# THE ROCKET-SLED LAUNCHING TECHNIQUE: ITS IMPLICATIONS ON PERFORMANCE OF REUSABLE BALLISTIC (ORBITAL/GLOBAL) TRANSPORT SYSTEMS

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## *Introduction*

During the 6,000 years since the invention of the wheel, man has traveled by foot, horse, locomotive, steamship, automobile, and airplane, while expending an exorbitant portion of the energy available to him for transporting himself and his belongings from one point on earth to another. Each new era of human progress has brought with it an augmented urgency for expanded transportation capacity, coupled with a compulsion for contracted transit time. Without doubt, the next two decades will witness impressive increases in airline traffic to comply with the implacable demands of an ever-increasing, progressively affluent international society. But will man be infinitely content when he can be whisked by the SST (Supersonic Transport) halfway around the globe at three times the speed of sound? Or, instead, will he then contemplate those absolute physical boundaries, pressing toward more realistic limiting velocities for antipodal travel? Now that the orbital rockets of the space age have equipped us with the means to travel at tremendous speeds, will not our children's children be motivated toward investigation of terrestrial applications for this new, revolutionary propulsive mode? Implicitly, this paper addresses itself to such potential developments of universal significance, and presents one possible solution to this challenging prospect.

Indeed, the energy requirements for the two objectives—global transportation and orbital flight—are grossly comparable, contrary to a popular misconception that space travel consumes enormous energy commitments. When the DC-8 jet transport cruises for 5.0 hours at a lift-to-drag ratio of 16, it means that the engines are applying a thrust equal to 1/16 of the weight of the airplane for the entire flight time. If somehow the energy from the airplane engine could have released in the absence of a gravitational field and drag, the vehicle would have accelerated at 1/16 g (2.0 ft/sec/sec) for 18,000 seconds, and would have attained a total (escape) velocity of 36,000 ft/sec. A subsonic jet aircraft can travel across the United States during an average flying time of

5.0 hours. Thus, a normal 2,500-mile cruise of a commercial airliner consumes energy (and fuel) with the same order of magnitude as is required for an earth-escape transport system, essentially because aircraft must combat gravity and drag incessantly during their atmospheric flight. However, vertically launched rocket transports can fight drag and gravity quickly (and therefore efficiently) during a very brief portion of their flight, and then coast unpowered for approximately 88% of their total flight time to their orbital destination.

### *What Size Transport System?*

As is the case with preliminary commercial airplane design, any reusable transportation system must be sized for maximum cost-effectiveness, in order

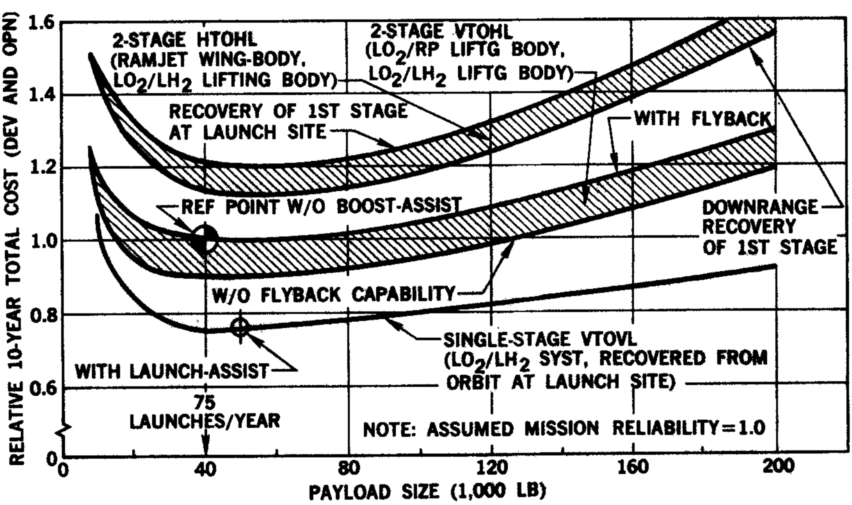


FIGURE 1. Optimum payload size and cost comparison of reusable launch vehicles. (Orbital transport vol. = 30M lb over 10 years.)

to capture an appreciable portion of the potential market. FIGURE 1 demonstrates conclusively that an optimum payload size *does* exist for orbital transport rockets. This observation is valid because, although larger launch vehicles require a greater development cost commitment, they can inject a fixed volume of payload into orbit with fewer flights, and therefore incur lower operational costs. Conversely, smaller launch vehicles necessitate lower development costs, but due to the larger number of flights required for transporting an equivalent total payload, refurbishment costs (and, consequently, the direct operating costs) are correspondingly increased. These two general considerations tend to shape the plotted curves with a concave characteristic.

For each of the three representative types of reusable launch vehicles investigated, a minimum total cost occurs at a payload capability of approximately 40,000 to 50,000 pounds. It is interesting to note that the two-stage horizontal takeoff, vertical landing (HTOVL) device would cost about 20 percent more than a comparable two-stage VTOVL at this payload size. However, the single-stage VTOVL machine would incur a 10-year total cost some 25 percent less than the two-stange VTOVL (adopted as a basic reference point during the study). Additionally, it should be noted that the requirement to recover at the launch site by flying back the first stage of any two-stage launch vehicle tends to increase the total 10-year costs by approximately 10 percent. By comparison, the entire single-stage vehicle, which can be "parked" in orbit for 24 hours, can be returned to the launch site without requiring any additional energy release. Accordingly, a ballistically recovered single-stage vehicle was configured at approximately a 40,500-pound cost-optimum payload size (See Figures 2 and 3).

## *The Conceptual Hyperion Transport*

Perhaps now, while we contemplate how our next space vehicle should operate, we should recognize that this decision with its far-reaching ramifications could revolutionize all previous concepts of transportation—if the vehicle were designed with the basic versatility to satisfy government and civilian mission objectives, alike. FIGURE 3 defines one conjectural solution to this complex goal.

The principal advantage offered by this type of vehicle, called Hyperion for identification, is the operational flexibility that it offers. Initially, it was evolved as a reusable booster concept, capable of delivering up-rated Saturn gross payloads (20 tons) to orbit with improved economy for Post-Apollo misisons. It could also be used for resupplying space stations in orbit. Tanker versions of this orbital booster model could refuel other Hyperion vehicles in Earth orbit. Hence, it would be provided with the capability of landing on the Moon with massive payloads of cargo for use in the construction of a permanent lunar base.

However, space applications alone do not appear to warrant expenditure of the 1.5 to 2.0 billions of dollars required for its development. Such a vehicle should be designed for adaptability to a broad spectrum of missions—if it can compete for a share of the commercial transport market, its development might be justified. Initial cost of the vehicle, like that of a transport jet aircraft, could then be substantially amortized over a period of time because it would be recoverable and reusable.

Hyperion would have a bell-shape configuration 100 feet high (one-third as tall as Saturn V) and 48 feet wide at its greatest diameter. It would weigh more than one million pounds—one-sixth as much as Saturn V. The upper end would contain a passenger area, with two deck levels fitted with individual couches, on which passengers of the future would ride during their brief flight through space. A sister-ship for orbital flights would be distinguished by its taller cargo-payload section. It would carry only a limited number of passengers and a two-man crew, but its performance characteristics would parallel those of the Hyperion global transport.

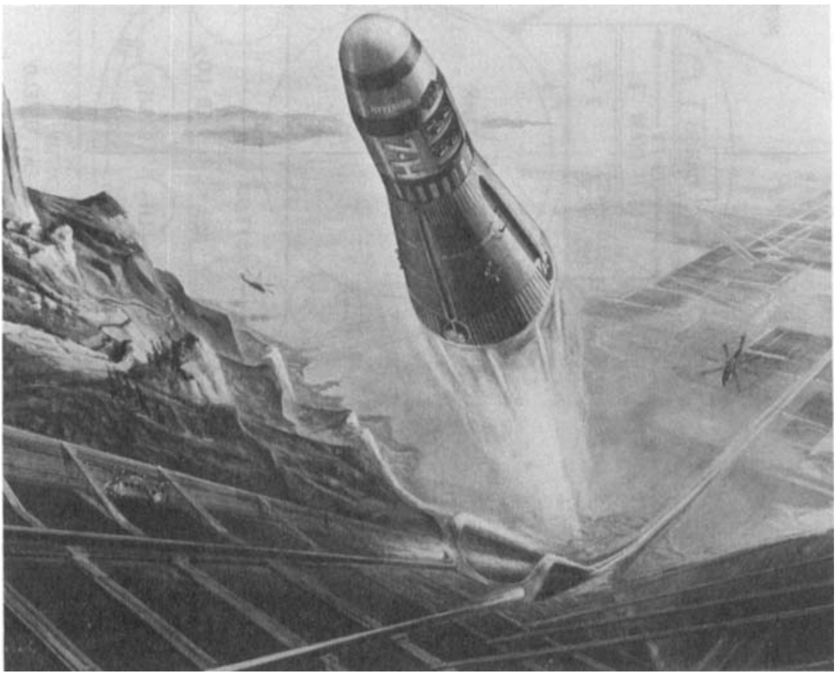

FIGURE 2. Sled-launch of Hyperion passenger rocket.

Hyperion would be capable of transporting 110 passengers or 15 tons of high-priority cargo to any point on earth, at average speeds of 17,000 mph, without subjecting the passengers to any more than three g's during boost or atmospheric entry. A Hyperion-type transport would, in all probability, be developed initially for orbital applications, and later adapted to civilian use, just as the KC-135 was the forerunner of the commercial jet transport.

Not only would the huge rocket employed in space-lifting the passengers be powerful enough to transport massive payloads of humans or cargo, but it

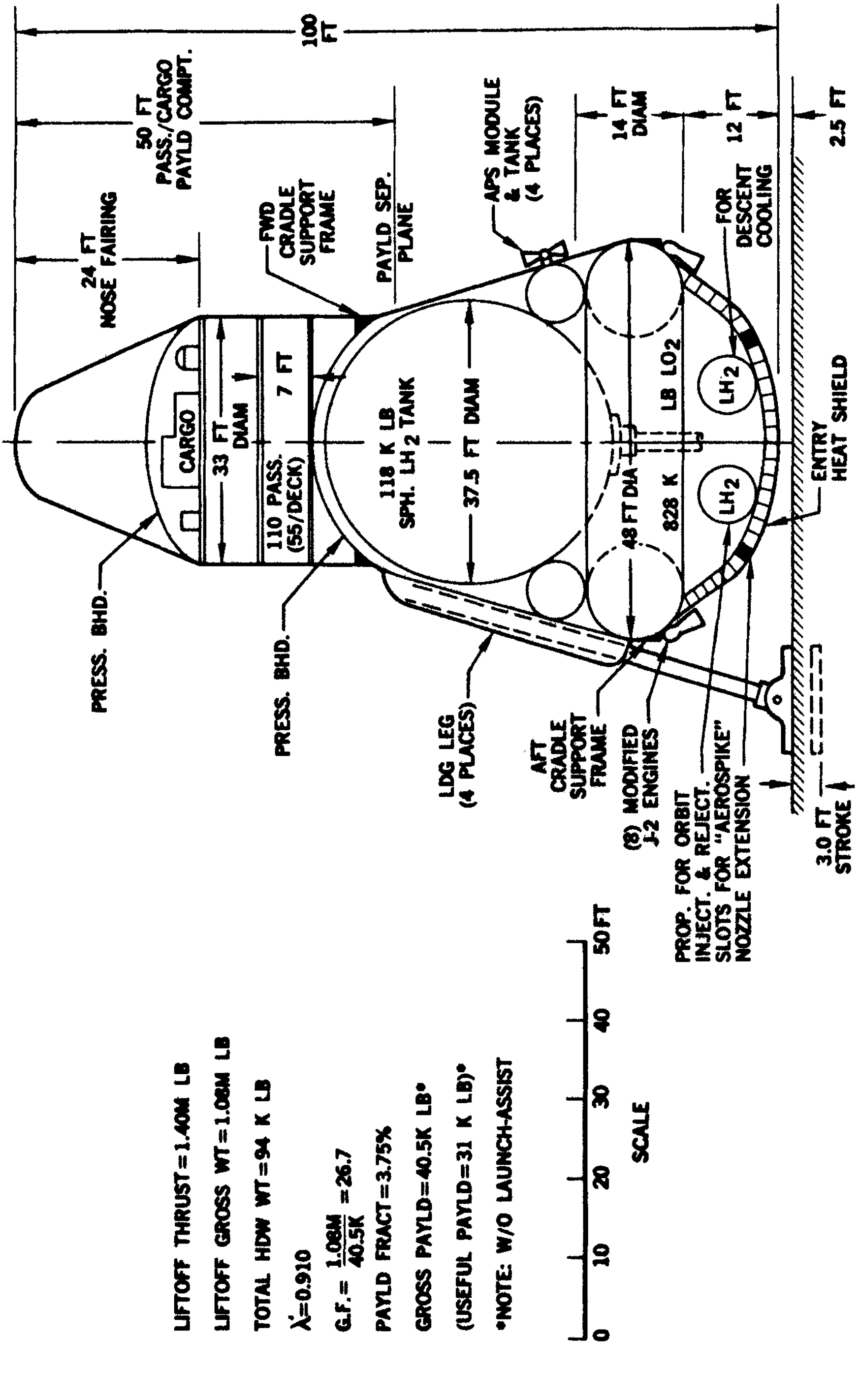


FIGURE 3. Reusable Hyperion VTOVL rocket configuration.

would also be able to land almost anywhere on earth without the previously prepared runways required by airplanes. In the event of an emergency during flight, personnel and vehicle could be recovered safely at sea through the use of self-contained, inflatable spherical pontoons; hence, a Hyperion-type vehicle could land in the ocean or on any unprepared piece of ground.

Key to the versatility of Hyperion is its multipurpose propulsion system, which could develop over one million pounds of thrust at liftoff. Aerodynamic lifting and control of the vehicle would be facilitated by using the technology demonstrated during re-entry and recovery of the Apollo space capsule.

Prior to touch-down on earth, similar to the technique that will be employed in the Apollo moon landing, the propulsion system would cancel vertical velocity, allowing the craft to hover while choosing a landing site. The vertical landing would be accomplished on four extensible legs that adjust automatically for stability on uneven terrain. Conventional modes of debarkation for the passengers could be used at "spaceports" which, by the time the global transport vehicle would be operational, could have been established near most key cities throughout the world. If unpopulated areas were not available for spaceports, offshore landing and launching facilities might be considered.

### *The Unattractive Aspects of Single-Stage Vehicles*

With the advent of the improved capability offered by high-energy liquid propellant ($LO_2/LH_2$) combinations, it became evident that advanced booster designers should perhaps attempt to duplicate the operational features (rather than appearance) of the airplane; that is, the ability to take off from the point of departure and arrive at the destination *in one piece*, without having stages fall off along the way. Accordingly, the single-stage-to-orbit concept was born. However, it must be recognized that such an operational mode is not without its deficiencies. As depicted in FIGURE 4, the principal reservation associated with this type of system is related to its performance sensitivity. With such a vehicle, any inadvertent reduction in its propellant mass fraction ($\lambda' = 0.91$) or vacuum specific impulse ($I_{sp} = 464$ sec) could result in a disproportionately large degradation in payload capability. As suggested by FIGURE 5, any appreciable decrease in impulsive velocity requirements would significantly diminish this objectionable performance sensitivity.

### *The Launch-Assist Solution to Performance Sensitivity*

FIGURE 6 illustrates that even with only a subsonic boost-assist, the Hyperion orbital capability can be increased by 8,000 pounds, for an improvement of 21 percent. Such an attractive option would immediately suggest that a small

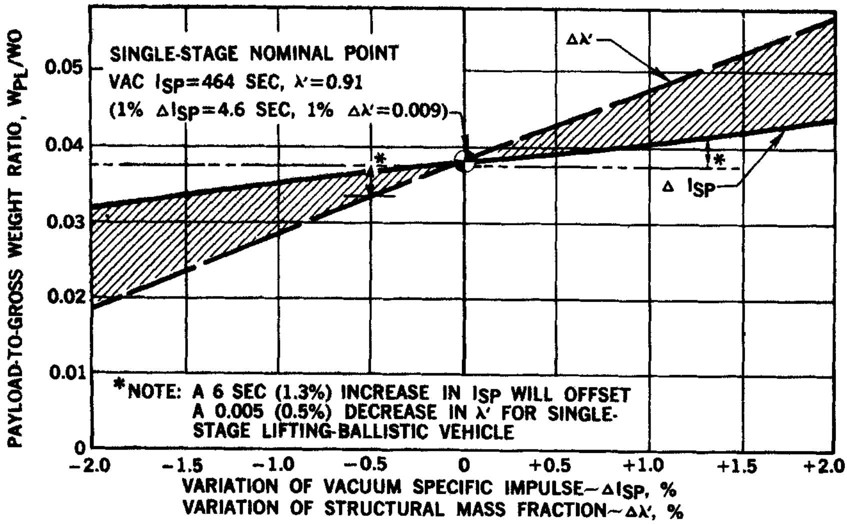


FIGURE 4. Payload fraction sensitivity to variations in $I_{SP}$ and λ', (reusable launch vehicles).

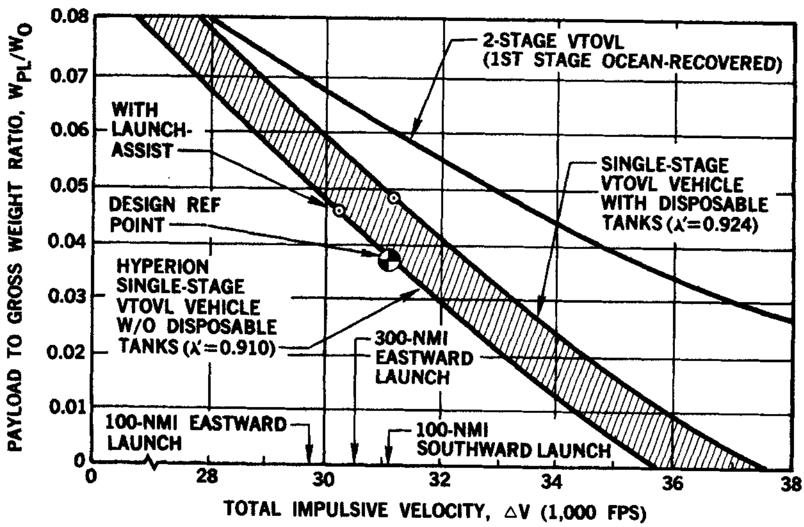


FIGURE 5. Payload fraction sensitivity to variations in impulse velocity, (reusable launch vehicles).

"lofter," half-stage or zero-stage, could be incorporated as an addition beneath the main vehicle configuration to alleviate the sensitivity problem. This zero-stage would impact downrange in the Atlantic during an easterly launch from Cape Kennedy.

It has recently been emphasized by an authoritative government official that "water-recovery is inelegant, expensive and likely to complicate greatly

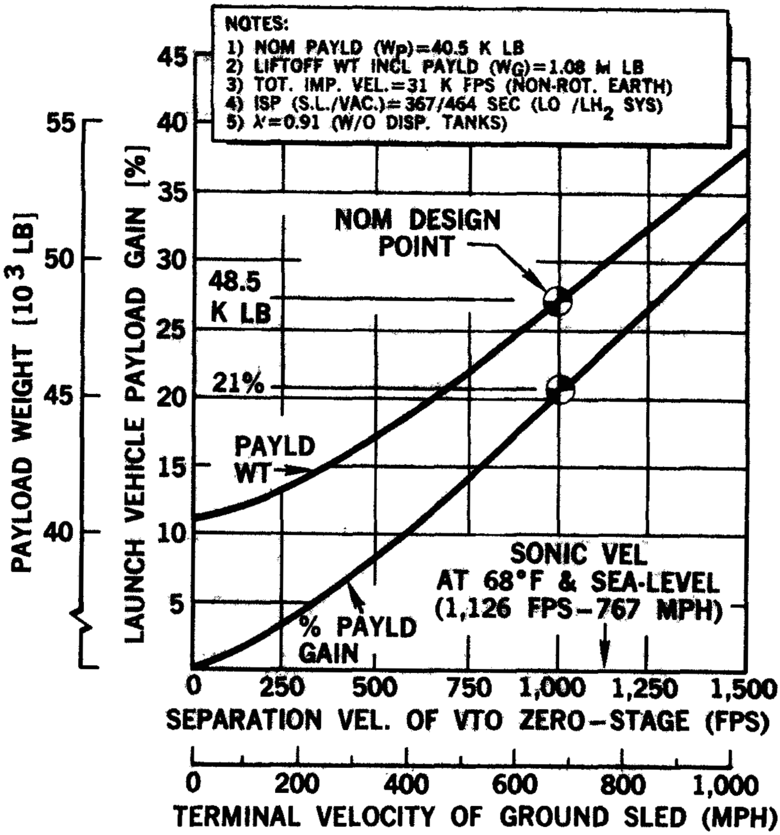


FIGURE 6. Orbital/antipodal vehicle performance improvement due to launch-assist.

the problems of refurbishment." Nevertheless, a recoverable type of zero-stage was analyzed and compared in FIGURE 7 with a "captive" reusable rocket sled, each capable of imparting a 1,000 fps velocity increment to the basic Hyperion vehicle. Each device, therefore, offers equivalent payload increase. It was determined that, in fact, excessive refurbishment cost rendered the zero-stage extremely unattractive, in spite of its lower comparative weight.

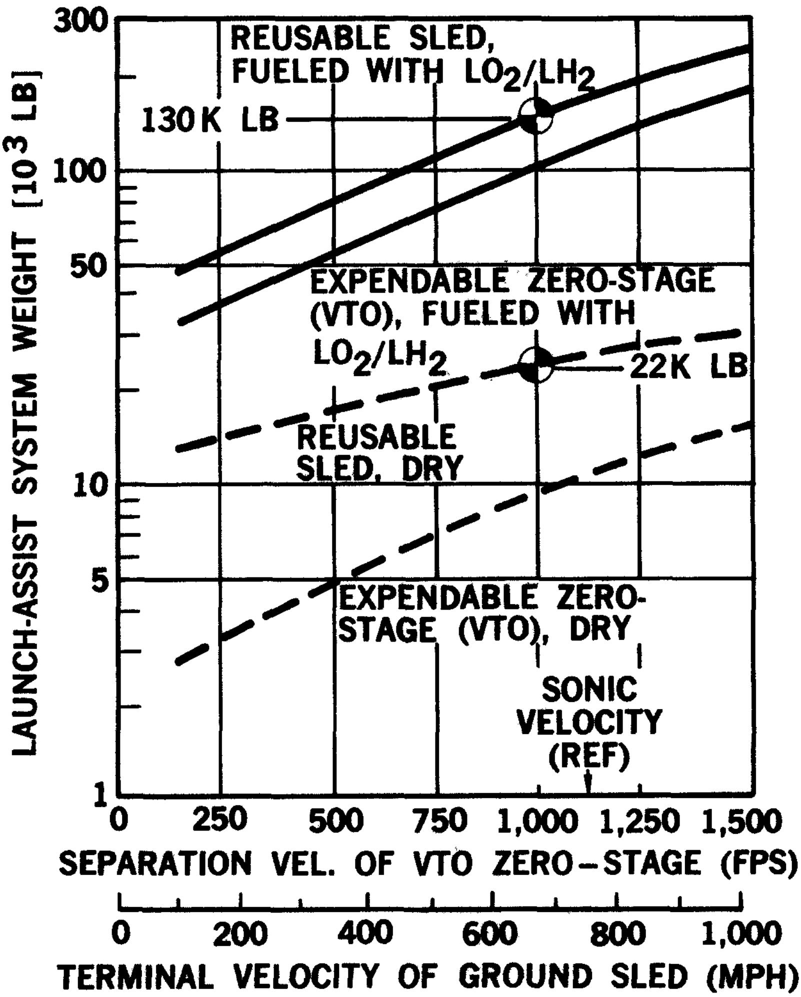


FIGURE 7. Weight of rocket-propelled boost devices for single-stage to orbit vehicle.

The nonrecurring costs for each of the two systems under consideration were of the same magnitude ($25 million). These expenditures included R&D cost, unit (airframe and engine) cost, and facilities cost. (The cost of carriage and 3.5 miles of track were included in the rocket-sled nonrecurring cost). The recurring costs, however, were 2.5 times as much for the VTO zero-stage, compared with an estimated $100,000/launch for the rocket-sled. These costs included propellants, launch services, and refurbishment for the launch-assist devices, but excluded cost of operating the basic Hyperion vehicle.

FIGURE 8 describes a representative rocket-sled design. In reality, this rugged ground-accelerator is nothing more than a "captive" reusable propellant tank, since the Hyperion's main engines are used for sled propulsion. However, the vehicle motors are fed from the sled-contained tanks during take-off assist prior to separation.

In recent years, a sled-assist-takeoff method has been considered in connection with two-stage winged or lifting-body recoverable orbital transports. This technique was probably first proposed by the late Prof. Eugen Sanger in his antipodal bomber project of almost three decades ago. It can be shown that payload increase becomes progressively more significant as the terminal velocity of the launching sled is increased. Therefore, in this paper, the influence of sled velocity on orbital payload gain has been presented parametrically, covering the range up to 1,000 mph ground speed.

The experimental French "Aerotrain" uses the air-cushion principle while being propelled on an inverted T-shaped track made of precast reinforced concrete. By early 1967, it had traveled a total of 7,000 miles and had carried 3,800 passengers. The test runs, conducted on a 4.2-mile track at Limours, demonstrated the validity of the following seven conclusive points: 1) Air cushions provide stable lift and guidance, 2) there are no concentrated loads on track, 3) air cushions reduce track maintenance to occasional realignments, because there is no friction and little wear, 4) the inverted T-section makes derailment virtually impossible, 5) the vertical upright of the track effectively provides two opposite surfaces for emergency braking, 6) the train has attained speeds of 188 mph, and speeds above 215 mph are planned, and 7) for track lengths up to 300 miles, the air cushion train is less costly to operate than air travel systems.

An air-cushion launch sled capable of speeds of up to 1,000 mph could evolve from the experience gained with Aerotrain-type vehicles. To accom-

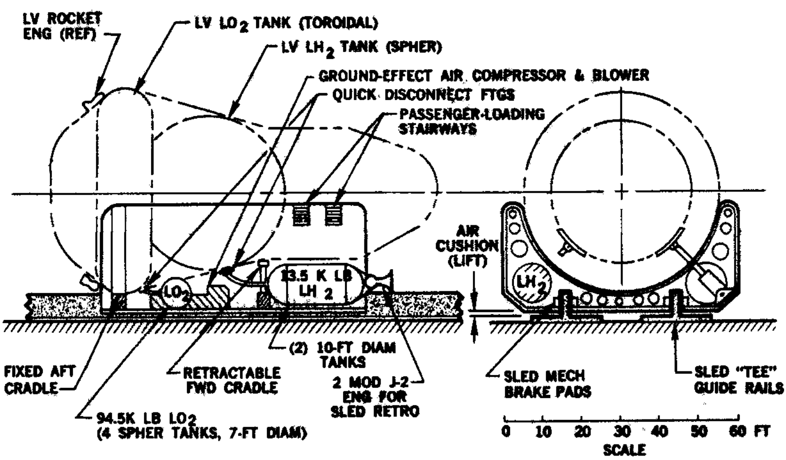


FIGURE 8. Reusable rocket-propelled "air-cushion" sled using launch vehicle motors.

modate the large launch weight and size of the Hyperion vehicle, the 680 mph sled would have to provide a means of generating an increased air-cushion pressure. Additionally, a dual-track arrangement would be required for guidance

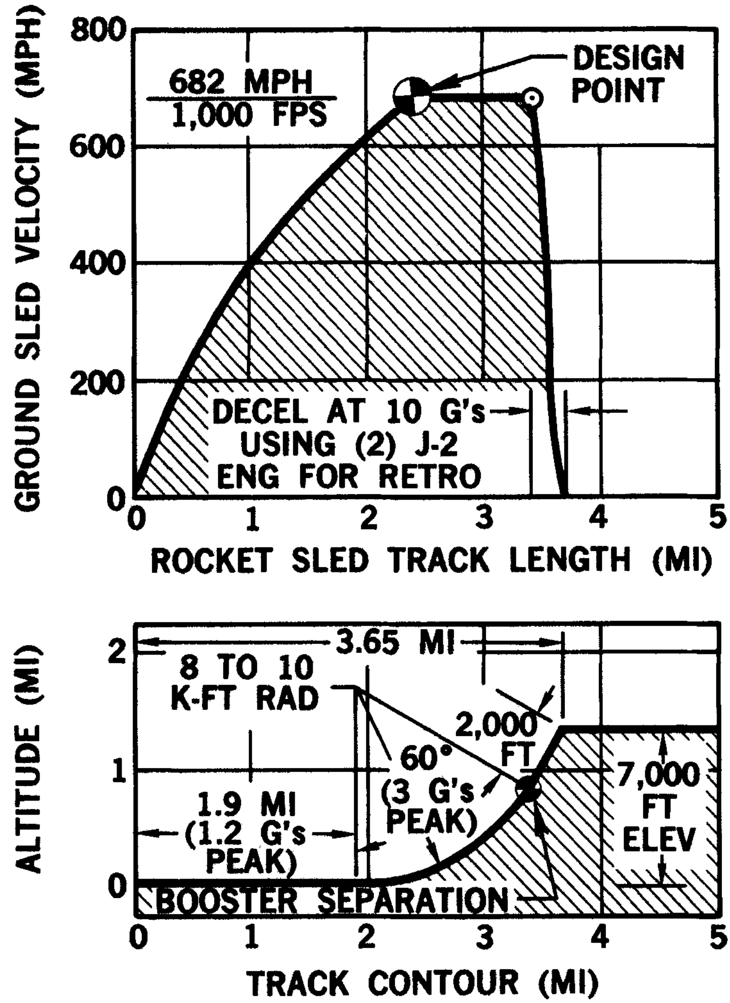


FIGURE 9. Ground accelerator track characteristics.

stability, for reduction of the required unit pressure of the air cushion, and for the improvement of braking ability in the event of a launch abort.

FIGURE 9, which defines the track characteristics, illustrates how the vehicle would accelerate horizontally to 680 mph along the two-mile stretch of level track, building up to an acceleration of 1.2 g's. The vehicle then continues, at constant velocity, up the curved track (10,000-ft radius) to an altitude of approximately one mile along a mountain slope. Due to the change in direction along the curved track, the passengers would be subjected for a brief period to a peak acceleration of 3 g's, about the same as they will experience during the throttled-boost phase, or during the lifting-ballistic atmospheric entry.

At the end of the curved sled-run, when the vehicle is oriented 30° from the vertical, it is separated from the sled to begin the powered ballistic ascent to its destination by using propellants from its own tanks, and by using conventional thrust vector control. Upon separation and takeoff of the flight vehicle, the sled-mounted retro-engines are ignited for braking the unmanned sled (at 10 g's). As the sled continues along the inclined 2,000-ft length of straight track, mechanical brakes and gravity will assist in stopping it's upward motion. The sled would then return by gravity to the "spaceport" located in the valley below, under a controlled-coasting condition.

## *Mission Profile*

Aside from orbital flights with cargo and passengers, perhaps the most intriguing application for Hyperion is its potential use as a "commercial" passenger transport to global destinations. Contemplate, if you will, the advantages of rocket travel in the 1980's on a ballistic trajectory from New York to London or to Buenos Aires in 26 minutes. The rocket-propelled vehicle could be commercial transport's greatest boon since the introduction of the airplane. Hyperion could carry passengers 20 times faster than the jet airliner of today, and seven times faster than the forthcoming supersonic transports.

As an example of a typical flight, booster burnout would occur about six minutes after liftoff, at an altitude of 70 miles. By then, Hyperion would be traveling at a speed of 17,000 mph and during the next 12 minutes would coast out of the atmosphere in an arc, attaining a maximum height of 125 miles. The greater part of the trip would take place above the atmosphere, where drag is nonexistent.

Following a gentle downward curve, the vehicle would eventually re-enter the atmosphere, where it could be maneuvered. It would be oriented so that its blunt end was forward; the base of the vehicle would be cooled by circulation of liquid hydrogen. After re-entry, four rocket engines would be ignited to provide the retro-thrust necessary for a soft landing. Within sight of the spaceport, Hyperion would hover and extend landing legs in preparation for touchdown.

The entry corridor, for either the orbital or suborbital missions, is bordered (on the higher velocity and smaller flight path angle side) by the lift skip limits. These represent the limit entry capability for a vehicle pulling either a positive

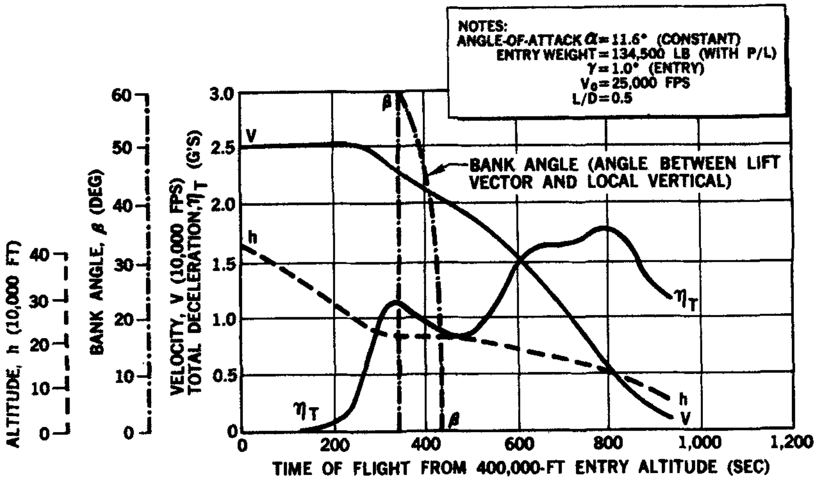


FIGURE 10. Lifting-ballistic descent trajectory (atmospheric flight parameters).

(lifting) or negative (nose-down dive) penetration without skipping. The corridor is bordered (on the lower velocity and larger flight-path angle side) by the 3-g deceleration curves for L/D's of 0.5 to 1.0. The corridor to be considered here is the L/D of 0.5 for the 3-g limit and the positive-lift skip limit.

The data presented in FIGURE 10 for the lifting entry deceleration limits are representative for a loading ($W/C_LS$) of 100 psf. Available data indicates, however, that deceleration is insensitive to the entry weight at the $-1.0°$ flight path, and at the 25,500 fps entry velocity.

To ensure that mission constraints (deceleration and minimum heating) will be met upon re-entry, the exit conditions for a desired ballistic range must be selected from within the entry corridor. This limits the burnout (entry) conditions to velocities less than 25,800 fps and flight-path angles less than 4°. It should be noted that ballistic ranges up to 180° are safely available and, therefore, any point on the Earth can be reached with a satisfactory re-entry.

The bank angle $\beta$ shown in the plot, is defined as the angle between the lift vector and its projection into the local vertical dive plane. At the point where the 1-g skip-out condition is reached (approximately 300 sec after entry), the vehicle rotates about the velocity vector to the bank angle where the vertical lift component equals the centrifugal and local gravity force. Bank angle is then slowly reduced to zero while the vehicle is flying at constant altitude. Past this point, an equilibrium glide condition exists down to the 50,000-ft altitude, where terminal operations commence. Throughout entry to terminal altitude flight, the L/D is held constant by holding the angle-of-attack constant at approximately 12°.

To restrict the maximum deceleration to less than 2-g's, the bank angle is modulated to achieve various descent trajectories within the maneuverability envelope. Maximum lateral range occurs when the bank is held constant at 45°, and maximum deceleration occurs where the bank angle is held constant at 90° (i.e., a ballistic case).

At 50,000-ft, the vehicle will be commanded to fly zero angle of attack (free fall) down to the engine ignition altitude (possibly as low as 2,500 ft). The main engine will then cancel the terminal vertical velocity at the specified altitude and will rotate the flight path ($\gamma$) to 90°.

Extra-atmospheric ballistic ranges are obtainable with a wide range of burnout conditions. By constraining the burnout altitude to 400,000 ft (exit altitude), burnout velocity and flight-path angle combinations can be calculated for any ballistic range. The extra range obtainable by a lifting entry is shown in FIGURE 11, in which a maneuverability envelope is presented for an entry velocity of 25,500 fps and an entry flight path angle of −1.0°.

As shown in FIGURE 12, the predicted touch-down area for the lifting–ballistic entry of Hyperion, would be an ellipse two nautical miles long and one wide. The dispersion for uncontrolled ballistic (Mercury-type) recovery has been determined to be 140 mi downrange and 46 mi crossrange. Such a large error in landing does not meet the requirements of the Hyperion missions, which, like Gemini, would utilize a lift vector and offset CG for spacecraft control during re-entry. The Gemini flight was tracked, and ground commands were issued to the spacecraft to improve landing accuracy. Average aim point miss distance for the last Gemini and Apollo flights was 3.7 nautical miles. This accuracy is especially significant in view of the fact that the ability to control ceases at an altitude of 100,000 ft.

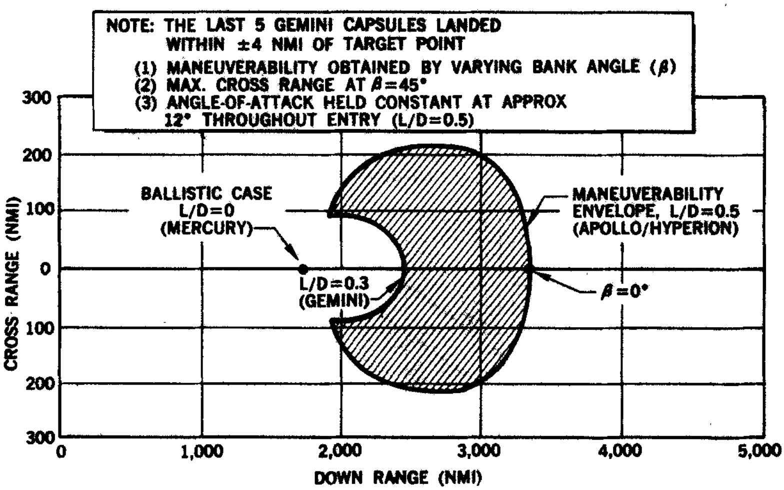


FIGURE 11. Atmospheric entry maneuverability envelope.

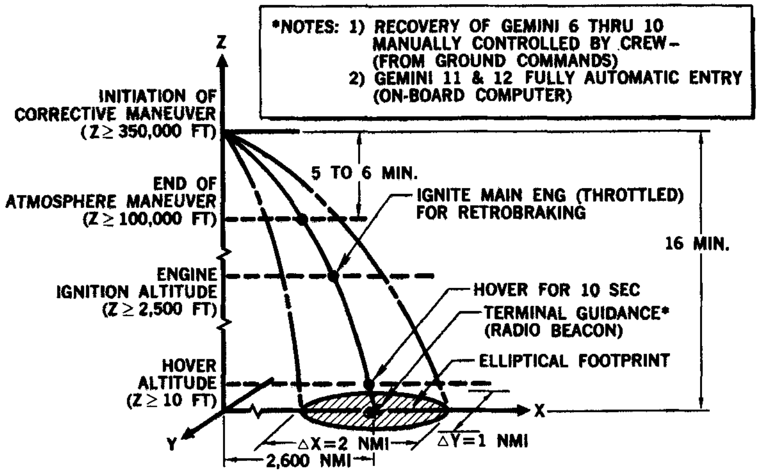


FIGURE 12. Landing profile and footprint.

*Predominant Considerations*

As has historically been the case with all radical transportation developments, cost-effectiveness will dictate the relative attractiveness of the system. FIGURE 13 indicates that the cost for a Hyperion flight article (without sled) has been estimated at $35 million, based on a single-unit production. This is comparable to the $45 million per copy estimated for the supersonic transport (SST).

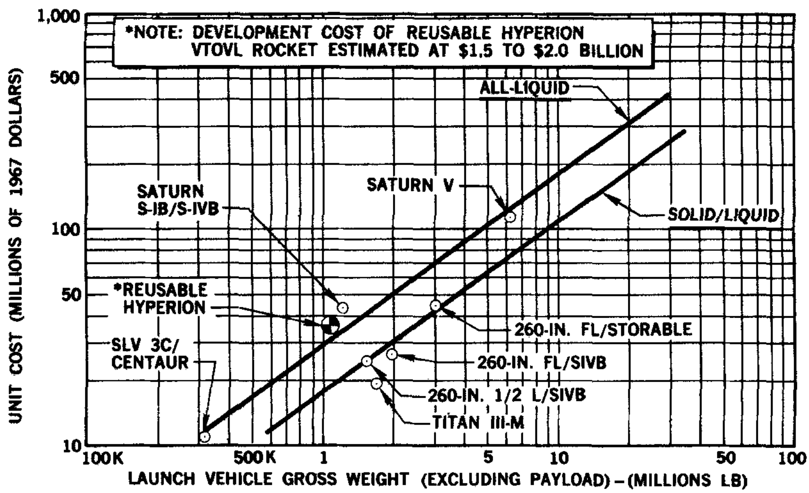


FIGURE 13. Trends in expendable launch vehicle costs.

Even their development (R&D) costs are comparable; that is, in the vicinity of $1.5 billion. However, it should be recognized that the supersonic transport will not offer improved comfort, safety, or economy over the subsonic jetliner. Its principal advantage lies in its increased speed. Accordingly, if higher speeds (and lower transit times) constitute a significant index to human progress, then it is not premature to speculate on transportation modes capable of providing the ultimate suborbital speed of 17,000 mph for terrestrial transportation. Speeds greater than this magnitude would inadvertently propel the travelers into orbit.

Equally significant as the cost implication, is the consideration of universal public acceptance. The sonic boom problem—the largest single threat to the success of the supersonic transport—and its effective control constitute an enormous engineering challenge. "Boom carpets," 60 to 100 miles wide, may restrict the SST's permissible overland routes, in order to avoid the possibility of leaving abandoned "prehistorical sites in ruins. Unless its resulting ground overpressure can be reduced to satisfy an acceptable, international flight criterion of not more than 2.5 psf, the SST may eventually be limited to transoceanic flights, severely compromising the economic payoff for such a craft. The pressure field, felt in the ground as a sharp crack or boom, is generated by the shock waves propagated from the SST nose and aerodynamic surfaces during horizontal flight. It is this characteristic—the *horizontal* flight of the SST—that is worthy of note. During level flight, the damaging and disturbing effect of the boom is felt by population centers along the entire flight path. Mr. Bo Lundberg, a Swedish aeronautics expert, has estimated that each SST flight across the United States would lay down a "boom carpet" that would assault the eardrums of 10 million people and terrifying millions more. Prof. Karl Ruppenthal, director of Stanford's transportation management program, recently commented, "Both the governments of Germany and Switzerland have said already that they will forbid SST flights over their territories, if their populations find them to be annoyances." As a possible solution to this problem, the cruise altitude of the SST can, subject to maximum ceiling limitations, be increased from 40,000 to 60,000 feet in order to attenuate the ground annoyance.

Clearly, any rocket-propelled horizontal takeoff reusable launch vehicle would be faced with the similar problem of a sonic boom tracking the vehicle on the ground. The magnitude of this problem would be compounded if such a transport system were required to remain within the atmosphere for extended periods in order to satisfy Supersonic Combustion Ramjet (Scramjet) or air-breathing propulsion requirements. By comparison, the vertically launched ballistic transport completely circumvents the sonic boom problem, although its rocket engines generate a less objectionable noise (of a completely different nature), aimed toward the immediate vicinity of the takeoff site.

During a typical ascent, the vertical takeoff rocket would reach transonic velocity approximately one minute after liftoff, when it has acquired an altitude of 25,000 feet. At this relatively low altitude, the predictable Mach-1 shock wave would be impinged on the nose of the vehicle, whose flight path angle is then a mere 10° from the vertical. However, the vehicle with its propagated sonic boom is traveling *away* from the ground, rather than parallel to it. Accordingly, the acoustic energy of the boom is dissipated or refracted by atmospheric wind and temperature gradients. Consequently, no boom at all reaches the ground, even at the launch pad directly beneath the vehicle, in spite of any existing meteorological conditions (low clouds) that may tend to focus or amplify the noise. Generally speaking, the vehicle would reach a speed of Mach-3 approximately 110 seconds after liftoff, when at an altitude of 75,000 feet and at a flight path angle of 45°. Under these conditions, the vehicle, on its "gravity-turn" trajectory to its destination, is beginning to approach the level flight attitude of the SST. The rarified atmosphere at this altitude would tend to inhibit sound transmission. More significantly, the velocity and direction of the vehicle with its attached pressure wave are still moving away from the earth, even at the corresponding flight path angle.

Operational terminals for commercial rockets must be located sufficiently remote from populated areas to avoid complaints of engine noise. And yet, these spaceports must be near enough to urban centers not to dissipate the reduced-time advantage associated with transporting passengers and goods at rocket speeds. The city center of Cocoa Beach, Fla., is located a mere 12 miles from the Atlas launch pads at Cape Kennedy, 15 miles from the uprated Saturn 1 launch site, and 18 miles from the Saturn V launch complex. During any particular space launch, only an innocuous low-intensity rumble is heard by Cocoa Beach residents. Separation distances of this magnitude between spaceports and cities would appear completely acceptable, provided the thrust level of the operating commercial rockets does not exceed the 7.5 million–pound thrust of Saturn V.

The engine noise of a VTOVL rocket during vertical landing is at a significantly lower level than during take-off. The thrust magnitude necessary for terminal volocity cancellation and hover prior to touch-down is greatly reduced, since the vehicle has consumed 90 percent of its liftoff weight (propellants) in transit to its antipodal destination. Hence, only 10 to 12 percent of the initial thrust required at launch is necessitated during a typical landing maneuver. The problem of noise from the rocket engine would be reduced in accordance with the decreased thrust level.

Even today, ground traffic to and from airports is becoming progressively more congested and increasingly intolerable to the traveling public. VTOVL helicopter flights, which connect the airport terminals with major city hotels and principal suburban locations, are enjoying dramatic popularity and impressive financial success. Unquestionably, the helicopter would again prove to be a most attractive device for spanning the 20-odd miles between future spaceports and their adjacent cities.

### *Reusable Launch Vehicles and the Subsonic Airplane Analogy*

Given a reusable vehicle, the extensive preflight preparations and exhaustive checkout procedures that are now mandatory every time an expendable booster is launched, may eventually be reduced to a level comparable with that of commercial airlines. Only when such simplified launch operations can be realized will the Hyperion global-transport vehicle become operationally feasible.

In air transport operations, there appears to traditionally exist a constant ratio (3:1) between total operating cost and fuel cost. Can we expect the same ratio to hold true for future projections of launch vehicle operations? The use of a commercial subsonic jet transport as a basis for extrapolation toward eventual reusable booster flights can be confusing—the DC-8, for example, is a combined spacecraft/booster and, if at all comparable to any one type of space system, it would be a reusable one-stage to orbit transport.

Few of us would dispute the contention that development of a reusable one-stage to orbit rocket system would *indeed* provide a notable engineering challenge. However, it does not appear unrealistic to adopt the Hyperion rocket as an example of such a representative vehicle, since it is similar in design to one invented by the principal author of this paper that NASA considered attractive enough to warrant patent procedures (Patent No. 3,295,790 was awarded to NASA on January 3, 1967). The Hyperion vehicle is capable of injecting a 31,000-pound useful (transferable) payload into orbit, while consuming 946,000 pounds of propellants (118K lb of $LH_2$, and 828K lb of $LO_2$). By the late 1980's, when such a vehicle might become operational, it has been estimated by The La Fleur Corporation of Los Angeles that $LH_2$ may cost as little as 9.1¢/lb, and $LO_2$ may cost 0.42¢/lb, or an average cost of 1.51¢/lb for a mixture ratio (oxydizer/fuel) of 7/1—about the same as the cost of kerosene today. These estimates include the cost of mass production manufacturing facilities. The patented La Fleur process would obtain $LH_2$ from natural gas, rather than from crude oil, as is current procedure.

Even if it be assumed that the La Fleur estimates are optimistic *by a factor of four*, the cost of propellants for each launch of the hypothetical Hyperion vehicle without rocket sled would then amount to about $60,000. For the sake of conservatism, let us now assume that rocket operations will never be less than *twice as expensive* as airline operations. Accordingly, we can speculate that total operating costs will be six times the propellant costs. Each orbital launch would then cost approximately $360,000, or about $12 per pound of payload.

An orbital launch is grossly comparable in energy and cost ($360,000) with a ballistic flight to antipodal destinations on earth. Since the useful payload of the Hyperion-sized vehicle can be converted to the equivalent of 110 passengers, it appears conceivable that each round-trip ticket to orbit (or halfway around the globe in 45 minutes) may eventually cost slightly over $3,000. It should be noted that, compared to airplanes, the return trip from orbit constitutes a real "bargain," so far as the nonexistent fuel costs are concerned. Moreover, should earth-orbit, indeed, emerge as a popular tourist destination, such a mission would become the exclusive domain of the orbital rocket—the air-breathing device could not even compete above the atmosphere for a portion of this commercial market. Clearly, the enormous potential of the Inter-Continental Ballistic Transport (ICBT) demands a large-scale technical assessment, to determine its proper perspective within the total spectrum of the forthcoming transportation systems (r)evolution.

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