SuperHero Microturbines

Why microturbines?

Power density is inversely proportional to length (1/L). Small turbines have the potential to reduce cost, mass, and volume per unit power output and they are more amenable to mass production.

Microturbines can provide power on a scale appropriate for homes, vehicles, and persons.

Microturbines can provide power as needed, when needed, where needed, and with the voltage/current ratio needed via modularity and without the long construction times associated with legacy power plants. Timex needs to be considered along with Capex and Opex even if harder to measure.

Microturbines can provide reliability, maintainability, and throttleability by modularity.

Microturbines can provide combined heat and power (CHP). ~60 million U.S. homes have natural gas supply. A microturbogenerator with exhaust heat used for space heating and water heating can have >90% overall efficiency, provide reliable low-cost electricity and reduce grid dependence. Natural gas is much less costly than electricity, and much less subject to outages.

Utilities are attractive organizations for sales, finance, and maintenance of SuperHero systems.

SuperHero microturbogenerators are attractive for uninterruptible power supplies and emergency power production.

SuperHero backpack microturbogenerators can provide electricity and compressed air for construction and landscaping tools. SuperHero microturbine driven machine tools can provide high power density and cooling.

SuperHero technology encompasses a family of microturbines that include relatives of Hero's Aeolipile. The technology allows high power/cost, high power/mass, and high power/volume microturbines. The family includes atmospheric source heat engines, internal and external combustion heat engines, topping and bottoming cycle heat engines, boiler feed pumps, immersive self-propelled, self-cooled, liquid rocket turbopumps, thrusters, fans, condensers, expanders, liquefiers, mixed flow compressors, motors, generators, power convertors. centrifugal blowers, open and closed cycle air conditioners, dehumidifiers, and reactors.

Why haven't microturbines been more successful, despite the potential benefits?

Large turbomachines dominate in commercial air transport and electricity generation, but as the size of legacy turbomachines are reduced, some of the beneficial characteristics are reduced, often to a degree that render them unable to compete with other means.

Cost: the cost of legacy turbomachines is due in large part to the manufacturing processes associated with complex blading, and the cost of materials able to operate with high thermal and mechanical loads. SuperHero microturbines incorporate manufacturing simplicity and commodity materials.

Efficiency: efficiency is proportional to $L^{2/3}$ (square/cube law), but the loss mechanisms associated with scale reduction in turbomachines are mitigated in SuperHero microturbines by using enclosed passages to avoid rotor to stator leakage, by the use of phase change working fluids, and by advantageous heat exchange with the environment associated with increased surface/volume, especially with cryogenic fluids. SuperHero microturbines can use the spaces between the tubes of the rotating tube arrays as compressors or fans and the rotor drag can also be useful thermodynamically, especially in the case of cryogenic liquids.

Increased shear force: the reduction in passage size associated with scale reduction in microturbines implies increased shear force per unit fluid flow (<Re) and this increase in the ratio of shear to inertial force is associated with increased drag. The relative shear force increase may be inevitable, but not inevitably bad. Small passages allow increased heat transport rates and SuperHero microturbines can be designed to operate with laminar flow where drag is proportional to velocity rather than the square of velocity associated with turbulent flow. Laminar flows also produce less noise.

Fig.1 SuperHero Tipjet Reaction Microturbine

The radial tubes in the arrays of Fig.1 are composed of 1.5mm OD X 0.1mm wall thickness (17Ga) 304 stainless steel hypodermic tubing.

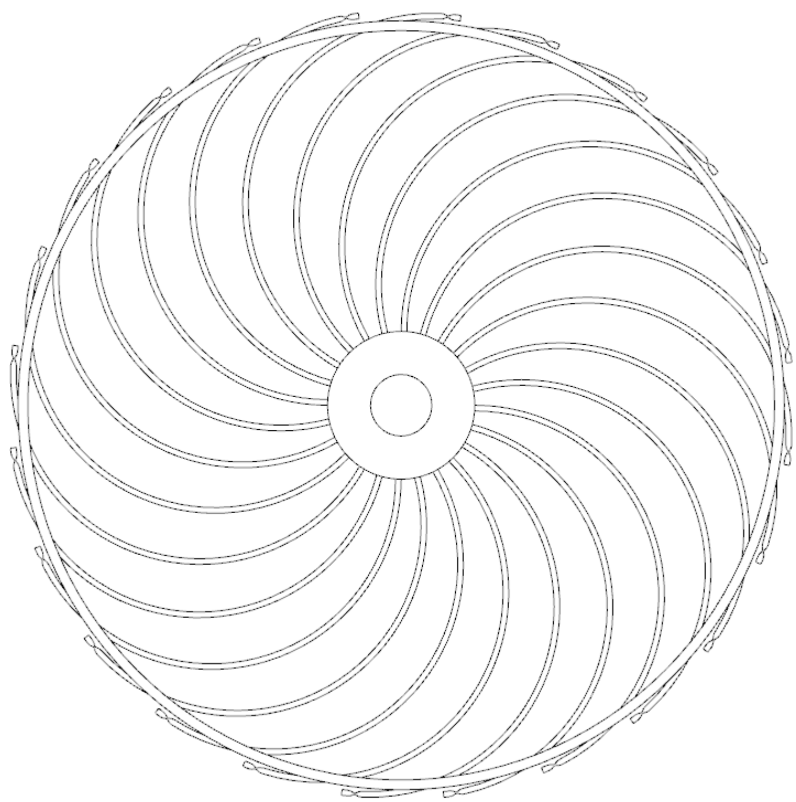

Fig. 2 SuperHero Tipjet Reaction Turbine with Backswept Passages

Fig. 2 is a SuperHero centrifugal microturbine rotor comprising a backswept stainless steel hypodermic tube array with C-D nozzles via plastic deformation and with brazed 4GPa tire cord wire supporting rings. Backswept tubes reduce drag and increase fill factor

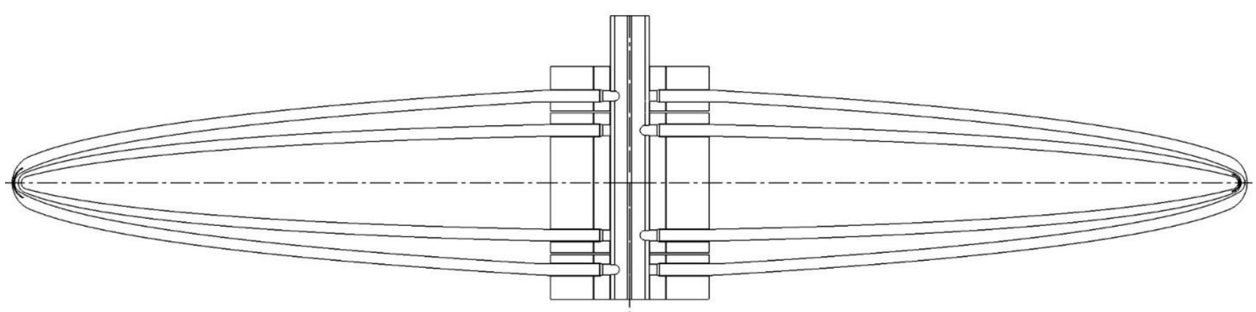

Fig.3 Contrarotating Parabolic Tube Array Schematic

Fig.3 is a pair of contrarotating radial reaction turbine arrays that can provide intense mixing and additive torque to opposing turbine array.

Superhero microturbines can generate higher pressures in a single stage than multistage legacy microturbines.

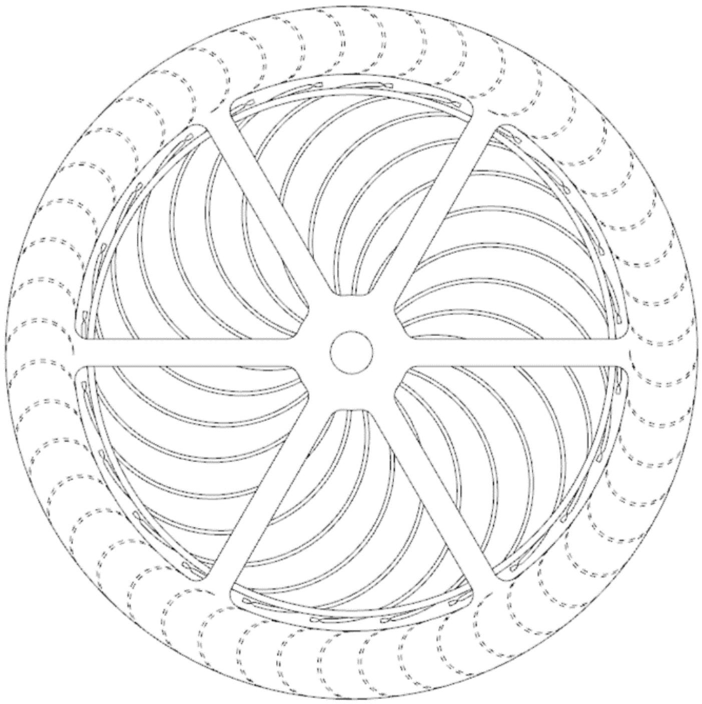

Fig. 4 SuperHero Tipjet Reaction Turbine with External Impulse Contrarotor

In Fig. 4 the SuperHero inner reaction turbine output drives a concentric contrarotating impulse turbine and the large number of nozzles provides high power density. One or more concentric contrarotating impulse turbines can be used. External contrarotors can induce and accelerate atmospheric air.

SuperHero microturbines can have many rotating tube arrays and bilateral entry.

SuperHero microturbines can provide net positive suction head for pumping unpressurized propellants.

Contrarotor spokes can be increased in number and used to induce air.

Incoming fluid passage between static axle and rotor can provide hydrostatic journal bearing.

A classic argument against tip jets is that efficient operation requires unrealistic tip speeds.

SuperHero microturbines combine modern materials and proprietary design to allow much higher tip speeds than legacy reaction turbines and the technology provides several means to use the energy downstream of the jets, including rockets, concentric contrarotating radial outflow impulse turbines, contrarotating tipjet rotors, entrainment, volutes, blown wings, and deswirl vane arrays.

One or more contrarotating impulse rotors can be used in radially outflowing SuperHero microturbine systems to provide output power with inner reaction turbine output driving the contrarotors with benefits including increased efficiency, lower output rotational rate for connection to drives, reduced exhaust temperature, and reduced exhaust velocity.

Contrarotating neighboring reaction turbine tube arrays allow jets from one rotor to add torque to neighboring rotor/s. The jets from one rotor encounter opposing high velocity flows from neighboring rotors. Contrarotation can provide intense mixing, reacting, and combustion and can be used to reduce or control output torque.

The rotating tube arrays in SuperHero microturbines cause fluids introduced through the central hollow axle to be accelerated in the tubes and ejected tangentially at the tube ends.

The tube arrays can be configured as centrifugal, axial, or mixed flow compressors and blowers.

SuperHero microturbines are rotating high power density heat exchangers capable of extremely high pressures i.e., thousands of atmospheres. The extreme pressures are confined to small regions which also serve as high-rate heat exchangers. Torque can be additive and/or subtractive.

A large population of small jets allows increased coupling with the neighboring airstream for mass, momentum, and heat transfer. Jet expansion implies a reduction in temperature that can be mitigated by close association with the neighboring airstream. The neighboring airstream may be at atmospheric temperature or preheated.

Systems can have bilateral entry for increased power density and reduced thrust loads.

A rotor with 0.1m radial length liquid phase rotating at 45krpm will develop a centrifugal pressure equal to $(1/2\rho r^2\omega^2)$. A liquid air density ρ=870kg/m^3 X 0.5 X 0.1m^2 X ω4,710^2=9.65 X10^{7}N/m^2 or 965atm with an angular velocity of 471m/s.

17 Gauge thinwall 304 SS hypodermic tubing has an OD of 1.5mm, a wall thickness of 0.1mm, and a tensile yield strength of 944MPa. The hoop stress at 1,000 atmospheres (s=pr/t) is 650MPa, which yields a safety factor of ~1.5 at 1,000atm, and the high pressure is confined to a very small region, allowing low wall mass and cost. 2GPa 301 stainless steel allows 2X pressure increase and 4GPa wire braided sleeve and helical bottlebrush inserts allows much greater pressure increase. Low temperature and cryogenic SuperHero microturbines benefit from increased material strength at low temperature and the ability to use advanced nonmetallics such as carbon fiber and graphene.

A helical “Bottlebrush” internal structure can be used to provide an array of ties normal to tube axis to resist outward pressure forces and provide extended surface area for heat exchange. The bottlebrush can use 4GPa wires and attach to the tube ID by brazing. Adding a helical moment counters Coriolis force causing flow to follow the trailing edge of the tube wall and prevents Dean vortices due to tube curvature. 4GPa central twisted wire array can provide increased axial tensile strength. The bottlebrush can be catalyzed to react with fluids in passage and operate as a chemical process reactor or the rotor can be powered by hydrogen peroxide with bottlebrush catalysis.

The small diameter thinwall tubes and high rotation rates in SuperHero microturbines provide high heat transfer rates, but extended surfaces can be used to greatly increase heat transfer rates. Commercially available 635 mesh (635 wires/inch in each of 2 axes) (250 wires/cm in each of 2 axes) stainless steel twill weave wire cloth with 18um wire can be used to create a very high heat transfer rate rotating heat exchanger/engine. The wire cloth elements can be bias cut at 45^0 to equalize heat transfer for wires in both axes and to reduce edge affects. The wire cloth elements are anchored at the hub and brazed to the tube arrays. Custom wire arrays can use high strength steel wires with copper cladding for increased heat transfer and brazing. The wire arrays can be brazed to the trailing edge of the tubes, making the tube arrays part of a hierarchal flow organization.

The rotating wire cloth arrays are somewhat analogous to crossflow filtration schemes. The high surface velocity parallel to the wire cloth arrays and the pressure difference across the wire cloth arrays provide very high heat exchange rates. The system can be designed for air to make a single pass through the capillary mesh.

SuperHero hierarchal microscale heat exchangers are attractive because small elements have increased surface/volume, smaller boundary layer, and the cost, mass, and volume of the system can be reduced.

Ref.1 details free convection heat transfer from small features. Pulavarthy Thesis CHARACTERIZATION OF HEAT TRANSFER COEFFICIENT AT MICRO/NANO SCALE AND THE EFFECT OF HEATED ZONE SIZE. "The measured heat transfer coefficient varied from 4650 W/m^{2}K in a 10 μm X 20 μm freestanding specimen to 16,300 W/m^{2}K for the same specimen 2 μm away from a neighboring solid surface". "It is to be noted that the results discussed in this section are for the experiment carried out at atmospheric pressure."

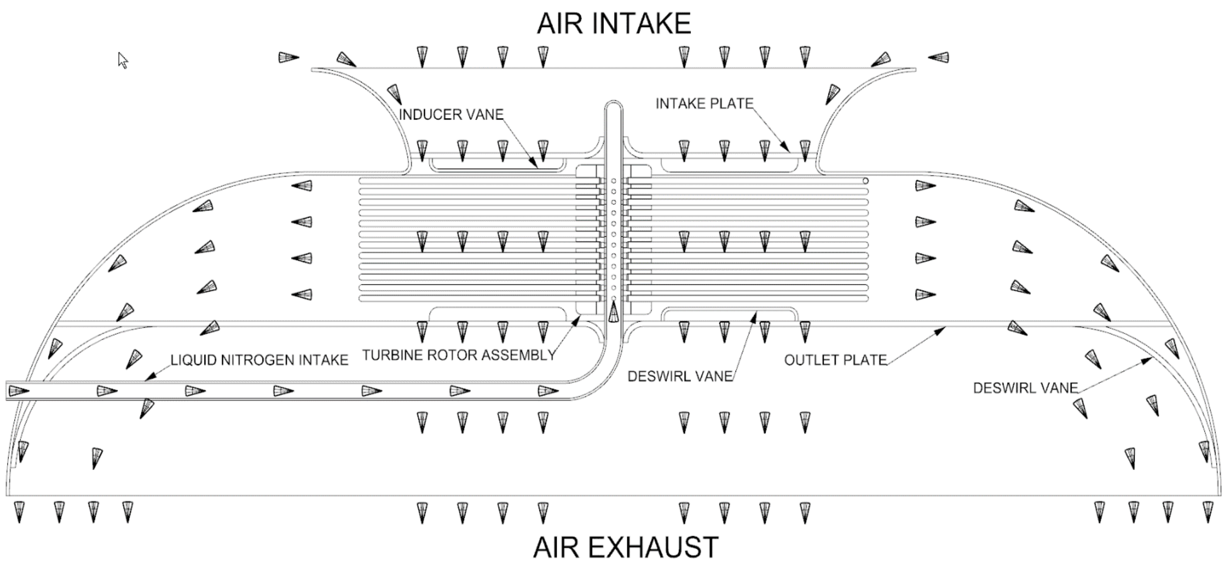

Fig. 4 SuperHero Thruster Section View Schematic

Fig. 4 is a centrifugal thruster composed of 12 rotating tube rows with 24 backswept tubes per row.

SuperHero microturbines can have shaft output and turbine groups can be arrayed around a bull gear to drive a ducted fan or propellor or for general reduced speed shaft work such as for automobiles.

SuperHero Flight Vehicles

Why Fly

Flight is "innately" cheaper, safer, faster, and more enjoyable than surface travel.

Flight is cheaper

Birds travel an order of magnitude faster than their earthbound brethren with equal mass and metabolic rate and therefore use 1/10 the energy to transport a given mass a given distance ("A sparrow, which is identical in mass and metabolic rate to a mouse, flies an order of magnitude faster than a mouse runs, and so has a minimum cost of transport an order of magnitude lower than that of a mouse" Proceedings of the National Academy of Sciences USA, Volume 95, pages 5448-5455, May 1998 Engineering). Sparrows are on the low efficiency end for birds, with soarers like albatross at the top.

Birds are also able to travel more directly between two points and to exploit favorable air motions. There are many instances where surface vehicles have to travel great distances to access a nearby region because of water or mountains. The San Francisco Bay Area is a typical example where hours can be spent in traffic to access a region a few miles distant.

Surface travel in these circumstances can be hundreds of times costlier and more time consuming than flight.

Maintaining a flight infrastructure is much less costly and disruptive than maintaining a system of roads, rails, and streams. Flight transport can reduce road traffic and has no road, rail, or stream width limitations. Surface (2D) transportation requires an enormous amount of time and resources for construction and operation.

Everyone on Earth is connected by air, flight joins people separated by mountains, oceans, and hostile intermediaries. Flight can greatly reduce the resources needed for transportation.

Why should aircraft cost more than cars? Flight vehicles can have much more even structural loading. Automobiles have four small contact patches and must be strong enough to suffer indignities like hitting a pothole while braking. Roadable aircraft have been poor cars. Aircraft can be lighter than cars per person or per unit payload, Consider the vehicle mass per person in planes, cars, trains, and ships.

Flight is Safer

Flight allows for greater distance from surface obstacles and between vehicles. Roads represent a small portion (~1%) of the Earth's surface and are restricted to the surface. Flight vehicles can cover 100% of the Earth's surface and access a large number of flight levels via 3D rather than 2D travel. The distance between vehicles can be much greater via increased surface coverage, additional flight levels, straighter paths, and shorter trips.

Flight vehicles can travel at steady and predictable speeds and air transport is more automatable. Reduced blocking from surface obstructions aids cameras, RADAR, LIDAR, SONAR, vehicle to vehicle, vehicle to ground, and vehicle to satellite communication. We also have much more experience with automated flight.

The safety of legacy flight vehicles is compromised by the need to take off and land at high speed, the proximity of other vehicles at the takeoff and landing sites, the need to maintain a certain speed to be airborne, and the lack of passive safety features.

Flight vehicles with thrust greater than mass can provide increased utility, including the ability to stop in midair, change direction rapidly to prevent collisions, easily refuel inflight, and takeoff and land in dense urban environments.

Flight vehicles also can be designed to have stable high drag descent and controlled structural deformability, making collisions, and forced landings less dangerous. Ballistic parachutes can provide additional safety.

Multiple technological advancements have increased our ability to develop low cost, robust, integrated control, communication, and navigation systems that can provide greatly increased travel safety and convenience while reducing resource expenditure.

Flight is Faster

Flight paths are more direct and do not suffer the speed limitations associated with surface obstructions encountered by road, rail, and water vehicles.
Flight offers time saving for people and critical cargoes and capital cost can be reduced by more frequent flights.

Flight is More Enjoyable

Earth from above is more beautiful; our view of it is much greater, and it yields a better understanding of our environment. Flight is typically smoother as it does not require the stopping and starting associated with surface travel and it allows much greater freedom of movement via the third dimension. Drone photography demonstrates the beauty from above.

Epilog

This is the time in our history for the transition to flight. We need to reduce the cost and planform area for personal vehicles capable of vertical takeoff and landing (VTOL).
Mass market personal air travel requires reductions in cost and increases in safety and power density. Entry level 2 place helicopters (Robinson R22) start at ~$300,000.00, 10X the cost of a car and they require large rotor swept areas ($46m^2$) and skilled operators. Cost needs to be reduced by a factor of 10 and power per unit plan area needs to be increased a factor of 10 for mass market VTOL vehicles.

Progress in computers, artificial intelligence, radio communication, GPS, cameras, LIDAR, RADAR, SONAR, and inertial sensors, have the potential to greatly increase safety and efficiency, while reducing necessary operator skills.

Much of the area of a city is taken away by roads and parking regions. Aerial vehicles do not require roads and can park from above, thereby reducing parking space access roadways.

Deliveries can be made via roof rather than obstructing traffic. Parking on roofs reduce the need for a retailer/homeowner/+, to have a parking region. They also increase security and allow our cities to be walkable, bikeable, and livable. All of a sudden, a lot more room is available in cities. Apartments, cafes, markets, parks, amphitheaters, + seem a better choice than parking lots. Upward mobility is the future.

Low cost personal air travel is also a route to lower home cost as we can easily travel further and over rough terrain and water. We can live in more natural settings without the need for roads and a grid.

The democratization of rocketry will make point to point rocket travel commonplace.
Ford felt the automobile could free people from the vagaries of the mass transit system. We now need to be freed from the vagaries of the automobile. The wheeled cart has been very useful but it is time to rise above it.

Markets for flight vehicles include people who need to cross a river or a swamp or a mountain range or escape or provide aid or put an air conditioner on a roof. Short hops can be more efficient as less propellant mass is required. Remote regions often lack roads and low cost manned and unmanned flight vehicles are attractive.

High power/mass means increased speed and range. SuperHero thrusters and liquid air allow high power/mass and high propellant mass fraction craft with a low cost propellant that can be made anywhere.

Liquid propellant powered VTOL craft can use a large portion of propellant for vertical ascent and be relatively light for translation and vertical descent vs. "battery systems" with constant mass.

A roll of photovoltaics and a SuperHero Claude liquefier provide flight. If we run out of air we can roll out a PV array and make our own.

Stable fliers can be achieved by situating the mass below the lifting means.

VTOL flight vehicles can be created by domical elements surrounded by SuperHero thruster arrays. The thruster inflow can create a subatmospheric pressure on the upper surface of the domical elements that adds to the upward force from the thruster downflow.

Thrust vectoring can replace control surfaces. Domes can be atop cylinders with propellant at bottom to create stability and to provide crush space. Domes and/or cylinders can be personal cabins or much larger cabins for passengers, cargo, and propellant. Heat can be added for increased power density. A small amount of onboard propane can greatly increase the energy and power density. The thrusters and interstitial regions can form a continuous perimeter surface to maximize subatmospheric pressure on the domical upper surface.

A VTOL craft including a vertical cylinder with a domical nose propulsor can become a horizontal tube and wing flier. The domical upward propulsor used for VTOL can become a nose propulsor for translational flight and wings can be used to increase efficiency.
Domical elements can be transparent via free blown polycarbonate sheet.

SuperHero thrusters can be used as adjunct subsystems such as for airliners to land and takeoff anywhere via VTOL.

Consider a flight vehicle with a 2.5m diameter convex upward polycarbonate hemisphere surrounded by an annular array of 24 SuperHero thrusters with a combined entry area of $1m^2$ and an intake velocity of 100m/s. Assume an effective 100KΔT for liquid air propellant (78K)and atmospheric air (273K). $100m^3/s$ X $1.2kgs/m^3$ X 1kJ/kg.K X 100KΔT=1.2MJ/s ($12Mw_t$)or 12 megawatts potential thermal power.

Each thruster contains 12 rows of 15cm length backswept tubes and 24 tubes/row. 24 axially aligned 635 mesh (250 wires/cm in each of 2 axes) 18um dia. wire stainless steel twill weave bias cut wire cloth elements 2.5cm X 15cm are brazed to the trailing edge of each of the tube groups.

The surface area of the wire mesh array=250wires/cm X 2 axes X 0.0018cm wire dia. X π X 2.5cm width X 15cm length X 24 radial tube groups X 24 thrusters =$61{,}073cm^2$ or $6.1m^2$. Assuming a free convection heat transfer coefficient of $3{,}000w/m^2K$ for 18um wire, an increase in velocity of 10X yields ~$9{,}000w/m^2K$ as the heat transfer coefficient increases with the square root of velocity and with a ΔT of 100^0K for a liquid air propellant yields $900{,}000w/m^2$ X $6.1m^2$=~$5.5Mw_t$ or 5.5 megawatts thermal energy input to the array. The limiting thermodynamic efficiency is 273K-78K/273K=0.71.

SuperHero microturbine heat transfer rate can be increased >10X by etching and by the growth of dendrites on the wire cloth surface and provide SuperHero microturbines with multimegawatt/kg thermal input. The ΔT can also be increased 10X by combustion supported by wire arrays which can also be catalyzed. Small feature size, laminar flow, high velocity, high pressure difference across the wire mesh, reduced viscosity via cryogenic fluids, and frictional heating, contribute to the high heat exchange rates. The atmosphere also yields dropwise water condensates for cryogenic propellants with a heat transfer coefficient ~100 kW/m^2K. A small amount of propane can be carried to greatly increase energy and power density.

Drag is minimized by combining laminar flow and massive end stage parallelism. Laminar flow is important because laminar flow drag is proportional to velocity whereas turbulent flow drag is proportional to the square of velocity and because turbulent flow increases the probability of a "fully heated or cooled" parcel being recirculated and exposed to additional and unnecessary drag.

The rotating arrays can be seen as porous bladed centrifugal compressors and blowers. The boundary layers associated with the blade surfaces is removed due to the pressure difference across the mesh, thereby reducing drag, and the dissipative vortices associated with legacy centrifugal flow machines are prevented.

Radial outflow contrarotating impulse turbines can be used to increase airflow.

Ascent flight economics auger for straight up as fast as possible to minimize mass and time in a gravitational environment, and to exploit the positive feedback loop associated with SuperHero atmospheric source heat engines.

Descent flight economics auger for high L/D wings.

Annular arrays of ground mounted Lasers can be used to increase power for VTOL. The thruster nozzles can be specular reflectors formed to concentrate the Laser radiation onto the turbines.

A single person flier can use a 0.75m dia. dome with a vertical cylinder below for a standing person and propellant below. Translational flight can use wings with a person in prone position.

VTOL capability greatly reduces landing gear cost, mass, volume, drag, and associated stresses on the vehicle and allows takeoff and landing without runways and airports and thereby greatly extends the use of air travel and reduces the infrastructure cost. Inflatable landing gear (external air bags) can be used for safety.

VTOL tube and wing flyers can be realized with spanwise serial arrays of SuperHero thrusters on wing trailing edge flaps that can be rotated from “horizontal” orientation for forward flight to vertical orientation for VTOL and further rotation for rearward thrust and they can be varied for roll and yaw control. The blown flaps can cause subatmospheric pressure on the wing upper surface in all positions. Blown flaps for VTOL become blown wings for forward flight. Additional thruster arrays can be placed on the trailing edge of rotatable forewings. The forewings/canards can be rotated thru 360^0 for lift, thrust, and pitch control.

SuperHero microturbines make high speeds, high altitudes, and high climb rates possible, all leading to reduced travel time. Range also increases with increasing power density.

Porpoising in and out of the atmosphere is attractive for long duration flights.

For efficient travel in a gravitational environment, such as between two points on Earth, it makes sense to spend as little time opposing gravity as possible. It follows from this to use propellant as rapidly as possible. Legacy flight vehicles have been limited in the pursuit of this goal by insufficient thrust/mass, high drag, surface heating, engine altitude limits, and structural concerns.

High speed flight also offers the potential for saving on capital cost via more frequent flights and the saving of time, especially for critical cargoes.

The combination of low cost liquid air propellant, and low cost high power/mass thrusters makes flight much more available.

The missing ingredient in VTOL has classically been power density. The extreme power density and low cost associated with SuperHero technology enables the proliferation of VTOL craft.

Personal aerial vehicles, including wing suits, jet packs, fly boards, and heavy lift quad copters become simple and affordable. A liquid nitrogen Dewar backpack, a shoulder bar, and 2 pairs of Superhero thrusters. Liquid nitrogen is more available than liquid air. Many welding shops sell liquid nitrogen. 20 liter liquid nitrogen Dewar's are available from Amazon for $370.

Stasis is attractive. A low cost "Eye in the sky" can be provided by a black parachute with a central liquid air SuperHero microturbine and a shuttle propellant supply. Cryogenic propellants are also attractive for electronics and sensor powering and cooling. A 50m^2 black parachute can supply >50kw$_t$ thanks to direct, diffuse, and reflected solar radiation.

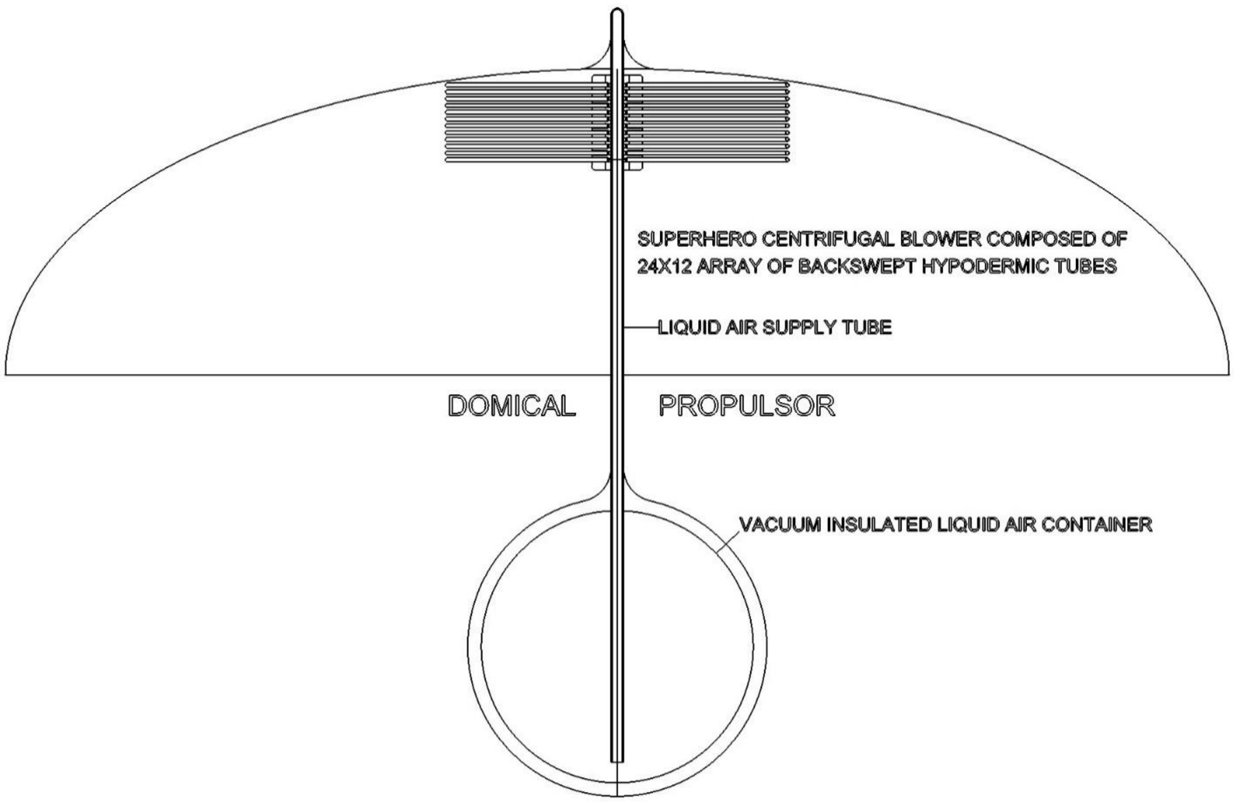

Fig. 5 Domical Flier Schematic

Domical propulsors with radial outflow SuperHero turbomachines (Fig.5) can form toroidal roll vortices with exterior downflow and interior upflow. For every downflow there is an equal and opposite upflow and the use of this upflow allows increased efficiency.

SuperHero Liquid Fuel Rockets

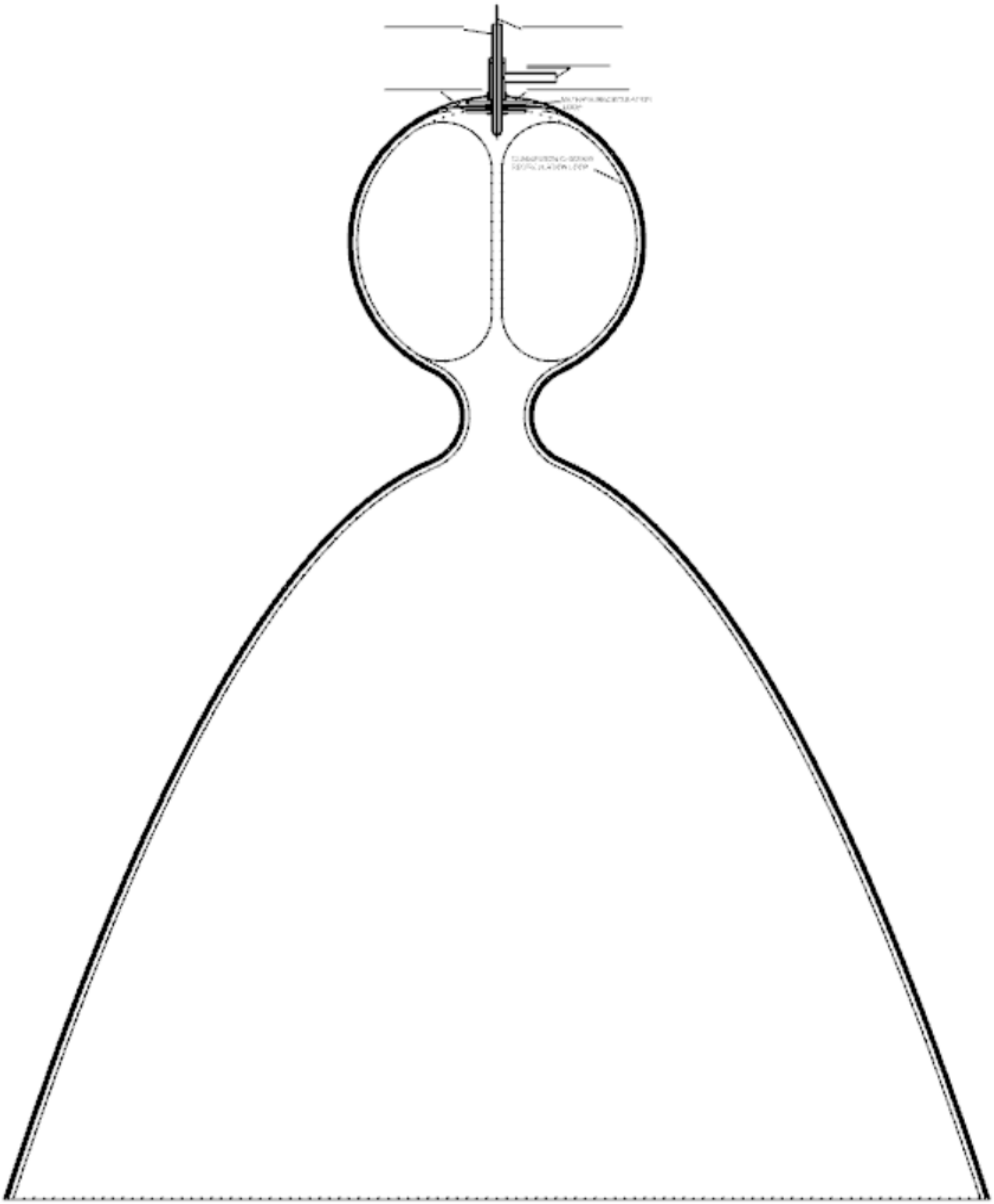

Fig. 6 SuperHero Liquid Rocket with Self-propelled Self-cooled Immersed Turbopumps

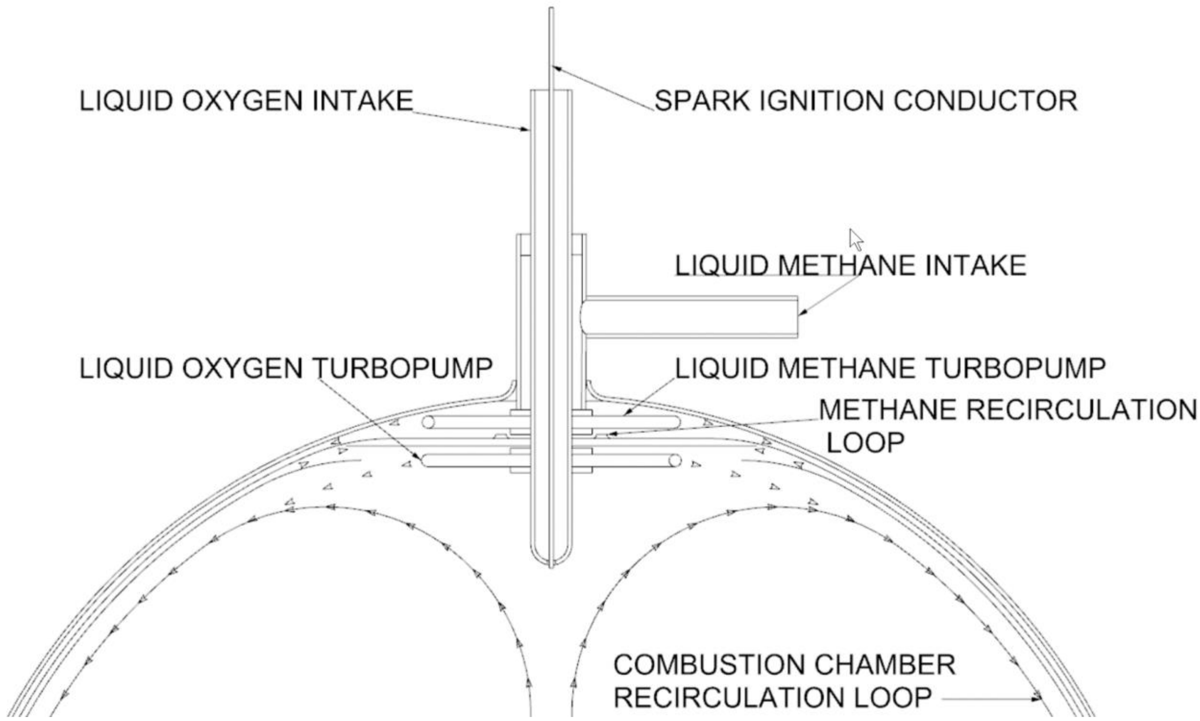

Fig. 7 SuperHero Liquid Rocket with Self-propelled Self-cooled Immersed Turbopumps

Figs. 6&7 are simplified schematic views of novel low cost liquid rocket engines.
A lightweight liquid fueled rocket engine shell can be composed of a brazed composite of copper Foil/Screen/Foil/Screen/Foil with pressure forces absorbed by an exterior matrix of brazed brass clad high strength steel wire.

In Fig. 6&7, an immersed SuperHero microturbine pumps methane or oxygen down the outermost annular passage of the Foil/Screen/Foil/Screen/Foil composite and up the innermost annular passage where it enters the combustion chamber to meet and mix with the oxygen or methane being pumped by another immersed SuperHero microturbine. A toroidal hot gas recirculation loop in the combustion chamber is used to enhance mixing and to heat the propellant in the immersed turbopumps.

To minimize the work of circulation required for engine cooling, the copper foils can have optimized photoetched aperture arrays to allow some of coolant from the outer downward passage to flow to the inner upward passage, and to allow some flow from the inner passage to the engine chamber. Photoetched apertures can also be used to direct flow from the inner passage to the coolant turbopump in a recirculation loop.

The wire comprising the brazed wireform exterior matrix can be applied via an electrically conductive wheel which resistively heats the wire as applied in conjunction with the electrically conductive copper composite shell in a process similar to roll spot brazing. The wire matrix application can be via a programmable robotic arm with an annular grooved wheel for wire capture in conjunction with the shell capable of rotation about the engine axis. The initial wire layer can be a close packed annular helix for structure and hoop strength.

The “roll brazing” system allows freedom of angular placement by rigidizing the wire connection as applied. 4GPa tire cord wire is typically brass plated and the plating thickness can be increased for brazing.

Foil and screen elements can be plastically deformed in halves via hydroforming or matched tools. Assembly for inner to outer layers can include rotating halves 90^0 in each successive layer. Inner and outer foil layers can be Laser welded.

Foil/Screen/Foil composites are attractive for heat exchange, structure and mixing and can provide a surprising large volume for fluid passage.

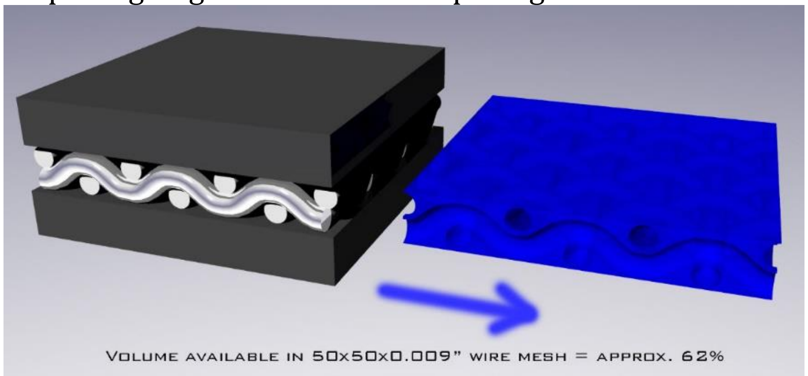

Fig. 8

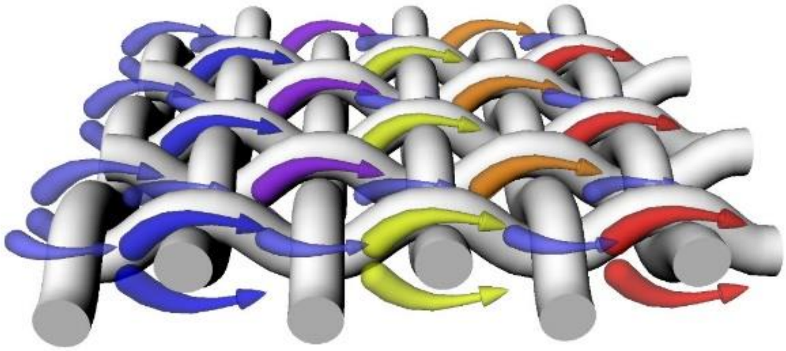

Fig. 9 Flow Paths Thru Wall Confined Screen (Wire Cloth)

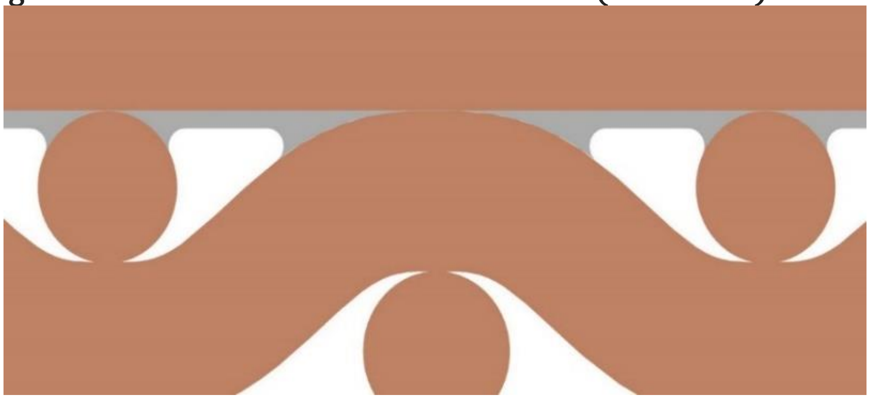

Fig. 10 Screen and Wall Connected by Braze Metal Shown in Gray.

Microturbines and associated elements can be installed sequentially in opening at shell top with sequential brazing or welding of shell components.

SuperHero turbopumps can also be used to create expansion deflection rocket nozzles.

Annular arrays of SuperHero liquid fueled rocket engines (Figs.6&7) can be placed around the upper regions of vertical cylindrical rockets for stability and reduced footprint with directional control via thrust vectoring.

Staged cylindrical flight vehicles can be concentric to allow the 2nd and later stages to use pressure in the space between stages like a gun to benefit from the reaction mass potential offered by the earlier stage. Propellant tankage can be annular and/or at bottom.

SuperHero cryogenic thruster arrays can be used to power the 1st stage of multistage rockets to reduce cost and footprint.

Rocket descent energy can be captured by using the high air velocity to drive SuperHero turbomachines for air liquefaction.

Automobiles can use modules integrating inboard brakes with SuperHero microturbines and associated gearing. Each wheel can have its own microturbine/s and braking system to avoid the need for a differential and to improve vehicular control. Braking heat can add to turbine power.

Trucks and trains are excellent candidate for liquid air power. The chassis/structure can be made of tubes and the tubes can store liquid air for uses including SuperHero Atmospheric Source Heat Engines, SuperHero exhaust heat recovery microturbines and/or SuperHero turbochargers can be used to provide cold pressurized air to internal combustion engines. Subway trains can have onboard power. Superhero turbomachines are attractive as the downstream cycle in combined cycle heat engine applications.

Travel speed can be used to create a positive feedback loop in cryogenic Superhero turbomachine applications by increasing air intake velocity and the corresponding air mass flow rate. When the atmosphere is the heat source, the air mass flow rate is a limiting factor and increased velocity can increase the air mass flow rate and power density. Flying can provide greatly increased mass flow rate and power density.

Ships are attractive candidates for liquid air propulsion due to "square cube law", i.e., the drag is proportional to the wetted area (L^2), while the storage is proportional to the volume (L^3). The future of drag reduction in ships is boundary layer air (ALS) and liquid air and SuperHero microturbines are attractive for the production of the massive amounts of air needed.

Ref. 2 Drag Reduction of Ships by Microbubbles Yoshiaki Kodama1 , Akira Kakugawa1 , Takahito Takahashi1 , Shigeki Nagaya1 and Takafumi Kawamura2 1 National Maritime Research Institute of Japan kodama@srimot.go.jp 2 The University of Tokyo “as the amount of injected air increases, skin friction reduction effect by microbubbles increases up to 80%. Ships such as tankers play a major role in marine transportation. They are very large and move very slowly. They are especially suited to microbubbles. One reason that they are suited is that their skin friction drag component occupies about 80% of the total drag”.

Container ships often have thousands of refrigerated containers and the containers can be the evaporators(heat exchangers) for liquid air turbogenerators, including for propulsion.
Shkval torpedoes use a gas boundary layer to allow speeds >200knots. Submarines can use liquid air for speed bursts similar to Shkval.

Reactor

High pressure chemistry can be achieved in SuperHero continuous flow reactors composed of radial arrays of rotating “U” tubes with one end of each tube connected to the intake end of the axle and the opposite end connected to the output end of the axle.

Continuous flow reactors can be achieved with tipjet rotors which can deliver products in gaseous, vapor, or powder form and they can rapidly cool media by expansion.

Extreme pressures are possible and bottlebrush interior elements can be used for mixing and catalysis. High heat exchange rates allow cooling of exothermic reactions.
Concentric heating can be used to optimize thermal history. Induction and radiation are 2 options.

"U" tube rotors can operate in vacuum for high rotational rates without drag.

Rotating Heat Exchangers/Boiler Feed Pumps

SuperHero rotating "U" tube heaters and boilers allow fluid entry in a hollow axle and fluid exit in the opposite end of a hollow axle with a blockage between entry and exit.
Downstream turbines can be used to drive SuperHero boiler feed pumps. High pressure steam boilers used for electricity generation have tube wall thicknesses ~1cm to withstand the pressures used whereas SuperHero steam boilers can have tube wall thicknesses ~0.01cm, 1/100 the thickness and 1/100 the tube wall thermal resistance. The boiler cost, mass, and volume are greatly reduced as is the thermal response time. The wire mesh elements can be used as flame holders and/or combustion/heat can be added upstream. Modular arrays of SuperHero boiler feed pumps can replace large scale boiler feed pumps and offer another means of throttling.

Electrodynamics/Electronics

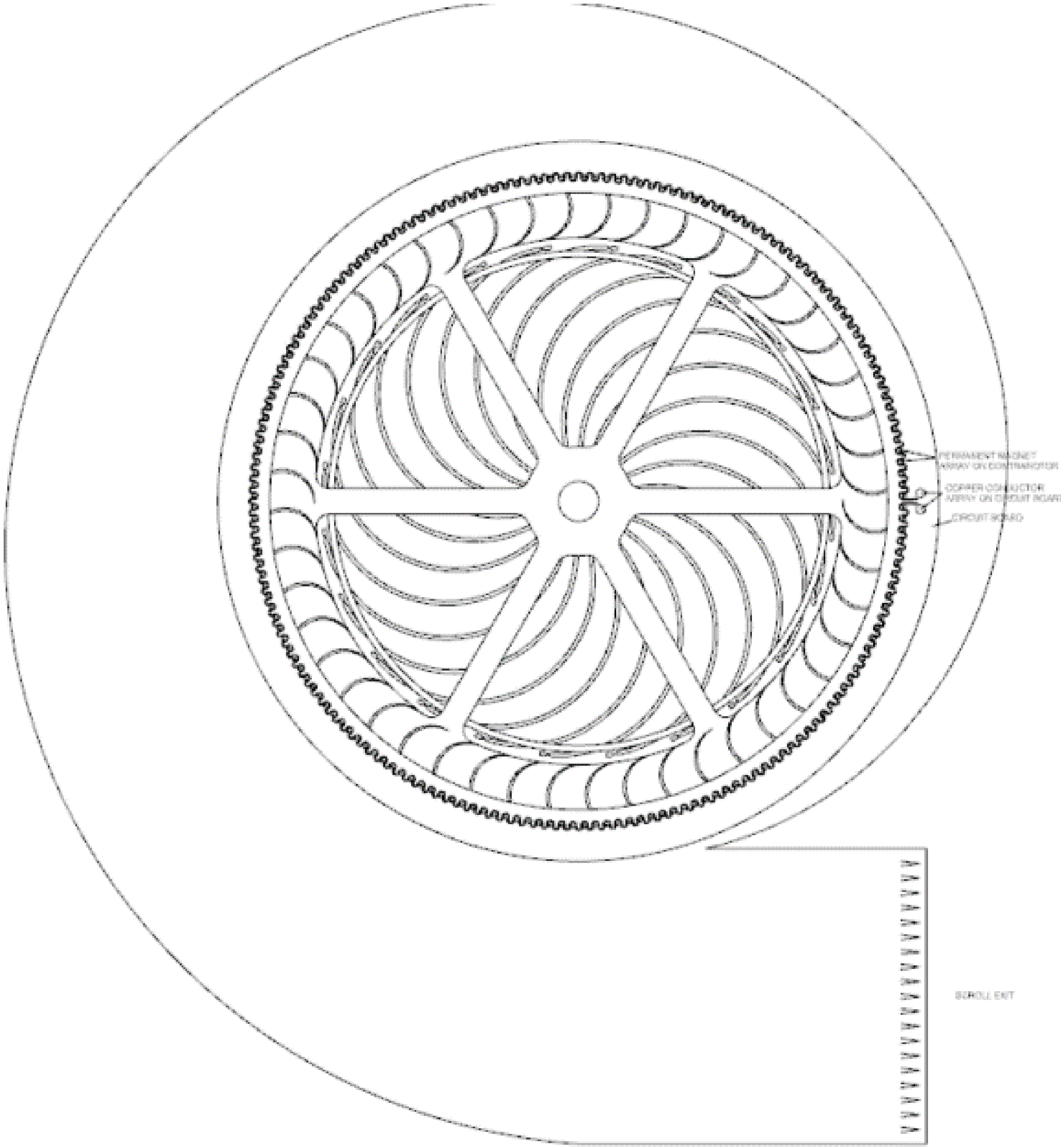

Fig. 11 SuperHero Turbogenerator with External Contrarotor and Scroll Output

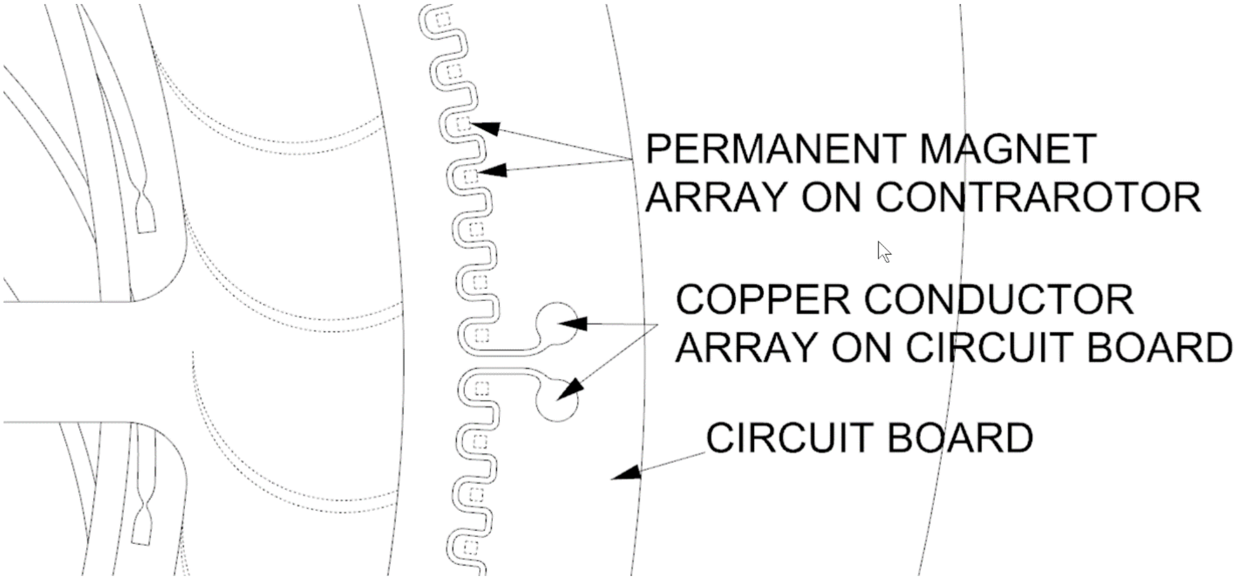

FIG. 12 AC SuperHero Electrodynamic Convertor

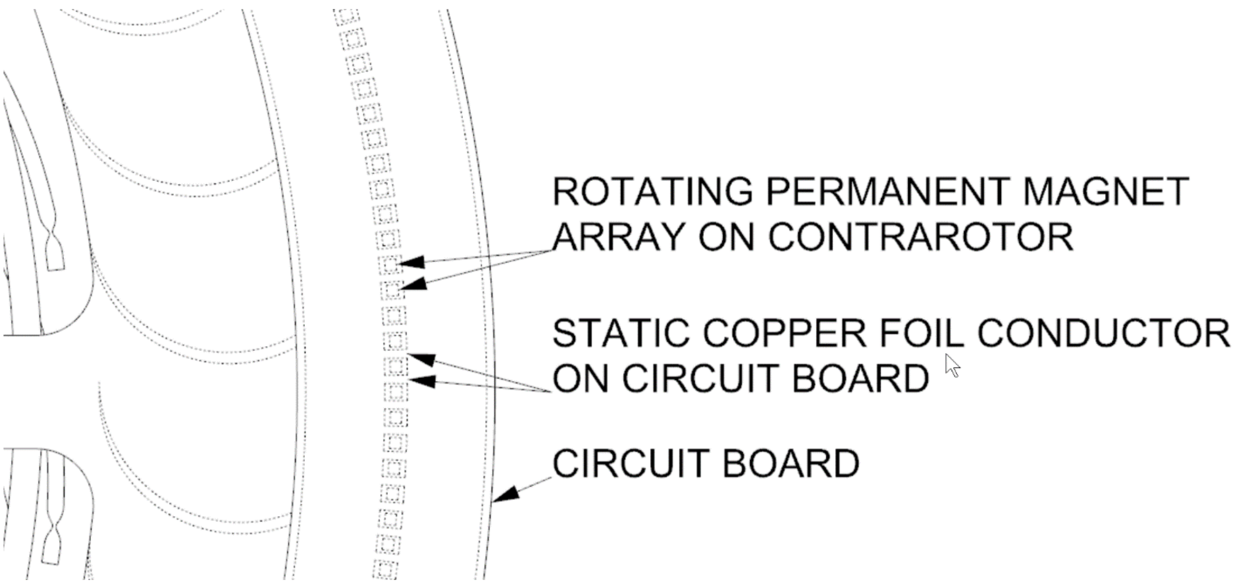

FIG. 13 DC SuperHero Electrodynamic Converter

Rotating permanent magnet arrays on one or both faces of external contrarotors induce current in etched copper foil conductors on the circuit boards. Foil conductors offer better form factor than circular section conductors and scaling law augers for small magnets.

Poles can be closely spaced to increase frequency and power density.
Compact planar electrodynamic converters have wide applicability.
Powerful and powerfully cooled light sources can be created with LASERs/LEDs operated by turbogenerator directly i.e., each pole or pole group can operate one or more light sources. Heat exchange can be enhanced by the cool exhaust from a cryogenic SuperHero microturbines and by closely spacing rotors and circuit boards. A rotor to stator/circuit board gap can provide air bearing.

Rotating electronics are very attractive as they can be powered by SuperHero microturbines and cooled at very high rates with output from Superhero cryoturbines. The heat from the electronics is used to power the SuperHero cryoturbines.

Rotating power converters offer reduced cost, mass, and volume, and increased heat transfer.

Rotors can provide mechanical capacitance with 100X the energy density of electrostatic capacitors. Mass can be added for additional mechanical capacitance.

Multiple inputs and outputs are possible in a given rotor and multiple disc rotors offer further opportunities.

Electrical communication between rotors and stators can be via permanent magnet arrays on rotors and/or stators and/or annular high frequency transformers. Optical communication between rotors and stators can be via LEDs/Lasers and detectors.

Electrodynamic/electronic rotor systems can be shaft driven and separated from fluid systems to avoid contamination.

SuperHero microturbines with volute output are good candidates for powering blown wings, rotors, and fans via spanwise thin section low pressure jets on the foil upper surface.

HVAC

Cryogenic or atmospheric air SuperHero microturbines can provide low pressure air to power large diameter ceiling fans via "blown wing" type scheme. Upper surface tangent blowing via linear spanwise slots can propel the rotor and deliver temperature controlled air. Cold air can be via expansion of atmospheric air and/or liquid air and warm air can be via SuperHero turbogenerator compression heating and/or electric resistance heating. The blown wing surface provides heat exchange with the local atmosphere.

SuperHero microturbines can be electrically driven to create air cycle air conditioners. Atmospheric air can be compressed and the heat of compression transferred to the local atmosphere via an axial flow configuration with an annular band confining outward flow. The air emitted tangentially from the jets is subject to expansion cooling and can feed a scroll for output to cooled space.

A 0.1m radial length rotor at 60krpm operating @STP can provide 2 atmospheres pressure and expansion cooling yields a temperature reduction of ~40^{0}C for isothermal compression and adiabatic expansion. Actual temperature reduction will be less. Automotive turbochargers can produce >3 atmospheres without passage enclosure.

SuperHero microturbine air conditioners can integrate motor, compresssor, heat exchanger, expander, and fan to create a low cost, low mass, compact product with rapid cooling and easy personalization.

SuperHero air cycle air conditioners can operate as dehumidifiers. Exhaust expansion can be sufficient to liquify the water vapor in the exausting air and direct it to a receiver.

SuperHero External Combustion Microturbines

External combustion can be used to heat fluids within the rotating tubes. Liquid propellants are attractive as pressure is proportional to density. Liquids can be used in conjunction with gases in slug flow schemes to pressure gases and combined fluids. The external combustion can be local or remote i.e., it can be from sources including internal combustion engine exhaust, unilateral or bilateral attached combustors. Combustion can be within the turbine space supported on the wire mesh array and/or downstream of reaction turbine with external impulse contrarotor/s. Turbines can be shrouded to increase efficiency. High power density recirculating water steam engines are attractive and H_2, HC, and alcohol fuel combustion produce water which can be recycled. Superhero microturbines can be designed with bilateral entry for increased power density and reduced thrust loads.

Fuels include: H_2, natural gas, LPG, gasoline, alcohols, alcohol/water blends, and E85.

Very high power density engines can be created by separating liquid air into liquid oxygen and liquid nitrogen and using liquid oxygen and fuel for combustion on catalytically coated meshes, avoiding nitrogen oxides and the need for a compressor. The combustion can power SuperHero liquid nitrogen fed reaction turbines with output from the reaction turbines operating concentric contrarotating impulse turbines. Nitrogen as a working fluid is less corrosive than steam. Liquid air can be produced and separated during periods of reduced demand.

SuperHero Internal Combustion Microturbines

SuperHero internal combustion microturbines can use stored compressed air prepressurized by SuperHero liquid piston compressors and/or directly pressurize air with fuel or water as liquid piston and/or use stored or directly created liquid air or liquid oxygen.

Alcohol/water mixtures are especially attractive as they allow increased overall propellant density and can be produced locally from a wide range of feedstocks. Alcohol/water mixtures are relatively clean burning and alcohols will combust in any proportion with air above a certain temperature.

Ignition means include compression ignition, induction heating, spark, and catalysts.
Recirculating liquids allow near isothermal air compression via liquid piston.

Liquid oxidizers are very attractive for heat engines. SuperHero internal combustion engines can benefit from the use of liquid air or liquid oxygen rather than the typical high pressure air supplied directly by engine output. A portion of the engine output can be used to drive liquefiers during low demand periods and the stored liquid air or liquid oxygen can be used for high demand periods. Liquid air or liquid oxygen offers increased power density, increased efficiency, increased throttleability, and increased cooling.

Surface vehicles in mountainous travel can operate liquefiers during downhill periods from engine power and vehicle gravitational energy and use the liquid oxidizer during uphill periods. Liquid air and liquid oxygen are more easily stored than compressed air. Flight vehicles can use liquid oxidizers for VTOL, rapid climb, and very high altitude operation.

Electricity demand variations can be better accommodated by incorporating liquid oxidizers into the cycle.

SuperHero internal combustion microturbines are of increased scale when compared to externally heated SuperHero microturbines.

SuperHero internal combustion engines can use backswept rotating arrays of concentric tubes that provide oxidizer in the annular region between the inner and outer tubes. The oxidizer can flow to the central fuel containing tube/region by apertures that vary with tube radial distance. Aperture means include braided wire tube, helical wire with varying aperture, and photoetched tube. Channel materials can be catalytic. The inflowing oxidizer cools the inner tube.

Spacing between tubes can be via woven wire cloth, twisted wire helices, helical wire wound with finer wire, and axial wire arrays. Helical pitch can vary with length.

The assemblages can be brazed for structure and heat exchange. Internal parts can be plated for brazing. One or more concentric contrarotating impulse stages can be incorporated.

Bottlebrush Structure/Heat Xngr/Reactor

A helical "Bottlebrush" internal structure can be used to provide an array of ties normal to the tube axis to resist outward pressure forces. Bottlebrush inserts can be used to provide catalysis, increase the number of fluid passages, increase strength, increase heat transport, increase fluid velocity, increase fluid path length, reduce Coriolis force effects, reduce Dean vortices, and increase surface area. Fluids can follow helical flights with some probability of passage thru porous flight for high rate heat exchange. Bottlebrush inserts can be attached to tube via welding, brazing, or soldering. Friction via rotation and/or oscillation can be used to weld, braze, or solder the bottlebrush to the tube ID.

SuperHero Continuous Detonation Engines

Continuous detonation engines have proved difficult, but SuperHero cryogenic microturbines can provide the pressure ratios, the phase change expansion ratios, and the temperature ratios sufficient for continuous detonation. The pressure ratios, the phase change expansion ratios, and the temperature ratios combine to provide a system where meters/second intake flows can easily support continuous kilometers/second detonation waves.

Concentric tube systems with radial inflow from external liquid air or liquid oxygen can provide the cooling rates needed for continuous detonation. Mixing occurs after entry to the inner tube and as a consequence the inner tube is not exposed to the direct heat of combustion. Helical flows can be used to further concentrate maximum temperatures near the central region.

Helical inserts can be used to enhance detonation and increase path length.

SuperHero Nuclear Microturbines

SuperHero nuclear microturbines can be used with recirculating nitrogen. Nuclear heating of nitrogen can be used to evaporate nitrogen in SuperHero microturbines.

A Liquid Air Economy

Why Liquid Air?

A liquid air economy has many benefits. Liquid air can be made anywhere, no need to mine it, no need to refine it, it is non-polluting, relatively safe, and it can be made at low cost with SuperHero Claude cycle liquefiers.

Liquid air can provide short-term and long-term storage for intermittent sources such as photovoltaics and wind.

Liquid air is attractive as a "utility." It is cheaper to distribute liquid air in a district or a building for air-conditioning, air make up, compressed air, refrigeration, electricity production, fan operation, electronics cooling, and electronics powering, than to provide these services individually. Liquid air can be supplied via a recirculating loop manifold. Personalized cool, clean fresh air can be provided at low cost and with low noise and heat can be added via electricity from SuperHero liquid air turbogenerators.

Compressed air is also an attractive utility and would be used much more with greater access. Superhero microturbines can provide quiet compressed air at low cost. Compressed air can be provided from liquid air by “U” tube type SuperHero microturbines. Compressed air can be provided by SuperHero liquid piston recirculating water air compressors.

Compressed air can be provided by liquid air ported to a storage vessel and then closed off from the supply vessel and using atmospheric heat to evaporate and thereby pressurize the air in the compressed air storage vessel. Compressed air can be provided from liquid air by a pump made from a pair of check balls with a heat exchanger between. Compressed air can be provided by liquid air pumps and heat exchangers for continuous supply.

Liquid air can be transported by pipelines, trucks, trains, planes, and ships. Storage can be refilled as needed.

Liquid air allows existing fuel stations to become liquid air stations.

Liquid air offers fast fill vs. the long waits associated with battery systems.

Liquid air is storable without pressurization. Oil and gasoline storage tanks can be converted to liquid air storage tanks.

Liquid air controls require less cost, mass, and volume than electrical controls, including those required for automotive battery systems.

Liquid air storage vessels can be used as structural elements for mobile and stationary systems. Car, truck, train, plane, and ship structures can be made of tubes used for liquid air storage. Building structures can be formed from tubes used for cryogenic liquid storage.

Energy density. Liquid air at high pressure can have energy densities ~200Whr/kg, less that Li-Ion, but greater than Lithium Iron Phosphate, which Tesla and other EV mfrs. are transitioning to due to the reduced cost and increased safety. Electric vehicle batteries require costly heating, cooling, and control systems that further reduce their useful energy density. Liquid air vehicles have reduced mass with travel, especially important with aircraft.

Power density. Liquid air SuperHero atmospheric source heat engines can provide power densities 10-100 times as great as battery systems and without the concern of overheating.
In server farms Superhero liquid air turbogenerators can both power and cool the electronics. Electronics can operate at much higher power densities and with better efficiency, reliability, and durability via lower operating temperatures and modularity and cryogenic cooling allows the use of lower bandgap semiconductors such as Germanium.

A liquid air economy can use liquid nitrogen and liquid oxygen. Liquid oxygens reactive potential makes it much more valuable than liquid nitrogen. Liquid oxygen can be used for combustion to greatly improve power density and to prevent oxides of nitrogen, it can be used for breathing, it can be used for high altitude operation, including rockets for point to point and space travel, and it is useful in many chemical processes. Liquid oxygen can be used for a SuperHero combustion engine topping cycle and liquid nitrogen can be used for a SuperHero cryogenic engine bottoming cycle.

SuperHero Atmospheric Source Heat Engines

SuperHero atmospheric source heat engines can have high thermodynamic efficiency with cryogenic fluids. Additional benefits include safety, no need for ignition, no reaction time limits, no combustion space needed, drag heating utility, and boundary layer viscosity reduction via reduced temperature. Atmospheric source heat engines are limited by atmospheric air mass flow rate and this can be increased by increasing travel speed, a positive feedback loop.

Bottom up Thermodynamics

Thermodynamic efficiency is proportional to the absolute temperature ratio.
Maximum thermodynamic efficiency=1-$T_{low}/T_{high.}$ For liquid air T_{low} @78^{0}K and ambient temperature T_{high} @273^{0}K (1-78/273=0.71), or 71% maximum thermodynamic efficiency.
To achieve a similar thermodynamic efficiency with ambient temperature being T_{low}, T_{high} must be ~900^{0}K (1-273/900=0.7). The higher operating temperature requires costlier materials and implies heat loss to the environment rather than heat gain from the environment as is the case with liquid air.

SuperHero microturbines with cryogenic propellants can convert sensible heat from atmospheric air and latent heat from atmospheric water vapor to rotational motion which can be used for electricity generation, shaft work, or thrust.

Atmospheric energy conversion. Sensible heat. A vehicle travelling at 120k/h (33m/s) provides ~42kg/s of air to a 1m^2 aperture. 42kg/s X 100^{0}K ΔT X 1kJ/kg/^{0}K=4.2Mw_t. A portion of the thermal energy can be converted to rotational energy and used to generate electricity, mechanical drive, or thrust.

Atmospheric energy conversion. Latent heat. Water liquid/gas latent heat of phase change energy =2.3kJ/gm. A vehicle travelling at 120k/h (33m/s) provides 33m^3/s of air to a 1m^2 aperture. Air at STP and 50% humidity contains 33m^3/s X 11.5 gms H_2O/m^3 X 2.3kJ/gm=873kJ/sec or 0.87Mw_t. Hydrocarbon and hydrogen fuel combustion can add to water production. SuperHero cryogenic microturbines can provide freshwater from the atmosphere via condensation.

SuperHero cryogenic microturbines are attractive for working in hot areas, foundries, metalworking, ceramics, and glass industries. SuperHero cryogenic liquid nitrogen microturbines are attractive for working in flammable and explosive environments.

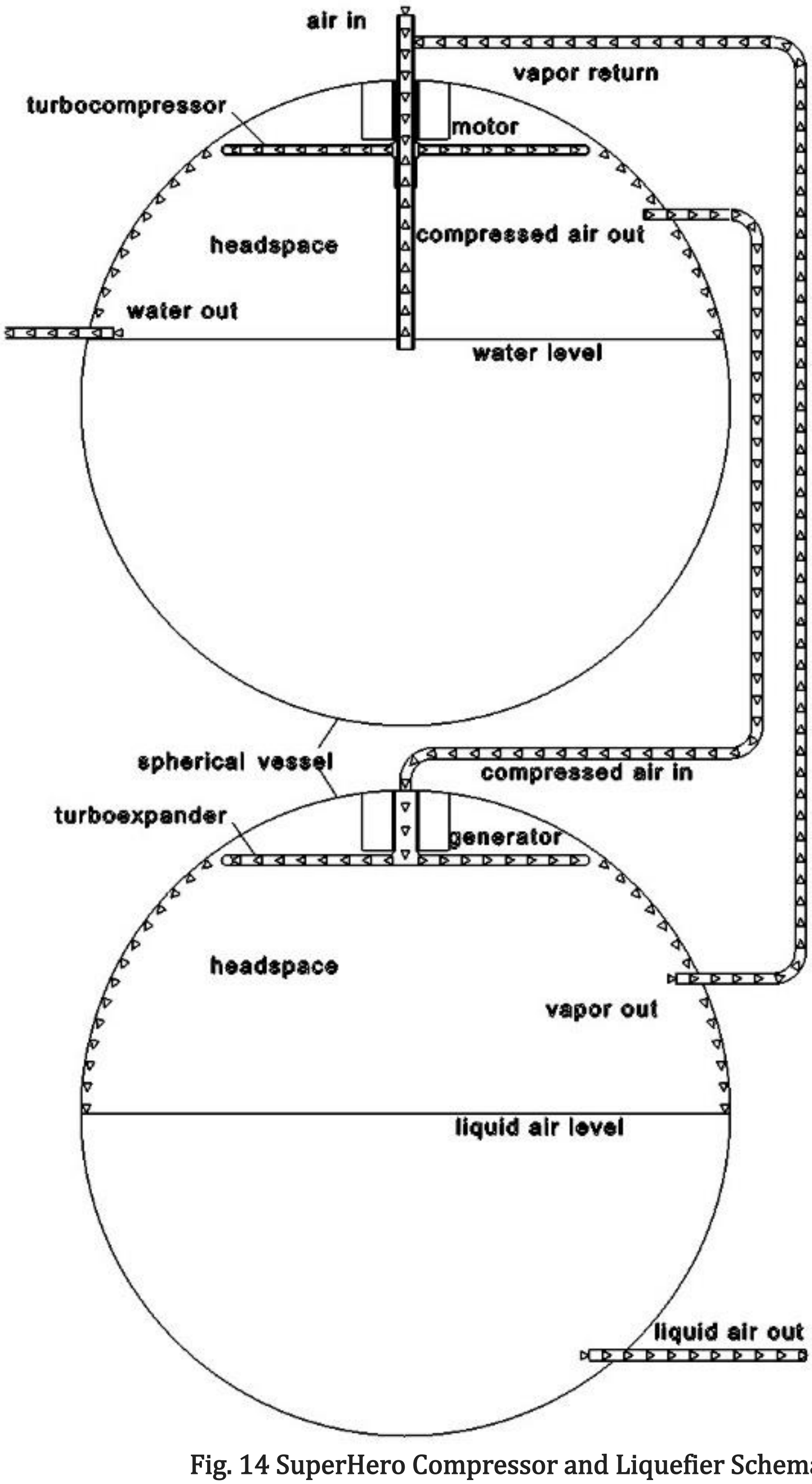

Fig. 14 SuperHero Compressor and Liquefier Schematic

The motor driven SuperHero microturbine in the upper spherical container in Fig.14 uses recirculating water as a periodic liquid piston to provide near isothermal air compression.
The compressed air from the upper spherical container can be expanded in the lower spherical container by a SuperHero microturbine expander to liquify the air in a Claude cycle.

Cryogenic CO_2 Capture

SuperHero cryogenic microturbines can reduce the exhaust temperature from carbon containing fuel combustion sufficient to change the phase of CO_2 from a gas to a solid (dry ice) while delivering useful power. The CO_2 can be inertially separated at the source vs. trying to separate CO_2 from the atmosphere @400 parts per million.

LNG regasification facilities can be used to produce liquid air.

A thermos of liquid air and a small cryoturbine fan can provide a portable air conditioner without electricity.

SuperHero cryogenic microturbines can power refrigerated delivery vans. Large numbers of refrigerated trucks spend their day in traffic with the engine idling and with the refrigeration system operating to keep the food cold and with an air conditioner operating to cool the operator.

Liquid air can be used for projectile propulsion.

SuperHero cryogenic microturbines can use heat from solar radiation, engine exhaust, industrial processes, and other sources to increase efficiency and power density.

Epilog

Liquid Air Vehicles (LAVs) will displace EVs due to lower overall cost, including lower overall environmental cost. We will look back and say you know there were people who thought that batteries would be cheaper than air.