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AEROSPACE CAN HELP SOLVE
THE GROUND TRANSPORTATION PROBLEM

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ABSTRACT

Ground transportation has many common features with air and space travel and as a result the experience in aerospace is applicable, but cannot be applied without change. Ground vehicles and aircraft must safely and comfortably transport people, however the weight of the ground vehicle can be increased over the aircraft to realize cost savings. Basic lessons in dynamics, structures and fluid mechanics are applicable. The application of systems engineering disciplines learned on space and missile programs can be very effective. Many new people-mover concepts of current interest are excellent examples of application of system thinking. Finally, aerospace can make the same real contributions to the socio-economic aspects of ground transportation as it has to air transportation by developing and supplying the user better products that can be operated at a lower passenger cost.

INTRODUCTION

The title of this paper has been chosen deliberately and carefully. Aerospace can help - it cannot solve the problem by itself. The Ground Transportation systems of the future will be the child of two parents: Ground Transportation Systems and Methods as we know them, and Aerospace Technology. As in any family relationship there will be give-and-take. Both will contribute and both will respect the contribution of the other and will learn from it. There will be coordination and cooperation, not competition. Aerospace will come to the partnership bringing skills and experience from the realm of air travel, as might be expected, but also in a very definite way from the realms of space travel and of missile systems. It is the purpose of this paper to point out in a general way four areas in which these contributions may be made, with specific examples of each.

- Technology
- Cost Analysis
- Systems Management
- Innovations and/or Social-Political Considerations

It is our belief that ground transportation will be improved, that there will be viable options to increased use of the automobile, and that safe, reliable, convenient and attractive transit systems can be developed - and that the Aerospace Industry will play an increasingly important role in this development.

TECHNOLOGY

Potential Aerospace contributions to Ground Transportation logically begin with Aerospace Technology, where Aerospace has learned the necessity of working key technical problems in depth, and demonstrated its capability to do so.

This capability is built on theory, analysis and calculation, but even more it is built on experiment and tests - wind tunnels, material testing laboratories and dynamic laboratories - and, more recently, electronic laboratories, computers, simulators and space chambers. (Figures 1 and 2).

Wind tunnel tests can be used at very low speed, to determine, for example, the effects of rounding the corners of rectangular-box people-movers even where they never go faster than 30 mph. They can be used at much higher speed for optimizing the shape, reducing drag, minimizing side loads and eliminating undesirable lift on such vehicles as the new Tokkaido Line train. Similar testing, not necessarily in conventional wind tunnels, will enable forces to be obtained on Tracked Air Cushion vehicles running in U-shaped guideways, or on advanced air cushion pad configurations (Figure 3).

Ground transportation problems sometimes require a different emphasis than Aerospace problems. Figure 4 is a general chart indicating load carrying capabilities of various modes of transportation, based on a method used by Von Karman in 1950. The drag, or steady-state thrust required, for lifting a given weight tends to be lower for various ground transportation modes than for commercial airplanes. That is, weight requirements are not as stringent and more emphasis can be placed on achieving lower cost.

The application of Aerospace Technology to ground transportation is not limited, however, to considerations of drag, lift and performance. The realm of "Aerospace Technology" is to be con-
sidered quite broadly — it must include human engineering, command and control technology, communications systems, system simulations and disciplined procedures of safety, reliability and testing.

There have been ground transportation systems derived from these technologies for many years. Consider, for example, the Minuteman Transporter-Erector in Figure 5. This is one of the largest vehicles ever to travel on U. S. highways. The vehicle concept, design, detailed specifications and qualification testing were by The Boeing Company. The tractor was fabricated by General Motors and the container by Cessna. It carries a missile 60 feet long and loads up to 80,000 lbs. It can travel 40 mph, climb 16% grades, and turn in a 50' radius. It has environmental control of temperature and humidity and can travel off-highway's with a secondary suspension that keeps the loads less than 2g even when travelling at full speed over 3" washboards. It was produced by the Aerospace Industry in 1962 and used constantly, with some improvements, since then.

Or, consider the Lunar Rover (Fig. 6). This is a 1971 vehicle. It weighs only 500 pounds but carries a 1000 pound payload. It is electric powered, 4 wheel drive with steering of two wheels or all four wheels. A single hand controller controls speed, directing and braking. It will climb a 20 degree slope or surmount a 12 inch obstacle and it will operate in a hard vacuum and +250° or -250°F, and will live through a Saturn V takeoff. It, also, is a product of "Aerospace Technology". Some day some of the lessons learned in its design, construction and testing will be used in earth-bound transportation units.

When this happens, it will not be the first time where such fallout has occurred. The anti-skid, or anti-wheel-lock devices developed for airplanes are now beginning to be used on automobiles. The communication systems developed for military airplanes, which provide data transmission in noisy environments and voice privacy modes for moving vehicles will someday be used to guide small people-movers around large university campuses without being misdirected by student pranksters.

There are other kinds of Aerospace Technology to apply to Ground Transportation. Figure 7 shows Minuteman combat crews on a 24 hour alert duty tour. What we see here may be the future equivalent of a street-car conductor, or bus-driver, or locomotive engineer. Just as former Air Force pilots are now underground, manipulating and monitoring computer complexes, so will transportation operators of the future be in many cases. And much of the experience for such operations may come from such "Aerospace" operations as the Minuteman Launch Control Center and AWACS.

Already there are in existence in aircraft companies such facilities as the Man/Machine Interface Facility shown in Figure 8. This is a general-purpose facility to explore reactions and capabilities of men in real-time control of advanced systems involving complex computing equipment. Equipment such as this, already developed and available in the Aerospace Industry, will help bring into being relatively easily the automated operations of future ground transportation projects.

Along with this facility there will be the requirements for systems modeling and simulation and for software. Aerospace technology has considerable experience in both.

Models have been developed for planning transportation systems, showing inter-relationships of schedules, stops, passenger loads, vehicle performance, economics, etc.

Models have also been developed, and extensively used, in military applications and air transportation applications for predicting total life-cycle costs of a system. (These are discussed in the following section.)

Sometimes the development of reliable, foolproof and accurate software is the biggest problem of all, and here Aerospace experience is more than adequate. Lunar Orbiter (Fig. 9) was completely controlled from the earth as it circled low over the moon, took detailed pictures of the backside of the moon for the first time in history and transmitted them to the earth. Over 3/4 million instructions were developed in advance, delivered on schedule and used flexibly. AWACS early warning systems will have even more complexity, for its software requires one million instructions to be prepared. The control of typical ground transportation systems will not be too difficult when based on this experience.

COST ANALYSIS

One of the first things an Aerospace firm learns in entering the civil market is that there is an entirely different approach to costs. The civil market tends to a very simple approach, where "low bid" reigns almost supreme. In the ground transportation field this is often characterized by a two step process - establishment of a Qualified Bidders List and a straight low bid on a project. It does not matter if one bidder is "very well qualified" and another "just barely qualified" - all end up on the same list. Superior performance, or added features - even desirable features - pay little or no part in the selection process.

The market place in Air and in Space has insisted that a low cost is required to win but the Aerospace Industry has learned that it is necessary to deal with costs in a sophisticated way in order to offer the "lowest price" product approach. That is, they believe that "It is not what you pay but what you get for what you pay." They tend to balance weight and complexity with cost, so that the end product is "cost effective". A good example is the ordinary wing flap. Wing flaps can
be very complex and costly, but from a long-term standpoint they are much less costly than having a wing of twice the area and carrying the extra weight and drag through years of high speed flight.

This is illustrated for the airplane as a whole in Figure 10. Over a period of 25 years airplanes have become very much more complex and sophisticated, with a tremendous increase in cost. In 1940 a DC-3 could be bought for $100,000, in 1950 a DC-6 could be bought for $1,000,000, in 1960 a 707 would run $4.5 million. In the late 1960’s a stretched DC-8 would run $9 million and a 747 more than twice that. The important fact is, however, that all this complexity and technology and cost was "cost effective", so that the cost to the passenger (with all the additional comfort and speed) was actually less than in 1950 — and far less than the rise in general living costs.

Life-cycle costs, including life-time maintenance, spares, repairs, etc. as well as initial cost are important. For example, as many commuters know, the Long Island Railroad has a considerable problem with window breakage, and very often runs cars with broken windows even in adverse weather conditions. The maintenance and repair costs on windows is very high; but if the car builder tries to propose a car design and a window design that would reduce or eliminate these high costs for perhaps a slight increase in initial cost, the "system" does not always allow for such proposals.

Typical data, shown in Figure 11, bears out the reduction in life cycle cost brought about by good support planning. For modest increases in initial cost the advantages of advanced development and greater depth of planning for life-time support are significant. The data shown have been estimated for 3 fairly complex systems (B-1, ASMS and AWACS) and would be true for other systems of the same complexity. Very simple systems would have less cost savings but the impact would be important for any modern transit system.

We hope that we will be able to reduce the overall costs to the civil sector by applying the same complete analysis that an airline, for example, does in deciding between a DC-10 and L-1011 airplane which may meet essentially the same general specifications. That is, to consider whether the airplane will have had previous airline experience on other airlines, the past record of the engine manufacturers, gross differences in maintenance man hours or equipment, probable passenger acceptance, growth capability, range or payload beyond minimum specs, etc.

It is recognized that there is a converse side that also has truth — that the ground transportation customer does not want or need continuous "improvements" leading to overruns and delivery delays, nor does he want brilliant concepts unproven in actual operation. Still it is obvious that the introduction of Aerospace outlooks to the commercial-industrial world will lead to changes and to better transportation systems and better, more convenient transportation, at a lower price to the customer.

SYSTEMS MANAGEMENT

The Aerospace industry has, as we have seen, many technologies immediately applicable to transportation problems, it has the background and training to acquire newer technologies, and it has facilities to develop and verify the new technology data. In some ways, however, what we have is that unique and directly applicable to ground transportation problems is a disciplined planning process, often called systems management. Granted that in most cases eighty percent of the good from this process comes from systematically thinking through what you want to achieve, and how you are going to do it before you actually do it. Nevertheless, this management method is really more than that. Out of the great aerospace programs, and especially Apollo, have come a number of systems management concepts which have been formalized into working systems at every level and become an integral part of a way of doing business in aerospace firms.

The general definition of what we are talking about is given in Fig. 12 and the principal components are listed in Figure 13.

The application of these factors to Ground Transportation could be the subject of an entire paper. For my purpose, it is sufficient to say —

(1) That full application of this disciplined management process to Ground Transportation Systems has yet to be made and that attempts to go in this direction to date have ranged from adequate to downright poor,

(2) That full application is going to be required. Ground transportation systems costing from $25 million to $150 million and occasionally to the $1 billion level, in initial costs alone, plainly require this treatment — especially in this field where trends have been more toward lack of program success than to widespread program acceptance and financial success,

(3) That, as one important facet of my basic theme, I firmly believe that this is one area where Aerospace know-how can help solve the problems of ground transportation.

INNOVATIONS AND SOCIAL-POLITICAL CONSIDERATIONS

Aerospace's classical role has been to apply completely innovative approaches to transportation problems, in an effort to give a high quality product and increasingly economical transportation.

Consider first the way in which workers, or employees, will be used in the system. This relates to the manpower costs of the system, which in many cases will be the largest single cost of
transportation. To take a simple, but extreme case, consider the invention of the "stewardess" - good-looking young girls who can be obtained at moderate salary, and yet who all by themselves collect and verify tickets, serve meals, pour drinks, run motion-picture machines, instruct passengers in the use of safety equipment and act as the representative of the pilots in emergency or special situations. This is in contrast to the "traditional" railroad operation. Whoever saw a conductor serve a sandwich? A very pertinent, and difficult, problem in any transportation system is that of balancing the effort, and the responsibility, between the on-board operating crew and the support crew located on the ground or at a fixed central control location. At one extreme is the driver of a long-distance highway bus - when he is on the road, no one knows where he is or what trouble he is in. A train crew is under some control from block signals and from switchmen operating on the basis of signals from a control location. An airplane flight crew has even more "help" from ground controllers. The pilot has immediate communications when he needs it. He is quite definitely under some control from a central source. He is assigned specific flight routes. In case of a ground accident he may be diverted from his airport, or in a midair emergency he may be told to make a temporary 180 and go away. He may be helped by advisories relative to severe weather, etc.

At the far extreme of this spectra is the lunar space crew where the three men on board are supported by a hundred men and several huge computers - with almost infinite additional back-up when needed. This is "cost-effective" for space travel where the cost of putting all of the capability on-board would be very large.

In approaching new and innovative systems of ground transportation there are "people-mover" concepts which are excellent examples of such analysis. The basic objective of a "people-mover" or "collection and distribution system" is to move many people to a diversity of destinations with everyone going directly to his own destination, without intermediate stops. Here the analysis shows that the only cost-effective way of doing this is to have many small (6 to 10 passenger) cars moving under computer control with no salaried employee on the car. A good example is the Alden-Boeing collection and distribution system. The car is shown in Figure 14. A typical layout, which could be a university campus, a large airport, or a central business district is shown in Figure 15. If there is to be direct-to-destination operation, stations must be "off-line", with all deceleration, stopping, starting and acceleration done on the "off-line" track. This requires "passive switching" - preferably with no moving track parts, as shown in Figure 16, using the guidance wheels shown in Figure 17. A small-scale working model of this operation is shown in Figure 18, sketches of operational lines and stations are shown in Figures 19 and 20.

The entire operation must be computer controlled, with a minimum of central monitoring operators so that this ground transportation system ends up looking very similar to Figures 7 and 8.

The basic point to be made here is that in balancing the on-board personnel with central control personnel there is no single answer for all modes of transportation. We must be innovative, we must be free to develop the optimum answer in each case. It is precisely this background of flexibility and innovative approach that the Aerospace Industry has to bring to ground transportation systems.
FIGURE 2. SPACE CHAMBER

FIGURE 3. ADVANCED AIR CUSHION PAD CONFIGURATIONS

NOTE

Figures 1, 6, 16, 17, 18 and 20 are not available for preprint.
FIGURE 4. LOAD-CARRYING CAPABILITY

FIGURE 5. MINUTEMAN TRANSPORTER ERECTOR
• 4-WHEEL DRIVE, BATTERY ELECTRIC POWERED
• CREW OF TWO PLUS 170 LB SCIENCE EQUIPMENT
• SPEED 16 KM/HR; RANGE 70 KM
• VARIABLE SPEED, FORWARD AND REVERSE WITH BRAKING
• FRONT AND REAR STEERING
• BOX-TYPE CHASSIS AND WHEELS FOLD FOR COMPACT STORAGE IN LM

FIGURE 6. LUNAR ROVER VEHICLE
Figure 10. Cost Trends in Airline Travel

- **Passenger Fare - Cents per Mile**
- **Airplane Cost - Millions of Dollars**

**COST OF LIVING (BASED ON 1957-59)**
INADEQUATE SUPPORT PLANNING

DEVELOPMENT 15%

OPERATIONS & SUPPORT 50%

PRODUCTION 35%

GOOD SUPPORT PLANNING

DEVELOPMENT 22%

OPERATIONS & SUPPORT 28%

PRODUCTION 50%

- Based upon figures from three proposed advanced military systems, compared to baseline data for Minuteman, B-52 and current aircraft and electronic ground systems.

- For typical cost breakdown details see "Logistics Spectrum", Spring, 1971

FIGURE 11. LIFE CYCLE COSTS

SYSTEMS MANAGEMENT

- The consideration of all components, assemblies, interfacing equipment,
- And the production, operating and support requirements
- In the creation of a design to satisfy a mission function.

FIGURE 12
SYSTEM MANAGEMENT COMPONENTS

- PROGRAM INTEGRATION
  - PLANNING
  - MANAGEMENT
  - PROGRAM CONTROL
  - PROGRAM REVIEWS
- REQUIREMENTS ANALYSIS
- OPERATING CONCEPTS
- DESIGN AND TEST
  - DESIGN REVIEWS
  - TEST MANAGEMENT AND ANALYSIS
  - SAFETY ANALYSIS
  - RELIABILITY AND QUALITY ASSURANCE
  - MAINTAINABILITY ANALYSIS
- PRODUCTION
- OPERATIONS
- SUPPORT
  - MAINTENANCE
  - LOGISTICS
  - TRAINING

FIGURE 13

FIGURE 14

14-11
FIGURE 15. TYPICAL LAYOUT - COLLECTION AND DISTRIBUTION SYSTEMS

FIGURE 19
14-12