Air bearings, Air skis

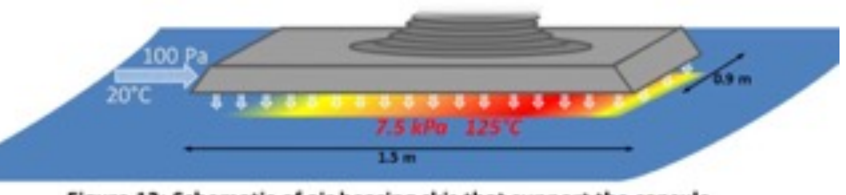


Figure 12: Schematic of air bearing skis that support the capsule.

Hyperloop Alpha is designed with air bearing skis. This is a popular concept for vacuum tube transportation, which originated with the invention of the hovercraft in the 1960s. It is the defining technology for Hyperloop, and has generated great interest and a strong following. But public enthusiasm alone will not elevate the skis, they need solid scientific principles to work.

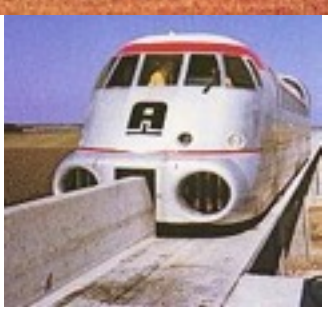
Air suspension trains have proved to be unsuccessful , various projects in the 60's and 70's consumed decades of research, and were all eventually scrapped. Some projects did function, but failed economically due to high air compressor power. But in a near-vacuum where the air density is 1000 times less, the power required for the same lift force increases by 20-30 times, and the compressor needs to be impossibly large.

This page looks at the performance of air skis from different perspectives.
The spreadsheet supporting these calculations is here,
View it in Dropbox or download the Excel file

History. Hovercraft, hovertrains and the French Aérotrain

The hovercraft was invented by Christopher Cockerell in the 1950's, which led to a wave of proposals for air-cushion vehicles, including trains. He found that it is much more efficient to blow the air in through a slot around the edge of the cushion, creating a 'momentum wall'. All later designs all used a flexible skirt to reduce the gap and airflow.

Most hovercraft projects have been defeated by the high power requirements of the lift fan, all that remain are a few amphibious and recreational craft. But for Hyperloop in a near-vacuum, the power to lift the pod would be 20-30 times greater, which would be impossible.



The French Aérotrain was the most successful, it achieved the remarkable speed of 430 kph (267 mph) in 1974. It used a large gas turbine to power the 9 air compressors for lift, and 2 more turbines for thrust. The project was finally scrapped in favour of what would become the TGV high-speed-rail.

Airflow calculations

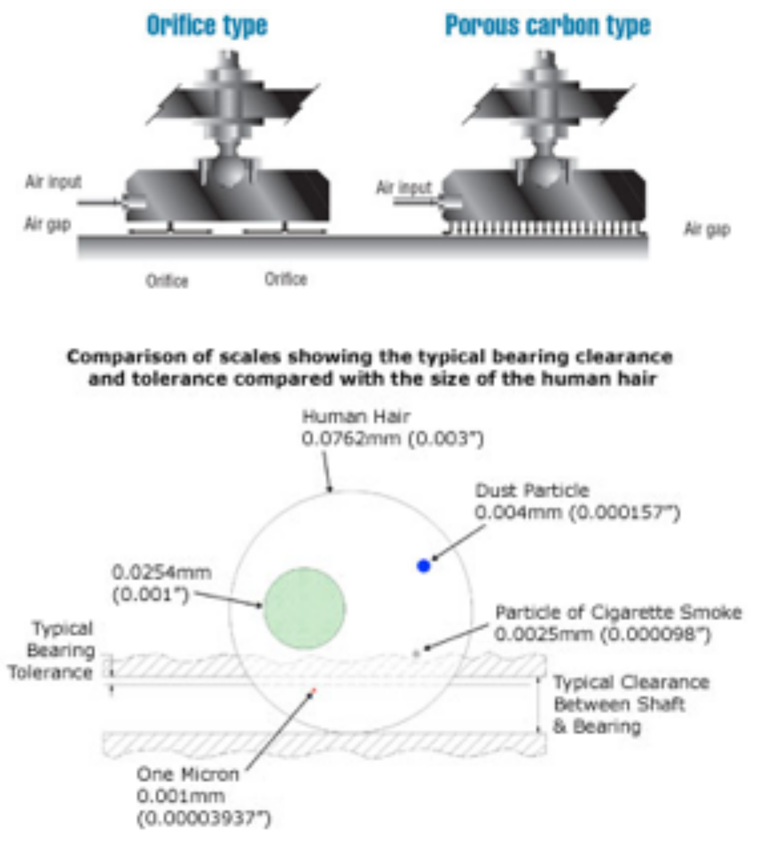
These calculations calculate the flow rate out of the gap between the skis and the tube wall. It assumes that there is no pressure drop between the air inlet of the ski and the outflow gap.

Number of skis	28
Gap thickness	1 mm
Gap exit area	0.134 m2
Pressure under skis	9,400 Pa
Pressure in tube	100 Pa
Outflow=speed of sound	401 m/s (400 K)
Density air under ski	0.082 kg/m2
Outflow volume	53.9 m3/s
Outflow mass reqd.	4.41 Kg/s
Alpha's compressor output	0.20 Kg/s

The pressure differential between the skis and ambient provides the lift force. As we reduce the ambient pressure, the differential must remain the same to give the same force. At atmospheric pressure, Alpha would have a 1.09:1 pressure ratio between the skis and ambient, with a low air outflow speed. But at the 0.1 kPa pressure of the tube, the pressure ration is 94:1 with a high outflow speed. Fortunately, Kantrowitz limits the outflow speed to the speed of sound.

Modern air bearings

Modern air bearings work well, they utilise the viscosity of a very thin film of air. But this film is microscopic, air bearings rely on mirror-finish surfaces measured in microns (1/1000 mm), which is necessary for air to become a viscous layer.



The diagram shows the required clearances compared to the size of a human hair (big circle). This is clearly impractical for the vacuum tube, which is a large structure subject to thermal distortion, load distortion, and the economics of precision machining. The tube tolerances will be measured in mm, not microns.

But even if we could machine the tube with the required perfection, there is the problem of viscous drag. At 1,200 kph and the required film thickness, the rate of shear across the air film is very high. With 38 sq m of ski area, the viscous drag would be intolerable. And there is no precedent for air bearings running in a near-vacuum, or at very high speed.

Compressor inlet size

This is a simple calculation of the size of the inlet of the compressor.

Number of skis	28
Gap thickness	1 mm
Gap exit area	0.134 m2
Pressure under skis	9,400 Pa
Pressure in tube	100 Pa
Pressure ratio	94:1
Inlet and ski exit gap have same mass flow	
Compressor inlet area	12.6 sq m
Compressor inlet diameter	4.0 m

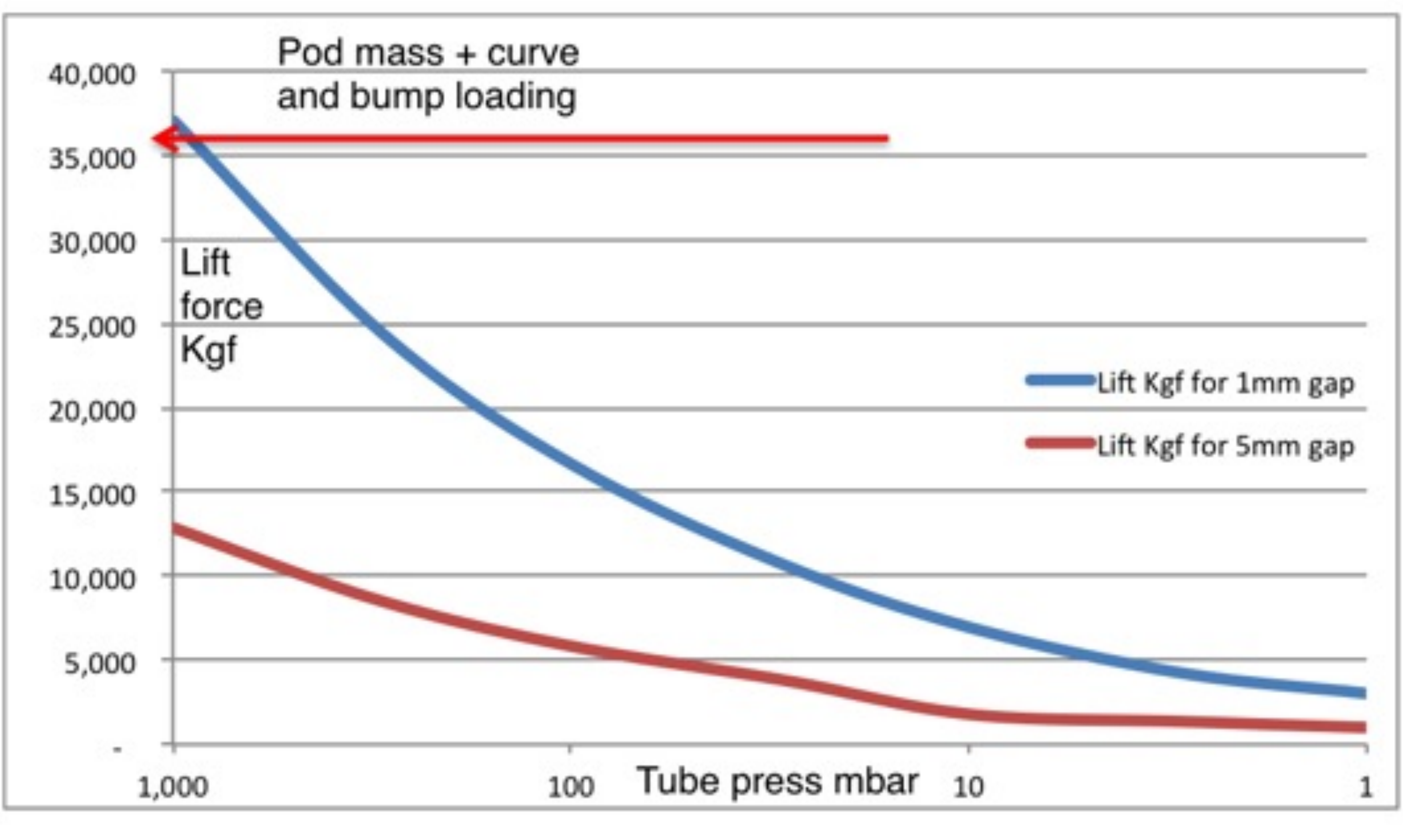
This again is based on Kantrowitz and Choked flow, which limits the outflow speed from the skis to the speed of sound, if the pressure ratio is > 2.

But the compressor inlet must be large enough so the inlet speed is below Mach 1.

So the inlet and outflow are at similar speeds, but the pressure ratio is 94:1, so the outflow density is 94 time higher. Hence, the inlet area must be at least 94 time bigger than the ski exit gap.

This requires the compressor inlet to be about 4 m diameter, which is larger than the diameter of the tube.

Lift force



The graph shows how the lift force from the skis reduces when the tube pressure is reduced, for a constant compressor power and gap. It shows the lift reducing rapidly with tube pressure.

As the tube pressure is reduced, the pressure ratio between the ski and the tube increases, and so the airflow speed increases. When the ratio is about 2, the outflow speed is limited to the speed of sound.

Alpha's lift force and power match quite well initially. Is this just coincidence, or did they calculate the compressor power based on atmospheric pressure?

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