respect. The jet engine surprisingly turns out to be one of the most efficient propulsive systems, primarily because of a very careful matching of its cycle to the operating conditions of the aircraft it propels. Even after-burning aircraft like the SST turn out to be very efficient in their speed range. The cyclist, based on his caloric intake during a cycling day, is quite competitive with the combustion engine.

"Only the vehicles incorporating levitation, such as the hovercraft or the helicopter, show disappointing efficiencies; here much of the power is required for support of the vehicle and does not contribute to the forward propulsion."

The second component of Energy Cost cited by Dr. Cockshutt is the frictional resistance that the vehicle encounters during travel. Engineers normally express this in a term called the Lift/Drag (L/D) ratio which describes the aerodynamic or frictional cleanliness of the vehicle. Since this ratio is the inverse of the frictional resistance, the higher a vehicle's L/D value, the cleaner or more friction-free is its movement, and the smaller is the Energy Cost parameter.

For any given vehicle, on land, sea or in the air, an increase in velocity results in an increase in frictional resistance, with a proportionate decrease in the L/D ratio. If the velocity is increased by a factor of two, the frictional resistance is increased by a factor of up to four, depending on the frictional mechanisms involved.

"The L/D ratios for the automobile and subsonic aircraft are about the same, falling into the range between 15 and 20," says Dr. Cockshutt. "This gives some idea of the much greater frictional cleanliness of an airplane, since it travels about ten times as fast as a car. The box car in a freight train has a Lift/Drag value of about 250. The reason for this excellent value is the low drag of the box car's steel wheels on smooth rails and the aerodynamic efficiency of the system (only the first car of the normally-long freight train encounters high air resistance). The marine tanker, because of the fact that so little surface is in contact with the environment through which it moves, has one of the best L/D ratios, with values from 1,000 to 1,800. For every ton of gross weight, there is only one to two pounds of frictional resistance when it moves along at 15 knots (25 feet per second)."

Dr. Cockshutt's attention also has been directed at the cost of transmitting energy itself. Oil and gas pipelines have been shown to have L/D ratios of about 190 and 40 respectively, the lower figure for gas resulting from the much higher velocity of transmission normally used. Unfortunately pipes cannot be built conveniently with diameters greater than four feet, which creates a problem since the drag in the system is caused by the "scrubbing" friction of the fuel passing over the inner walls.

"Pipelines typically consist of a number of smaller units laid in parallel," says Dr. Cockshutt.

"The Trans-Canada Pipeline is, in effect, a river of natural gas flowing from Alberta to Ontario. Ten per cent of the fuel entering the system never gets to the other end; it is used in the pumps that keep the fuel moving. The way to conserve on transmission energy is to increase the number of pipes operating in parallel and, if possible, decrease the flow velocity of the fuel by operating at a higher pressure."

The third component of Energy Cost is the structural efficiency of the transporting system, the ratio of the payload to the total weight transported. Pipelines operate at 100 per cent efficiency in this regard, since nothing but payload moves through the pipe. The low Energy Costs of the marine tanker and the box car stem to a considerable degree from their high ratios of payload to total weight. On the other hand, the principal reason for the high Energy Costs of the automobile is the low structural efficiency of the system; passengers weighing a few hundred pounds are transported in a vehicle weighing about two tons.

With aircraft there is a tradeoff between the payload and the amount of fuel carried. On long overseas flights where large amounts of fuel are necessary, there is a pronounced reduction in structural efficiency compared to the shorter stag domestic runs. This is reflected in the fact that the short stage DC-9 can show lower Energy Costs than the long-range 747 jumbo jet.

"A suggested alternative to pipelines and tankers in the removal of the northern slope Alaskan oil is a fleet of huge aircraft," says Dr. Cockshutt. "Boeing has prepared a design proposal for such a craft, called the RC1 Resource Carrier. It would weigh about three and a half million pounds fully loaded, be well over the length of a football field, and be propelled by 12 of the most powerful jet engines ever built. These large dimensions allow the aircraft to carry huge payloads of oil (up to 65 per cent of the weight can be oil) giving a structural efficiency that lowers the Energy Cost to a level of eminent respectability."

Dr. Cockshutt emphasizes that it would be a mistake to assume that Energy Cost is the only factor to consider when deciding on a method of transportation.

"The hovercraft may well be inefficient," he says, "but there are some terrains such as tundra or ice-strewn waters where it is the most practical means of travel. In the long run i may be more economical to operate these vehicles in sparsely populated areas than to build expensive airfields or road beds that might be obsolete a few years later. The SST is another case in point. Although in the short term of our energy crisis the plane's high fuel consumption may seem immoral, nonetheless it is an enormously productive aircraft. Because of its high speeds it may make two or three times as many flights as subsonic aircraft over the same time span. It therefore would be incorrect to assume that a system that is expensive in term of Energy Cost is inherently bad or uneconomic."

Figure 4 recapitulates some of the lowest cost systems, along with some that are more expensive. The best systems lie on the diagonal sloping upward from the right, from the marine tanker moving at 25 feet per second to the supersonic transport moving at 2,000 feet per second. In increasing the speed by a factor of 100, the Energy Cost increases by a factor of 1,000.

What price speed? Dr. Cockshutt avers that his criteria of energy costs do not per se give any credit for speed.

"It is very difficult to put a value on speed," he says. "As the graph clearly shows, if speed is not needed to transport payloads, then in terms of the Energy Costs, it is better to mov more slowly. While speed is not necessary in cargo transportation, people obviously place great value on reduced travel times. One of the salient points of the study is that in terms of Energy Cost and the comparison of current planes and cars, one gets the airplane speed for nothing. Because the value tha passengers place on speed lies outside these energy considera tions, it is difficult to include it in a criterion of excellence. However, for the vast majority of transportation activities, a minimum speed consistent with the product transported will lead to significant energy conservation." □ Wayne Campbell