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Space Guidance Analysis Memo #25

To: Distribution
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Subj: Guidance Dynamic Requirements on SCS

It is assumed that the autopilot can be represented for dynamic analysis purposes by Fig. 1 which is extracted from Ref. 1. In this diagram, the notation is

F - vehicle thrust
ℓ - distance c. g. to nozzle
J - moment of inertial (pitch, yaw)
K_A, K_M, K_S, K_N - autopilot gains available for adjustment
τ_M – time constant, nozzle response

The interface between the stabilization and control system and the guidance system occurs, as indicated on the diagram, in front of the gain K_A. At this point the guidance system produces an error signal in pitch (and in yaw) which is to be nulled by the autopilot.

Preliminary analysis indicates that the performance function associated with the configuration

$$\frac{\theta}{\theta_C} = \frac{1}{\left[\frac{S^2}{(W_M/2.61)^2} + \frac{2(.924)S}{W_M/2.61} + 1\right]\left[\frac{S^2}{(W_M/2.61)^2} + \frac{2(.383)S}{W_M/2.61} + 1\right]}$$

is satisfactory for $W_M (W_M = 1/\tau_M)$ of 30 rad/sec or higher. Configurations yielding lower band widths or less damping may be acceptable but must be negotiated.

The term $\frac{F\ell}{J}$, which is notated as W_V^2 in Ref. 2, significantly affects the dynamic response of the thrust vector direction control loop (the guidance loop) as may be seen from Fig. 2. (Fig. 2 assumes the existence of the auto-pilot postulated above.)

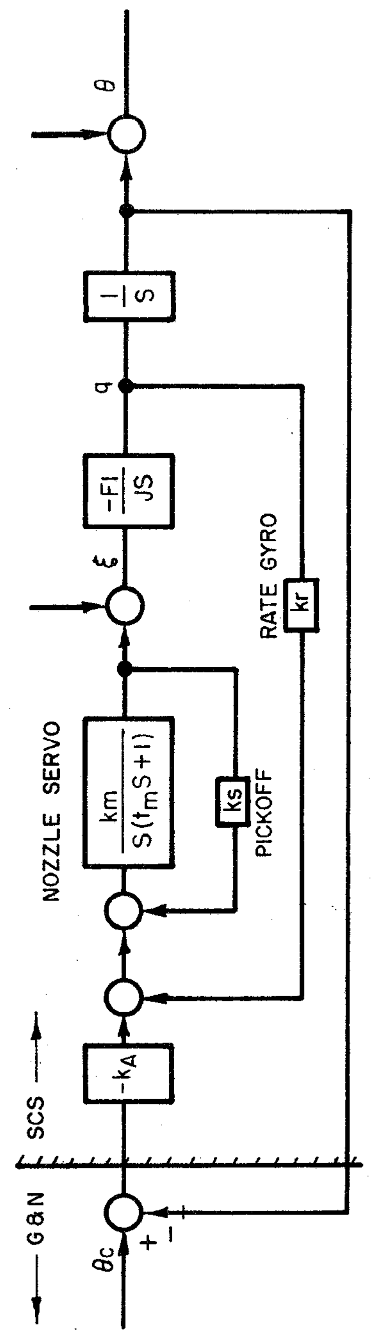
The magnitude of W_V appears to place an upper limit on the band width of the outer (guidance) loop. MIT does not have specifications on the expected magnitudes of this value during powered flight, although reference 2 contains two "typical cases". MIT is currently assuming W_V will not be less than the number in Fig. 32 Ref. 2, $\sqrt{F\ell / J} = 1.549$. Since this number is intimately connected with the overall design of the Apollo vehicle, MIT hesitates to place even tentative specifications on this number. However, coordination with MIT on the expected values of $F\ell / J$ must occur.

$$\theta_C \longrightarrow \frac{\left(1 - S^2/W_V{}^2\right)}{\left[\frac{S^2}{(W_M/2.61)^2} + \frac{2(.924)S}{(W_M/2.61)} + 1\right]\left[\frac{S^2}{(W_M/2.61)^2} + \frac{2(.384)S}{W_M/2.61} + 1\right]} \longrightarrow \theta + \delta \text{ (thrust direction)}$$

Figure 2

Ref. 1 NAA Inter-office ltr. S & CA - 62-11: Rate-Gyro & Mig-gyro TVC Autopilots

Ref. 2 Stabilization & Control Analyses, 1 July - 31 July unit member reporting: J. A. Jansen, R. E. Miller, C. L. Pond



$$k_m = \frac{2-\sqrt{2}}{4\,k_r}\;\frac{W_m^2}{W_v^2}$$

$$k_\delta = \frac{2}{2-\sqrt{2}}\;\frac{k_r W_v^2}{W_m}$$

$$k_A = \frac{2-\sqrt{2}}{4}\;W_m k_r$$

$$\frac{\theta}{\theta_c} = \frac{1}{\left[\frac{S^2}{(W_m/2.61)} + \frac{2(.924)}{W_m/2.61}S + 1\right]\left[\frac{S^2}{(W_m/2.61)^2} + \frac{2(.383)}{W_m/2.61}S + 1\right]}$$

Fig. 1 Design equations and transfer function for an attitude - hold autopilot.