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INSTRUCTIONS FOR THE USE OF THE MARQUARDT IBM 7040 COMPUTER PROGRAM

CONTROLLED TETHERING IN SPACE

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INSTRUCTIONS FOR THE USE OF THE MARQUARDT IBM 7040 COMPUTER PROGRAM

CONTROLLED TETHERING IN SPACE

Project 349

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FOREWORD

This instruction document, has as its genesis, the analytical expressions derived by R. W. Adlhoch and reported in The Marquardt Corporation Report No. 6092, "An Investigation of Controlled Tethering in Space," dated 26 February 1965. The referenced report is a result of NASA Contract NAS1-3912.

CONTENTS

I. IDENTIFICATION

1. Job 3127 - Astronaut Retrieval

2. Fortran

3. D. P, Muhonen - January 1965

II. SUMMARY

The Astronaut Retrieval Program is designed to simulate the motion of an orbiting system of three bodies joined by two elastic tether lines. One body, the space vehicle, is assumed to have a distributed mass and therefore has non-zero dimensions and moments of inertia. The other two bodies, the astronaut and the anchor, are simulated as point masses. The system therefore contains twelve degrees of freedom consistent with the constraints imposed by the connecting tethers. Provision is made for the reel-in and reel-out of the tether lines, so the program is particularly applicable to astronaut retrieval problems where more than two bodies are used. In the present version of the program, variations in tether lengths are handled by describing the second order time derivatives of the unstressed cable lengths as functions of time, tension, unstressed cable length, and its first derivative. Constants in these functions are input, allowing flexibility in the description of these functions. Provision is also made for maintaining a constant tension on the astronaut tether line. If the desired reel-in and reel-out philosophy cannot be described by these functions, another philosophy can be easily inserted with minor reprogramming.

The computer deck is written in FORTRAN IV and MAP, and it is set up for use with IBSYS on the IBM 7040 Computer after the leading and trailing control cards are added. Subroutine MCKLØK examines the computer interval timer for the printout of computer execution time. If the computer is not provided with an interval timer similar to that in the 7040, MCKLØK is replaced with a dummy subroutine having the same name. If IBSYS is not used, the SIBFTC cards are removed from the beginning of each subroutine deck; and MCKLØK, the only MAP subroutine, is replaced with a FORTRAN dummy.

The input and output for this program are in polar coordinates, but because the analytical description is simpler, the computations are handled in Cartesian coordinates. The logic of the program largely consists of the solution of a set of simultaneous differential equations. The set includes eleven second-order and twelve first-order differential equations, which are converted into a system of 34 first-order equations. The Adams-Moulton four-point method is used in the numerical integration procedure. This method provides for an estimation of local truncation error and allows the user to vary the integration step size as needed. A maximum local error is input in the program, and the step size is

changed by a doubling-halving procedure to maximize computer efficiency. In regions of high frequency oscillations, very small step sizes are required to retain sufficient accuracy. Since the Adams-Moulton method requires past information at constant integration step size, the Runge-Kutta fourth-order formula is used to "restart" whenever the step size is changed.

III. PROGRAM RESTRICTIONS AND LIMITATIONS

A. Error Codes

No error returns are provided in the program. Care should be taken in setting up the input deck so that all input parameters are read into the correct core locations.

B. Estimate of Running Time

Each integration step requires about 0.33 second if it is printed out. Since each printout requires the solution of a set of coordinate transformations, time can be significantly reduced by not printing each point. The time interval is allowed to vary to keep the local integration error within input bounds, so it is difficult to give a total time estimate for a typical run.

C. Miscellaneous Limitations and Restrictions

1. It is nearly impossible to estimate the accumulated integration truncation error when solving a set of differential equations by numerical techniques. Only upper bounds for local errors can be estimated. These estimates are used in adjusting the integration step size.

2. The following items are programmed into the present program, but the logic is set up so that they can be changed into other functional forms with minor reprogramming:

   a. Astronaut reel-in is described by specifying either a constant line tension or the second order time derivative of unstressed cable length as a function of time, tension, unstressed cable length, and its first derivative.

   b. Anchor mass reel-out is described in a manner similar to the astronaut reel-in, except constant line tension is not provided for.

   c. Zero thrust is applied to the vehicle.

   d. Zero thrust is applied to the astronaut.

3. The following decks must all be included in the working deck:

   a. Job 3127 - Main Program

      This deck contains the basic program logic. All subroutines are called by the main program.

   b. Subroutine INPUT

      This deck handles all input logic and the conversion of polar coordinate input parameters into the Cartesian variables used in computation.

   c. Subroutine DIFEQ

      This deck contains the evaluation of all derivatives and related functions. Any reprogramming of control philosophies will be done in this subroutine.

   d. Subroutine AMRK

      This deck contains the numerical integration logic.

   e. Subroutine ØUTPUT

      This deck handles the conversion of the Cartesian coordinate parameters to the output polar form. All output logic is also included.

   f. Subroutine MCKLØK

      This deck examines the computer interval timer for printout of computer execution time.

IV. INPUT-OUTPUT FORM

A. Definition of Input Parameters: (See Appendices of the applicable basic report for further details.)

1. HEAD(I): 72 characters of alphanumeric data printed at the top of each page

2. TIN: Initial time (sec)

3. DTIN: Minimum allowable integration step size (sec). This should be smaller than the minimum interval required to keep local truncation error within the desired bounds. All intervals will be some 2^n multiple of DTIN.

4. DTPRIN: Time print interval (sec). Printout will occur only at approximate increments of DTPRIN.

5. TMAX: Maximum time (sec). Computation ceases when time, the independent variable, exceeds this value.

6. RMIN: Minimum distance between astronaut and space vehicle (ft). Computation ceases when this distance becomes less than RMIN.

7. H: Orbital radius (miles)

8. XI: Tracking system constant ξ, control system deadband

9. AK1: Tracking system constant K_1, first order gain constant

10. AK2: Tracking system constant K_2, second order gain constant

11. THEA: θ_A for vehicle attitude (deg)

12. PHIA: ϕ_A for vehicle attitude (deg)

13. PSIA: Ψ_A for vehicle attitude (deg)

14. THEO: θ_o for vehicle position (deg)

15. PHIO: ϕ_o for vehicle position (deg)

16. RO: R_o for vehicle position (ft)

17. THE1: θ_1 for astronaut position (deg)

18. PHI1: ϕ_1 for astronaut position (deg)

19. R: R_1 for astronaut position (ft)

20. THE2: θ_2 for anchor mass position (deg)

21. PHI2: ϕ_2 for anchor mass position (deg)

22. RR: R_2 for anchor mass position (ft)

23. THEVO: θ_{VO} for vehicle velocity (deg/sec)

24. PHIVO: ϕ_{VO} for vehicle velocity (deg/sec)

25. RVO: R_{VO} for vehicle velocity (ft/sec)

26. THEV1: θ_{V1} for astronaut velocity (deg/sec)

27. PHIV1: ϕ_{V1} for astronaut velocity (deg/sec)

28. RV1: R_{V1} for astronaut velocity (ft/sec)

29. THEV2: θ_{V2} for anchor velocity (deg/sec)

30. PHIV2: ϕ_{V2} for anchor velocity (deg/sec)

31. RV2: R_{V2} for anchor velocity (deg/sec)

32. ØM1: ω_1, vehicle rotation rate component (rad/sec)

33. ØM2: ω_2, vehicle rotation rate component (rad/sec)

34. ØM3: ω_3, vehicle rotation rate component (rad/sec)

35. S1: S_1, tether attach point coordinate (ft)

36. S2: S_2, tether attach point coordinate (ft)

37. S3: S_3, tether attach point coordinate (ft)

38. AI1: I_1 vehicle moment of inertia component (slug ft^2)

39. AI2: I_2 vehicle moment of inertia component (slug ft^2)

40. AI3: I_3 vehicle moment of inertia component (slug ft^2)

41. AN1: N_1 component of unit normal vector to vehicle at attach point (ft)

42. AN2: N_2 component of unit normal vector to vehicle at attach point (ft)

43. AN3: N_3 component of unit normal vector to vehicle at attach point (ft)

44. WO: Vehicle weight (lb)

45. W1: Astronaut weight (lb)

46. W2: Anchor weight (lb)

47. AMU1: Elastic factor, astronaut tether line

48. AMU2: Elastic factor, anchor tether line

49. CNUMBER: Number of C(I) constants to be input. Provision is made to vary the number of input constants because it is anticipated that control functions will be reprogrammed to require a different number of constants. CNUMBER should be set to 26, with the program version in effect at the time of this writeup.

50. C(1): Upper bound for $|\dot{\eta}|$, where η is the angular deviation of astronaut tether from normal to vehicle at point of attachment.

51. C(2): τ_1 = min (time, C(2)). (See equation under parameter 53 for usage of τ_1.)

52. C(3): ρ_1 = max $(R_1'$, C(3)). (See equation under parameter 53 for usage of ρ_1; R_1' is astronaut unstressed cable length.)

53. C(4),----,C(10): Coefficients in equation for second derivative of astronaut unstressed cable length.

$$\ddot{R}_1' = C(4) + C(5)\tau_1 + C(6)\tau_1^2 + \frac{C(7)}{T_1 + C(10)} + C(8)\rho_1 + C(9)\dot{R}_1'$$

T_1 is astronaut cable tension; other variables are described under parameters 51 and 52.

54. C(11): Upper bound for $|\ddot{R}_1'|$ (See parameter 53.)

55. C(12): τ_2 = min (time, C(12)). (See equation under parameter 57 for usage of τ_2.)

56. C(13): ρ_2 = min $(R_2'$, C(13)). (See equation under parameter 57 for usage of ρ_2; R_2' is anchor unstressed cable length.)

57. C(14),----,C(20): Coefficients in equation for second derivative of anchor unstressed cable length

$$\ddot{R}_2' = C(14)+C(15)\tau_2+C(16)\tau_2^2 + \frac{C(17)}{T_2 + C(20)} +C(18)\rho_2 +C(19)\dot{R}_2'$$

T_2 is the anchor cable tension; other variables described under parameters 55 and 56.

58. C(21): Upper bound for $|\ddot{R}_2'|$ (See parameter 57.)

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59. C(22): Line damping rate

60 C(23): Maximum line hysteresis

61. C(24): Maximum allowable local integration error. On the basis of a numerical estimate for local truncation error the integration time interval will be adjusted by doubling and halving to keep the absolute error within the bounds $\left[0.01\ C(24),\ C(24)\right]$.

62. C(25): Line slack command

$$C(25) \left\{ \begin{array}{l} = 0. \text{ if line compression allowed} \\ \neq 0. \text{ if line required to slack} \end{array} \right.$$

63. C(26): Constant astronaut line tension command

$$C(26) \left\{ \begin{array}{l} = 0. \text{ if reel-in governed by equation of parameter 53} \\ = \text{Astronaut line tension if required constant} \end{array} \right.$$

B. Input Formats

1. Parameter 1. FØRMAT (12A6)

2. Parameters 2.-49. FØRMAT (6E12.8)

3. Parameters 50.-63. FØRMAT (6E12.8)

C. Output Parameters

1. All input items are printed.

2. With each point of printout, the following parameters are listed (vector components are in polar coordinates with reference to the moving coordinate system):

   a. Current time

   b. Vehicle attitude components

   c. Astronaut line tension

   d. Anchor mass line tension

e. Vehicle rotation rate components (with reference to vehicle axes)

f. Angular deviation of astronaut tether from normal to vehicle at point of attachment

g. Astronaut speed along tether line

h. Anchor speed along tether line

i. Outside torque components applied to vehicle lever arm lever

j. Vehicle position components

k. Astronaut position components

l. Anchor mass position components

m. Anchor mass position components with origin at vehicle

n. Vehicle velocity components

o. Astronaut velocity components

p. Anchor velocity components

q. Angular momentum components of astronaut about system mass center

r. Angular momentum components of anchor about system mass center

3. When the run terminates, the computer execution time is printed out.

D. <u>Test Case Input-Output</u>

These can be found in the binder on file under section INPUT-OUTPUT.

THE Marquardt CORPORATION
VAN NUYS, CALIFORNIA

REPORT 6091

TMC 8673

FORTRAN FLOATING DATA

MAC A 1194

ASTRONAUT RETRIEVAL

PROGRAMMER	DATE	DECK NUMBER	JOB NUMBER	PAGE OF
			3127	

DESCRIPTION

2 – 9	14 – 21	26 – 33	38 – 45	50 – 57	62 – 69	SEQ. 73 – 80
TIN	- DTIN	DTPRIN	TMAX	RMIN	H	01
XI	AK1	AK2	THEA	PHIA	PSIA	02
THEO	PHIO	RO	THE1	PHI1	R	03
THE2	PHI2	RR	THEVO	PHIVO	RVO	04
THEV1	PHIV1	RV1	THEV2	PHIV2	RV2	05
ØM1	ØM2	ØM3	S1	S2	S3	06
AI1	AI2	AI3	AN1	AN2	AN3	07
WO	W1	W2	AMU1	AMU2	CNUMBR	08
C 1	C 2	C 3	C 4	C 5	C 6	09
C 7	C 8	C 9	C 10	C 11	C 12	10
C13	C14	C15	C16	C17	C18	11
C19	C 20	C21	C 22	C 23	C 24	12
C25	C26					13
						14

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