The Unmanned Aerial Systems Flight and Payload Challenge

Paper Submission (Stage 1)

By Team:
The University of Calgary, Trek Aerospace, ComplexSys Solutions, and 4Front Robotics
(aka Team: Rescue Drones)

High Payload/Speed Highly Maneuverable UAV for Urban SAR Operations

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Abstract (500 words)

Limitations of conventional VTOL rotor assemblies include the fact that takeoff and landing on non-horizontal surfaces are problematic, payload capabilities are limited, and energy consumption is high. Consequently, UAV pilots are generally trained to avoid landing on surfaces at an angle in excess of 5 or 10 degrees, and VTOL operations in, for example, mountainous terrain and within urban disasters are challenging.

Another limitation of conventional rotor assemblies is that downward airflow, also termed "downwash", when obstructed re-enters the rotor space, thereby interfering with the lift forces generated by the rotor. Depending on the nature and proximity of the obstruction, this renders the aircraft difficult to control and restricts the ability of aircraft to operate in confined areas, e.g. in canyons or between tall city buildings.

The proposed UAV relates to a novel implementation of a rotary wing aircraft having unique rotor assemblies and characteristics including between 50%-70% greater payload capabilities, extended maneuvering capabilities to penetrate helicopter impenetrable environments and increase flight times in the order of 50% when compared to similar size UAVs.

The proposed embodiment referred to as a Highly Maneuverable UAV is derived from concept aircraft developed at the University of Calgary and 4Front Robotics. The UAV is a rotary wing aircraft comprising: two main tilting shrouded propellers and a horizontal tail propeller. To enhance the reaction time and maneuverability of the aircraft all propellers rotate at a constant energy optimum speed and their thrust is controlled via variable pitch propeller assemblies. The two main propellers rotational axes are positioned equidistantly on either side of the longitudinal axis of the fuselage. The three propellers operate to control both horizontal, vertical and control pitch-hover movements of the aircraft. For this, the main propeller spars are movable during use to independently alter their tilting angle.
The proposed VTOL aircraft comprises a horizontal tail propeller which the main purpose is to enable stationary or otherwise pitch-hover maneuvers enabling the UAV to maneuver in any confined space encountered in natural and otherwise urban search and rescue operations.

To increase payload capacity and reduce aerodynamic ground and wall effects the proposed vehicle's main propellers will include an optimum designed shroud where the fixed ring structures in use will be co-planar with the rotor blades.

To maximize thrust and minimize ground/wall airflow disturbances the spar holding each of the main propellers and transversally extending in opposite direction from the fuselage will be controlled to rotate around its transversally extending rotational axis permitting a controlled pivoting each spar at different (dihedral) angles in a vertical plane that is parallel and spaced apart from the vertical plane of the longitudinal axis of the aircraft's fuselage.

The target time for each payload will be at least 50% more when compared to available UAVs of similar size. The energy source will be a hybrid system enabling the aircraft to switch between gas and battery power when and if needed (e.g., gas when increase payload is needed and battery operation when fuel emissions and noise are of concern).

Project Description: Highly Maneuverable UAV

For the proposed UAV we define maneuverability as: *The ability to change attitude and direction on three axes/dimensions*. For this, the proposed UAV will generate the required forces and moments on each axis, where maneuverability is decoupled from velocity, meaning that the *vertical take-off and landing* (VTOL) UAVs will retain the ability to change attitude (roll, pitch and yaw)) and direction at zero airspeed, and even at negative airspeeds (e.g., moving backwards). This also implies the capability of our UAV to fly at zero airspeed (hover) while maintaining full three-axis control (e.g., pitched hover allowing the UAV to take-off and land from unprepared highly slopped terrain (suitable to be used in any chaotic environment found by first responders. In the most generalized terms, the proposed aircraft's maneuverability will enable it to:

- Change *attitude* around the aircraft's three axes (longitudinal, lateral, and vertical).
- Change *velocity* on the aircraft's three axes, and in the three spatial dimensions (1 vertical and 2 horizontal).

Thus, following on from our definition, changes in *attitude* on each axis will be created by the *moments* acting on the aircraft on the corresponding axis and are resisted by the *mass moments of inertia* of the aircraft on that axis. Furthermore, changes in velocity on each axis will be created by the *forces* acting on that axis and are resisted by the *mass inertia* (mass, or weight) of the aircraft. Thus, to increase maneuverability the proposed highly maneuverable UAV for USAR operations, we will lower the *inertias* of the aircraft and increase the available *moments* and *forces*.

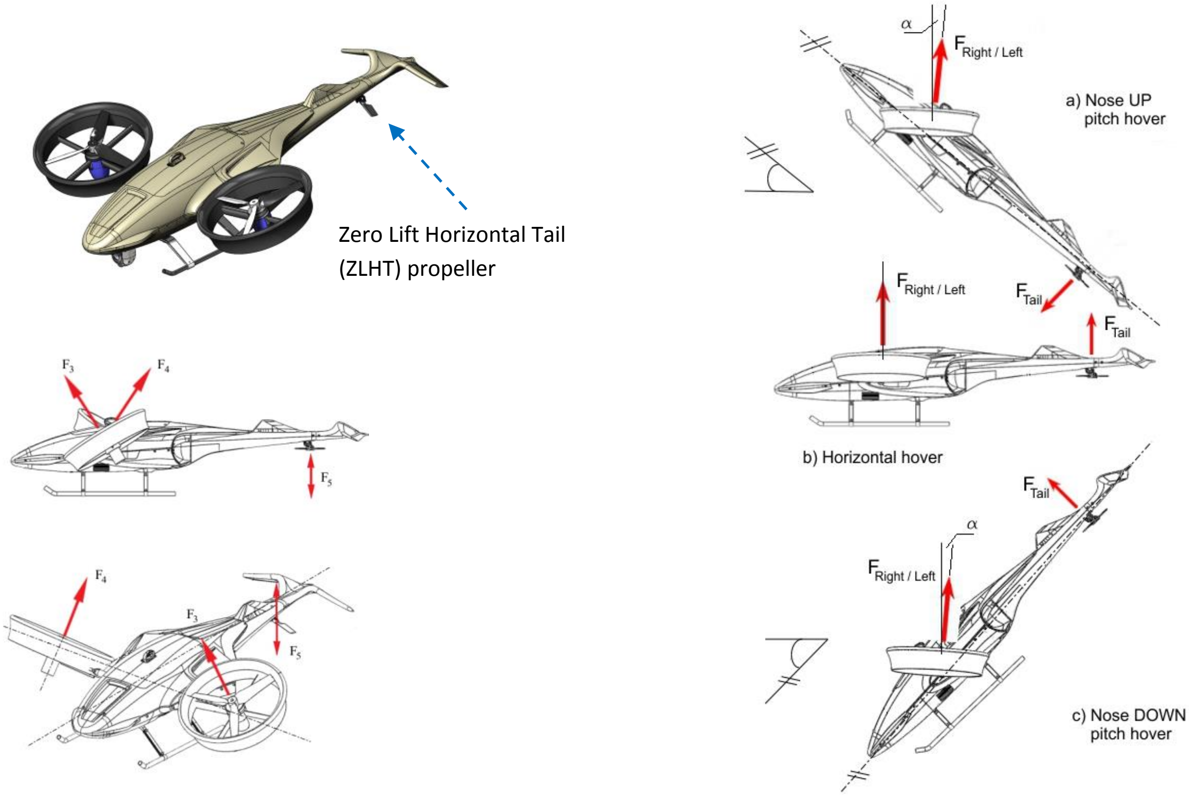
The proposed UAV will be a scalable vehicle and can use our 9" and 16" ducts, as well as 600 mm and 800 mm ducts that the team has developed and tested in the past. The vehicle's core abilities will include: between 50%-70% greater payload capabilities, extended maneuvering capabilities in confined, structured or unstructured, environments, at low altitudes, or in close proximity to infrastructure spaces to penetrate helicopter impenetrable environments, and increase flight times in the order of 50% when compared to similar size UAVs, and the ability to hover and land while in a non-zero pitch attitude in static (e.g., mountainous or urban disaster terrains) or dynamic tilting platforms (e.g.. vessels in rough seas). These flying features enable the UAV to position and orient its sensors as needed to locate victims, collect mission specific data, etc. in adverse situations. Thus, USAR personnel will be able to deploy the UAV from any surface regardless of how rough the terrain is and be able to provide assistance in diverse situations.

The vehicle will be easily enhanced (future versions), when and if needed, with the addition of a set of wing + canards system, to be operated as a transitional aircraft (having the capability to fly in either VTOL of fixed-wing mode) and thus enabling fast SAR response and reaching the any site where an incident has occurred promptly. The vehicle is based on a layout having twin ducted fans flanking a central fuselage (Figure 1).

The UAV will be able to be electrically or gas powered, or use hybrid power (gas + batteries) and automatically switch between gas or battery operated as needed when increased payload or when silent flight mode with zero emissions is required (e.g., flight in confined spaces and in close proximity to victims). Except for the shrouded design (which cannot be easily scaled) the UAV will be modular and thus able to be manufactured in various sizes depending on needs. The UAV will use two counter-rotating variable-pitch propellers enabling it to effectively cope with disturbances such as wind gusts. Using a specialized and proprietary CFD software program, TASPA (Trek Aerospace Shrouded Propeller Analysis), to design shrouded propeller modules, the design of the shrouds will protect each propeller against collisions and reduce possible human accidents. It will also enable between 50% to 70% more payload capacity when compared to similar size UAVs, thus enabling to transport larger *Urban Search and Rescue* devices/equipment to assist first responders and victims.

The shrouded props tilt, individually, about a single axis and an active horizontal tail propeller will be used as the primary means of flight control to perform knife-edge maneuvers (e.g. pitched hover) not possible by other aircraft. When flying in confined spaces the, downwash generated by the propellers may bounce from the ground, walls, and ceiling creating adverse wall/ground effects on the vehicle pushing/pulling it away from its intended trajectory. To cope with such flow effects the UAV will generate a flight path (using a 3D navigation algorithm developed by the team for confined spaces), and the control system forecasts the wall/ground effects (based on a proprietary CFD mathematical expression derived from Computation Fluid Dynamic simulation studies) that it will experience during flight.

The UAV will determine its flight path and maneuvers taking into account the UAV's physical shape, its flying characteristics, and the terrain's geometry. As a result the UAV is able to take-off and land (deployed and retrieved) from highly sloped, prepared or unprepared terrain (e.g., 50 degrees of inclination) and perform acrobatic maneuvers at zero speed. These features enable it to position and orient its sensors as needed to locate victims, collect mission specific data, etc. in adverse situations. Over time the UAV will be enhanced to fly at higher speeds within confined spaces for faster response, and carry a robotic arm to manipulate the environment (e.g., open doors and move debris).



a) UAV's layout.

b) Pitch-hover.

Fig. 1: Proposed Highly maneuverable UAV for SAR.

Flight Characteristics

Along with other improvements, the discovery of a distance-less control system (no need for typical control surfaces such as ailerons positioned away from the aircraft's fuselage) will enable an aircraft type that has been highly attractive, yet unattainable in the past; Dual-fan VTOL aircraft. The unique flying characteristics of the proposed vehicle, will e enabled by the team's previous R&D work in design, control, CDF, etc. allowing long-range flight similar to a fixed wing aircraft. The proposed aircraft is now not only practicable but can have advanced capabilities beyond any expected previously. The unique flying characteristics of the proposed UAV are due to four striking developments:

1) Shrouded dual lift-fans are operated as *Control Moment Gyroscopes* (or CMGs, used for spacecraft attitude control), eliminating the need for reactive devices such as ailerons positioned at sufficient distance away from the vehicle's center of mass for effective pitch control in hover. The fans' longitudinal-tilt facility associated with this operation also allows advanced features not seen in helicopters, such as the ability to pitch while remaining in a stationary hover.
2) The shrouded propellers are designed to enhance lift by 50% to 70% when compared to similar size VTOL UAVs. These are used for lift and roll in horizontal flight, thereby eliminating conventional wings and ailerons.
3) The use of either an aircraft *Moving Mass System* (MMS), which allows the aircraft to dynamically manipulate its center of gravity, enhancing the maneuverability of the UAV at any velocity including zero speed, or using a (PTC patent No: PCT/CA2016/051197) *Zero Lift Horizontal Tail* (ZLHT) propeller to maintain a perfectly balanced aircraft despite fuel consumption or the addition of payload sensors, or to induce perfect aircraft's pitch control. Either is these devices (i.e., MMS or ZLHT) will be used to change the attitude of the aircraft as needed.
4) Effective control and navigation algorithms specially developed for 3D complex, confined environments.

Control

The UAV characteristics, listed above, will allow for a new system which uses only the dual lift-fans themselves and the ZLHT for control. The UAV will harnesses the intrinsic gyroscopic properties and driving torques of the spinning fans for vehicle pitch control. This eliminates the need for peripheral control elements or lift devices. The system will enable agile and compact VTOL air vehicles having greater maneuverability, payloads and flight time capabilities by generating pure, sizeable moments rather than just forces. Pitch control of the vehicle is independent of any distances to its center of mass, and therefore the UAV will be smaller in size, for the same payload, without incurring any loss in control authority. Two elements will enable this system to operate effectively; the lift fans that can be tilted about the lateral axis while either the aircraft's center of mass is simultaneously adjusted in the longitudinal axis or the Zero Lift Horizontal Tail thrust is adjusted to control the pitch of the vehicle. These control systems, generate substantial gyroscopic, fan-torque, and pitching moments. The sum of these moments generates a significant and precise pitch-control moment to maneuver the vehicle.

The combination of duct tilting and ZLHT, provides a static pitching moment allowing the aircraft to remain level in hover despite any pitch imbalances such as off-center loading. A corollary of this is the ability to pitch while stationary, a particularly advantageous feature allowing direct target-pointing and VTOL from sharply inclined surfaces. In this case the fans will be tilted longitudinally so that their axes' of rotation remain vertical, thereby not translating the aircraft, while changing the ZLHT generates the necessary pitching moment.

In general, duct tilting and tail vertical thrust, cause pitching, however they can be combined in various ways to obtain separate, independent control of the aircraft's attitude. This control separation allows nearly independent 6-axis control of the air vehicle: i) Roll control by differential propeller thrust; ii) Pitch, in flight and at zero velocity, using the proprietary MMS or the ZLHT and ducted fan tilting; iii) Yaw, primarily by differential duct tilting, fore and aft; iv) Lateral motion, currently coupled to roll; v) Vertical motion by collective propeller thrust; and vi) Forward/backward motion by coupled duct tilting, fore and aft. There will be three main attitude control systems on the aircraft:

1) *<u>Duct Arm Tilting</u>* – The duct arms are able to tilt along the pitch axis of the vehicle. This facilitates yaw control, forward flight, and pitched hovers. The duct arms are linked to control servos using lightweight plastic/aluminum composite gears. These servos control the angle of the ducts relative to the longitudinal axis of the fuselage.
2) *<u>Variable Pitch Propellers</u>* – The variable pitch propellers allow fine control of thrust from each duct. This system allows for roll control, and cruise efficiency, in addition to some yaw control as well.
3) *<u>Zero Lift Horizontal Tail Propeller System</u>* - A horizontal tail propeller provides control of the moments acting on the longitudinal axis of the UAV. By changing the thrust produced by this propeller, in concert with the duct arm tilting system, the pitch angle of the fuselage can be precisely controlled, and held in position.

ZLHT (*Zero Lift Horizontal Tail*)

The ZLHT provides an enhanced reactive and immediate means to control the UAV. We have developed and tested a manually controlled UAV prototype, where pitch hover maneuvers at any angle within the range of $\pm 90°$ have been achieved. By using the ZLHT and moving the shrouded propellers upward the following four enhancements will be achieved: a) Enhanced payload, b) Faster aircraft reaction times, c) Enhanced pitch hover capabilities, and d) Reduced fluid ground and wall effects. With these enhancements we will improve aircraft capability to perform missions not previously possible by other UAVs on the market. The proposed UAV will be prototypes and simulated and experimentally tested in both manual control and autonomous flight.

The oblique propeller spars which will reduce the ground/wall flow effects when flying at low altitudes and within confined spaces will be a key innovation which defeats the capability of other UAVs on the market for confined spaces. This is a defining transformative technology which we believe will; not be easily duplicated by competitors.

Furthermore, during pitch hover maneuvers, the UAV will be able to maintain full ability/control to move in any direction. Based on comprehensive CDF work performed by the team, the main thrust propellers will be tilted approximately 6° upward in the lateral direction (dihedral angle). It was found by slightly tilting the main propellers upward we will be able to significantly reduce the ground effect ceiling. Thus, enhancing the flying abilities in close proximity to obstacles and improving the control effort when performing landing and taking off maneuvers from any type of terrain. As a result the vehicle will be far more stable (when compared to any other UAV systems) when flying in close proximity to obstacles and reducing what is known as ground effects against the ceiling or walls in confined spaces.

Landing on moving targets such as vessels undergoing an oscillating behavior while under the presence of obstacles has been a challenge. Although from a mission specific level, the UAV can be commanded to follow well defined paths in terms of GPS positioning, adjusting its operation to autonomously land on a highly dynamic platform such as a moving navy ship has been problematic until now. The multi-tasking operation required to steer (yaw and roll), descend and pitch the UAV simultaneously without colliding with the moving platform is a highly complex and distracting task for any aircraft pilot. The proposed UAV will enable landing on a rocking moving (translating) platforms.

High speed Flight

Transition to high speed flight - or fixed-wing mode - will be achieved by tilting the duct arms forward up to 90 degrees, during which longitudinal (pitch) stability is maintained by differential thrust, the ZLHT, and by horizontal stabilizer on the tail of the aircraft. This characteristic, can be used if required for extended range or higher speeds as fixed wing lifting devices will be easy to be incorporated into the UAV's shell for enhanced performance and even longer flight endurance, as indicated by some of our recent R&D work. Such concept aircraft is illustrated in Figure 2.

Additional Features

In addition to the above characteristics the UAV will also possesses the following additional benefits, thanks to its twin ducted fan design:

- A Low noise signature due to the optimal design of the shrouds and propellers blades.
- A high noise decay rate with distance. This is due to the higher frequency of noise generated by the high rotational speeds of the fans.
- A smaller footprint with increased payload time. UAV's with shrouded propellers can operate closer to obstacles and even make contact with them, without fear of catastrophic damage.

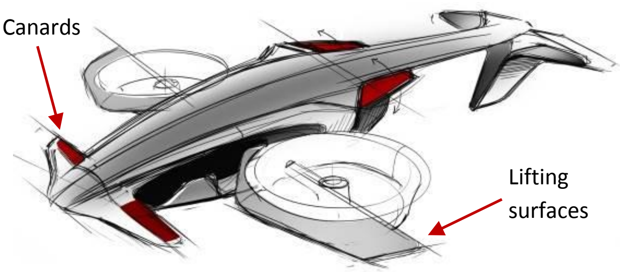


Figure 2: UAV high speed concept.

Power-plant

Electrical power for the UAV will be stored in an onboard bank of Lithium Polymer batteries using approximately six, 2.5Amp-hour batteries, and one 5.0Amp-hour battery, for a total of 20Amp-hours at a nominal voltage of 18.5 volts. A small gas engine might be used and combined with the batteries as a hybrid power system. The power plant is fed into ducted fans. For electric models, the power is delivered to an electric motor in the fan nacelle, and for gas models, it is delivered in the form of shaft rotation at the fan nacelle gearbox.

The aircraft's thrust fans will use a *Variable Pitch Propeller* (VPP) system, which will enable dynamic adjustment of the blade angle of attack. This capability will allow much finer control of the thrust and optimal rpm relationship within the fan thus maximizing energy consumption. Control of this relationship is important in order to maximize efficiency and payload capacity. The VPP system will enhance the reaction time of the UAV when faced with wind or other disturbances such as ground and wall flow effects and temperature gradients, which can be encountered when entering confined spaces and flying inside burning buildings. The optimized ducted fans, will serve more than a protective covering for the blades; it provides the following additional benefits:

1) **Increased static thrust:** will produce up to 50-70% higher static thrust than a similar size free propeller.
2) **Increased dynamic thrust:** will produce higher dynamic thrust, up to 200KT airspeed, at which point, the drag from the duct negates any gains it provides.
3) **Reduced noise:** will be half as loud as an equivalent free propeller.
4) **Increased safety:** protect the spinning blades from obstacles, and protect persons near the aircraft from the fan.
5) **Provide lift in forward flight:** acts as a ring-wing when in forward flight, augmenting lift from the fans, and reducing power required for cruise.

The duct and propeller combo design will be optimized for static thrust performance with the selected motor. For example, for a 15 pound (6.8kg) vehicle at 3600' MSL, with nominal blade pitch, liftoff will occur at a propeller rotational speed of 4595 rpm. By lowering the blade pitch, the propeller will be forced to turn faster to generate the same lift. The fan blades will operate slightly less efficiently, but due to the reduced current draw, the motor will be operating in a more efficient range, hence one of the reasons for using a VPP system.

Structure

To reduce the weight of the UAV and enhance its payload and flying time characteristics as well as make it resistant to high temperatures possibly encountered in Urban SAR operations the aircraft's structure will be primarily composed of carbon fiber composite panels (including a monocoque, a structure in which the chassis is integrated with the body) which will be joined by plastic or aluminum structural components depending on the local stress and strain predicted in flight maneuvers. In addition to the carbon fiber paneling, a central stiffening truss structure will be added to provide additional compression support for the carbon components making it more robust to the potential harsh conditions.

TEAM'S RESUMES & EXPERTISE

Team Members and Expertise

The team comprises 10 individuals and 4 collaborating organizations: the Univ. of Calgary - UofC (Canada), 4Front Robotics Ltd. (Canada: www.4fronrbotics.com), Trek Aerospace (USA: www.trekaero.com), and ComplexSys Solutions (Canada: www.complexsys.ca/). The following are the key members.

Name	Role on the team
Dr. Alejandro Ramirez-Serrano Ph.D. Mechanical Eng. M.Sc. Computer Science - AI M.Sc. Mechanical & Aerospace Eng. B.Sc. Mechanical Eng.	-Professor at the Univ. of Calgary & Founder and CEO;4Front Robotics: robot systems concept generation, main developer of technical concepts. Expertise in robot design, control and system integration. Patent applicant of highly maneuverable UAVs for USAR. Industrial experience includes R&D engineer at ABB Corporate Research, and R&D fellow at Argonne National Labs – West.
Mr. Roberts Bulaga M.Sc. Aeronautical & Astronautical Eng. B.Sc. Aeronautical & Astronautical Eng.	-President, Chief Engineer (Trek Aerospace), specializes in aircraft systems engineering, structural design, computational fluid dynamic (CFD) analysis, performance analysis, component testing, and flight-testing. Rob has been an active pilot for over 30 years, using his commercial pilot's license for glider and banner towing, flight instruction, aerobatics, and air show performances
Mr. Steven Trembath B.Sc. Mechanical Eng.; Pilot	-UAV and Aircraft Technology Officer; Aircraft and mechanical engineering design; Aircraft Computational Fluid Dynamics.
Mr. Mohsen Majnoon M.Sc. Systems Eng. M.Sc. Electrical Eng. B.Sc. Biomedical Eng.	-R&D Control and electronics engineer; dynamic equations for rotary systems, navigation expert and optimal control for Vertical Take-off and landing systems. Designed controllers for target tracking applied in Search and Rescue Operations.
Mr. Romas Krivelis B.Sc. Electrical Eng. President UofC UAV club	-Hardware, firmware and software development for experimental platforms and unmanned aerial vehicles; Circuit design to debugging.
Mr. Frank Jansen M.Sc. Mechanical Eng. Pre-masters Systems & Control B.Sc. Aerospace Eng.	- Founder and CTO (ComplexSys Solutions), several years of experience in hardware, firmware and software development for experimental platforms and unmanned aerial vehicles; modelling and systems engineering services applied to heavy equipment and simulation industry. Significant experience sizing and integrating electronics and mechanical systems in unmanned systems.
Mr. Ashraf M. Kamal Ph.D. Candidate Mechanical Eng. M.Sc. Mechanical Eng. B.Sc. Mechanical Eng (aircraft mechanics	-Current Ph.D. student at the University of Calgary under the supervision of Dr. A. Ramirez-Serrano developing transitional UAV systems. Extensive experience in aircraft flight mechanics, Modeling, Simulation, testing and identification of aircraft flight dynamics and their stability including CFD and wind tunnel testing

The team has a combined 70+ years of experience designing, developing and testing using unmanned vehicles, with a special focus on unmanned aerial vehicles (UAVs). Dr. Ramirez-Serrano and his team focus on highly maneuverable UAVs capable of autonomously navigating in highly confined spaces. The environments considered, include collapsed buildings, urban canyons, and forested areas below the treetop canopy. Industry focuses include mining, oil & gas, search & rescue, and urban policing.

The team has a strong technical background. Two members have postgraduate degrees in Mechanical Engineering (robotics area), Two in Electrical Engineering, one has an additional degree in Aerospace engineering, and the team leader has a Doctoral degree with combined degrees in Mechanical Engineering, two Master degrees, one in Mechanical & Aerospace Engineering and a second in Computer Science – Artificial Intelligence. Dr. Ramirez-Serrano and his team have developed a diverse set of technologies that are being further enhanced to enable UAVs to fly where current UAVs cannot fly. These technologies also allow UAVs to perform acrobatic maneuvers and effectively maneuver in confined environments. These developments have been featured at the ***National Aviation and Space Museum*** in Ottawa, Canada (2012), and have received the ***2014 ASTech award*** - Alberta's highest science and technology honor - in the category of "Outstanding Achievement in Applied Technology and Innovation" for work over the past 11 years developing UAV technologies. Dr. Ramirez-Serrano and collaborators have also received the ***Price of Excellence at World Innovation Day Geneva Switzerland Competition (Aug. 2014)***: Innovation for Health Competition in collaboration with University of

Calgary's Faculty of Medicine and the Alberta Children's Hospital for developing and using humanoid robotics and control cooperation software tools for pediatric care (i.e., reducing stress and pain in children undergoing diverse medical procedures in hospital via humanoid robots).

The team ended in 2nd place during the ***2015 Indra's International Community Award: From Idea to Reality*** as the most voted proposal by the Drones for Good Community, and obtained the ***2nd place in the 2016 International UAE Drones for Good award competition*** among more than 1017 submissions received from 167 countries.

The team members bring experience from a wide range of related areas including service robotics, intelligent robot control, mechanical and aerodynamic analysis, custom aircraft and machinery design, *The University of Calgary Solar Car* Mechanical team, Medical Physics, and robotics for pediatric care. One team member holds a private pilot's license and brings such knowledge to the UAV domain. All team members are entrepreneurs and have participated in the creation of start-up companies such as Solar Computers (business developer), ComplexSys Solutions, Trek Aerospace and 4Front Robotics Ltd.

Team has a strong technical, industrial and academic background and experience in the fields of:

- Mechanical, Aerospace, and Electrical engineering
- Computational fluid dynamics (applied to aircraft systems)
- Computer Science and Programming – artificial intelligence
- Aircraft and machinery design
- Mechanical and aerodynamic analysis
- Intelligent robotic control

We are an integrated team that designs the hardware and software required to produce fully functional unmanned vehicles.

SHORT RESUME

Dr. Alejandro Ramírez-Serrano
Professor University of Calgary, and Founder/CEO 4Front Robotics Ltd.

Dr. A. Ramirez-Serrano is a full time professor at the University of Calgary, where he has served on diverse roles including a former director of the graduate program and current founder and director of the Autonomous Reconfigurable Robotic Systems Research Laboratory. Dr. Ramirez-Serrano performs research and development activities in the area of unmanned vehicle systems (UVS).

Dr. Ramirez-Serrano is also the founder and CEO of 4Front Robotics, a Calgary based robotic company that develops highly maneuverable drones and custom field unmanned vehicles for deployment in highly confined spaces such as collapsed building.

Dr. Ramirez-Serrano has a bachelor degree in Mechanical Engineering (from the Universidad Autonoma Metropolitana - Mexico), two Master of Science degrees, one in Mechanical & Aerospace engineering (from the Illinois Institute of Technology - USA) and a second in Computer Science in the area of Artificial Intelligence (from the Monterrey Tech - Mexico). He also has a Doctorate degree in Mechanical & Industrial Engineering (from the University of Toronto - Canada).

His industrial experience include mechatronic engineer at ABB Corporate Research (Sweden), and research engineer at Argonne National Laboratory - West (USA) where he developed smart field robotic devices.

His areas of expertise are in the design of VTOL (Vertical Takeoff and Landing) and transitional aircrafts, control, navigation, and modeling of UVS and robots for deployment in search and rescue operations. His work also includes the development of humanoid robotics with applications to pediatric care where Dr. Ramirez-Serrano has employed robots to significantly reduce children stress, increase children's hospital experience, and reduce the time nurses and doctors take to apply a given procedure in some cases by more than 50%.

Current projects of Dr. Ramirez-Serrano include work with diverse organizations and companies including NASA, Genesis, and Veerum. Dr. Ramirez-Serrano's next set of goals in pushing UAV technology to the next level include the development of highly maneuverable transitional UAV systems and aerial manipulators. His work includes aircraft design and control, reconfigurable ground and aerial systems, development of humanoid robots for health care, and development of high speed unmanned vehicle for challenging operations.

Publications (95 Conference and 38 Journal papers):

Sample Conference Papers:

C1. Ashraf M. Kamal D., and **Ramirez-Serrano A.**, "Development of a Preliminary Design Methodology for Transitional UAV", AIAA Science and Technology Forum and Exposition, January 8-12, 2018, Gaylord Palms, Kissimmee, Florida, USA.

C2. Majnoon, M., Samsami, K., Mehrandezh, M., and **Ramirez-Serrano, A.**, "Mobile-target Tracking via Highly-maneuverable VTOL UAVs with EO Vision", Conference on Computer and Robot Vision, Victoria, BC, Canada, June 1-3, 2016.

C3. Bagheri, P., **Ramirez-Serrano, A.**, and Pieper, J.K., "*Adaptive Nonlinear Robust Control of a Novel Unconventional Unmanned Aerial Vehicle*", 14th Intl. Conf. on Intelligent Systems and Control, November 11-13, 2013, Marina del Rey, USA.

C4. Gress, G., and **Ramirez-Serrano, A.**, "*Using Particle Swarm Optimization to Determine Controller Coefficients: Defining and Tuning Attitude Controllers for VTOL Air Vehicles*", Intl. Conf. on Intelligent Systems and Agents, July 22-24, 2013, Prague, Czech Republic.

C5. Amiri N., **Ramirez-Serrano A.** and Davies R., "Integral Backstepping Control of an Unconventional Highly Maneuverable Unmanned Aerial Vehicle", *Intl Conf on Unmanned Aircraft Systems* (ICUAS), Philadelphia, PA, USA, June 12-15, 2012.

C6. Jansen, F., and **Ramirez-Serrano, A.**, "Agile UAV Navigation in Highly Confined Environments", *IEEE Systems, Man and Cybernetics (IEEE SMC)*, October 9-12, 2011, Anchorage, Alaska, USA.

C7. Amiri N., **Ramirez-Serrano A.** and Davies R., "Modelling of Opposed Lateral and Longitudinal Tilting Dual-Fan Unmanned Aerial Vehicle", *18th IFAC World Congress*, Milan, Italy, Aug. 28-Sept. 2, 2011.

C8. Hosseini, Z, Martinuzzi, R. J,. and **Ramirez-Serrano, A.**, "Analyzing the performance of a hovering rotor in ground effects to improve the controlling aspects of VTOL Vehicles in confined spaces", *ASME 2010 Fluids Engineering Summer Meeting*, August 1-4, Montreal, Canada, 2010.

C9. S.S. Dhaliwal and **A. Ramirez-Serrano**, "Modeling and Simulations of Double-Ducted VTOL UAV for Flight within Obstructed Dynamic Environments", *UVS Canada Conf.*, Ottawa, ON, Canada, Nov. 4-7, 2008

Sample Journal Papers:

J1. Gress, G., and **Ramirez-Serrano, A.**, "Enabling passive hover stability in bicopters using lift-propeller gyroscopic properties", *Journal of American Institute of Aeronautics and Astronautics* (AIAA), Vol. XX, No. YY, Year 2017, pp. ZZ-ZZ, (Under review).

J2. Bagheri, P., **Ramirez-Serrano, A.**, and Pieper, J.K., "*Adaptive Nonlinear Robust Control of a Novel Unconventional Unmanned Aerial Vehicle*", J. of Control and Intelligent Systems, Vol. 43, No. 1, 2015.

J3. Amiri N., **Ramirez-Serrano A.** and Davies R., "Integral Backstepping Control of an Unconventional Dual-Fan Unmanned Aerial Vehicle", *J. of Intelligent and Robotic Systems*, 2012.

J4. C. Nicol, C.J.B. Macnab, **A. Ramirez-Serrano**, "Robust Adaptive Control of a Quadrotor Helicopter", *IFAC Journal of Mechatronics*, Vol 21, No. 6, pp. 927-938, September 2011.

J5. C. Coza, C.J.B. Macnab, and **A. Ramirez-Serrano**, "An Adaptive-Fuzzy Control for a Quadrotor Helicopter Robust to Wind Buffeting", *The International Journal of Robotics Research.*

Example Magazine Articles:

M1. Ramirez-Serrano, A., "Robots to the rescue: Saving lives with unmanned vehicles", *The Conversation Canada* http://theconversation.com/robots-to-the-rescue-saving-lives-with-unmanned-vehicles-90516, January 24, 2018

Recent Graduate Students – last 10 years [Graduated (current students under supervision)]

Post-doc-fellows: 3 *PhD: 8 (5)* *MSc: 26 (5)* *BSc:* 19 (2)

SHORT RESUME
Robert W. Bulaga – Principle Investigator
President / Chief Engineer – Trek Aerospace

Mr. Bulaga has been Trek's Chief Engineer since 1996. He received his BS and MS in Aeronautical and Astronautical Engineering from the University of Illinois. He was responsible for the design and testing of the one-man VTOL Flying Exoskeletor Device (Springtail, aka SoloTrek) developed under a previous successful DARPA contract. Mr. Bulaga's major strengths are in aerodynamic/fluid dynamic analysis, performance, stability and control, structural and mechanical design, systems engineering, FAR 23 type certification, component testing, flight test, creative problem solving, and aircraft accident investigation. He is responsible for the development of Trek's three dimensional CFD models, TASPA, used to design Trek's core technology, which results in the superior ducted fan performance. Mr. Bulaga was responsible for the aerodynamic and fluid dynamic analysis, performance, stability and control analysis, structural and mechanical design, and systems engineering on that project.

Prior to joining Trek, Mr. Bulaga worked in a variety of positions, including Senior Aeronautical Engineer, Chief Engineer, Fluid Dynamicist, Systems Engineer, and Lead Aeronautical Engineer. While at McDonnell Douglas, Mr. Bulaga was involved in the development of the F- 15E and National Aerospace Plane (NASP). His responsibilities included vehicle synthesis, aerodynamic design, drag estimation and reduction, stability and control, wind tunnel testing, and data analysis. He also performed analysis involving payload range, endurance and envelope capabilities and conducted design trade studies to optimize weight, performance, and control.

Relevant (sample) Publications:

1. Moshier, Michael W. and Robert W. Bulaga, "Wind Tunnel Performance Investigation of the SoloTrek XFV Ducted Fan", *unpublished*, March 2001.
2. Abrego, Anita I. & Robert W. Bulaga, "Performance Study of a Ducted Fan System", American Helicopter Society International, January 2002.
3. Bulaga, Robert, "Shrouded Propeller Performance Modeling", *unpublished*, 2005.
4. Bulaga, Robert, "Springtail EFV / Dragonfly UMR", SAE International, Paper Number 2005-01-3185.
5. Bulaga, Robert, "Ducted Fan Efficiency and Noise", SAE International, Paper Number 2005-01-3186.
6. Gillespie, Ed and Robert Bulaga, et.al., "Wind Tunnel Performance Comparison of a 54" Diameter, Pusher, Shrouded Prop to a 77" Diameter, Tractor, Free Prop", *unpublished*, December 2007.
7. Bulaga, Robert W. and Joshua N. Portlock, "FlyKart – Mini Personal Air Vehicle", AIAA DOI: 10.2514/6.2016-3613, June 2016.