N87-17833

Regulation of the SCOLE Configuration

by

Gregory A. Norris
Emmanuel G. Collins
Robert E. Skelton
Purdue University

REGULATION OF

THE SCOLE CONFIGURATION

INVESTIGATORS

Gregory A. Norris

Emmanuel G. Collins

Robert E. Skelton

PERFORMANCE REQUIREMENTS

(I) MAINTAIN RMS OF THE STEADY STATE LINE-OF-SIGHT (LOS) ERROR WITHIN A SPECIFIED BOUND.

(II) MAINTAIN STEADY STATE ACTUATOR VARIANCES AS CLOSE AS POSSIBLE TO SPECIFIED BOUNDS.

ORIGINAL SCOLE CONFIGURATION

- LOCATION OF 2 PROOF MASS ACTUATORS NOT SPECIFIED.
- 42 SENSORS PROVIDED.

OBJECTIVES

(I) DETERMINE LOCATIONS FOR PROOF MASS ACTUATORS.

(II) DETERMINE A REDUCED SET OF SENSORS.

(III) DESIGN A CONTROL LAW TO MEET PERFORMANCE REQUIREMENTS FOR LOS ERROR AND ACTUATORS.

- SOLUTIONS TO THE 3 PROBLEMS ARE INTERDEPENDENT.
- CHOICE OF ACTUATORS AND SENSORS INFLUENCES CONTROL LAW.
- CHOICE OF CONTROL LAW INFLUENCES SENSOR AND ACTUATOR SELECTION.

LINEARIZED DYNAMICAL MODEL

VECTOR SECOND ORDER MODAL FORM

$$\ddot{\eta} + D\dot{\eta} + \Omega^2\eta = \bar{B}(u+w)$$

output vector y

$$y_1 = LOS_x \ , \quad y_2 = LOS_y \ , \quad y_3 = LOS_z$$

$$E(LOS\ error)^2 = (Ey_1^2 + Ey_2^2 + Ey_3^2)^{1/2}$$

$$y = C_p\eta$$

measurement vector z

$$z_{p,r} = \text{position \& rate measurement vector}$$

$$= P_p \eta + P_v \dot{\eta} + v_{p,r}$$

$$z_a = \text{acceleration measurement vector}$$

$$= Q\ddot{\eta} + v_a$$

$$= Q(-\Omega_\eta^2 - D\dot{\eta} + \bar{B}u + \bar{B}w) + v_a$$

$$z = \begin{bmatrix} z_{p,r} \\ z_a - Q\bar{B}u \end{bmatrix} = M_p \eta + M_v \dot{\eta} + v$$

where

$$M_p = \begin{bmatrix} P_p & 0 \\ 0 & -Q\Omega^2 \end{bmatrix}$$

$$M_v = \begin{bmatrix} P_v & 0 \\ 0 & -QD \end{bmatrix}$$

$$v = \begin{bmatrix} v_{p,r} \\ v_a + Q\bar{B}w \end{bmatrix}$$

=> ASSOCIATED SENSOR NOISE (v) & ACTUATOR NOISE (w) ARE CORRELATED

- MODEL OBTAINED USING CUBIC BEAM ELEMENT SHAPE FUNCTIONS FOR BEAM BENDING AND LINEAR SHAPE FUNCTION FOR BEAM TWIST.
- 32 MODES IN ORIGINAL MODEL.
- MODAL COST ANALYSIS USED TO REDUCE TO 23 MODE DESIGN AND EVALUATION MODEL.

MODAL COST ANALYSIS

modal cost rank	mode no.	modal cost	freq. (hz)	mode type
1	1	infinite	0	rigid body
2	2	infinite	0	rigid body
3	3	infinite	0	rigid body
4	5	.911e+07	.299e+00	bending (roll)
5	7	.363e+07	.118e+01	bending
6	4	.336e+07	.276e+00	bending (pitch)
7	6	.138e+07	.811e+00	bending
8	8	.955e+06	.205e+01	bending
9	10	.673e+04	.551e+01	bending
10	9	.556e+04	.478e+01	bending
11	11	.246e+02	.123e+02	bending
12	14	.365e+01	.243e+02	bending
13	17	.245e+01	.395e+02	twist
14	12	.305e+00	.129e+02	bending
15	16	.116e+00	.390e+02	bending
16	15	.349e-01	.256e+02	bending
17	26	.995e-02	.109e+03	bending
18	25	.377e-02	.103e+03	bending
19	13	.376e-02	.237e+02	bending
20	29	.174e-02	.140e+03	bending
21	35	.836e-03	.215e+03	bending
22	20	.597e-03	.586e+02	bending
23	28	.370e-03	.139e+03	bending
24	23	.125e-03	.817e+02	bending
25	19	.310e-04	.581e+02	bending
26	34	.275e-04	.215e+03	bending
27	32	.617e-05	.175e+03	bending
28	31	.294e-05	.175e+03	bending
29	27	.131e-05	.135e+03	twist
30	24	.140e-07	.106e+03	twist
31	30	.134e-07	.167e+03	twist
32	33	.413e-08	.200e+03	twist
33	22	.298e-10	.811e+02	bending
34	18	.340e-11	.515e+02	twist
35	21	.226e-13	.782e+02	twist

- FIRST 5 FLEXIBLE MODES DOMINATE MODAL COST
- BEAM BENDING DOMINATES MODAL COST

CONTROL LAW DESIGN VIA

THE OUTPUT VARIANCE ASSIGNMENT ALGORITHM

- ITERATIVE ALGORITHM DEVELOPED BY SKELTON AND DELORENZO

- OBJECTIVE IS TO CHOOSE DIAGONAL Q AND R IN THE LQG COST FUNCTIONAL

$$\nu = E_\infty(y^T Q y + u^T R u)$$

S.T. THE LQG CONTROL LAW SATISFIES

$$E_\infty y_i^2 = \sigma_i^2 \quad (\text{or} < \sigma_i^2) \quad \forall \quad i = 1 \rightarrow n_y$$

WHILE MINIMIZING

$$\sum_{i=1}^{n_u} \frac{E_\infty u_i^2}{\mu_i^2} .$$

bounds on input variances

SENSOR AND ACTUATOR SELECTION VIA INPUT/OUTPUT COST ANALYSIS

- SUBOPTIMAL APPROACH.

- BASED ON DECOMPOSING COST FUNCTION

$$\nu = E_\infty(y^T Qy + u^T Ru)$$

as

$$\nu = \sum_{i=1}^{n_y} \nu_i^y + \sum_{i=1}^{n_u} \nu_i^u$$

$$\nu = \sum_{i=1}^{n_u} \nu_i^w + \sum_{i=1}^{n_z} \nu_i^v .$$

- DEFINES ACTUATOR EFFECTIVENESS,

$$\nu_i^{act} = \nu_i^u - \nu_i^w$$

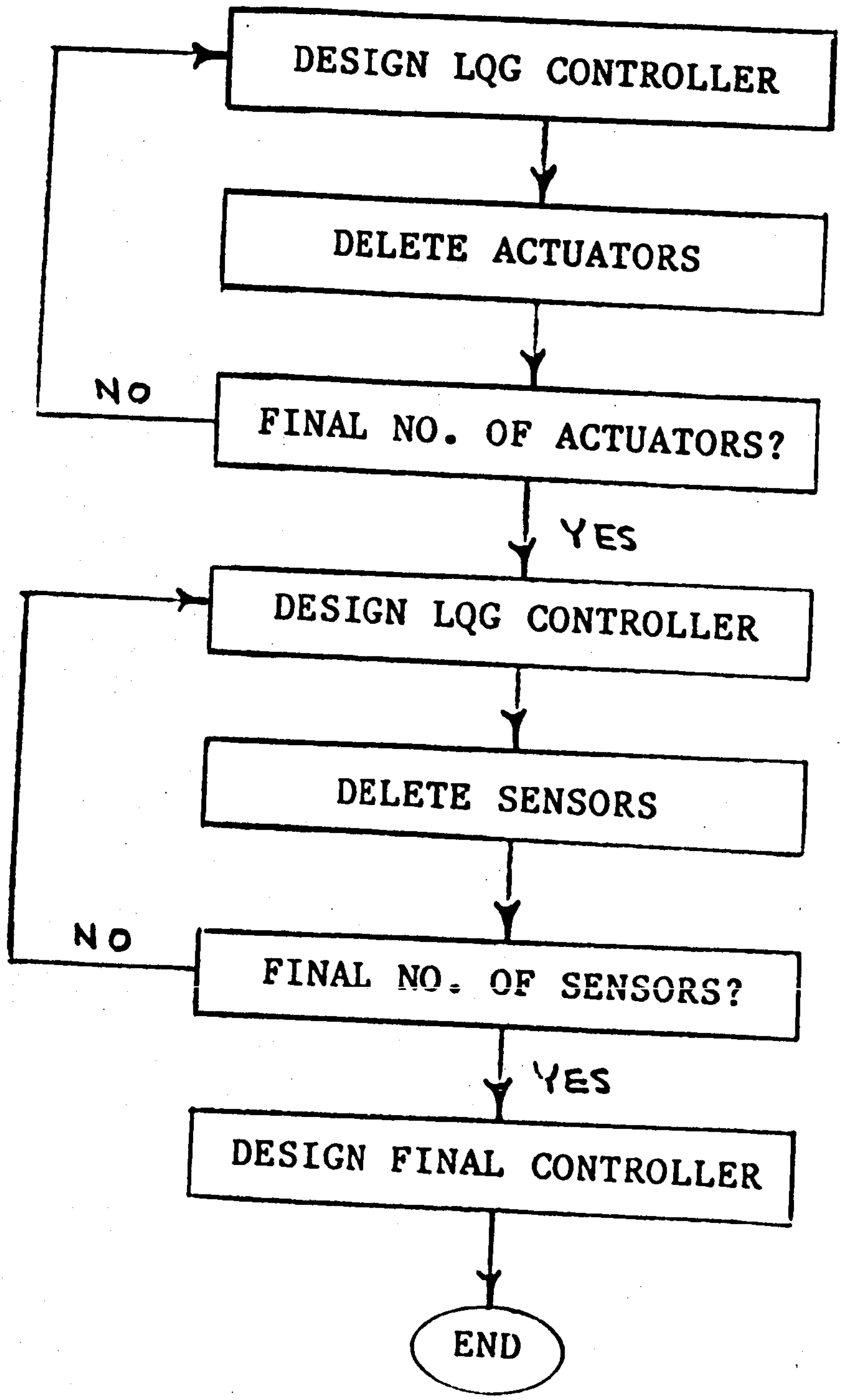
AND SENSOR EFFECTIVENESS

$$\nu_i^{sen} = \nu_i^v .$$

- DELETES ACTUATOR(S) OR SENSOR(S) WITH LOWEST EFFECTIVENESS VALUES.

SOLUTION PROCEDURE

- BEGIN WITH LARGE SET OF PROOF MASS ACTUATORS AT FIXED LOCATIONS



SOME RESULTS

ORIGINAL SCOLE PROPOSAL

rms(los error) < .02 deg

OUR FINDINGS

if noise through shuttle cmgs only:

rms(los error) > .045 deg

if equivalent noise through all actuators:

rms(los error) > .075 deg

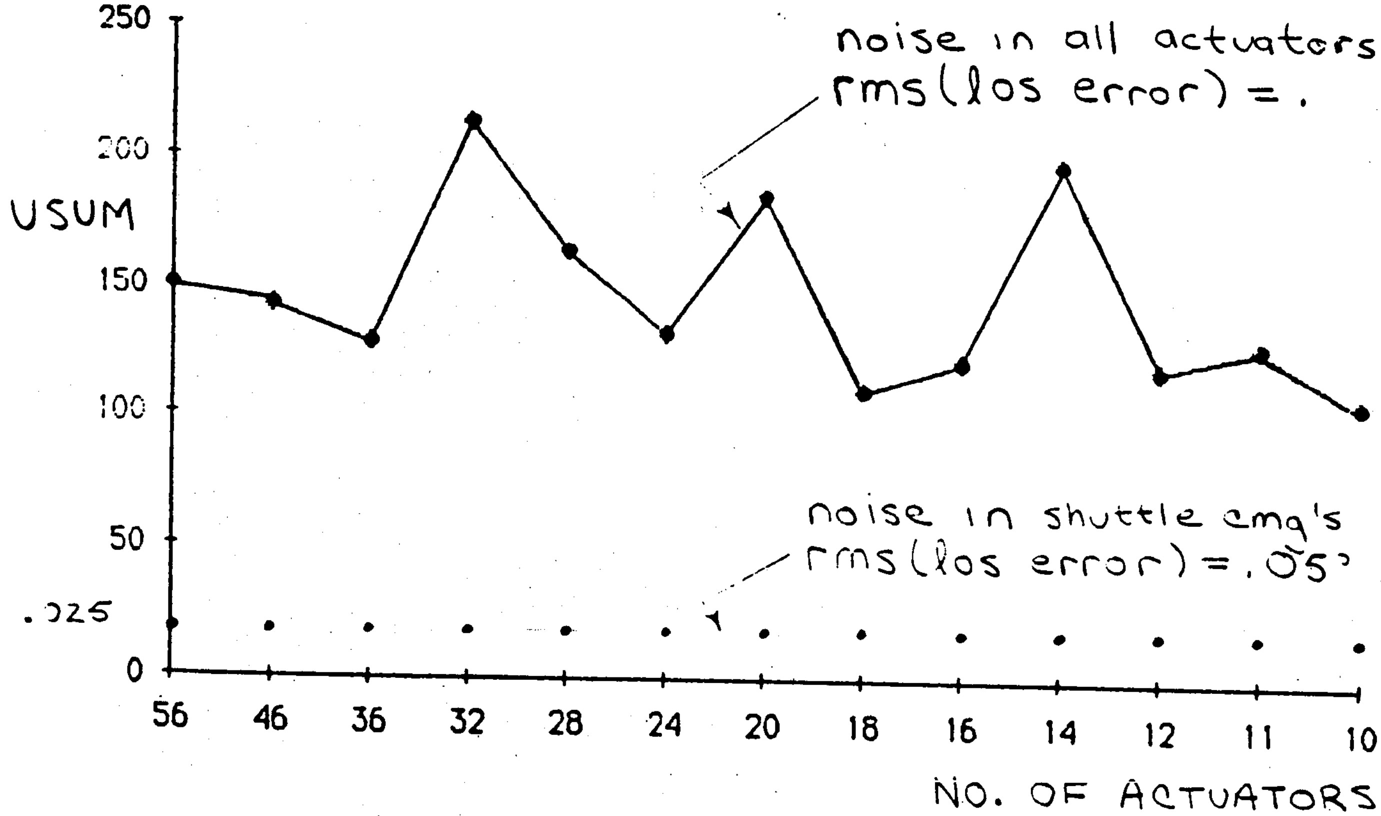
CONCLUSIONS

- ORIGINAL SPECS ON LOS ERROR ARE NOT ACHIEVABLE.
- MUST MODIFY LOS SPECS.

ACTUATOR SELECTION

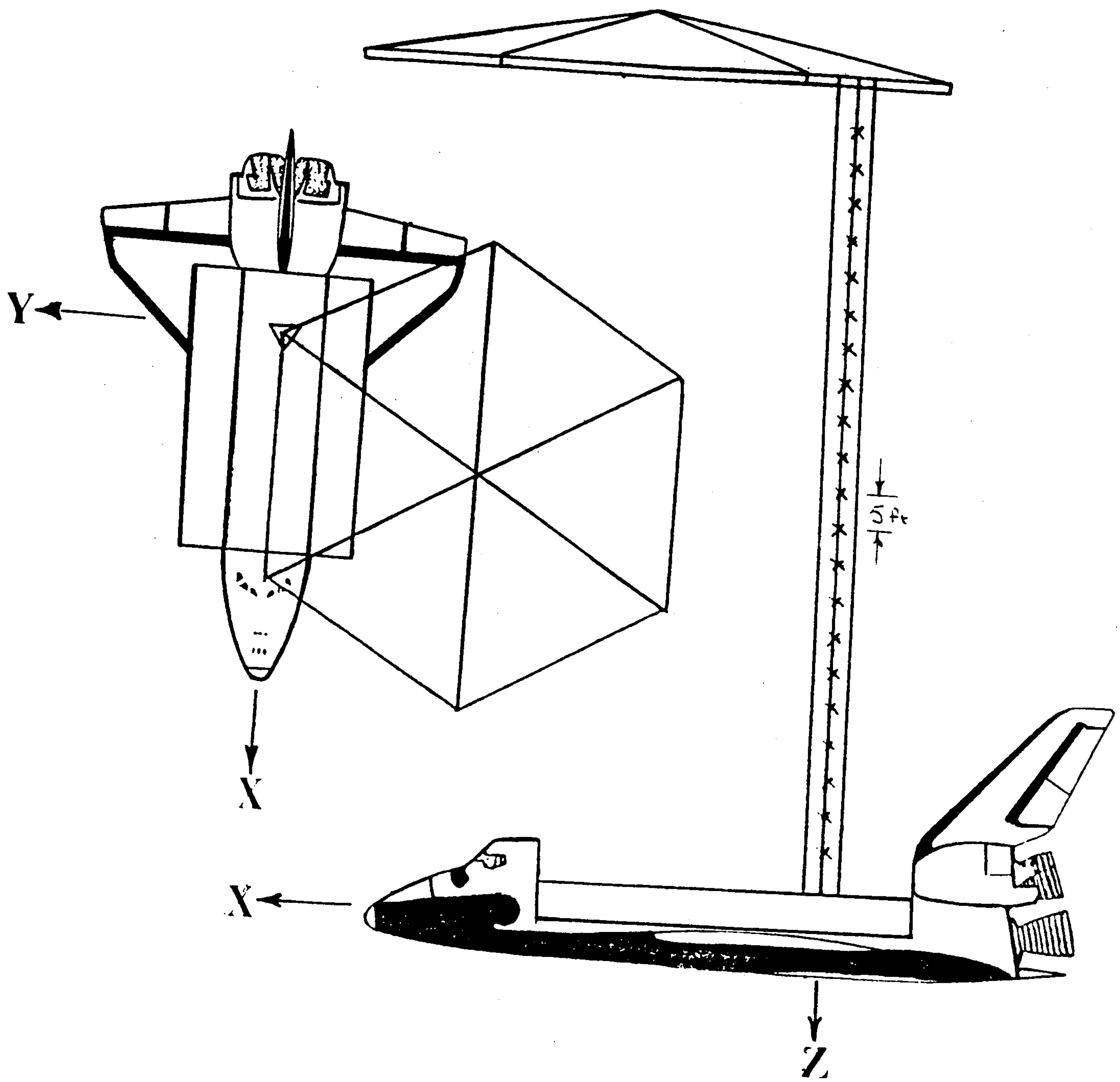
DEFINE

$$USUM = \sum_{i=1}^{n_u} \frac{Eu_i^2}{\mu_i^2} = \text{dimensionless measure of total control effort}$$



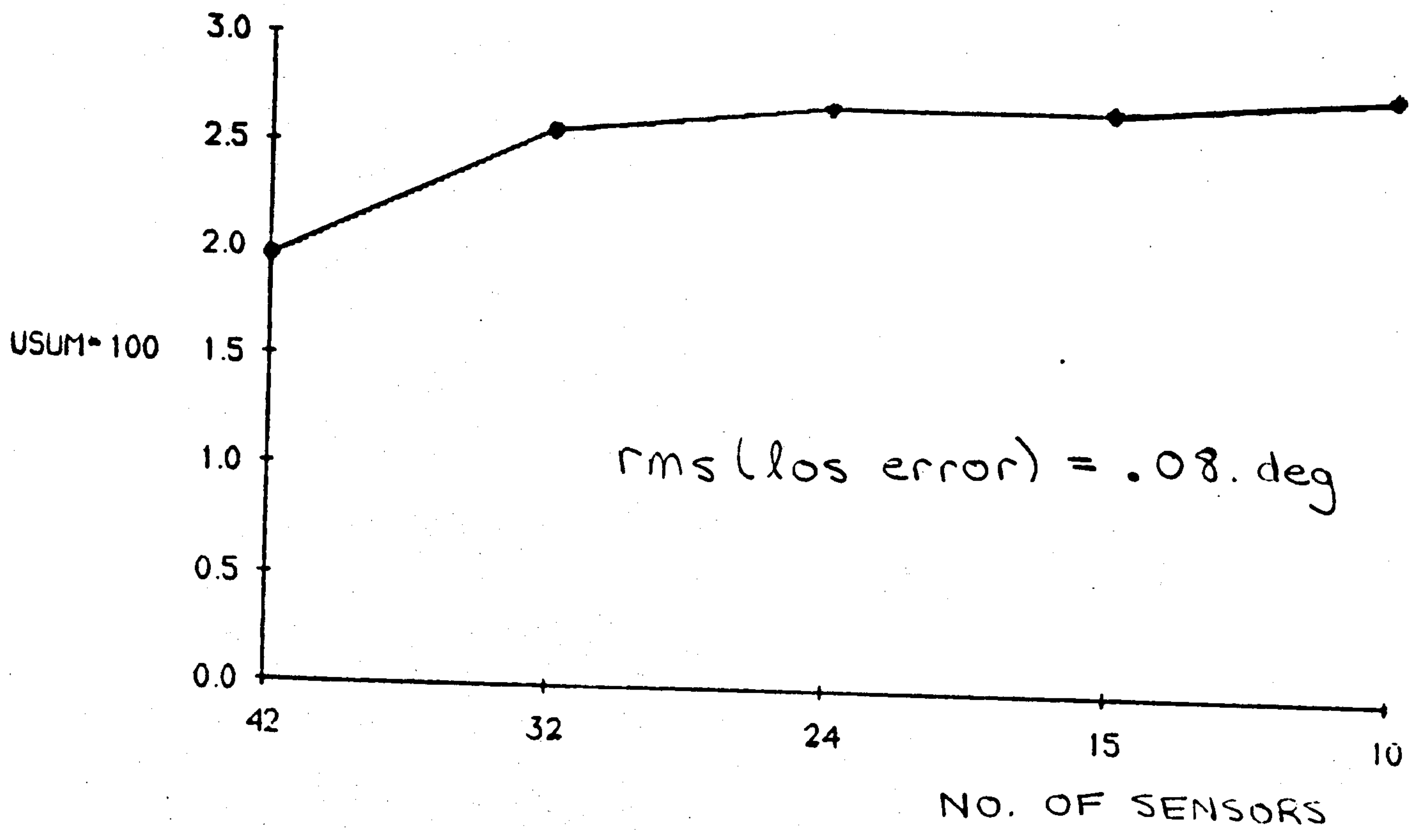
FINDINGS

- BY USING REDUCED SET OF ACTUATORS THERE IS A 50% SAVINGS IN CONTROL EFFORT (AS MEASURED BY USUM).



• PROOF MASS ACTUATORS NEAR TOP OF THE BEAM ARE MORE EFFECTIVE

SENSOR SELECTION



- GOOD PERFORMANCE MAY BE ACHIEVED WITH A MUCH SMALLER SET OF SENSORS.

CONCLUSIONS

(I) RMS(LOS ERROR) $\leq$ .02 DEG IS NOT ACHIEVABLE.

RMS(LOS ERROR) $\leq$ .05 DEG IS ACHIEVABLE IF NOISE IS ONLY THROUGH SHUTTLE CMG'S.

RMS(LOS ERROR) $\leq$ .08 DEG IS ACHIEVABLE IF (EQUIVALENT) NOISE IS THROUGH ALL ACTUATORS.

(II) PROOF MASS ACTUATORS SHOULD BE PLACED NEAR TOP OF MAST.

(III) GOOD PERFORMANCE MAY BE ACHIEVED WITH A (SIGNIFICANTLY) REDUCED SET OF SENSORS.