Appendix B

Noneconomic Criteria

Capacity of a space transportation system can be described in terms of maximum annual launch rate or payload tonnage. However, capacity is actually multifaceted and is better described by a set of numbers: the maximum launch rate of each fleet[1] to each of several reference orbits, along with trade-offs among these, if any (e.g., sharing of launch pads by different fleets).[2]

Flexibility is the "ability of the space transportation system to . . . respond to schedule, payload, and situation changes with . . . responsiveness . . . [and] capacity, "[3] " . . . and to satisfy missions in more than one way."[4] For example, a fleet's ability to share traffic (carry some or all payloads manifested for a different fleet) improves the flexibility of a multi-fleet system. Flexibility may be valued for its own sake or indirectly, if it contributes to resiliency, operational availability, or access probability.

Reliability is the probability with which a system will perform an intended function. A system designed to perform several distinct functions will have a reliability corresponding to each function. For example, a fully reusable vehicle would be designed to transport payloads to orbit safely anc3 return safely. The probability that it will reach orbit and safely deploy a payload (its ascent reliability) is greater than its mission success reliability—the probability that it will reach orbit, safely deploy a payload, and return. Mission success reliability is a commonly used criterion, but reliabilities of non-critical subsystems are also of interest because they affect maintenance costs.

High reliability contributes to, but is not required for, resiliency and operational availability; it is necessary for high probability of access and return. Ascent and return reliabilities determine the risks of loss of payloads and reusable vehicle components; these risks include expected replacement costs as well as nonfinancial risks, e.g., to national security or political support of space programs. One of the difficulties in using reliability as a criterion is the uncertainty in estimates of the reliabilities of operational vehicles and, especially, proposed vehicles.

Because perfect reliability is unattainable, the marginal cost *of reliability* must increase without bound as reliability approaches 1.0, and a lower reliability must be optimal (see figure 2-4 in chapter 2). The optimal reliability would be the reliability at which the value of reliability less the cost of achieving that reliability is greatest. The value of reliability has been estimated in some cases by calculating the expected replacement costs of payloads and reusable vehicle components; such estimates have been used to argue, e.g., that reusable systems with reliability below .985 should not be considered as viable candidates. However, such estimates are likely to undervalue reliability because they neglect intangible risks. The costs of providing various reliabilities have been estimated by considering different configurations of critical components (e. g., engines) with different degrees of redundancy, totalling component costs, and estimating reliability from estimates of component reliabilities.

Resiliency is the ability of a space transportation system to adhere to launch schedules despite failures—to "spring back" after failure. A fleet is considered to be resilient if the probability of a failure while recovering from a failure is less than 0.35.[5] This criterion is derived from several assumptions:

1. Payloads are launched at a nominal launch rate until a failure occurs.
2. After a failure, launch attempts cease for a duration called the downtime, during which the cause of the failure would be investigated and corrected; however, the reliability of the launch vehicle is assumed to remain the same.
3. Reservations for some payloads scheduled to be launched during the standdown are assumed to be canceled; the rest, a fraction called the backlog factor, are added to the pre-failure backlog (if any) of payloads queued for launch.
4. When launches resume, payloads are launched at the maximum launch rate (the surge rate) at which the system can operate in an effort to reduce the backlog. Meanwhile, new payloads are readied for launch at the nominal launch rate and are added to the backlog.
5. Launches continue at the surge launch rate until the backlog is eliminated, unless another failure occurs first.

[1]A fleet is that portion of a space transportation system which consists of launch vehicles of a single type, e.g., the Shuttle fleet, the Titan-IV fleet, etc.

[2]Capacity was not used as a screening criterion in STAS because candidate architectures were required to have sufficient capacity to fly all missions in the mission model. Excess capacity contributed to architecture scores indirectly through effects on operational flexibility and resiliency, etc.

[3]Joint Task Team, *National Space Transportation and Support Study 1995-2010,* Annex E ("DoD Functional/Operational Requirements"), May *1986,* p. *5.*

[4]Ibid., Annex C, p. *12,* tab. *2-3.*

[5]The resiliency of each fleet of a multi-fleet space transportation system may be calculated as though it were the only fleet, if no fleet can carry payloads manifested for a different fleet. The resiliency of the multi-fleet system is considered inadequate if the resiliency of any of its fleets is inadequate. If the fleets can share payloads, calculation of the probability of a failure during a surge period can be very complicated.

If the probability of a failure during a surge period exceeds 0.35, it is unlikely that the backlog can ever be eliminated after a first failure.' However, resiliency may be made as good as desired by changing any one (or any combination) of three of the four parameters that determine fleet resiliency: reliability, downtime, and nominal launch rate. Increasing surge launch rate results in only limited improvement in resiliency.[7]

Operational Availability is the probability that a fleet, or a multi-fleet system, will be operating (i.e., not standing down) at a randomly selected time.[8] Operational availability is intimately related to resiliency; a fleet or system with high resiliency will have a high operational availability. Reducing downtime can make operational availability as great as desired; a fleet that never stands down is always available, even if unreliable. A mixed fleet is not required for high operational availability.

Access Probability is the probability that a space transportation system can launch a payload *and* that the payload will reach its operational orbit intact. Two kinds of access probability can be distinguished: probability of access on demand, and probability of access on schedule. High probability of access on demand requires flexibility—so that a high-priority launch can be scheduled quickly when required for national security—and high probability of access on schedule, so that the scheduled launch will most likely be successful. Probability of access on schedule is operational availability (the probability that a launch can be attempted when scheduled) times vehicle reliability (the probability that the payload will reach its intended orbit intact if launched).[9 10]

A space transportation system is often said to provide *assured access* if it provides means for placing high-priority payloads in their operational orbits on demand with high probability. Access probability depends on the payload—and the variety of vehicles that can launch it—and is more important for some payloads than for others.

“Harry Bernstein & A. Dwight Abbott, “Space Transportation Architecture Resiliency,” (El Segundo, CA: The Aerospace Corp., March 1987).

‘The probability of a failure during a surge period (P_F) may be calculated from the formula

$$P_F = 1 - P_s^{T_d\,K(T\#?n / (S-1)}$$

where P_s *is* the launch vehicle reliability, R_n is the nominal launch rate, SR_n is the surge launch rate, S is the surge factor (SR_n / R_n), Td is the downtime, and $K(T_d)$ is the backlog factor, which depends on the downtime. Downtime is defined as the interval from a failure until the next operational launch attempt. $K(T_d)$ = 1— Td/6 is assumed.

‘This does not mean that it must always have an unreserved vehicle on a pad ready to launch on a day’s notice.

[9]N .b.: traffic sharing is not required. Cf. STAS groundrule A-1: “Viable architecture will be based *on* a mixed fleet concept for operational flexibility. As a minimum, two independent (different major subsystems) launch, upper stage, and return to Earth (especially for manned missions) systems must be employed to provide assured access for the specific, high priority payloads designated in the mission model. ”

[10]If downtime has not been minimized, traffic sharing may improve access probability, otherwise it can reduce it. If a reliable launch vehicle fails, using a backup vehicle that is less reliable than the primary launch vehicle payload will decrease the probability of getting the shared payloads to orbit safely. If the primary vehicle were indeed more reliable, it would be safer to use it while accident investigation proceeds; its unreliability, even if due to systematic problems, would be lower. Moreover, it would be costly to maintain a backup fleet.