WHS-026-1
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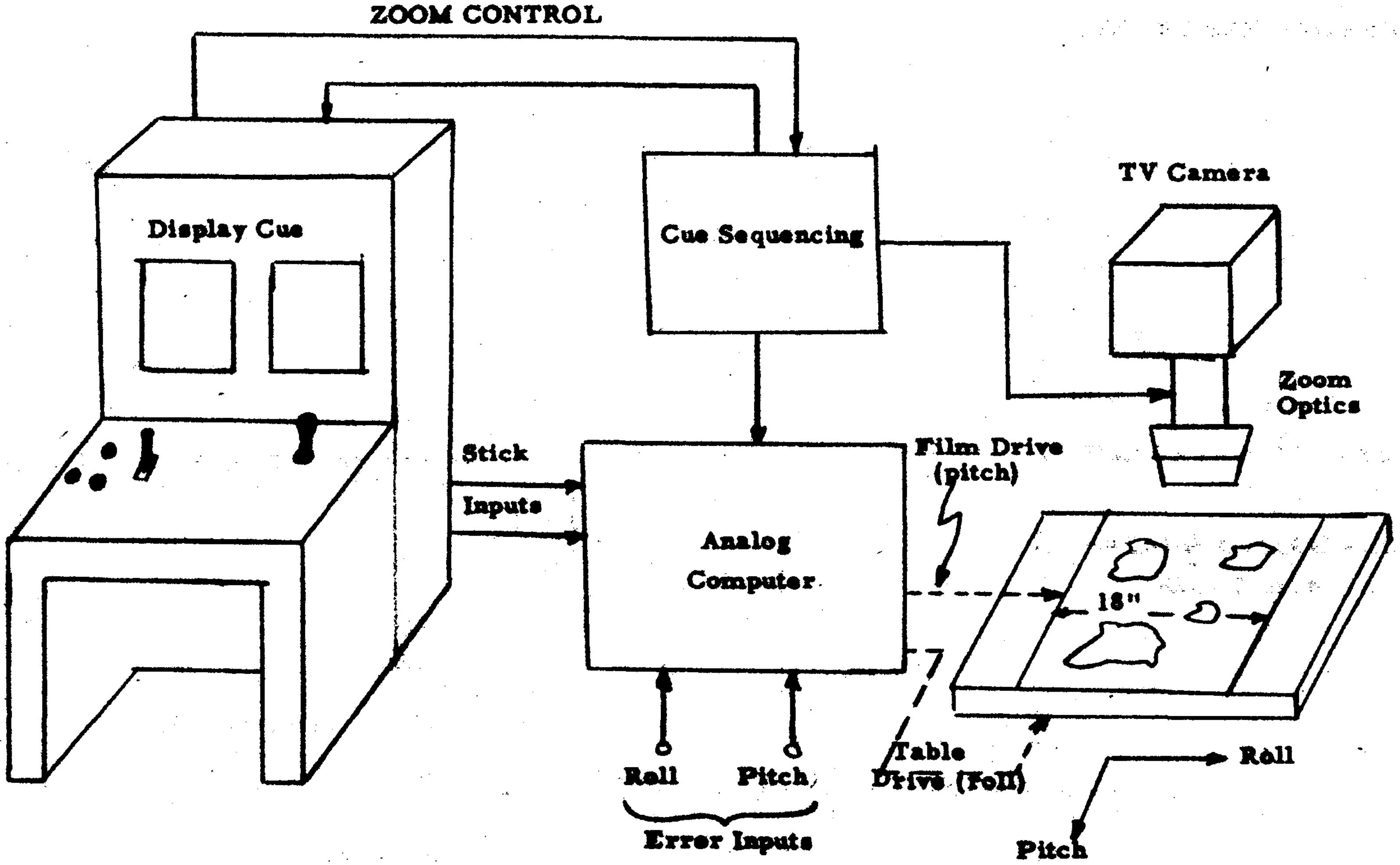
9 June 1966

- SIMULATION STUDIES
- BACKUP ANALOG ACQUISITION AND TRACKING UNIT

SIMULATION STUDIES

- PERFORMED ON LMSC SIMULATOR 6/1-2/66
- OPERATORS (FLIGHT CREW)
  - R. TRULY
  - J. TAYLOR
- PURPOSE
  - EXTEND DATA ON MANUAL TRACKING CAPABILITY TO $>$ 1% RATE AIDING ERRORS
  - EVALUATE UTILITY OF AN AUGMENTED CONTROL STICK
- OBJECTIVES
  - PROVIDE BASIS FOR EVALUATION OF EFFECTIVENESS OF LESS ACCURATE RATE AIDING TECHNIQUES (E.G., A SIMPLE ANALOG BACKUP TO THE DIGITAL COMPUTER)
  - PROVIDE BASIS FOR FURTHER STUDY OF CONTROL SYSTEM DESIGN WRT MAN



DISPLAY POWER:

ACQ:	8.4 - 25.2
MADS:	100 - 165

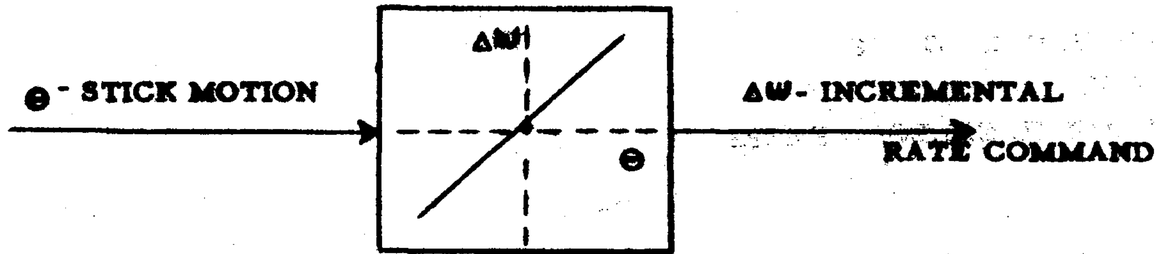
TABLE DRIVE CAPABILITY (EQUIV.)

ACQ:	7.5°/sec max., .075°/sec min
MADS:	< .1° sec max 5-7°/hr. stiction

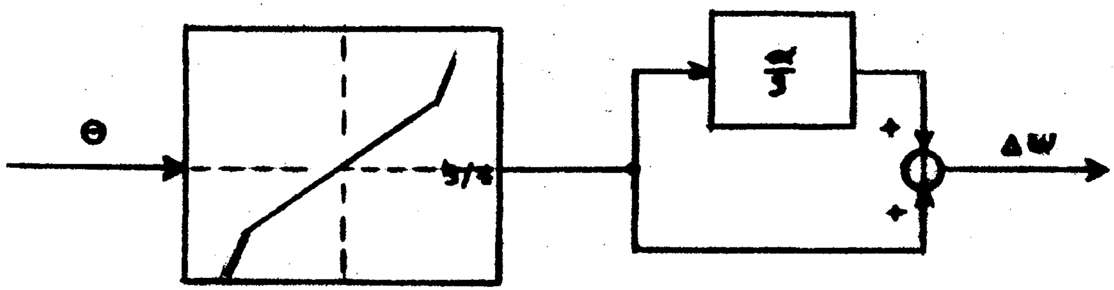
LMSC SIMULATOR

CONTROL STICK TRANSFER FUNCTIONS

- "BASELINE"

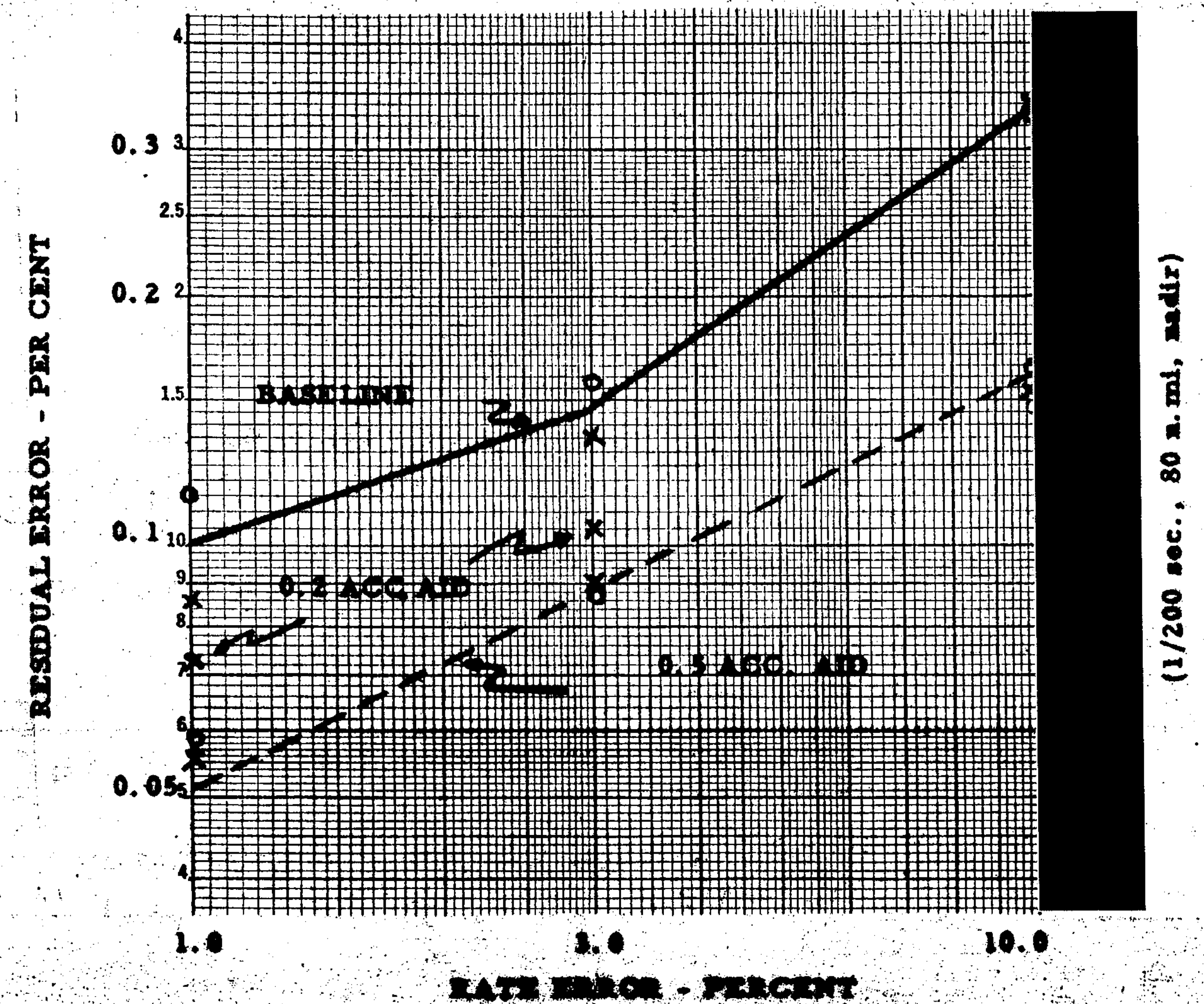


- NONLINEAR ACCELERATION AUGMENTED STICK



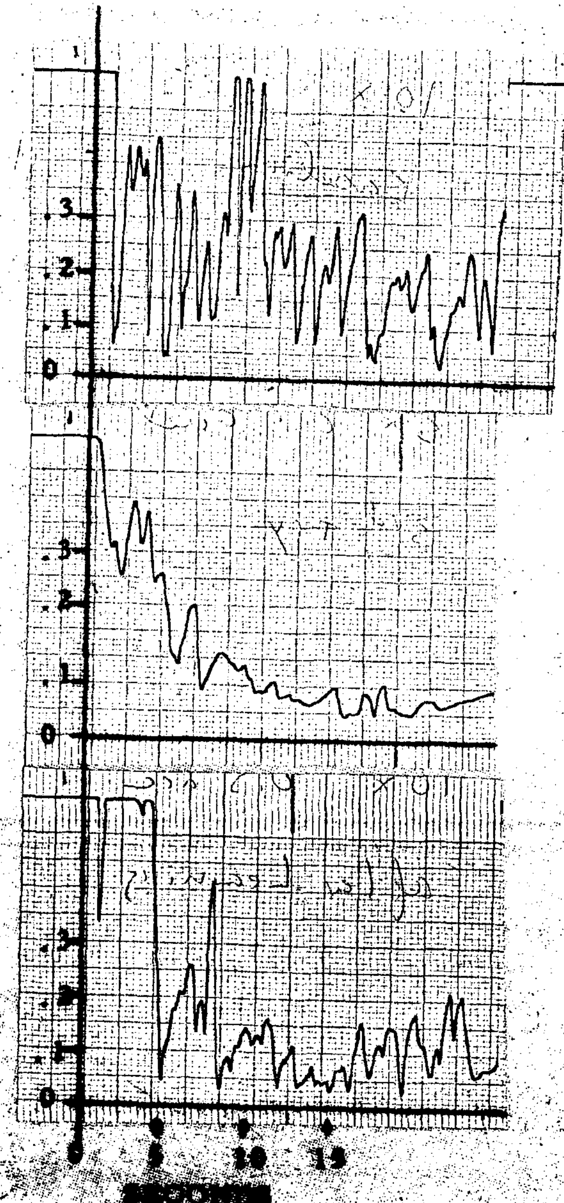
STUDY CASES

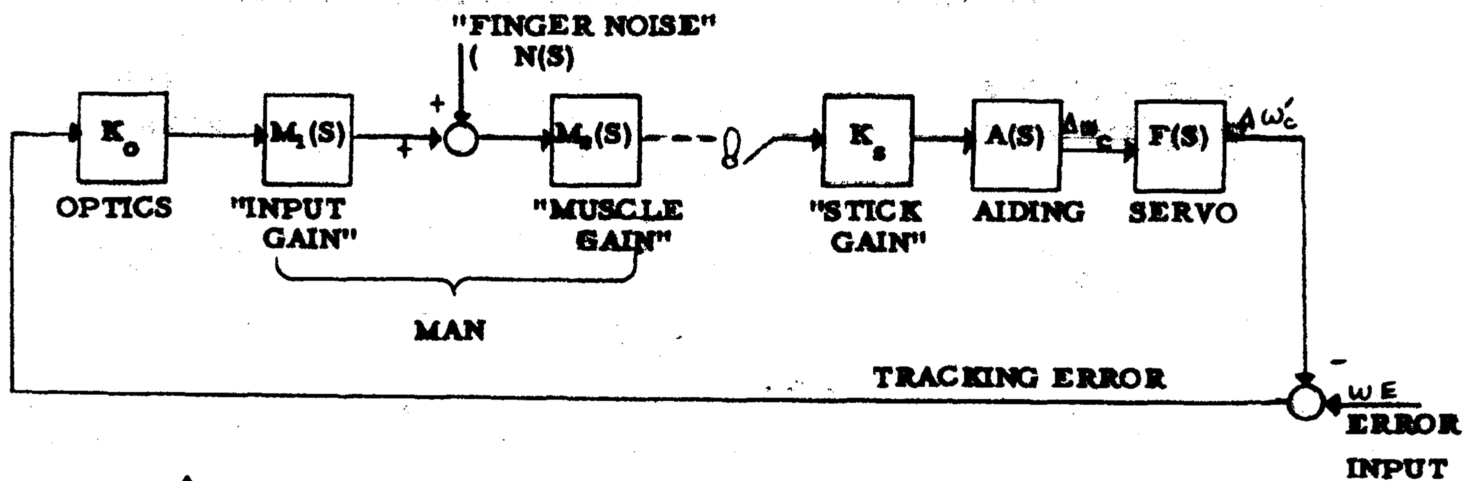
PERCENT ERROR	STICK TYPE	STICK GAIN	ACCEL. AUGMENTATION
1	LINEAR	1	O
3	"	3	O
10	"	10	O
1	NONLINEAR	1	O
3	"	3	O
1	"	1	.2
3	"	1	.2
10	"	1	.2
3	"	1	.5
10	"	1	.5
10	"	2	.5



RESIDUAL ERROR - PER CENT
0.3
0.2
0.1
0.05
BASELINE
0.2 ACC AID
0.5 ACC. AID
(1/200 sec., 80 n.mi, nadir)
1.0
3.0
10.0
RATE ERROR - PERCENT

	RATE ERROR	ACCELERATION AUGMENTATION
BASELINE TYPICAL	10 X	0
BEFORE LEARNING (3RD TRIAL)	3 X	0.5
AFTER LEARNING	10 X	0.5





$$G(S) \triangleq K_o M_1(S) K_s A(S) F(S)$$

- IN PASS BAND ($G(S) > 1$)

$$\Delta\omega^2 = \int_0^{BW} \left(\frac{\omega_E(S)}{G(S)}\right)^2 + \left(\frac{N(S)}{K_o M_1(S)}\right)^2 df$$

BW = BANDWIDTH
f = FREQUENCY

- ASSUME MAN'S "MUSCLE GAIN" IS ADAPTIVE TO INPUT ERROR OVER RANGE OF INTEREST
  - / THEN HE INCREASES G(S) SUCH THAT $\frac{\omega_E S}{G(S)}$ = CONSTANT WITH BW PROP TO MUSCLE GAIN
  - / $\Delta\omega$ IS THEN PROPORTIONAL TO $(\text{BANDWIDTH})^{1/2}$
- WITH ACCELERATION, AIDING, ONE ALLOWS A REDUCTION IN "MUSCLE GAIN" BY RAISING G(S) IN THE LOW FREQUENCY REGION, THUS IMPROVING STEADY STATE RESPONSE.

FUTURE EFFORT

- SIMULATOR IMPROVEMENT
  - REDUCE EFFECT OR TABLE STICTION - (MECH. MODS OR SCALING)
  - REDUCE AVAILABLE ACQUISITION TIME
  - IMPROVE CONTROL STICK FEEL - (DAMPING & SPRING RETURN)
  - RESCALE COMPUTER SIMULATION FOR HIGHER RATE AIDING ERRORS
  - PROVIDE FOR TESTING VARIOUS STICK FUNCTIONS

- ANALYTICAL EFFORT
  - DEFINE A "USEFUL" MODEL FOR MAN IN THIS FUNCTION
  - DETERMINE DESIGN/STABILITY CRITERIA FOR ACCEL/JERK STICK FUNCTION AUGMENTATION
  - GENERATE RATE ERROR INPUT DATA FOR THE VARIOUS ERROR SOURCE CONSISTENT WITH THE ANALOG BACKUP DESIGN: CORRELATE POINTING AND RATE ERRORS
  - DETERMINE SIMPLE MINIMAL TRANSIENT ACQUISITION TO PRIMARY HANDOVER TECHNIQUES

FUTURE EFFORT(CONT)

- SIMULATION
  - STICK FUNCTION OPTIMIZATION FOR TRACKING
    - STICK FEEL
    - AUGMENTATION: ACCEL + HIGHER ORDER AIDING
    - RATE ERROR LEVEL FROM 1% TO 10% V/h
    - VERIFICATION OF MODEL/STABILITY BOUNDARIES FOR MAN.
  - INITIALIZATION STUDY - MINIMIZE ACQUISITION AND RATE KILLING TIME
    - OPERATOR TRAINING
    - ACQUISITION TO PRIMARY HANDOFF TECHNIQUES
    - ACQUISITION STICK FUNCTION
    - PRIMARY STICK FUNCTION
  - ESTABLISH TRADEOFFS BETWEEN SETTLING TIME AND TRACKING

SUMMARY

0 - SIMULATION EQUIPMENT INADEQUATE TO SHOW FULL
PERFORMANCE CAPABILITY

1 - MAN CAN PRODUCE SATISFACTORY RESULTS WITH
INPUT RATE ERRORS AS HIGH AS 10% V/h

2 - MAN APPEARS TO BE GAIN ADAPTIVE
STICK GAIN ADJUSTED FOR INDIVIDUAL COMFORT

3 - STICK AUGMENTATION BY HIGHER ORDER FUNCTIONS
IS A FRUITFUL APPROACH TO IMRROVE
PERFORMANCE

4 -- SETTLING TIME IS REDUCED BY EXPERIENCE

ANALOG ACQUISITION & TRACKING BACKUP

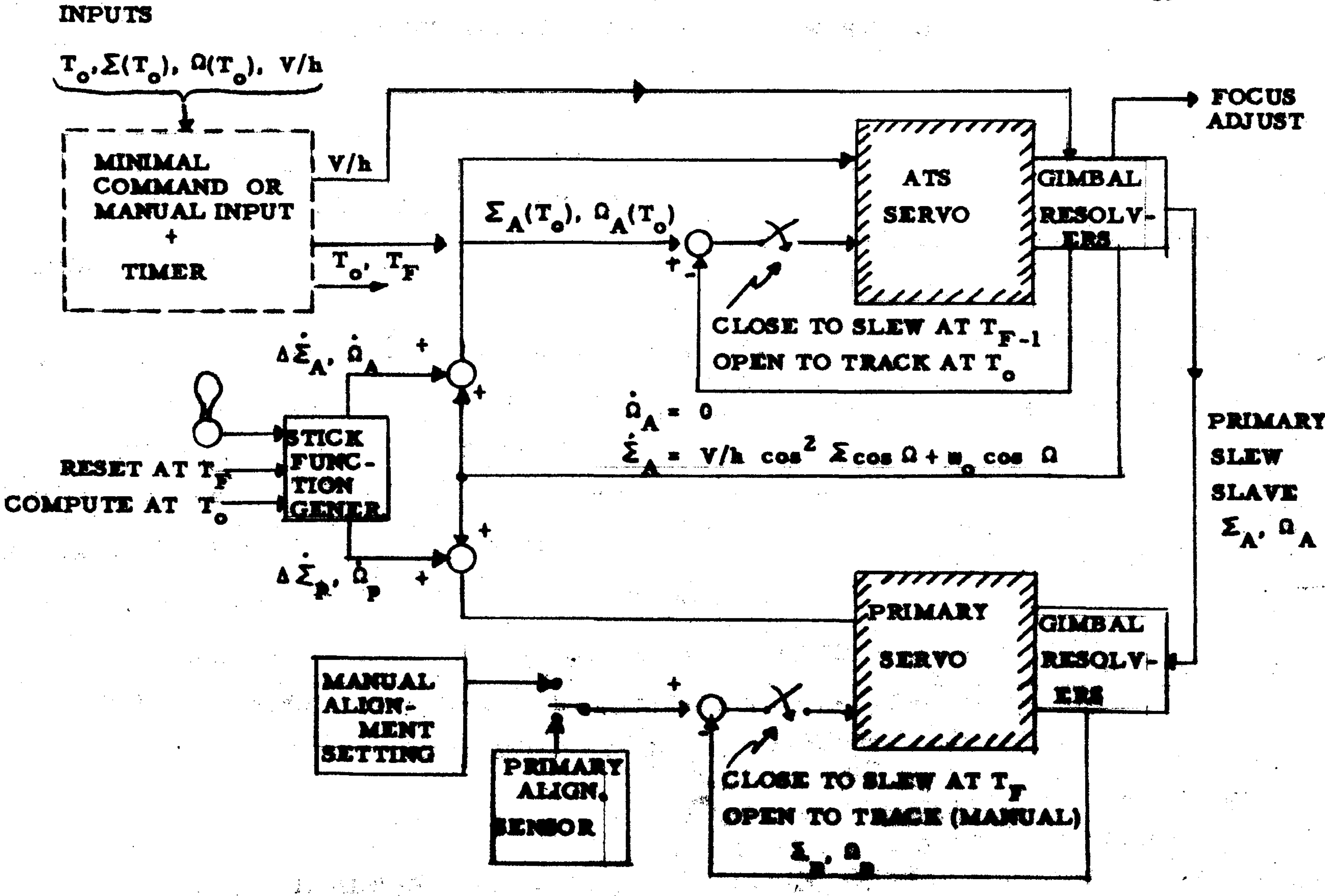
- CONCEPT
  - PROVIDE EFFECTIVE BACKUP FOR COMPUTER & COMMAND S/S FAILURE
  - MINIMAL INTERFACE WITH PRIMARY HARDWARE
  - SIMPLE AS POSSIBLE TO ALLOW MISSION CONTINUATION
- POINTING ACCURACY
  - UNAIDED: 1 - 2 DEG. ; AIDED: 0.1 - 0.2 DEGREE
- RATE ACCURACY
  - UNAIDED: 3 - 5% V/h ; AIDED: 0.1 - 0.2% V/h
- EXCLUSIONS/SIMPLIFICATIONS
  - NO NAVIGATIONAL UPDATING
  - NO AUTOMATIC MODE
  - SINGLE TARGETS ONLY. (NO CLUSTER CAPABILITY)
  - INDEPENDENT OF ACTS ELECTRONICS
  - MANUAL OR MINIMAL COMMAND UNIT IMPUTS ONLY

FAILURE MODE COMPARISON

FAILED ELEMENTS	ANALOG BACKUP	NO ANALOG BACKUP	UNMANNED
DATA READOUT	OK	OK	OK
ONE ACQ SCOPE	OK	OK	NA
ONE CONSOLE	OK	OK	NA
DRAGLAR ACCEL	OK	OK	MARGINAL/DEAD
ATTITUDE CONTROL	OK, EXCEPT FOR VALVES	OK, EXCEPT FOR VALVES	DEAD
V/H SENSOR	OK	OK	MARGINAL/DEAD
STAR TRACKER	OK	OK	MARGINAL
FORMAT SERVO	OK	OK	MARGINAL
DIGITAL COMPUTER (S)	OK	DEAD	DEAD
COMMAND SUBSYSTEM	OK (LESS TARGETS)	DEAD	DEAD
FOCUS SERVO	MARGINAL	MARGINAL	MARGINAL
PRIMARY SERVO	BACKS UP ONLY SHAFT ENCODERS	DEAD	DEAD

BACKUP DRIVE APPROACH

- SERVO CONTROL
  - RESOLVER CHAIN TRACKING FUNCTION GENERATION/CONTROL
  - RESOLVERS GEARED TO SERVO GIMBALS
  - ATS SERVO USED AS A COMPUTER
  - ESTIMATED WEIGHT: $\leq$ 20 LBS
  - ESTIMATED POWER: $\leq$ 25 WATTS
- COMMAND FUNCTION
  - MINIMAL COMMAND UNIT OR MANUAL RESOLVER SETTINGS & TIMER
  - INPUTS: STEREO AT ACQUISITION, OBLIQUITY, $^V/h$, ACQUISITION TIME; STEREO AT ACQUISITION FIXED FOR A PASS



BACKUP DRIVE BLOCK DIAGRAM

$$\omega_y = \left\{ \frac{1/2\ \text{[redacted]}}{b_x + \tan\Theta\,(s\Omega\, b_y - c\Omega\, b_z)} \right\} \left\{ c^2\Sigma\, c\Omega \frac{v}{h} + c\Omega\, w^{\circ} \right.$$

[redacted]

$$- \tan\Theta\,(\omega_y^b b_z - \omega_z^b b_y) + s\Omega\,(\omega_z^b - \omega_x^b b_z) - c\Omega\,(\omega_x^b b_y - \dot{q}_z)$$

$$+ \left[(\tan\Theta\, s\Sigma - c\Sigma\, c^2\Omega)\, b_z^2 + (s\Sigma + \tan\Theta\, c\Sigma)(s\Omega\, b_y - c\Omega\, b_z) + c\Sigma\, s2\Omega\, b_y b_z \right] \dot{\lambda}_x$$

$$+ \left[s2\Sigma\, s\Omega + (s^2\Omega(\tan\Theta\, s\Sigma - c\Sigma) - \tan\Theta\, c^2\Omega)\, b_y + s\Omega c\Omega\,(c\Sigma - \tan\Theta(1+s\Sigma))\, b_z \right] \dot{\lambda}_y$$

$$\left. + \left[-s2\Sigma\, c\Omega + s\Omega c\Omega\,(c\Sigma - \tan\Theta(1+s\Sigma))\, b_y + (c^2\Omega(\tan\Theta\, s\Sigma - c\Sigma) - \tan\Theta\, s^2\Omega)\, b_z \right] \dot{\lambda}_z \right\}$$

$$\omega_x = \left\{ \frac{1}{b_x + \tan\Theta\,(s\Omega\, b_y - c\Omega\, b_z)} \right\} \left\{ (s\Omega\, b_y - c\Omega\, b_z - \tan\Sigma)(s\Omega\, \omega_y^b - c\Omega\, \omega_z^b) + \frac{1}{c\Sigma}(s\Omega\, b_y - c\Omega\, b_z)\,\omega_x^b \right.$$

$$- \left[s\Omega c\Omega\,(b_y^2 - b_z^2) - \tan\Sigma\,(c\Omega\, b_y + s\Omega\, b_z - c2\Omega\, b_y b_z) \right] \dot{\lambda}_x$$

$$\left. - \left[\frac{c\Omega}{c\Sigma} + s\Omega\,(c\Omega\, b_y + s\Omega\, b_z) \right] \dot{\lambda}_y - \left[\frac{s\Omega}{c\Sigma} - c\Omega\,(c\Omega\, b_y + s\Omega\, b_z) \right] \dot{\lambda}_z \right\}$$

ω_x, ω_y = inertial pitch & roll gimbal rates

Ω = roll gimbal angle $\Sigma = 2\Theta - \pi/4$ = mirror stereo angle

$\underline{b}$ = optical axis vector $\underline{\omega}_b$ = vehicle inertial rate

$\dot{\underline{\lambda}}$ = line of sight rate

BASELINE RATE EQUATIONS

SMEAR ANALYSIS - ACQUISITION SCOPE

+ 30° ɛ, 0° Ω, 80 n. mi.

ERROR SOURCE		IN-TRACK SMEAR	°/SEC	X-TRACK SMEAR
VEHICLE ATTITUDE (.5° ALL AXES)		.011	°/SEC	.023
VEHICLE RATES (.02 °/SEC ALL AXES)		.02		.022
EPHEMERIS (4 K, 2 K, 2 K FT)		.01		-
ORBITAL RATE (.2%, .1° EQUIV. 500 FT/SEC)		.007		.005
SCOPE BASE ALIGNMENT (.5°)		.011		.023
ACQUISITION SCOPE ANGLES				
Σ (1° SET, 1° STANDOFF)		.044		-
Ω (1° SET)		-		-
ACQUISITION SCOPE RATES (.015 °/SEC)		.03		.013
SERVO COMPUTER ACCURACY (1%)		.03		.03
	RSS	.081 °/SEC		.051 °/SEC
POINT ACQUISITION TO TARGET (.15°)		.005	(REMOVE .044 ABOVE)	-
	RSS	.067 °/SEC		.051 °/SEC

1% V/h ≅ .03 °/SEC.

SMEAR ANALYSIS - PRIMARY W/O MANUAL CONTROL

$30^\circ \Sigma$, 0° Ω, 80 n. mi.

ERROR SOURCE	IN-TRACK SMEAR	X-TRACK SMEAR
ACQ SCOPE HANDOVER	.067 °/SEC	.051
SUBTRACT ROLL RATE CONTRIBUTOR (USING INERTIAL DRIVE)	--	(.017)
OPTICAL AXIS ALIGNMENT (1°)	.038	.02
POINTING ERROR (.15°)	.005	
RATE ERROR OF SERVO (.005°/SEC)	.01	.004
RSS ERROR AT Σ =+30°	.079 °/SEC	.052 °/SEC
COMPUTER ERROR INCREMENT TO Σ = -30°	.12	---
RSS ERROR AT Σ = -30°	.143 °/SEC	.052 °/SEC

FUTURE EFFORT

- ANALYTICAL
  - DETAIL DESIGN OF CONCEPT
  - DECIDE ON COMMAND FUNCTION APPROACH (PERHAPS USE BOTH)
  - DETERMINE METHOD OF MECHANICAL INTEGRATION: INTEGRATE INTO BASELINE
  - FIX STICK FUNCTION
  - DETERMINE FEASIBLE OPERATIONAL CYCLE TIMES

- MANAGERIAL
  - EVALUATE COST EFFECTIVENESS OF APPROACH (ES)
  - REPLACE ONE COMPUTER WITH BACKUP OR ADD TO PRESENT SYSTEM?
  - EVALUATE IMPACT ON SCHEDULE, TEST, ETC.
  - COST ($<$ 100 K/COPY ESTIMATED)
  - KEEP IT SIMPLE - IT'S A BACKUP!