Readers' Forum

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Contents

Further Comments on "Standing Detonation Waves in a Combustion Tunnel"

Thomas C. Adamson, Jr.
Associate Professor, Aeronautical and Astronautical Engineering Department, The University of Michigan, Ann Arbor, Mich.

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RECENTLY, Kovitz[1] attempted to explain the anomalous results obtained by Gross and Chinitz[2] in a supersonic combustion tunnel. Specifically, he presented a gross method to explain the movement of a standing detonation wave to a new location as the amount of hydrogen injected was changed, along with speculation as to whether this same method might be of value in explaining the so-called hysteresis effect (persistence of the detonation wave, once formed, even after the incoming temperature has been reduced below the value necessary to start the reaction). In this method it was assumed that all upstream flow properties other than fuel flow remained constant, and that any reaction occurring at the injector was negligible.

There are many possible explanations for the results obtained by Gross and Chinitz. One of these includes the possibility that the above-mentioned wave movement and hysteresis simply do not exist under constant upstream conditions and that, in fact, in the Gross-Chinitz tunnel, an unknown amount of reaction occurred at the fuel injector. Keeping in mind the constant incoming Mach number and the structure of the detonation wave, this explanation makes the most physical sense. Additional validity is ascribed to this explanation by the fact that Nicholls[3] was unable to reproduce these anomalous results in his facility. However, decisive proof has been given by Rhodes.[4] Using the Gross-Chinitz combustion tunnel, which has been moved to the Arnold Engineering Development Center, Rhodes reports the following results,[4]: "the phenomena observed at Fairchild, in which the position of the normal shock is a function

Contributors Please Note

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(1) Five, double-spaced, typewritten, manuscript pages (8½ by 11 in.), including wide margins, equations, and headings, equal one printed page.

(2) For every illustration, deduct at least one-half or as much as one manuscript page, depending on the size of the illustration.

of the fuel flow and the wave is stable at a much lower temperature than that required to ignite it, was duplicated. Under these conditions, a flame near the tip of the hydrogen injector and a sodium emission upstream of the normal shock were seen. The hydrogen injector was modified to inject fuel at the throat of the tunnel. Under these conditions, no flame at the injector and no evidence of reaction upstream of the shock were seen. Also, although there was a temperature rise in the test section upon the addition of hydrogen from the injector, there was no movement of shock. No evidence of reaction was seen in the test section when the inlet temperature was reduced below the ignition point."

It seems clear that (1) the varying shock position and hysteresis phenomena do not exist with constant upstream conditions, and thus (2) Kovitz' analysis is not relevant.

References

[1] Kovitz, A. A., *Some Comments on Standing Detonation Waves*, Journal of the Aerospace Sciences, Readers' Forum, Vol. 28, No. 1, pp. 75–76, January 1961.

[2] Gross, R. A., and Chinitz, W., *A Study of Supersonic Combustion*, Journal of the Aero/Space Sciences, Vol. 27, No. 7, pp. 517–524, July 1960.

[3] Nicholls, J. A., and Dabora, E. K., *Recent Results on Standing Detonation Waves*, AFOSR TN-60-441, May 1960. Presented at the Eighth International Symposium on Combustion held at California Institute of Technology, August 29–September 2, 1960.

[4] Rhodes, R. P., *Standing Detonation Wave*, Proceedings of Fourth Contractor's Meeting on Airbreathing Combustion, AFOSR TN-60-1253, p. 5, October 1960.

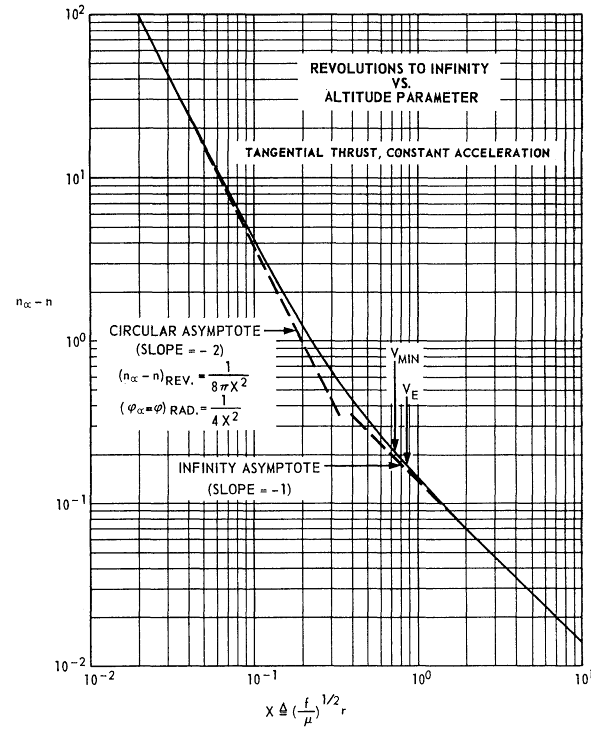

FIG. 1.

Transit Angle for Low-Thrust Spacecraft

Frank M. Perkins
Staff Systems Analyst, Engineering, Convair,
A Division of General Dynamics Corporation, San Diego, Calif.
September 30, 1960

THE COMPLETELY GENERALIZED SOLUTION for trajectory prediction of low-thrust spacecraft employing a tangentially directed, constant-thrust acceleration and operating in a single gravity field is presented in reference 1. The relations between altitude, velocity, flight-path inclination, and time are presented in parametric form as single-valued solitary curves applicable for flight all the way from an initial circular orbit on out to infinity. These curves apply to all tangential, constant-acceleration, low-thrust flight paths starting in circular orbit at any altitude about any planet.

Reference 1 omitted the solution for the angle subtended at the center of the gravity source by the travel of the spacecraft (range or transit angle). This solution is presented in Fig. 1 as a number of revolutions, starting at any point on the trajectory and ending as the spacecraft approaches infinity, versus the altitude parameter X. To determine the revolutions traversed between any two points on the trajectory, it is merely necessary to take the difference between the two points on Fig. 1. The altitude parameter X is defined in reference 1 as follows:

$$X = a^{1/2}(r/r_0) = (f/\mu)^{1/2} r \tag{1}$$

where r = distance from center of planet
f = thrust acceleration = force/mass
μ = gravity constant (distance^3/time^2) = $r^2 g$
g = gravity acceleration (at any altitude)
a = dimensionless thrust acceleration = $f/(\mu/r_0^2)$

and where subscript 0 denotes the initial circular orbit.

The equation for the circular asymptote of Fig. 1 is obtained by putting Eq. (14) of reference 1 into local differential form, substituting the circular velocity relationship from Eq. (20) into this, and integrating to infinity. Of course, circular flight does not apply all the way to infinity, but for the purpose of obtaining the circular asymptote, it may be assumed to apply in the mathematical sense.

The slope of the infinity asymptote of Fig. 1 may be derived as follows. By definition, the rate of change of the transit or range angle φ and radius distance r with time are,

$$\dot{\varphi} = (V \cos \theta)/r \tag{2}$$

$$\dot{r} = V \sin \theta \tag{3}$$

where θ is the flight-path angle measured above local horizontal.

At α $$\sin \theta \rightarrow 1.0 \tag{4}$$

Dividing Eq. (2) by Eq. (3) and bearing in mind that Eq. (4) yields

$$d\varphi/dr = \cos \theta / r \tag{5}$$

Multiplying both sides by $r/(\varphi_\alpha - \varphi)$ and then putting r in terms of the altitude parameter X results in the following:

$$\frac{d \ln (\varphi_\alpha - \varphi)}{d \ln X} = \frac{-\cos \theta}{\varphi_\alpha - \varphi} = -\frac{\rightarrow 0}{\rightarrow 0} \tag{6}$$

Since both the numerator and denominator of the right-hand side of Eq. (6) approach zero, the value of this fraction is equal to the ratio of the time differentials of the numerator and denominator at infinity. Performing the differentiation and substituting Eq. (4) into the numerator yields

$$\frac{d \ln (\varphi_\alpha - \varphi)}{d \ln X} = \frac{\dot{\theta}}{-\dot{\varphi}} \tag{7}$$

As the vehicle approaches infinity, the gravity which had caused the flight path to turn becomes negligible compared to the thrust acceleration, and the flight path approaches a straight line. Under these conditions, the rates of change of both flight-path angle $\dot{\theta}$ and transit angle $\dot{\varphi}$ approach $V \cos \theta / r$. Therefore,

$$\dot{\theta} = \dot{\varphi} \tag{8}$$

and the logarithmic slope of Eq. (7) becomes minus one:

$$\frac{d \ln (\varphi_\alpha - \varphi)}{d \ln X} = -1.0 \tag{9}$$

It is interesting to note that although the flight-path angle changes from 39.2° at the parabolic escape point to approach