an angle as to see the aft horizon. Accordingly, an alternate scheme was devised. The forward telescope was set at the correct control angle so that it just intersected the horizon at the 65° control attitude, whereas the aft telescope was aimed almost directly out of the side of the vehicle. At this angle, it would see the horizon for a sizeable portion of the vehicle revolution regardless of the pitch angle. In this configuration only the forward telescope is used as a control transducer as long as the forward telescope sees the earth once per vehicle revolution. If the forward telescope does not see the earth once per revolution, the signal from the aft telescope is used to torque the vehicle nose down to where the forward telescope can again obtain control. This function is accomplished by a time-delay, lockout circuit actuated by the forward telescope signal. In all other respects the system operates as the pitch control previously described.

The entire flight-tested system weighed under 18 lb, including tankage, $1\frac{1}{2}$ lb of nitrogen, and battery supply, and it used only 18 transistors and two moving parts—the rate gyro and the solenoid valve. With only minor mechanical redesign, the same system could be flown at a weight of under 12 lb.

The results of the flight test proved to be almost identical to the preflight computer study results. The coning was limited to the body rate of 4°/sec, which produced a ±2° cone, and the mean of the coning angle was well within the $\pm\frac{1}{2}$° of the command angle required, for the entire design flight time. The vehicle reached steady-state conditions within the first 5 sec of operation and remained there throughout the design control phase.

As a result of the successful flight test of the miniguide system and the excellent agreement of the actual flight results with the preflight computer studies, plans are under way to use the vertical control version of miniguide on three probes to be fired within the next two years in a horizon-definition study program.

Rocket Vehicle Weight Trades for Injection Missions

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Nomenclature

g = acceleration due to gravity at earth's surface, 32.2 ft/sec^2
I_{sp} = specific impulse
V = velocity
W = weight

Subscripts

1 = first stage
2 = second stage
BO = burnout
D = drop
E = empty
I = inert
LP = loaded propellant
M = margin
0 = initial
P = expended propellant
P/L = payload
R = residual propellant (trapped + allowance)

Received November 12, 1963; revision received December 19, 1963.

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Table 1 Estimated error in approximate trades

Stage and range of operation	Estimated error
Booster, liftoff to suborbital	5 to 20%
Upper, suborbital to injection	0 to 10%
Kick, orbital to superorbital	0 to 5%

Introduction

Any change in a rocket vehicle parameter is reflected as a related change in either vehicle empty weight or propellant margin, if the total characteristic velocity is held fixed. Approximate evaluations of such "tradeoffs" are useful at almost every phase of system development. Among these uses are: 1) evaluation of preliminary design changes, 2) assessment of the effects of uncertainties and tolerances in vehicle parameters, 3) determination of performance gains from ejected weights, and 4) determination of performance margins.

Vehicle Definition

Once a set of terms that describe the makeup of the vehicle has been defined (as in the Nomenclature), the interrelations between the various parameters to be traded are established:

$$W_E = W_I + W_{P/L} \tag{1}$$

$$W_{BO} = W_E + W_M + W_R \tag{2}$$

$$W_0 = W_{BO} + W_P \qquad W_0 = W_E + W_{LP} \tag{3}$$

$$W_{LP} = W_P + W_M + W_R \tag{4}$$

$$W_{0_2} = W_{BO_1} - W_{D_1} \tag{5}$$

The differentials of these defining equations establish the interdependence of the trades. With one or two terms held constant, the partial differentials, or influence coefficients, for other parameters can then be obtained. For example, from Eq. (2),

$$dW_{BO} = dW_E + dW_M + dW_R \tag{6}$$

Let

$$dW_{BO} = (\partial W_{BO}/\partial W_E)dW_E \tag{7}$$

Then, with W_R held constant

$$(\partial W_{BO}/\partial W_E) = 1 + (\partial W_M/\partial W_E) \tag{8}$$

Approximate One- and Two-Stage Trades

Expressions can be written for empty weight and margin trades in terms of the vehicle parameters, W_0, W_{BO}, I_{sp}, and μ, where $\mu \equiv W_0/W_{BO}$. These expressions are helpful in gaining a further understanding of the effects of vehicle parameter changes on payload capability and propellant

Table 2 Single-stage trades; partials of W_E and W_O

With constant	For G =	$\partial W_E/\partial G$ =	$\partial W_{BO}/\partial G$ =
W_M	W_{LP}	β	β
W_M and W_{LP}	I_{sp}	$m \ln\mu$	$m \ln\mu$
	W_R	$-u\beta$	$-\beta$
	W_I	0	0

Table 3 Single-stage trades; partials of W_M and W_{BO}

With constant	For G =	$\partial W_M/\partial G$ =	$\partial W_{BO}/\partial G$ =
W_E	W_{LP}	u^{-1}	u^{-1}
W_E & W_{LP}	I_{sp}	$(\mu\beta)^{-1} m \ln\mu$	$(\mu\beta)^{-1} m \ln\mu$
	W_R	-1	0
W_{LP}	W_E	$-(\mu\beta)^{-1}$	μ^{-1}

Table 4 Second-stage empty weight trades; first-stage depletion cutoff

For G =	$\partial W_{E_2}/\partial G_1$ =	$\partial W_{E_2}/\partial G_2$ =
W_{LP}	$\xi\beta_1(1+\xi)^{-1}$	$(\beta_2-\xi)(1+\xi)^{-1}$
I_{sp}	$m_2(1+\xi)^{-1}\ln\mu_1$	$m_2(1+\xi)^{-1}\ln\mu_2$
W_R	$-\xi u_1\beta_1(1+\xi)^{-1}$	$-u_2\beta_2(1+\xi)^{-1}$
W_I	$-\xi(1+\xi)^{-1}$	0

margin. The method used to derive the tradeoffs is similar to that of Ref. 1; the results are basically an extension of that work. The expressions are approximate in that gravity and drag losses are neglected in the derivation, but the accuracy is sufficient for many purposes (see Table 1).

The expressions for the approximate tradeoffs are found from the differentials of the defining equations (1–5) and from the statement that the total characteristic velocity is held fixed:

$$dV_{\text{total}} = d(V_1 + V_2) \equiv 0 \tag{9}$$

or

$$0 = d(gI_{sp_1}\ln\mu_1 + gI_{sp_2}\ln\mu_2) \tag{10}$$

Equation (10) becomes:

$$I_{sp_1}\left[\frac{dW_{0_1}}{W_{0_1}} - \frac{dW_{BO_1}}{W_{BO_1}} + \frac{dI_{sp_1}}{I_{sp_1}}\ln\mu_1\right] + I_{sp_2}\left[\frac{dW_{0_2}}{W_{0_2}} - \frac{dW_{BO_2}}{W_{BO_2}} + \frac{dI_{sp_2}}{I_{sp_2}}\ln\mu_2\right] = 0 \tag{11}$$

Let

$$\beta \equiv (\mu - 1)^{-1} \tag{12}$$

Then

$$(\mu\beta)^{-1} = W_P/W_0 = \text{propellant fraction} \tag{13}$$

Finally, let

$$m \equiv W_0\beta/I_{sp} \tag{14}$$

The resulting tradeoffs (or influence coefficients, which are partials with respect to G, where $G = W_{LP}$, I_{sp}, etc.) for single-stage vehicles are shown in Tables 2 and 3. The existence of two sets of burnout weight trades shows the need to specify either constant margin or empty weight.

Two-stage trades fall into two categories:

1) The first stage is programed for a "depletion cutoff," and it can be low in cutoff velocity; the deficiency is made up by the second stage. Second-stage empty weight and margin tradeoffs on this basis are shown in Tables 4 and 5, respectively.

To shorten the expressions, the parameter ξ is defined:

$$m_2/m_1 \equiv \xi = W_{02}\beta_2 I_{sp1}/W_{01}\beta_1 I_{sp2} \tag{15}$$

2) The first stage is programed for a "guidance cutoff"; it has a propellant margin and a constant cutoff velocity. Then the one-stage trades in Tables 2 and 3 are applicable to the second stage. In addition:

$$\partial W_{E_2}/\partial W_{D_1} = -\mu_2^{-1} \qquad \partial W_{M_2}/\partial W_{D_1} = -(\mu_2\beta_2)^{-1}$$

More accurate trades for the booster phase may be found by the methods of Ref. 2.

Table 5 Second-stage margin trades; first-stage depletion cutoff

For G =	$\partial W_{M_2}/\partial G_1$ =	$\partial W_{M_2}/\partial G_2$ =
W_{LP}	$\xi\beta_1(\mu_2\beta_2)^{-1}$	$u_2^{-1} - \xi(\mu_2\beta_2)^{-1}$
I_{sp}	$m_2(\mu_2\beta_2)^{-1}\ln\mu_1$	$m_2(\mu_2\beta_2)^{-1}\ln\mu_2$
W_R	$-\xi(u_1\beta_1)(\mu_2\beta_2)^{-1}$	-1
W_I	$-\xi(\mu_2\beta_2)^{-1}$	
W_E	. . .	$-(1+\xi)(\mu_2\beta_2)^{-1}$

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TV Missile Terminal-Flight Simulator

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A SIMULATOR display designed and built by Grumman specifically for the evaluation of missile control systems in which an operator "flies" the missile by a control stick while watching the target area on television is described. A mechanical/optical device, driven by an analog computer, projects the target area on a screen, which is viewed by closed-circuit TV. The terrain in the target area is realistically displayed, in correct perspective for the missile's instantaneous position and altitude. Each flight terminates when the missile impacts the ground. This synthetic display can be used to determine miss-distance sensitivity to gusts, winds, missile speed, optical axis orientation and field of view, aerodynamic and dynamic factors, and control-system mechanization (e.g., strapped-down or gimballed camera, rate, or position autopilot).

The terminal-flight simulator was designed to meet the following requirements: 1) TV presentation of the terrain seen during the terminal phase, viewed in correct perspective for the missile's instantaneous location and attitude; 2) six degrees of freedom at response levels well above those expected of an actual missile; 3) flight-path versatility enabling the operator to fly various trajectories; and 4) an inexpensive, easily changed, realistic terrain model.

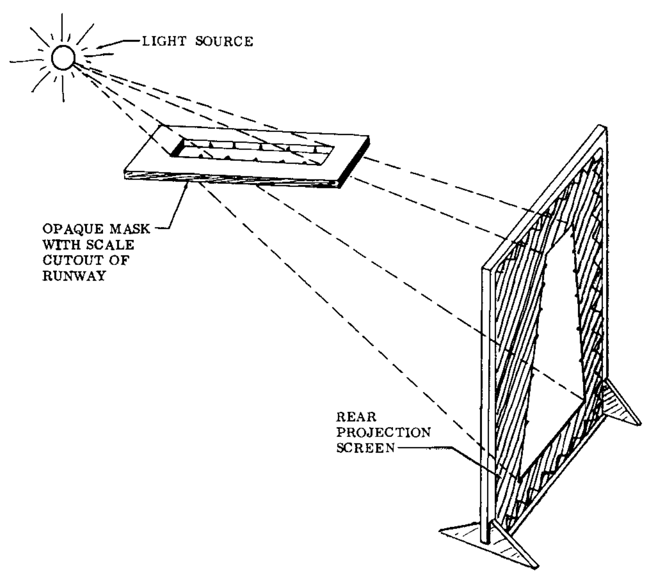

Fig. 1 Runway projection.

Presented at the AIAA Simulation for Aerospace Flight Conference, Columbus, Ohio, August 26–28, 1963 (no preprint number; published in bound volume of preprints of the meeting); revision received March 9, 1964.

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