weighting factors of the corners. W can take on the values 0, $\frac{1}{3}$, $\frac{2}{3}$, and 1, to account for either full, partial or no shadow on the triangular segment. The local pressure coefficient becomes $C_p' = WC_p = WK \cos^2\theta$.

A minor requirement imposed by the foregoing technique is that adjacent cross sections have the same number of defining points. Abrupt changes in cross section might require an increase in the number of points per section but this could be handled easily, by restarting the calculation at that section with more points per section.

References

[1] Gentry, Arvel E., "Hypersonic Arbitrary-Body Aerodynamic Computer Program, Mark III Version," DAC 61552, April, 1968, Douglas Aircraft Corp., Long Beach, Calif.

[2] Brong, E. A., and Matlin, S., "A Program for the Computation of Newtonian and Free Molecule Forces and Moments for Arbitrary Bodies," TIS 63SD210, Jan. 1963, General Electric Co., Reentry Systems Dept., Philadelphia, Pa.

A Ferry Package for Transporting Reusable Spacecraft and Launch Vehicles

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Nomenclature†

C_L = lift coefficient
C_l = rolling moment coefficient; $C_{l\beta} = \Delta C_l/\Delta\beta$
C_m = pitching moment coefficient; $C_{m_\alpha} = \Delta C_m/\Delta\alpha$
C_n = yawing moment coefficient; $C_{n\beta} = \Delta C_n/\Delta\beta$
L/D = lift-drag ratio
α,β = angles of attack and sideslip, respectively
$\delta_a,\delta_e,\delta_r$ = aileron, elevon, and rudder deflections
Λ = sweep angle

Introduction

THE concept of a reusable "space shuttle" capable of rapid turn-around offers promise of major reductions in the cost of space transportation. It would take off vertically with the first stage separating at a velocity of 9,000–15,000 fps and landing horizontally at a conventional landing field.

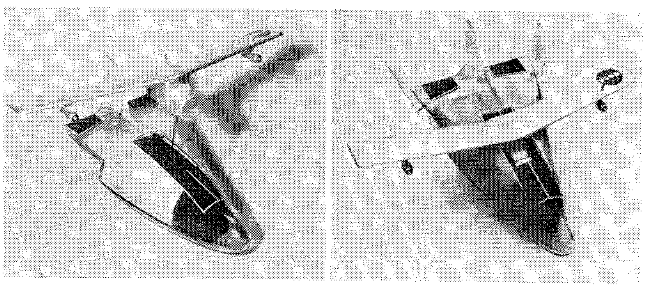

Fig. 1 HL-10 with ferry package.

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† The lateral data are referred to the body system of axes and the longitudinal data to the stability axes. The reference center of moments was located at 53% of the body length aft of the nose. All coefficients are based on body planform area, length, and span.

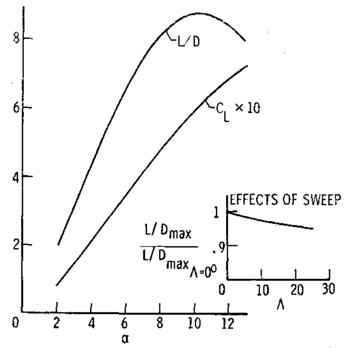

Fig. 2 Trimmed characteristics, HL-10 with ferry package with straight wing.

The second stage would continue into orbit with a capability of returning to Earth with or without cargo for a conventional horizontal landing. Ground rules under which NASA's recent preliminary contractual studies were conducted specified booster cruise-back to a field adjacent to the launch site. Normally the orbiter would also return to this site; however, other conditions dictated by mission and/or weather may necessitate landing elsewhere. In this event, the ability to ferry the vehicle from the landing site to the launch site is needed. To provide satisfactory cruise performance, higher subsonic L/D than is generally afforded by lifting bodies is desirable. Concepts employing fixed or extendable wings can provide this capability, but significant savings in gross lift-off weight are possible if only enough performance is provided to assure safe landing.

This Note deals with a proposal to increase subsonic L/D of the orbiter for ferry purposes through the use of a "ferry package" consisting of wings and engines attached to a fuel tank which is fitted into the vehicle cargo bay (Fig. 1). The concept is shown as it might be applied to the HL-10, a representative lifting body whose performance has been thoroughly studied in wind-tunnel and flight tests. The basic principles of this concept could be applied to most orbiters being considered in the current space shuttle studies. For those configurations whose subsonic L/D is satisfactory, engines and fuel tanks might constitute the total unit.

Aerodynamic Characteristics

Aerodynamic characteristics of ferry configurations with straight and swept wings of aspect ratio 10 are shown in Figs. 2 and 3 as obtained from tests at a Mach number of 0.3 and Reynolds numbers up to 15×10^6 based on body length. The results shown summarize curves of trimmed performance and

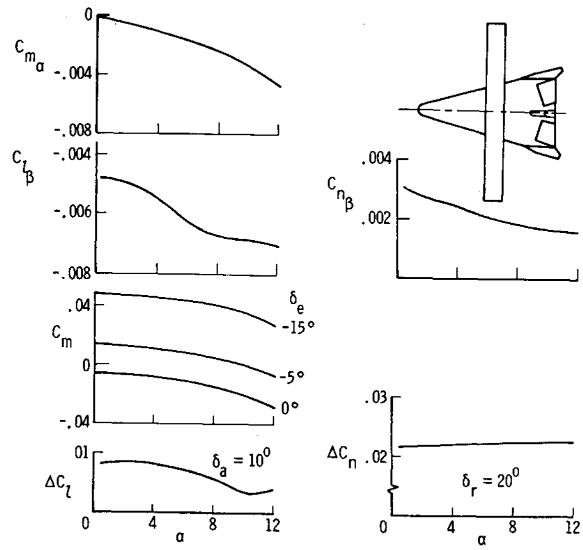

Fig. 3 Stability and control parameters—HL-10 with wing.

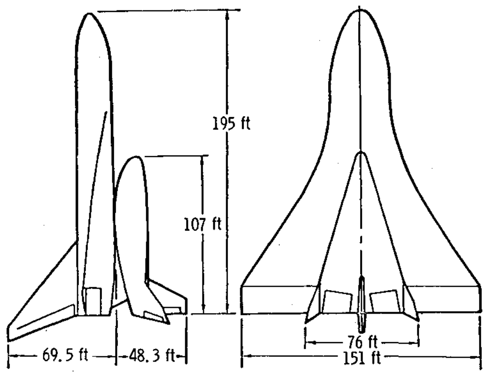

Fig. 4 Configuration selected for further study.

stability derivatives to angles of attack above L/D_{max}. A maximum trimmed lift-drag ratio approaching 9 (Fig. 2) occurs at an angle of attack of 10° and a lift coefficient of 0.6. Tests with swept wings reduced maximum L/D as shown in the insert.

The longitudinal, lateral, and directional stability characteristics of the configuration with quarter-chord of this straight, untapered wing set at 52% of the body length, are shown in Fig. 3. This configuration is longitudinally stable at all positive angles of attack and neutrally stable at $\alpha = 0$. The stability level can be increased by a slight rearward movement of the wing or by sweeping. The configuration is laterally and directionally stable throughout the test range. Various control parameters provided by movable surfaces on the basic vehicle only are shown on Fig. 3 also. For the wing position of the present tests, little more than 5° of elevon deflection is necessary for trim over the angle-of-attack range. The aileron and rudder control parameters shown are very similar to those of the basic vehicle whose control effectiveness has been adequately demonstrated in flight tests.

Application to Space Shuttle

To show the application of the ferry package concept to a full-scale launch vehicle system, the configuration‡ shown in Fig. 4 is used. The system can put a 25,000 lb, 15-ft-diam by 30-ft-long payload into a 300-mile circular orbit and has a return cargo capability of the same amount. The orbiter with the ferry package attached is shown in Fig. 5; this package is installed by removing the payload and payload hatch doors and then bolting to the cargo attachment fittings. The only other required connections are electrical for engine operation.

Table 1 is a weight summary of the complete shuttle system. The landing weight of neither orbiter nor booster is greater

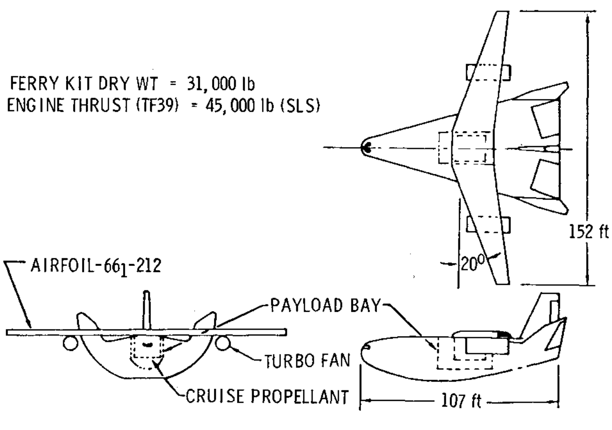

Fig. 5 HL-10 ferry configuration.

‡ Configuration studied by McDonnell Douglas Astronautics Corp. in NASA's recent Phase "A" space shuttle contracts.

Table 1 Two-stage weight summary (lb)

Vehicle length, ft	Orbiter 107	Carrier 195
Thermostructures	91,470	249,600
Landing system	9,190	22,310
Main propulsion system	527,750	2,302,860
Secondary propulsion system	38,790	2,250
Landing propulsion system	24,710	100,900
Subsystems and crew	13,310	11,070
Cargo	25,000	...
Gross pad weight	730,220	2,688,990
Liftoff weight	730,220	2,671,920
Second stage separation	730,220	...
Injected weight	230,229	511,880
Retrograde weight	197,690	511,880
Entry weight	195,760	511,880
Landing weight	185,800	450,940
Dry weight	156,470	438,230
Gross lift-off weight	3,402,140	

Table 2 Sensitivities[a]

Parameter	Const. glow $\frac{\Delta W_{PL}}{\Delta \text{ parameter}}$	Const. P/L $\frac{\Delta W_{GL}}{\Delta \text{ parameter}}$
1st-stage inert wt	−0.16 lb/lb	+6.5 lb/lb
2nd-stage inert wt	−1.0 lb/lb	+38.0 lb/lb
Cruise range (booster)	−152 lb/nm	+5,790 lb/nm
Go around (orbiter)	−377 lb/min	+12,400 lb/min

[a] P/L weight, 25,000 lb; P/L size, 15′ D × 30′ L; glow, 3.40 MLB.

than that of current transports. In Table 2, weight sensitivities for the reference space shuttle configuration are shown. The high penalties associated with the onboard provision of cruise range and go-around capability are of particular interest here. For the orbiter, these penalties are directly tied in with those for second stage inert weight and indicate that lift-off weight increases more than 6 tons/-min of power subsonic flight.

The estimated dry weight of the ferry package was 31,000 lb (Fig. 5). To incorporate such a system in the orbiter results in prohibitive increases in liftoff weight; providing onboard fuel alone for a modest 300-mile cruise, increases the lift-off weight by one-half million pounds. Ranges of over 1000 miles at sea level are easily obtainable using the system shown in Fig. 6. The range was computed using data from the subsonic tests of the HL-10 with wings and includes allowance for nacelle drag and interference effects.

Although the ferry package concept has not been completely developed, feasibility has been clearly illustrated. On the selected vehicle, the stability and control effectiveness appears adequate for subsonic cruise. Portions of the concept might also be applied to the wing-body configurations; how-

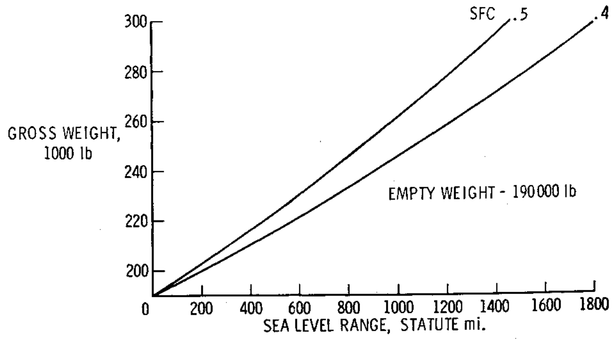

Fig. 6 Range of HL-10 with ferry package.

ever, because of their relatively high subsonic L/D, cruise for these configurations is feasible without additional wing area. For this class of vehicle, the ferry package might consist of cruise engines and fuel tanks only. Although this discussion has focused primarily on the orbiter, carrier weight also may be substantially reduced by downrange landing and application of the ferry package concept for fly-back.

The TIROS Operational Satellite (TOS) System as a Case Study

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THE TIROS Operational Satellite (TOS) System of the Environmental Science Services Administration (ESSA) became operational in February 1966, with the launch of ESSA I. Since that date it has operated continuously, with no breaks in service. This excellent record is due in no small part to the high degree of cooperation, coordination, and intelligence interchange which has been developed among the three agencies concerned, namely; NASA, ESSA and RCA (the prime contractor). Most of the day-to-day interchange is accomplished by the working teams at the NASA/GSFC (Goddard Spaceflight Center) TOS Project Office, the ESSA National Environmental Satellite Center (NESC), which operates the system, and the RCA TOS Project Office, which has designed and built most of the system and hardware.

This Note presents some of the lessons learned with respect to the following areas: whole system design, coordination, redundancy, simplicity vs sophistication, and centralized data processing (economy or bottleneck?).

Whole System Design

There is a great tendency to concentrate on the satellite and sensors, to give less consideration to the ground station needs and to assume that the data processing and data output systems will fall in place. A typical unconsidered item might be the formatting of the data to provide for the simplest and most reliable recognition and reduction in the data processing phase. It is very possible that the spacecraft sensors will equally easily permit several data formats, one of which is particularly amenable to the planned data processing. If the decision on format is made in ignorance of the data processing needs, however, the preferred format will probably not be the one selected.

The need for whole system design shows itself most clearly if a large number of ground readout stations will be accepting data from the satellite. It may make very good economic sense to make the satellite more complex or expensive, if by so doing, a large number of ground stations are made simpler, more reliable or even sufficiently less expensive. So long as the increased complexity of the satellite does not result in a disproportionate increase in failure probability, one would certainly want to select such an option—but the option must be available to select. In the ESSA system, one of the problems in the operation of our Automatic Picture Transmission (APT) System, which provides data to many independent ground stations, is that the slow degradation of the cameras results in less and less adequate pictures. Less adequate pictures also occur during the winter season, because of reduced surface lighting. Since there are a wide variety of ground receivers and recorders around the world, the capability of these various stations to overcome the picture deficiencies is varied. If NESC had elected to include in our APT cameras some form of remote controllable sensitivity, we might have readily compensated for these deficiencies to a large extent on the spacecraft, and provided better data at less expense to our various users. The added cost and risk of this feature on the spacecraft would have to be balanced against the improved utility of the received data.

Coordination

Perhaps the greatest difficulty in the early days of the operational meteorological satellite program resulted from a failure to provide sufficient continuing coordination between the agencies concerned. The tacit assumption was made that requirements could be adequately defined in writing. However, it was found that the written word is a very poor device for coordination. It can be extremely valuable as a record of what has been agreed orally, when both parties know what the other means by the written word; it can be worse than useless without the oral coordination to guarantee understanding. Over the years NASA, ESSA, and RCA have developed relatively elaborate, but very effective coordination procedure for the meteorological satellite program. At the top is the Meteorological Satellite Program Review Board (MSPRB). Chaired jointly by the Associate Administrator for Space Science & Applications of NASA and the Administrator of ESSA, it provides the vehicle for major policy and funding decisions. The MSPRB meets several times a year. At these meetings each agency reviews its present program status and funding, then jointly they examine the proposed program for the next 12–18 months. Policy decisions on major program tradeoffs or problem areas are often made, or differences aired for further review. Since the board includes members or observers from several organizational levels below the principals, it provides an especially effective vehicle for coordinated guidance throughout both organizations.

At the working level is the TOS Working Group. This unit is comprised primarily of NASA/GSFC, ESSA/NESC and RCA personnel at the principal technical supervisory level and meets monthly. It reviews recent progress in the project, problems which have arisen, and possible solutions. It assigns responsibility for further investigation of unresolved problems. It provides a means for coordinated implementation of the MSPRB decisions and passes on to ESSA and NASA management and to the MSPRB problems requiring policy decision. Below both of these formal bodies, there is a continuing coordination on a day-to-day basis at the working level. Both GSFC and NESC have designated individuals who have primary technical responsibility for their agency in specified areas (i.e., spacecraft operations, sensor status, communications, etc.). These personnel work directly with each other on any problems which arise in their specified areas. This method has been found to be much superior to the use of a single person for all coordination for each agency, since such single points of contact almost invariably become either bottlenecks or simply relay points. It is, of course, essential that the individuals who are the specified coordinators keep their superiors informed of the results of their coordination (and any others who may be affected). In fact, the TOS Working Group meetings serve to insure such intelligence distribution, since all of these special coordinators are members of the Group.

Finally, but by no means last in importance, NESC maintains an office right in the GSFC TOS Project area, staffed full time with personnel who are always available to provide a channel for questions not appropriate to the special coordina-

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