AerForce Microthruster Technology

An alternative to “Birdflight as the Basis of Aviation”

Personal flight vehicles are limited by cost, safety, power density, and operating difficulty.

AerForce Microthruster Technology provides extraordinary reductions in the cost, mass, and volume of propulsion systems and offers safety through stability, simplicity, controllability, and parallelism. VTOL, hovering, lack of rotating blades, and reduced footprint are further benefits.

Legacy “Birdflight” aircraft use a large area and a large radius to change the direction of a large air mass over a small angular range yielding a small change in pressure.

AerForce microthrusters use a small area and a small radius to change the direction of a small air mass over a large angular range yielding a large change in pressure.

Legacy “Birdflight” aircraft use convex surfaces and atmospheric forces. Convex surfaces are limited to 1 atmosphere pressure difference and much less in practice.

AerForce microthrusters use concave surfaces and internal forces offering pressure differences of hundreds of atmospheres.

$\Delta P=mV^2/r$. Fluid following a curve results in a radial outward pressure proportional to the fluid mass within the curve times the square of its velocity divided by the curves radius. The pressure increases with decreasing radius.

$F=ma$. Force equals mass times acceleration. As the radius is reduced the mass within the curve decreases and the acceleration increases, yielding constant force with changing radius. Force is constant for constant ma product.

$F=PA$. Force equals pressure times area. As the radius is reduced the pressure increases and the area decreases, yielding constant force with changing radius. Force is constant for constant PA product.

The benefits accrue on the small as it becomes possible to increase the force per unit cost, per unit mass, and per unit volume by scale reduction.

A large number of microthrusters with small radius and effective area similar to a single large radius thruster can yield a greater force. Increasing the number of microthrusters per unit area, per unit volume, and per unit mass increases power density.

Pressure vessel power density also favors the small as the required wall thickness of a pressure vessel is proportional to the radius for circular cylinders ($S=pr/t$) and for spheres ($S=pr/2t$), with toroids intermediate.

Acceleration can be increased by reducing the radius and increasing the velocity. AerForce annular microthrusters can have annular microLaval nozzles between the microthruster elements and neighboring surfaces and high input pressure can be used to increase velocity.

Additional forces are provided by the central jet exit and microthruster arrays can be arranged to reduce the atmospheric pressure on convex neighboring surfaces.

Microfluidics and microthermodynamics are attractive for propulsion as power density is inversely proportional to size (1/L). A flea can jump hundreds of times its size; an elephant not at all.

Fig.1

Fig.1 shows both faces of a microthruster element formed from 50 um thick AISI 304 stainless steel. The microthruster has a major radius of 2.7mm, a minor radius of 0.2mm, and a curvature of 140^0 angular extent. The small radius and compound curvature increase stiffness/mass. The microthrusters in Fig. 2 and 3 have an outer planar region for annular Laval nozzles. Annular microthruster major and minor radius and angular range can vary with application. Microthruster elements can be separated by annular elements with curved section to create annular Laval nozzles between the microthrusters and the separators with the sonic line being near the gap between the curved section of the separator and the neighboring microthruster elements which can be curved or planar. See Fig. 2

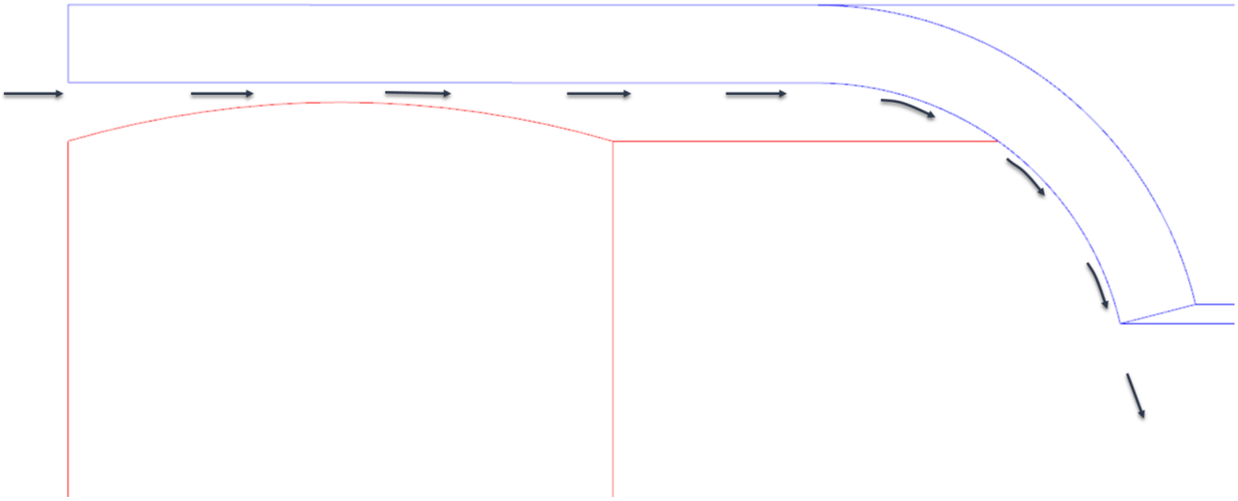

Fig.2

Fig.2 shows the microthruster flow path from entry through annular Laval nozzle and propulsive arc.

AerForce microthrusters can be increased in power density (thrust/weight) by weight reduction, radius reduction, velocity increase, pressure increase, heat increase, and design optimization to yield thrust to weight ratios >1,000.Spacing between microthrusters and separators can be achieved by deformations, upsets, and/or additions in microthruster elements and/or separators.

Microthruster assemblages can be consolidated and axially restrained by means including weldments, brazing, soldering, adhesives, threaded elements, and snap rings.

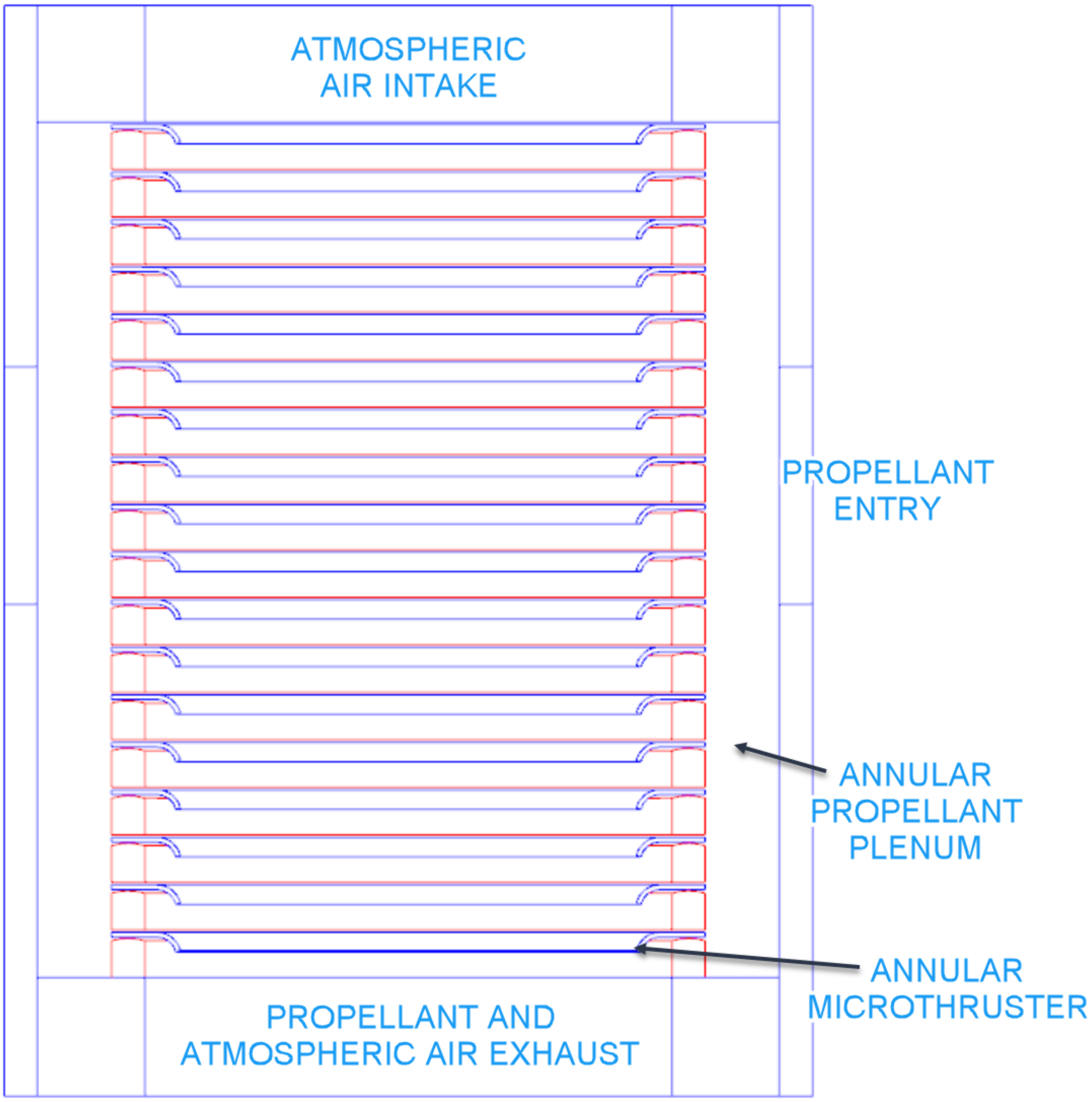

Fig.3

Fig. 3 is a schematic cross-section of a microthruster array and its containment tube. Propellant flow is radially inward and can provide wall cooling with reactive propellants. The system includes 2 phases, the 1st phase being the force generated by the microthruster array and the 2nd phase being the force generated by the axial jet developed in the system interior. Reactive propellants can greatly increase the forces.

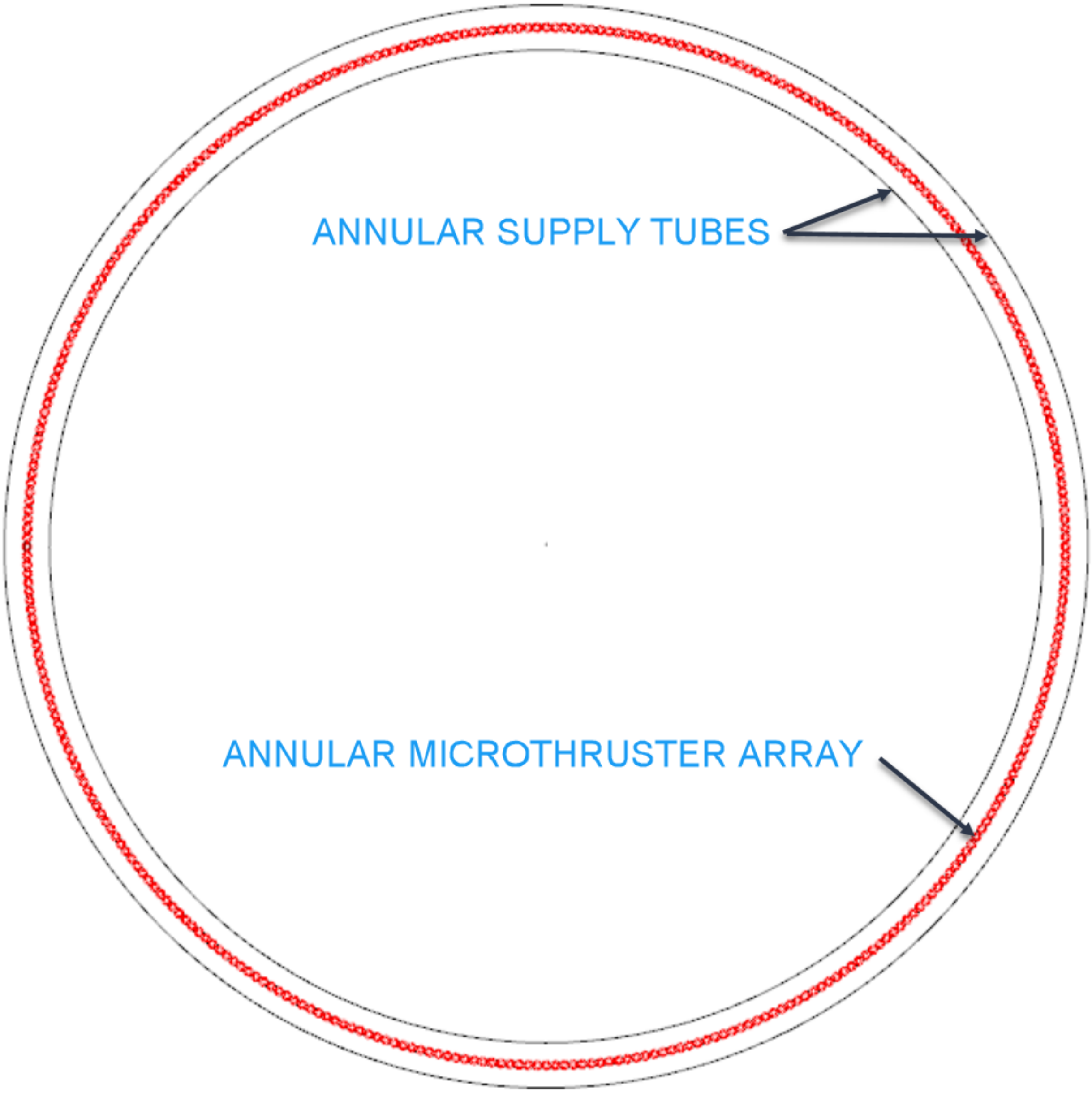

Fig.4

Fig.4 is a 1 meter diameter AerForce annular propulsion system with a pair of annular supply tubes feeding 360 microthruster array tubes, each containing 100 annular microthrusters. Each microthruster has an effective area of ~5mm^2 for a total effective area of 36,000 X 5mm^2=0.18m^2. ($\Delta P=mV^2/r$) Assume an effective mass within the arcs of 0.1 gms, a velocity of 400m/s, and a radius of 0.2mm. 0.0001kg X 160,000 ÷0.0002=80,000 Pascals or Newtons per square meter X 0.18m^2= 6,400 Newtons or ~ 650kgs force.

The propellant flow rate of 40gm/s means 400 kgs of liquid air propellant would provide 166 minutes or 2.77 hrs. of flight time at that force (thrust) level. The propellant mass decreases with flight time vs. constant mass for batteries and the flight profile can be arranged to initially travel more vertically to achieve the desired flight altitude and thereby fly with reduced mass.

The high thrust/weight ratio possible with AerForce microthruster arrays allows VTOL, hover, rapid acceleration, and high speed, but the propellant flow needed for horizontal flight can be <1/10 as great with the addition of a wing, allowing greatly increased range and duration.

The annular assemblages can be structural elements and divided into 6 radial sections for safety and for control by variable thrust.

The pair of annular supply tubes that feed the microthruster array tubes are brazed to the microthruster array tubes at semicylindrical removed regions at the midplane of the annular supply tubes. The entire assembly can be furnace brazed and the 360 microthruster containing tubes can be brazed together to yield a robust structure.

Flow Organization

Laminar flow is attractive as drag is proportional to velocity in laminar flow vs. the square of velocity in turbulent flow. Means to maintain laminar flow in AerForce microthrusters include small passage size and causing the fluid to follow the concave surface of the propulsive arc allowing laminar flow to be maintained at high Reynolds numbers via inertial confinement. The lesser the radius, the greater the inertial confinement to the concave surface and laminar flow is also quieter than turbulent flow.

AerForce microthrusters high thrust/mass allows VTOL with no moving parts and increased propellant capacity for increased duration and range.

Annular microthrusters are attractive for avoiding end effects.

Systems and flows can be organized for particular applications, such as maximizing lifting capacity or minimizing the energy needed for flight. Boost-glide schemes.

AerForce microthrusters can operate without atmospheric air, foregoing altitude limits.

Modularity allows a large range of system sizes, from microscopic to very large scale.

The microthruster array entrainment ratio can vary with application.

AerForce microthruster systems can serve as heat exchangers to heat and gasify propellants.

The force yielded by AerForce microthrusters is proportional to supply pressure.

Supersonic flow can be achieved with compressed air at 1 atmosphere. Shop air is typically ~8 atmospheres. Firefighters and divers use compressed air at 300 atmospheres. Liquid air and other liquid propellants can be supplied at much greater pressures. Automotive fuel injection systems operate >1,000 atmospheres.

The smaller the radius, the thinner the boundary layer and thinner boundary layers can support steeper pressure gradients.

Crummer teaches a fluidynamic perspective that is applicable to AerForce microthrusters. https://arxiv.org/pdf/nlin/0507032

Crummer. “All aerodynamic forces on a surface are caused by collisions of fluid particles with the surface.” Increase the pressure by controlling the particles at the working surface rather than distant particles.

The flow distribution hierarchy can use Murray’s rule type branching.

Safety

Arrays can be placed well above the center of mass for stability. A high degree of parallelism, simple control via thrust vectoring, and the ability to hover and operate at low velocity improves indoor and outdoor safety.

Propellants/Propulsion

Non-reactive propellants include compressed air, liquid air, water, air over water, and steam.

Reactive propellants include hydrogen, hydrogen peroxide, alcohols, and hydrocarbons.

Catalysts and catalytic coatings can be used to aid ignition and combustion.

Propellant pumps can be used to allow low pressure and unpressurized propellant storage.

Propellant pumps can provide throttling and thrust vectoring. Pedal powered pumps are attractive for personal vehicles.

Vertical bifacial thin film photovoltaic arrays can be suspended below aircraft for operating air compressors for propulsive air and powering sensors in “Eye in the sky” applications. Vertical bifacial thin film photovoltaic arrays can be towed like advertising banners and provide lit adverts.

Photovoltaics can be used to compress or liquify air on the ground for propulsive uses.

Elastic pressure vessels can be used to store pressurized propellants, providing more even pressure and reduced shipping and storage volume. Vehicle surfaces can be composed of pairs of fiber reinforced urethane sheets pressurized to become an array of inflated spherical containers. Spherical containers are beneficial for flight as spherical wall stress is (pr/2t) vs. (pr/t) for circular cylinders and hence weight can be reduced. Toroidal vessel stresses are intermediate between circular cylinders and spheres.

AerForce microthruster arrays high thrust/weight allows a large propellant mass to be flown for increased duration and range and making a low cost, low energy density propellant viable. Liquid air is a low cost propellant that can be made anywhere via photovoltaics. Pumps can be used to pressurize liquid air for increased power density, throttling, and to allow unpressurized storage.

Gasification of liquid air can be via microthruster systems acting as heat exchangers.

Liquid air has high thermodynamic potential i.e., 273^0K-100^0K/273^0K=0.63 or 63%, and coreactants can be used to increase the thermodynamic potential and power density, Photovoltaics and liquid air offer low cost make anywhere propellant for flight and much more.

Control

Differential thrust control can be via a joystick deforming a radial array of 6 elastomer tubes within a central tube with the 6 tubes feeding a 6 sector annular distribution tube. The joystick contains 2 spheroidal elements, the one nearest the operator constrained by a spheroidal bearing element and the further one used to deform elastomeric tubes to control flow for differential thrust.

Differential thrust control can be via multiple propellant pumps.

Propellant feed can be periodic for pulsed proportional control and for increased efficiency.

Applications

Mass market VTOL personal aircraft become possible via a decrease in cost and an increase in safety and power density.

A simple personal flight vehicle combines an AerForce microthruster and propellant backpack array with kinesthetic control.

Annular microthruster arrays can surround domical elements and create subatmospheric pressure regions on the convex surfaces of the domical elements which can be part of flight vehicles.

mono-A single place aircraft can be composed of a vertical cylinder topped by a transparent polycarbonate hemisphere surrounded by an annular microthruster array. The user stands up aided by a bicycle seat. A pedal operated propellant pump can serve as throttle. Propellant can be stored in the bottom of the cylinder and the region can provide crush space. A rear cusp in the area below the dome can be used for drag reduction and storage. A wing can be added for increased range and duration.

Multiple annular arrays can be used in a variety of schemes. Linear/rectangular and annular microthruster arrays can be used with legacy flight vehicles and vehicles in general.

Inflatable elements can be used for cabins, propellants, lifting surfaces, and crash protection.

Cabin surfaces can be composed of fiber reinforced elastic urethane propellant containers.

Fabric reinforced hose can be embedded in rigid urethane foam for propellant storage, vehicle structure, and crash aid.

AerForce microthruster arrays can be used to create simple high power density internal combustion jet engines with high thrust at zero forward speed and positive feedback loop analogous to ramjets.

Reacting systems add complexity, but dramatically increase power density.

Reactive liquid propellants can be heated and gasified by the heat from products in the combustion regions.

Liquid propellants can be supplied at high pressure by pumps.

AerForce microthrusters are attractive for jet engines and rockets. Atmospheric air entrained and accelerated by the microthruster exhaust into the central region of the array can be used for combustion with coreactant introduced via microthrusters. Hot surface or spark ignition can be used. Propane is an attractive fuel for AerForce microthruster jet engines with wall cooling provided by reactant inflow. Kerosene, ethanol, and gasoline are attractive and more available but require pumps.

Compressed air and liquid air microthruster engines can use both propellant air and entrained air for combustion with coreactant introduced through central tube.

Ramjets typically need high vehicle velocity to operate, but AerForce microthruster systems can provide high thrust at zero vehicle velocity, allowing VTOL ramjets and benefit from ramjets positive feedback loop.

AerForce microthruster ramjet projectiles can be made in a large range of sizes.

AerForce microthruster arrays can be used as tip jets for generators, fans, drones, and helicopters.

Microthrusters can be formed into Laval nozzles for supersonic flow, the array exhaust can be a Laval nozzle, or the system can feed an expansion nozzle for supersonic flow.

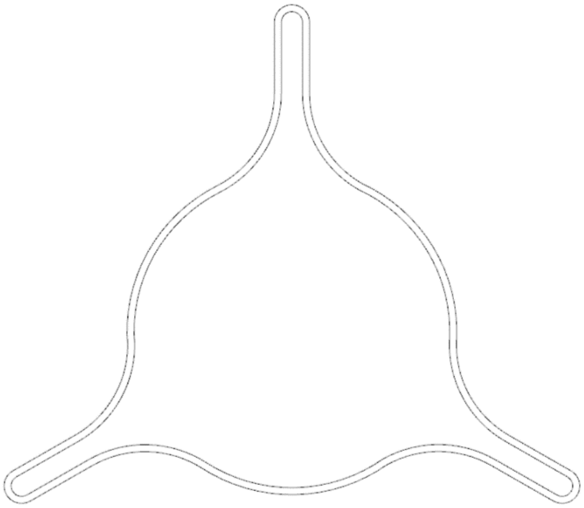

Fig.5

Fig.5 show a cross-section of a central self-cooled axial propellant/coreactant feed tube for jets and rockets with 3 radial regions that contact the annular radial inflow microthruster array. The propellant tube can feature downward facing apertures and micro Laval nozzles. The propellant tube can be a stack of similar sections with propellant outflow between the sections. Propellants/coreactants can be fed from the top via an annular supply tube.

A rocket with a liquid air 1st stage that detaches after use negates the footprint costs of legacy rockets. Rockets are least effective at stall and the boost allows larger payloads.

Annular microthruster systems can be installed at the upper region of rockets to aid stability.

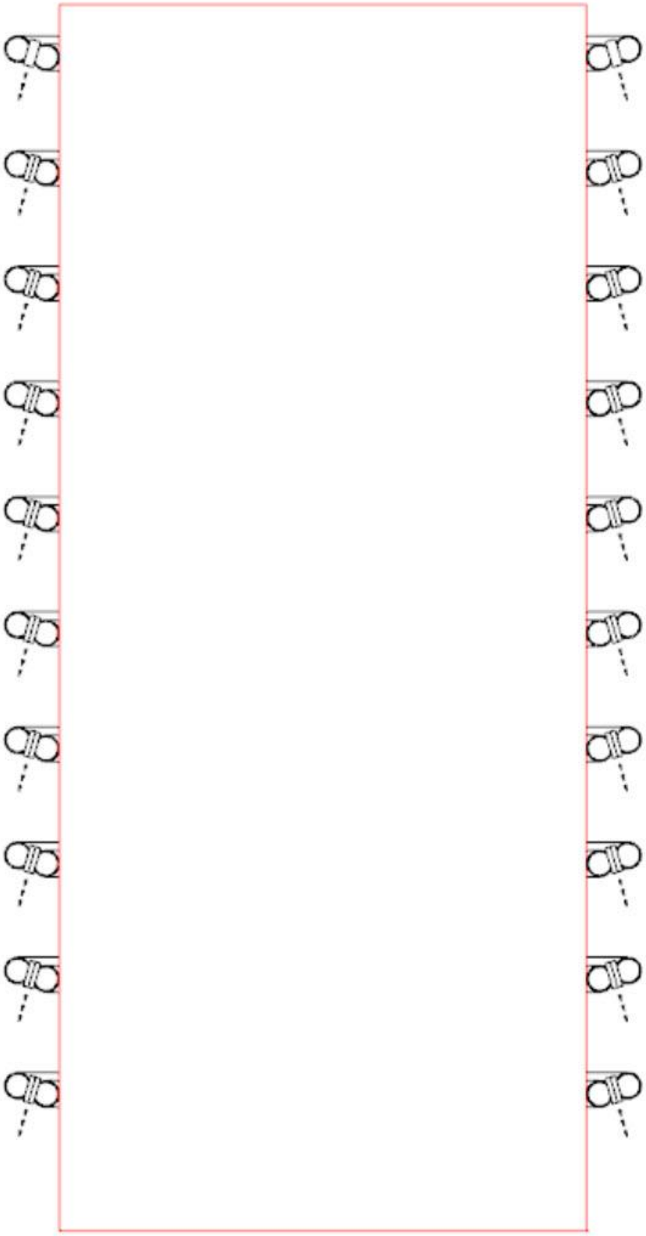

Fig. 6

Fig. 6 is a schematic cross-section view of a cylindrical rocket body with 10 annular microthruster arrays. The “Rocket Ring of Fire” benefits include reduced cost, weight, and footprint in addition to increased area for engines, increased stability, and thrust vectoring.

The rings can be part of the rocket structure helping to maintain circularity and absorbing hoop stress. Rockets can use existing propellant combinations i.e., LOX/CH4 and the propellants can provide self-cooling. Rockets can combine coaxial radial inflow and radial outflow microthruster arrays with the annular combustion region between microthruster arrays. 50um AISI 347 is readily available and the system can be designed to preheat propellants via convective contact with the microthrusters.

The future of rockets and of propulsion is on the small, specifically large populations of small radius annular microthrusters. Power density is 1/r. There really is plenty of room at the bottom. See Aerforce Microthruster Technology at johnpopovich.net

Eye in the sky. A low cost eye in the sky for communications, police, fire, and traffic management with a real time gods eye view for automated vehicles.

Arrays of low cost AerForce eyes in the sky can be tethered, inflight refueled, periodically replaced, and/or powered by vertically suspended bifacial thin film photovoltaic arrays.

Long term hover is attractive for many applications. Cameras, communications, radar, advertising, and lighting where and when you want it via remote control.

Airships can benefit from a lightweight lift and propulsion means. Hybrid airship Eye in The Sky. Liquid air can be used for lift, propulsion, and ballast control. Liquid air can also provide refrigeration, air-conditioning, and cooling of electronics and sensors.

Indoor flight. Low noise, small footprint, and lack of rotating blades brings flight indoors for warehousing, patrolling, inspecting, manufacturing, and general travel for people and goods.

AerForce microthruster propulsion systems can be used for surface vehicles, water vehicles, and underwater vehicles. Waterborne vehicles experience surface drag which can be reduced by an air layer between the surface and the water. Aerforce microthruster propulsion systems can provide drag reduction in addition to propulsion.

Tethered applications include manufacturing robots suspended from the ceiling with a wide range of motion.

Short haul applications are many. Crossing the river and package delivery via disposable delivery drones powered by compressed air are examples.

Hierarchal drones. The mothership. 2/3 Law augers for a large flight vehicle to carry and disperse smaller vehicles for increased range and reduced cost.

Sky crane. Construction aid.

Firefighting, painting, window washing,

Agriculture uses including watering, weeding, fertilizing, crop monitoring, planting, harvesting, security, and tree trimming.

Self-propelled air heater powered by propane or natural gas.

Actuators.

Epilog

The importance of scale in propulsion systems cannot be overemphasized. We often go big when the benefits accrue on the small. There really is plenty of room at the bottom.

Microfluidics and microthermodynamics are the future of propulsion, specifically large populations of small radius microthrusters.

AerForce annular microthrusters avoid end effects and Dean vortices, and they are easy to manufacture by stamping.

A high degree of end stage parallelism is attractive for overall effectiveness and beneficial for safety.

AerForce propulsion systems allow flight vehicles with reduced footprint.

AerForce microthruster technology has patent pending status.

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Addendum 1

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). And sparrows are on the low efficiency end for birds, with soarers like the 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 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 can be more automated. 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.

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, 20X the cost of a car and require large rotor swept areas ($46m^2$). Power per unit plan area needs to be increased ~10X for compact VTOL vehicles. Helicopters also require skilled operators.

Progress in computers, artificial intelligence, radio communication, satellites, including 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. Personal aerial vehicles do not require roads and can park from above, thereby reducing parking space access roadways. They can park on roofs to greatly 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.

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.

Addendum 2

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.

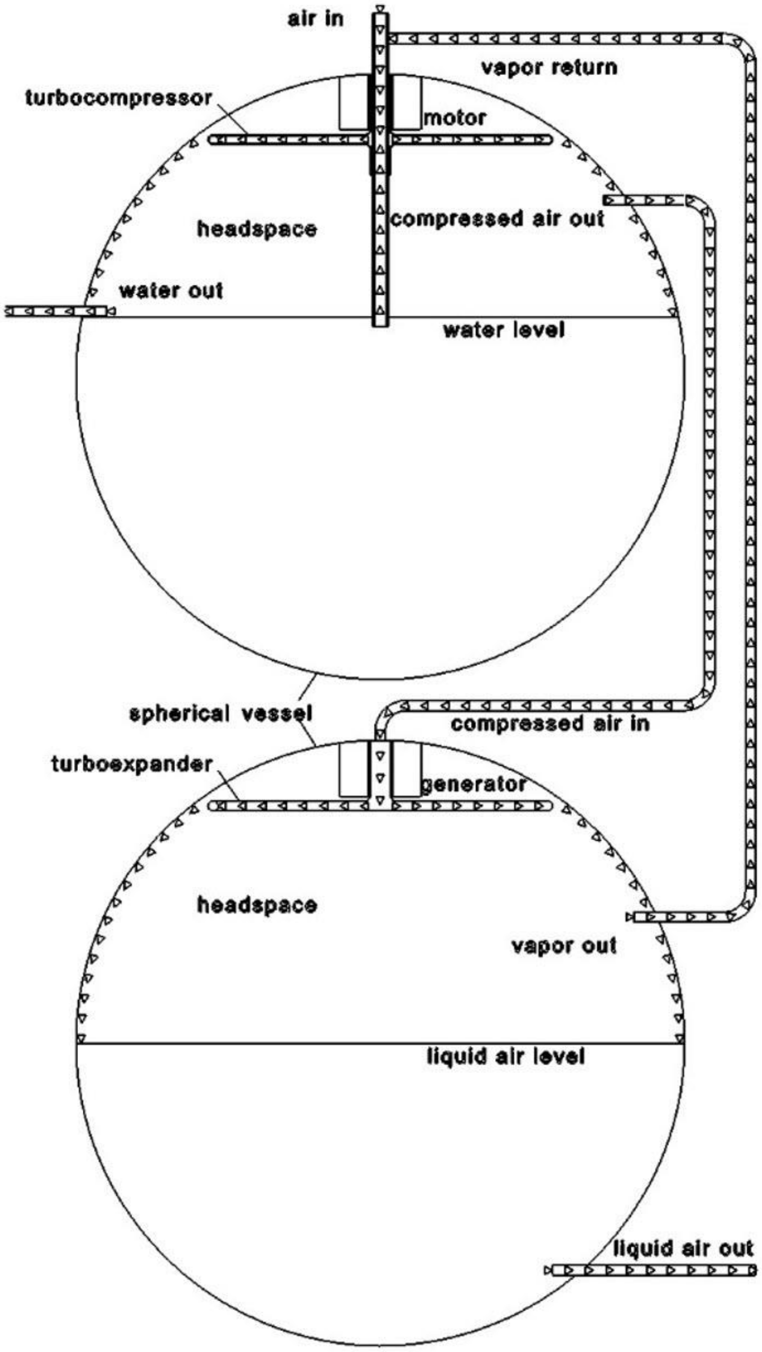

Fig. 1 SuperHero Claude Cycle Compressor and Liquefier Schematic

The motor driven SuperHero turbomachine in the upper spherical container in Fig.1 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 expander turbine to liquify the air in a Claude cycle.

Heat from electrodynamic conversion can be used to prevent bearing freezing in liquid air systems. The integration of generators and motors with the rotor bearings and seals of liquid air systems allows the heat associated with electrodynamic conversion to be used to prevent seizure.

Liquid air can provide short-term and long-term storage for intermittent sources including photovoltaics and wind. Liquid air storage does not require pressurization.

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. Heat can be added via electricity from SuperHero liquid air turbogenerators.

Compressed air is an attractive utility and would enjoy greater use with greater access. Superhero turbomachines can provide quiet compressed air at low cost. Compressed air can be provided by SuperHero liquid piston recirculating water air compressors, by liquid air ported to a storage vessel, closed off from the liquid air supply vessel and heated by the local atmosphere to evaporate and thereby pressurize the air in a compressed air storage vessel, by a pump made from a pair of check balls with a heat exchanger between, and by liquid air pumps with downstream heat exchangers.

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. Existing tanks can be internally insulated for liquid air storage. Liquid air is storable without pressurization. Oil and gasoline storage tanks can be converted to liquid air storage tanks. Liquid air can be stored in underground cavities,

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

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 that can be used for liquid air storage. Truck and train chassis are very attractive candidates for tubular structures. Building structures can be formed from tubes used for cryogenic liquid storage.

Energy efficient buildings often suffer from poor air quality as a consequence of reduced communication with the local atmosphere and liquid air can provide clean air in these applications. Clean makeup air can be especially valuable in hospitals. Operating rooms lamps can be designed to emit clean air to displace room air and operating team emissions in addition to liquid airs ability to provide cooling for the light sources and associated electronics.

Energy is proportional to pressure and liquid air at high pressure can have energy densities ~200Whr/kg, less than Li-Ion, but greater than Lithium Iron Phosphate, which 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 powered vehicles have reduced mass with travel, especially important with aircraft.

Liquid air SuperHero atmospheric source heat engines can provide power densities 10-100 times as great as electric motors 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. Cryogenic cooling allows the use of lower bandgap semiconductors such as Germanium.

A liquid air economy will 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 limited by the absolute temperature ratio. Sadi Carnot gives us the thermal equivalent of height. If the temperature ratio is half, half of the thermal energy can be converted to work.

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 turbomachines 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. Air specific heat @300K=1kJ/kg.K. A liquid air powered vehicle travelling at 120k/h (33m/s) provides ~40kg/s of atmospheric air to a 1m^2 aperture. 40kg/s X 100^{0}K ΔT X1kJ/kg.K =4MJ/s or 4Mw$_t$. A portion of the thermal energy can be converted to rotational energy by SuperHero turbomachines 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$_t$. 100% humidity doubles this figure. Cryogenic SuperHero turbo machines can provide freshwater from the atmosphere via condensation.

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

Cryogenic CO_2 Capture

SuperHero cryogenic turbomachines can benefit from the exhaust temperature associated with carbon containing fuel combustion and change the phase of CO_2 in the exhaust from a gas to a solid 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.

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

Liquid air can be used for projectile propulsion.

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

Epilog

Liquid Air Vehicles (LAVs) can 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.”

You cannot create batteries with photovoltaics, but you can create liquid air.

The future is cool.

Addendum 3

SuperHero Microturbines

Why microturbines?

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

SuperHero technology encompasses a family of microturbines that include relatives of Hero’s Aeolipile.

SuperHero 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.

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

SuperHero 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.

Superhero microturbines can provide reliability, maintainability, and throttleability by modularity.

Superhero microturbines can provide combined heat and power (CHP). ~60 million U.S. homes have natural gas supply. A SuperHero 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 less costly than electricity and less subject to outage.

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.

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

Large turbomachines dominate in commercial air transport and electricity generation, but when the size of legacy turbomachines is 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 liquid working fluids, and by advantageous heat exchange with the environment associated with increased surface/volume, especially with cryogenic fluids.

SuperHero microturbines use rotating tube arrays as compressors or blowers and the rotor drag can also be useful thermodynamically, especially in the case of cryogenic liquid propellants.

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.

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.

Fig.1

Fig.1 is a 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. Superhero microturbines can generate higher pressures in a single stage than multistage legacy microturbines by using liquid propellants.

The rotating tube arrays in SuperHero microturbines cause fluids introduced through a central hollow axle to be accelerated in the tubes and ejected tangentially at the tube ends or returned to the hollow axle as gas via “U” tubes. The small radius 90^0 turn at the tip yields high force.

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 causes 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.

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

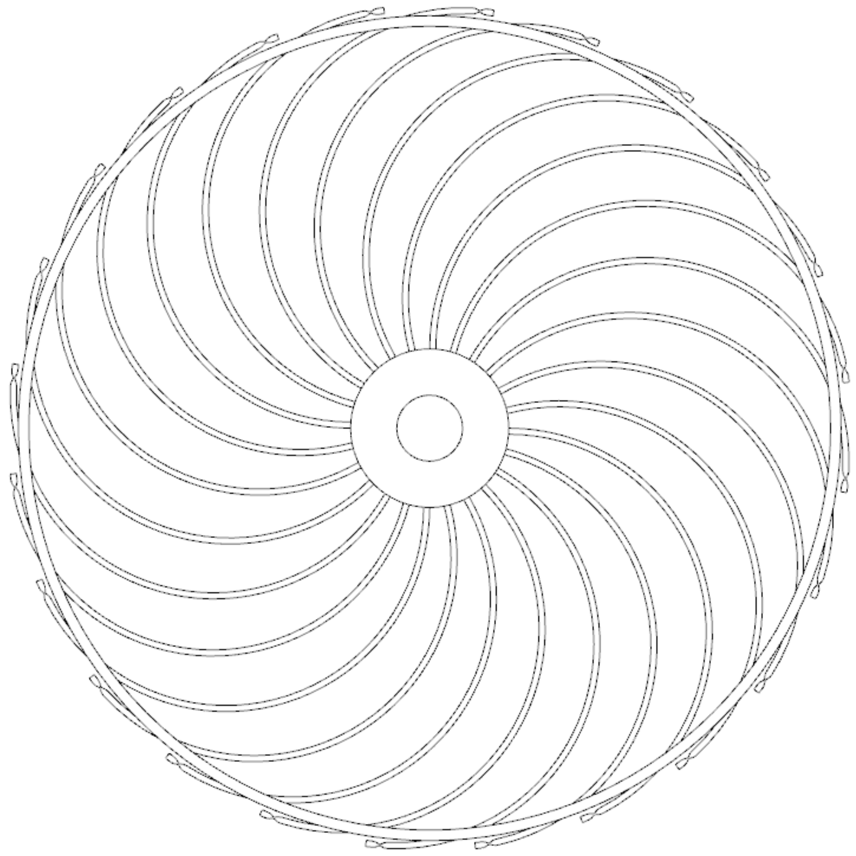

Fig. 2

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

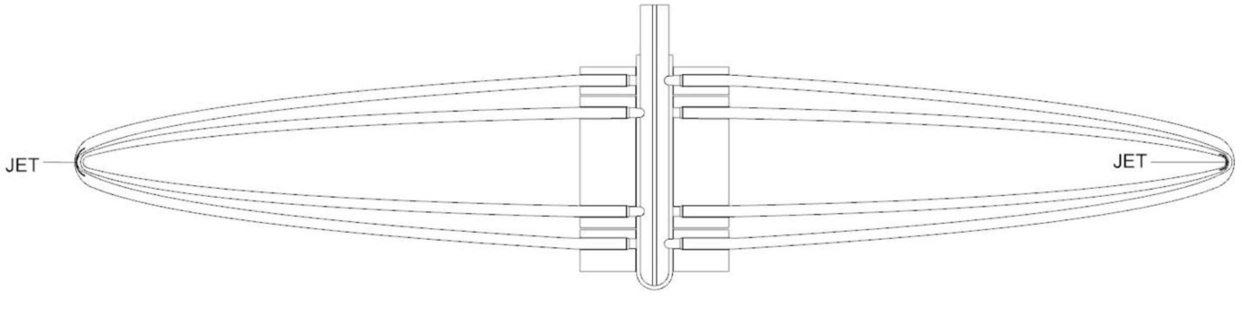

Fig.3

Fig.3 is a pair of contrarotating radial reaction turbine arrays that can provide intense mixing and add torque to opposing turbine array. The jets from one rotor encounter opposing high velocity flows from neighboring rotors. The contrarotation can provide intense mixing, reacting, and combustion.

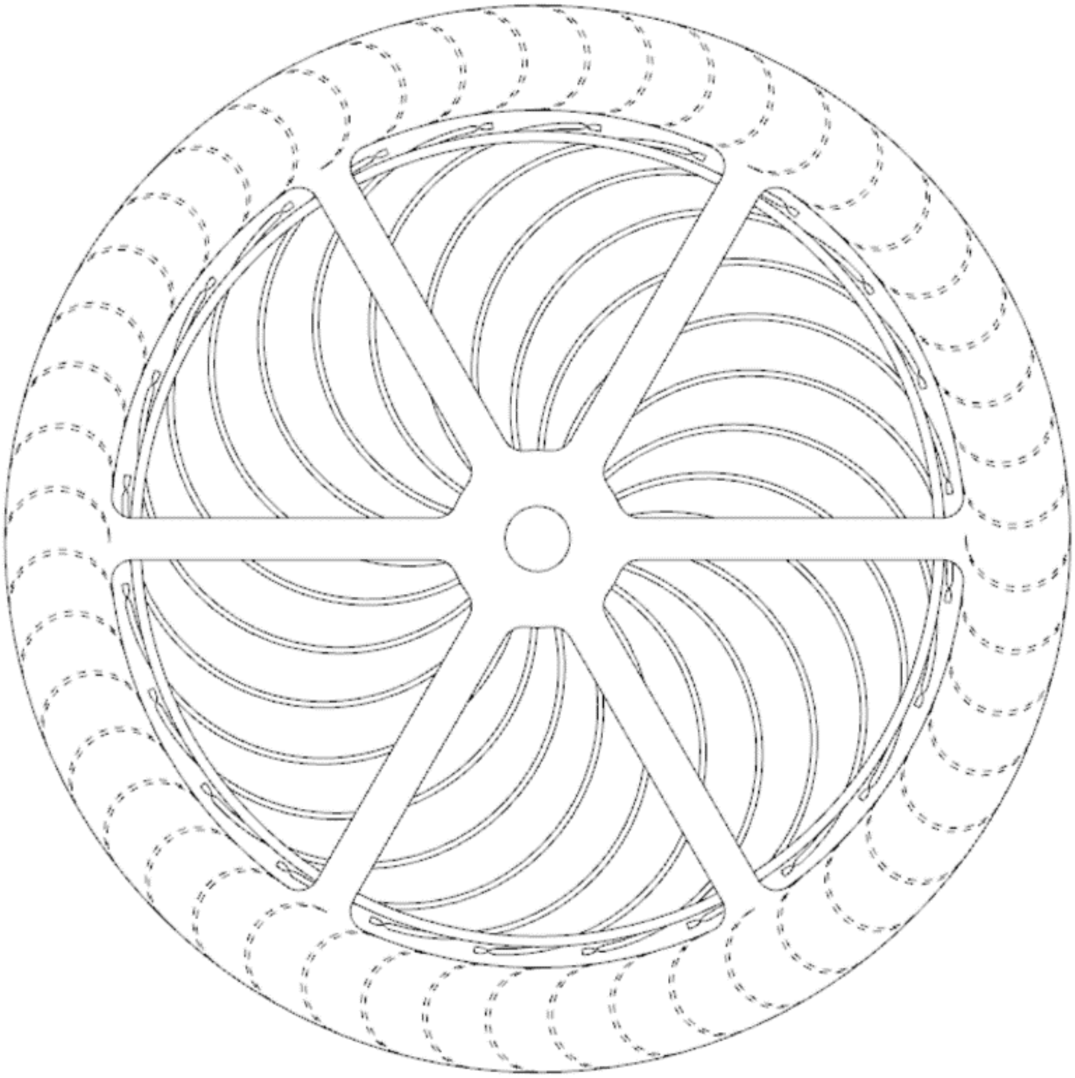

Fig. 4

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 turbine stages can be used in radially outflowing SuperHero microturbine systems to provide output power with increased efficiency, lower output rotational rate for connection to drives, reduced exhaust temperature, and reduced exhaust velocity.

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

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

The incoming fluid passage between static axle and rotor can provide a hydrostatic journal bearing.

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 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 the 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 the 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 can provide increased axial tensile strength. The bottlebrush can be catalyzed to react with fluids in passage for combustion or operation as a chemical process reactor.

The 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 can be 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 transfer rates. The system can be designed for air to make a single pass through the capillary mesh.

SuperHero hierarchal microscale heat exchanger power density is due to the high surface/volume ratio associated with the fine wire mesh, the related thin boundary layers, massive end stage parallelism, and laminar flow.

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.”