

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

TO : See Addressees

DATE: December 22, 1965

FROM : Mr. Brown, R-ASTR-NGD

SUBJECT : Status of the development of the AS-501 navigation equations

1. The purpose of this memo is to define the areas in which further navigation studies need to be performed for the purpose of defining the AS-501 navigation equations. There are four phases of flight in which the navigation equations may be different. The first phase of flight is from GPR to some fixed time after first S-IVB cutoff. To my knowledge there have not been any studies performed to determine the navigation equations for this phase of the flight. Since this phase of the flight is similar to Apollo Saturn IB launch vehicle the navigation equations used in the AS-203 LVDC may be satisfactory, but a study needs to be performed to verify these equations.
2. The next phase of the flight is from some fixed time after first S-IVB cutoff to the beginning of the restart preparations. There have been several navigation studies performed for this phase of the flight. The results of these studies are presented in charts 1 through 6. Chart 1 presents the maximum errors in displacement and velocity occurring during three near circular orbits of flight when the third and fourth harmonics are neglected. The velocity and displacement errors are the magnitude of the vector difference not the difference in the magnitude of the vectors. The standard gravitation model of the earth is the Fischer model of the earth. The gravitation equations included the effects of all harmonics through the fourth.
3. Maximum errors in displacements and velocity occurring during three near circular orbits for the different integration techniques are presented in chart 2.
4. Maximum errors in displacement and velocity occurring during 20,000 seconds of flight in elliptical orbits for different integration techniques are presented in chart 3.
5. Maximum errors in displacement and velocity occurring during three orbits for approximations to the atmospheric density are presented in chart 4.
6. Maximum errors in displacement and velocity for different approximations to the venting model of the S-IVB stage for three orbits are presented in chart 5.
7. Maximum errors in displacement and velocity occurring during three orbits of flight due to platform hardware errors are presented in chart 6.

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8. From the data presented in charts 1 through 6 the navigation equations for this phase of the flight may be defined, if this phase of the flight was the last phase of flight. Since there is another phase of coast navigation it is necessary to investigate that phase of the flight before defining the navigation equations for the coast phases.

9. The third phase of flight is from the beginning of restart preparations to some fixed time after second S-IVB cutoff. To my knowledge there have not been any studies performed to determine the navigation equations for this phase of the flight. Since this phase of the flight is a powered phase the navigation equations used from GRR to the first S-IVB cutoff should be satisfactory for this phase of the flight, but a study needs to be performed to verify these equations.

10. The next phase of the flight is from some fixed time after second S-IVB cutoff to the separation of the spacecraft. To my knowledge there have not been any studies performed to determine the navigation equations for this phase of the flight. Therefore, a study needs to be performed to determine the navigation equations for this phase of the flight.



Harold E. Brown

6 Enc:

1 - 5 charts

6 classified chart upon request

Addressees:

R-ASTR-NG, Mr. Seltzer

R-ASTR-NG, Mr. Brooks

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cc:

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APPROXIMATION	MAX DISPLACEMENT ERROR (km)	MAX VELOCITY ERROR (m/s)	TYPE OF ORBIT
NEGLECT THIRD HARMONICS	0.500	0.4700	NEAR CIRCULAR
NEGLECT FOURTH HARMONICS	0.280	0.3600	NEAR CIRCULAR
NEGLECT THIRD AND FOURTH HARMONICS	0.720	0.7300	NEAR CIRCULAR
A = NOMINAL R AT INJECTION IN CERTAIN PARTS OF THE THIRD AND FOURTH HARMONICS *	0.005	0.0007	NEAR CIRCULAR
A = NOMINAL SEMI-MAJOR AXIS IN CERTAIN PARTS OF THE THIRD AND FOURTH HARMONICS.* APOGEE = 600 km PERIGEE = 185 km	0.040	0.0480	ELLIPTICAL

* A = EQUATORIAL RADIUS OF THE EARTH

CHART 1: NAVIGATION ERRORS DUE TO APPROXIMATIONS TO THE GRAVITATIONAL MODEL OF THE EARTH FOR THE TIME REQUIRED TO COMPLETE THREE NEAR CIRCULAR ORBITS OR THREE ELLIPTICAL ORBITS

THREE ORBITS WITH OPTIMUM INTEGRATION TIME STEP (Δt)			
SCHEME	MAX DISPLACEMENT ERROR (km)	MAX VELOCITY ERROR (m/s)	Δt (s)
4 PASS RUNGE KUTTA	1.10	0.93	60
3 PASS RUNGE KUTTA	1.50	0.96	60
SHANKS	0.90	0.76	48
RUNGE KUTTA GILL	0.43	0.47	120

CHART 2: NAVIGATION ERROR DUE TO DIFFERENT INTEGRATION SCHEMES FOR THE TIME REQUIRED TO COMPLETE THREE NEAR CIRCULAR ORBITS

ELLIPTICAL PARKING ORBITS WITH A 185 KM PERIGEE ALTITUDE

SCHEME	APOGEE ALTITUDE (km)	MAX DISPLACEMENT ERRORS (km)	MAX VELOCITY ERRORS (m/s)	FLIGHT TIME (s)
3 PASS RUNGE KUTTA	185	1.42	1.68	20,000
	400	1.43	1.65	20,000
	600	1.35	1.48	20,000
4 PASS RUNGE KUTTA	185	1.33	1.58	20,000
	400	1.29	1.48	20,000
	600	1.27	1.44	20,000
SHANKS	185	1.18	1.33	20,000
	400	1.15	1.33	20,000
	600	1.12	1.23	20,000
RUNGE KUTTA GILL	185	0.47	0.59	20,000
	400	0.53	0.61	20,000
	600	0.56	0.65	20,000

CHART 3: NAVIGATION ERRORS DUE TO DIFFERENT INTEGRATION SCHEMES FOR 20,000 SECONDS IN ELLIPTICAL ORBITS

ATMOSPHERIC DENSITY (ρ)	MAX DISPLACEMENT ERROR (km)	MAX VELOCITY ERROR (m/s)
$\rho = .5308 \times 10^{-9}$ $V_r = 739.4$	0.158	0.188
$\rho = .5308 \times 10^{-9}$	0.134	0.158
$\rho = [.574 - .0173 (h - 183)] \times 10^{-9}$	0.028	0.034
NEGLECTED	3.960	4.700

CHART 4: NAVIGATION ERRORS DUE TO APPROXIMATIONS IN THE ATMOSPHERIC DENSITY MODEL OF THE EARTH FOR THE TIME REQUIRED TO COMPLETE THREE NEAR CIRCULAR ORBITS

NAVIGATION MODEL OF THE VENTING	MAX DISPLACEMENT ERROR (km)	MAX VELOCITY ERROR (m/s)
NEGLECTING THE TRANSVERSE LOX VENTING	0.048	0.056
NEGLECTING THE LOX VENT & LH ₂ OVERRIDE	9.000	10.000
NEGLECTING THE ULLAGE & LH ₂ OVERRIDE	18.000	22.000
NEGLECTING THE LH ₂ CONTINUOUS VENT & LH ₂ OVERRIDE	100.000	120.000
NEGLECTING ALL VENTS & ULLAGE IMPULSES	136.000	150.000
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT 10% OF THE CONTINUOUS VENT	11.000	13.200
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT 20% OF THE CONTINUOUS VENT	22.300	26.800
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT THE MAX HEATING OF THE CONTINUOUS VENT	18.000	21.600
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT THE MIN HEATING OF THE CONTINUOUS VENT	19.800	23.600
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT 10% OF THE ULLAGE	1.850	2.120
NAVIGATION HAS A KNOWLEDGE OF ALL ESCAPING GASES EXCEPT 10% OF THE LOX VENT	0.890	1.000

CHART 5: NAVIGATION ERRORS DUE TO ERRORS IN THE VENTING MODEL FOR THE TIME REQUIRED TO COMPLETE
THREE NEAR CIRCULAR ORBITS