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The American Turboliner
A Progress Report

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ABSTRACT

ASME Paper 75-GT-108, "The American Turboliner", described the first gas turbine-hydraulic passenger trains manufactured in the U.S.A and subsequently placed in service by AMTRAK. The paper also developed design criteria for future improvements. This paper reviews the performance of these trains in their twelve years of service and describes the improvements in railway gas turbines which have been accomplished during this time. The potential for additional improvements is also developed and the significance of these improvements in the development of longer, higher speed trains for potential applications in the U.S.A. is explored to complete the progress report.

1.0 INTRODUCTION

A little more than 14 years ago an ASME Paper (Pier and Foster, 1975) was presented at the Gas Turbine Conference in Houston, Texas describing the Americanization of the very successful French RTG Gas Turbine train. The paper also discussed the potential applications for the technology in North America. At that time the shock of the energy crisis was just being felt and there was a strong impetus to move towards more energy efficient modes of transport. Studies by Wickens(1971) had shown that the following elements or goals play a major role in convincing the traveler to use the train:

- Availability
- Frequency
- Convenience
- Cost to User
- Comfort/Environment
- Speed/Trip Time
- All Weather Capability
- Congestion Relief

The turbine powered train offered a response to these goals which could be implemented on existing rail without the high cost of electrification. Because of its low axle loading, 19 tons(17.3T) as opposed to 24.8 tons(22.5T) for a typical electric locomotive and 32.8 tons(29.8T) for a diesel electric locomotive, the turbine train could travel at high speeds with safety and with minimum rail impact(Fig 1).

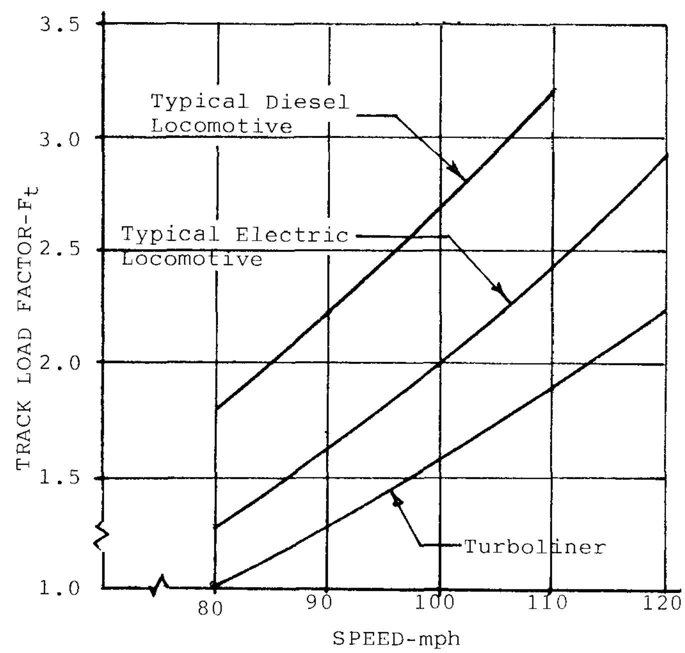

Figure 1 **TRACK LOAD FACTOR(F_t) COMPARISON**

Where:
$F_t=[F_d][F_1]$
F_d=Dynamic Load Factor=V_1^2/V_o^2
V_o=80 mph
V_1=Increased Speed
F_1=Axle Load Factor=$\frac{\text{Axle Load-Other}}{\text{Axle Load-Turbo}}$

In 1973, AMTRAK bought seven of these trains designated TURBOLINERS and built by ROHR Industries of Chula Vista, California under license from the French builder, ANF Industrie. The TURBOLINERS were placed in service in the last half of 1976 in the New York City-Buffalo Corridor and have remained in

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that corridor in the ensuing years, enjoying a high degree of passenger acceptance while developing an enviable record for reliability. While the track in this corridor does not generally qualify as high speed, the trains attain speeds of 110 mph(177 km/hr) and offer a trip time of 2:08 from Albany to New York City. Passenger growth rate for the 142 mile (228 km) trip between Albany and New York City has been almost five times the AMTRAK average, proving again that competitive trip times do generate traffic. (McCarthy,1988)

While the primary purpose of this paper is to provide a review of the TURBOLINER Trains' performance with particular attention to the turbine-hydrodynamic drive train, it will also examine today's environment as it affects the demand for high speed rail service, the possibilities for alternate fuels, the type of turbine powered trains which will be required and the technology advances which will make such trains possible.

2.0 TURBOLINER PERFORMANCE REVIEW

The TURBOLINER is a five car unit train with a power car on each end (Fig 2). Passenger capacity is 263 and maximum revenue speed in the Buffalo-New York City corridor is 110 mph(177 km/hr). The train includes a cafe car for light meal and beverage service. Each power car includes an 1139 hp(850 kw) free shaft gas turbine driving a two axle cardan shaft connected power truck through a Voith Hydrodynamic transmission. The traction turbine in the power car as origonally delivered was a Turbomeca TURMO IIIR with a geared output speed of 5700 rpm.(Subsequent upgrade will be discussed later) Both turbines operate in unison by means of trainline command wires to provide a total of 2278 gross horsepower (1700 kw) for propulsion. Each power car also includes a 300 kw, 480 volt, 3 phase, 60 hz auxiliary power unit(APU). One of these units supplies the entire hotel load for the train, APU duty being alternated to extend miles between overhauls. The APU is a Turbomeca ASTAZOU IVC with an MTE alternator.

To operate in the tunnels in and out of New York City an electric propulsion system capable of operating from the 600 VDC 3rd rail is included in each power car. This system which is limited to 45 mph, is also trainlined and is so designed that the change from gas turbine propulsion to electric or from electric to gas turbine can be made without stopping the train. The traction motor is connected to the transmission by means of an over-running clutch and an auxiliary shaft.

Performance of the trains to date will be evaluated in terms of reliability, maintainability, and service generated improvements.

2.1 RELIABILITY AND MAINTAINABILITY

Reliability in railroad operations is usually expressed in terms of availability, that is, the percentage of time that the equipment is available to meet revenue service demands. 100% reliability implies no maintenance downtime and so is essentially unattainable. The TURBOLINERS have consistently shown availability of 90% or better since their introduction with the most recent evaluation showing 94%.

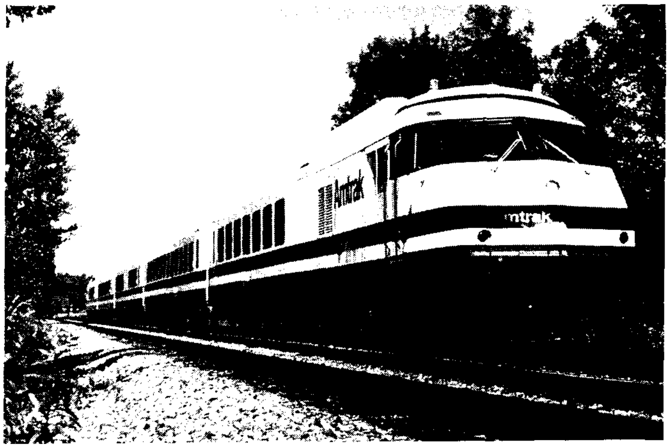

Figure 2 **THE AMERICAN TURBOLINER**

Availabilty such as this can be attributed not only to reliable subsystems but also to maintainability inherent in the basic train design. Unit exchange for all major subsystems permits fast removal and replacement of a defective unit with the train being returned to service in a minimum time. Repairs to the defective unit can then be carried out in the controlled environment of the maintenance shop. This also shortens downtime for preventive maintenance. As an example, the traction turbine can be removed and replaced in about four hours and a complete changeout of the traction turbine, transmission and auxiliary power unit can be accomplished in less than a week. Figure(3) shows repair frequencies for major devices and the average cost per mile for this perventive maintenance. As might be expected, the turbines, which require virtually no attention between overhauls, dominate these numbers. Major reductions in the turbine costs per mile have been accomplished in the past ten years through extension of TBO's and work is continuing to lower the specific cost of the overhaul. It is interesting to note the very low cost per mile for the Voith Hydrodynamic Transmission reflecting its specific design for this service.

SUBSYSTEM	COST/TRAIN $	FREQUENCY 000's Miles	COST/MILE $
TRACTION TURBINE-TURMO XII	325,000	268	1.213
TRACTION TURBINE-TURMO III	130,000	238	0.546
TRANSMISSION	3,128	1500	0.005
POWER TRUCK	12,000	400	0.030
APU TURBINE-ASTAZOU	150,000	476	0.315

Figure 3 **MAINTENANCE FREQUENCY AND COST TURBOLINER POWER TRAIN AND APU**

2.2 SERVICE GENERATED CHANGES

Relatively few changes have been required in the TURBOLINER Trains since their introduction. Even though the climate in the New York City-Buffalo Corridor with summer temperatures of 95°F (35°C) and winter temperatures of -20°F(-29°C), is much more severe than that experienced in France, the trains have performed reliably in all seasons.

The primary turbine problem encountered related to low temperature was wax formation in the #2 diesel fuel resulting in fuel filter restriction and loss of power. This was corrected by installing higher capacity heaters in the fuel delivery system.

To improve starting reliability and simplify maintenance, high energy ignition was retrofitted to both the TURMO IIIR Turbine and the ASTAZOU IVC Turbine. This system eliminates the high pressure starting fuel pump and so simplifies the starting sequence. Engines including this modification are identified with the suffix "2" in the designation as in TURMO IIIR2.

Track conditions in the New York City-Buffalo Corridor resulted in more severe shock loading of the drive train components than had been anticipated. As a direct result, axle gear box cracking occurred and the truck builder agreed to replacement with strengthened units. To provide better damping in the secondary suspension system, Amtrak installed a second shock absorber at each secondary spring.

The disc brakes supplied with the trains were constructed with a separate hub so that wear components could be replaced without removing the hub. Service experience showed that the road shocks referred to above tended to loosen the disc-hub interface resulting in premature failure. This was solved with one piece brake discs wherein the hub, web and disc were cast as a unit. Since the brake disc wears out at some multiple of wheel wear-out, it is easy to press off and replace a disc when renewing wheels.

The TURBOLINER Trains were the first AMTRAK equipment to incorporate heatless desiccant dryers in the air system. This innovation eliminated winter freeze-ups and summer lubricant wash-off while permitting more flexibility in the location and configuration of air lines. The origonal dryers were of the single tower type which regenerate in the "off" cycle of the air compressor. Since the compressor duty cycle was calculated at less than 50%, it was believed that this would be adequate. However experience showed that there were enough occasions of extended compressor operation to make this approach unsatisfactory. The single tower dryers were replaced with twin tower dryers with the cycle controlled by a timer and water accumulation in the air line and in air devices was eliminated.

The TURBOLINER Power Cars as delivered included contoured impact resistant windshields. Extensive wind tunnel testing(Pier 1975) had shown that the curved windshield reduced the drag coefficient sufficiently to affect maximum speed and assured freedom from turbulence in the turbine intake area at high speeds. However, shortly after the trains entered service the Federal Railroad Administration (FRA) revised the impact and penetration specifications for locomotive windshields reflecting growing problems with vandalism. This required re-specification of the contoured windshield involving development time and cost as well as unit cost. Windshields are a high replacement item in the New York City-Buffalo Corridor as in other AMTRAK services and it became apparant that the long lead time and high cost of an FRA compliant contoured windshield could not be justified in 110 mph service. The windshield openings were therefore modified to accept flat impact resistant panes meeting FRA specifications and all trains are now so equipped.

3.0 TURBINE IMPROVEMENTS

The TURMO IIIR Turbine built by Turbomeca which was standard with the seven trains delivered in 1976 is a dual shaft engine ISO rated at 1139 hp(850kw)(Fig 4). It is a helicopter turbine with modifications to suit it for railway service such as the ability to start and run on #2 diesel fuel oil, the standard on North American railroads.TBO for this engine was 2000 hours and its BSFC was 0.689 lb/bhp-hr(420g/kwh). The TURMO IIIR has one axial and one centrifugal compressor stage, an output speed of 5700 rpm and weighs 777 lb(353 kg).

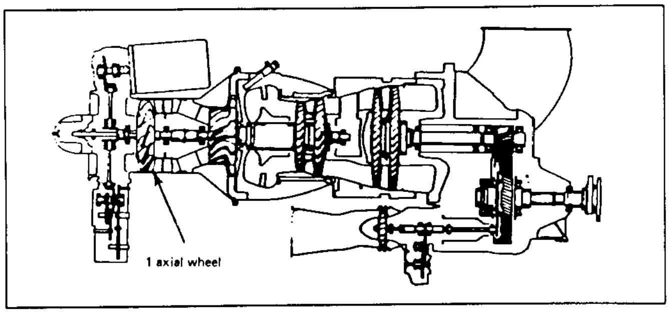

Figure 4 **TURMO IIIR TRACTION TURBINE**

While this engine proved to be very reliable, improvements in TBO, BSFC, and power output were considered desirable. Turbomeca was able to increase the TBO to 3500 hours with experience and engine improvements. In 1981 it introduced the TURMO XII engine (Fig 5) with an ISO rating of 1542 hp(1150 kw), a BSFC of 0.563 lb/bhp-hr(346g/kwh), and a TBO of 4000 hours. Its dimensions were such that it was physically interchangeable with the TURMO IIIR. These achievments were accomplished primarily by adding an axial compressor stage. There is a potential for TBO improvement to 5000 hours as more service experience is gained.

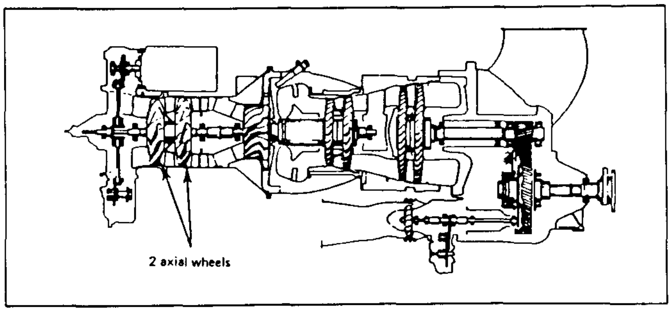

Figure 5 **TURMO XII TRACTION TURBINE**

After trial service in France, TURMO XII engines were retrofitted on half of the origonal Turboliner Power Cars starting in 1986 with the TURMO IIIR remaining in the balance of the power cars. The additional power makes it possible to run on the TURMO XII engine while cruising with the TURMO IIIR engine being used as a booster when maximum performance is required. This takes full advantage of the better TURMO XII BSFC as well as adding to the train miles between TURMO IIIR turbine overhauls.

The ASTAZOU APU as provided on the Turboliner Trains had a TBO of 1500 hours, typical of small solid shaft engines at that time. With engine improvements and the benefits of better filtration, TBO was gradually increased to 4000 hours and it now appears that with the introduction of squeeze film lubrication TBO will reach 5000 hours by 1990. Fig (6) shows the pattern of TBO increase from 1972 to the present as well as the anticipated future improvement. Since only one APU is required to meet the power demand of the five car Turboliner Train, each APU runs only half of the time, thus doubling the effective TBO in terms of train miles.

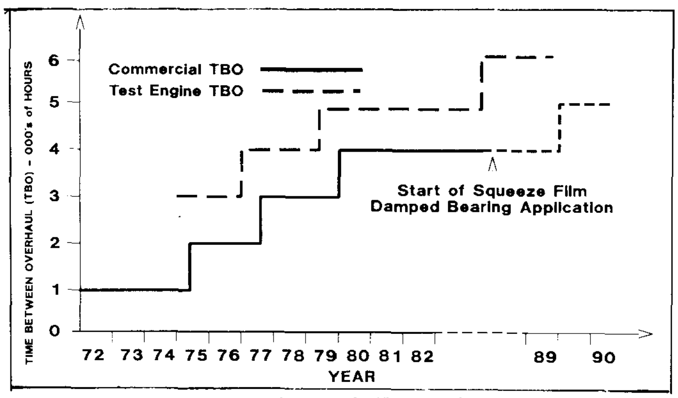

Figure 6 **ASTAZOU IVC TURBINE TBO IMPROVEMENT**

4.0 FUTURE IMPROVEMENTS

4.1 TRACTION TURBINE

While the TURMO XII engine was being developed for railway service as an upgrade of the TURMO IIIR, the MAKILA 1A1 Turbine was introduced in 1977 to power the Super Puma helicopter. This turbine utilized the proven technology of previous Turbomeca Turbines while incorporating new features such as modular construction(Fig 7) and easy internal inspection (Fig 8). It also included three axial compressor stages as well as a centrifugal stage and was ISO rated at 1819 hp(1357 kw).

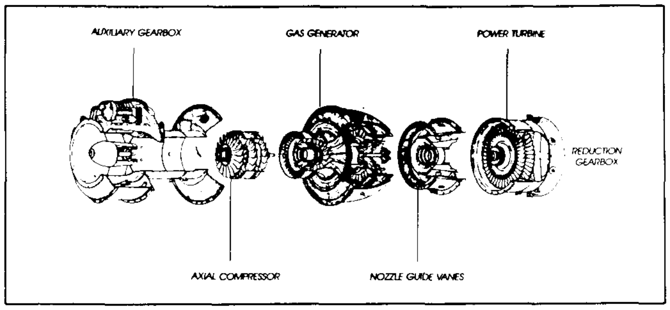

Figure 7 **MODULAR DESIGN MAKILA 1F HELICOPTER TURBINE**

The helicopter turbine led to a railway test version, the RAILWAY DEVELOPMENT ENGINE (Fig 8) which went into trial service on the French National Railways (SNCF) in October, 1988. The RAILWAY DEVELOPMENT ENGINE (RDE) is derated to 1542 hp(1150 kw) to accomodate the use of #2 diesel fuel. BSFC is 0.476 lb/bhp-hr (296g/kwh), a 15.5% improvement over the TURMO XII and a 31 % improvement over the the TURMO IIIR. While the modular construction of the RAILWAY DEVELOPMENT ENGINE permits changeout of the hot end at the minimum TBO with total engine removal for overhaul at 10,000 hours, experience in railway service has shown that it is preferable to minimize maintenance in place and pull the total engine for rebuild in a controlled environment. In view of this, it is unlikely that the RAILWAY DEVELOPMENT ENGINE will be commercialized but rather, following the test program, its proven performance features will be incorporated in future versions of the TURMO XII. Figure (9) compares significant parameters of the TURMO IIIR, TURMO XII, and RDE Turbines.

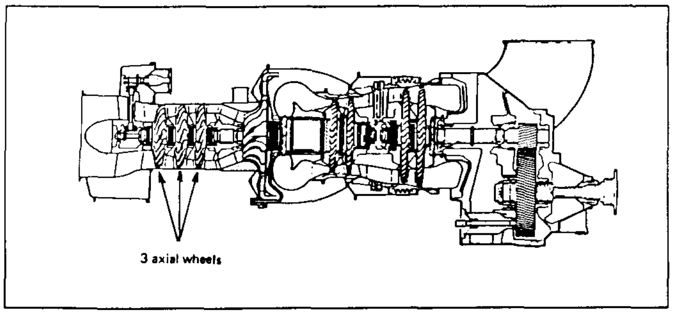

Figure 8 **RAILWAY DEVELOPMENT ENGINE (RDE)**

PARAMETER	TURMO IIIR	TURMO XII	RDE
Nominal Power-hp(kw)	1139(850)	1542(1150)	1542(1150)
Thermal Efficiency-%	20	24	28
Compressor Stages	2	3	4
Compressor Ratio	5.1:1	7.85:1	9.9:1
Air Flow-lb(kg)/sec	12.4(5.65)	15.6(7.1)	12.1(5.5)
BSFC-lb/Bhp-hr(g-kwh)	0.689(420)	0.563(346)	0.476(296)
Fuel	Diesel #2	Diesel #2	Diesel #2
TBO-hr	2000	4000	6000★
Weight-lb(kg)	777(353)	1074(488)	902(410)
Length-inches(mm)	78.6(1996)	84.3(2142)	74.9(1902)
Width-inches(mm)	26.7(679)	28.2(717)	28.2(717)
Height-inches(mm)	27.5(699)	34.5(877)	34.5(877)
★ Anticipated			

Figure 9 **TRACTION TURBINE COMPARISON**

4.2 TURBINE LOGIC AND CONTROL

The present TURBOLINER Trains use relay logic for turbine control and monitoring (Pier and Williams, 1976). While this control has been reliable and has performed acceptably in railway service,it is large, heavy and expensive. Turbomeca has recently developed a Digital Electronic Control Unit (DECU) with improved monitoring and built-in diagnostics. The new control unit has a volume of 561 cubic inches (9.2 liters)and a weight of 26.5 lb.(12 kg) as compared to 24313 cubic inches(39.9 liters) and 300 lb.(136.4 kg) for the origonal unit. One of these DECU's entered trial service on SNCF last October with the RDE Turbine referred to above.

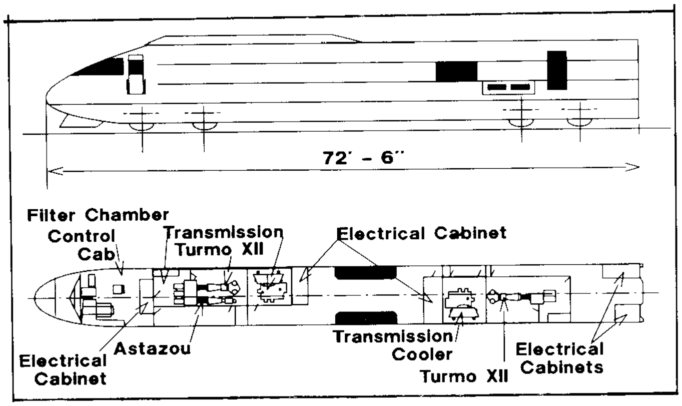

Figure 10 **DUAL TURBINE POWER CAR**

4.3 DUAL TURBINE POWER CAR

The TURBOLINER presently running in North America normally has a five car consist as described earlier. Future demand for higher capacity, high performance trains with 6 to 8 coaches will require twice the tractive effort. To accomplish this a dual turbine power car is proposed(Fig 10). Such a power car will use the present drive train(Fig 11) on both trucks rather than on just the lead truck. Because there will be no passenger compartment in the Dual Turbine Power Car, it will be shorter, 72'-6"(22.1 M) as opposed to 86'-10"(26.5 M)) for the present single turbine power car. Two such Dual Turbine Power Cars will be used in a push-pull configuration with six to eight coaches. Figure (12) shows a typical eight car (six coach) consist and its characteristics. Control of all four turbines will be from a single handle in the leading control cab. The engineman will have the the ability to select any combination of turbines at any time from his control console with synchronization then being automatic. Top speed of the train within the limits of tractive effort and train resistance will be determined by the final drive gear ratio. This axle gear ratio presently limits top speed to 137 mph(220 km/hr) which assures good performance at 125 mph, the maximum speed presently permitted in North America. As new lines are built with fewer curves and speed restrictions, adjustments can be made to provide maximum speeds up to 150 mph(241 km/hr). The rolling stock has been tested at speeds up to 168 mph(270 km/hr)

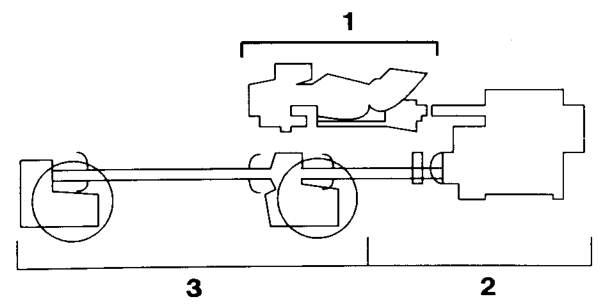

Figure 11 **THE POWER TRAIN**

CONSIST: Power Car II, 4 Coaches, Cafe Coach, Custom Coach Power Car II

Length-ft (meters)	642(195.7)
Number of Seats	
Coach	340
Custom	48
Total	388
Weight, empty, ready-to-run-tons (tonnes)	477(433)
Weight, Maximum-tons (tonnes)	512(465)
Traction Power, Net-hp(kw)★	5536(4130)
Power/Weight-Maximum Weight	10.8
Revenue Speed-mph(km/hr)	125(200)

Figure 12 **TURBOLINER EIGHT CAR TRAIN**

4.4 APU ALTERNATIVES

As noted above, the ASTAZOU IVC APU delivers 300 kw to supply the maximum hotel load for the train. Anticipated hotel loads for the six and eight coach trains contemplated would be 403 kw and 511 kw respectively. This would require simultaneous operation of both APU's with loss of redundancy advantages and a 50% reduction in effective TBO. Running both APU's at a BSFC of 0.689 lb/bhp-hr(420 g/kwh) would also consume 60 gallons(227 l) of fuel per hour. To take advantage of the lower BSFC of the TURMO XII Turbine, it has been proposed that the APU alternator be driven from an auxiliary shaft on the transmission. Since speed and therefore frequency will vary with traction turbine speed it will be necessary to convert the output to regulated DC and then invert to 3 phase, 60 hz, 480 volt power. The alternator will be sized to carry the full hotel load so that one alternator will always be in reserve. Such an arrangement should save both first cost and operating cost. For applications where the full turbine output is needed for tractive effort,separate APU's will still be required and the level of redundancy and type of APU will be governed by customer preferance.

In the special case where turbine operation is prohibited and electric drive is required for operation in unventilated tunnels, a new set of variables is introduced into the APU equation since the traction motor also requires an auxiliary transmission shaft. While there are a number of possible approaches to this problem, their discussion is considered beyond the scope of this paper.

4.5 ALTERNATE FUELS

While #2 diesel is the standard fuel on North American railroads and while a gas turbine burning this fuel has a relatively clean exhaust compared to a railway diesel, growing concerns with air pollution make consideration of turbine grade methanol interesting as an alternate fuel. Turbine grade methanol is made from natural gas and contains 10% water. Its heating value is only 47% of that of #2 diesel fuel oil and it is presently more costly on a Btu basis (J. Dufus,4/86) but it has the advantage of 64 to 78% lower nitrous oxide emissions, lower hydrocarbons, and lower luminosity which produces less heat and so extends TBO. There is no known experience with turbine grade methanol in railway gas turbines and there is relatively little with industrial turbines. Industrial Turbine experience with natural gas has generated TBO's as high as 20,000 hours, however, several times that attained with fuel oil. The varying load requirements of the railway application would probably result in a TBO of no more than 10,000 hours but this would provide 4 to 5 years between overhauls. While the 1985 cost per million Btu's for methanol is 1.6 times that of #2 diesel fuel oil, it is believed that higher volume production as the result of increased demand would bring the cost of methanol down to a level which could make it cost effective. The higher BSFC would require more fuel tank capacity to maintain range, adding about 3000 lb(1364 kg) to the empty, ready-to-run-weight. It would also be necessary to redesign the fuel delivery system for methanol compatibility. To explore these possibilities in more detail, additional studies and a funded demonstration program in a problem area such as the Los Angeles-San Diego Corridor would seem to be indicated.

5.0 THE TURBOLINER IN HIGH SPEED RAIL

The present very real demand for high speed rail in North America is driven primarily by the need for cost effective congestion relief(Coogan,1987). It is recognized that in an era of massive federal budget deficits, funding for even the most worthy of high speed rail projects will probably have to come from the local entities which will benefit the most. These entities in turn will look to break-even operations as a goal, and perhaps as a criteria, for financing. In this environment, the turbine powered train offers proven technology with a short lead time and a minimum requirement for right-of-way improvements(Pier, 1988). Typical corridor candidates for application of the technology are shown in Fig(13). Note that some of the best candidates such as Los Angeles-Las Vegas at 341 miles, Miami-Orlando at 263 miles, and Dallas-Houston at 240 miles have no present service. However, active planning is underway in each of these corridors. In Florida, planning for the Miami-Orlando Corridor has advanced to the proposal stage and technologies are presently being evaluated.

CORRIDOR	ROUTE MILES	AVERAGE SPEED (mph)	PASS PER YR. 1000s
NEW YORK CITY-BOSTON	232	54	1900
LOS ANGELES-SAN DIEGO	128	47	1500
NEW YORK CITY-BUFFALO	439	56	1000
CHICAGO-ST LOUIS	282	55	300
CHICAGO-DETROIT	279	42	300
CHICAGO-MILWAUKEE	86	60	200
SEATTLE-PORTLAND	186	45	100
LOS ANGELES-LAS VEGAS	341	★	★
MIAMI-ORLANDO	263	★	★
DALLAS-HOUSTON	240	★	★
WASHINGTON-RICHMOND	109	★	★

★ No present corridor service

Figure 13 **TYPICAL CORRIDOR CANDIDATES**

Speed/Trip Time and Cost to User were two of the goals of high speed rail discussed above. Fig(14) shows how a 3 hour trip time in the Boston-New York City Corridor would compete with the air shuttle in terms of time and cost on a center city to center city basis. From this it would appear that the rail fare could be doubled without affecting the rail advantage appreciably. This would have the potential of making the service financially viable as well.

Figure (15) shows the impact of trip time in two virtually identical corridors, Boston-New York City and Washington-New York City. When the Washington-New York City trip time was lowered to 2 hours and 40 minutes, a

	TURBOLINER		AIR	
	TIME	FARE	TIME	FARE
BOSTON CBD-TERMINAL	0:10	3.00	0:30	6.00
TICKETING & BOARDING	0:10	38.00*	0:10	89.00
MODE TRAVEL	3:00		1:00	
INTERMODAL TRANSFER	0:10		0:30	
TERMINAL-NYC CBD	0:15		1:15	6.00
	3:45		3:25	101.00
AIR ADVANTAGE			0:20	
AIR PREMIUM				60:00
TIME VALUE/HR				180.00
* AMTRAK FARE + 15% FOR HIGH SPEED SERVICE				

Figure 14 **TRIP TIME-COST COMPARISON**

was lowered to 2 hours and 40 minutes, a time competitive with the city to city air travel time, AMTRAK reported that 40% of the air shuttle passengers switched to the train. On this basis, a 3 hour rail trip time from Boston to New York should generate 800,000 additional rail passengers per year and reduce airport congestion by a like amount.

	NYC-WDC	NYC-BOSTON
MILES	225	232
TIME	2:40	4:25
PASSENGERS ALL MODES	8-9 Million	8-9 Million
AIR SHUTTLE	2.1 Million	2.1 Million
AMTRAK	1.5 Million	0.6 Million

Figure 15 **TRIP TIME-RIDERSHIP COMPARISON**

Figure(16) using data generated by FRA in 1985 titled Northeast Corridor, Achievement and Potential, shows in broad terms the the comparitive capital costs to accomplish the three hour trip time in the Boston Corridor with turbine train technology and with full electrification.

NYC-BOSTON	RTL	ELECTRIC
TRACK	100	100
ELECTRIFY	0	340
TRAINS	200	200
TOTALS	300	640

Figure 16 **CAPITAL COSTS-3 HR TRIP (MIL$)**

6.0 CONCLUSIONS

The TURBOLINER Trains introduced in 1976 have performed very well requiring only minimum changes in the origonal design. Technological changes in the traction turbine have improved both the maintenance and operating costs while reliability has remained high. Operating speeds are generally below the optimum level for the trains due to right-of-way restrictions. When higher average speeds can be attained, additional economic gains can be anticipated. Future applications of higher capacity trains will use the proven drive train components of the present trains in dual turbine locomotives. These turbine locomotives will propel trains of six to eight coaches at speeds well in excess of 125 mph (200 km/h) offering a low cost, reliable high speed rail solution to intercity transportation.

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