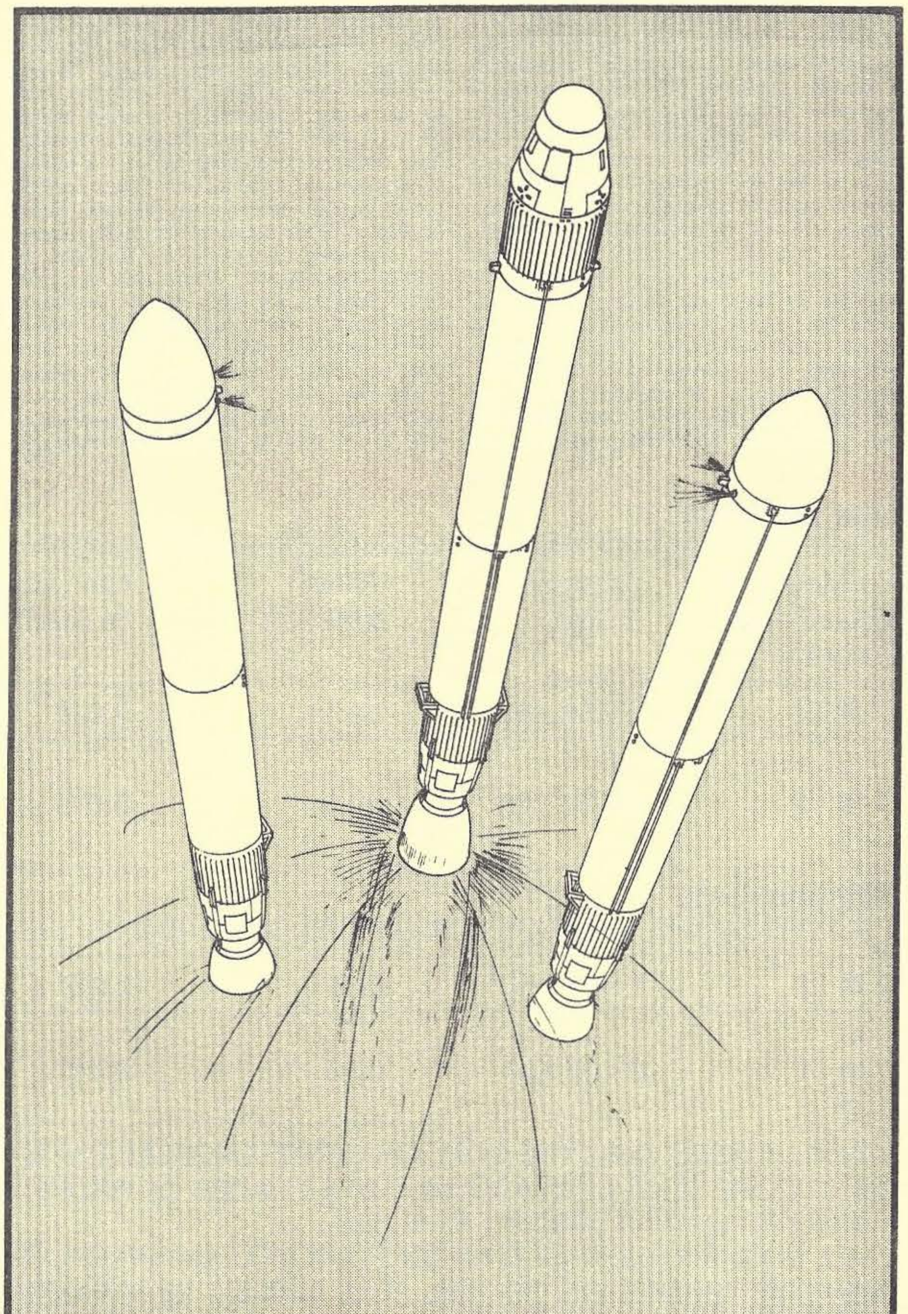
THE FOUNDATION
COMMERCIAL SPACE REPORT

LARGE LAUNCH VEHICLE PROSPECTS BRIGHTEN

Commercial Booster Could Transport Freight for Fraction of Shuttle Cost

Thirty miles above the surface of the earth, the first stage of the LLV burns out and begins to fall away. In a few moments, the expended propellant tanks will break away from the engine capsule assemblies. The tanks will be destroyed as they fall back into the atmosphere, while the engine capsules will be recovered at sea about two hundred miles from the launch site.



During the last decade, many private and NASA-funded studies have concluded that the cost of transportation to orbit and beyond will be the dominant expense for any commercial space venture. One excellent example of this fact is the Beneficial Uses of Space study (performed by General Electric) which calculated that space shuttle transportation costs could contribute as much as 70% of the total cost of a product manufactured in space. Another is the several reports produced by industrial and government researchers on satellite power stations, wherein direct costs of transport amount to half of the total investment needed to build the powersats.

With this obvious fact already documented, it might be astonishing that relatively little attention is being paid to the business of commercial space transportation. Readers of the *Report* will of course point to the OTRAG firm in West Germany and Zaire as one example of a private, low cost launch vehicle concern, but in reality the OTRAG tariffs are not much lower than the Space Shuttle. By way of comparison, the Shuttle will cost between $325 and $2000 per pound lifted to low earth orbit, depending on final program operating costs and utilization. The OTRAG vehicles will fly a pound for about $270.

However, most responsible observers of the space industrialization effort are convinced that costs must fall to under $50 per pound (and probably as low as $10) before any widespread space exploitation can be implemented. With this in mind, market-oriented designers at Foundation, Inc. began a project several years ago which was aimed at providing unmanned freight transport to low earth orbit for costs which are close to those needed. Officially titled the "Large Launch Vehicle" project, the size and simplicity of the booster caused project staff to adopt the in-house name "The Big Dumb Booster".

The LLV project was initiated to provide low cost bulk cargo transportation to space for propellants, living and factory modules for space stations, and raw materials. High on the list of potential payloads were also consumables for space stations and factories. It doesn't take much imagination to see what benefits could be achieved in space systems design if the cost of consumable materials could be lowered drastically. Further, the cost of actual systems aboard spacecraft would benefit from the reduced transport expense since hardware on-board would no longer have to be designed with weight-savings in mind.

The Large Launch Vehicle

The LLV is a modular, semi-recoverable, two-stage, chemical launch system employing liquid oxygen as the oxidiser and kerosene as the fuel.

The segmental configuration of the vehicle is important in reducing the cost of development as well as the overall sensitivity of the system to weight and performance variations.

The vehicle module is semi-recoverable. Recovery is not a new concept insofar as it is applied to boosters, but it has never been suggested before that identical modules in a staged vehicle of this nature would be recovered both downrange out of the ocean, but also from orbit after the payload has been delivered. While recovery crews may have to seek the outboard engine capsules several hundred miles downrange, the capsule in orbit may be recovered at the launching site. The propellant tanks, on the other hand, are not returnable. Attempting to recover the large and flimsy tank complicates the process of return immensely, and as such has never been done in previous programs. The recovery of an 'Apollo-like' capsule, however, is straightforward and has been done many times, both from orbit and suborbitally. Since the propellant container can be made the cheapest and simplest portion of the vehicle (yet complicate recovery and reuse attempts) it makes sense not to try and retrieve it. The more expensive structure and equipment such as the pumps, engine, guidance and control and steering mechanisms are recovered in the engine capsule assembly.

The modular nature of the booster also allows for reasonable and considered programs to improve performance (thus reducing operational costs and costs per pound of delivered payload). As an example consider the engine. Initially an engine designed for the now abandoned water-recoverable pressure-fed Space Shuttle booster will be used. This is a low-performance, technically primitive device. The engine is a low-pressure, ablatively-cooled, pintle (or center) injector type. The design is very similar to the one used on the second stage of the McDonnell-Douglas Delta rocket and the Lunar Module Descent Stage. It is a very low cost (a prototype cost less than $15,000 in 1971, compared to costs 600 times higher for other engines in its thrust range), rugged (it was test fired successfully after forty-five days of sea water immersion), versatile engine (fired on *three* different propellant combinations in the same engine) and has a record of combustion stability unmatched in U.S. rocket engine development history. (Combustion stability is one of the most dangerous, annoying and expensive problems in engine development.) There are less than forty parts in the main engine assembly, excluding the turbomachinery and pumps used to supply propellants to the combustion chamber. The disadvantage to this engine is the low exhaust velocity delivered, only 2680 meters/second, leading to a payload of only 26,000 pounds in minimum configuration. However, by using an uprated F-1 engine from the first stage of the Saturn Five moon rocket, the payload potential of the modular vehicle can be tripled, reducing the costs per pound by a third. Thus it would be possible to begin operations with the simple low-performance engine and then uprate (with no major changes to the engine capsule) when resources permit.

Besides its obvious advantages in manufacture and operation, the modular nature of the booster allows great flexibility, through its clustering options, in the development of the system and in the type of payloads which may be carried to orbit. Such flexibility also permits latitude in delivered performance of the engine and the final weight budget of the structure, two common problems in launch vehicle development. Also, the development sequence leading to operational staged boosters can be economically tested by flying only one module on suborbital missions prior to full-scale investment in the LLV.

(Below) Performance for two different engine systems of the LLV are listed. Initially a lower performance engine will be used to lessen development costs, however, as traffic increases, it will become necessary to use a version of the Saturn Five main engine. It may be possible to mix engines between stages as well, for example using an F-1 engine in the central core, with cheaper engines in the outboard modules.

PERFORMANCE
(LOW PERFORMANCE ENGINE, AVERAGE EXHAUST VELOCITY = 2550 M/SEC.)

No. Modules[A] Inboard = ■ Outbrd. = □	Gross Wht.[B] (In Kgs.)	Thrust[C] (In N(10^6))	Max. Acceleration (In Gravities)	Payload (In Kgs.)
□ ■ □	1 864 260	24.5	4.63[D]	12 343
□ □ ■ □ □	3 107 100	40.8	3.04[D]	35 504

PERFORMANCE
(F-1 TYPE ENGINE, AVERAGE EXHAUST VELOCITY 2940 M/SEC.)

□ ■ □	1 864 260	24.5	2.85[D]	39 775
□ □ ■ □ □	3 107 100	40.8	3.74[E]	77 345

A) IN ALL CASES, ONLY THE CORE OR CENTER MODULE ENTERS ORBIT.

B) THE CORE MODULE IS ASSUMED OFF-LOADED OF PROPELLANT IN AN AMOUNT EQUAL TO THE PAYLOAD TO SIMPLIFY ANALYSIS.

C) ALL ENGINES BURNING AT LIFTOFF; PROPELLANT INTERCONNECT BETWEEN STAGES.

D) ENGINE THROTTLING TO 25% FULL THRUST BY TURBOPUMP SHUTOFF. FOUR PUMPS/ENGINE

E) THROTTLE TO 50% FULL THRUST.

Economics

Previously noted observations by General Electric and powersat proponents suggest there should be much more emphasis on lowering co. :s than exist today. But due to both bureaucratic and technical inertia, and to what author Arthur C. Clarke calls 'failure of nerve and failure of imagination', the implementation of well considered and clearly demonstrated technologies has been obstructed. It is necessary to show the synergistic effects of the application of innovative technologies discussed earlier and principles of economics which individually are well accepted (or obvious) but which together produce a major, possibly controversial, step into the future.

Let's examine the cost estimates previously given for payload delivered into low earth orbit. Primary considerations are fuel costs; expendable tank material and manufacture costs; recovery and refurbishment expenses; operation, insurance, overhead burdens; and amortization of capital facilities such as engine recovery capsules and tracking facilities. The table on page 22 is an estimated breakdown of costs based on many years evaluation of vehicle development expenses. For this example, a two outboard/one inboard arrangement is proposed. The payload in this case is 26,000 pounds; the cost per pound is $53. If the F-1 engine is employed, the payload will rise and the cost per pound will be reduced to $16. In any case, this LLV freighter is five times as cheap as the next cheapest launch vehicle, the OTRAG-10000.

There will be strong disagreement with these estimates by some aerospace planners. The key assumption here is the use of mature technologies in manufacture and operation of the system to lower cost of expendable vehicle tank structure (the dominant cost) to about $14/kilogram ($6/lb.). This is up to twice the cost of a luxury automobile, equivalent to the cost of many missles and aircraft of the 1940's and 1950's, and compares favorably with the costs of aircraft *structure* in both general and commercial aviation. At this juncture it is necessary to point out that a simple modular launch vehicle, carefully designed, is orders of magnitude less complex than commercial jet aircraft, and is even less complex in terms of parts count, than an automobile.

Low costs have not been realized heretofore in this business primarily because: 1) the boosters were outgrowths of military weapons systems, 2) they were developed under government specifications and contracts, and 3) there was little or no commercial application which would have forced down the prices. The LLV will hopefully change this situation.

The potential of this modular vehicle may be illustrated by this note: any *one* of many dozen markets would *in themselves alone* justify the development of this vehicle. A prime example is the use of the booster to dispose of the large amount of accumulating nuclear waste from power reactors. It could be economically launched into deep space or deorbited into the sun. □

(Below) System parameters are estimated in the chart below. Foundation researchers believe that the final module design can produce vehicles which have only 5% of their weight as structure. Several studies by NASA and industry support this conclusion, and the McDonnell-Douglas Delta first stage, used to launch most comsats, already operates at this level.

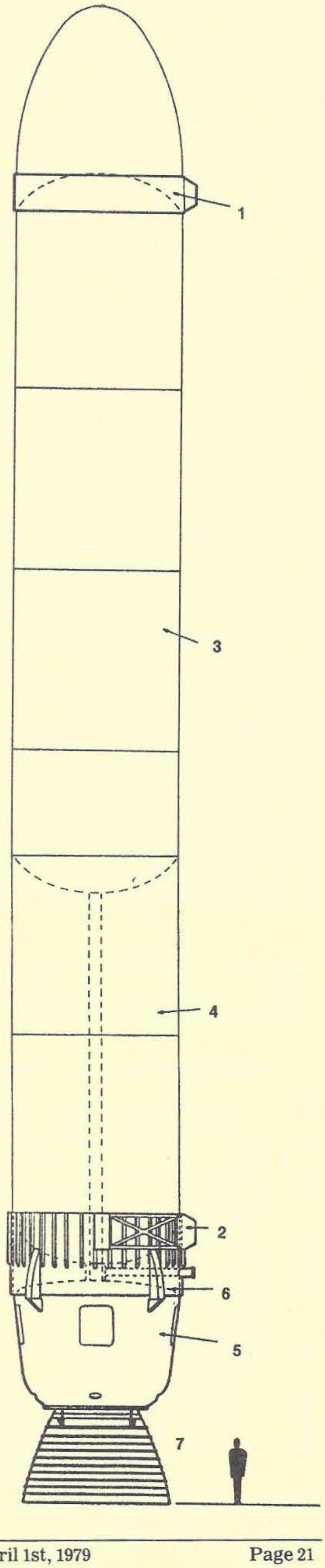
LLV MODULE PERFORMANCE FACTORS

GROSS WEIGHT	621 420	KILOGRAMS
PROPELLANT WEIGHT (USED)	589 670	KILOGRAMS
WEIGHT INJECTED	31 750	KILOGRAMS
THRUST PER ENGINE	816 470	KILOGRAMS FORCE
SEA LEVEL EXHAUST VELOCITY	2 206	METERS/SECOND
VAC. EXHAUST VELOCITY	2 667	METERS/SECOND
AVERAGE EXHAUST VELOCITY	2 550	METERS/SECOND
APPROXIMATE OVERALL LENGTH	43	METERS
DIAMETER (MODULE)	5	METERS
MIXTURE RATIO	2.4:1	OXIDISER/FUEL

(Right) A view of a single LLV module. Each module, whether or not it is part of the first or second stage of the vehicle, is basically identical to every other module. One possible change would be the addition of an enlarged exhaust bell for engines on central core modules, since this increases performance of the engine when operating above the atmosphere. Note the figure of a human for scale.

FORWARD ATTACH POINT	*1*
AFT ATTACH POINT	*2*
LIQUID OXYGEN TANK	*3*
KEROSENE TANK	*4*
RECOVERABLE ENGINE CAPSULE	*5*
HEAT SHIELD	*6*
ENGINE EXHAUST BELL	*7*

LLV MODULE



COSTS ESTIMATION

PROPELLANT	
3 MODULES LIQUID OXYGEN @ $.06 US/KG. (920 000 KG/MODULE)	$ 75,600
3 MODULES KEROSENE @ .22 US/KG. (175 000 KG/MODULE)	115,500
TANK	
3 MODULES @ 13,000 KG. EACH	
MATERIALS (ALUMINUM = $2.65/KG.)	103,350
LABOR, TOOLING, ETC. ($11/KG.)	429,000
FACILITIES/OPERATIONS	
EST. AMORTIZATION 1000 FLIGHTS, 10 YEARS, $10,000/FLIGHT	10,000
RECOVERY/REFURBISHMENT	
RECOVER 3 ENGINE CAPSULES	30,000
REFURBISH/REPAIR $30,000/CAPSULE	90,000
ENGINE CAPSULE AMORTIZATION	
50 FLIGHTS/2,500,000 US DOLLARS EACH	150,000
CONTINGENCY	100,000
TOTAL EXPENSE	$1,103,450
PROFIT (30%)	331,035
CUSTOMER EXPENSE	$1,434,485
COST PER KILOGRAM OF DELIVERED PAYLOAD	$ 116.22

Using cost estimating procedures which are standard in industry, it is believed that the operational cost of the LLV in production can be as much as twenty times cheaper per pound delivered to earth orbit than the Space Shuttle. However, the LLV is not designed to be man-rated, thus the Shuttle would continue to have an advantage in the delivery of humans and sensitive cargo to orbit. The LLV freighter could complement Shuttle by delivering propellant, raw materials, and powersat components and other bulk cargo.

The **Report** is published monthly, and has a subscription price of $20 per year ($15 per year for students, $25 per year for institutional and library subscriptions and $25 per year for overseas airmail). Back issues are available at $2 each from September, 1977. Xerographic copies may be substituted as stocks are depleted. Address all correspondence to Foundation, 85 East Geranium Avenue, St. Paul, MN 55117 or call (612) 370-0990. Editorial Direction Gary C. Hudson; Special Assistance: Resident Fellows E. Anne Roebke and T.A. Brosz; Staff Artist: David Egge. The **Commercial Space Report** accepts VISA/Bankamericard and Master Charge. Please give us your full credit card number, expiration date, and the four digit Interbank number (Master Charge only). Your signature is also required on mail orders. Phone orders accepted at (612) 370-0990. No collect calls please. **Foundation, Inc.** was incorporated in 1971 as a non-profit 501(c)(3) Minnesota Corporation. The company is a diversified research and development organization formed to engage in advanced scientific and technology studies. Funds are provided by contract research for industry, as well as by donations, gifts and internal business profits. Capabilities include theoretical research and study, systems research and development of services and products. A high level of effort is presently being expended in astronautics, especially the commercial utilization of outer space and the need for economical space transportation. **Foundation** has a permanent and consulting staff of professionals to call upon including engineers, designers, scientists, communications experts, management specialists and the like. Corporate headquarters is presently in St. Paul, Minnesota. The **Commercial Space Report** is a concentrated effort to report all areas of private and industrial initiatives in the development of space. We hope it will stimulate ideas by raising questions and offering innovative concepts contributed by acknowledged leaders in the field. If you have any comments, ideas or requests for information or articles, we encourage you to contact us.

NEWS NOTES:

CORRECTIONS... Last issue we labeled the most recent Soviet manned space mission as Soyuz 24, when in fact, it is Soyuz 32. Additionally, we note that the News Note of September's Report titled "Soviets Test Wingless Airplane" was based on false information, and is in fact, in error. However, research on electroaerodynamic flight has been performed in the US and Japan, and presumably in the USSR.

FREE SPACE... Reason magazine, which calls itself a "forum for analysis and commentary, with emphasis on individual liberty", has devoted a single issue to the topic of space business. Articles include two by Robert Poole, Jr.: "There's a New Age Dawning" and "Free Space!" (which appeared in the Commercial Space Report, October and November, 1978). Additionally, Peter Vajk, well-known space settlements researcher, produced "No More Doomsday", a refutation of the Limits to Growth concept. Gary Hudson, of Foundation, and Philip Chapman, former astronaut and Arthur D. Little staffer, teamed to write "Gateway to Space", a discussion of the Earthport project and the commercial benefits of space. The special issue, titled "Goodbye, Spaceship Earth: The Dawn of Private Ventures in Space" was published as Vol. 10, No. 12, April, 1979. Contact Reason, Box 40105, Santa Barbara, CA 93101.

ASTEROID WILDERNESS?... Washington, D.C....Dr. George W. Wetherill, Director of the Department of Terrestrial Magnetism of the Carnegie Institution in Washington, writing in the March 1979 Scientific American, has suggested that the Apollo-Amor asteroids might be declared a wilderness area. The quote: "It is likely that the Apollos, together with a few comets, represent the only accessible source of nonterrestrial carbon compounds and water in nearby space, a source that requires about 25 million years to be replenished. Perhaps it would be better if the region of space occupied by the Apollo objects and their close relatives the Amor objects were declared an inviolable 'wilderness area'." It all depends on what you consider 'nearby space', or 'a few comets', we suppose. Dr. Wetherill has apparently not heard about water on any of the Galilean satellites or the Martian surface.

SPACE COURSE... Over 22 prominent people from the aerospace industry, NASA, the military and academia have been scheduled to speak at a California State University at Northridge summer course titled "Update on Space". Organized by Dr. B.J. Bluth in the Department of Sociology, the course will run from 9:30-11 AM, Monday through Friday, June 25th to August 3rd. The overall focus will be on the sociological dimension of the move into space--the impact on the quality of life here on earth, and the new problems and solutions of our space future. Write Dr. Bluth in Northridge, CA 91330, or call her at (213) 885-3591 for more information.

L.A. SPACE EXPO... Los Angeles...A five day "Earth/Space Expo" will be held in Los Angeles at the Santa Monica Civic Center from July 18th to the 22nd in celebration of the 10th anniversary of the first manned moon landing. The five days will feature space benefits, careers, exploration and general topics, with exhibits from NASA and the aerospace industry and speakers. Admission is free.

TV SATELLITES FREE?... Broadcasting magazine has reported that RCA American Communications, Inc., along with Viacom International (a major TV syndicator), and the Post-Newsweek Stations group have announced plans to test an experimental program involving free earth stations for local TV stations. The idea is to provide free ground stations to users who would then buy syndicated TV programs from the business group. The programs would be transmitted over the RCA Satcom domestic communication satellites. Reaction by the TV industry was mixed, with some questioning whether they want an earth station which only "looks" at the RCA satellite. Estimates are that it could cost RCA $20 million to equip stations with free ground antennas.

CONCRETE SPACE FUTURE... London...Do large space structures belong to the kingdom of concrete and rock or the ephemeral world of of rockets, jumbo-jets and supertankers? Dr. D.J. Shepard, writing in the January 1979 issue of the British Interplanetary Society's Spaceflight magazine, believes the former. In an article titled: "Concrete Space Colonies", he points out that the proven technology of concrete and rock has amassed 10^{16} hours of experience in large space structures (like the moons, planets and asteroids of the solar system). In a serious examination of the technology and projected life of the colonies, he concluded that the use of extraterrestrially derived prestressed concrete would be most appropriate for large, mobile structures like a space settlement. By way of analogy, Shepard points to the largest mobile construct ever built, the Ninian Central, a half million ton prestressed concrete oil platform used in the North Sea. The article goes on to show that the use of concrete will permit much higher safety levels within the colony, as well as reducing the problems of leakage, limiting the need for painting the interior, and lessening the feeling of being within a cold, metal pressure vessel. Also, the inert and long-lasting concrete colony would have its radiation shielding provided as a function of the wall, rather than being an add-on. Considering all factors of safety, economics and architecture, Shepard finds a concrete colony to be far superior in all respects to a metal structure. Why then wasn't it considered by US space settlement designers? Shepard feels that this oversight was due to the fact that civil engineers in the US are not knowledgeable about the widespread use of concrete in place of steel and aluminum in Europe. He notes that the technology of prestressed concrete has languished in the US as compared to Europe.

KILLER SATELIITE UPDATE... The possible Soviet geosynchronous killer satellite reported in the last issue of the Report has been labeled a failed comsat by the USSR. The satellite, called "Ekran", was launched February 18th. There is still no comment from US officials.