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ON THE USE OF THE OCM'S QUADRATIC OBJECTIVE FUNCTION AS A PILOT RATING METRIC

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In several previous works, (Refs. 1-3) a correlation between the magnitude of the quadratic objective function from an optimal control pilot model and the subjective rating of the vehicle and task has been discussed. Since such a correlation would provide a valuable tool for handling qualities research and flight control synthesis, as used in Reference 4 and 5 for example, validating it over a wide range of tasks and plant dynamics is appropriate.

To this end, an anlysis of Arnold's (Ref. 6) simulation results for fourteen aircraft configurations flight tested earlier by Neal and Smith (Ref. 7) has been completed. A fixed set of pilot model parameters, given in Table 1, were found for all cases in modeling the simulated <u>regulation</u> task. The agreement obtained between performance statistics is shown in Figure 1, and a strong correlation, shown in Figure 2, was obtained between the cost function and rating. Furthermore, modeling the same fourteen configurations in the <u>tracking</u> task used by Neal and Smith indicated reasonable correlation as well, considering no experimental data is available from the Neal and Smith tests to check the pilot model parameters in this case.

However, when evaluating other configurations tested by Neal and Smith that included higher-order control system dynamics, the pilot rating/cost magnitude sensitivity, or the slope of the regression, appeared to be greater. This is indicated in Figure 3.

All these configurations have identical short period eigenvalues (which would yield Level 1 ratings according the the Mil Spec. 8585B), and yet ratings as high as eight were obtained in the flight tests due to the other dynamic modal characteristics.

The significant factors are that correlation between pilot rating and cost function <u>is</u> evident for these cases, but the sensitivity (slope) of the rating would seem to be much greater than that exhibited in the previous figure . The reasons for this apparent difference in sensitivity are

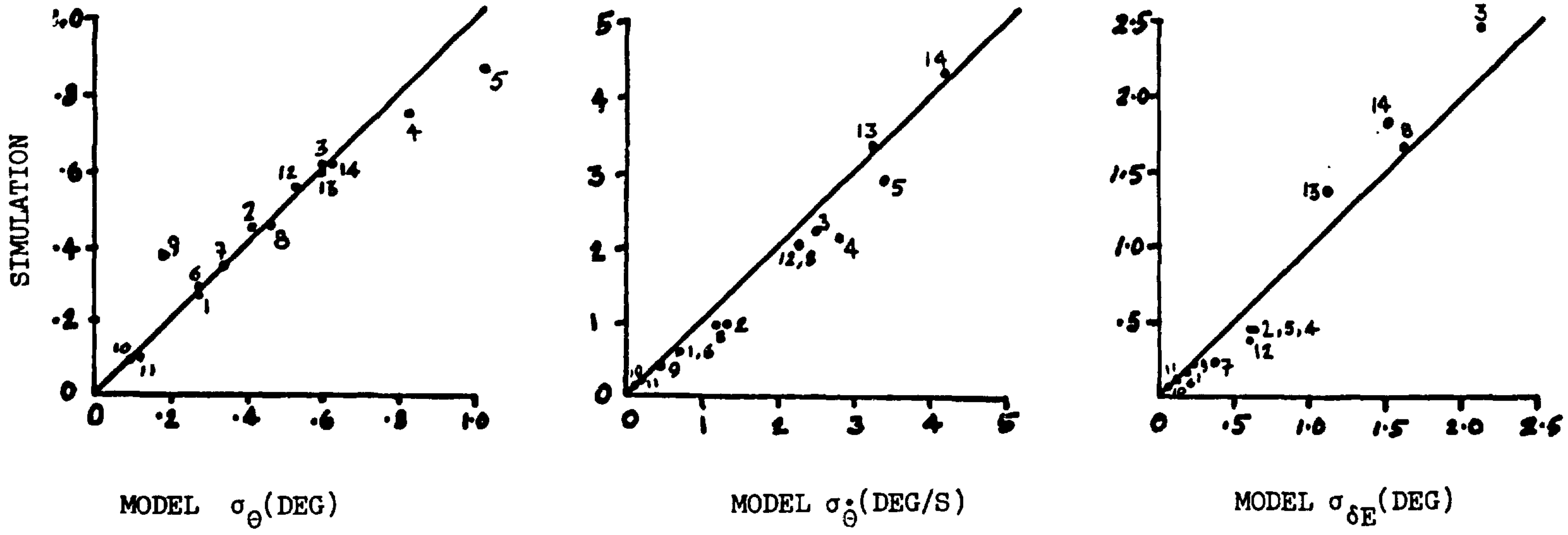

FIG. 1, CORRELATION BETWEEN ARNOLD'S SIMULATION AND MODEL RMS PERFORMANCE

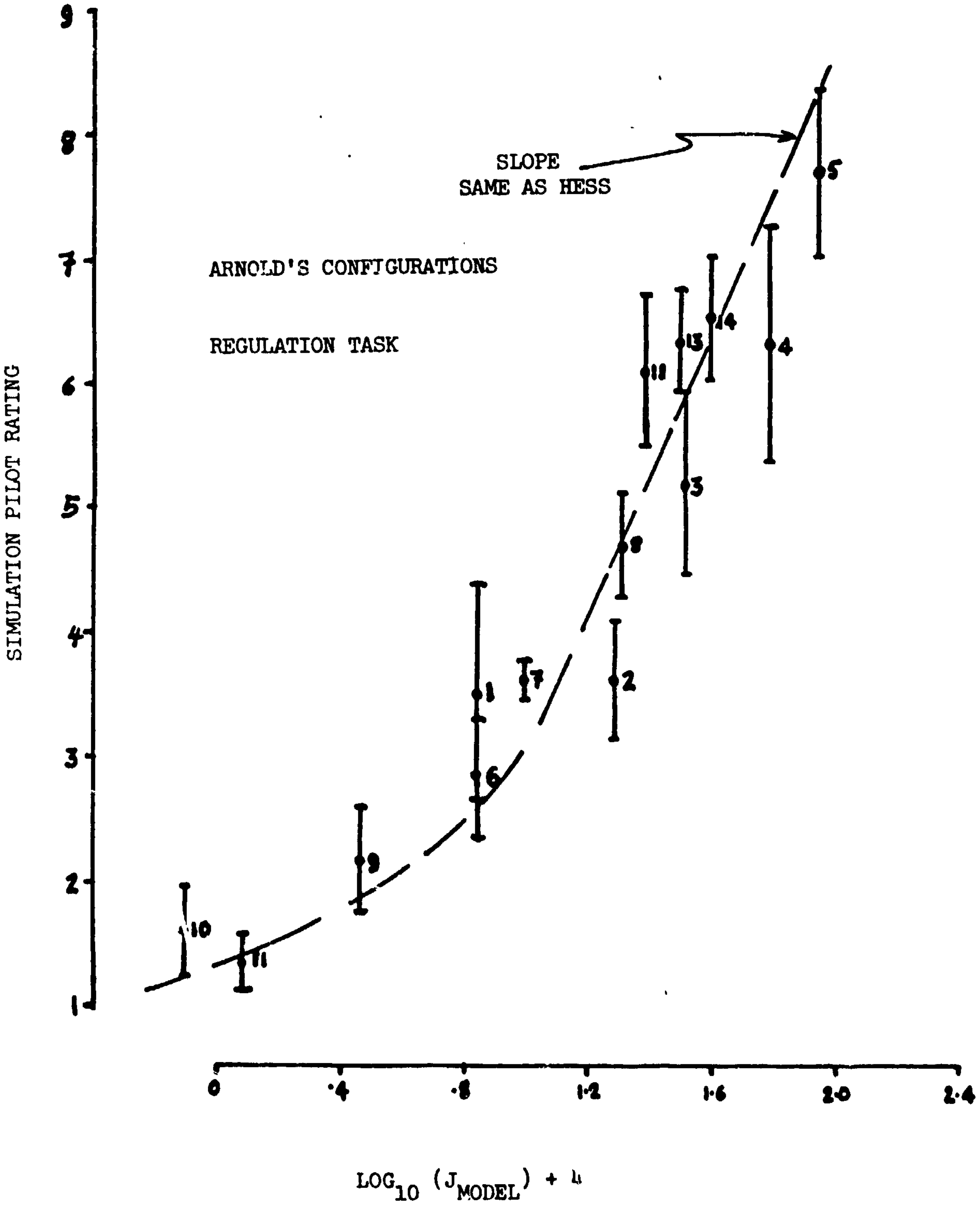

FIG. 2, OBJECTIVE FUNCTION/PILOT RATING CORRELATION

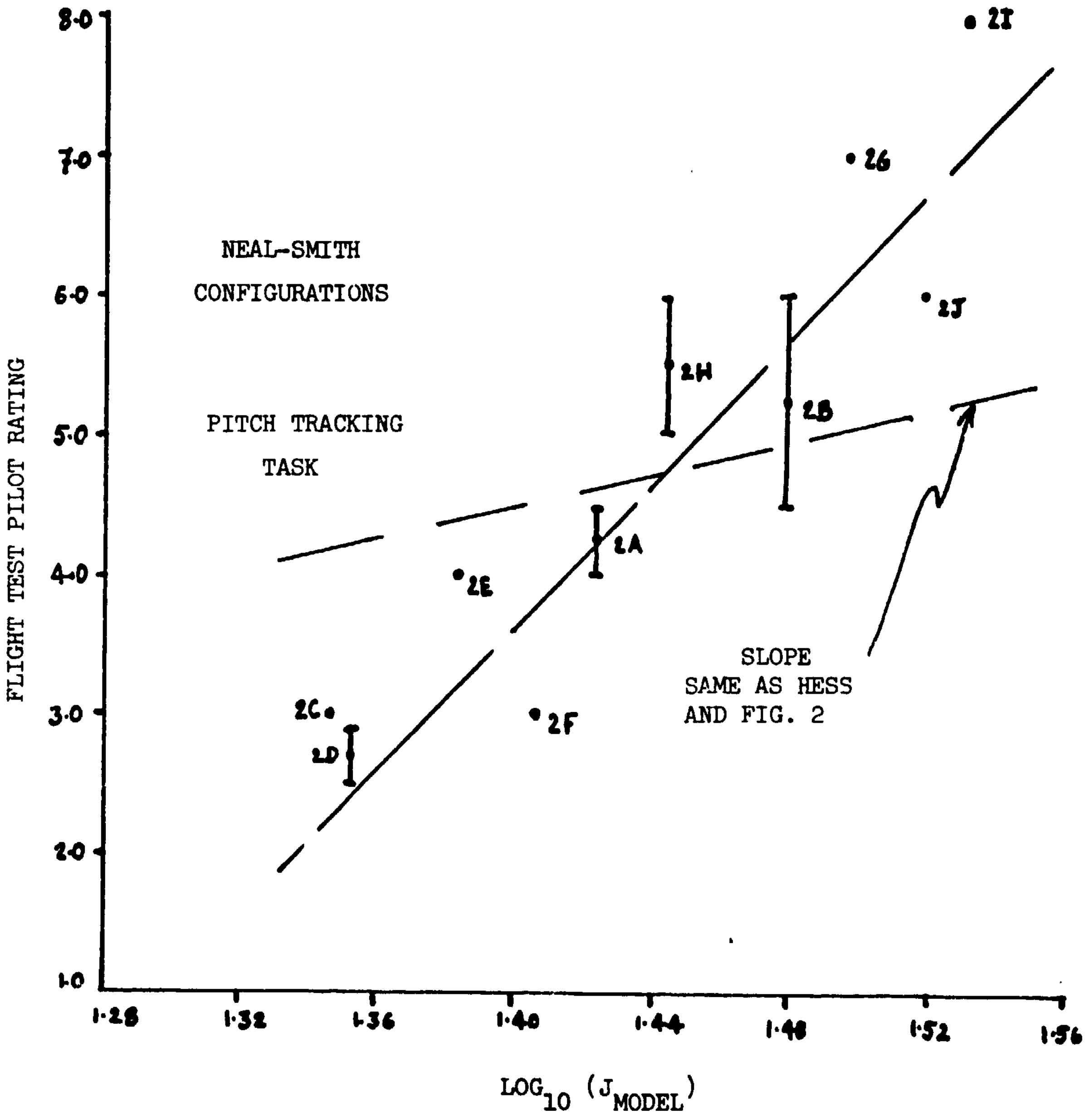

FIG. 3, CORRELATION FOR HIGH-ORDER DYNAMICS CONFIGURATIONS

Table 1

Pilot Model Parameters For Arnold Simulation Cases

Observation vector,	$\bar{y}_p^T = [\theta_{error}, \dot{\theta}_{error}]$
Objective function weights,	$Q_\theta = 25.0$ $Q_{\dot{\theta}} = 0.1$
Fractional attention allocation,	0.5 on θ and $\dot{\theta}$
Full attention observation noise ratio,	-20dB
Observation thresholds,	$T_\theta = .002°$ $T_{\dot{\theta}} = .004°/sec$
Observation delay,	$\tau = 0.2$ sec
Neuromuscular lag,	$\tau_N = 0.1$ sec
Neuromotor noise ratio,	-20dB
Control input δ_{stick} to minimize	$J_p = E\left\{\lim_{T\to\infty} \frac{1}{T}\int_0^T (Q_\theta \theta^2 + Q_{\dot{\theta}}\dot{\theta}^2 + g\delta_{st}^2)dt\right\}$

open to conjecture at this point, but the following are put forth as possibilities.

1) The sensitivity is greater for dynamics significantly different from "rigid-body-only" dynamics, with which the pilot has more familiarity. Just as rating sensitivity is often higher for greater task difficulty, the significantly different dynamic characteristics may lead to more sensitive ratings from the pilots.

2) Or, the sensitivity is not really different from that shown previously, but the pilot model is incorrect for these aircraft and hence the cost function is not correct. Note that in the absence of rms statistics from the experimental work, we are not really confident that the pilot model, calibrated from simulation results on low-order dynamics, is correct. Even possible too is that the OCM of the pilot may need modification when investigating higher order dynamic systems. At any rate, the effect of pilot model inaccuracies may be the prediction of an incorrect trend or sensitivity here.

It appears that when significant higher-order dynamics are due to aeroelastic (or other low damped) modes, the latter hypothesis can be supported.

To be considered are the fixed-base simulation results of Yen (Ref. 8), in which a B-1-type vehicle was evaluated in an attitude tracking task with a very low-frequency discrete command signal. Three cases (given below) of vehicle dynamics are considered, each including short-period, phugoid, and two aeroelastic modes.

Table 2

Three Cases of Vehicle Dynamics

	ζ_{sp}	ω_{sp} rad/sec	ζ_{ph}	ω_{ph} rad/sec	ζ_{1e}	ω_{1e} rad/sec	ζ_{2e}	ω_{2e} rad/sec
1.	0.5339	2.806	0.0197	0.0708	0.0494	13.312	0.0215	21.354
2.	0.5235	2.572	-0.0006	0.0573	0.0877	8.789	0.0213	21.356
3.	0.5217	1.769	Real Roots +0.0910 -0.0767		0.1999	5.866	0.0213	21.357

Now the simulated and modeled (via OCM) tracking error and pilot rating are given in Figures 4 and 5. Specifically note the results for case 3, in which the phugoid is unstable and the first elastic mode frequency is very low.

Now the total attitude angle observed by the pilot is the sum of the rigid, or mean axis attitude plus the change in local attitude due to structural flexure, or

$$\theta_{Total} = \theta_{Rigid} + \theta_{Elastic}$$

If it is assumed that the pilot is attempting to regulate total attitude error given by

$$\varepsilon_T = \theta_{Command} - \theta_{Total}$$

the tracking error obtained from the model is significantly less (1.9°) than obtained in simulation.

However, if the rigid, or <u>mean-axis error</u> is assumed to be regulated, rather than total error, the results agree extremely well! That is, this mean-axis error, given by

$$\varepsilon_{Mean} = \theta_{Command} - \theta_{Rigid}$$

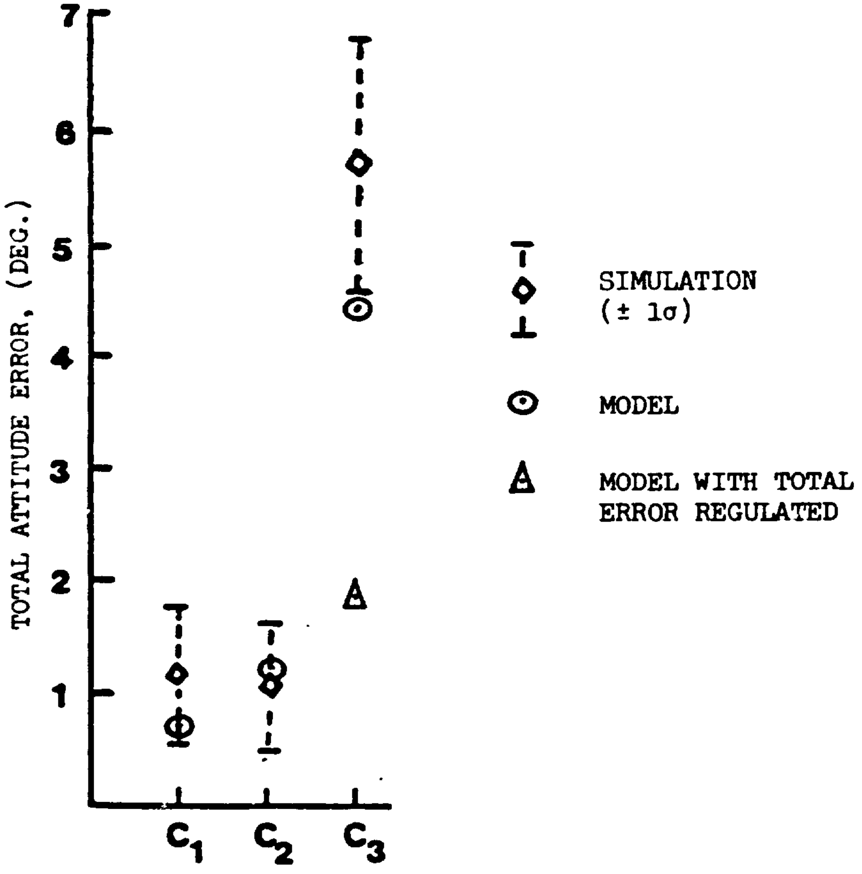

FIG. 4 ATTITUDE ERROR COMPARISON

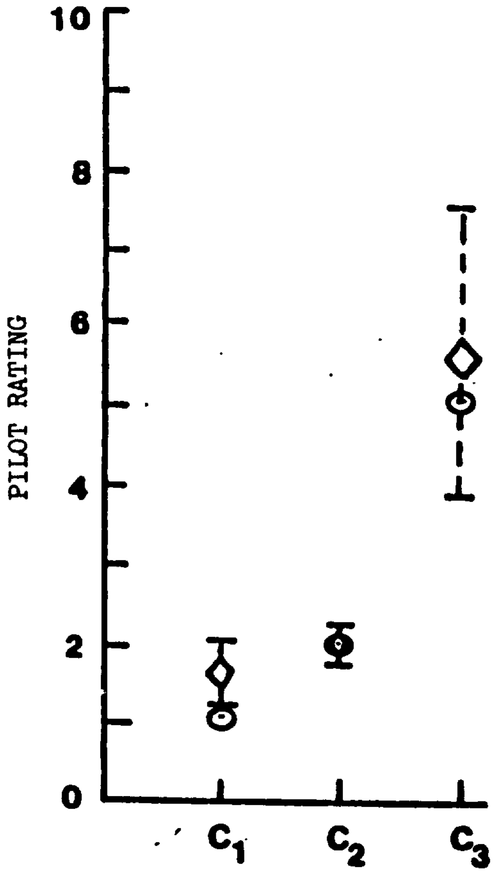

FIG. 5 PILOT RATING COMPARISON

is weighted in the pilot's objective function rather than total error, and since total attitude and total error is what is being observed by the pilot, he must estimate $\varepsilon_{\text{Mean}}$ and then attempt to minimize the estimate. Finally, the pilot rating results are obtained by using this different objective function with the original sensitivity (slope) from Figure 2!

Based on this approach, it appears that rating sensitivity is constant, and that the degradation in rating and performance for case 3 may be primarily due to the difficulty in estimating the mean-axis error when the aeroelastic mode frequency approaches that of the "rigid-body" or mean-axis short period frequency. Furthermore, this approach is in contrast to that of Swaim, (Ref. 9) where the assumption of a reduced-order pilot model is made.

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