MIT Instrumentation Laboratory

DG MEMO NO. 1068

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FROM: J. L. Nevins and R. A. Larson

DATE: 10 May 1968

SUBJECT: Trip Report to AMES - 504 1st Stage Simulation with Manual Takeover.

ATTENDEES: Brent Creer, Gordon Hardy (Project Leader), Dick Kurowski (analytical design), and the authors.

General

The fixed base simulation flown at AMES is the latest of a continuing series of manually steered Saturn booster studies made by the Flight Simulation Lab. Of interest, also, is a previous study where the upper stages(SII, SIVB) were manually steered into orbit. (Copies of the AMES memos describing these simulations are in the 23D files and may be requested from the secretary.)

For this simulation, the first 160 sec (2 min and 39 sec) of flight for the 504 booster are simulated. Elements simulated are shown in Fig. 1. For the dynamics the 1st and 2nd structural bending modes(1.0 cps and 1.75 cps, DR=0.005), the 1st slosh mode of the SIC fuel and oxidizer tanks and the SII LOX tank [0.5 cps, DR=0.04 (SIC), DR=0.46 (SII), dynamic mass $\cong$ 30% of total initial mass], the LV attitude filter and associated rate loop and filter booster actuator and engine dynamics, the CMC boost polynomial, the proposed CMC "filter" for manual steering (Fig. 2 & 3), an RHC on/off controller with a fixed trim rate command of 1^{o}/sec with integration, a west wind of 75 meters/sec at 10,000 meters altitude (max 'q'), and with the inertial packages for the LV and the S/C compensated for their location with respect to the bending modes.

The game is played as follows: Following L.O. the vehicle climbs vertically for 10 sec at which time the roll ~~and pitch~~ program commences. For this launch azimuth (72^{o}) and trajectory the vehicle rolls 18^{o} and pitches at 0.5^{o}/sec (nominal pitch profile is 90^{o}(vertical) to 24^{o}). At any time an ST-124 platform failure can occur. Visual cues L/V guidance warning light, attitude error build up on the FDAI, and rate buildup on the FDAI rate needles. For our runs we had the ST-124 failure (TA fail) occur at 20 sec. after liftoff (Runs 0-7 and 9 thru 11). We did try one run with a platform fail at max q (70 sec) (Run No. 8). Nominally, we would wait about 10 sec* for the secondary visual cues [attitude error and rate (about 2^{o} and 1^{o}/sec)] to build up before switching from IU to CMC. It is surprising how sluggish the vehicle is. For Run No. 8 we still did not actuate the IU/CMC switch for 7.7 seconds after we got the L/V guidance failure light.

The following modes were flown (Fig. 4):

*The actual IU/CMC switch over times are listed in Co. 7 of Table 1.

a. Mode 1 - CMC boost polynominal. (Fig. 4a & 4b) Also included was the proposed CMC 2nd order Tustin filter (Fig. 2 & 3) and a trim rate of 1^{o}/sec from the RHC.

b. Mode 2 - No CMC boost polynominal - constant inertial pitch attitude (Fig. 4c). The rest of the system was the same as mode 1.

Mode 1 may be flown two ways, with or without manual inputs illustrated by Fig. 4a and 4b. In 4a the system is flown without manual inputs (Run 2). The result is an offset from the nominal trajectory caused by the crewman's time delay in switching to the CMC once the IU package has failed (time of failure = TA). If he switches quickly, of course, the offset will be minimal.

With manual inputs (Fig. 4b) (Runs 3, 4, 5, 6, 7, 10, 11), the crewman flies the booster back to the nominal path using the FDAI and DSKY and a placard that calls out pitch, H, $\dot{H}$, and V_I for every 10 seconds of flight. [Note: for this mode H, $\dot{H}$, and V_I can be ignored.] A fairly trivial task to fly; also, I suspect, a fairly trivial one to automate.

Mode 2 (Fig. 4c) (Runs 8, 9, and 11), the constant inertial mode, requires manual inputs continuously (or pulsed continuously) because the system does not include a pitch polynominal. The system is flown similar to Mode 1 except the pilot needs to take into consideration H, $\dot{H}$, V_I as well as the pitch/time profile. This is not a difficult task either. On the Cooper pilot rating scale (DG Memo No. 857A) Mode 1 has been rated 1 and Mode 2 has been generally given a 1-2 rating by MSC pilots and astronauts.

Simulation Runs

A total of 14 runs were flown (Table 1). Eleven were Mode 1 and three were Mode 2. Since the system was as sensitive to the "computation cycle" used [Note: apparently this means that a snapshot of the data is made and all computations are performed at the specified cycle time,] as it was to the presence or absence of the filter. The following groups of runs were flown.

Case	Mode	Filter Yes	Filter No	Computation Cycle (milisec.)	Remarks
1	1	1		310	Well behaved
2	1		1	310	Well behaved
3	1		1	100	Unstable, uncontrollable
4	1	1		100	Well behaved
5	1	1		560	Marginally stable
6	*1	1		400	Unstable, uncontrollable
7	2	1		310	Well behaved

The simulation was well behaved and relatively easy to fly. However, when it went unstable it was uncontrollable because of the very low fixed gain of the RHC (1^{o}/sec).

* Flown by AMES personnel.

Case 1, was flown with and without manual inputs. Thus, the proposed mode 1 system, without manual inputs or filter, may already be implemented if the present CMC "computation cycle" is the same as demonstrated on the AMES simulator (310 millisec). However, verifying that the overall loop is really stable will be quite a chore because a really accurate simulation of the LV including the propellant utilization system as well as the higher order bending modes apparently does not exist.

Conclusions

1. For the High-q abort minor changes in the present CMC mechanization would allow either time for an abort or the 1st stage burn to be completed. It is not necessary to mechanize the RHC to accomplish this limited goal.

Unfortunately, verifying that the loop mechanized is stable and well behaved would be difficult and time consuming, because accurate simulations of the LV guidance and the G&N system do not exist, at least not in the same location.

Another aspect of the verification problem is the critical relationship between CMC "computation cycle" and the loop stability (Table 1). Indications are that more accurate simulations of the booster structure, fuel slosh, and the LV guidance computation cycles are needed to verify the stability of the proposed steering loops.

Run No. (1)	CP	Mode	Filter Yes	Filter No	Computational Cycle (millisec)	TA Fail (Sec)	IU/CMC SW Dwn (Sec)	Remarks
0	Nevins	1	x		310	———	———	Demonstration
1	"	1	x		"	———	———	Demonstration
2	"	1	x		"	20.0	33.2	No stick inputs
3	"	1	x		"	20.0	24.15	Evaluation of handling qualities
4	"	1	x		"	20.0	27.05	Evaluation of handling qualities
5	"	1		x	"	20.0	26.97	Well behaved, a little more activity on rate needles (Pitch $\cong 0.5^{\circ}$/sec).
(2) 6a, 6b	"	1		x	100	20.0	?	Unstable, uncontrollable
6c	"	1	x		100	20.0	26.07	Well behaved
(3) 7	"	1	x		560	20.0	22.72	Marginally stable, pitch rate oscillation $\cong 2^{\circ}$/sec.
8	"	2	x		310	70.0	77.72	An additional task, not difficult
9	"	2	x		310	20.0	32.85	An additional task, not difficult
10	R. Larson	1	x		310	20.0	31.10	Evaluation of handling qualities
11	"	2	x		310	20.0	30.80	Evaluation of handling qualities

(1) All runs used the I.C.'s and disturbing forces listed on P1 and P2

(2) Booster appeared to take several seconds from 1st divergence to breakup.

(3) AMES has flown with a 400 millisec computation cycle and found the system was unstable and uncontrollable.

TABLE 1

2. Ames has also studied manual steering of the upper stages (SII and SIVB) to accomplish a desired orbit. Again the crewman uses the DSKY and a placard which calls out a nominal pitch program and H, $\dot{H}$, and V_I every 30 seconds. Unfortunately, the simulation was limited because the bending mode input to the IMU was not correct. The inertial package location simulated was the location of the ST-124 inertial package in the SIVB instead of the IMU located in the CM. (See Fig. 5) Also, the propellant utilization system and the resultant pitch attitude oscillation of the booster (approx. $\cdot 15^{o}$) was not simulated. Again, verification with an accurate simulation would be an extremely costly thing to implement, in terms of schedule, because of the lack of proper facilities.

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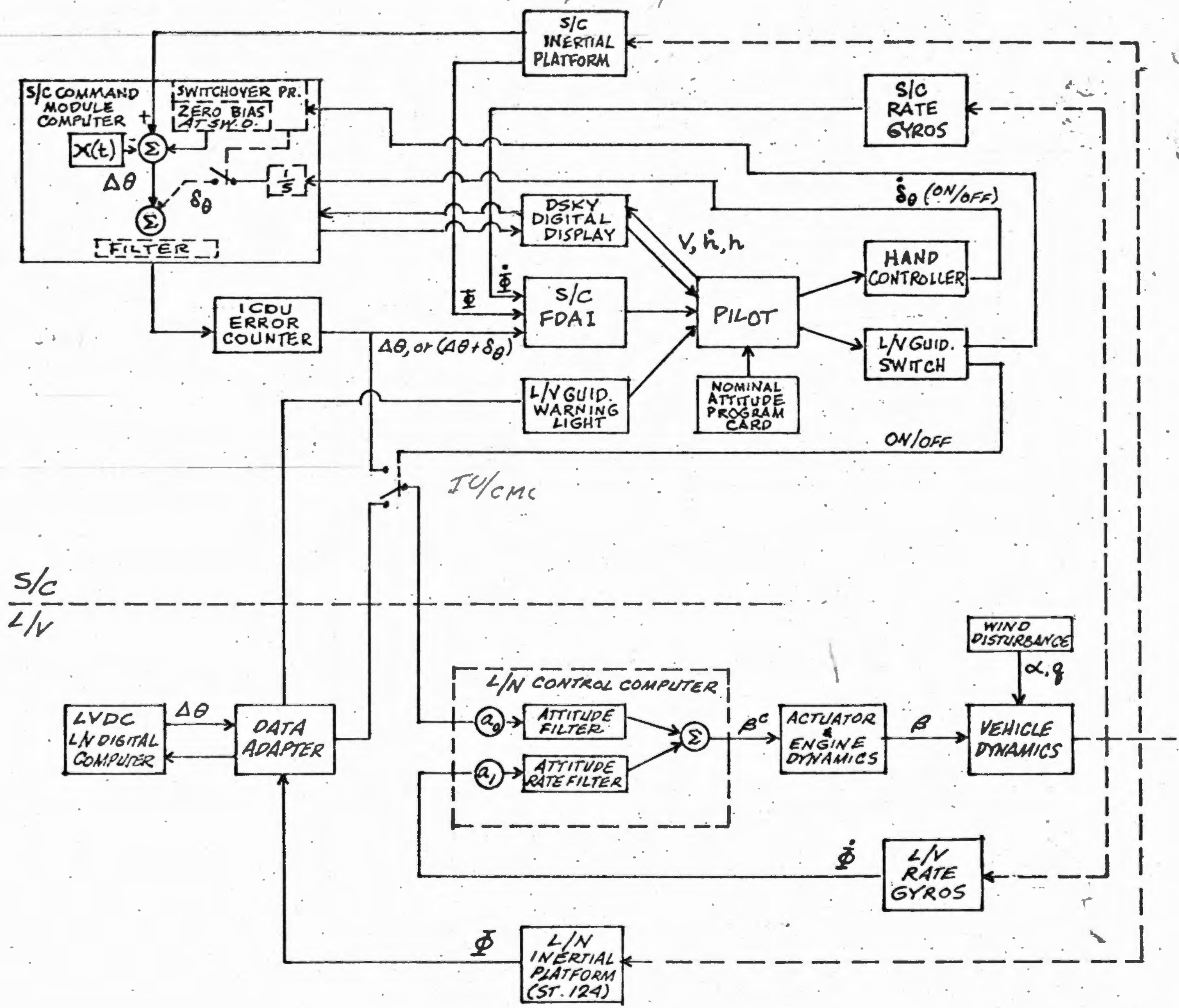


Fig 1

Dick Kurkowski 5/10/68

Analog Filter:

$$\frac{6^2}{s^2 + 2(.6)(6) + (6)^2}$$

42-381 50 SHEETS
42-382 100 SHEETS

SATURN FILTER

TABLE OF COEFFICIENTS

Coeff.	$i=1$ Finite Differences	$i=2$ z-Transform	$i=3$ Tustin Method
j_i	$\frac{K\omega^2T^2}{1+2\zeta\omega T+\omega^2T^2}$	0	$\frac{K\omega^2T^2}{4+4\zeta\omega T+\omega^2T^2}$
k_i	0	$\frac{K\omega T}{\sqrt{1-\zeta^2}}e^{-\zeta\omega T}\sin(\omega T\sqrt{1-\zeta^2})$	$\frac{2K\omega^2T^2}{4+4\zeta\omega T+\omega^2T^2}$
l_i	0	0	$\frac{K\omega^2T^2}{4+4\zeta\omega T+\omega^2T^2}$
m_i	$\frac{2(1+\zeta\omega T)}{1+2\zeta\omega T+\omega^2T^2}$	$2e^{-\zeta\omega T}\cos(\omega T\sqrt{1-\zeta^2})$	$\frac{2(4-\omega^2T^2)}{4+4\zeta\omega T+\omega^2T^2}$
n_i	$\frac{-1}{1+2\zeta\omega T+\omega^2T^2}$	$-e^{-2\zeta\omega T}$	$\frac{-(4-4\zeta\omega T+\omega^2T^2)}{4+4\zeta\omega T+\omega^2T^2}$

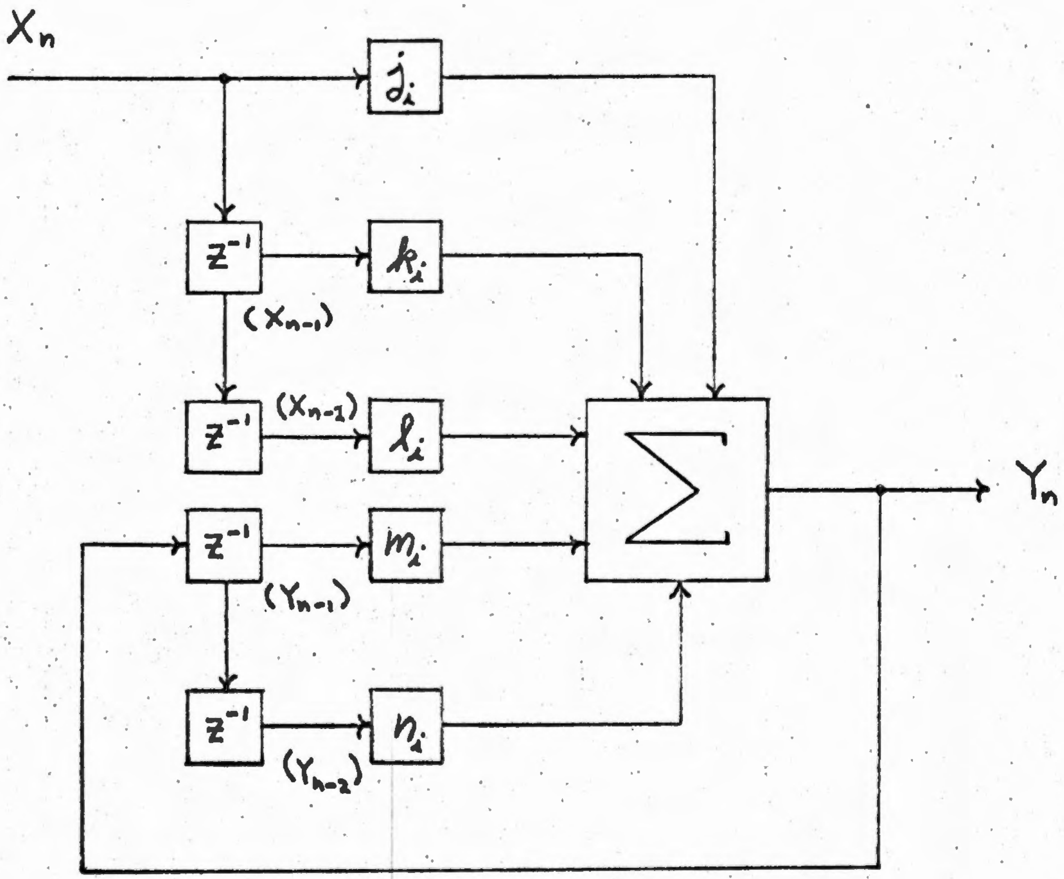
Note:

$$Y_n = j_i X_n + k_i X_{n-1} + l_i X_{n-2} + m_i Y_{n-1} + n_i Y_{n-2}$$

Fig 2

SATURN FILTER

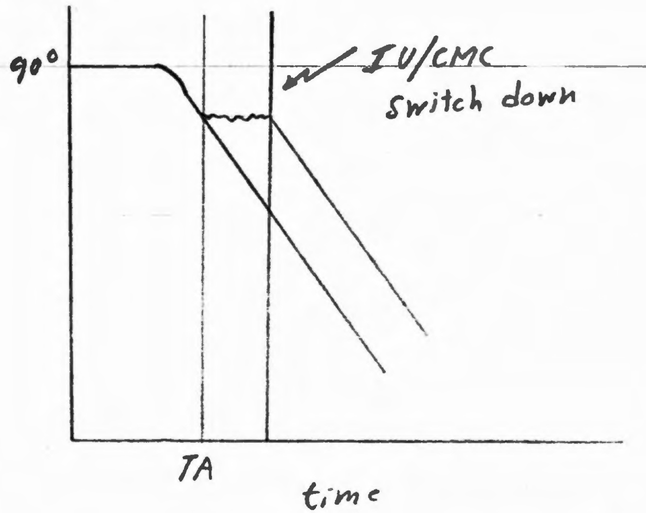
(GENERAL SCHEMATIC) (Tustin Technique)



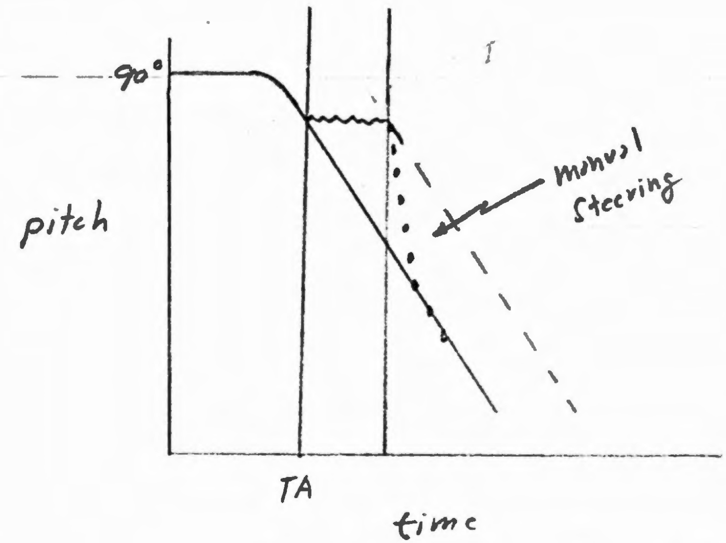
Note:

$$i = \begin{cases} 1 & \text{Finite differences method} \\ 2 & \text{Z-Transform method} \\ 3 & \text{Tustin method} \end{cases}$$

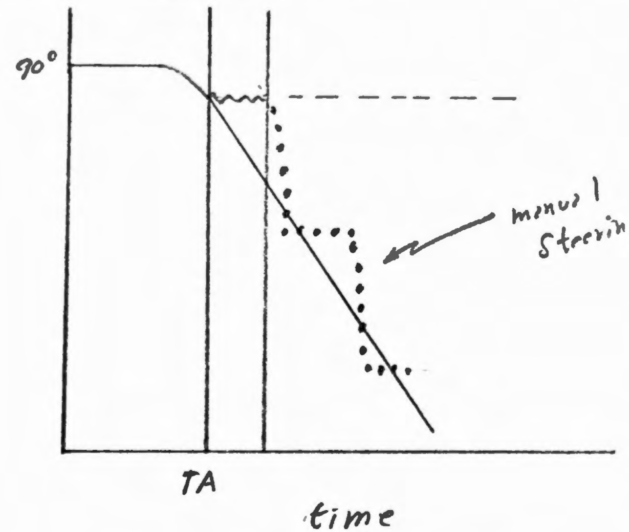
Fig 3



a. Mode 1 – no manual inputs

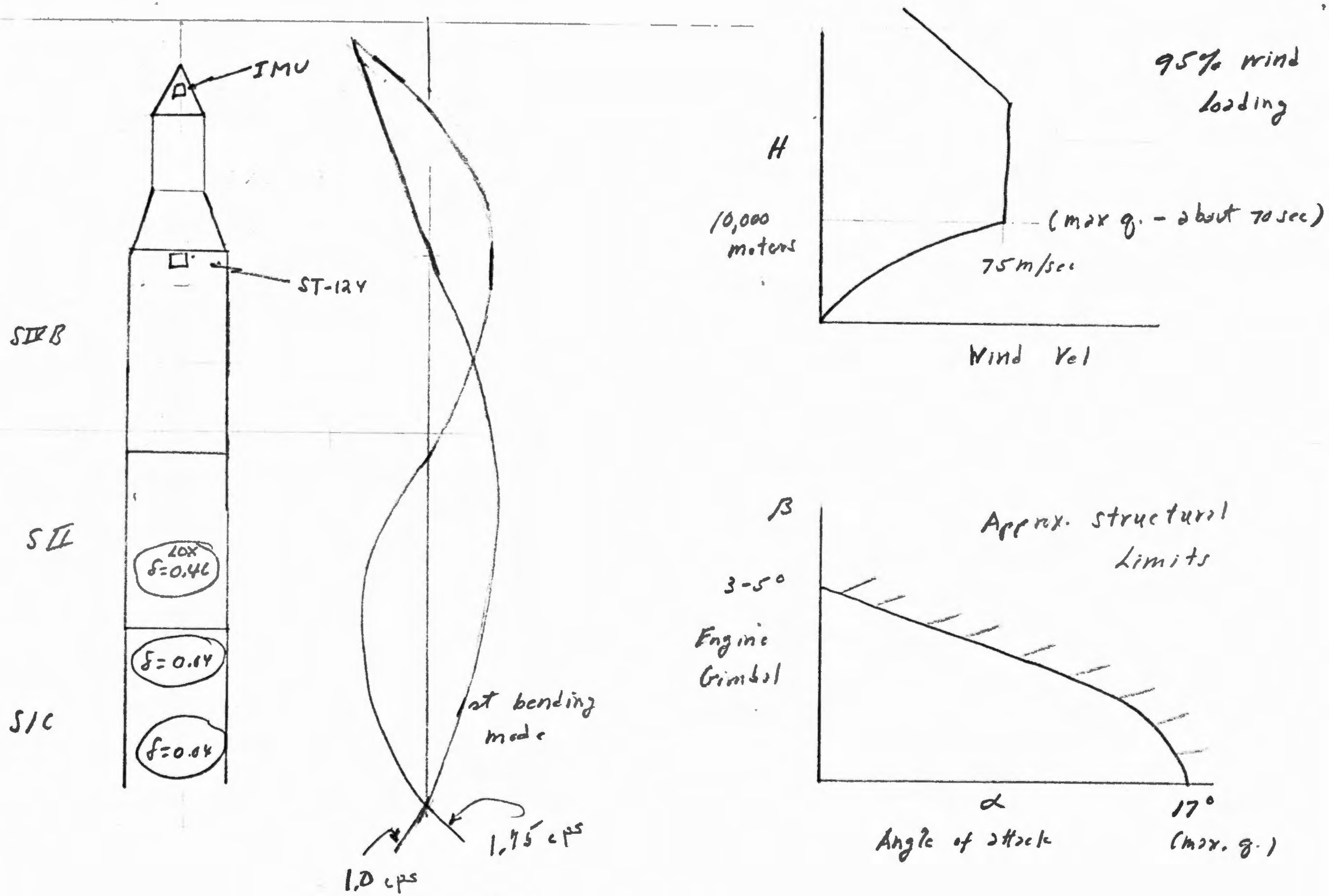


b. Mode 1 – manual steering to remove offset



c. Mode 2 – constant inertial attitude

Fig 4



IMU
ST-124
SIV B
S II
S/C
LOX
δ=0.46
δ=0.14
δ=0.04
1st bending mode
1.0 cps
1.75 cps
95% wind loading
H
10,000 meters
(max q. - about 70 sec)
75 m/sec
Wind Vel
β
Appx. structural Limits
3-5°
Engine Gimbal
α
Angle of attack
17°
(max. q.)

Fig 5