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ONE IDEA FOR A NEXT GENERATION SHUTTLE

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ABSTRACT

In this configuration, the current Shuttle External Tank serves as core structure for a fully reusable second stage. This stage is equipped with wings, vertical fin, landing gear, and thermal protection. The stage is geometrically identical to (but smaller than) a single stage that has been tested hypersonically, supersonically, and subsonically in the NASA Langley Research Center wind tunnels. The three LOX/LH engines that currently serve as main propulsion for the Shuttle Orbiter, serve as main propulsion on the new stage. The new stage is unmanned but is equipped with the avionics needed for automatic maneuvering on orbit and for landing on a runway. Three rails are installed along the top surface of the vehicle for attachment of various payloads. Payloads might include third stages with satellites attached, personnel pods, propellants, or other items.

INTRODUCTION

Current shuttle orbiters have made over 100 trips to orbit delivering everything from personnel to telescopes and research laboratories. The vehicle design was arrived at after much consideration of mission requirements and vehicle system costs. In the Shuttle design the propellant for the orbiter component is carried in an external tank which is expended. Two solid rocket boosters (SRBs) are used to provide stage I lift-off thrust and impulse. They are operated in parallel with three LOX/LH orbiter engines. The orbiter, with an enclosed cargo space of 15-ft diameter by 60-ft length, is driven to orbit on three LOX/LH engines, having staged the two solids. The two solids are recovered by parachute. The orbiter reenters and lands on a runway without the aid of airbreathing jet engines [1].

OVERALL SYSTEM DESCRIPTION

In this (new) 'idea' the solid rocket boosters (SRBs) are still used. However, the external tank, or 'ET', is re-configured with wings, a vertical tail, and landing gear thus rendering it recoverable. No enclosed cargo bay is provided; rather payloads are carried 'piggy-back' on the body structure (Fig. 1). The resultant configuration (serving now as the replacement orbiter) is unmanned but is equipped with all the avionics necessary for on-orbit-auto-docking, reentry, and landing. The new orbiter vehicle is configured so as to replicate the aerodynamic shape of a design that has been extensively tested in Langley Research Center wind tunnels. This design is referred to as the 'Circular Body Earth-to-Orbit Vehicle' (CBV, Refs. 2 through 4). An artist's rendition of the vehicle appeared on the cover of the Winter 1998 issue of SAWE WEIGHT ENGINEERING, Vol. 58, Number 2. The vehicle was sized for delivery of payloads as a single stage.

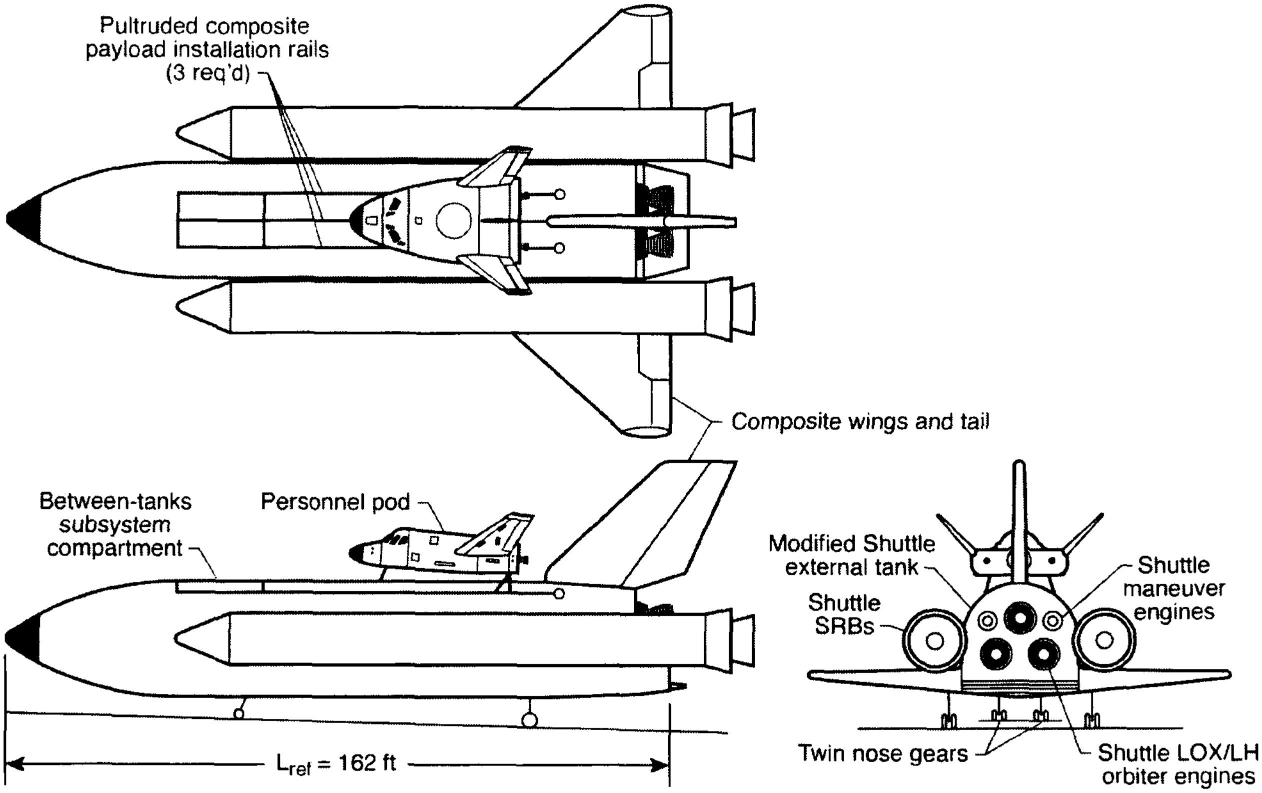

Figure 1. Fully Reusable Shuttle (FRS) shown with a personnel pod as a payload.

FULLY REUSABLE TWO STAGE SHUTTLE

The following is a subsystem-by-subsystem description of an 'idea' for a fully reusable (next generation) Shuttle. Each subsystem description is given in the same order as that used in the coded mass properties documents for the current Shuttle program. Size comparisons between current Shuttle, a Circular Body Single Stage, and the Fully Reusable Shuttle (FRS) are given for major structural components in Table I.

Table I. Orbiter Geometries Compared

Item	GEOMETRIES COMPARED		
	Shuttle	CBV Single Stage	FRS*
Reference Length	107.5	196.8	162.0
Nominal Body Dia.	NA	32.8	27.0
Geometric L/D	NA	6	6
Exposed wing areas (plan), ft^2	1922	4372	2963
Theoretical Wing area, ft^2	2690	6982	4731
W/C_DA (entry), lb/ft^2	59	38	34
Tail Profile Area, ft^2	375	1435	972

*Fully Reusable Shuttle

WING GROUP

The current shuttle wing is fabricated principally from aluminum. The internal structure consists of fairly conventional ribs and spars. Half ribs are added in between major ribs to minimize panel deflections for the installation of reusable surface insulation (RSI). Aluminum honeycomb sandwich panels are utilized in a limited area just ahead of the main landing gear wheel wells.

The wings of the new vehicle would be fabricated using a graphitic composite. All wing cover panels would be fabricated using honeycomb cores and woven graphitic face sheets. A minimum number of internal ribs and spars are employed. The FRS wing is in general, similar in geometry to the current Shuttle wing except that it is 'photographically' enlarged.

TAIL GROUP

The tail for the new vehicle would also be fabricated from graphitic composite. Like the current Shuttle, a 'split rudder' would be employed rendering it usable for both speed braking and directional control. Tail size is based on an assumed tail volume coefficient that matches that of the current Shuttle Orbiter (tail volume coefficient herein defined as the product of tail profile area and distance to the vehicle's nominal c.g.). Since the CBV's c.g. is more rearward at 72% versus the Shuttle at 65% to 67.5%, this renders the tail disproportionally even larger than that for the Shuttle.

BODY GROUP

As stated earlier the current Shuttle ET would serve as the focal point for the body of the new vehicle. The three space shuttle main engines (SSMEs) would be installed directly onto the base of the 27-ft diameter ET. An open truss structure would transmit engine thrust loads into the aft skirt of the hydrogen tank. The reaction control system (RCS), the orbital maneuver system (OMS), the auxiliary power units (APUs) and an aft avionics module would all be installed in this area.

In order to better match cycle life to the expected number of repressurizations (i.e. missions), the gauge of the LOX and LH walls would be increased. In addition, ring frames and stringers would be added to the LOX tank. The arrangement for attaching the SRBs to the ET would be essentially preserved. In this configuration, axial thrust is transmitted from the forward SRB fittings in a load path that provides support principally for the 1.4 million lb LOX load. An access hatch 14 ft wide by 21 ft long is provided in the intertank adaptor between LOX and hydrogen tanks. A portion of the intertank volume is used for the forward avionics bay and electrical power generation.

Three pultruded graphitic beams are provided that extend from the forward end of the vertical fin to the forward end of the access hatch [5]. Payloads are attached to these three beams. The three beams, at their forward end, serve also as load paths around the access hatch for the inertial load of the LOX propellant located forward. Axial loads, imposed on the three beams (principally by launch acceleration), are taken out at the forward ends of the beams in tension and shear. The remainder of the beam support fittings carry only lateral and 'punch' loads. Wing loads are carried through the LH tank by means of two deep internal ring frames and two wing spars. This transmission of wing loading through a cryogenic tank occurs in the same general area as thrust loads are presently transmitted from the current Shuttle orbiter into the tank. Nose gear loads are transmitted into the forward end of the LH tank with special pivots and support structure.

A fairing is added to the rear of the ET hydrogen tank. This fairing serves as the enclosure for the propulsion systems and the aft avionics module. Also, in order to enhance the applicability of the wind tunnel data of references 2 through 4, the current ogive of the ET-LOX tank would have to be altered back approximately to Shuttle-ET station 536 (Fig. 2). (The radius of curvature of the ET in the ogive area is less than that for the circular body vehicle).

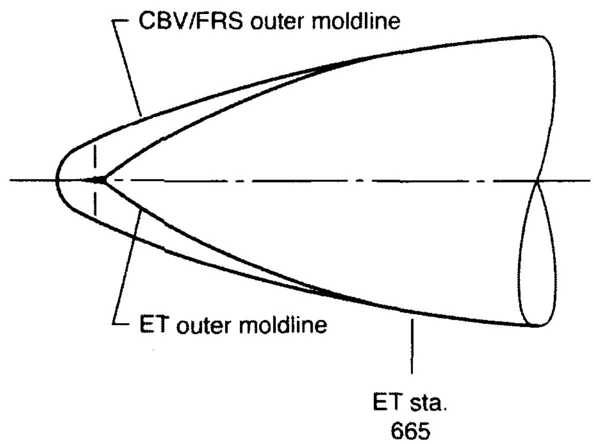

Figure 2. Comparison of Ogive Outer Moldlines, Wind-Tunnel-Tested Circular Body Vehicle Versus ET.

The changes required for the ET to serve as the body for the FRS vehicle would be considerable. The least of which is the replacement of the nose cone with a reinforced composite of more generous radius and an alternate configuration of the LOX vent valve system. On the positive side many of the jigs, fixtures, transportation equipment, buildings, and other facilities would be adaptable to the FRS use of the ET. The weight allowance for the original ET-LOX tank has been increased substantially. This is to allow for the addition of ring frames, stringers, thicker gauge skin and more slosh baffles (Table II).

Table II. Tank Weight Comparison, lb

	Shuttle ET	FRS
LOX Tank	12,520	25,000
LH	31,739	36,800
Intertank	13,500	13,500

Table III. Prelaunch Weight Comparisons Not Including SRBs.

	Shuttle ET	FRS
Orbiter Dry	167,351	281,984
External Tank	75,834	0
Personnel	3.950	0
Payload	65,000	35,000
Miscellaneous* & Fluids	37,000	39,500
Prelaunch Weight	349,135	350,984

*Includes usable OMS and RCS

THERMAL PROTECTION SYSTEM

The thermal protection system (TPS) wetted area for the FRS vehicle is approximately twice that of the current Shuttle (i.e., 13,122 ft^2 compared to 6,745 ft^2). The system would generally be that used on the Shuttle except for known advances in the technology that could be applied. Factors that render the FRS inherently lower in average unit weight are the absence of the more abrupt discontinuities found in the current Shuttle's outer moldline. On the current Shuttle, increased density of tiles and special shapes are required around the pilots' canopy and around the two Orbital Maneuver System (OMS) pods. On the FRS, the OMS, RCS, and supply systems are submerged and there is no crew cabin canopy.

Also, the chines on the current Shuttle (in the transition region from bottom-to-side surface of the orbiter body) require special tiles. On the FRS vehicle the transition from bottom centerline heating rates to sides of the circular cross section are more gradual. Also, a savings in weight and cost of the TPS on the FRS vehicle accrues through the absence of mechanically linked doors otherwise required on the Shuttle for cross-feed of LOX and LH propellants. Overall the much lower planform loading at entry of the FRS vehicle than shuttle will yield a lower heat load per unit area of TPS (Table I, compare W/CdAs). Most of the current Shuttle TPS for area coverage has higher-than-needed maximum temperature limits.

LANDING GEAR

Landing gear, very similar to the current Shuttle's, would be employed. However, twin nose gear assemblies would be used instead of one (Fig. 1). Also, the nose gear steering and braking would be accomplished using electrical systems instead of hydraulic [7].

PROPULSION

All of the main and auxiliary propulsion systems (currently used on the current Shuttle) would be used on the FRS. Changes to the main propulsion (i.e., SSMEs) should be minimal but one known change would be the null positions of the three engines. The LOX and LH disconnects, now used between ET and SSMEs would be retained. This configuration of the main feed system is proposed in order to allow for recovery of the engines on orbit for use on a planetary mission or return to Earth. Rendering the engines easily disconnectable at the gimbal and gimbal actuator points increases the weight and complexity of the system; however, eliminating the need for actuators and doors across a structure/heat shield boundary is an attribute not available in the Shuttle system.

PRIME POWER

The prime power on the Shuttle includes (typically) three Fuel Cell Sets and three hot gas turbine Auxiliary Power Units (APUs). The systems (as generally configured) should be adaptable to the FRS vehicle. However, an alternative to APUs and hydraulics for surface controls and engine gimbals, might involve the use of high voltage batteries and electric motors. If batteries and electric motors are used, all of the prime power could be housed forward in the intertank section. Motor controllers would also be placed in the intertank volume. The desirability of placing prime power so far from its use-point, is based on the assumption that the weight penalty of extra electrical cabling is more acceptable than the extra weight of long (high pressure) hydraulic lines that would be required for the same forward location of prime hydraulic power.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT

For the current Shuttle and a crew of 7 to 8 persons, the environmental control and life support is substantial – over 5000 lb. If crew are included, weight must be budgeted for such items as seats and escape provisions. A crew of two could be housed in the intertank region but only with two flush-mounted viewing ports. For the FRS versions without crew, 300 lb is allotted for selected active and passive thermal control. For isolated cases wherein active cooling is required, this would be achieved by using closed convective systems. Principally, however, heat sink and phase change materials would be used for cooling where needed at specific line replaceable units.

AVIONICS

The unmanned FRS will have all the avionics that the current Shuttle has, including guidance, navigation and control, and communications and tracking. However, it will not have displays and controls since it is unmanned. Some additional software would include provisions for auto-docking on orbit. Substantial savings in weight and power consumption can be assumed (over Shuttle) principally because of the rapid advances in the technology in these fields. With regard to the idea of an unmanned Earth-to-orbit transport, the current Shuttle (for all intents and purposes) already has this capability – only a few changes and additions in software being needed.

PAYLOADS

Payloads are installed on the pultruded strongbacks (Fig. 3 and 4). Every payload-FRS combination would have to be wind tunnel tested for validation of the aerodynamics. The ascent aerodynamics are not as critical as the return aerodynamics and most missions involve delivery of payloads without return. This lessens the criticality of the aerodynamic knowledge required for any given mission. In an abort, payload(s) could be ejected as one option. The strongbacks allow for attachment of payloads at any station within a 70-ft length. This architecture facilitates c.g. management. One option, when a personnel pod is attached, is to provide the necessary umbilical and software for the pod crew to actively control the 162-ft orbiter. All jetisonable payloads would be equipped with separation motors. The use of twin tails for enhanced clearance of payloads during separation is an option.

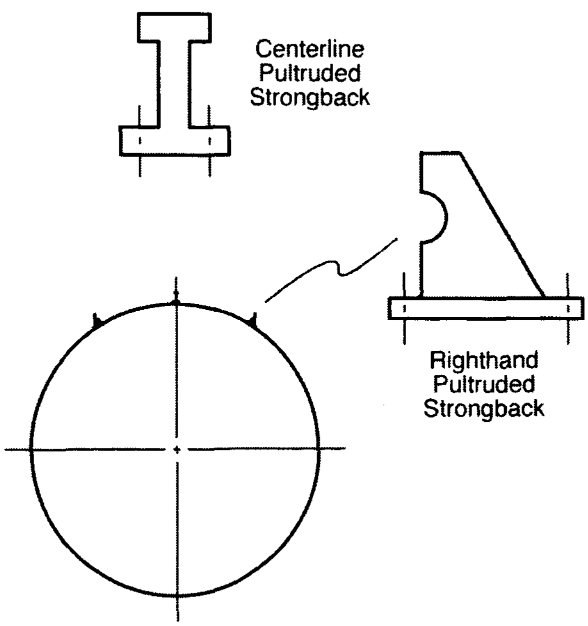

Figure 3. Pultruded Strongbacks.

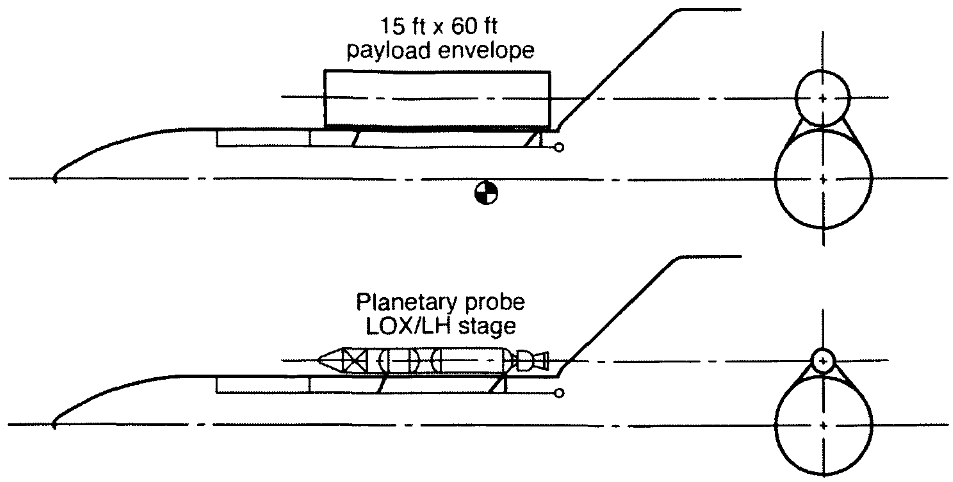

Figure 4. Example Payload Module Installations.

A personnel pod is shown as a space tug carrying a 7,500-lb Shuttle engine – the engine being a possible component of a rocket assembled in orbit for a fast-track mission to Mars (Fig. 5). For the engine weight and location shown, an additional 12° gimbal angle is needed on the personnel pod propulsion engine.

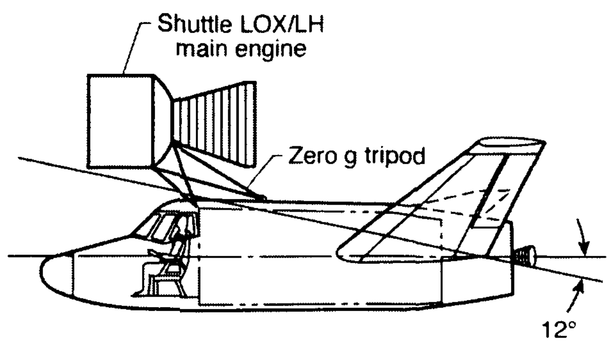

Figure 5. Personnel Pod, Dualing as a Space Tug.

For still another option, the ET without wings or vertical tail can be used to deliver logistic modules for the support of the same Mars mission mentioned above (Fig. 6). In this concept, the Shuttle solids are still recovered by parachute. The ET, however, is expended. The three SSME engines could be disconnected and either returned to earth on an FRS for future use, transported to a way-station for use on a future lunar or planetary mission, or expended. An earlier reference variation on this concept would be for example a Shuttle Derived Vehicle (Ref. 9). That particular SDV concept was designed for payloads in the 140000 lbm to 185000 lbm range depending upon the degree of deviation from the original STS system. However the theme of an evolved development approach is consistent for FRS and SDV systems.

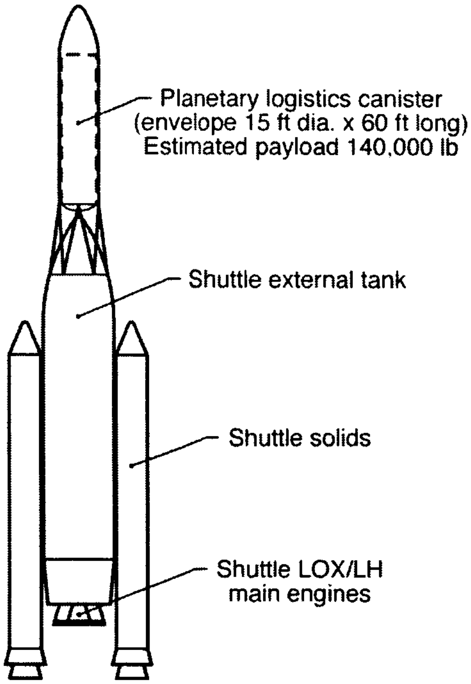

Figure 6. Shuttle-derived Launch Vehicle Configured for Planetary Missions Logistics Support.

JET-ENGINE-SELF-FERRY MODULE

The self-ferry module is desirable on the FRS because of its size. The yoke that serves as structure for two jet engines also serves as storage for the cruise fuel and the engine supporting subsystems (Fig. 7). The only interfaces between the ferry module and the FRS are electrical and mechanical. All electrical interfaces would be accommodated using a single umbilical. The jet propulsion module is placed on the vehicle using a conventional crane.

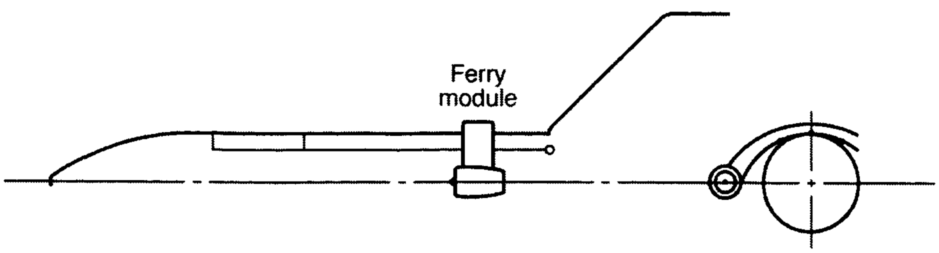

Figure 7. A Self-Ferry Module For The Fully Reusable.

MASS PROPERTIES AND AERODYNAMICS

Any given configuration for a vehicle that flies is no better than the combined exactness of the mass properties and the aerodynamics. The interplay between mass properties and aerodynamics can be well illustrated by a discussion of the three methods of providing directional control that were tested for the original Circular Body Vehicle (Fig. 8). They included a conventional aft vertical fin (a rudder), a forward vertical fin (or dorsal), and two wing mounted tip fins [2-4].

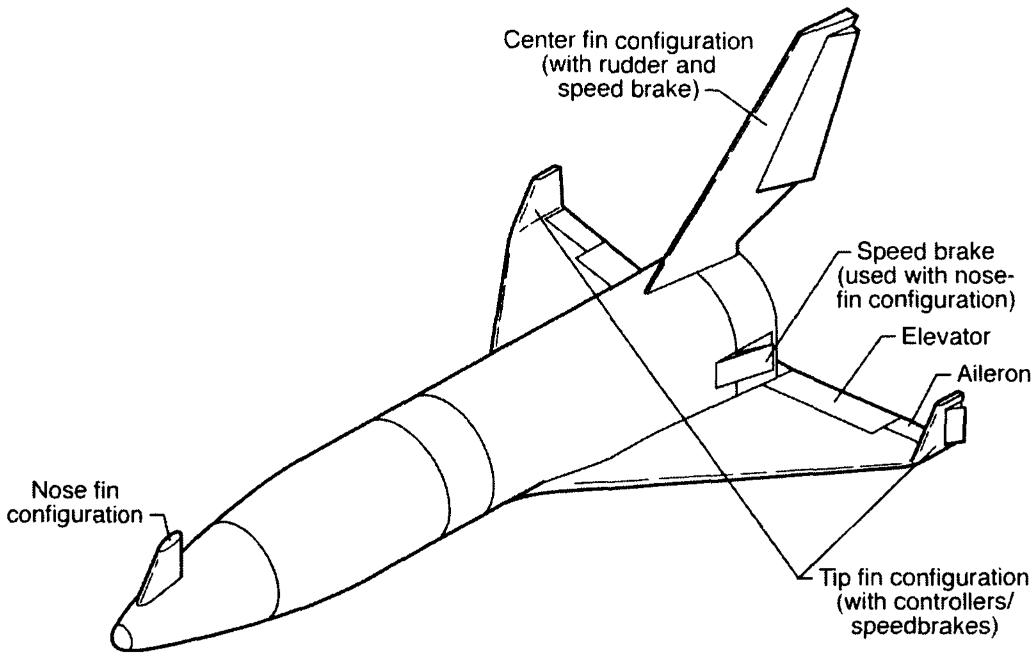

Figure 8. Wind tunnel model showing three fin arrangements investigated.

The current Shuttle's rear-mounted vertical tail, with split rudder, serves for directional control and as a speedbrake for energy management. The energy management function is essential for controlling touchdown point, based in turn on the vehicle velocity on final approach; referred to as Terminal Area Energy Management (or TAEM). The Shuttle vertical tail does all the other good things that are needed for an Earth-to-orbit transport, the most important of which is that of providing stable lateral directional control.

The experimental dorsal, it is estimated, would weigh about one eighth that of a conventional aft vertical fin and represents mass added forward, improving balance of otherwise tail-heavy vehicles. Also the dorsal would require very little actuator power, being an all-movable surface pivoted very near its nominal center of pressure. However, the device renders the vehicle unstable in yaw making it necessary to provide an active stability control system. In addition, extra movable surfaces have to be added near the rear of the vehicle to provide the energy management function. For this design speedbrakes were included at the rear of the vehicle in the vicinity of the engine compartment. For the speedbrakes tested, at 30-degree deflection, drag increased by approximately 45 percent. Tail-mounted speedbrakes (deflected 30°) also yielded a 45 percent increase in drag. (Table IV). All measurements were made at 4° angle of attack and M = 0.3.

Table IV. Lateral Directional Control Surface Comparisons

Device	Profile Areas, ft^2	Weight, lb	Vehicle Cd Speedbrake Settings		Percent Increase In Drag	Vehicle C.G., %	Vehicle Dry Wt, klb
			0°	30°			
Conventional Tail	972	6020	0.06	0.087	45	71.5	290
Tip fins*	215	1400	0.03	0.060	100	70.8	245
Dorsal	72	256	NA				
Auxiliary* Speed Brake	140	740	0.03	0.046	45	70.6**	242

*2 surfaces

**Combined vehicle c.g. including dorsal and auxiliary speedbrakes.

Tip fin controllers can provide directional control but the system does not provide stability and therefore also must be actively controlled. Tip-mounted fins are less unstable directionally than the dorsal. Also, unlike the dorsal, the tip fin controllers could be deployed symmetrically to provide the speedbrake function. Both the dorsal and tip fin controllers have less tendency to induce a pitch-up or roll motion of the vehicle when deflected than a conventional tail. A comparison of the three devices for lateral directional control is given in Table IV.

Comparisons include weight of the three devices, their effect on overall vehicle drag, L/D, and c.g. The conventional tail is by far the heaviest and causes the greatest regression of vehicle c.g. rearward. Also, its presence creates the greatest amount of drag. Both the dorsal and tip fin installations yield vehicle drag coefficients in the 0.03 range compared to 0.06 for a conventional tail. The supersonic L/D for a FRS equipped with a conventional tail is approximately 5 but is over 7 when equipped with a dorsal or tip fins. The increased drag of the vertical aft fin (or tail) effects a modest reduction in insertable payload due to a greater ascent drag losses. This, however, is of little consequence relative to return from orbit unless the vehicle is configured with jet engines for a planned subsonic cruise period.

SUMMARY REMARKS

The integration of the current Shuttle ET into the transportation system as a reusable element, as suggested by this paper, may be a reasonable next step. One of the reasons for utilizing composites for wing and tail is to reduce the amount of regression rearward of the vehicle's center of gravity. Compared to a single stage, the main propulsion system weight is much lower because the Mode I LOX /RP engines (that one might use on a single stage) have been eliminated. In the design of this paper, the two Shuttle solids as a first stage provide the needed lift-off thrust and added impulse necessary to reach orbit.

Paradoxically, the c.g.'s for the FRS vehicle are still in the 71 to 72 percent range. The single stage vehicle of references 2 through 4 was tested for an assumed 72% c.g. The current Shuttle orbiter c.g. is trimmable in the 65.0 to 67.5 percent range. The FRS vehicle c.g. is still somewhat rearward because of the absence of a crew, crew compartment and all of the support equipment located forward.

ACKNOWLEDGEMENTS

Over the years NASA Johnson Space Center (JSC) personnel have assisted Langley by providing "real" weights of subsystems for a space transportaion, i.e. the current Shuttle. This mass properties information provided a sound basis for the derivation of weights for future shuttles. To those involved, principally personnel assigned to the mass properties work at JSC, but too numerous to name, we are greatly indebted.

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