POWER REQUIREMENTS OF EXTERNALLY AND INTERNALLY PROPELLED LOW-BLOCKAGE VEHICLES IN NON-EVACUATED TUBES.

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INTRODUCTION

The advantages of large-clearance vehicular suspensions in high-speed tube transport systems have been discussed elsewhere (Ref. 1). The fact that these suspensions make it impractical to use any of the existing modes of external propulsion has so far caused little concern, because it has been shown (Ref. 2) that the propulsive power demands in non-evacuated tubes are anyway far lower with the internal modes. It should be noted, however, that Ref. 2 deals only with situations involving large losses in the transfer flow. The existence of internal modes which are not only more practical but also more economical than any conceivable external mode has so far been established only for these situations.

The superiority of internal propulsion is not quite so obvious when the transfer losses are small -- as is the case, for example, when the vehicle and its supports are well streamlined and the blockage ratio is small. The use of external propulsion on vehicles having large-clearance suspensions cannot be ruled out on the sole ground that it is difficult, or even impossible, in the present state of the art. New methods may still be devised for its practical utilization on such vehicles. It is important, therefore, that the relative magnitude of the power demands with internal and external propulsion be re-evaluated for low-loss situations. This is the object of the present paper.

As in Ref. 2, the tube will be assumed to be long enough to make it permissible to treat the flow as steady in the vehicle-fixed frame of reference. Heat exchanges with the surroundings will be neglected.

SYMBOLS

A		cross-sectional area of the tube
B	=	$\frac{\gamma-1}{\gamma}\;\frac{1+\gamma M_\infty^2}{1+\frac{\gamma-1}{2}M_\infty^2}$
c_p	=	specific heat at constant pressure, for air
D	=	$M\left(1+\frac{\gamma-1}{2}M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$
f_v		vehicle-fixed frame of reference
F	=	$pA(1+\gamma M^2)$ stream force in f_v
ℓ	=	percentage loss of stagnation pressure in transfer passage
$\dot{m}$	=	$\rho_\infty A u_\infty$ mass flow rate in f_v
M		Mach number relative to f_v
N	=	$M(1+\frac{\gamma-1}{2}M^2)^{\frac{1}{2}}(1+\gamma M^2)^{-1}$
p		static pressure
p^o		stagnation pressure in f_v
$\mathcal{P}$		power required
P	=	$\mathcal{P}/\rho_\infty A u_\infty$ power factor
u		flow velocity relative to f_v
T		static temperature
T^o		stagnation temperature in f_v
Z	=	$N^{\frac{\gamma+1}{\gamma-1}}\;D$
γ		ratio of specific heats for air
ϵ	=	$(F_1 - F_\infty)/(F_1 - F_2)$
θ		thrust required in external propulsion
ρ		density of the air

Subscripts

∞	undisturbed regions within tube
1	near flow in f_v ahead of vehicle
2	near flow in f_v behind vehicle

EXTERNAL PROPULSION

The action of the tube on the air within it ahead of station 1, as observed in f_v, is that of a friction pump which increases the stream force from F_∞ to F_1 and produces, therefore, the stagnation temperature increment

$$T_1^\circ - T_\infty^\circ = \frac{F_1 - F_\infty}{\rho_\infty A u_\infty c_p} u_\infty$$

There follows

$$\frac{T_1^\circ}{T_\infty^\circ} = 1 + B\left(\frac{F_1}{F_\infty} - 1\right) \tag{1}$$

The continuity equation in f_v, from upstream ∞ to 1, may be written in the form (Ref. 3)

$$\frac{F_1 N_1}{F_\infty N_\infty} = \left(\frac{T_1^\circ}{T_\infty^\circ}\right)^{1/2}$$

which, with Eq. 1, yields

$$\frac{F_1}{F_\infty} = \frac{1}{2}\left(\frac{N_\infty}{N_1}\right)^2 B \left\{1 + \left[1 + 4\left(\frac{N_1}{N_\infty}\right)^2 \frac{1-B}{B^2}\right]^{1/2}\right\} \tag{2}$$

Frictional forces on the surface of the vehicle do no work in f_v. Neglecting the work done by the tube on the transfer flow between stations 1 and 2, the continuity equation between these two stations in f_v can, therefore, be written in the alternative form (Ref. 3)

$$F_1 N_1 = F_2 N_2 \tag{3}$$

$$\frac{p_2^\circ}{p_1^\circ} = \frac{D_1}{D_2} \tag{4}$$

From Eq. 3,

$$F_1 - F_\infty = \epsilon (F_1 - F_2)$$

$$= \epsilon F_1 \left(1 - \frac{N_1}{N_2}\right) \tag{5}$$

Finally, Eqs. 2 and 5 yield

$$\frac{2}{B}\left(\frac{N_1}{N_\infty}\right)^2 \left\{ 1 + \left[1 + 4\left(\frac{N_1}{N_\infty}\right)^2 \frac{1-B}{B^2} \right]^{1/2} \right\}^{-1} = 1 - \epsilon + \epsilon \frac{N_1}{N_2} \qquad (6)$$

Given M_∞, F_∞ , ϵ , and ℓ (hence p_2^o/p_1^o), Eqs. 4 and 6 can be solved for M_1 and M_2. Then F_1 is calculated from Eq. 2 and the thrust required is obtained as

$$\begin{aligned} \Theta &= F_1 - F_2 \\ &= \frac{1}{\epsilon}(F_1 - F_\infty) \end{aligned}$$

The power required is

$$\begin{aligned} \mathcal{P} &= \Theta u_\infty \\ &= \frac{1}{\epsilon} F_\infty u_\infty \left(\frac{F_1}{F_\infty} - 1\right) \\ &= \frac{1}{\epsilon} p_\infty A u_\infty \left(1 + \gamma M_\infty^2\right)\left(\frac{F_1}{F_\infty} - 1\right) \end{aligned}$$

Therefore,

$$P = \frac{1}{\epsilon}\left(1 + \gamma M_\infty^2\right)\left(\frac{F_1}{F_\infty} - 1\right) \qquad (7)$$

Results of these calculations are plotted in Figs. 1 and 2 for two travel Mach numbers* (.5 and .7) and for two extreme values of ϵ . The condition ϵ = 1 represents a situation in which stream force perturbations behind the vehicle are negligible in comparison with those ahead of it; whereas ϵ = .5 represents a situation in which the two perturbations are of the same magnitude and of opposite signs. The exact value of ϵ is still unknown (Ref. 2). In a sealed adiabatic tube it is believed to be 1.0.

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* The travel Mach number is defined as the travel speed of the vehicle relative to the tube divided by the speed of sound in the undisturbed air.

DISCUSSION OF RESULTS AND CONCLUSIONS

The power requirements of external propulsion, for any given travel Mach number, fall within a narrow band, indicating that the overall loss with this kind of propulsion is relatively insensitive to changes in the distribution of flow disturbances in the adjacent air columns.

All other conditions being equal (including the stagnation pressure loss in the transfer passage), the power requirement of correct internal propulsion in the design condition is always lower than the minimum power requirement of external propulsion. Of course, the power requirement of incorrect internal propulsion can be as high as -- or higher than -- that of external propulsion.

These results confirm that the mode of propulsion which is most practical -- if not the only feasible one -- for tubed vehicles with large-clearance aerodynamic support is also potentially the most economical one from the standpoint of power demands for all configurations.

ACKNOWLEDGMENT

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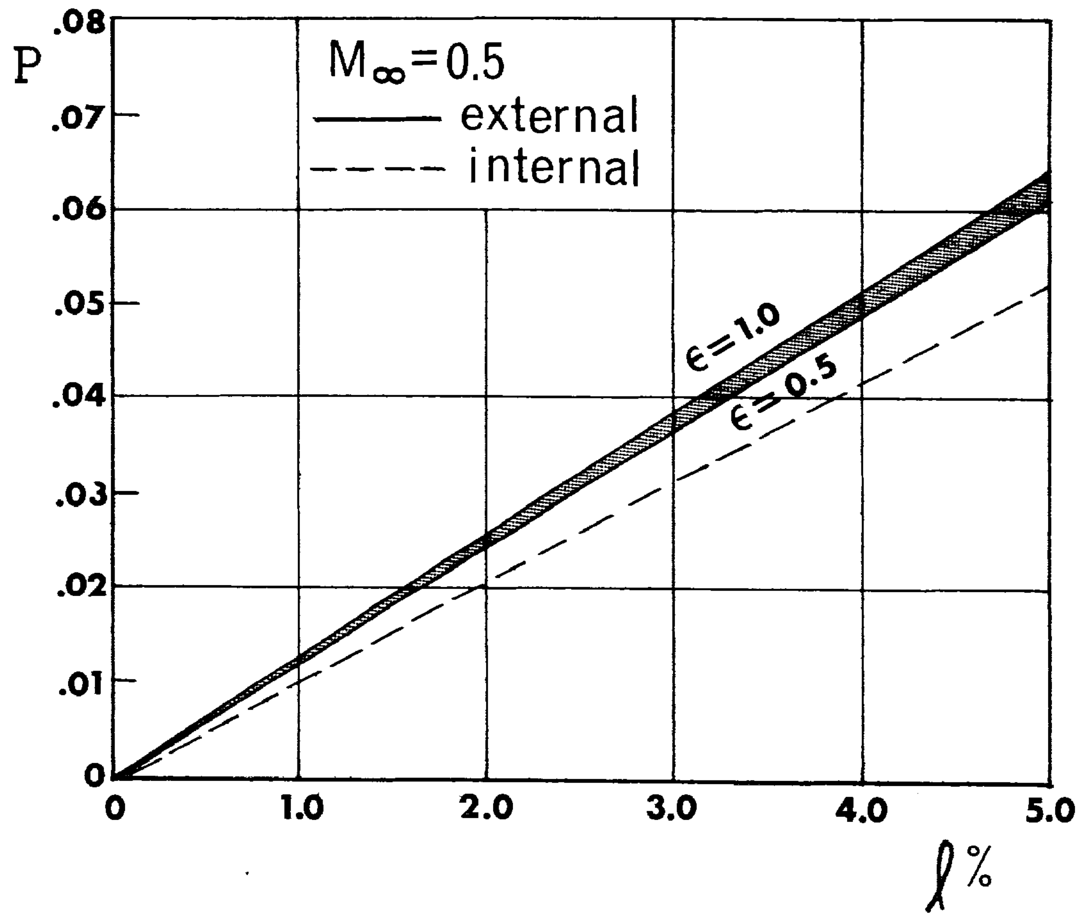

P
.08
.07
.06
.05
.04
.03
.02
.01
0
$M_\infty = 0.5$
external
internal
$\epsilon = 1.0$
$\epsilon = 0.5$
0
1.0
2.0
3.0
4.0
5.0
$l\%$

FIG. 1

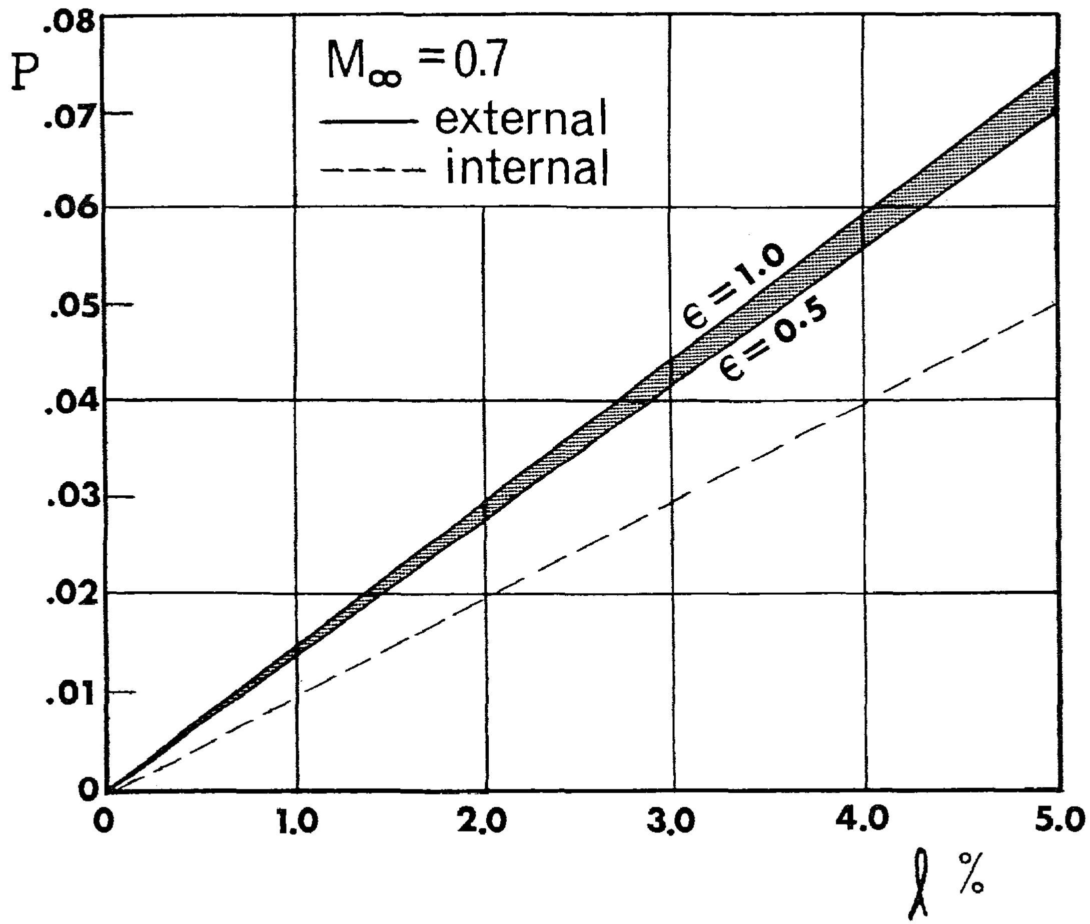
P
$M_\infty = 0.7$
external
internal
$\epsilon = 1.0$
$\epsilon = 0.5$
.08
.07
.06
.05
.04
.03
.02
.01
0
0
1.0
2.0
3.0
4.0
5.0
ℓ %

FIG. 2