Aerodynamics in a Hydrogen Atmosphere: Supersonic Tube Vehicle

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The supersonic tube vehicle is a new concept in high-speed transport [Miller, 2008]. Operation of a vehicle in a hydrogen atmosphere, because of the low density of hydrogen, would increase sonic speed and dramatically decrease drag relative to air. A hydrogen atmosphere necessitates that the vehicle operate in a hydrogen-filled tube or pipeline. To prevent leakage of air into the tube, hydrogen pressure is slightly above outside air pressure, and the tube serves as a phase separator. Mach 1.2 in air corresponds to only Mach 0.32 in hydrogen, the ratio of the speed of sound in the two phases, and thus the vehicle can be supersonic with respect to air outside the tube while remaining subsonic inside. Because energy consumption is a function of the first power of gas density, the hydrogen atmosphere would reduce energy consumption at a given speed by a factor of 14 relative to air.

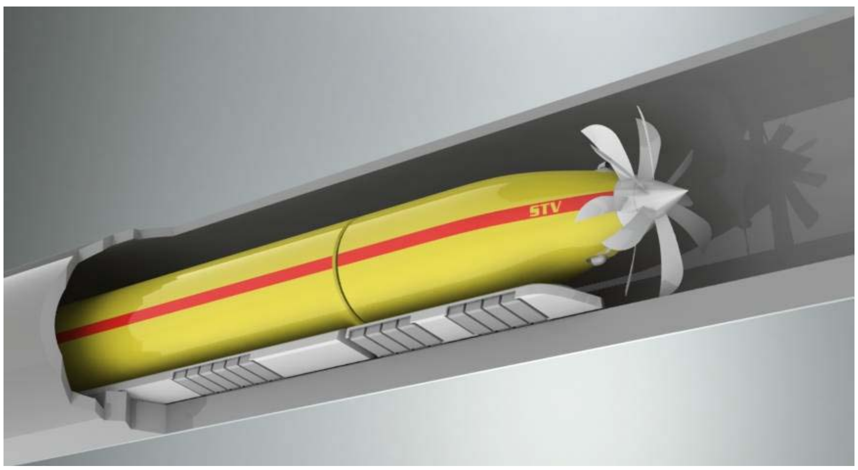

Fig.1. Supersonic tube vehicle (STV) in its hydrogen tube: Cutaway model shows front locomotive, first railcar, contra-rotating propfan propulsion, and levitation on aerostatic gas bearings. Fuselage outer diameter is 2.69 m, the fuselage diameter of the Q400 transport airplane, and tube inside diameter is 5.00 m. Tube hydrogen pressure is slightly above outside air pressure.

The proposed supersonic tube vehicle (STV), a cross between a train and an airplane, is multi-articulated, runs on a guideway within the tube, is propelled by contra-rotating propfans, and levitates on hydrogen aerostatic gas bearings (see Fig. 1). Vehicle power is provided by onboard hydrogen-oxygen fuel cells. Hydrogen fuel is breathed from the tube itself, liquid oxygen (LOX) is carried onboard, and the product water is collected and stored until the end of a run. Breathing fuel from the tube solves the problem of hydrogen storage, a major challenge of contemporary hydrogen fuel-cell vehicles.

Because of hydrogen's low density and high sonic speed, the STV is capable, in theory, of cruising at Mach 2.8 and concurrently consuming less than half the energy per passenger of a Boeing 747 at a cruise speed of Mach 0.81.

The maximum speed of the STV is the speed at which the propeller-blade tips enter the transonic region in hydrogen, and the practical maximum cruise speed was determined by aerodynamic extrapolation of the cruise speed of the propfan Antonov An-70. Assuming the Mach number for the onset of the transonic region for the blade tips in hydrogen is the same as that in air, the maximum cruise speed of the STV should be larger than that of the An-70 by the ratio of the speed of sound in hydrogen at 300 K to its speed in air at 223 K, corresponding to an altitude of 10 050 m. Thus, the maximum cruise speed of the

STV is estimated as 3500 km/h (Mach 0.74) in hydrogen, which corresponds to Mach 2.8 in air at sea level outside the tube.

Required propulsion power *P*, normalized for number of seats and distance, at supersonic speed with respect to air outside the tube has been derived by two mathematical methods utilizing aerodynamic extrapolation of the power required by the Bombardier Q400 in air and in hydrogen [Miller, 2008; Miller, 2009]. Normalized energy consumption E_0 was then computed as $E_0 = P_0\, t_0$, where P_0 is the computed power and t_0 is the time to traverse one kilometer at constant speed. Comparison of energy consumption with empirical data for transport aircraft, namely, the Boeing 747-400 and Bombardier Q400, utilized more than 28 thousand data points for the airplanes.

Several other aspects of feasibility of the concept have been completed. These include calculations showing that the vehicle is able to carry sufficient LOX and water to make a nonstop transcontinental supersonic run of 3960 km at 1500 km/h (see Fig. 2).

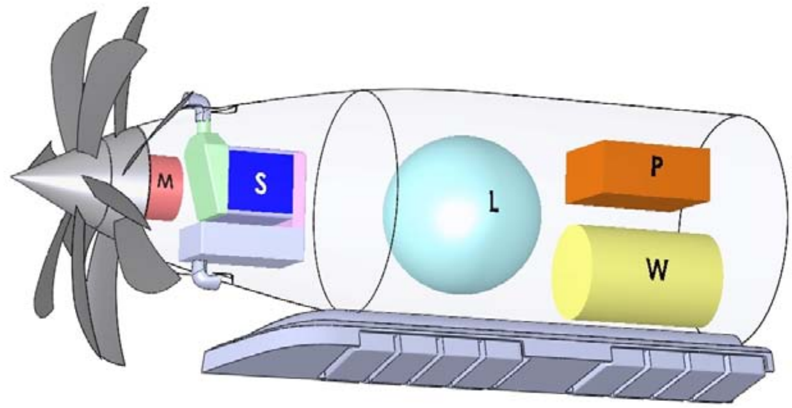

Fig 2. X-ray view of an STV locomotive: As treated in the original paper [Miller, 2008], this drawing shows feasibility of the following for supersonic transit: (a) Fuelcell stacks of the required power can be packaged within the vehicle; (b) adequate LOX can be carried onboard to allow nonstop transcontinental operation; and (c) water produced during the run can be stored onboard. The components shown are M = propulsion motor, S = fuel-cell stacks, L = LOX system, P = power electronics, and W = water holding tank. Components S, L, and W are to the scale of the fuselage diameter of 2.69 m.

This presentation will discuss the new field of aerodynamics in a hydrogen atmosphere within a tube. Propulsion efficiency in hydrogen will be unchanged from air if the propeller advance ratio is suitably adjusted. Mach waves in hydrogen are proposed as analogous to those in air but geometrical features will be magnified by a factor of 3.8, and practical supersonic speed with respect to hydrogen inside the tube is unlikely because of wave reflections. Mathematical treatment of a new kind of drag, *gap drag*, the increased drag caused by incompressible gas flow between vehicle and tube, will be discussed.

References

Miller, A. R., Hydrogen tube vehicle for supersonic transport: Analysis of the concept, Int. J. Hydrogen Energy. 33 (2008) 1995-2006

Miller, A. R., “Beyond aircraft: Supersonic hydrogen tube vehicle.” In: Proceedings of the World Hydrogen Technologies Convention, New Delhi, India, 25-28 August 2009

Presenter's Biographical Sketch

Arnold R. Miller, PhD

Dr. Miller is the president of three companies: Fuelcell Propulsion Institute, Vehicle Projects Inc, and Supersonic Tubevehicle LLC. Until 1998, he was a research professor at research universities, including the University of Illinois. Prof. Miller published numerous papers in refereed journals such as the Journal of the American Chemical Society. From 1994 to 1998, he was founding Director of the Joint Center for Fuel-Cell Vehicles at Colorado School of Mines. His first company, the nonprofit research-focused Fuelcell Propulsion Institute, has operated since 1996. As President of Vehicle Projects Inc, founded in 1998, he frequently presents its work at leading international conferences; the company develops large prototype fuelcell vehicles, such as the 130 t switch locomotive that is currently operating in Los Angeles. In 2007, he founded the independent company Supersonic Tubevehicle LLC, whose mission is to develop the theory and hardware prototypes of supersonic vehicles operating in a hydrogen atmosphere on aerostatic gas bearings. Dr. Miller received his PhD degree in chemistry from the University of Illinois, Urbana-Champaign. Additional information can be found at www.ArnoldRMiller.net