• 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 Cue**

**TV Camera**

**TABLE DEVI**

**Electronic Camera (Equiv.)**

**MAE**

**NRO APPROVED FOR RELEASE 1 JULY 2015**

**ZOOM CONTROL**

**Display Cue**

**Cue Sequencing**

**Analogue Computer**

**Films Drive**

**Roll**

**Pitch**

**Error Input**

**Inputs**

**Zoom Control**

**Stick**

**Inputs**

**18"**

**TABLE DRIVE CAPABILITY (EQUIV.)**

**ACQ:** 7.5°/sec max., .075°/sec min

**MADE:** 4.4°/sec max

**5-6°/hr. Station**
CONTROL STICK TRANSFER FUNCTIONS

- "BASELINE"

- NONLINEAR ACCELERATION AUGMENTED STICK
<table>
<thead>
<tr>
<th>PERCENT ERROR</th>
<th>STICK TYPE</th>
<th>STICK GAIN</th>
<th>ACCEL. AUGMENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LINEAR</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>NONLINEAR</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>&quot;</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>1</td>
<td>.2</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>1</td>
<td>.5</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>1</td>
<td>.5</td>
</tr>
<tr>
<td>10</td>
<td>&quot;</td>
<td>2</td>
<td>.5</td>
</tr>
</tbody>
</table>

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BASELINE TYPICAL

BEFORE LEARNING (3RD TRIAL)

AFTER LEARNING

RATE ERROR

ACCELERATION AUGMENTATION

10 X

3 X

10 X

0

0.5

0.5
\[ G(S) = \frac{K_0 M_1(S) K_s A(S) F(S)}{G(S)} \]

- **IN PASS BAND** \( G(S) > 1 \)
  \[ \Delta \omega^2 = \int_0^{\infty} \left( \frac{\omega_f(S)}{G(S)} \right)^2 + \left( \frac{N(S)}{K_0 M_1(S)} \right)^2 \, df \]

  \( BW = \text{BANDWIDTH} \)
  \( f = \text{FREQUENCY} \)

- **ASSUME MAN'S "MUSCLE GAIN" IS ADAPTIVE TO INPUT ERROR OVER RANGE OF INTEREST**
  \( \text{THEN HE INCREASES} \ G(S) \ \text{SUCH THAT} \ \frac{\omega_f S}{G(S)} = \text{CONSTANT} \)
  \( \text{WITH BW PROP TO MUSCLE GAIN} \)
  \( \Delta \omega \text{ IS THEN PROPORTIONAL TO (BANDWIDTH)}^k \)

- **WITH ACCELERATION, AIDING, ONE ALLOWS A REDUCTION IN "MUSCLE GAIN"**
  \( \text{BY Raising} \ G(S) \ \text{IN THE LOW FREQUENCY REGION, THERE IMPROVING} \)
  \( \text{STEADY STATE RESPONSES} \)
FUTURE EFFORT

- SIMULATOR IMPROVEMENT
  - REDUCE EFFECT OR TABLE STICION - (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/111
  - VERIFICATION OF MODEL/STABILITY BOUNDARIES FOR MAN.
- INITIALIZATION STUDY - MINIMIZE ACQUISITION AND RATE KILLING TIME
  - OPERATOR TRAINING
  - ACQUISITION TO PRIMARY HANDBOFF 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 IMPROVE PERFORMANCE

6 - 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% /h ; AIDED: 0.1 - 0.2% /h

- EXCLUSIONS/SIMPLIFICATIONS
  - NONAVIGATIONAL UPDATING
  - NO AUTOMATIC MODE
  - SINGLE TARGETS ONLY. (NO CLUSTER CAPABILITY)
  - INDEPENDENT OF ACTS ELECTRONICS
  - MANUAL OR MINIMAL COMMAND UNIT INPUTS ONLY
**FAILURE MODE COMPARISON**

<table>
<thead>
<tr>
<th>FAILED ELEMENTS</th>
<th>ANALOG BACKUP</th>
<th>NO ANALOG BACKUP</th>
<th>UNMANNED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Readout</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>One ACQ Scope</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td>One Console</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td>Draglar Accel</td>
<td>OK</td>
<td>OK</td>
<td>MARGINAL/DEAD</td>
</tr>
<tr>
<td>Attitude Control</td>
<td>OK, EXCEPT FOR VALUES</td>
<td>OK, EXCEPT FOR VALUES</td>
<td>DEAD</td>
</tr>
<tr>
<td>V/H Sensor</td>
<td>OK</td>
<td>OK</td>
<td>MARGINAL/DEAD</td>
</tr>
<tr>
<td>Star Tracker</td>
<td>OK</td>
<td>OK</td>
<td>MARGINAL</td>
</tr>
<tr>
<td>Format Servo</td>
<td>OK</td>
<td>OK</td>
<td>MARGINAL</td>
</tr>
<tr>
<td>Digital Computer (5)</td>
<td>OK</td>
<td>DEAD</td>
<td>DEAD</td>
</tr>
<tr>
<td>Command Subsystem</td>
<td>OK (LESS TARGETS)</td>
<td>DEAD</td>
<td>DEAD</td>
</tr>
<tr>
<td>Focus Servo</td>
<td>MARGINAL</td>
<td>MARGINAL</td>
<td>MARGINAL</td>
</tr>
<tr>
<td>Primary Servo</td>
<td>BACKS UP ONLY SHAFT ENCODERS</td>
<td>DEAD</td>
<td>DEAD</td>
</tr>
</tbody>
</table>

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**SECRET SPECIAL HANDLING**
BACKUP DRIVE APPROACH

• SERVO CONTROL
  • RESOLVER CHAIN TRACKING FUNCTION GENERATION/CONTROL
  • RESOLVERS GEARED TO SERVO GIMBALS
  • ATS SERVO USED AS A COMPUTER
  • ESTIMATED WEIGHT: < 20 LBS
  • ESTIMATED POWER: < 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
\[ \omega_y = \left\{ \frac{\partial}{b_y + \tan \theta (s_b y - c_b y)} \right\} \{ c_2 c_a \frac{\partial}{\eta} + c_a \omega^0 \} \\
- \tan \theta (s_y^b - \omega_y^b y) + s_a (s_y^b - \omega_y^b y) - c_2 (s_y^b y - \partial) \]
+ \left[ (s_2 + \tan \theta \ce (s_2 + \tan \theta \ce (s_2 b_y - c_b y_2)) + c_2 s_2 a b y_2 \right] \lambda_x \\
+ \left[ s_2 s_a + (s_2 (\tan \theta s_x - c_2) - \tan \theta \ce s_x) b_y + s_2 a (c_2 - \tan \theta (s_2 b_2)) \right] \lambda_y \\
+ \left[ -s_2 c_2 + s_2 a (c_2 - \tan \theta (s_2 b_2)) b_y + (c_2 (\tan \theta s_x - c_2) - \tan \theta s_x b_2) \right] \lambda_z \} \\
\]

\[ \omega_x = \left\{ \frac{1}{b_x + \tan \theta (s_b y - c_b y)} \right\} \{ s_2 b_y - c_b y - \tan \theta (s_2 b_y - c_b y_2) + \frac{b_x}{c_2} (s_b y - c_b y) \omega_x \}
- \left[ s_2 c_2 (b_y - b_2) - \tan \theta (c_b y + s_2 b_2 - c_2 b y_2) \right] \lambda_x \\
- \left[ \frac{b_x}{c_2} + s_2 a (c_b y + s_2 b_2) \right] \lambda_y - \left[ \frac{b_x}{c_2} - c_2 a (c_b y + s_2 b_2) \right] \lambda_z \} \}
\]

\[ \omega_x, \omega_y = \text{inertial pitch} \& \text{roll gimbal rates} \]

\[ a = \text{rol} \text{l} \text{ g} \text{i} \text{m} \text{b} \text{a} \text{l} \text{a} \text{g} \text{e} \]

\[ \beta = \text{2D} - \theta - \tau_v = \text{mirror stereo angle} \]

\[ b = \text{optical axis vector} \]

\[ \omega_b = \text{vehicle inertial rate} \]

\[ \lambda = \text{line of sight rate} \]

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**Baseline Rate Equations**

---
**SMEAR ANALYSIS - ACQUISITION SCOPE**

+ 30° E, 0° N, 80 n. mi.

<table>
<thead>
<tr>
<th>ERROR SOURCE</th>
<th>IN-TRACK SMEAR °/SEC</th>
<th>X-TRACK SMEAR °/SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEHICLE ATTITUDE (0.5° ALL AXES)</td>
<td>0.011</td>
<td>0.023</td>
</tr>
<tr>
<td>VEHICLE RATES (0.02 °/SEC ALL AXES)</td>
<td>0.02</td>
<td>0.022</td>
</tr>
<tr>
<td>EPHEMERIS (4 K, 2 K, 2 K FT)</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>ORBITAL RATE (0.2%, 0° EQUIV. 500 FT/SEC)</td>
<td>0.007</td>
<td>0.005</td>
</tr>
<tr>
<td>SCOPE BASE ALIGNMENT (0.5°)</td>
<td>0.011</td>
<td>0.023</td>
</tr>
<tr>
<td>ACQUISITION SCOPE ANGLES</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(1° SET, 1° STANDOFF)</strong></td>
<td>0.044</td>
<td>-</td>
</tr>
<tr>
<td><strong>(1° SET)</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ACQUISITION SCOPE RATES (0.015 °/SEC)</td>
<td>0.03</td>
<td>0.013</td>
</tr>
<tr>
<td>SERVO COMPUTER ACCURACY (1%)</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>RSS</td>
<td>0.081 °/SEC</td>
<td>0.051 °/SEC</td>
</tr>
<tr>
<td>POINT ACQUISITION TO TARGET (0.15°)</td>
<td>0.005 (REMOVE 0.044 )</td>
<td></td>
</tr>
<tr>
<td>RSS</td>
<td>0.067 °/SEC</td>
<td>0.051 °/SEC</td>
</tr>
</tbody>
</table>

1% V/A ± 0.03 °/SEC.
### SMEAR ANALYSIS - PRIMARY W/O MANUAL CONTROL

30°Ω, 0°Ω, 80 n.mi.

<table>
<thead>
<tr>
<th>ERROR SOURCE</th>
<th>IN-TRACK SMEAR</th>
<th>X-TRACK SMEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACQ SCOPE HANDOVER</td>
<td>0.067°/SEC</td>
<td>0.051°/SEC</td>
</tr>
<tr>
<td>SUBTRACT ROLL RATE CONTRIBUTOR</td>
<td>--</td>
<td>(0.017)°/SEC</td>
</tr>
<tr>
<td>(USING INERTIAL DRIVE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPTICAL AXIS ALIGNMENT (1°)</td>
<td>0.038°</td>
<td>0.02°</td>
</tr>
<tr>
<td>POINTING ERROR (.15°)</td>
<td>0.005°</td>
<td>0.004°</td>
</tr>
<tr>
<td>RATE ERROR OF SERVO (.005°/SEC)</td>
<td>0.01°/SEC</td>
<td></td>
</tr>
<tr>
<td>RSS ERROR AT Σ = +30°</td>
<td>0.079°/SEC</td>
<td>0.052°/SEC</td>
</tr>
<tr>
<td>COMPUTER ERROR INCREMENT</td>
<td>0.12</td>
<td>---</td>
</tr>
<tr>
<td>TO Σ = -30°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSS ERROR AT Σ = -30°</td>
<td>0.143°/SEC</td>
<td>0.052°/SEC</td>
</tr>
</tbody>
</table>
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!