sure in such a region is uniform, the center of pressure of the jth strip is given by

$$\bar{x}_j' = \left[(C_{p4} - C_{p1})\ell_{Lj}\left(x_{pj}' + \frac{\ell_{Lj}}{2}\right) + (C_{p5} - C_{p2})\ell_{Mj}\left(x_{pj}' + \ell_{Lj} + \frac{\ell_{Mj}}{2}\right) + (C_{p6} - C_{p3})\ell_{Tj}\left(x_{pj}' + \ell_{Lj} + \ell_{Mj} + \frac{\ell_{Tj}}{2}\right)\right] / [(C_{p4} - C_{p1})\ell_{Lj} + (C_{p5} - C_{p2})\ell_{Mj} + (C_{p6} - C_{p3})\ell_{Tj}]$$

where ℓ_{Lj}, ℓ_{Mj}, and ℓ_{Tj} are local airfoil-strip chords defined in Fig. 2. Hence, the strip pitching moment about the Y' axis, the strip rolling moment about the X' axis, and the strip yawing moment about the Z' axis are, respectively,

$$M_{pj}' = -F_{Nj}'\bar{x}_j', \qquad M_{Rj}' = F_{Nj}'y_j', \qquad M_{yj}' = -F_{Aj}'y_j'$$

Summing j over all of the strips of a fin, one obtains for a fin

$$F_N' = \sum_{j=1}^{n} F_{Nj}', \qquad F_L' = \sum_{j=1}^{n} F_{Lj}'$$

$$F_A' = \sum_{j=1}^{n} F_{Aj}', \qquad F_D' = \sum_{j=1}^{n} F_{Dj}'$$

$$M_p' = \sum_{j=1}^{n} M_{pj}', \qquad M_R' = \sum_{j=1}^{n} M_{Rj}', \qquad M_Y' = \sum_{j=1}^{n} M_{Yj}'$$

The center-of-pressure coordinates are then

$$\bar{X}' = M_p'/F_N', \qquad \bar{Y}' = M_R'/F_N'$$

Transforming back to the XYZ system by Eq. (1), the force and the moment on a fin have, respectively, the components

$$\begin{pmatrix} F_A \\ F_S \\ F_N \end{pmatrix} = [A] \begin{pmatrix} F_A' \\ 0 \\ F_N' \end{pmatrix} = \begin{bmatrix} F_N'\sin\delta + F_A'\cos\delta \\ \sin\Gamma\,(F_A'\sin\delta - F_N'\cos\delta) \\ \cos\Gamma\,(F_N'\cos\delta - F_A'\sin\delta) \end{bmatrix}$$

$$\begin{pmatrix} M_R \\ M_P \\ M_Y \end{pmatrix} = [A] \begin{pmatrix} M_R' \\ M_P' \\ M_Y' \end{pmatrix} = \begin{bmatrix} M_R'\cos\delta + M_Y'\sin\delta \\ M_P'\cos\Gamma + \sin\Gamma\,(M_R'\sin\delta - M_Y'\cos\delta) \\ M_P'\sin\Gamma + \cos\Gamma\,(M_Y'\cos\delta - M_Y'\sin\delta) \end{bmatrix}$$

Obviously, the fin dihedral angle Γ causes a side force F_s to the vehicle. Note that F_A' and F_N' are also Γ-dependent. Thus, the task of minimizing or eliminating F_s is very much involved in hypersonic flow conditions. Furthermore, note that in hypersonic flows it is difficult to decouple the roll forcing moment and the roll damping moment, or the pitch forcing moment and the pitch damping moment, in general.

The associated aerodynamic coefficients are, respectively,

Lift coefficient:

$$C_N = (F_N\cos\alpha - F\sin\alpha)/A_r$$

Wave drag coefficient:

$$C_{DW} = (F_N\sin\alpha + F_A\cos\alpha)/A_r$$

Pitching moment coefficient:

$$C_m = M_p/A_rL_r$$

Rolling moment coefficient:

$$C_\ell = M_R/A_rL_r$$

where A_r is the reference area and L_r is the reference length.

The preceding analysis is for one fin panel. The aerodynamic characteristics for multiple fin panels can be obtained by summing corresponding aerodynamic characteristics over all fins.

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Jerry M. Allen
Associate Editor

Columbus: To Mars with Solar-Electric Propulsion

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Introduction

HUMAN travel to Mars is being considered as part of the space exploration initiative. Nuclear propulsion appears to have several benefits, but the problem of launching concentrated fissionable material into orbit and starting a reactor in a low-Earth orbit may prove too difficult to be solved in a society that is increasingly concerned with safety and ecology. Chemical propulsion leads to very massive vehicles when the desired mission design includes a rapid transfer between planets to minimize radiation damage and also includes a long stay at Mars to allow the crew to recover from the flight out before the return flight. Solar-electric propulsion offers a reasonable alternative, but it also has problems. Assembling a large array at a low-Earth-orbit node is difficult, and the long trip time from the assembly orbit to the high-Earth orbit where the crew would join the main vehicle leads to awkward mission planning.

Contents

A design for a human trip to Mars using solar-electric propulsion is proposed. The key feature of this design is that the solar array is divided into three identical parts. Each part carries cargo to a rendezvous point. Because each of the three parts carries a different cargo mass, they can be launched from the low-Earth-orbit assembly point at different times and all arrive at the rendezvous point at the same time.

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Columbus is a design for a mission to Mars that uses solar-electric propulsion that avoids the major problems. The key feature is that the solar array needed for the interplanetary leg is divided into three parts for the Earth spiral. The three parts carry unmanned cargo to the high-Earth-orbit rendezvous point. The three cargo packages are not equal in mass. The package launched first is heaviest and thus requires the longest time to travel to the rendezvous point, and the package launched last requires the shortest time for the spiral. When the three packages arrive at the rendezvous point, the human crew arrives in a small vehicle with chemical propulsion.

Figure 1 shows the assembled Columbus vehicle, with the three large solar array parts joined, looking at the planform from the illuminated side. Each array has a thruster package, shown as a square above the array. A major structural keel is shown running from the point where the arrays join and passing under the thruster to the outer edge of each array. Figure 2 shows the side view of one part, where the crew module is visible. The truss carrying the solar array is the long horizontal linear framework. Both the top and bottom thruster packages are visible on booms above and below the solar array. The crew modules are located near the point where the three solar arrays attach, and tunnels provide access among them during the flight.

The time line for the mission is shown in Fig. 3. The first package (Pinta) is assembled from five launches of a heavy-lift vehicle and then starts to spiral from Earth. The second package (Nina) is assembled from the next three launches. The final package (Santa Maria) requires only two launches. After the crew joins the Columbus at the rendezvous point, the Mars leg starts.

The Columbus design provides for a crew of six to travel to Mars on a 1000-day conjunction-class mission. The total mass that would depart from low-Earth orbit was found to be 536×10^3 kg. Dividing the solar array into three parts appears to have several advantages. The requirements of the node are minimized. The problems caused by the Earth spiral time are reduced.

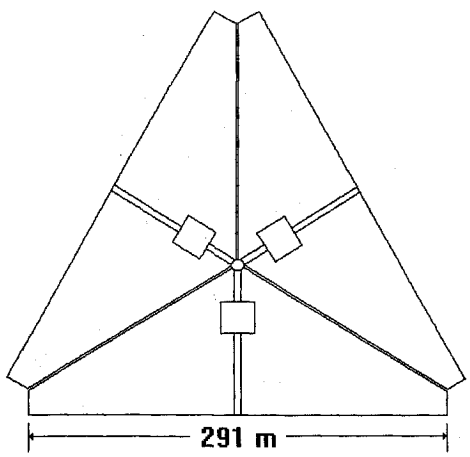

Fig. 1 Top view of Columbus.

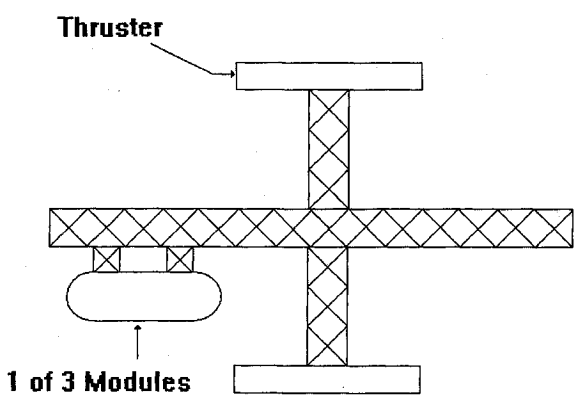

Fig. 2 Side view of one part of Columbus.

MILESTONE ITEMS	2019	2020
PINTA CONSTRUCTION	▽——▽	
LAUNCHES 1 TO 5	▽▽▽▽▽	
PINTO TO HIGH EARTH ORBIT	▽——▽	
NINA CONSTRUCTION	▽—▽	
LAUNCHES 6 TO 8	▽▽▽	
NINA TO HIGH EARTH ORBIT	▽——▽	
SANTA MARIA CONSTRUCTION	▽—▽	
LAUNCHES 9 TO 10	▽ ▽	
SANTA MARIA TO HIGH EARTH ORBIT	▽—▽	
CREW AT SPACE STATION	▽_▽	
CREW TO HIGH EARTH ORBIT	▽	
HELIOCENTRIC LEG TO MARS	▽——	

Fig. 3 Timeline for the Columbus mission.

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Antoni K. Jakubowski
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Deployed High-Temperature Superconducting Coil Magnetic Shield

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Introduction

In any manned space mission that lasts for an extended period of time and involves travel beyond the magnetosphere, the danger posed by radiation becomes of tantamount importance.[1,2] Radiation shielding must be considered for a permanently manned lunar base or a manned expedition to Mars. The radiation hazard that will be encountered during

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