Assuming that there is no significant accumulation of condensate, the condensate removal rate is

$$\dot{m}_e = \dot{m}_i - \dot{m}_v \tag{A3}$$

where $\dot{m}_v$ is the rate of vapor mass accumulated inside the radiator. If the volume occupied by the condensate inside the radiator is negligible, then

$$\dot{E} = \dot{m}_v u_g = \rho_v \dot{V} u_g \tag{A4}$$

where u_g is the specific internal energy of the vapor. The energy balance, Eq. (A1), can be rewritten as

$$\rho_v u_g \dot{V} = \dot{Q}_L h_g / h_{fg} - \epsilon \sigma A (T^4 - T_s^4) - (\dot{Q}_L / h_{fg} - \rho_v \dot{V}) h_f - P\dot{V} \tag{A5}$$

It can be shown that Eq. (A5) is identical to Eq. (1).

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Companion: An Economical Adjunct to the Space Shuttle

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Introduction

THE Space Shuttle provides routine transportation from Earth to low-Earth orbit. The purpose of this note is to introduce the concept of a "Companion" system which would operate with the shuttle to provide lower cost transportation.

The Companion system would operate as shown in Fig. 1. The Shuttle would be launched and would deliver a payload in the usual manner. The Companion system would be subsequently launched and would also deliver a payload. The Companion booster would fly back to the launch site for reuse. The Companion orbital stage would rendezvous with the Shuttle Orbiter and would be returned to Earth in the payload bay of the Orbiter. Two constraints that apply to the concept are that the Shuttle Orbiter could not return a payload other than the Companion orbital stage and that the Companion system would have to be launched into the same orbital plane as the Shuttle. Because many Shuttle missions involve delivery of satellites bound for geosynchronous orbit and orbit-transfer stages, the first constraint would still allow frequent operation of the Companion system. The second constraint may mean that the Shuttle Orbiter would need to stay in orbit an extra day or two before the Companion system could be launched and recovered.

The primary benefit of the Companion system would be its low operating cost. Because all components except the payload shroud would be reusable, the cost of a Companion mission could be significantly lower than the cost of a Shuttle mission or an expendable launch vehicle with an equal payload. Although actual costs are difficult to estimate because no experience exists for similar systems, the cost per flight would certain be less than $10 million and possible less than $1 million. The development cost of the Companion system would be less than the development cost of reusable systems that do not operate in conjunction with the Shuttle because such systems would require entry and recovery system that would increase costs directly and through size increases. Application of typical cost estimating relations to the Companion system indicates that the development cost could be considerably less than a billion dollars if most of the subsystems are adapted from existing vehicles.

System Description

Figure 2 shows the general characteristics of the Companion system, and Table 1 lists the system masses. The orbital stage is cylindrical and is sized to fit in the payload bay of the Shuttle Orbiter. Two boosters are placed on opposite sides of the orbital stage. The rocket engines on the orbital stage and both boosters operate from liftoff to staging. The boosters stage at

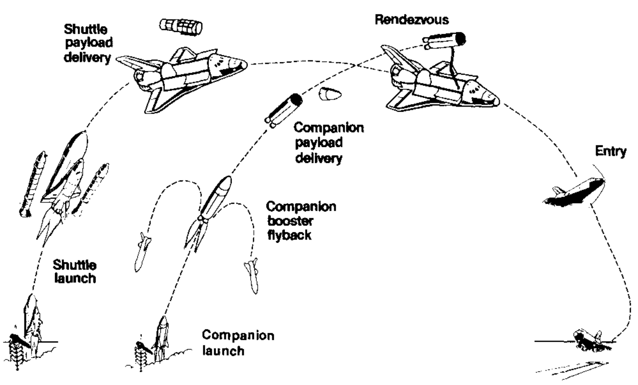

Fig. 1 Companion system operations.

Table 1 Masses of companion system, kg

Orbital stage	8,200
Payload and shroud	10,100
Burnout	18,300
Propellant	152,900
After staging	171,200
Boosters (two)	15,00
Before staging	186,200
Propellant	71,800
Gross	258,000
Orbital Stage	8,200
Oxygen	130,800
Kerosene	44,200
Hydrogen	1,900
Gross	185,100
Booster (one)	7,500
Oxygen	17.700
Kerosene	5,900
Hydrogen	300
Gross	31,400

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