CG(I,1)=Z(I,1)+R(I)*C(I)
380 CG(I,2)=Z(I,2)+R(I)*S(I)
390 CGX=CGX+W(I)*CG(I,1)
400 CGY=CGY+W(I)*CG(I,2)
410 SW=SW+W(I)
420 NEXT I
430 CGX=CGX/SW
440 CGY=CGY/SW
445 LPRINT:LPRINT:LPRINT
446 LPRINT "*****"
447 LPRINT
450 LPRINT USING "### CGX=###.##### CGY=###.#####":IT,CGX,CGY
455 LPRINT
460 OMEG(I)=OMEGA(I)
470 ALPH(I)=ALPHA(I)
480 FOR I=2 TO NSEG
490 OMEG(I)=OMEGA(I)-OMEGA(I-1)
500 ALPH(I)=ALPHA(I)-ALPHA(I-1)
510 NEXT I
520 L=1
530 FOR I=1 TO 8
540 FX(I)=FXA(I)
550 FY(I)=FYA(I)
560 XMOMT(I)=AMOMT(I)
570 NEXT I
580 GOTO 790
590 IJ=IJ+1
600 SAVEO=OMEG(IJ)
610 SAVEA=ALPH(IJ)
620 OMEG(IJ)=0
630 ALPH(IJ)=0
640 L=0

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650 GOTO 1720
660 OMEG(IJ)=SAVEO
670 ALPH(IJ)=SAVEA
680 PRINT
690 FOR IJI=1 TO NSEG
700 PCTX=(FX(IJI)/FXA(IJI)-1)*100
710 PCTY=(FY(IJI)/FYA(IJI)-1)*100
720 PCTM=(XMONT(IJI)/AMONT(IJI)-1)*100
730 LPRINT USING"## ## ## #####.## #####.## #####.##":IT,IJ,IJI,PCTX,
    PCT,PCTM
740 NEXT IJI
745 IF IJ=2 THEN IJ=1 ELSE GOTO 590
747 LPRINT "*****"
750 IT=IT+1
760 GOTO 120
780 END
790 FX(NSEG+1)=0
800 FY(NSEG+1)=0
810 XMONT(NSEG+1)=0
820 I=NSEG
830 FOR SUN=1 TO NSEG
840 J=1:K=0:L=L
850 J1=J-1
860 KSGN=(-1)^K
870 CGK1=CG(J,K+1)
880 K2=2-K
890 CGK2=CG(J,K2)
900 IF L < > 0 GOTO 920
910 IF L = 0 GOTO 990
920 FORCE=OMEGA(J)^2*(CGK1-Z(J,K+1))+KSGN*ALPHA(J)*(CGK2-Z(J,K2))
930 IF J1 = 0 GOTO 1110
940 IF J1 < > 0 GOTO 950
950 FOR I=1 TO J1
960 FORCE=FORCE+OMEGA(I)^2*(Z(I+1,K+1)-Z(I,K+1))+KSGN*ALPHA(I)*(Z(I+1,K2)
    -Z(I,K2))
970 NEXT I
980 GOTO 1110
990 FORCE=0
1000 FOR I=1 TO J
1010 FORCE=FORCE+OMEG(I)^2*(CGK1-Z(I,K+1))+SGN*ALPH(I)*(CGK2-Z(I,K2))
1020 NEXT I
1030 IF J1 < > 0 GOTO 1050
1040 IF J1=0 GOTO 1110
1050 FOR I=1 TO J1
1060 SUM1=0
1070 FOR K1=I TO J1
1080 SUM1=SUM1+OMEG(K1+1)*(CGK1-Z(K1+1,K+1))
1090 NEXT K1
1100 FORCE = FORCE+2*OMEG(I)*SUM1
1105 NEXT I
1110 FORCE=FORCE*XMASS(J)
1120 IF K <> 0 GOTO 1140
1130 IF K = 0 GOTO 1150
1140 FORCE=FORCE-W(J)
1150 FX(I)=FORCE+FX(I+1)
1160 J=1
1170 K=1
1180 L=L
1190 J1=J-1
1200 KSEN=(-1)^K
1210 CGK1=CG(J,K+1)
1220 K2=2-K
1230 CGK2=CG(J,K2)
1240 IF L < > 0 GOTO 1260
1250 IF L = 0 GOTO 1280
1260 FORCE=OMEGA(J)^2*(CGK1-Z(J,K+1))+KSGN*ALPHA(J)*(CGK2-Z(J,K2))
1261 IF J1 < > 0 GOTO 1263

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1262 IF J1 = 0 GOTO 1400
1263 FOR I=1 TO J1
1264 FORCE=FORCE+OMEGA(I)^2*(Z(I+1,K+1)-Z(I,K+1))+KSGN*ALPHA(I)*(Z(I+1,K2)
-Z(I,K2))
1265 NEXT I
1266 GOTO 1400
1280 FORCE=0
1290 FOR I=1 TO J
1300 FORCE=FORCE+OMEG(I)^2*(CGK1-Z(I,K+1))+SGN*ALPH(I)*(CGK2-Z(I,K2))
1305 NEXT I
1310 IF J1 <> 0 GOTO 1330
1320 IF J1 = 0 GOTO 1400
1330 FOR I=1 TO J1
1340 SUM1=0
1350 FOR K1=I TO J1
1360 SUM1=SUM1+OMEG(K1+1)*(CGK1-Z(K1+1,K+1))
1370 NEXT K1
1380 FORCE=FORCE+2*OMEG(I)*SUM1
1390 NEXT I
1400 FORCE=FORCE*XMASS(J)
1410 IF K <> 0 GOTO 1430
1420 IF K = 0 GOTO 1440
1430 FORCE=FORCE-W(J)
1440 FY(I)=FORCE+FY(I+1)
1450 XMOMT(I)=R(I)*(FX(I)*S(I)-FY(I)*C(I))+XMASS(I)*ALPHA(I)*(XK(1)^2-R(I)^2)
+XL(I)*(FX(I+1)*S(I)-FY(I+1)*C(I))+XMOMT(I+1)
1460 I=I-1
1470 NEXT SUN
1480 IF L <> 0 GOTO 1500
1490 IF L = 0 GOTO 1650
1500 LPRINT SPC(16);"FX";SPC(12);"FY";SPC(13);"F";SPC(11);"PHI";SPC(7);"MOMENT
1510 FOR I=1 TO NSEG
1520 IF FX(I) <> 0 GOTO 1540
1530 IF FX(I) = 0 GOTO 1570
1540 PHI=TAN(FY(I)/FX(I))
1550 IF FX(I) < 0 GOTO 1590
1560 IF FX(I) => 0 GOTO 1600
1570 PHI=90
1580 GOTO 1610
1590 PHI=PHI+PI
1600 PHI=PHI/CONST
1610 F=SQR(FX(I)^2+FY(I)^2)
1620 LPRINT USING"### ## ## #####.#####.#### #####.### ## ## ##.##
#####.####";L,I,IT,FX(I),FY(I),F,PHI, XMOMT(I)
1625 NEXT I
1630 Q=Q+1
1640 IF Q=1 THEN GOTO 1650 ELSE 660
1650 FOR I=1 TO 8
1660 FXA(I)=FX(I)
1670 FYA(I)=FY(I)
1680 AMOMT(I)=XMOMT(I)
1690 NEXT I
1700 GOTO 590
1720 FX(NSEG+1)=0
1721 FY(NSEG+1)=0
1722 XMOMT(NSEG+1)=0
1723 I=NSEG
1724 FOR KSK=1 TO NSEG
1725 L=0:J=I:K=0
1740 J1=J-1
1750 KSGN=(-1)^K
1760 CGK1=CG(J,K+1)
1770 K2=2-K
1780 CGK2=CG(J,K2)
1790 IF L <> 0 GOTO 1810
1800 IF L = 0 GOTO 1880

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1810 FORCE=OMEGA(J)^2*(CGK1-Z(J,K=1))+KSGN*ALPHA(J)(CGK2-Z(J,K2))
1820 IF J1 < > 0 GOTO 1840
1830 IF J1 = 0 GOTO 2010
1840 FOR I=1 TO J1
1850 FORCE=FORCE+OMEGA(I)^2*(Z(I+1,K+1)-Z(I,K+1))+KSGN*ALPHA(I)*(Z(I+1,K2)
-Z(I,K2))
1860 NEXT I
1870 GOTO 2010
1880 FORCE=0
1890 FOR I=1 TO J
1900 FORCE=FORCE+OMEGA(I)^2*(CGK1-Z(I,K+1))+KSGN*ALPHA(I)*(CGK2-Z(I,K2))
1910 NEXT I
1920 IF J1 < > 0 GOTO 1940
1930 IF J1 = 0 GOTO 2010
1940 FOR I=1 TO J1
1950 SUM=0
1960 FOR K1=I TO J1
1970 SUM1=SUM1+OMEGA(K1+1)*(CGK1-Z(K1+1,K+1))
1980 NEXT K1
1990 FORCE=FORCE+2*OMEGA(I)*SUM1
2000 NEXT I
2010 FORCE=FORCE*XMASS(J)
2020 IF K < > 0 GOTO 2040
2030 IF K=0 GOTO 2050
2040 FORCE=FORCE-W(J)
2050 FX(I)=FORCE+FX(I+1)
2060 K=1
2070 J1=J-1
2080 KSGN=(-1)^K
2090 CGK1=CG(J,K+1)
2100 K2=2-K
2110 CGK2=CG(J,K2)
2120 IF L < > 0 GOTO 2140
2130 IF L = 0 GOTO 2190
2140 FORCE=OMEGA(J)^2*(CGK1-Z(J,K+1))+KSGN*ALPHA(J)*(CGK2-Z(J,K2))
2150 IF J1 < > 0 GOTO 2165
2160 IF J1 = 0 GOTO 2290
2165 FOR I=1 TO J1
2170 FORCE=FORCE+OMEGA(I)^2*(Z(I+1,K+1)-Z(I,K+1))+KSGN*ALPHA(I)*(Z(I+1,K2)
-Z(I,K2))
2175 NEXT I
2180 GOTO 2290
2190 FORCE=0
2200 FOR I=1 TO J
2210 FORCE=FORCE+OMEGA(I)^2*(CGK1-Z(I,K+1))+KSGN*ALPHA(I)*(CGK2-Z(I,K2))
2215 NEXT I
2220 IF J1 < > 0 GOTO 2235
2230 IF J1 = 0 GOTO 2290
2235 FOR I=1 TO J1
2236 SUM1=0
2240 FOR K1=I TO J1
2250 SUM1=SUM1+OMEGA(K1+1)*(CGK1-Z(K1+1,K+1))
2260 NEXT K1
2270 FORCE=FORCE+2*OMEGA(I)*SUM1
2280 NEXT I
2290 FORCE=FORCE*XMASS(J)
2300 IF K < > 0 GOTO 2320
2310 IF K = 0 GOTO 2330
2320 FORCE=FORCE-W(J)
2330 FY(I)=FORCE+FY(I+1)
2340 XMOMT(I)=R(I)*(FX(I)*S(I)-FY(I)*C(I))+XMASS(I)*ALPHA(I)*(XK(I)^2-R(I)^2
+XL(I)*(FX(I+1)*S(I)-FY(I+1)*C(I))+XMOMT(I+1))
2350 I=I+1
2360 NEXT KSK
2370 IF L < > 0 GOTO 2390
2380 IF L = 0 GOTO 2530

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2390 LPRINT "  FX          FY          F          PHI          MOMEN
2400 FOR I=1 TO NSEG
2410 IF FX(I) < > 0 GOTO 2430
2420 IF FX(I) = 0 GOTO 2460
2430 PHI=ATAN(FY(I)/FX(I))
2440 IF FX(I) < 0 GOTO 2480
2450 IF FX(I) > = 0 GOTO 2490
2460 PHI = 90
2470 GOTO 2500
2480 PHI=PHI+PI
2490 PHI=PHI/CONST
2500 F=SQR(FX(I)^2+FY(I)^2)
2510 LPRINT USING"# # ## #####.### #####.### #####.### #####.#
#####.###" :L, I, IT, FX(I), FY(I), F, PHI, XMOMT(I)
2520 NEXT I
2530 GOTO 660

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