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Conceptual Design of a Personal Aerial Vehicle Using Co-Flow Jet Airfoil

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A flying wing personal aerial vehicle (PAV) is designed using a co-flow jet airfoil (CFJ); it is designed to take-off and land on regular roads and highways, at take-off speed of 60mph. The advantages of using CFJ throughout the entire PAV are the enhanced lift/stall margin and thrust generation. It has a targeted range of 500miles, at a cruise mach number of 0.3 at an altitude of 10,000ft with a payload of 3 passengers. The aspect ratio achieved is 2.5 with the addition of an elliptical wing to increase the wing span of the PAV. The mass flow of the jet that covers the surface of the wings needed is of 19kg/s, requiring a power of 684hp (510kW) to pump the jets to such mass flow rate. Given these conditions, the CFD analysis is still in progress.

Nomenclature

AR = aspect ratio
b = wing span
s = wing area
PR = total pressure ratio
$\dot{m}$ = mass flow rate
U = velocity
V = velocity
C_m = momentum coefficient
ρ = density
γ = ratio of specific heats

I. Introduction

AIR transportation has itself become intrinsic with the quality of life we have come to enjoy. Flexibility and freedom of the personal automobile is an important aspect of our culture and quality of life, yet the personal air vehicle for transportation has not developed in any significant way. To improve rapid and mass transport, a new style of transportation is essential to facilitate the movement of individuals from place to place without the irritation of numerous complications. It is also important to consider what is already out there, and come up with an idea that can operate with the resources and facilities that exist, such as existing highways and roads. The world is slowly overpopulating and there is a limited ground space in which people can move themselves around, therefore air transportation is the future.

To answer the aforementioned problems, our objective is to create a Personal Aerial Vehicle (PAV) that can be used in regular highways; therefore its dimensions are going to be restricted by those allowed by the highway regulations for safety and transportation[1]. The technology used will be the co-flow jet airfoil, recently developed by Zha et al.[2] The CFJ airfoil will be applied throughout the entire body of the PAV to significantly increase lift, stall margin, and generate thrust as the propulsion system.

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The co-flow jet airfoil is designed with an injection slot near the leading edge and a suction slot near the trailing edge on the airfoil suction surface. The slots are opened by translating a large portion of the suction surface downward. A high energy jet is injected tangentially near the leading edge in the same direction of the main flow, and the same amount of mass flow is drawn in near the trailing edge, which results in a zero-net mass-flux flow control. The turbulent shear layer between the main flow and the jet causes strong turbulence diffusion and mixing under the severe adverse pressure gradient, which enhances the lateral transport of energy from the jet to the main flow allowing the main flow to overcome the severe adverse pressure gradient and remain attached at high angles of attack. The high energy jet induces high circulation and hence generates high lift. The energized main flow will fill the wake velocity deficit, which results in a reduced drag or thrust (negative drag). The level of lift enhancement, drag reduction, and stall margin increase of the CFJ airfoil is very dramatic, as proved by wing-tunnel tests[3,4,5].

An interesting feature of the CFJ airfoil is its super suction at the leading edge, which produces such a low pressure at the LE that thrust is generated. The contributions of the force in the streamwise direction due to jet injection and suction momentum are mostly canceled out by each other because the injection and suction flow rates are the same. The drag reduction mechanism of the CFJ airfoil, therefore, is not due to the momentum thrust from the jet. It is due to the large circulation induced by the co-flow jet. A CFJ airfoil hence achieves a similar feature to that of a bird's flapping wing, which relies on the leading edge super suction to generate thrust and high circulation to generate lift. The CFJ airfoil generates both lift and thrust with a fixed wing. This feature is used in the new concept PAV as the propulsion system to generate thrust[6].

The use of the CFJ on the PAV has several advantages which make this technology quite the innovation for this kind of application. Given that the CFJ is used as the propulsion system for the PAV, it is an all integrated system in which the airframe and propulsion are all compacted in one. In addition, because the CFJ acts as propulsion then with the lack of a turbine the PAV is low in noise and therefore contributing to the comfort and atmosphere around the vehicle when in operation. The CFJ also provides high lift and stall margin, which in return increase the safety of the PAV, safety being one of the main concerns when considering the transportation of people. With the CFJ, the PAV then has a low stall velocity and therefore a low take-off and landing velocities. This way, the PAV is able to operate and take-off in regular highways given that it will not surpass speed limits, keeping the roads in which it travels safe.

The CFJ will always be on during the entire flight mission. The lift enhancement and thrust generation can be controlled by adjusting the injection total pressure, and hence the jet mass flow rate, throughout the mission according to different needs. In this way, the co-jet flow will also be used as the control system for the PAV to control the yawning and rolling.

II. Mission

The main objective is to design a personal aerial vehicle that will carry 3 passengers short distances in a reasonable time frame. The idea is to have the PAV parked at the individual's house, drive it to any road where it can reach a velocity of 60mi/h, take-off and then land it at another highway or road close to the destination of choice.

The targeted range is of 500 miles (an approximate 3 hours of flight), having a cruise mach number of 0.3 at an altitude of 10,000ft, at which the cabin does not need to be pressurized.

Table 1 below shows a list of the main specifications of the PAV calculated throughout the paper.

Table 1. Main Specifications for the PAV

Specification	CFJ PAV
AR	2.5
Width	2.6m
Length	5.6m
Total Height	3.19m
Body Height	1.35m
Weight	1,950kg
Cruise Mach	0.3
Altitude	3,048m (10,000ft)
Vtake-off	96km/hr (60mph)
Vland	120km/hr (75mph)
Range	804km (500miles)

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Max Power Required	684hp
Power at Cruise	550hp
Payload	300kg
Dihedral Angle	5^o
Passengers	3
Take off/landing Distance	0.3km
Vstall	44.4km/hr (27.6mph)

III. General Configuration

A flying wing design is used for the whole PAV with the CFJ airfoil applied to the entire body. The airfoil that is used is a 25% thickness airfoil with the profile shown in Fig. 1.

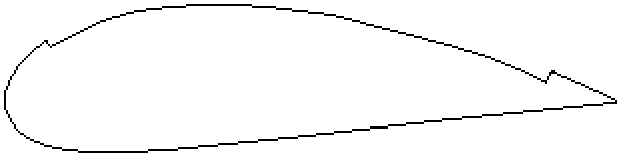

Figure 1. Baseline section for the 25% thickness airfoil used throughout the entire PAV

In order to increase the aspect ratio of the PAV, the wing span should be increased. Due to the limitations of the road width, an elliptical wing is attached to the top of the flying wing configuration, which significantly increases the aspect ratio and also has the effect to reduce induced drag. Fig. 2 shows a snapshot of the PAV generated using the program Pro/Engineering.

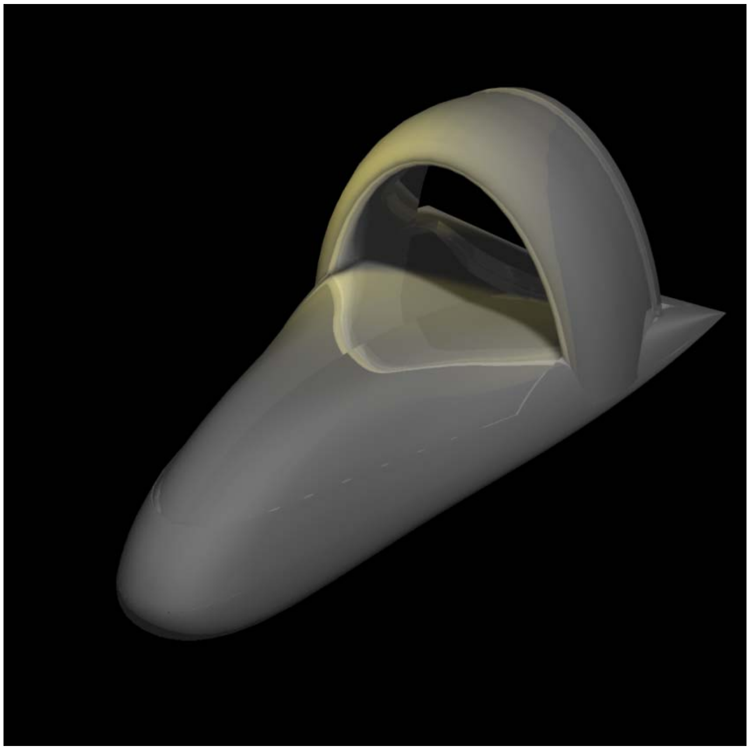

Figure 2. The PAV generated using Pro/Engineering

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Figure 3 is a snapshot of the PAV at an arbitrary angle. Figure 4 is a shot of the front view in which the 5° dihedral angle applied to the main wing body for lateral static stability can be seen. Figure 5 is a shot of the side view of the PAV, showing the aerodynamic shape of the flying wing design.

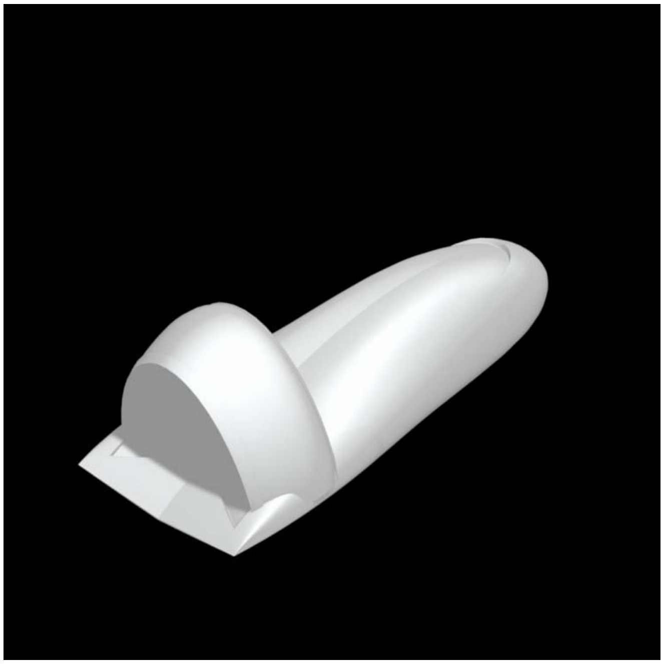

Figure 3. The PAV generated using Pro/Engineering

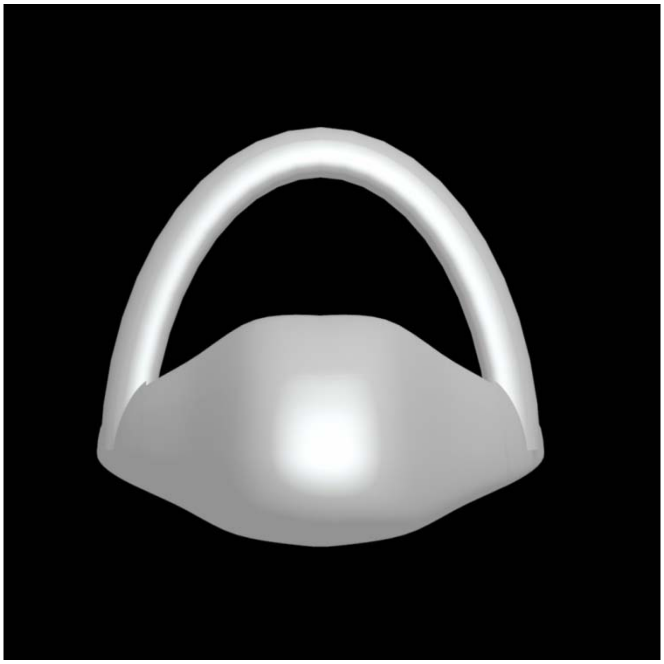

Figure 4. Front view of the PAV showing the wing dihedral angle of 5°

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Figure 5. Side view of the PAV

The PAV has a maximum airfoil thickness of 1.4m, therefore having a length of 5.6m because of the 25% airfoil thickness used throughout the entire aircraft. The width of the PAV is 2.6m in order to be able to circulate and take off on a highway lane according to the highway and safety performance criteria. Following these dimensions, the main wing body has a total top surface area (wing area) of 7.28m^2. For comparison, the dimensions of a Cessna C150L were used; length 6.56m (21.5ft), height 2.11m (7ft), wing span 10.17m (33.3ft), and wing area of 14.8m^2 (159.5ft^2).

The elliptical wing on the top has a total perimeter length of 4.84m and a height of 1.85m from the center of the main wing to the center of the elliptical wing. Following these dimensions, the elliptical wing has a top surface area (wing area) of 5.48m^2. For aspect ratio considerations the projected wing-span and wing area will be used, which are 2.3m and 2.3m^2, respectively.

The general configuration and main dimensions of the PAV can be seen on Fig. A.1 on the appendix.

The current aspect ratio of the aircraft is calculated to be 2.5 based on the following definition,

$$AR = \frac{b^2}{s} \tag{1}$$

Where, the wing span is the addition of both the length of the main and elliptical wings. The surface area is the addition of both the wing areas of the main and elliptical wings.

The volume of the PAV is 7.3m^3, which is sufficient to carry a payload of 3 passengers with their luggage, pumps to power the co-flow jets, the engine to run the pumps, fuel and fuel tanks.

IV. Volume and Power Analysis

The minimum volume that can hold the capacity of three people comfortably and be able to operate the aircraft is approximately 1.7m^3, with headroom and leg room of one meter each. This is taken from the interior specifications of a BMW Z4 that is used as the reference for the minimum dimensions of the PAV. This leaves sufficient room for baggage, engine, pumps, pipes and the fuel.

The power required to pump the jet is determined by the jet mass flow rate and the total pressure ratio to overcome the total pressure loss of the jet[2-5]. The formulation is the one shown in Eq. (2),

$$P = \frac{\dot{m}_j C_p T_{o1}}{\eta}[(PR)^{\frac{\gamma-1}{\gamma}} - 1] \tag{2}$$

Where, $\dot{m}_j$ is the CFJ mass flow rate, T_{o1} is the total temperature at suction slot, PR is the pressure ratio, η is the efficiency, and γ is the ratio of specific heats. Assuming a conservative pressure ratio of 1.3, total temperature of 272.8 K, and an efficiency η of 0.8.The co-flow jet mass flow rate is calculated from the momentum coefficient defined as:

$$C_m = \frac{\dot{m}_j V_j}{0.5\rho_\infty U_\infty^2 S} \tag{3}$$

Where, V_j is the injection jet velocity, which is assumed to be three times the freestream velocity[5], and ρ_∞ and U_∞ are the freestream density and velocity. Assuming a momentum coefficient of 0.15, freestream velocity of 89m/s (M=0.3), and jet velocity of 269m/s (M=0.9).The max co-flow jet mass flow rate was found to be 19kg/s at sea level.

From Eq. (2), the maximum power calculated is 510kW (684hp) at sea level for take-off. The power will be used to decide the appropriate pumps and engine to power the co-jet flow jet. Several pumps will be used given that the control system for the PAV will be controlled by the jets on the surface of the wings; therefore, the different pumps will carry out a percentage of the total power mentioned above.

Figures 6 and 7 below show the volume and position of the passengers (yellow) and engine (red) inside the PAV.

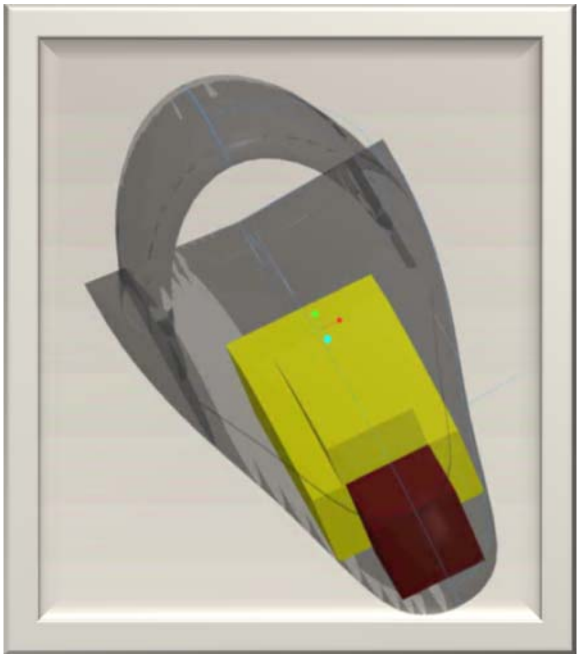

Figure 6. Volume of engine (red) and passengers (yellow) inside PAV

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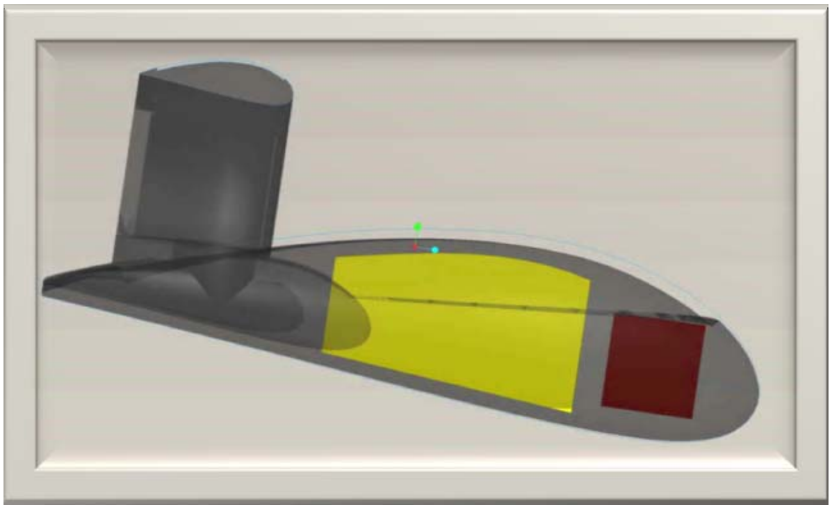

Figure 7. Volume of engine (red) and passengers (yellow) inside PAV

To satisfy the mission goal, an efficient and powerful system is needed. Some theories were studied and compared, showing below the one preferred for the PAV given the fact that it fulfills the needs established.

Internal Combustion engine using Gasoline

An engine optimized for maximum power and endurance capability was designed. Thus the best engine designed for this within our limits was the W-16 engine proposed by Bugatti. This 16-cylinder mid-engine, at 710 mm long is no larger than a conventional V12 unit, and due to its lightweight construction weighs only about 400 kilos. Its compact dimensions are due to the unique arrangement of its cylinder banks in a W configuration. Two VR8 blocks, each with a fifteen degree bank angle, are joined in the crankcase to form one engine. Both eight cylinders are set at an angle of ninety degrees to each other and are aspirated by a total of four exhaust gas turbochargers. The engine delivers 1001 hp at 6,000 r.p.m. and provides a maximum torque of 1250 Newton-meters at between 2,200 and 5,500 r.p.m.

The 16 cylinders in 4 banks of 4 cylinders, or the equivalent of two narrow-angle V8 engines mated in a "W" configuration. Each cylinder has 4 valves, for a total of 64, but the narrow V8 configuration allows two camshafts to drive two banks of cylinders so only 4 camshafts are needed. The engine is fed by four turbochargers, and it displaces 8.0 L (7,993 cc/488 in^3) with a square 86 by 86 mm bore and stroke.

This propulsion system provided for the additional weight of the engine in the PAV of 400 kilograms, while still giving enough power for take-off.

The power system described above seems to be the one preferred for the PAV given the fact that it fulfills the needs and it is already available in the market. The engine mentioned is remarkably compact. It measures just 710 mm (27 inches) long, 889 mm (35 inches) wide and 730 mm (28.7 inches) high.

Unique in engine design is the integration of knock and misfiring detection in an ion current system. Because the multiplicity of cylinders means very quiet running and ensures that the velocity difference will be extremely small in the event of a cylinder misfire, cylinder-selective detection by measuring rough running is not reliable enough. Therefore, Bugatti Ion Current Sensing (BIS) is used. The ion current flowing at each spark plug at the time-point of ignition is monitored by a separate evaluation sensor system. The data obtained is passed to both engine control units. If knocking combustion or a misfire is detected, the associated control unit immediately initiates countermeasures, such as retardation of the ignition time-point, shutdown of the cylinder or reduction of the charge pressure. This generates the maximum performance from the engine in a stable and clean manner.

A. Exhaust System

For 1000 hp propulsion power, provided by the engine, the system demands approximately 2000 hp to be additionally generated as heat energy during combustion. Half in each case is dissipated in the exhaust gas and cooling water. To do this, the engine has two water circuits. The larger of the two with 40 liters of cooling water has three coolers in the front section of the car, to keep the engine at operating temperature. The second circuit, called the low-temperature system, has a separate water pump and contains 15 liters of cooling water. These are used to cool, by up to 130 degrees, the charged air, heated during compression in the turbochargers, in two heat exchangers mounted on the engine. The cooled, charged air then passes through two 'air manifolds' into the combustion chamber, which it then leaves as exhaust gas at approximately 1,000 degrees. It then passes through the turbines of the exhaust gas turbochargers. This causes the exhaust gas to expand, so that it is cooled by up to about 150 degrees, is then cleaned in the catalyzer and then it is exhausted.

B. Fuel and Fuel Tank

The rear section of the monocoque is designed with a hollow space to hold the 98-litre saddle fuel tank which surrounds the transmission and which is separated from the passenger area. The saddle fuel tank is designed to hold more fuel than a standard fuel tank. Saddle fuel tanks include two compartments for storage of fuel connected by a bridge. The saddle tank fuel delivery system involves two fuel pumps, one positioned in each compartment of the tank. Each pump provides the fuel from its respective compartment to the engine. The tank was large enough to hold at least 544kg (1200 lbs) of fuel, enough to meet the mission requirements at the most extreme conditions. This means that a 90 gallon tank must be installed in the PAV. The tank is Vertical Fuel Transfer Tank — 90 Gallon, Model# 72118 with dimensions 1.52m (60in.)L x 0.36m (14in.)W x 0.66m (26in.)H. If not this tank there is one that would most likely fit in the space provided. It is an auxiliary fuel tank, constructed of 0.32cm (.125 inch) 3003 marine grade diamond plate aluminum with a brightly polished finish that does not exceed 19 inches tall.

C. Air Pump/Rotary Ambient Blower

A pumping system is needed to pump the CFJ. The pump requirements included a minimum flow rate of 2,700 CFM as well as a maximum height of 0.76m (2.5ft) inside the fuselage. Volume was not to exceed $0.4m^3$ ($14ft^3$) to allow for ducting room. The maximum RPM rate allowed was 6500 RPM due to engine requirements, which was more than enough to power a rotary pump. Once the application was known we were able to find a pump that held within these limits.

Tuthill Vacuum & Blower Systems has one pump that meets the requirements set by the PAV dimensions and is called the M-D pneumatic Equalizer. This pump has a pressure ratio of 2, which is good for the pressure ratio of 1.3 assumed in the calculations, and it also has a maximum flow rate of 6,000 CFM which gives more than the required air flow that is needed. At a volume of $0.21m^3$ ($7.5ft^3$) it will actually save space both in width and in length for other components. The height neared its maximum limit but it is able to fit it inside the PAV.

Figure 8. Picture of rotary ambient blower

The weight involved to reach both the required power and flow rate can be a concern because when the weight is increased so are the flow rate and power required. The durability of this pump is very high and is easy to maintain with a self sustaining cooling under high pressures.

V. Landing Gear

There are two main problems that a good landing gear must attend to. The landing gear must keep the plane balanced while on the ground and it must withstand the forces subjected to the aircraft by the ground. The first problem can be remedied by correctly positioning the landing gear. Shocks and tires help with the second problem.

The nose-wheel layout of landing gear was chosen over a tail-wheel or bicycle layout. The reason for this is that certain advantages of the nose-wheel layout are critical for a road traveling PAV[7]:

1) While the aircraft is on the ground, the fuselage, and hence the cabin floor is roughly horizontal.
2) The view of the pilot when taxiing is relatively good
3) The nose-wheel helps prevent overturning when braking
4) Initial takeoff has low drag
5) Less bouncy during landing

A tail-wheel layout cannot be used because the aircraft points upwards during taxiing. This means the cabin will also point upwards, resulting in reduced visibility and awkward driving. The bicycle configuration cannot be used as it requires small wheels on the side called outriggers. These would not be preferable during high speed taxiing as outriggers are easily overloaded.

Figures 9 and 10 show how the nose-wheel gears are laid out.

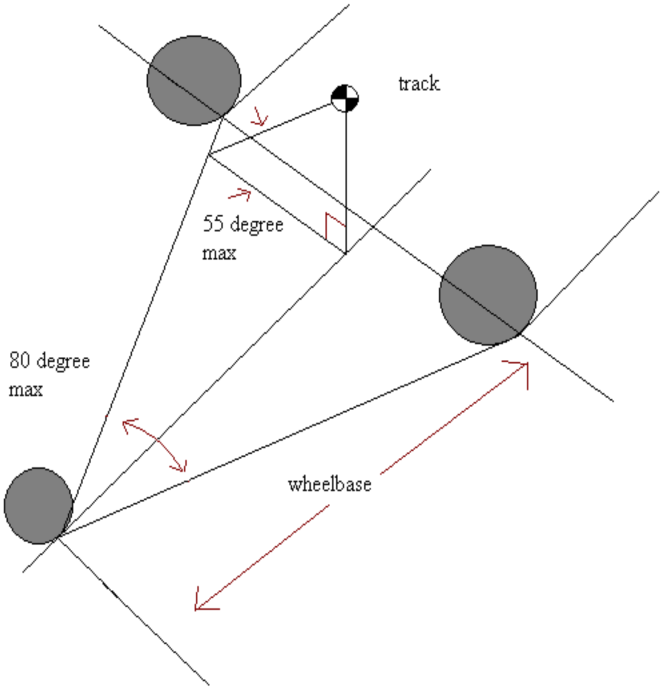

Figure 9. Layout rules part 1. Nose-wheel diameter around 2/3 diameter of rear wheels.

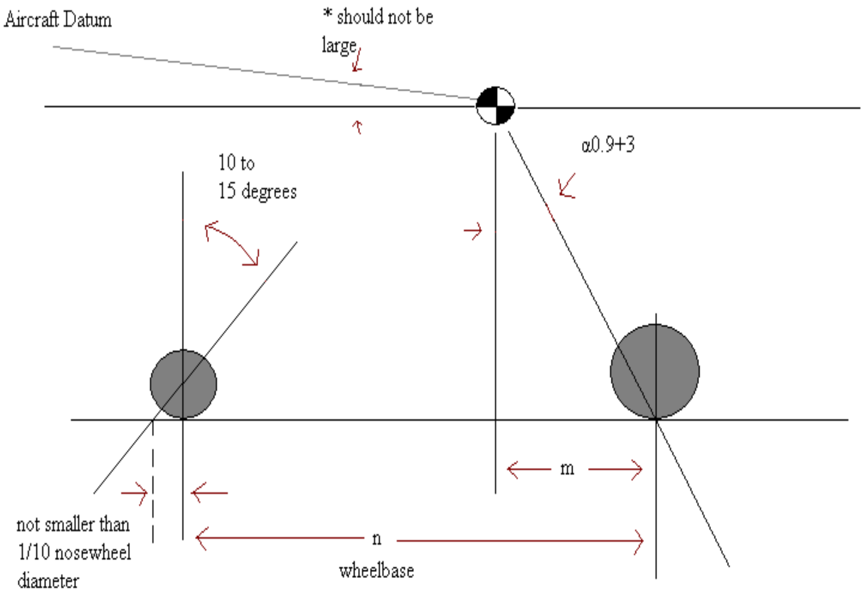

Figure 10. Layout rules part 2. α0.9 is the angle of attack at 0.9 coefficient of lift. 0.08 < m/n < 0.15

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After several iterations of the landing gear using these rules and a center of mass calculation revealed the following position of the landing gear.

1) Wheelbase = 3.8 meters
2) Track = 2.2 meters
3) Lowest point of the plane is 0.74 meters above ground
4) Main gears are positioned 4.3 meters down from the nose of the plane

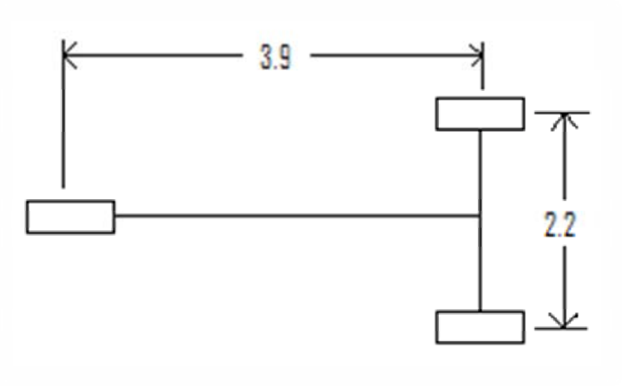

Figure 11. Basic layout and dimensions of wheel position

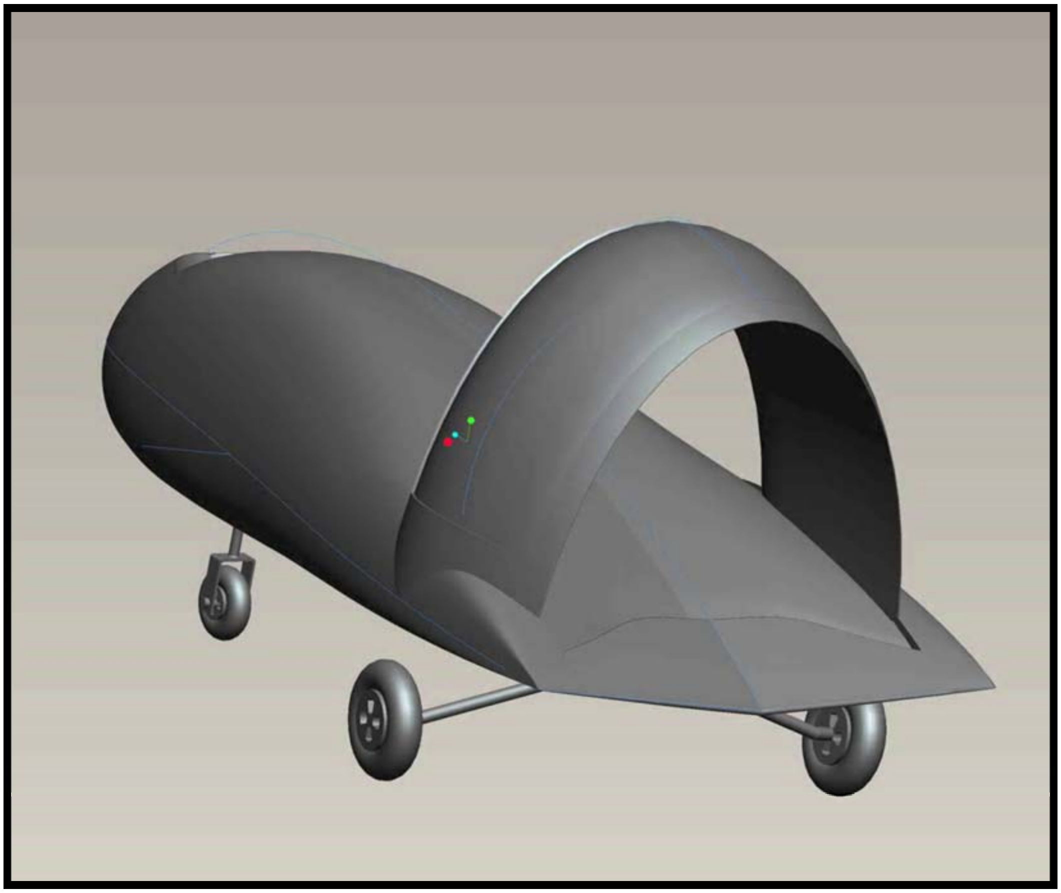

Figure 12. PAV with landing gear

Reactionary forces caused by the ground on the PAV have not yet been calculated. After they have, further calculations will be done for the tire and shock absorber design. The choice of using retractable or static landing gear is one of the greatest problems in the design of the landing gear for the PAV. It is most probable though, given the size of the PAV, that a static set of external gears will be used.

VI. Materials

The lighter the PAV the better, therefore lightweight materials with high strength are going to be used throughout the vehicle whenever possible. Composite materials are the ones that best suit these requirements and also they are quite reliable for aerospace applications.

For the skin, the composite material graphite-epoxy will be used. This was chosen because of its low density of 1600 kg/m^3. For the rest of the structure, which includes the ribs and spars, lightweight 8090 T3 Al-Li alloy will be used. The CFJ must always be taken into consideration so the ribs and spars do not interfere with it.

VII. Structure

The highest possible level of safety for the driver and passenger in all driving situations is one of the prime objectives of the development of the PAV. The passenger cell is comparable to the cockpit of a fighter jet and is designed in a monocoque construction as a survival cell for three persons. The development goals of the PAV were to create a high standard of torsional rigidity, passenger protection and lightweight construction. The centre frame housing the passengers is formed by lightweight 8090 T3 Al-Li alloy, which is built in the same way as a fighter cockpit. The rear section of the semi monocoque design is designed with a hollow space to hold the 1000-litre saddle fuel tank which surrounds the transmission and which is separated from the passenger area. The tank area forms part of the monocoque.

The front section consists of an aluminum frame structure weighing only 34 kilos, which holds the front section vehicle components, which include the radiator package, steering system and battery. In addition to this, the front section of the PAV is designed as a crash structure which deforms in a defined manner in the event of an accident, thereby absorbing kinetic energy.

A carbon fiber crossbeam screwed onto the two longitudinal supports forms the front edge of the frame structure. The steel frame mounted beneath it as a structural element accommodates the 16-cylinder engine. Because of the considerable heat given off by the engine and, in particular, the turbocharger, which operates with exhaust gas with a temperature of up to 1.000 °C, this frame structure is made of rust -free, heat-resistant stainless steel.

The pilot' and passengers' view, is unmatched. They sit underneath a clamshell-type canopy whose forward and center sections are made of a single piece of polycarbonate, offering the pilot an excellent forward view. Visibility covers a full 360 degrees in the horizontal and from 15 degrees down over the nose through the vertical and back to directly behind. The sideways view extends down to a depression angle of 40 degrees. The optical quality is high, and the curved surfaces offer minimal optical distortion.

The transparent part of the canopy is 0.5-inches thick, and was designed to resist the impact of a 4-pound bird at 350 knots. However, even if the canopy happens to fail under the impact of an especially large bird, the heads-up display is sufficiently robust to provide additional back-up protection for the pilot.

The elimination of the normal windshield arch improves the forward view, but this means that the entire transparency has to be as thick as the front portion, which is designed to survive bird strikes.

The air intake is located at a point just in front of the cockpit. The ventral location of the air intake subjects it to minimal airflow disturbance over a wide range of flight conditions and aircraft maneuvers, since the forward fuselage tends to shield the intake from the full effects of aircraft maneuvers, minimizing the effects of sudden changes in the angle of attack on airflow into the engine, fuel and tanks, flight system and the drive shafts, along displacement blower and Co-flow jet system and the car's oversized dimensions, all add weight. Even though the body is sculpted in carbon fiber to minimize its mass, the PAV weighs in at about 4,300 pounds (1,950 kg). For comparison, a Dodge Viper weighs about 1,000 pounds (454 kg) less and a Cessna 150 weighs 1600 pounds (726 kg).

Ribs and Spars

A sum of the internal weights at take off is required to design the structure of the aircraft. This is done at take off because the aircrafts will have all expendable payload as well and all its fuel. These maximum loads will create the greatest momentums and require the stronger structure.

The material chosen for the skin and stingers was the composite material graphite-epoxy fiber laid unilaterally in an epoxy matrix. This was chosen because of its low density of 1600 kg/m^3 and has a compressive yield stress of 67,000 pounds and a tensile yield stress of 92,000 pounds.

Each rib will have a spar at 15% and 65% chord. The stringer thickness and skin thickness were found next to the front and rear spar and on the upper and lower surface. These thicknesses were then reduced linearly along each rib from leading to trailing edge. For the upper surface, “Z” stringers were used, while “J” stringers were used on the lower surface.

VIII. Interior Design

Figure 13 below shows the general configuration of the interior of the PAV, showing the location and arrangement of the three passenger positions.

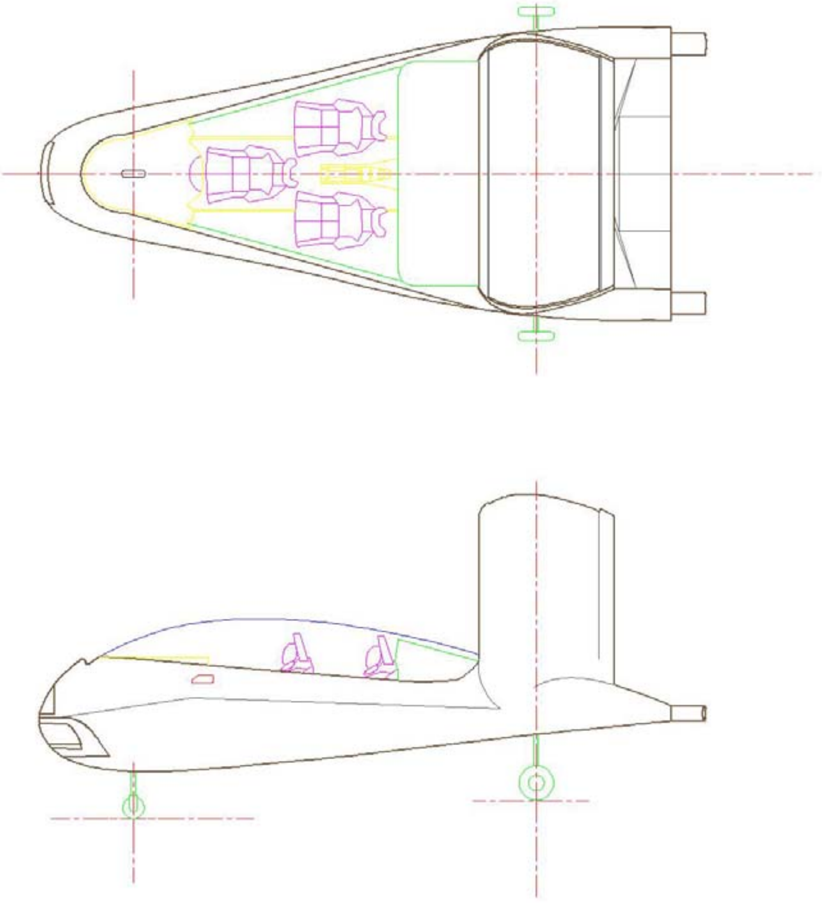

Figure 13. Basic layout of the interior design and passenger position

VIII. Control System

In order to use the least amount of moving parts, the CFJ will have a big role in the control system of the PAV. A 5° dihedral angle is also applied to the main wing body for lateral static stability.

For rolling, the CFJ located in the main wing body will be used. The PAV is basically divided in half and by changing the speed of the CFJ on any side, there will be difference in lift and therefore the PAV will be controlled to diminish the rolling it will experience while flying.

For yawning, the CFJ located in the elliptical wing will be used. The vertical sides of the elliptical wing on each of the left and right sides will be the ones in which the speed of the flow of the CFJ will be changed in order to create the difference in pressures that will control the yawning of the PAV.

For pitching it is harder to make use of the CFJ, as a result the addition of a flap on the back of the PAV will be needed and therefore move up or down to maintain the stability that the vehicle needs in the air.

A. Transmission and Clutch

The 7 speed Dual clutch System will be chosen for the PAV to achieve the 1001 hp needed. The twin-clutch gearbox combines the dynamic advantages of a manual gearbox with the convenience of an automatic. One significant differentiation criteria compared to the classic automatic gearbox is that no torque converter is used as a moving-off element. Instead, the gearbox has a twin clutch that is composed of two wet-running multi-disc clutches.

The twin-clutch gearbox is arranged longitudinally ahead of the mid engine. The 16-cylinder engine is located directly ahead of the front axle. Both the gearbox and the engine are designed as dry sump units - something that is particularly important in terms of achieving a lower centre of gravity. The gearbox is shifted in manual mode using gear shift paddles behind the steering wheel or a joystick lever in the center console. This gives a short gear shift time and maximum gearshift comfort. The gear shifts of the seven speed gearbox take place sequentially at paddles behind the steering wheel and there is no clutch pedal. The double clutch transmission shifts from one gear to the next in a maximum of 0.2 seconds.

B. Steering

The landing gear system on the PAV is a conventional aircraft tricycle configuration consisting of a nose landing gear and a left and right main landing gear. Each landing gear includes a shock strut with two wheel and tire assemblies. Each main landing gear wheel is equipped with a brake assembly with anti-skid protection. The nose landing gear can be steered. The nose landing gear is located in the lower forward fuselage, and the main landing gears are located under the main body.

Nose steering systems are hydraulically actuated and can either be electronically or mechanically controlled. The steering actuator serves the dual function of providing steering and dampening (when steering is not engaged).
Steering on a typical aircraft is accomplished by swiveling the lower portion of the nose-wheel shock strut. A rotary type vane of hydraulic steering unit is mounted on the fixed portion of the chock strut and is linked to the swiveling portion to which the nose-wheel is attached. For turns requiring a greater steering angle, the pilot can usually use differential braking, in which case the steering unit is automatically disengaged and the nose-wheel swivels freely.

For the PAV, the nose wheel will be steerable before take-off and after nose wheel touchdown at landing. The nose wheel is electro-hydraulically steerable through the use of the general-purpose computers and the co-flow jet system, in conjunction with the flight control system in the control stick steering mode. Nose wheel steering is advantageous to allow positive lateral directional control of the PAV during landing in the presence of high crosswinds and blown tires. Modifications of the nose wheel steering system have been incorporated to allow a safe high-speed engage of the nose wheel steering system.

For safety reasons the PAV will feature a collapsible steering column (energy absorbing steering column) which will collapse in the event of a heavy frontal impact to avoid excessive injuries to the driver. Non-collapsible steering columns very often impaled drivers in frontal crashes.

C. Navigation System

Along with working on a Small Aircraft Transportation System, there are two problems holding back personal air travel on a massive scale: midair collisions and complicated piloting mechanisms. Merely providing these vehicles is not enough, however, if everyday people are to use them, knowing to track thousands of these vehicles is essential. And knowing is half the battle.

Collision deterring navigation systems are key to transforming highways into skyways. Regular people can’t be trusted to avoid pasting themselves against office buildings. Instead, the PAV’s will use GPS and cell phone technology to automatically broadcast information and location and speed to ground based towers. From the ground an automated computer system would update the flight path of every sky vehicle and provide instant directions – automatically avoiding collisions and minimizing flight time. Meanwhile, onboard sensors will detect nearby trees, buildings and power lines and avoid collisions. Thus for most of the flight the human ‘driver’ can take care of anything besides flying, like sightseeing.

At some point, however, the pilot driver must be called to steer. Since most people love to play video games, this design will be controlled by simple video game-like joysticks. Automatic collision-avoidance technology and self correcting flight controls should allow just anyone to master his or her own personal aerial vehicle.

D. Battery System for Starting

Choosing a proper battery system for the PAV is also important. A suitable car battery is needed in order to supply power to the starter and ignition system to start the engine, supply the extra power necessary when the vehicle's electrical load exceeds the supply from the charging system, and act as a voltage stabilizer in the electrical system. The battery evens out voltage spikes and prevents them from damaging other components in the electrical system. This is a large battery used to turn the starter motor within a car, or other motor vehicle. It is also the most powerful battery described so far. Its strength is gained by linking many separate cells together into one powerful battery. Plates of lead oxide and lead metal are immersed in sulfuric acid electrolyte. The electrons to the lead batteries and change it into lead sulfate. Once the car battery starts the engine, a generator engine runs and recharges the battery, reversing the reaction.

The starting system consists of an electric starter motor and a starter solenoid. When you turn the ignition key, the starter motor spins the engine a few revolutions so that the combustion process can start. It takes a powerful motor to spin a cold engine. The starter motor must overcome:

* All of the internal friction caused by the piston rings
* The compression pressure of any cylinder(s) that happens to be in the compression stroke
* The energy needed to open and close valves with the camshaft
* All of the "other" things directly attached to the engine, like the water pump, oil pump, alternator, etc.

Because so much energy is needed and because a car uses a 12-volt electrical system, hundreds of amps of electricity must flow into the starter motor. The starter solenoid is essentially a large electronic switch that can handle that much current. When you turn the ignition key, it activates the solenoid to power the motor.

Figure 14. Battery System for the PAV

Since our vehicle will be capable of flight, we decided to use a DESSC (Diagnostic Engine Starting System Controller) from RSL electronics. It is an all digital replacement for the original Engine Starting System (ESS) controller of the F-16 aircraft.

The DESSC significantly improves the engine starting system performance and reliability. Similarly, it increases flight safety and readiness. Additionally, the DESSC streamlines maintenance and significantly reduces its costs. With dimensions of (HxWxL) 5.0" x 4.1" x 10.1" (128x103x268)mm and a small weight of 4.8 lb (2.2 Kg) it is a great addition to this vehicle. With this system no additional modifications to the vehicle were necessary and it covers the entire starting system, including:

- Diagnostics provides automatic fault isolation to the component level
- Pilot alert when unsafe condition is detected
- Disables unsafe starting
- Auto recording all engine starts for in-depth diagnostics and trending
- Monitoring and recording of JFS exceedances
- Fault detected as soon as power is applied to the aircraft

IX. Conclusion

The conceptual design of a personal aerial vehicle using co-flow jet airfoil (CFJ) is presented in this paper. The PAV is designed to take-off and land in regular roads and highways and to carry 3 passengers for short distances in a reasonable time frame by flying at an altitude of 10,000ft and at a speed of 0.3 Mach. An aspect ratio of 2.5 was achieved by adding an elliptical wing on top of the main body flying wing design, keeping the PAV within the regulated dimensions of a highway for safety purposes. The CFJ airfoil applied throughout the entire vehicle is used as the propulsion system of the PAV needing 685hp of power to produce the necessary mass flow rate for lift at take-off. This power will be provided by an internal combustion engine which delivers 1001hp. As a result of the CFJ technology, the PAV has a low stall velocity, high stall margin and high lift making this vehicle able to operate safely at regular roads and highways. Currently the CFD analysis is in progress.

Several conclusions were made at the end of the design of the PAV. The power required to create the mass flow rate at sea level requires a large engine and engine system, while the pumping required for the mass flow rate at altitude requires a large pumping system. In terms of plan form design, the PAV allows for feasible fitting of all components necessary for flight, while still being able to fit all components necessary for use of the Co-Flow Jet Airfoil, which was one of the main concerns. As each new technology becomes refined, especially the CFJ which is found in a large part of the vehicle, the new discoveries will be applied to the PAV expanding its frontiers.

Appendix

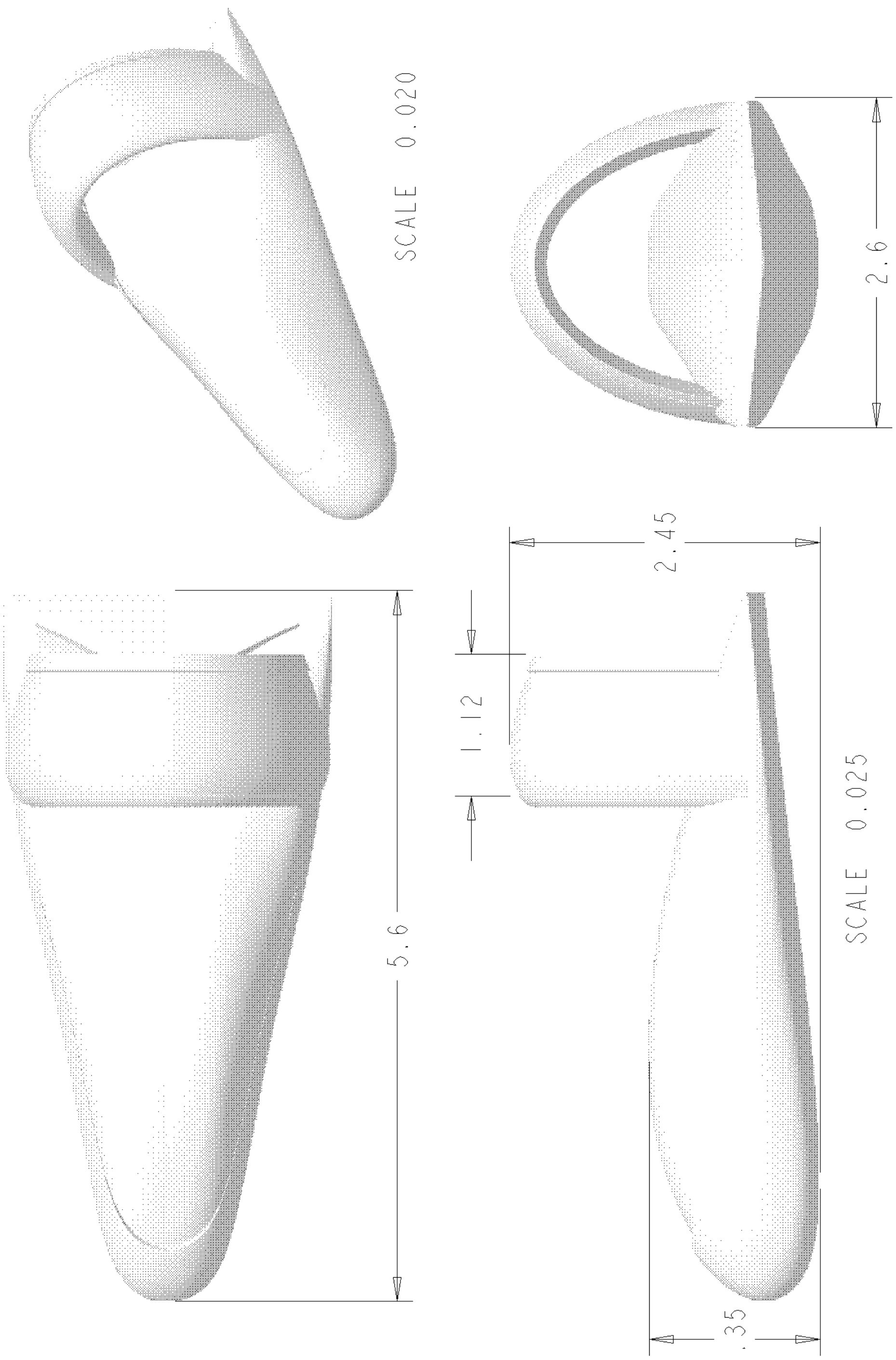

Figure A.1. Main views and dimensions of the PAV with CFJ airfoil

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References

[1] North American Free Trade Agreement Land Transportation Standards Subcommittee, "Highway Safety Performance Criteria In Support of Vehicle Weight and Dimension Regulations: Candidate Criteria & Recommended Thresholds" Working Draft for Consultation, Nov. 1999.

[2] Zha, G.-C., Carroll, B., Paxton, C., Conley, A., and Wells, A., "High Performance Airfoil with Co-Flow Jet Flow Control," AIAA Paper 2005-1260, Jan. 2005; also *AIAA Journal* (submitted for publication).

[3] Zha, G-C., and Paxton, C., "A Novel Airfoil Circulation Augment Flow Control Method Using Co-Flow," NASA CP-2005-213509, June 2005; also AIAA Paper 2004-2208, June 2004.

[4] Zha, G-C., Carroll, B., Paxton, C., Conley, A., and Wells, A., "High Performance Airfoil with Co-Flow Jet Flow Control," AIAA Paper 2005-1260, Jan. 2005; also *AIAA Journal* (submitted for publication).

[5] Zha, G-C., Paxton, C., Conley, A., Wells, A., and Carroll, B., "Effect of Injection Slot Size on High Performance Co-Flow Jet Airfoil," *Journal of Aircraft* (to appear 2006).

[6] Aguirre, J., Zha, G-C. "Design and Study of Engineless Airplane Using Co-Flow Jet Airfoil."AIAA Paper 2007-4441. June 2007.

[7] Fielding, John P., *Introduction to Aircraft Design*, Cambridge University Press, New York, 1999, p. 84.