Papers —

Eighth Annual Meeting

"Man & Transportation"

September 6-9, 1967

Montreal, Quebec, Canada

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TRANSPORTATION RESEARCH FORUM

The Tracked Hovercraft System of High Speed Land Transport

*by D. S. Bliss**

1. Introduction

Throughout history it has been found that all progress depends upon communication; in the furtherance of international relations, the development of the national economy, or co-operation between individuals, good communications are essential for success. It follows that good transport is necessary for good communications because the best communication is the actual meeting of people.

In national economic development, the rate of progress can be significantly affected by the quality of internal transport. In this context, transport is not an end in itself; it is the means of furthering commerce. The prime requirement of transport is that it should provide acceptably short journey times over distances accordant with existing conditions and the pace of life. If it does not fulfill this requirement, continued expansion of the economy is likely to be retarded.

It is suggested in this paper that high speed land transport can in some instances fulfill this requirement; furthermore, there is considerable qualitative evidence that the Tracked Hovercraft system of high speed land transport is likely to be the most economic method.

2. Traffic Problems in Cities

The suggestion that a very high speed vehicle may help solve traffic problems in cities, where high speeds obviously cannot be used, could at first seem strange but the following observations demonstrate its validity.

When a country develops, its centres of population increase in size from villages to large cities containing a relatively small central business area which results from the strong desire of people to be at the centre of affairs and in easy communication with others.

The 'Daily commuter traffic problem' is, of course, caused by the radial influx of people from the expanding peripheral area to the business centre, the density of traffic increasing toward the centre.

The direct approach to this problem has been to provide more roads and train services. Evidence to date indicates that these endeavours have the end effect of increasing the severity of the problem, possibly as a result of encouraging the central area to expand in size. Whatever the reason, there is little doubt that the commuter problem is increasing rather than improving. More unfortunate is the fact that in the central areas themselves, traffic con-

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gestion is reaching a level which is frustrating and inefficient and which could eventually strangle movement within the very area created by the desire for good communication.

A very simple analysis of the problem has been made, which suggests that the final solution will not be found by improving transport within the city alone.

Clearly, an increase in the density of central area population has a proportional effect on the traffic flow rate at any point on the approach to it. It may not be generally realised that for a given density of population, increasing the size of the area will also increase the traffic flow rate across its boundary. This is because the area enclosed increases proportionally to the diameter, whereas the access perimeter only increases linearly with the diameter. In practice increases in both size and central area population density probably takes place at the same time. Fig. 1 illustrates this trend.

In continuance of this simple hypothetical example of what could be the result of expanding a large existing city to allow two or three times the present commercial activity, let us assume that the number of people involved is proportional to the scale of commercial development and that the average density of the residential areas remains unchanged. The following table can be compiled for the idealised case of three possible methods of development:

(i) **Central Development** – radial expansion of one unit, similar to that which has happened in the past and is continuing today (Cases B and C).

(ii) **Regional development of residential centres** connected to the city by special transport links so that the residential centres may be separated from the city. (Cases B2 and C2).

(iii) **Regional development of new commercial centres** some considerable distance from the existing city (Cases B3 and C3).

The growth of population, city size, and traffic intensity is shown in Table 1 as ratios to the datum condition (Case A).

Fig. 2 is a diagrammatic representation of the cases in Table 1. There are three quantities in Table 1 (summarized in Fig. 2),which have important traffic and social implications. These are:

(i) The number of people in the central area is a measure of the traffic likely to be encountered within the city centre during the working day.

(ii) The traffic flow across the central area perimeter is a measure of the traffic congestion likely morning and evening.

(iii) The size of the peripheral residential area is a measure of the distance the outermost commuter must travel through increasing congestion as well as the distance of the nearest countryside from the city centre.

The indications of this simple analysis are that central development of cities can only lead to increasing traffic problems, both in the central area and

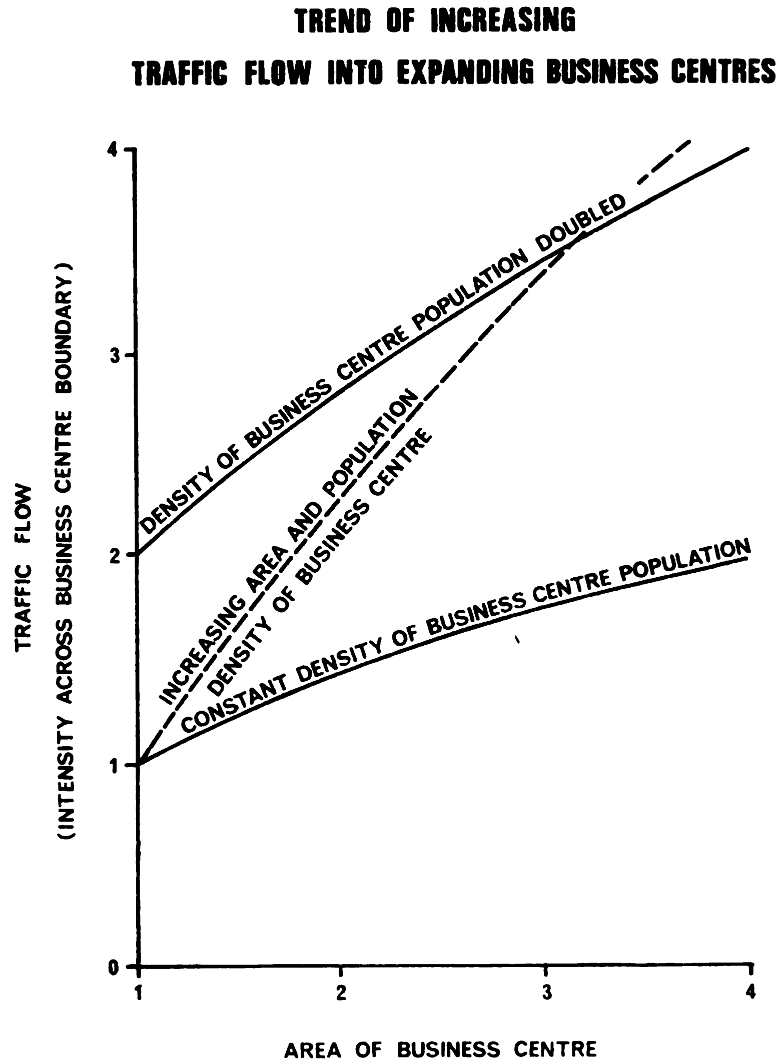


FIG. 1

the approaches to it. (Cases B and C). Preferably, the flow in one should not exceed the flow in the other. The commuting traffic problem can be considerably alleviated by regional development in the form of residential centres with direct transport links to the centre of the city; but the final problem, traffic inside the central area, can only be prevented from increasing in severity by keeping the activity within it to a manageable level (Cases B3 and C3).

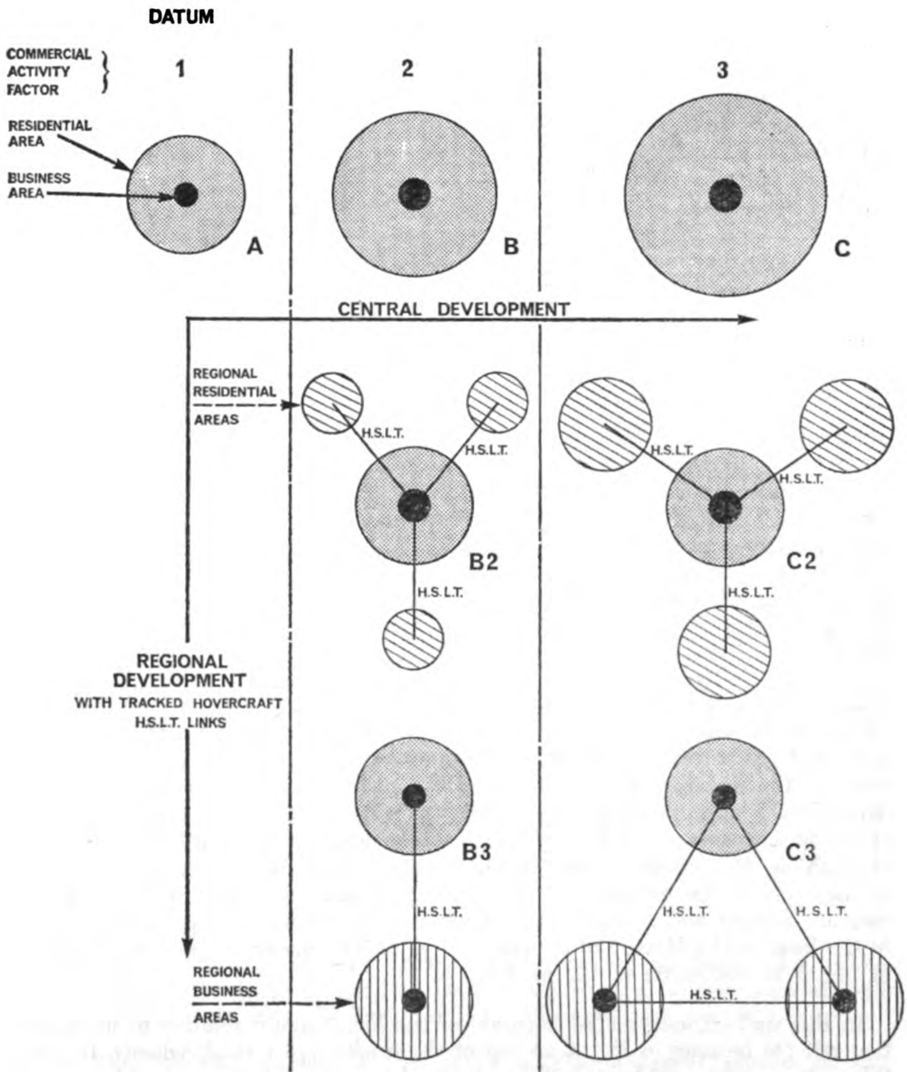
TABLE 1—DEVELOPMENT OF CITIES (All values show ratios to datum)

Measure of Commercial Activity	1	2			3		
Method of Development	Datum	Central Devt.	Regional Devt.		Central Devt.	Regional Devt.	
			Residential	Business		Residential	Business
Reference Fig. 2	A	B	B2	B3	C	C2	C3
Population Density Assumed	1	1	1	1	1.5	1.5	1
Central Business Area(s)	1	2	2	2	2	2	3
Central Area Population per centre	1	2	2	1	3	3	1
Traffic from Peripheral Residential Area per Central Area	1	2	1	1	3	1	1
Central Area Perimeter Length(s)	1	1.4	1.4	1	1.4	1.4	1
Traffic Intensity across Central Area Perimeter(s)	1	1.4	0.71	1	2.1	0.71	1
Long Distance Commuter Traffic	—	—	1(1)	—	—	2(1)	—
Long Distance Business Traffic	None	None	None	Yes(2)	None	None	Yes(2)
Peripheral Residential Area(s)	1	2	1	1	3	1	1
Peripheral Residential Diameter(s)	1	1.4	1	1	1.7	1	1
Regional Residential Area } each of 3 centres	—	—	0.33(3)	—	—	0.67(3)	—
Regional Residential Dia. } each of 3 centres	—	—	0.58	—	—	0.82	—
New Business Centres required	—	—	—	1(4)	—	—	2(4)

(1) Datum as Traffic from Peripheral Residential Area of CASE A. (2) No Datum.
(3) Datum as Peripheral Residential Area of CASE A. (4) Details as Datum City CASE A.

EXPANSION OF CITIES WITH INCREASE IN COMMERCE

(DERIVED FROM TABLE 1)



CASE	A	B	B2	B3	C	C2	C3
TRAFFIC INSIDE CENTRAL AREA	1	2	2	1	3	3	1
INTENSITY OF FREE TRAFFIC FLOW INTO CENTRAL AREA	1	1·4	0·71	1	2·1	0·71	1
SIZE OF CITY	1	1·4	1	1	1·7	1	1

FIG. 2

In other words, if a country is to continue to expand its economy without a proportional increase in traffic problems in cities, it must be done by means of regional rather than central development to the extent of dispersing its centres of commerce. If, however, this solution is to prove successful it is essential that the geographical separation does not result in a deterioration of communications between people.

The requirement of the transport system in these circumstances is that it shall connect the separated business centres of these regions so that, to the traveller, they appear no more distant than the suburbs of a present-day city from its centre. To achieve this end, direct centre to centre, fast, frequent, reliable, long-distance transport services are required. These must be closely integrated with efficient feeder services inside the central business areas. It is considered that high speed land transport will be the most effective means of fulfilling this need in many cases. H.S.L.T. using Tracked Hovercraft is therefore seen as an important factor in the future economic development of many countries.

3. The Tracked Hovercraft System of H.S.L.T.

The Tracked Hovercraft is a high speed vehicle which operates on a segregated track. The unique feature of the system is that by the use of air cushions for support and guidance, contact between the vehicle and track is eliminated. This alleviates track surface precision requirements as well as reducing wear and maintenance in vehicle and track. Vehicles, which can be designed to cover a range of sizes, may be operated singly as Hovercars or coupled together to form Hovertrains as required by particular applications. Fig. 3 shows the general appearance of a high speed Hovercar on its track in open countryside.

Traction is by linear electric induction motor which also does not require contact for its effectiveness. Power for the vehicle may be from a prime mover such as a gas turbine on board, driving an electrical generator providing current for the linear motor; or by electrical current collected from the track. An early working demonstration model which incorporated the basic elements of the system is shown in Figs. 4 and 5. The configuration of lift and guidance air cushion "Hoverpads" is seen in Fig. 5. Each of the Hoverpads is connected to the body of the vehicle by an air-spring suspension system. The air cushions are formed and sustained by an air curtain issuing from peripheral slots in the base of the Hoverpad as seen in Fig. 5. The linear motor is to be seen in Fig. 5 at the centre of the model.

In this six foot long model, location of the linear motor relative to its reaction rail (to be seen in Fig. 4 on top of the track), is by small wheels. In the full scale machine, guidance will be obtained by air cushions or possibly servo-mechanisms.

The track is a single beam, probably of concrete construction. It can be continuously supported at or beneath ground level, or elevated on pylons. The track section of the demonstration model is rectangular with linear motor rail and electrical conductors on the top face. A general layout of a possible two hundred seat vehicle (Fig. 6) shows a track section offering a number of ad-

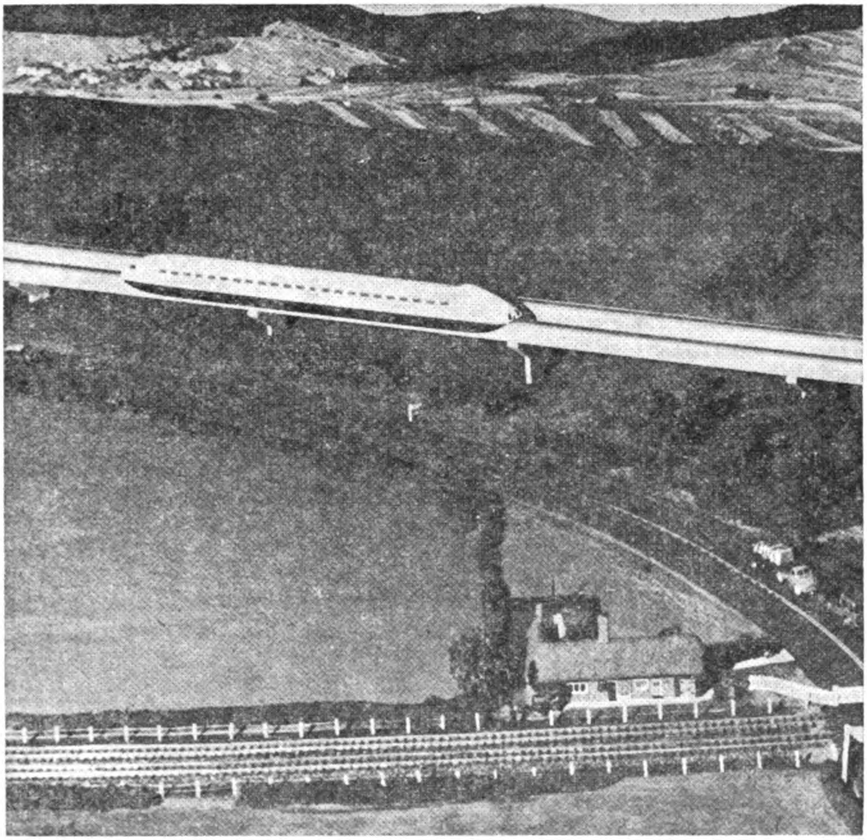


FIGURE 3

vantages. The revised track is T shaped in cross section with a relatively thick vertical member, offering a more economical use of concrete and some protection from the weather for the linear motor reaction rail and electrical conductors. Most important, there are no projections at all on the top surface to collect debris such as snow.

Speeds covering the complete range, from those at present in use to the highest speeds likely to be used in land transport, say, of the order of 500 m.p.h., are considered to be technically feasible with this system.

In the following section of the paper various technical aspects of the Tracked Hovercraft will be discussed as they affect, for example, the service, passenger comfort, or the over-all economics. As this is not intended as an engineering paper, no detailed discussion of the technical aspects of the vehicle will be made.

4. The Roles of Tracked Hovercraft

Two important roles for Tracked Hovercraft have already been indicated

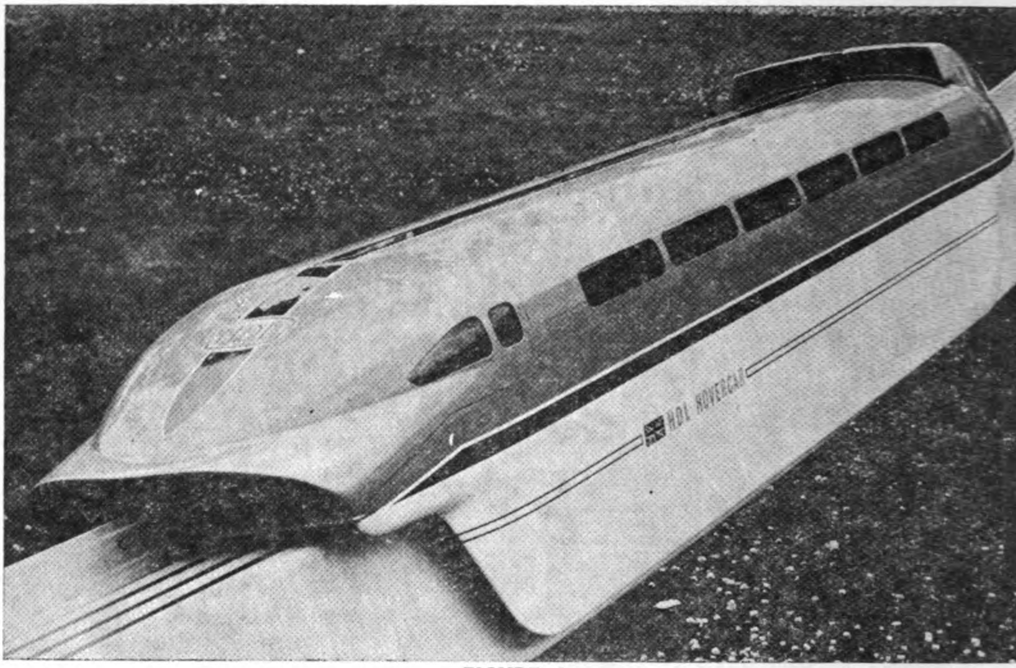


FIGURE 4

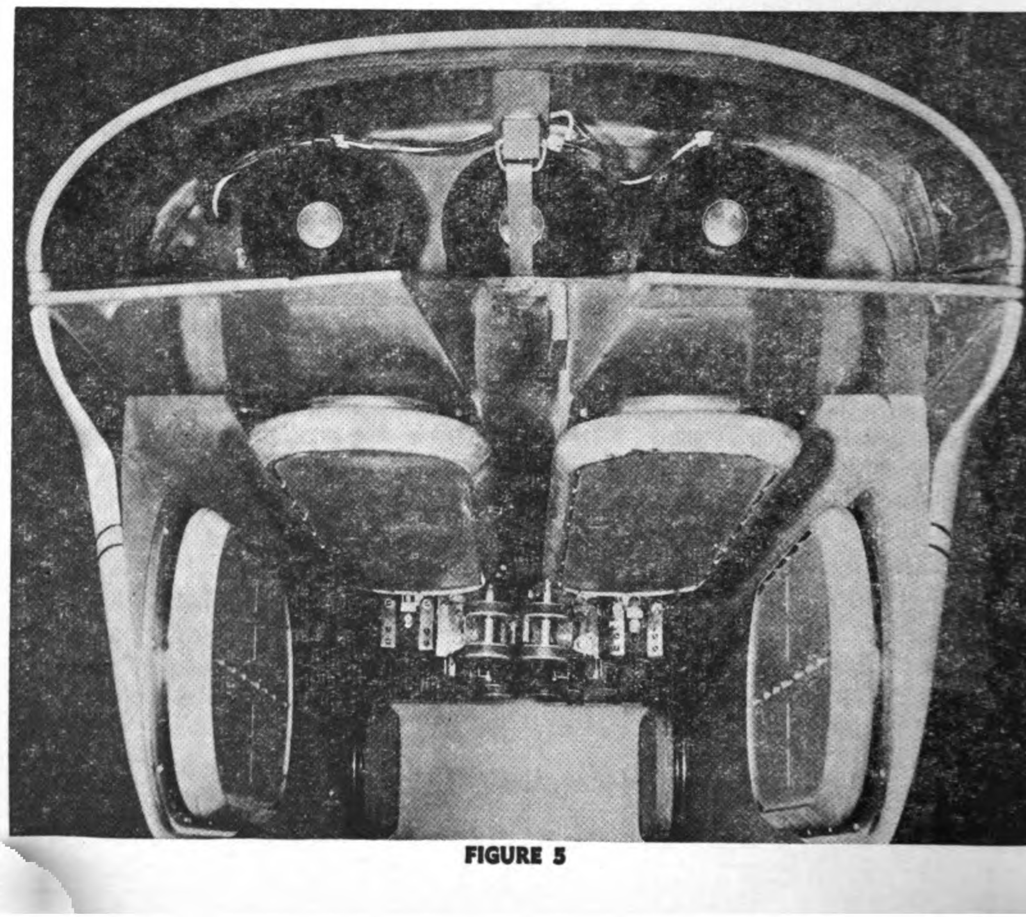


FIGURE 5

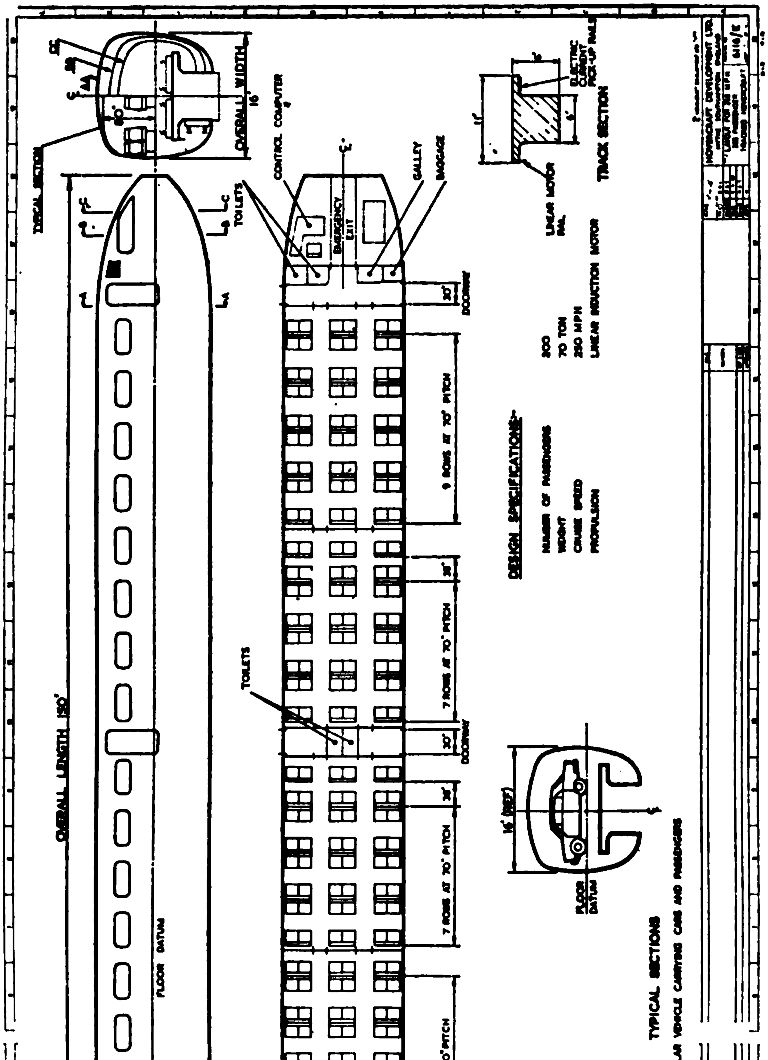

OVERALL LENGTH 150'
OVERALL WIDTH 16'
FLOOR DATUM
TYPICAL SECTION
CONTROL COMPUTER
TOILETS
GALLEY
BAGGAGE
EMERGENCY EXIT
DOORWAY
9 ROWS AT 70" PITCH
7 ROWS AT 70" PITCH
DESIGN SPECIFICATIONS:-
NUMBER OF PASSENGERS 300
WEIGHT 70 TON
CRUISE SPEED 250 MPH
PROPULSION LINEAR INDUCTION MOTOR
LINEAR MOTOR RAIL
ELECTRIC CURRENT PICK-UP RAILS
TRACK SECTION
TYPICAL SECTIONS
SHOWING SIMILAR VEHICLE CARRYING CARS AND PASSENGERS
HOVERCRAFT DEVELOPMENT LTD.

FIGURE 6

in a previous section of the paper. These are to provide a high speed long distance commuter service and a high speed inter-city or inter-regional service. The first of these roles is to extend the distance for commuting in an acceptable travelling time. To be fully effective the type of service offered to the commuter must be such that he will prefer to use it rather than his motor car. Also, of course, it must be closely integrated with feeder services at each centre. The objective in this application is to keep the car out of the city and to preserve areas of open countryside within a reasonable time to the city centre. The traffic distribution on the commuter service will show high peaks in the morning and evening and high passenger flow rates will be required at these times. This requirement is catered for by coupling Hovercars to make Hovertrains.

In its high speed inter-city and inter-regional role the objective is to allow a geographical dispersal of commercial activity without a loss of personal contact and communication between the separated elements. The services would be primarily for transporting passengers and mail and in some instances, motor vehicles. These latter might be relatively small city type cars to be used for travelling extensively in the destination region.

A significant part of the regular weekday traffic on these services will be executive business travel evenly spread throughout the day. Freight will also have to be conveyed, perhaps by special vehicles operating during the night.

Of these two applications, which have broadly the same final objective, the inter-city, inter-regional application is eventually likely to prove to be the most important. This is because it is, in effect, taking work to the people and results in less total travel being required. To a commercial transport operator this may sound a questionable proposition; but it must be accepted that travel in itself produces nothing and from a national standpoint the problem is to get people to work with the minimum of effort.

A third possible future use of high speed land transport is city centre to city airport links. As city limits expand and aircraft activity and noise increase, airports are likely to be located further from the centre of cities. If the city centre to airport journey is not to become an unreasonably long part of the total time of even international journeys by air, then direct, fast, city to airport links must be provided. These will also become increasingly necessary when the volume of air transport increases in order to prevent the airport traffic increasing road congestion in the city residential area. It is considered that for this application it is highly desirable that the vehicle should be able to travel up to the aircraft door, leaving the track if necessary.

The major roles of the Tracked Hovercraft system of high speed land transport are therefore summarized as:—

(i) To provide an increase in the distance which can be travelled in an acceptable commuting time, thus allowing residential areas to be separated from the city outskirts leaving areas of unspoilt countryside within easy reach of the city dwellers, and channeling traffic into defined and controlled lanes off the roads in the city residential area.

(ii) To provide direct services between the centres of cities or areas of regional development. Allowing business expansion to take place in geographically separated areas without a deterioration in access and communication.

(iii) To provide city centre to airport links over the increased distances made desirable by growth in air transport.

For completeness, it should be stated that it is considered that the Tracked Hovercraft will also find application in urban transport. This, however, falls into the category of rapid transit rather than high speed land transport and is not considered in this paper.

5. Speed Required

The speed required on a new system is defined by the acceptable journey time and the distance to be covered. Human tolerance of journey time in any one transport system is influenced to some extent by achievements in others. Within the next decade we are likely to see services across the North Atlantic by supersonic airliners connecting Europe to New York in about 3 hours of flying time. Acceptable journey times on land must be considered with this in mind, however unconnected it may seem technically.

Commuter travel times have steadily increased over the past years and times between home and office of well over an hour are now common in Britain. This is an unreasonable demand upon the working day. Commuting distances are likely to increase to well over 100 miles, perhaps to as much as 125-150 miles, in the time scale under consideration. This distance should then be covered in under 45 minutes.

In the case of inter-city transport the tolerable traveling time is dictated by the business executive who wishes to call in at his office in the morning, attend a meeting at the other centre and return to his own office in the working day. A working day of 8 hours with one hour in the office at each end of the day and 3 to 4 hours in the other centre, leaves 2 to 3 hours for travelling. On this basis, the journey time should not exceed 1 to 1-1/2 hours. In exceptional cases this could probably be extended to 2 hours for journeys of several hundreds of miles. To achieve the objectives of decentralisation, it may be necessary to travel 200 miles or more in these times.

From these arguments we have two desirable travel bands. First of 1/2 to 3/4 hours associated with distances of 50 to 125 miles for commuter travel and the second of 1 to 1-1/2 hours with a maximum of 2 hours to cover inter-city, inter-regional travel of over 200 miles distance. The performance requirements of the transport system defined, are shown in Fig. 7, which also shows the performance available with current overland transport systems. It is immediately apparent that scheduled domestic air services are completely outside the required performance zones. The best modern railway standard (New Tokaido Line) only meets the requirements over very short distances.

The performance of the conventional airline service operating from airports outside the city limits, with much improved ground connections is shown in Fig. 8 and compared with the desired performance standard. In

TRAVELLING TIMES
A. COMPARISON OF SOCIALLY DESIRABLE LIMITS AND CURRENTLY AVAILABLE STANDARDS

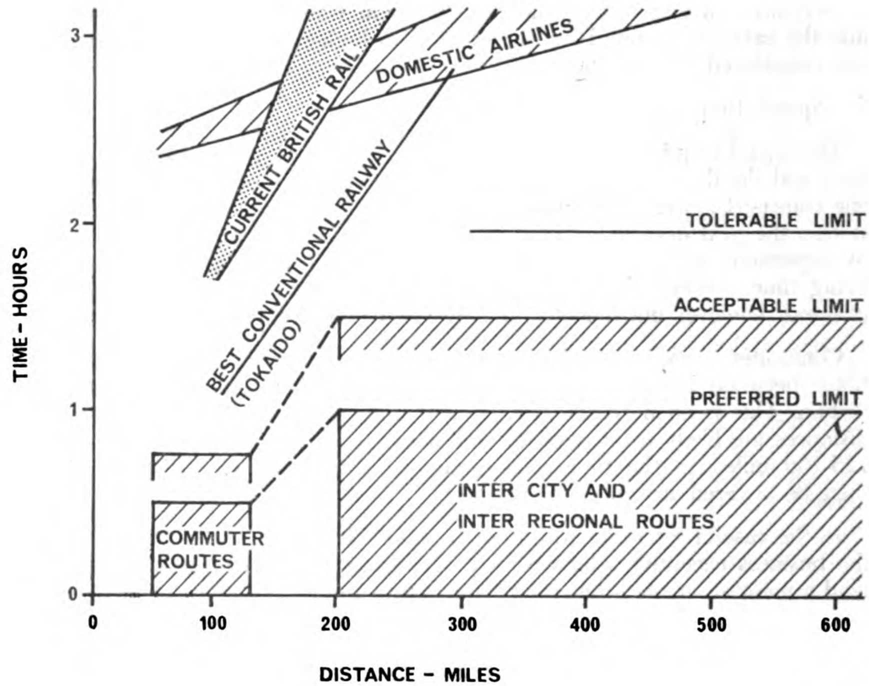


FIG. 7

general, this is still outside the required performance zone and it appears that only direct centre to centre transport services are likely to meet the defined performance standards.

From Fig. 8 a requirement of vehicle speeds can be formulated. This is indicated in Fig. 9 for commuter and inter-city services. (The requirements for airport links are likely to be similar to those of commuter services). Other considerations of practicability, economics, etc., may preclude the achievement of the highest of standards shown in this figure. However, it is suggested that this is the order of the performance standard which the travelling public will look for in land transport long before the end of this century.

6. Type of Transport Service

It has been shown in Fig. 9 that speeds of the order of 150-200 m.p.h. will

TRAVELLING TIMES
B. SOCIALLY DESIRABLE LIMITS AND POTENTIALLY AVAILABLE STANDARDS FROM:
(a.)——direct centre to centre services
(b.)- - -improved air services (see below ✱)

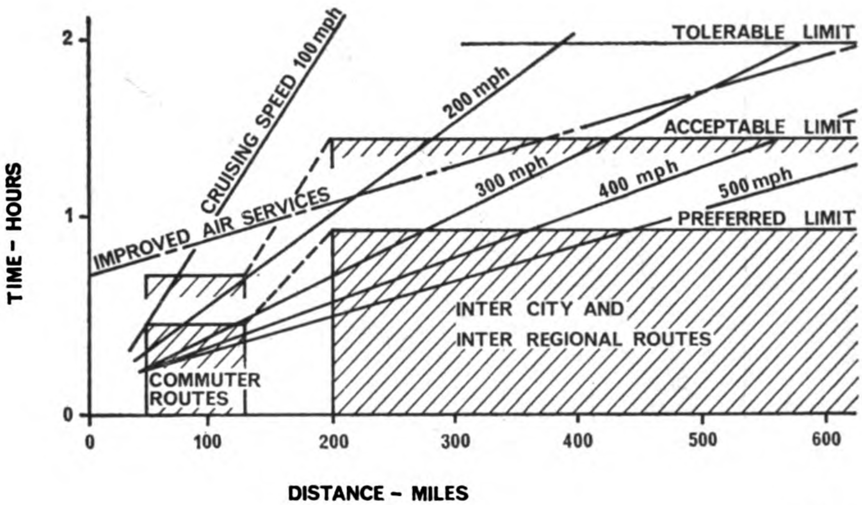


FIG. 8

* IMPROVED AIR SERVICE:- assumes that 500 m.p.h. cruise speed aircraft are used on all routes with the following ground services.

Assume city centre to airport perimeter = 12½ miles, with a 70 m.p.h. average speed connection service.

Therefore time taken city centre to airport perimeter	=	11 mins.
Airport perimeter to aircraft = 1 mile at 20 m.p.h.	=	3 mins.
Embarkation including baggage loading	=	2½ mins.
Taxying, take off and course setting	=	6 mins.
Total	=	22½ mins.

Assuming same allowances for landing and travel to city centre then

Total Journey Time = 45 mins. + Cruise Time.

be required for the long distance commuter routes and of up to at least 300 m.p.h. for the inter-city routes.

CRUISING SPEED REQUIRED TO ACHIEVE SOCIALLY DESIRABLE LIMITS OF JOURNEY TIME WITH H.S.L.T.

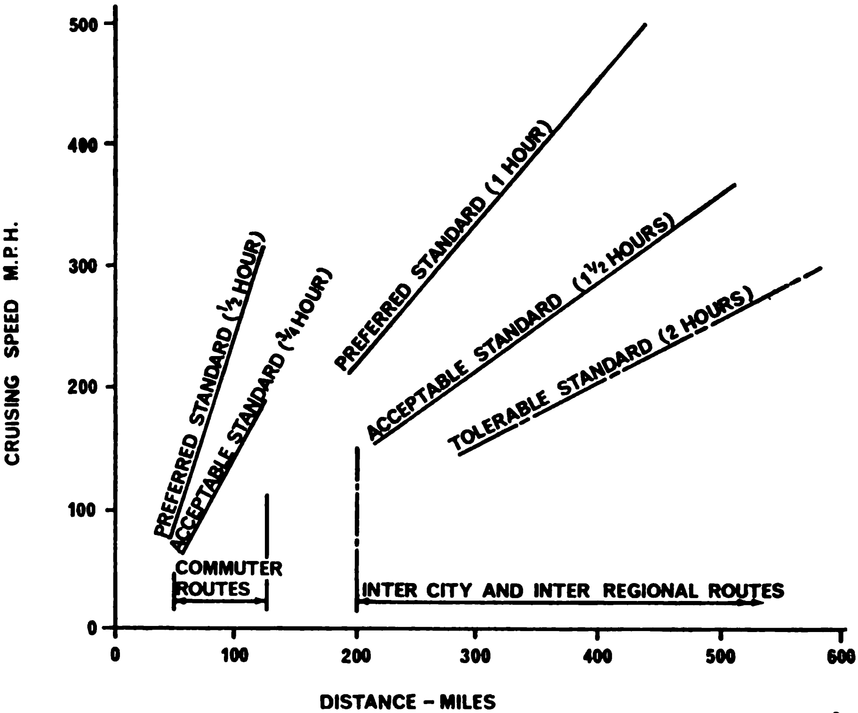


FIG. 9

The commuter services would obviously run from origin to destination without intermediate stops. The frequency would vary with demand.

In the case of the inter-city and inter-regional routes, a service without intermediate stops is also visualized. In addition to high speed, it is considered that a high frequency service is also required throughout the day if communication between the centres is to be maintained at the standard required. The frequency of departure will probably be related to the distance to be travelled with higher frequencies over the shorter routes. However, even for the longest distances contemplated no intending passenger should be expected to wait for more than 15 minutes at most during normal working hours if the service is to be attractive.

As a result of the high frequency of service and the relatively even distribution of traffic demand it is visualised that these services will be run by single unit vehicles — Hovercars.

From this brief discussion of transport principles it is clear that this is more than an improvement of the existing type of general service offered today. It is a new concept of transport service to supplement existing services for specific applications as described above. If the maximum advantages, which the new type of service can offer to the community are to be realised the system and the method of its operation should be planned without prejudice from what has been done before. Many established practices will need to be critically examined and retained or rejected on their merit, rather than because they exist.

One current practice which is clearly unacceptable for maximum efficiency and traffic capacity is that of operating vehicles at mixed speeds. This can introduce considerable traffic control complications on conventional railways, especially when occasional high speed trains are added to the system. It is considered that at any one time the new transport system must be a one speed system but there is no reason why the speed should not change during part of the 24-hour day.

This is important for the carriage of freight where high speeds are not likely to be justified, and which need not normally be transported at the same time as the high speed passenger services are running. Long duration passenger journeys will not occur by design; the demand for travel in the period between, say, midnight and 6 a.m. is not likely to be large. This period could be used to dispatch the lower speed freight vehicles.

Other established practices which might need re-examination are the use of points, or switching, and standardisation of track and vehicles between routes.

The technical difficulties and expense of constructing switches for use at high speed are formidable, if only due to the track length required for transfer from one track to another. It is far more likely that turntables and lateral transfer techniques at terminals with stationary vehicles will be found preferable for single unit vehicles.

The need for standardisation between routes should be closely examined, a most important factor being that of track gauge. Clearly if one route is ever likely to be connected with another in the future a standard gauge is essential. As it is possible that main routes in Britain may eventually be connected to European routes, standardisation is important in this case. On the other hand, the possibility of the North East Corridor joining the Californian Corridor would seem remote. In these cases it might be better if each were considered separately and the system tailored to individual requirements.

In the opinion of the writer, absolute standardisation of gauge is neither necessary nor desirable. Rather, a range of standards will be required to cover the whole speed range envisaged for all applications. It is most important that the several standardisation requirements in H.S.L.T. are studied and established at an early stage in its development.

7. Some Requirements of H.S.L.T. System

Some of the more important requirements of a high speed land transport system can be summarised as:—

1. Safety
2. Reliability
3. Passenger Appeal and Comfort
4. Social acceptability
5. Viability

These are discussed below in relation to the Tracked Hovercraft System and the way in which it meets these requirements.

7.1 Safety

Of all the requirements of transport, safety must rank as the most important. At the high speeds contemplated, what might be otherwise an incident or minor accident is likely to be a disaster. In particular, there must be no possibility of collision between vehicles. Equally, there must be no possibility of the vehicle leaving the track at speed.

The prevention of collision between vehicles calls for a reliable control system. At the high speeds required, no system which depends upon a human link interpreting and acting on a visual signal displayed at the track side or in the vehicle is likely to provide the required degree of safety. Only a fully automatic computer controlled system is likely to prove satisfactory for the fully developed system. This might operate on the basic principle that the vehicle slows or stops unless it receives signals to proceed from each of a number of channels covering every conceivable hazard (for example, vehicles too close; obstruction on track; track structural failure etc.) Such a system can be literally fail safe. Control systems using high frequency signals transmitted along track mounted wave guides, and which are capable of providing many separate channels of information, may be found suitable for vehicle location and communication when developed.

A high degree of track security and freedom from trespass is clearly necessary for safety. If tracks are laid at ground level a security fence will be required of a higher standard than is found on conventional railway wayleaves. The hazards to vehicle safety of bridges over a ground level track are considerable unless special precautions are taken and level crossings over a high speed high frequency route cannot be seriously considered in populated areas. From a social amenities viewpoint, a high security ground level track presents a formidable barrier dividing the countryside through which it passes. All things considered a ground level track does not seem to be desirable for high speed land transport.

A greater degree of security would result from placing the track on an embankment, the only bridges being underneath. Even so, a secure fence would have to be provided to prevent trespass, and the division of countryside remains.

Complete security, or as near complete security as is possible, could be provided by operating in a continuous tunnel. This introduces its own problems of freedom of legitimate access, (for example in the case of an emergency) as well as the cost of providing a tunnel of sufficiently large diameter for high speed operation.

The fourth possibility of a pylon supported elevated structure is the one currently favoured for the Tracked Hovercraft. This affords a considerable degree of security and allows access underneath without disrupting existing roads and other amenities. It also allows high voltage electrification to be carried at track level without the need for overhead catenaries. The cost of such an elevated structure, while greater than a ground level track, is likely to be considerably less than the corresponding continuous tunnel. The use of tunnels for Tracked Hovercraft is not precluded where necessary, for instance in the North East Corridor Project. Tunnels may also be required for access into built up areas and here the requirements for size may not be so severe as the vehicle is not so likely to be operating at its maximum speed.

Prevention of the vehicle leaving the track is, of course, essential. High speed vehicles must not only be safe in this respect but must be seen to be safe for the passengers' peace of mind. The Tracked Hovercraft cannot become de-railed in the normal sense as no conventional rails are employed. Furthermore, the proposed track section is such that special air cushions, sliding pads or rollers can act on a lower surface in an emergency to positively prevent vertical movement of the vehicle relative to the track greater than provided for in the suspension system design. The most likely causes of a hazard of this type are considered to be aerodynamic forces, especially those resulting from gusting winds. Vehicle movement sufficient to damage the suspension system might be set up unless some form of prevention device was employed. Whether or not such features are actually required will be determined during the experimental programme, which must precede the introduction of these vehicles, or any other H.S.L.T. vehicle, into service.

With an air cushion vehicle intended for operation at high speed, the consequences of failure of the air supply must be seriously considered. Again, this must be proved during the experimental programme.

An air cushion itself takes a finite time to decay. An elegant method of prolonging cushion decay may be possible by switching the linear motor so that it acts as a generator to drive the air cushion fans. In this case, the linear motor cum generator would also provide a braking force. In addition to devices to delay cushion decay, the design would include duplication of components to reduce the possibility of complete loss of cushion.

Emergency braking will be provided at high speed by aerodynamic means, such as air brakes on the body of the vehicle, which could be supplemented by braking parachutes. These will enable the speed to be reduced to a figure at which it is convenient to allow contact between vehicle and track on pads of a suitable braking material. Normal braking would be by means of the linear motor.

As sledge-type vehicles have operated on tracks up to speeds higher than those required of the Tracked Hovercraft system, there seems to be no reason why air cushion failure, if properly catered for, need present a safety hazard. Emergency stops made necessary by any cause could also be carried out using the same means.

7.2 Reliability

In a highly organised community, reliability of transport is of the utmost importance as a factor in economics and for the convenience of the travelling public. It has long been established that one of the best ways of achieving reliability is by employing the simplest means capable of achieving the desired end.

It is considered that the air cushion suspension and linear motor combination represents a significant step towards overall simplification of a high speed transport system. The elimination of contact between vehicle and track not only reduces wear and the maintenance required, but also removes a significant factor contributing to the deterioration of performance in service. It also results in a system less susceptible to track surface conditions in bad weather. Again, fundamentally, there are few mechanical moving parts in the system and air cushion Hoverpads do not suffer from size and load carrying limitations, in fact, efficiency increases with increased size.

7.3 Passenger Appeal and Comfort

If a passenger transport system is to succeed, clearly it must possess a considerable positive passenger appeal. A comfortable ride is an important factor contributing to passenger appeal. Considerable study has been made by numerous authorities of the limiting vertical acceleration which is acceptable for passenger comfort. Curves of limiting acceleration and frequency of encounter such as Fig. 10 (taken from M.I.T. Report PB 168

PASSENGER COMFORT LIMITS
VERTICAL MOVEMENT

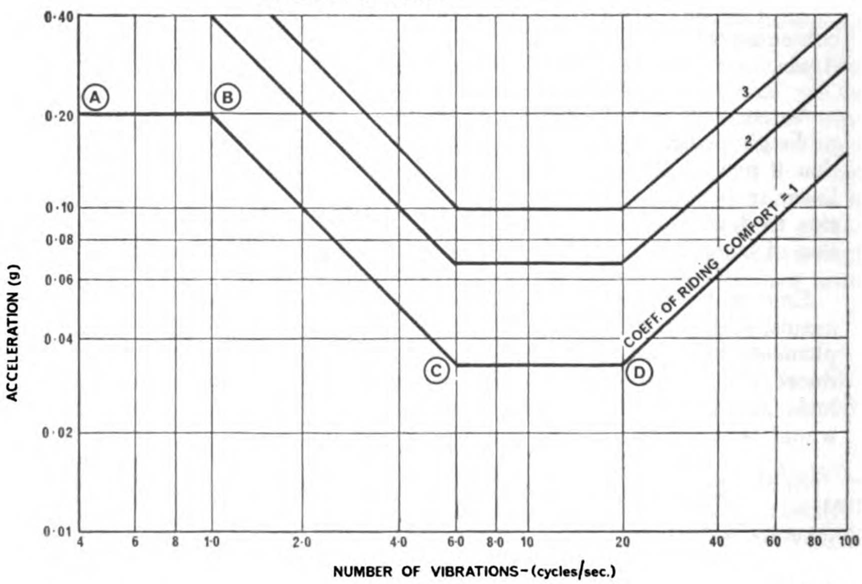


FIG. 10

6481), summarise the findings of this work. While further investigation is considered necessary in this field, the standards shown in this figure, are generally accepted as reasonable. This, and an associated standard of acceptable acceleration, are the most important design criteria in high speed surface transport — safety excepted. Together they define the path that the body of the vehicle must follow if the quality of the ride is to be acceptable.

The permissible deviation from a straight path in the vertical sense, of a vehicle travelling at 300 m.p.h. for the required standard of passenger comfort to be achieved, is shown in Fig. 11. It is seen that the permissible deviations are small especially where they occur over a short horizontal distance. The maintenance of a track surface to this standard would be expensive.

In the Tracked Hovercraft, in common with all other vehicles, the irregularities in the track surface of a few inches are absorbed by a suspension system which acts as a filter and reduces the movement of the vehicle body. The type of air cushion suspension to be used on the Tracked Hovercraft is a two stage suspension similar to that shown in Fig. 12. The permissible track surface irregularities which it can absorb and provide the required degree of passenger comfort is shown in Fig. 11, as a track surface profile requirement. This is based on measured results obtained from the prototype Hoverpad (Fig. 12), tested over a vibrating table. "Active" versions of this suspension system can be developed to increase the allowable track irregularities of low frequency, in the region of B in Fig. 11. The dotted lines in the lower left hand corner show the peak accelerations which are encountered by following the irregularities defined. It is seen that extremely high accelerations can be produced by a very small waviness in track surface at 300 m.p.h. In the Tracked Hovercraft these irregularities are absorbed by the thickness of the air cushion.

All track irregularities greater than the capacity of the suspension system must be within the passenger comfort zone shown in Fig. 11. The limit of the passenger comfort zone thereby defines the maximum waviness in the track and the alignment must be within these limits.

The distance required to negotiate changes of track level without causing passenger discomfort is shown in Fig. 13. Obviously, when these limits do not contain the local variations in ground level, cuttings, embankments, or high pylons must be resorted to.

For similar reasons, the horizontal curvature of the track is limited at high speed to a relatively large minimum radius. Banking the track allows the permissible radius to be reduced considerably as shown in Fig. 14.

The amount of bank angle, or super-elevation, which can reasonably be used in practice is probably limited. It is considered that an angle of super-elevation of about 10° may be a reasonable maximum value and that a steady lateral acceleration of 0.05g is comfortable. These values limit the lateral curvature as shown in Fig 14.

It clearly becomes increasingly hard to avoid difficult terrain as speed increases and, once encountered it is more expensive to overcome by cut-

SPECIFICATION OF TRACK SURFACE PROFILE FOR A 300 M.P.H. VEHICLE

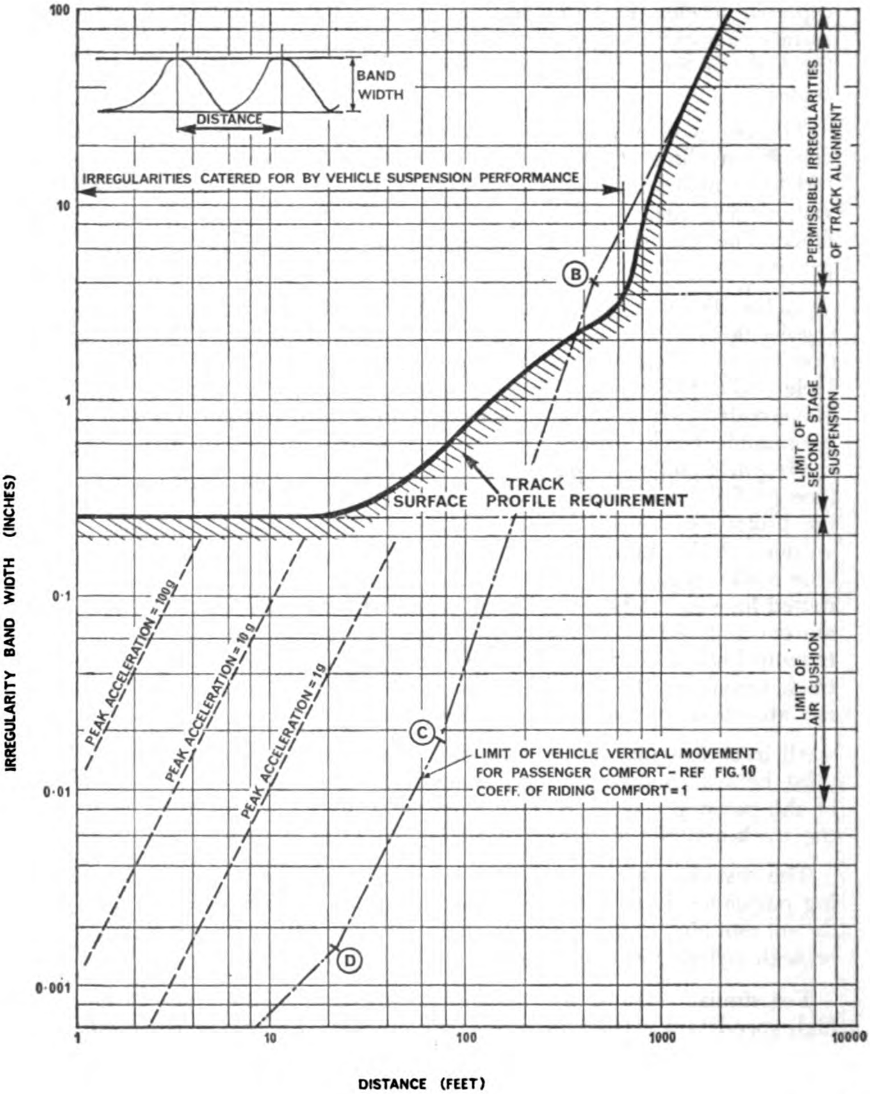


FIG. 11

tings or high pylons. These factors, which must be taken into account when planning routes, are most important in deciding the right applications and speed for H.S.L.T.

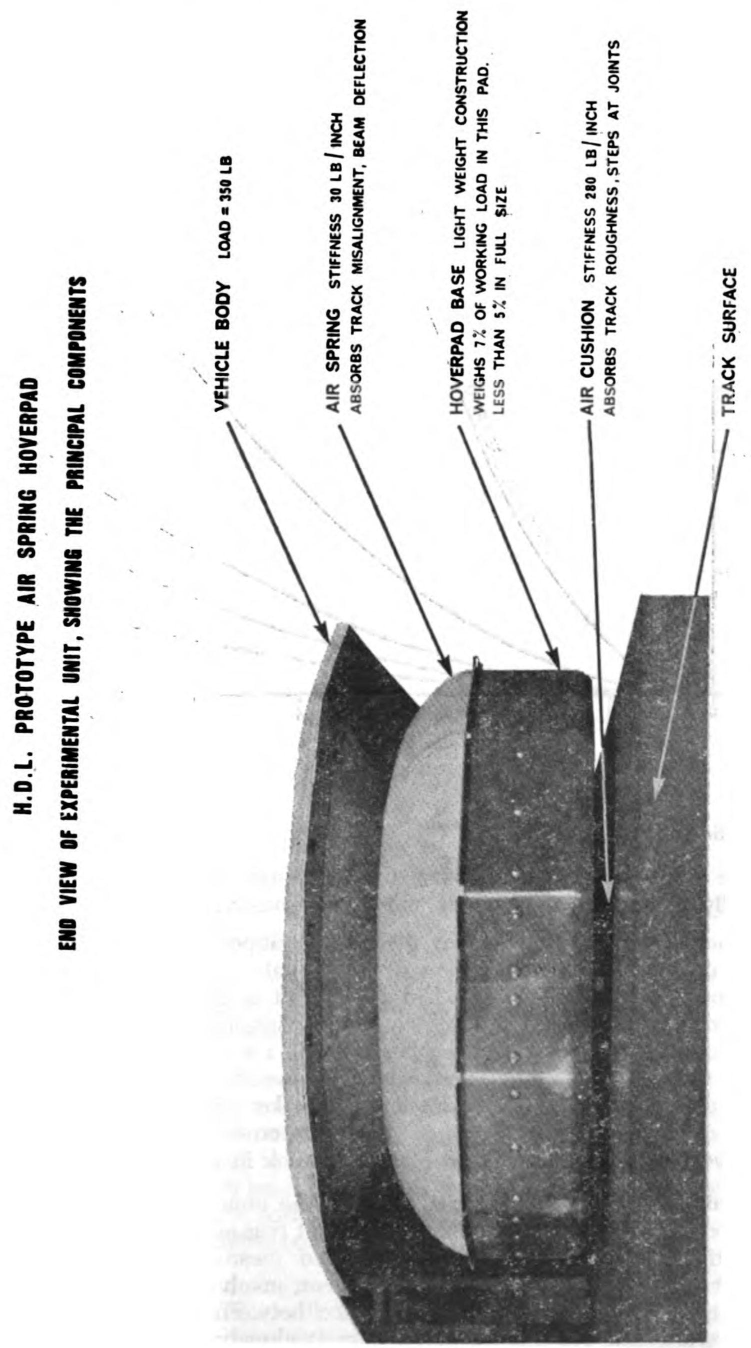

H.D.L. PROTOTYPE AIR SPRING HOVERPAD
END VIEW OF EXPERIMENTAL UNIT, SHOWING THE PRINCIPAL COMPONENTS
VEHICLE BODY LOAD = 350 LB
AIR SPRING STIFFNESS 30 LB/INCH
ABSORBS TRACK MISALIGNMENT, BEAM DEFLECTION
HOVERPAD BASE LIGHT WEIGHT CONSTRUCTION
WEIGHS 7% OF WORKING LOAD IN THIS PAD.
LESS THAN 5% IN FULL SIZE
AIR CUSHION STIFFNESS 280 LB/INCH
ABSORBS TRACK ROUGHNESS, STEPS AT JOINTS
TRACK SURFACE

FIGURE 12

DISTANCE REQUIRED TO OVERCOME GEOGRAPHICAL OBSTACLES
(Passenger comfort criteria = ·1g max. vertical acc^n)

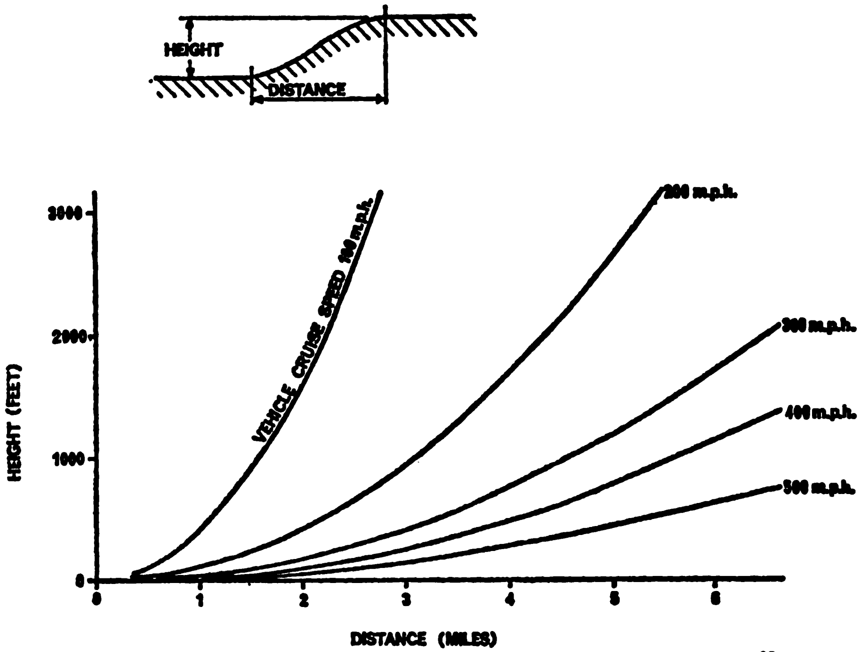


FIG. 13

7.4 Social Acceptibility

The transport system of a heavily populated country must not intrude visually or aurally to be acceptable to its society.

Whether or not an object is pleasing in appearance depends in many cases on the subjective reactions of individuals. An impression of the appearance of the elevated Tracked Hovercraft is given by Fig. 3. This is seen to be very like any other system employing an elevated track with the vehicle above the track, i.e. the beam riding monorail or elevated conventional railways. Very little can be done to alter its basic appearance but in areas of scenic beauty one can sometimes take measures to prevent spoiling the view. For example, where the route crosses a prominent skyline it may be thought worthwhile to place the track in a cutting.

Minimising noise is considered to be of the utmost importance in surface transport. This is one of the more important reasons why the electric linear induction motor is currently the favoured means of propulsion for the Tracked Hovercraft, it being virtually silent, involving no moving mechanical parts. This is a significant difference between the proposed Tracked Hovercraft, and other types of Hovercraft already produced. These latter are usually propelled by an airscrew originally designed for aircraft and

EFFECT OF SUPERELEVATION ON PERMISSIBLE
MINIMUM RADIUS OF CURVATURE

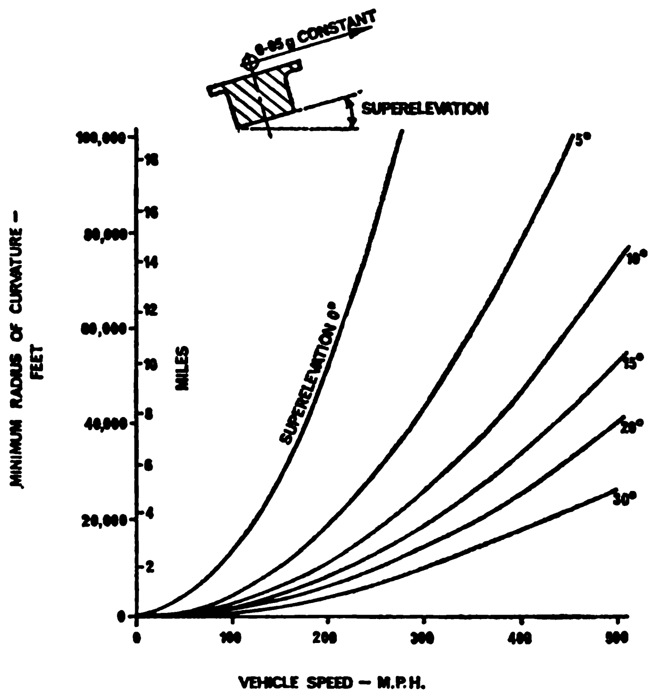


FIG. 14

using relatively high blade tip speeds. High propeller tip speed is usually the origin of the noise associated with current Hovercraft.

The other main sources of noise in the developed Tracked Hovercraft will be the motors, fans and airjets which form and contain the air cushions, and aerodynamic noise due to the passage of the vehicle.

The peripheral air jets used on the hovercraft are thin, 1/4" to 3/8" and they diffuse within a very short distance of the pad. Jet noise is primarily a function of jet velocity and temperature and these are comparatively low on Hovercraft. A further factor is that a large proportion of the total length of the peripheral jets are contained in the vehicle profile. This will reduce the external noise from this source. Similarly the fan and fan motor noise is also vehicle contained to some extent.

Aerodynamic noise, and general atmospheric disturbance, will, of course, increase with speed. This will be minimised by streamlining the vehicle body and reducing the gaps between it and the track — a necessity to keep the drag as low as possible.

While the noise levels involved can only be established by direct experiment, there is little reason for thinking that they need be higher than those of a conventional train traveling at the same speed, they could, in fact, be less.

7.5 Viability

The true measure for assessing the viability of transport is difficult to define, as it includes more than commercial profit. This is important today as many major transport undertakings show considerable financial loss yet continue to exist, so clearly other factors are also involved.

In the earlier parts of this paper, considerable stress was laid on communication as an essential part of economical development. The true test of viability might therefore involve the complete assessment of the state of a nation's wealth with and without the proposed transport system. Only if the contribution of the new transport system results in an overall improvement is it a viable part of the country's economy. In this wider issue, its own individual financial performance is of less importance. At the present, one can do no better than make the best possible assessment of the costs of the system, and perhaps, make rather qualitative comparisons with other ways of doing the same job.

In the case of the Tracked Hovercraft, as with any other tracked system, a considerable part of the total capital and running costs are associated with the track. This is shown in Fig. 15 which illustrates the effect of track cost and traffic flow on total operating costs and includes direct and indirect operating costs of a vehicle such as that in Fig. 6. To a first order these latter are unaffected by the traffic volume. Traffic flow, however, obviously has a direct effect on the cost associated with the track to be apportioned to each passenger. Fig. 15 is an attempt to combine these factors.

8. Competitive Transport System

From Fig. 8 it was clear that only V.T.O.L. aircraft and H.S.L.T. could provide the standard of transport performance required. The question therefore arises where do each of these methods fit into the transport spectrum?

Operationally, there is a fundamental advantage of travelling on the ground instead of in the air. In the event of emergencies the ground system can stop whereas the aircraft cannot. Again, the space requirements in the city centre for a ground transport system will certainly be less than even a V.T.O.L. airport, and the control system simpler.

Noise is almost certainly to be a major problem with V.T.O.L. aircraft when operated from a city centre at the frequency and scale visualised for the H.S.L.T. system. Both noise intensity and area affected will be much greater. A fundamental difference between a V.T.O.L. aircraft and a Tracked Hovercraft is that the aircraft must produce a jet thrust equal to its weight but the jet thrust in the Hovercraft is only a small percentage of the total weight.

Factors which favour the V.T.O.L. aricraft are that it does not require a fixed track and that higher vehicle speeds may be possible. This suggests that long distances, undulating country and relatively low traffic favours the V.T.O.L. aircraft and they may well find applications in these circumstances.

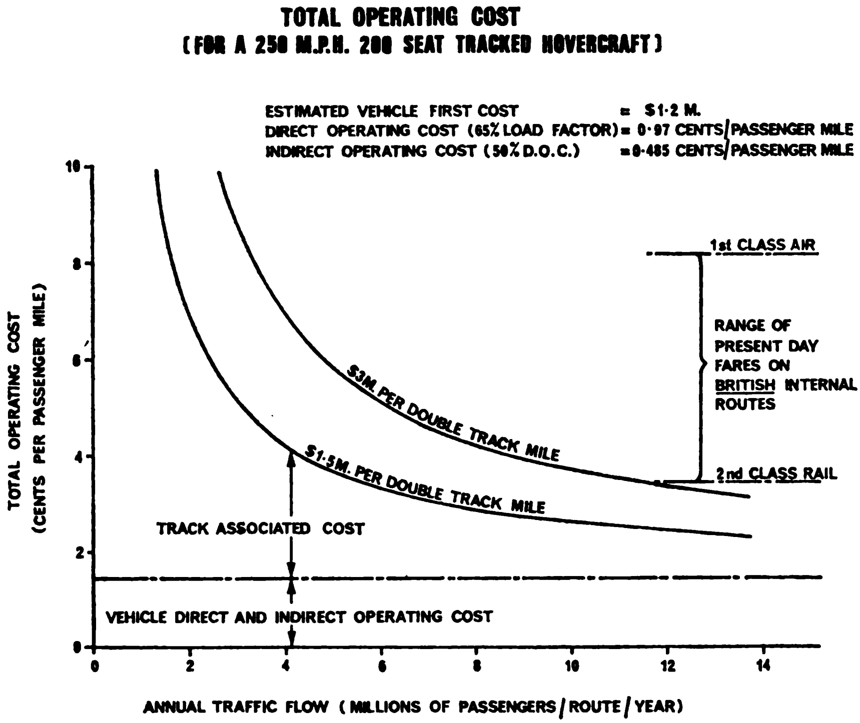


FIG. 15

It is difficult to generalise but it is thought that in reasonably favourable circumstances, distances up to about 500 miles may be best served by H.S.L.T.

9. Other Forms of H.S.L.T.

Besides air cushions, several other novel methods of suspension for H.S.L.T. are currently under investigation including electro-magnetic and permanent magnet suspension. If any of these, including air cushions, are to win favour they must show to advantage when compared with possible extensions of current practice of steel wheels running on steel rails.

A much better understanding of the hunting phenomena of coned steel wheels running on rails has recently been established, which allows much higher speeds to be considered than previously. However, it is the opinion of the writer that at the very high speeds under consideration, a more positive guidance of the vehicle than that given by a coned and flanged wheel alone is required for safety. Definite measures to prevent the vehicle leaving the track must be taken for the passengers' peace of mind. Also, it has been suggested by some authorities that traction force could be limited by wheel adhesion such that vehicle speeds might be limited. For these reasons it is considered that the conventional wheel-rail system as we know it today, may not be a suitable basis for the faster range of H.S.L.T.

The shortcomings of the conventional system can be overcome by providing a new configuration, for example, separate guidance wheels acting in the horizontal plane with a linear motor for traction. It follows that regardless of whether wheels or air cushions are used for support, a completely new transport system is required. The difference between the two approaches will be found in the degree of difficulty encountered in development, and the effect on costs of the different features of the system. Whichever system is used, a number of significant factors will be unaffected by the choice of means of support, for example the need for new wayleaves.

The main differences likely to be found between the air cushion and wheel systems can be summarised as:—

a) The need for steel rails.

b) The need for extreme accuracy in alignment of the steel rails requiring maintenance in service.

c) The greater unsprung weight of the wheel bogie.

d) The possibility of unacceptable noise and vibration from a steel wheel at high speed on a steel track.

e) A difference in the power requirement—probably favouring the wheel in some cases.

f) The possibility of more development potential in the case of the air cushion.

Some of these differences can materially affect the economics of the system. Steel rails are an extra item above basic track cost and a resilient layer may be required between rail and beam to minimise noise and vibration. A higher order of accuracy of alignment of steel rails will be necessary than that required of the concrete track used with air cushions. In the case of the wheel, track irregularities must be dealt with entirely by the mechanical suspension system, whereas the air cushion (which forms a first stage suspension system) alleviates the severity of this suspension problem (see Fig. 11). The effect of all track irregularities will be felt by the wheel itself and the loads imposed will cause wear and maintenance problem in both wheel and track.

The cost of maintaining rails to the accuracy necessary for the high speeds contemplated is speculative but it is understood that track maintenance has increased considerably on some railways when high speed trains were introduced. The life of steel rails, under the likely operating conditions, is also unknown, and replacement of a continuously bonded rail and resilient mounting on an elevated track, is not likely to be easy. On the other hand, as a result of the relatively low bearing pressures employed by the air cushion, the use of soft surface layers on the track which may be trimmed or filled to allow for settlement of the main structure is a possibility.

Air cushions provide a first stage suspension system which allows a coarser grade of track to be used since it is not in direct contact with the vehicle. To obtain these considerable advantages power must be expended to compress the air which forms the curtains to seal the cushion. The power required for air cushion suspension is shown in Fig. 16 for two sizes and air clearances of Hoverpad. This includes lift for power and propulsion power to overcome

POWER REQUIREMENT

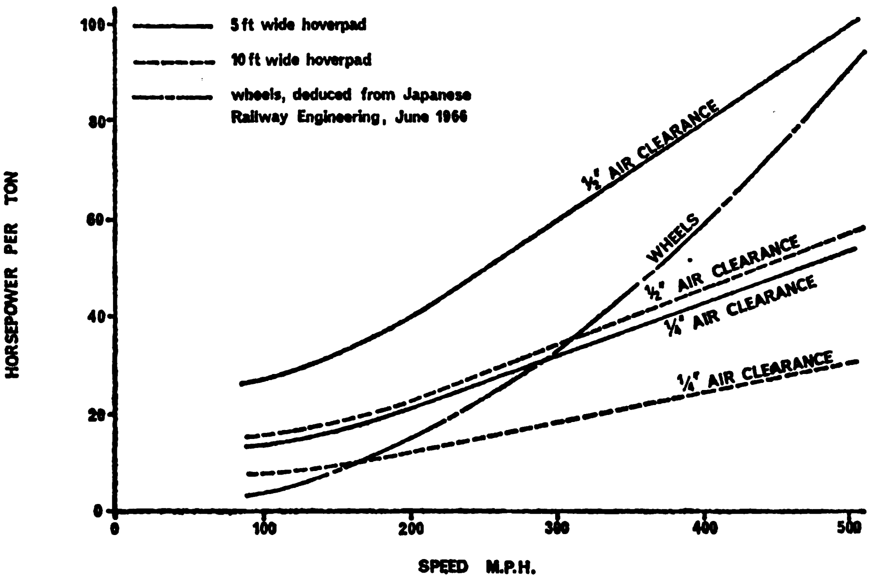


FIG.16

momentum drag. Data to hand on the power required by a steel wheel are generally limited. Until tests are carried out using wheels at representative speeds, the available data can only be extrapolated using laws found applicable at low speed. Power required to overcome wheel resistance so obtained is shown in Fig. 16 using comparable assumption of propulsive efficiency. It can be seen that while the wheel requires less power than air cushion at the lower speeds, this is not the case over the whole speed range.

There is nothing to suggest that using air cushions will cause any fundamental problems which would have been avoided by using wheels. But there is evidence that the development of Tracked Hovercraft could be easier and cheaper than for the equivalent wheeled vehicle. It is therefore considered that the Tracked Hovercraft will prove to be the most economic method of providing H.S.L.T. services.

10. Conclusions

In this paper the importance of H.S.L.T. to the future communication required for continued economic development has been shown, the requirements of performance, safety and reliability are examined and it is concluded that Tracked Hovercraft offer a good solution. It is then shown that Tracked Hovercraft are viable and that their development is likely to be easier than the comparable wheeled vehicle. Hence the Tracked Hovercraft is proposed as the method of H.S.L.T. best suited for these future transport needs.

Acknowledgements

The author wishes to thank the N.P.L. Hovercraft Unit managed by Hovercraft Development Ltd. for permission to publish this paper and members of the staff for their assistance in its preparation.