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AEROSPACE

POINTING AND TRACKING SIMULATOR

W. K. CLARKSON

HANDLE VIA BYEMAN
CONTROL SYSTEM
ONLY

MOL MANNED TRACKING DATA SOURCES

- o TRACKING STUDY LITERATURE
  - / MOSTLY RANDOM ZERO MEAN RATE ERRORS - NOT APPLICABLE
- o MAN-MODEL EQUATIONS
  - / IGNORE DUAL TASKS, ADAPTIVE BEHAVIOR - FALSE CONCLUSIONS
- o EXISTING SIMULATOR STUDIES
  - / SIMULATOR NOT MAN-LIMITED; INCORRECT CONFIGURATIONS (E. G., LMSC)

- o GE INTERIM SIMULATION - 1966
  - / CRUDE PART TASK SIMULATORS, MOSTLY INCONCLUSIVE RESULTS DUE TO FLUID STATE OF BASELINE AND SIMULATION LIMITATIONS.
- o ENGINEERING DEVELOPMENT SIMULATOR (EDS) - 1968
  - / COMPLETED SEVERAL SUCCESSFUL PART TASK SIMULATIONS, CONTROL/DISPLAY CONFIGURATION STUDIES, ETC. USING HYBRID COMPUTATION, STIMULUS MATERIAL
- o MISSION DEVELOPMENT SIMULATOR (MDS) - 1969
  - / COMPLETE PAYLOAD SIMULATION
- o MISSION MODULE SIMULATION EQUIPMENT/LAB MODULE SIMULATION EQUIPMENT (MMSE/LMSE)
  - / INTEGRATED PAYLOAD/VEHICLE SIMULATION, TRAINER

- o AEROSPACE POINTING AND TRACKING SIMULATOR - 1967-
  - / SUPPORT MANNED MOL POINTING AND TRACKING EFFORTS

PURPOSES OF AEROSPACE SIMULATOR

- SERVE AS AN AID TO CONTRACTOR TD
  - / "CALIBRATE TECHNICAL INTUITION"
  - / ANTICIPATE OPERATIONAL AND SIMULATOR DESIGN PROBLEMS
  - / VERIFY CONTRACTOR CONCLUSIONS AND SIMULATION RESULTS
- PERFORM PRELIMINARY NON-BASELINE AND LOW PRIORITY MISSION STUDIES
  - / PLANETARY TRACKING STUDY
  - / [redacted]
- COMPLEMENT/SUPPLEMENT CONTRACTOR STUDIES
  - / STICK TRANSFER FUNCTION STUDY
- DEMONSTRATION TOOL FOR AIR FORCE, PROGRAM OFFICE AND CONTRACTORS

CAPABILITIES

- PERSONNEL
  - / ELECTROMECHANICAL DEPARTMENT (SYSTEMS INTEGRATION SECTION, G&C LAB)
  - / MOL BIOASTRONAUTICS
  - / HYBRID COMPUTATION CENTER
  - / MOL FLIGHT CREW (SUBJECTS, CONSULTANTS)
  - / CONTROL SYSTEMS DEPARTMENT (CONSULTANTS)
- EQUIPMENT
  - / ANALOG COMPUTER (INITIALLY EAI 24D, NOW AD4)
  - / CONTROL STICK (FROM GE)
  - / CRT WITH OPTICS AND RETICLES
  - / MAGNIFICATION CONTROLLERS (BUILT BY G&C LAB)
  - / AUXILIARY SIMULATION EQUIPMENT (NOISE GENERATOR, RECORDER, ETC.)
  - / DATA REDUCTION - PROGRAMMA 101, MCC OPEN SHOP, AND ASCOL
  - / HYBRID EXPANSION CAPABILITY

ADVANTAGES RELATIVE TO CONTRACTOR FACILITIES

- CONVENIENCE
  - / PROXIMITY TO AEROSPACE
  - / AVAILABILITY OF FLIGHT CREW
  - / TWO-THREE MAN OPERATION, INCLUDING SUBJECT
- AVAILABILITY
  - / MINIMAL SCHEDULING CONSTRAINTS AND "DOWN TIME"
- FLEXIBILITY
  - / MINIMUM NUMBER OF ELECTROMECHANICAL PARTS
  - / FAST TURNAROUND TIME
  - / ANALOG COMPUTER PROGRAM EASILY CHANGED
  - / HYBRID CAPABILITY AVAILABLE
- FIDELITY
  - / TARGET POSITION AND RATE BEHAVIOR HIGHLY REALISTIC
  - / MINIMAL SIMULATOR PECULIAR ERROR
- COST
  - / NO CAPITAL EXPENDITURE
  - / MINIMAL OPERATING COST

SIMULATION TASKS

		EMD	PO	CREW
o	PROBLEM FORMULATION	X	X	X
o	MODELING	X		
	/ TOTAL TASK DEFINITION / ERROR SOURCE IDENTIFICATION AND SCALING / REQUIRED SIMULATION HARDWARE IDENTIFIED AND OBTAINED			
o	INITIAL PARAMETER MINIMIZATION	X		
	/ INITIAL SIMULATION SETUP, CHECKOUT, AND OPTIMIZATION / EVALUATION OF BASIC CONCEPTS AND REASONABLE PARAMETER RANGES			
o	PILOT STUDIES	X	X	X
	/ TWO CREWMEN, EXTENSIVELY TRAINED, AS SUBJECTS / FURTHER PARAMETER AND CONCEPT MINIMIZATION / FINALIZE EXPERIMENT PARAMETER & PROCEDURES			
o	FORMAL STUDIES	X	X	X
	/ SIX CREWMEN, FORMAL PRACTICE AND DATA RUNS			
o	DEMONSTRATION TO OTHERS AS APPROPRIATE	X		

PLANETARY TRACKING SIMULATION STUDY

PROBLEM STATEMENT

- DESIRE TO IMPROVE ON EARTH-BASED PLANETARY PHOTOGRAPHY (≈1 SEC RESOLUTION) USING MOL SYSTEM
- FEASIBILITY STUDY NECESSARY TO DETERMINE WHETHER MOL CREWMEN CAN TRACK PLANETS ACCURATELY ENOUGH TO OBTAIN BETTER RESOLUTION

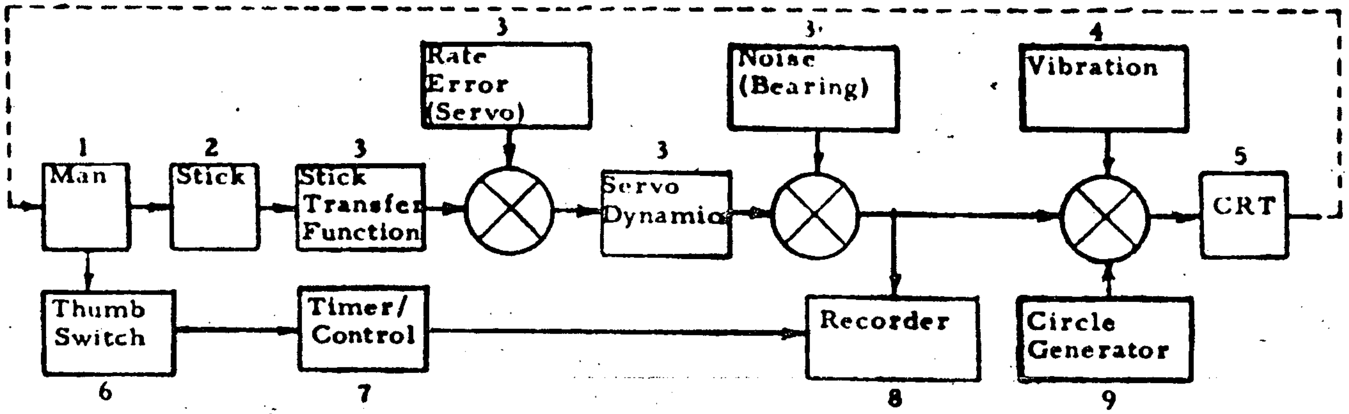
PERTINENT PLANET CHARACTERISTICS

PLANET	APPARENT EQUATORIAL ANGULAR DIAMETER (SEC)	EXPOSURE TIME (SEC)	APPARENT DIAMETER AT 1000X (DEGREES)
MERCURY	5-13 (7.2)	0.0034	2.0
VENUS	10-64 (24)	0.00116	6.7
EARTH	--	0.004	--
MARS	3.5-25	0.0209	7.0
JUPITER	31-50	0.089	14
SATURN	15-20	0.295	5.7
URANUS	3.4-4.2	1.176	1.2
NEPTUNE	2.2-2.4	2.28	0.67
PLUTO	0.4-0.6	13.3	0.17

PROCEDURES

- EACH CREW MEMBER TRACKED AND "PHOTOGRAPHED" EACH PLANET 15 TIMES AT 1000 POWER
- PEAK-TO-PEAK VARIATIONS IN TARGET POSITION DURING EXPOSURE TIME WERE OBTAINED FROM RECORDED DATA
- MAN'S PERFORMANCE WAS COMBINED WITH THE PERFORMANCE OF OTHER COMPONENTS (OPTICS, FILM, ETC.) TO OBTAIN OVERALL SYSTEM PERFORMANCE

SIMULATION BLOCK DIAGRAM



1. MOL FLIGHT CREW (6 MEMBERS)
2. GE INTERIM EXPERIMENT SIMULATION STICK (PENCIL-TYPE, NON RETURN TO ZERO, 45° CONE)
3. E.A.I. 24D ANALOG COMPUTER
4. SINE WAVE GENERATOR
5. H-P OSCILLOSCOPE (LOW PERSISTENCE)
6. THUMB SWITCH (BUILT BY G&C LABORATORY)
7. C.M.C. DUAL PRESET COUNTER/TIMER
8. BRUSH 8 CHANNEL RECORDER
9. CIRCLE GENERATOR (AUDIO OSCILLATOR AND LAG NETWORK, BUILT BY G&C LABORATORY)

IN PLACE OF THIS PAGE, AN UNCLASSIFIED DIAGRAM OF THE HYBRID COMPUTATION CENTER WILL BE SHOWN.

SYSTEM RESOLUTION - COMPARISON WITH GROUND-BASED CAPABILITY

PLANET	MOL			GROUND-BASED
	PHOTO RES. (LP/MM)	ANGULAR RES. (SEC)	SURFACE RES. (MI)	SURFACE RES. (MI)
MERCURY	120	0.13	52	400
VENUS	120	0.13	39	300
MARS	106	0.15	35	230
JUPITER	64	0.25	440	1800
SATURN	59	0.27	980	3600
URANUS	56	0.28	2200	7800
NEPTUNE	54	0.29	3400	12000
PLUTO	32	0.50	8200	---

CONCLUSION

PLANETARY PHOTOGRAPHY FROM THE MOL VEHICLE CAN SIGNIFICANTLY IMPROVE KNOWLEDGE OF SURFACE FEATURES OF THE PLANETS

NEAR PLANETS NOW INCLUDED AS POTENTIAL STR TARGETS

STICK TRANSFER FUNCTION (STF) STUDY

BACKGROUND

- DEFINITION OF BASELINE STF (LINE OF SIGHT ANGLE/STICK DEFLECTION) REQUIRED FOR SOFTWARE DEVELOPMENT AND OTHER MISSION EXPERIMENTS.

- ORIGINAL GE BASELINE STF BELIEVED UNACCEPTABLE FOR HIGH PRECISION, TIME CRITICAL TASK (RATE PLUS ACCELERATION - DERIVED FROM MAN MODEL).

- ORIGINAL EDS FIDELITY INSUFFICIENT TO PERFORM THIS EXPERIMENT IN A TIMELY MANNER.

- AEROSPACE AGREED (FALL 1967) TO DEFINE AND OPTIMIZE A PRELIMINARY STF FOR MO AND ATS IN A REALISTIC TIMELINE ENVIRONMENT.

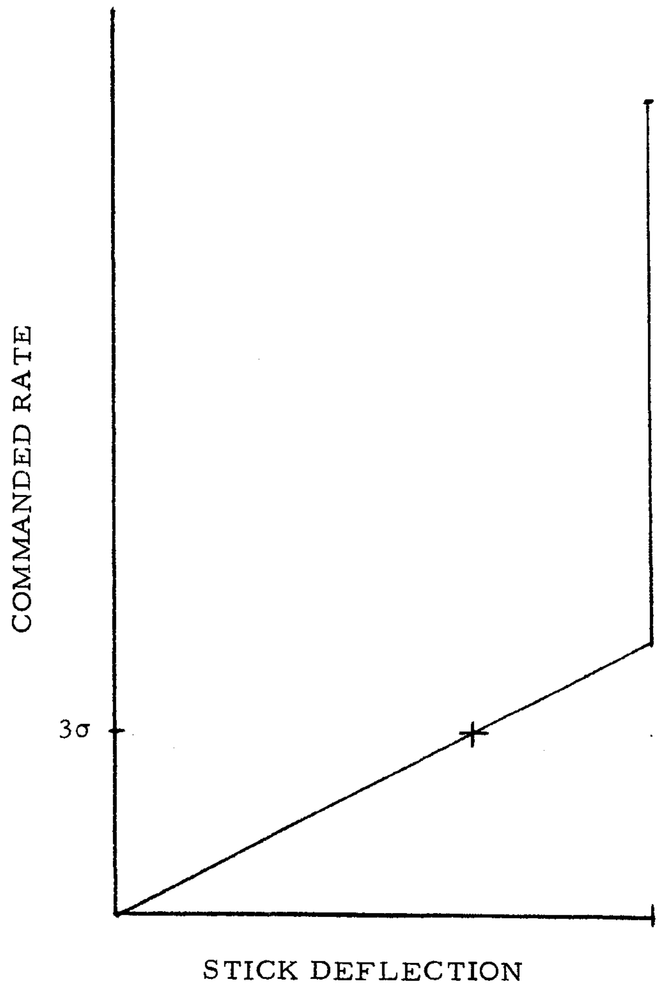
- FOLLOWING AEROSPACE STUDIES, GE AGREED TO VALIDATE RESULTS ON A MODIFIED EDS WHICH WOULD INCORPORATE REALISTIC SCENE AND DIGITAL ENVIRONMENT.

EXPERIMENT DESIGN

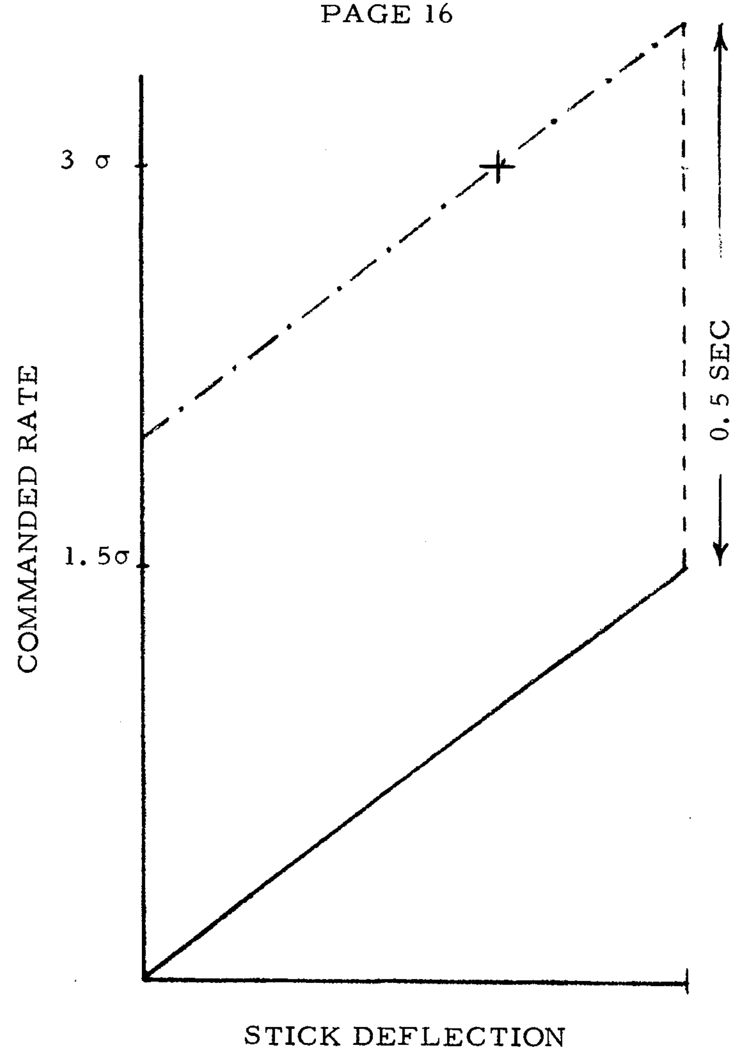
- CONTROLS
  - / 30 DEGREES HALF-ANGLE-CONE STICK - MODIFIED BY G&C LAB
  - / FOUR POSITION MAGNIFICATION CONTROL - BUILT BY G&C LAB
  - / DUAL RANGE ATS ZOOM CONTROLLER - BUILT BY G&C LAB
- DISPLAY
  - / CRT - SQUARE TARGET WITH SIZE PROPORTIONAL TO MAGNIFICATION
- TASK
  - / MO - RATE NULL DURING TIMED TARGET RUN
  - / ATS - CENTER AND RATE NULL
- ERROR SOURCES
  - / ALTITUDE AND MIRROR RATE MEASUREMENT ERROR ($COS^2 \Sigma$ EFFECT IN RATE) MO AND ATS
  - / SERVO RATE BIAS (CONSTANT RATE) MO AND ATS
  - / BEARING NOISE (LOW FREQUENCY RANDOM RATE) MO AND ATS
  - / INITIAL POSITION ERROR - ATS ONLY
- SCORING
  - / MO - TIME TO RATE NULL ($< 17 \mu r/SEC$), STEADY STATE NULLING AVERAGE
  - / ATS - TIME TO CENTER ($< \simeq 200$ FT), STEADY STATE NULLING AVERAGE

CREATION OF NEW STF TYPE

- PROBLEMS
  - / LOW GAIN RATE-ONLY STF GOOD FOR STEADY STATE RATE NULLING BUT LACKS AUTHORITY TO CATCH LARGE INITIAL CONDITIONS (RATE BIASES)
  - / HIGH GAIN RATE - ONLY STF IS NOISY AND JUMPY DURING STEADY STATE RATE NULLING
  - / ADDING ACCELERATION TO LOW GAIN RATE DEGRADES TIME TO RATE NULL AND STEADY STATE PERFORMANCE, AND REQUIRES UNNATURAL STICK MOTION
- OBJECTIVE
  - / CREATE A STICK TRANSFER FUNCTION TYPE WHOSE CHARACTERISTICS WILL CHANGE WITH THE TASK BEING PERFORMED
  - / A STF THAT CAN QUICKLY NULL A RATE "BIAS" IS NEEDED - I. E., A NON-LINEAR STF
- SOLUTION
  - / ADD HIGH GAIN ACCELERATION TERM TO LOW GAIN RATE TERM WHEN SUBJECT "RUNS OUT OF STICK"
  - / ACCELERATION TERM IS REMOVED WHEN STICK MOVES OFF END STOP, THUS CREATING A NEW OPERATING RANGE
  - / ΔRATE = ACCELERATION $\cdot$ Δt WITH Δt UNDER CONTROL OF CREWMAN
- SIMILAR PROBLEM OCCURS WHEN RAPID CENTERING REQUIRED ON ATS WHERE A POSITION BIAS IS NEEDED
- SOLUTION IS TO ADD HIGH GAIN RATE TERM TO LOW GAIN RATE TERM FOR EXTREME STICK DEFLECTIONS
  - / ΔPOSITION = RATE $\cdot$ Δt



TYPICAL RATE WITH END-STOP
RATE STF



TYPICAL RATE WITH END-STOP
ACCELERATION STF

MO STICK TRANSFER FUNCTION STUDY

- STF FORM TO BE OPTIMIZED - $K_1 + \frac{K_2}{S} + \frac{K_3}{S^2} + \frac{K_4}{S^2} \mu (d - 29^o)$

- INITIAL PARAMETER MINIMIZATION AND PILOT STUDY (TWO CREW)
  - / $K_1 = 0$; OTHERWISE VERY JUMPY RESPONSE AND FINGER NOISE
  - / $K_2 \neq 0$; OTHERWISE OSCILLATORY RESPONSE, INSTABILITY
  - / EITHER K_3 OR $K_4 = 0$; HAVING BOTH TERMS WORSE THAN EITHER ALONE
  - / GAINS OPTIMIZED FOR REMAINING STF CANDIDATES - $\frac{K_2}{S}, \frac{K_2}{S} + \frac{K_3}{S^2}, \frac{K_2}{S} + \frac{K_4}{S^2} \mu (d - 29^o)$

- FORMAL STUDY CANDIDATES: $\frac{\bar{K}_2}{S}, \frac{0.5 \bar{K}_2}{S} + \frac{0.25 \bar{K}_2}{S^2}, \frac{0.5 \bar{K}_2}{S} + \frac{\bar{K}_2}{S^2} \mu (d - 29^o)$

  WHERE VALUE OF $\bar{K}_2$ DEPENDS ON INITIAL CONDITION ASSUMPTIONS AND DESIRED OPERATING MODE

FORMAL MO STICK TRANSFER FUNCTION STUDY CONCLUSIONS (SIX CREW)

- o RATE WITH END STOP ACCELERATION STF HAS BEST OVERALL CAPABILITY AND FLEXIBILITY
  - / BEST RATE NULLING PERFORMANCE ($<5 \mu r$/SEC)
  - / TIME TO RATE NULL IS VERY GOOD ($\approx$ 2 SEC)
  - / PREFERRED BY MOST SUBJECTS
  - / RANDOM NOISE INTERACTION MINIMIZED
  - / HAS BEST TIME VERSUS RATE NULLING PERFORMANCE TRADEOFF FLEXIBILITY
  - / MOST EFFECTIVE PERFORMANCE AGAINST WIDE RANGE OF INITIAL CONDITIONS
- o RATE ONLY STF CLOSE IN PERFORMANCE BUT SIGNIFICANTLY LESS FLEXIBLE
- o RATE PLUS ACCELERATION STF POOREST

ATS STICK TRANSFER FUNCTION STUDY

- o STF CANDIDATES FOR PILOT STUDY
  - / RATE ONLY - GOOD, BUT HAS SIGNIFICANT FINGER NOISE AND SOMEWHAT OVERSENSITIVE
  - / RATE PLUS ACCELERATION - POOR
  - / RATE WITH END-STOP ACCELERATION - GOOD, BUT NOT OPTIMUM FOR CENTERING
  - / RATE WITH END-STOP RATE - BEST OVERALL PERFORMANCE AND FLEXIBILITY

- o PILOT STUDY CONCLUSIONS
  - / RATE WITH END-STOP RATE RECOMMENDED AS NEW BASELINE ATS STF

    $$\left(\frac{K_2}{S} + \frac{K_5}{S}\ \mu\,(d - 29^{o})\right); \qquad 2 \leq \frac{K_5}{K_2} \leq 3$$

  - / FINAL K_2, K_5 VALUES OR SPECIFIC RATIO NOT RECOMMENDED UNTIL FURTHER OPERATIONAL CONCEPTS DEFINED
    - WHEN WILL CENTERING BE PERFORMED (HOW OFTEN)
    - CENTERING TIME VERSUS ACCURACY TRADEOFF
    - ACTIVITY DETECTION/CENTERING PROCEDURES

GE VALIDATION STUDIES

- o MO
  - / VERIFIED ALL ASPECTS OF AEROSPACE STUDY
  - / RATE WITH END STOP ACCELERATION STF ADOPTED AS MO BASELINE

- o ATS
  - / GE VALIDATED RATE WITH END STOP RATE STF PERFORMANCE IN DIGITAL/STIMULUS ENVIRONMENT
  - / RATE WITH END STOP RATE STF ADOPTED AS ATS BASELINE

MISCONCEPTIONS RESOLVED USING AEROSPACE SIMULATOR

MISCONCEPTION	FACT
o STF GAIN SHOULD BE INVERSELY PROPORTIONAL TO MAGNIFICATION	o REAL, NOT APPARENT, RATES DETERMINE TASK; UNDESIRABLE SIDE EFFECTS
o STICK OUTPUT COUNTER SHOULD BE AUTOMATICALLY REZEROED AFTER EACH RUN	o MANUAL REZEROING NATURAL; UNDESIRABLE SIDE EFFECTS
o LEAD (ACCELERATION) SHOULD BE ADDED TO ANY STF OPTIMIZED ON AN ANALOG SIMULATOR TO COMPENSATE FOR DIGITAL PROCESSING LAGS	o ADDING LEAD DETRACTS FROM NATURAL STICK/SCENE RELATIONSHIPS
o MAN REQUIRES STICK EXTRAPOLATION TO MINIMIZE EFFECTS OF TEN TIMES/SEC SAMPLING	o SAMPLING AT TEN TIMES/SECOND HAS INSIGNIFICANT EFFECT. EXTRAPOLATION TECHNIQUES ARE PREDICTIVE AND TEND TO CREATE UNNATURAL SCENE MOTION
o SIMULATOR LOW RATE PERFORMANCE SHOULD BE SPECIFIED BASED ON MAN'S STATIC VISUAL RESOLUTION THROUGH THE OPTICS	o CREW CAN DETECT MUCH SMALLER MOTIONS (<1 MIN) THAN CALCULATIONS BASED ON STIMULUS AND OPTICAL QUALITY WOULD IMPLY

MISCONCEPTIONS RESOLVED USING AEROSPACE SIMULATOR
(CONTINUED)

MISCONCEPTION	FACT
o DIGITAL SCORING IS ADEQUATE FOR EXPERIMENTAL PURPOSES	o ON LINE ANALOG SCORING IS NEEDED FOR CREW TECHNIQUE OPTIMIZATION, DETECTION OF CREW FATIGUE, CREW MOTIVATION (AND SIMULATOR DEBUGGING)
o MOTOR SKILL EXPERIMENTS SHOULD INCLUDE ALL CREW MEMBERS TO GET MOST RELIABLE DATA	o BEST DATA OBTAINED BY USING AVAILABLE TIME TO TRAIN A FEW (2-6) HIGHLY MOTIVATED CREWMEN AS FAR DOWN THE LEARNING CURVE AS POSSIBLE
o MAN CAN NULL MOST OF THE BEARING NOISE	o MAN CANNOT NULL BEARING NOISE; ATTEMPT TO DO SO DEGRADES OVERALL RATE NULLING PERFORMANCE

AEROSPACE SIMULATOR IMPACT

- STF VALIDATION STUDY FORCED FIRST EDS HIGH FIDELITY CALIBRATION
- EDS MODIFICATION BASED ON AEROSPACE SIMULATOR DESIGN
- MDS DYNAMIC FIDELITY REQUIREMENTS BASED ON SIMULATION EXPERIENCE
- MDS CALIBRATION AND TEST PROCEDURES BASED ON AEROSPACE SIMULATIONS
- SOFTWARE DEVELOPMENT VERSUS HIGH FIDELITY MOTOR SKILL EXPERIMENT BETTER BALANCED IN SIMULATOR DESIGNS
- CREW PARTICIPATION IN CONTRACTOR EXPERIMENTS ENHANCED BY EXPERIENCE ON ALL ELECTRONIC SIMULATOR
- AEROSPACE PARTICIPATION IN CONTRACTOR EXPERIMENT PLANNING ENHANCED

FUTURE SIMULATOR EFFORTS

- [redacted]
- REFINEMENT OF ATS STF AND OPERATIONAL MODES
- RESOLUTION OF OTHER MAN-MACHINE TRACKING QUESTIONS AS THEY ARISE