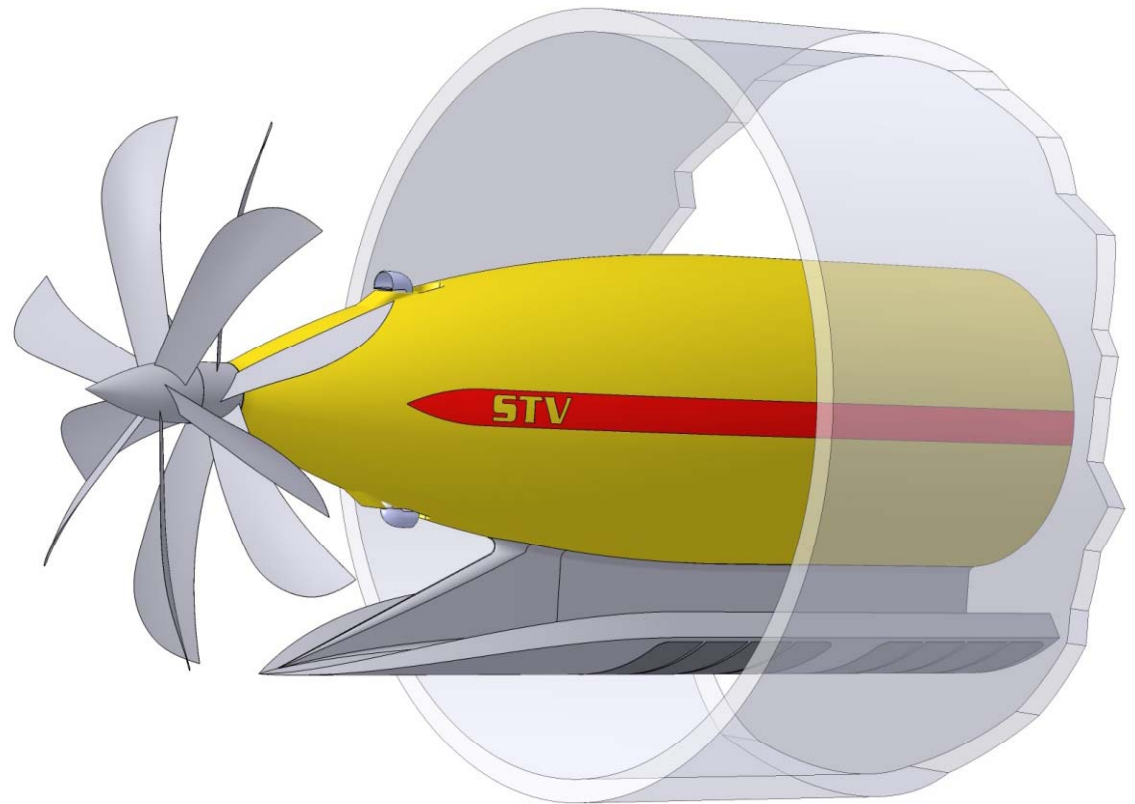


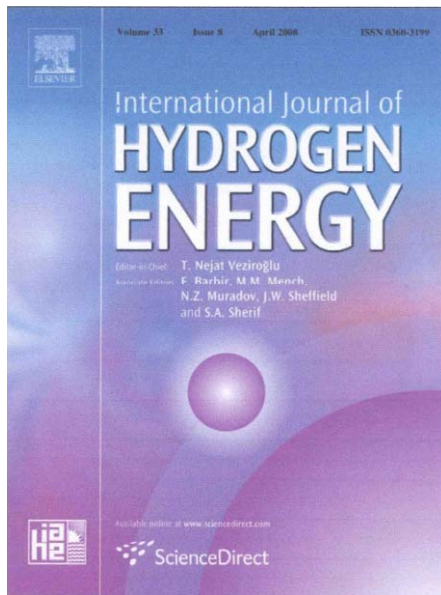
SUPERSONIC TRANSPORT WITH ZERO CARBON EMISSIONS

Arnold R. Miller, PhD
Supersonic Institute
Golden, Colorado, USA

Low Carbon Earth Summit 2011
Dalian, China
22 October 2011



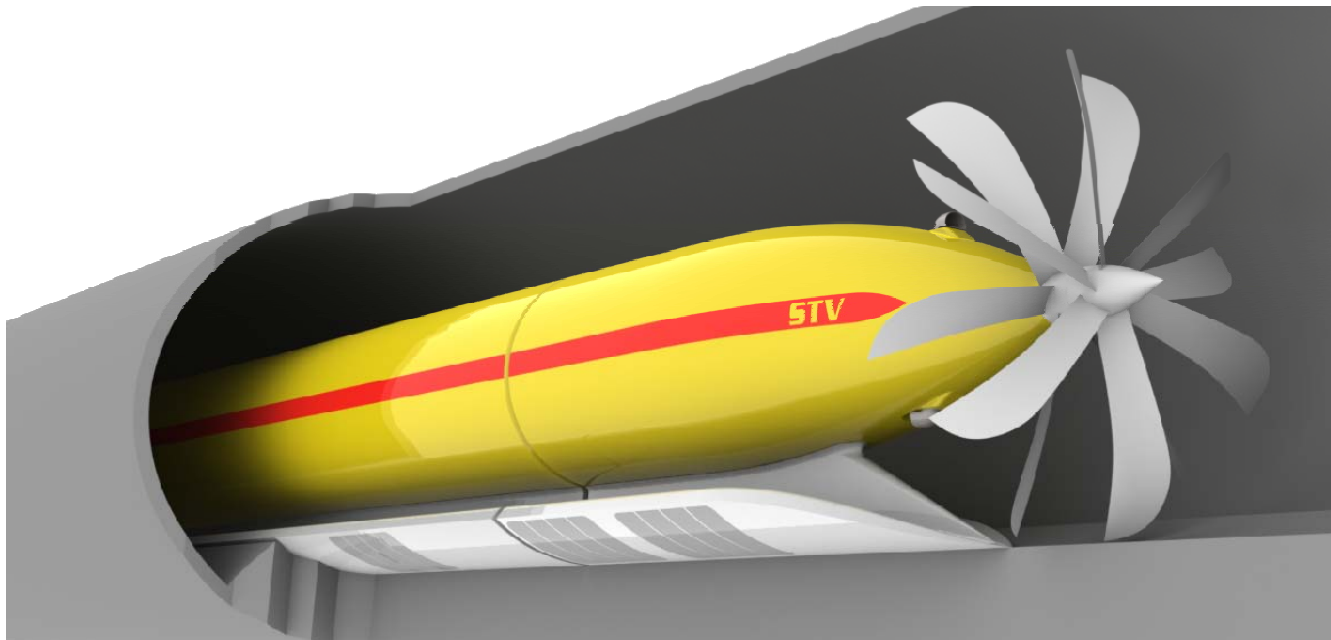
PUBLICATIONS



- **Hydrogen tube vehicle for supersonic transport: Analysis of the concept.** *Int. J. Hydrogen Energy.* 33 (2008) 1995-2006
- **Hydrogen tube vehicle for supersonic transport: 2. Speed and energy.** *Int. J. Hydrogen Energy.* 35 (2010) 5745-5753

SUPERSONIC TUBE VEHICLE: Concept

Operate a vehicle in a hydrogen atmosphere



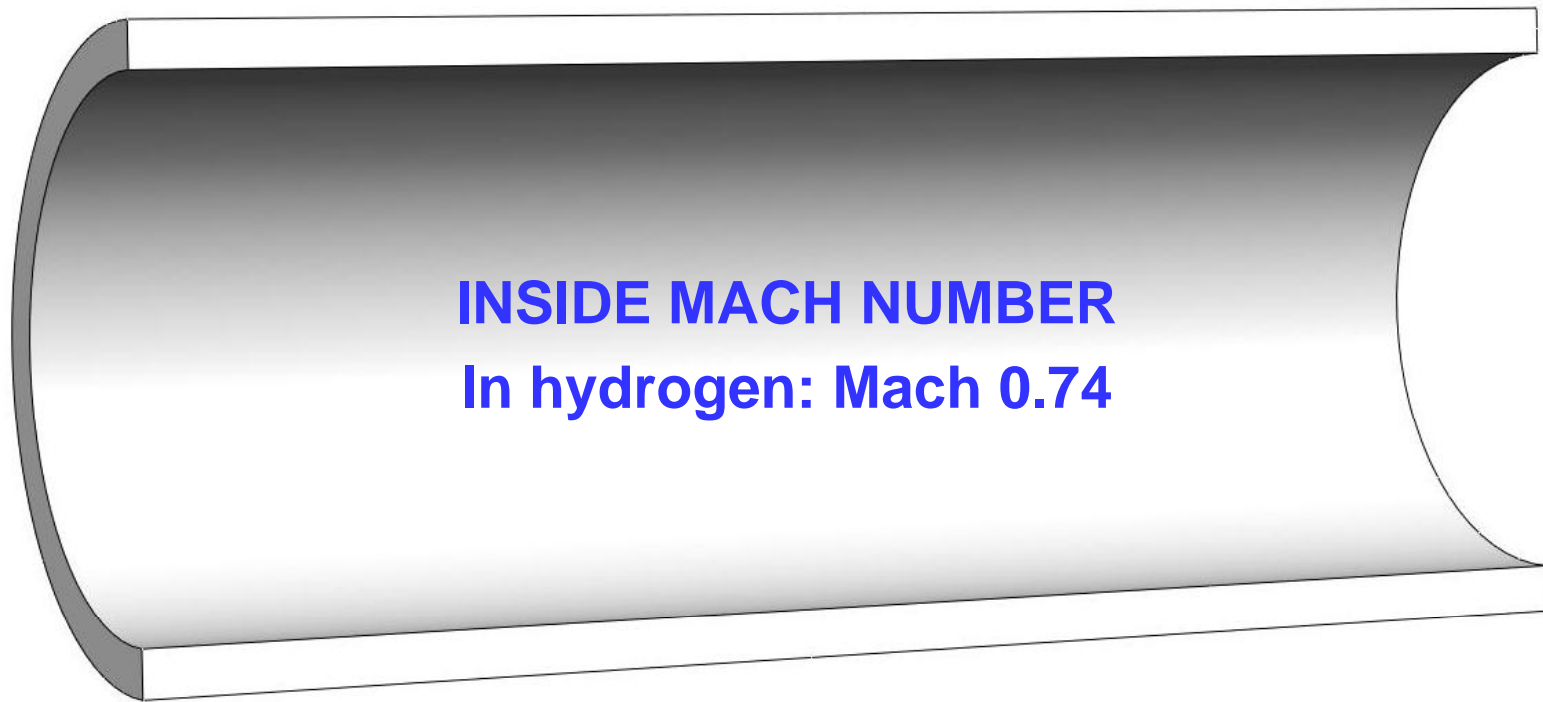
- Requires tube/pipeline
- Pressure ~ 1 bar
- Propeller propulsion
- Magnetic or gas-film levitation
- Fuelcell powered

- Onset of transonic flow increased by 3.8
- Parasitic drag reduced by 15
- Solves the problem of vehicular hydrogen storage

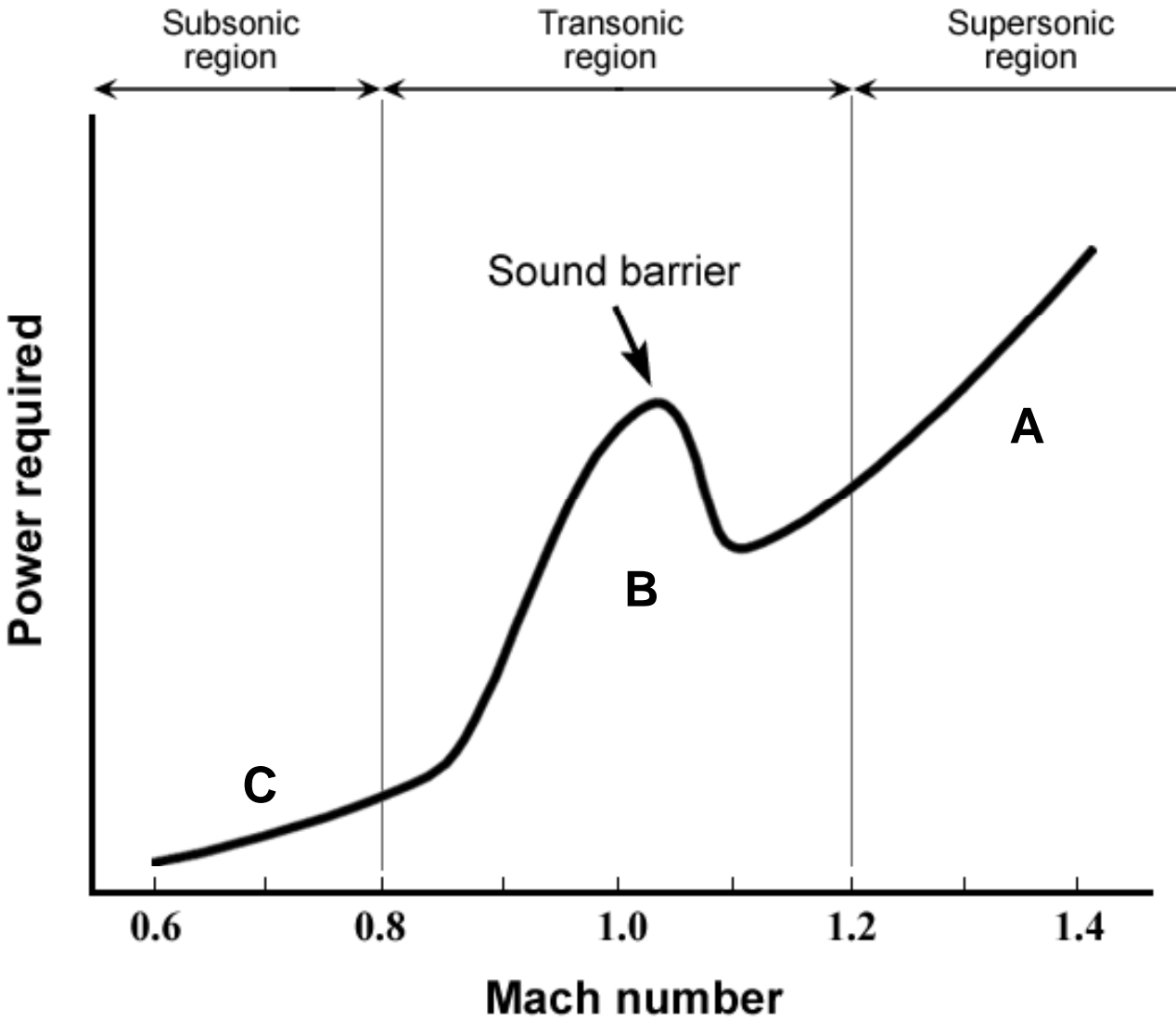
TWO MACH NUMBERS

OUTSIDE MACH NUMBER

In air: Mach 2.8



TRANSONIC LIMIT ON SPEED



ENERGY CONSUMPTION

Drag Equations

$$D_p = \frac{1}{2} C_p S \rho V^2$$

Parasitic drag

$$D_i = C_i W^2 / (\frac{1}{2} b^2 \rho V^2)$$

Induced drag

D Drag (induced drag ½ total for airplane)

C Drag coefficient

S Area

ρ Gas density (density of ~ 1/15 of air)

V Velocity

W Airplane weight

b Wingspan

$$E = Fd = Dd$$

$$P = TV = DV$$



SPEED AND ENERGY

- **Capable of Mach 2.8 (970 m/s)**
- **Concurrent low energy consumption – at 970 m/s, comparable energy per passenger-km of Boeing 747**

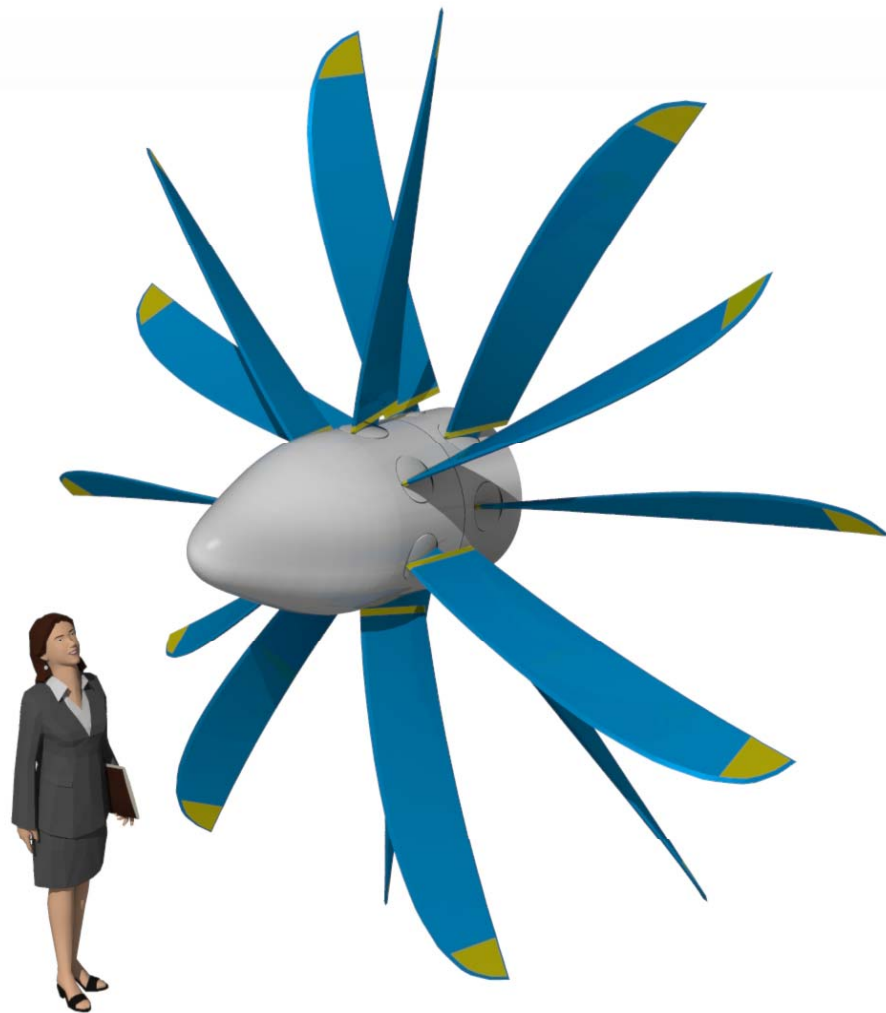
HYDROGEN PROPELLER

Diameter: 4.11 m

Blades: 14 (contra-rotating)

Frequency: 40.4 s⁻¹

Pitch: 24 m at 970 m/s





INVARIANCE

For given vehicle and speed, the following are invariant:

- **Actuator disc area at equilibrium**
- **Propulsive efficiency**
- **Pitch**
- **Helix angle**



PROPELLER EFFECTIVE SIZE

- **Maximum thrust required at $V = 0$**
- **Low density of hydrogen requires much larger actuator-disc area**
- **Effectively larger area attained by some combination of**
 - **Larger diameter**
 - **Higher frequency**
 - **More blades**
 - **Contra-rotation**



HAZARD SCENARIO

- **Tube hydrogen pressure is slightly above ambient pressure**
- **Flammability limits: 4-75 %**
- **If tube breached, leakage occurs to outside**
- **If ignited, flame would be to outside**
- **When tube pressure drops to ambient, flame would enter tube**
- **Would be extinguished as flame propagates away from breach**



SUMMARY AND CONCLUSIONS

- **Potential high speed coupled with low energy**
- **No carbon emissions from transport system**
- **Hydrogen propeller efficiency is same as air propeller**
- **Hydrogen propeller must be effectively larger to achieve acceleration**
- **Safety requires more analysis**
- **Construction of small prototype is justified by theory**