A New Look at Fast Trains

Fast trains are terrific. Travel 200 km in less than an hour. In a country of great distances they seem to be an obvious need. There are more than 50,000 flights each year between Melbourne and Sydney according to OAG.com. You can drive from Melbourne to surrounding provincial capitals faster than existing trains.

So it is no surprise that many people and governments have proposed them. It's like the Bradfield scheme to send water from North Queensland southwards and inland. You just know it would be great for Australia. The Federal Government has had fast trains on its agenda since 1979. There is a chronology available[1] which shows 93 major announcements over the period 1979 to 1998 when the chronology was written, an average of 4 per year. Five years had more than 10 major announcements about high speed rail.

The final report is always the same. It costs too much to put down the rail. The AECOM report of July 2011[2] has "The risk-adjusted cost estimate for the implementation of an overall HSR network would fall within the range of $61 billion to $108 billion (in $2011) ....". Taking the distance from Brisbane to Sydney to Melbourne as 1700 km, this makes the average cost per kilometre somewhere between $36M and $63M. The report has a table (D7) which identifies components of the cost like signalling (A$1,830,00 per km). It predicts a total cost of drainage, utilities, signalling, electrification, rails, sleepers, ballast, and grade separation for roads to be $6.65M per km, so the other $30M+ is for land purchase, earth works, tunnelling and viaducts.

As you would expect, there is considerable variation in the cost of high speed rail. The report "A profile of high-speed railways" of the Federal Government[3] shows costs of €10 m to €50 m (A$16 m to A$80 m) for rail lines inside Europe. The World Bank[4] asserts "*China's high speed rail with a maximum speed of 350 km/h has a typical infrastructure unit cost of about US$ 17-21m per km, with a high ratio of viaducts and tunnels, as compared with US$25-39 m per km in Europe and as high as US$ 56m per km currently estimated in California."* Even the Chinese with low labour costs and smart mass production methods cannot get the cost below A$20M per kilometre.

The profile report[3] also points out, in Table 3, that the European high speed trains connect cities of at least one million people (except for Strasbourg). Numerous analyses assert that the greater distances and smaller populations in Australia preclude High Speed Rail here[5]. It seems you need that millions of people at each end of a railway to generate enough trips to pay for the rail investment. In fact, Governments around the world subsidize rail transport[6] but politicians would want a lot of votes per million dollars, so they support links between large populations. While the Sydney to Melbourne rail

1 See https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/Publications_Archive/Background_Papers/bp9798/98bp16
2 See https://infrastructure.gov.au/rail/trains/high_speed/files/HSR_Phase1_Report.pdf
3 See https://bitre.gov.au/publications/2010/files/other_001_a_profile_of_high-speed_railways.pdf
4 See http://www.worldbank.org/en/news/press-release/2014/07/10/cost-of-high-speed-rail-in-china-one-third-lower-than-in-other-countries
5 One example is https://www.macrobusiness.com.au/2017/02/no-albo-australia-doesnt-need-high-speed-rail-2/
6 See https://en.wikipedia.org/wiki/Rail_subsidies

time looks unlikely to get under 3 hours, our government will instead spend the billions (six plus) on a new airport at Badgerys Creek.

But imagine if we had a vehicle, a cross between a train and an aircraft, which could travel over our existing rails at 250 km/h and also go around the Melbourne city loop. We could commute from provincial cities like Bendigo to Melbourne. Impossible you say? Standards won't allow it?

There are many reasons to reject the notion of high speed trains on old rails. People have tried it. The British began a project named Advanced Passenger Train- Experimental (APT-E) over 50 years ago[7]. Issues which stopped the development included nausea generated by the tilting process, a driver revolt because only one driver was planned, and trouble with the gas turbines which powered it. Queensland tried the X2000 Swedish tilt train but found "Consistent high speeds for a local Tilt Train would appear to require considerable track upgrading for success"[8]. You can run tilt trains to take curves at higher speed, but 250 km/h is way too fast even for a radius 400 m, and people suffer nausea on those trains[9] if they tilt too much.

Think of the level crossings and the kangaroos on the track. Electrification will cost a bomb if you persist with the 1500 Volt DC used in Melbourne, and how could you mix 25KV AC with 1500 V DC. The power required to drive a TGV style train weighing 400 tonne is about 9,000 kW[10]. How will you supply that? What about signaling? At 70 metres per second, you may only see a signal a few seconds before you might have to stop at it. The APT devised a new fluid based braking system (a water pump pushing water through a small hole!) to provide rapid deceleration. If you think those problems are hard, think about poor alignment issues where a wiggle or a bump in the tracks could derail a train if it was going fast enough. Unlike curves and level crossings, this problem can occur anywhere along the track, and can appear in one day. Track quality needs to be excellent and reliably excellent for the very fast trains of today.

Is there an escape from this deadly embrace of the difficulty of getting government to pay billions for Northern Hemisphere style high speed rail tracks, and the difficulty of going fast on the tracks we have? The recent anniversary of the moon landing is a great guide. We need to look back 57 years to the words *"We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills…".* In 1962 the United States decided to put a man on the moon in 8 years. I submit that that task was much more difficult than creating a vehicle which can travel quickly over old railway tracks, but we need lateral thought to solve the problem.

A story about the Lunar Excursion Module illustrates the issue. The original moon landing idea was a vehicle which would land on the moon and then take off and jet back to earth. The vehicle as landed on the moon would have to have enough fuel not only to enter low moon orbit, but to escape that orbit to return to earth. Mr Thomas Doolan realised that a significant amount of fuel was required to escape lunar orbit. Taking that fuel down to the moon and getting it up again would take more fuel. It would be better to have two vehicles – one to orbit the moon and one to descend to the surface –

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7 See http://www.rail.co.uk/rail-news/2016/inside-story-of-british-rail-250mph-train-of-future-apt/
8 See the report by David Foldi in www.railknowlegdebank.com/Presto/Content and https://www.railpage.com.au/f-t1836.htm
9 See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3205836/
10 See https://en.wikipedia.org/wiki/TGV.

and for them to separate and then reconnect after the landing and take-off. His superiors scoffed at this idea. So Thomas bypassed the chain of command and got to John C. Houbolt who clever enough to realise the benefit, and bold enough to pursue it. As they say, the rest is history.

Malcolm Turnbull saw a vision of fostering innovation, just as Jack Kennedy did, and now we have a multitude of recommendations for development of our capacity in Science, Technology Engineering, and Mathematics[11]. But we have not yet taken the critical step of issuing a challenge to inspire our students, teachers and voters. The economic studies showing the high cost of rail systems designed in the Northern hemisphere, which has persisted for 40 years in "cargo-cult" Australia, seems to me to be ample evidence of a technological need. Australia badly needs a different rail system because of the length of our lines and our low population density outside the state capitals. We should be embarrassed that Sweden, a country with less than half our population, could develop its own moderate speed train while we import systems from overseas.

We might think the British experience with the APT is evidence enough that the challenge is too great. But since then there have been a number of important technological developments which relate to these issues. Jet aircraft commonly bank at 30 degrees with virtually no passenger discomfort. Passengers sleep through these turns. Lithium Ion batteries are now being used to make trucks with a range exceeding 1,500 km. The Steadicam mount for movie cameras was invented by Garret Brown in 1975.

We cannot solve all the problems at once. The first issue to study is that which applies to the whole rail length (as distinct from curves, level crossings and stations), namely the alignment of the rails. If we can't solve that, there is no point trying to solve the others. Can we devise a train suspension which will provide a comfortable and safe travel, at high speed, say 250 km/h, over nearly straight tracks surrounded by open fields, but tracks which are not perfectly straight and level, but move laterally and vertically relative to a straight line as the train passes over them? This is a suspension problem. It is compounded by the need to hold the carriage accurately relative to the rails in many situations such as stations, tunnels, and when passing other trains. Is it possible to devise a suspension system which neither damages rails nor itself, and maintains high passenger comfort when running at 70 metres per second over the rails we already have, and yet holds carriages accurately when required? I think you can.

Replacing the rails with a large vacuum tube as suggested by Elon Musk in his Hyperloop concept, or with magnetic levitation apparatus could solve the problem, but that is traveling in the direction of higher cost per kilometer. Maglev is certainly more expensive that Shinkansen style tracks. The challenge I want to pursue is to achieve high speed at the lowest cost per unit length by investing mainly in the vehicle rather than the track. There will be changes to the rail infrastructure, for signaling at least, and possibly at some turns, tunnels or stations, but we must avoid the high cost of relaying the rails to a high precision on immovable ballast.

It is difficult to wean ourselves from the vast assembly of experience, standards, and practices which have developed in the last 200 years. We should begin with a truly out-of-left-field suggestion – a hover train, or as the Americans say, an air cushion train. I am not referring to magnetic levitation (MagLev) here. This option is to support the train with compressed air. There have been a couple of

11 https://www.education.vic.gov.au/about/programs/learningdev/vicstem/Pages/about.aspx

attempts to do this, each with specially shaped supports quite different from rails. The French Aerotrain is shown below[12].

The British also tried this approach, but both used a special track. The tracks had large areas of flat surface to support the air cushions which were around 3 mm thick, so the surfaces had to be quite accurate. Management of corners seems to be problem for both systems. The need for a special support is a dominant influence on the demise of the hover train. No-one tried to use existing tracks. If you do, you need a pressure much higher than normal hovercraft[13]. You need 10 kilo Pascals, (1/10th atmospheric) to support a 40 tonne carriage using an area 25 metres by 1.6 metres (40 square metres, 1 sq m per tonne, 10 kPa). You have to have a gap between the rails and the "skirt" above and air will escape through this gap. The air will escape at 413 feet/sec[14] i.e. 125 m/sec or 450 km/h at this pressure. For each millimeter height in the gap between the rails and the skirt, a train 150 m long will lose 18 cubic metres per second[15] requiring power of 180 kW to replace it. The gaps at the front and back each add another 30 cubic metres per second. For a 10mm gap at the sides you need at total of 2400 kW. But then you need some means of locomotion, and some means to keep the train fairly accurately over the tracks. The escaping air will surely create problems at stations and tunnels. Maybe the hover train is a bridge too far.

If you abandon the idea of a hover train then the best alternative is wheels. You would tie the wheels together in a bogie. We have to devise some mechanism which allows the bogie to dance about while the carbody travels smoothly above. The bogie would need to be very different from those in use today to reduce the forces on the wheels and track to those which cause no damage. Firstly, we would want the weight of the bogie to be as low as possible. Anything heavy should be in the carbody. Many components would have to be made from Aluminium. Secondly we would want the forces between the wheels and the rail to be spread over as much area as possible to reduce the

12 FlyAkwa - Own work 1-Jan-1974
13 See http://www.discoverhover.org/infoinstructors/guide4.htm = Which reports 335 N/m^2 =0.335 kPa
14 See https://www.engineersedge.com/fluid_flow/velocity_escaping_14031.htm
15 125*0.001*150 = 18.75. The front and back each add 125*1.6*.15

pressure between them. This is likely to mean larger wheels, say 1.5 m in diameter, and wheels whose profile matches the rail profile. It may not be possible to use beveled wheels to allow the outer wheel to cover a greater distance in a curve. Another mechanism, like separate motors for each wheel, to allow the outer wheel to rotate more rapidly whilst passing a curve, would be needed. This is all challenging, but at least conceptually possible.

Turning to the problem of the connection between the carbody and the new light weight agile bogie, one possibility is an active suspension train. This would connect the carbody and the bogie with linear actuators which are instructed to move the bogie relative to the carbody when the rails move relative to perfectly straight. Measure the deviation from perfect at each point in the rail journey, store the deviations in a computer system, and get the computer system to adjust the relative position of each bogie accordingly. The great advantage of railway systems here is that the driver cannot steer the train into, or out of, a bump so the arrival of deviations is much more predictable than on a road. Moreover, the steel rail is much less likely to develop a sizeable pothole. A disadvantage of railway systems is that the deviations include lateral deviations as well as vertical ones. Also, the steel rail can hold the sleepers up over collapsing ballast in a way which makes observation of that problem very difficult. The situations where rain or flood can erode the soil supporting the ballast, or drive mud up into the ballast to reduce its rigidity, pose a most serious threat to active suspension. They make overnight changes easily possible and without extensive instrumentation of the track, these changes are very difficult to detect. We should thoroughly explore alternatives before going to the trouble of measuring every bump and wiggle at each metre of every track we would like to service with an active suspension train. Perhaps the active suspension train is too difficult.

An alternative is a suspension system which is very soft when that is appropriate, but can be as hard as existing trains when the accurate positioning of the carriage relative to the rails is required. The soft suspension would allow significant movement, 10s of centimetres, with very little change in force holding that carbody up, and would be used on nearly straight tracks where the chance of collision with any object is insignificant. As the train approaches a station or a tunnel, the speed would be reduced and the train would switch to the hard suspension which will hold the train more tightly to the rails. Using **compliance** in the physics sense rather than the administrative sense, we need a suspension system with switchable compliance.

Soft suspensions are not new. The Steadicam is a camera mount which allows a movie camera to be supported by an operator is a way that allows the camera to stay at the same height while operator walks.

The spring suspension operates at a mechanical ***dis***advantage so that changes in the relative height of the operators harness relative to the camera made insignificant changes to the spring length and therefore the vertical force remains as the weight of the camera assembly. The suspension has high compliance. The operator uses his hands to make adjustments to the camera height and direction, and once made these need not be changed.

So we need a train where the forces supporting the carriage and keeping it centred above the rails are constant, scarcely changing as the rails move up and down, and left and right. Then, when entering a station or a tunnel, we need to somehow dramatically reduce the compliance of the suspension system, so that deviations measured in millimetres produce strong forces to hold the carriage accurately relative to the rails.

You could do this with cams and movable blocks which enable or disable springs of some sort on the bogie as conditions change. Given that the bogie is dancing about at high speed, this looks like a high risk strategy.

To reduce the weight of the bogie and the risk of failure when changing compliance, I devised a system which I believe can achieve adjustable compliance between the bogie and the carriage, where all the moving parts associated with compliance change are in the carriage, and the compliance can be changed quickly (100 ms). The plan is to operate in low compliance (hard suspension) at stations or passing tunnels or anything close to the train, but switch to high compliance (soft suspension) at other times. When the suspension is soft, the train should be able to operate at higher speed because the forces associated with inaccurate rails will be reduced.

Curves and grade changes immediately come to mind as problems for a really soft suspension. If the train enters a 3% incline at 70 metres per second, the gap between the carriage and the rails would change by 2 metres per second if the suspension was extremely soft. Turns are another matter which need extensive analysis which is beyond the scope if this discussion. Mercifully, there are 3 ways to deal with inclines and curves. The first is to slow down and switch to a hard suspension. This reverts the train to those running today. The second is to ensure that the transitions have no significant misalignments, so the train can switch to hard suspension during the transitions at high speed and back to soft suspension at high speed in the rest of the incline. The third way is combine active predictive suspension with the soft suspension system to make the soft suspension generate the forces required to keep the train on the tracks at high speed.

Of course the problems of power, signaling, level crossings and wild life on the track have not yet been addressed. But there is no point addressing them if the suspension problem cannot be solved. In essence then, the question I ask of the reader is "Suppose you have a train where the compliance of the suspension can be changed from being close to existing trains to really soft, say 10 times softer than normal, quite quickly. Will rail alignment (or lack thereof) prevent such a train from running at 250 km/h on at least some parts of the existing regional rail lines?"

If the answer is Yes, then please support this development. The potential benefits are huge, not only for rail expertise in Australia but for traffic congestion and the cost of housing. If the answer is No, then please let me know why it is No.