written as

$$\left(\frac{\partial Q'}{\partial t} - H'\right) A + \sum_{i=1}^{4} [(E - E_v)_i' C_x + (F - F_v)_i' C_y] = 0 \tag{20}$$

where

$$\begin{aligned} Q' &= \hat{y}Q \\ H' &= \hat{y}H \\ (E - E_v)' &= \hat{y}(E - E_v) \\ (F - F_v)' &= \hat{y}(F - F_v) \end{aligned} \tag{21}$$

It is clear that A and C are the cross-sectional AREA and the boundary LENGTH, respectively, of a control volume in a two-dimensional, curvilinear coordinate system.

The above discussion shows that the discretized flow equations in a two-dimensional, curvilinear coordinate system can be easily transformed to the axisymmetric system with the following steps:

1) Multiply the time marching term by the radial coordinate of the control volume centroid $\hat{y}$.

2) Reformulate the divergence of the velocity vector according to Eq. (9).

3) Multiply the flux terms with the radial coordinate of the boundary centroid $\bar{y}$.

4) Add the source term [due to the axisymmetric coordinate, Eq. (4)], multiplied by the radial coordinate of the control volume centroid $\hat{y}$ to the radial momentum equation.

Concluding Remarks

The axisymmetric flow equations have been organized in a vector form suitable for CFD applications. The physical meaning of the source term in the radial momentum equation due to the axisymmetric coordinate system is discussed. The details of the volumetric and surface integrations for a single cell are examined. A convenient method of modifying existing two-dimensional codes to axisymmetric ones is proposed. Most importantly, no numerical accuracy has been sacrificed in calculating the volume and surface areas of the control volume with this method.

Reference

[1]Taylor, A. E., and Mann, W. R., *Advanced Calculus*, 2nd ed., Wiley, New York, 1972, p. 486.

Technical Comments

Comment on "Propellant Production from the Martian Atmosphere"

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THE topic treated in the Note is fascinating. But I feel that the figures quoted are very optimistic.

Believing that 3.61 kWh suffice to produce 1 kg of propellant liquids, then the photocell area required on Mars surface (not movable, flat on surface, near equator) for production of 13 t propellant per (Earth) year would come to 600 m^2 with space-type photocells of today; a solar dynamic plant with a steerable parabolic mirror might require 13-m receiver diameter.

For a Hohmann-type manned Mars mission, this might be quite attractive; obviously, the first manned exploration could use this only if proper verification were available from prior unmanned Mars missions. Since I don't think this likely, maybe this plan is rather for growth potential for later manned flights, if the first one proved operationability!

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Reply by the Authors to H. O. Ruppe

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IN the Note,[1] the calculations of propellant production using the electrical power from a 100-m^2 solar-cell array were done approximately with information available at the time. This was justified because the central topic of the note was the determination of the specific impulses of the carbon monoxide and liquid oxygen mixture, and not the propellant production. In response to Ruppe's comments, we have redone the propellant production calculations. We found that our original production value of 13,000 kg of propellants in one Earth year from a 100-m^2 solar panel was too optimistic, but certainly not by a factor of six. A brief review of our principle assumptions and the revised calculations follows.

Our assumption that a 20% solar cell efficiency can be realized in the next two decades was probably conservative.

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