IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

FOIL BOARDING COMPANY, INC.
Petitioner,

v.

MHL CUSTOM, INC.
Patent Owner

U.S. Patent No. 9,359,044
IPR Case No.: IPR2024-00086

DECLARATION OF DR. JACOB LANGELAAN IN SUPPORT OF PATENT OWNER'S RESPONSE

I, Jacob Langelaan, hereby declare as follows:

1. I am the named inventor on U.S. Patent Nos. 9,359,044 ("the '044 Patent") and 9,586,659 ("the '659 Patent"), which are the subject of the present *inter partes* review (IPR2024-00086 and IPR2024-00085, respectively). Although I am the sole inventor of the '044 Patent and the '659 Patent, I do not have any current financial interest in these patents or in MHL Custom, Inc., which is the current assignee. I am being compensated for the time that I have devoted to assisting with these IPRs, including preparation of this Declaration, at my normal legal consulting rate, and I do not have any financial stake in the outcome of these IPRs.

2. My education and experience are set forth in the curriculum vitae attached hereto as Exhibit A. In summary, I have a Bachelor of Applied Science degree in Engineering Physics from Queen's University in Kingston, Ontario, Canada in 1992; I have a Master of Science degree in Aeronautics and Astronautics from the University of Washington in Seattle, Washington in 1994, where my research was in structural analysis of aircraft fuselage structures; and I have a PhD in Aeronautics and Astronautics from Stanford University in Stanford, California in 2006, where my dissertation was on state estimation for autonomous flight in cluttered environments. Between earning my Master's degree and my PhD, I was an engineer for de Havilland Inc. (now Bombardier Aerospace) for almost 5 years, where I worked in structures research and development, primarily on advanced

materials and damage tolerance analysis of reinforced structures, and also on cabin noise reduction in the acoustics and vibration group. Since earning my PhD, I have been a professor at Penn State University for almost 18 years. Specifically, I am a professor of aerospace engineering. My research areas are related to autonomous flight and unmanned aerial vehicles (UAVs), as well as vehicle dynamics and controls and design of flight vehicles. With my students I have authored 26 refereed archival journal papers and 67 refereed conference papers related to flight control, flight planning, data fusion, and other subjects connected to autonomous aircraft systems (commonly referred to as drones). I have also presented as a speaker at numerous conferences relating to autonomous and robotic aircraft. My teaching responsibilities at Penn State have included: aircraft stability and control; control of aerospace systems; aircraft design; aeronautics; estimation theory; global navigation satellite systems (GPS); and advanced air mobility.

HYDROFOIL ANALYSIS

3. Initially, I note that the term "hydrofoil" is a term of art that would be well understood to a person of ordinary skill in the art.[1] In that regard, a hydrofoil is

[1] I understand that in these IPRs, a person of ordinary skill in the art ("POSITA") is defined as having had at least a Bachelor's degree in engineering or physics with experience in fluid dynamics and experience with watercraft, aircraft, or hydrofoil craft, or at least a Bachelor's degree in the field of engineering specializing in naval architecture and substantial experience with naval architecture including some experience with watercraft, aircraft, or hydrofoil craft.

normally considered to consist of one or more fully submerged hydrodynamic surfaces capable of producing lift *(i.e.,* a force in the vertical direction). Typically, but not always, one of the hydrodynamic surfaces is larger than the other, and the hydrofoil is designed so that this largest surface provides the bulk of the lifting force. Smaller hydrodynamic surfaces may be designed to counteract hydrodynamic moments. This is functionally identical to the wing and horizontal stabilizer (sometimes called a horizontal tail) on an aircraft. Under certain conditions, an aircraft may be a "flying wing" with no tail, in which case the wing itself is designed to both provide lift and counteract moments. A hydrofoil can thus be thought of as an airplane that "flies" underwater. Note that objects whose main hydrodynamic function is to provide buoyancy *(e.g.,* pontoons, sponsons, outriggers, and submerged buoyant volumes) are not considered "hydrofoils." Similarly, an object whose main function is to provide drag *(e.g.,* a sea anchor) is not a hydrofoil, and neither is a propulsor (such as a propeller or pump jet). Further, an object whose main function is to counteract a hydrodynamic side force *(e.g.,* a dagger board or keel on a sailboat) is not a hydrofoil. Thus, for the remainder of this Declaration, and consistent with the understanding of a POSITA in the art, I will use the word **"hydrofoil"** to denote the system of wings and stabilizers that together provide lift force and counter hydrodynamic moments. Moreover, **"wing"** will be used to refer to the main lifting

surface(s) of the hydrofoil, and **"stabilizer"** will refer to surfaces whose main function is to counteract moments.

4. Collectively, the wings and stabilizers that comprise a hydrofoil generate a lift force, a drag force, a lateral force (commonly called a "side force"), a rolling moment, a pitching moment, and a yawing moment. To simplify matters, the following discussion will be restricted to the longitudinal (forward/back and up/down) degrees of freedom. The discussion of lateral/directional motion is similar. Note that a POSITA would normally separate these degrees of freedom for the purpose of analysis of stability. The longitudinal degrees of freedom include motion in the fore/aft direction, the up/down direction, and pitch rotation *(i.e.,* nose up/down rotation). The net hydrodynamic force and moment produced by a hydrofoil is the sum of the forces and moments produced by the wing(s) and stabilizer(s). Normally one computes moment about the center of gravity of the vehicle. The "net hydrodynamic force" is separated into <u>lift</u> and <u>drag.</u> Note that thrust from the propulsion system and the force from gravity are treated independently.

5. The magnitude of the lift force produced by the hydrofoil is commonly written:

$$L = \tfrac{1}{2} p v^2 S C_L \quad \text{[Equation 1]}$$

Where L is the magnitude of the lift force, p is the density of the fluid (water in the case of a hydrofoil, air in the case of an airplane wing), v is the speed relative to the fluid, S is a reference area (normally this is the area of the wing), and C_L is the lift coefficient. The lift coefficient, in turn, is provided by the following equation, which is dependent on the angle of attack α *(i.e.*, the angle between the incoming flow and the wing) and the pitch rate q *(i.e.*, the rate of change of the pitch angle of the vehicle).

$$C_L = C_{L0} + C_{L\alpha}\alpha + C_{Lq}q \quad \text{[Equation 2]}$$

The parameters C_{L0}, $C_{L\alpha}$, and C_{Lq} are dependent on the design of the hydrofoil *(i.e.*, the design of the wing(s) and stabilizer(s), as well as their locations with respect to one another). Thus, the lift force is dependent on fluid density, flow condition (speed and angle of attack), and design of the hydrofoil. Note that control surfaces such as flaps may also contribute to lift coefficient. However, the focus here is on hydrofoils without flaps, so this will be ignored for the remainder of the discussion.

6. In addition to lift force, a hydrofoil will generate a <u>drag</u> force D and a <u>pitching moment</u> M. The magnitude of the drag force and the magnitude of the pitching moment can be quantified as:

$$D = \tfrac{1}{2}pv^2SC_D \quad \text{[Equation 3]}$$

$$M = \tfrac{1}{2}pv^2S\bar{c}C_M \quad \text{[Equation 4]}$$

The drag coefficient C_D and the pitching moment coefficient C_M are given by the following equations, and, like the lift coefficient C_L, they are similarly dependent on

angle of attack. However, note that a POSITA typically expresses the drag coefficient as a function of the lift coefficient.

$$C_D = C_{D0} + kC_L^2 \quad \text{[Equation 5]}$$

$$C_M = C_{m0} + C_{M\alpha}\alpha + C_{Mq}q \quad \text{[Equation 6]}$$

Above, the parameter C_{D0} is the drag coefficient at zero lift, and k is a constant that is dependent on wing design and the particular airfoil chosen or designed for the application at hand. The parameter C_{m0} is the pitching moment coefficient at zero angle of attack and zero pitch rate, the parameter $C_{M\alpha}$ (commonly known as "pitch stiffness") is the derivative of pitching moment coefficient with respect to angle of attack, and the parameter C_{Mq} (commonly known as "pitch damping") is the derivative of pitching moment coefficient with respect to pitch rate. The parameters C_{m0}, $C_{M\alpha}$, and C_{Mq} are all dependent on the design of the wing(s) and stabilizer(s), the relative arrangement of the wing(s) and stabilizers(s), and on the location of the center of gravity with respect to the neutral point. Note that a hydrofoil (or airplane) with moveable control surfaces has additional terms in the equations for C_M, C_L, and C_D, which additional terms define the contributions of control surface movement to the total pitching moment coefficient, lift coefficient, and drag coefficient of the hydrofoil (or airplane). Again, since the focus here is on hydrofoils without moveable control surfaces, these terms will be ignored for the remainder of this

discussion. The design and stability implications of these "missing terms" will be discussed in Paragraph 15.

7. When a system is in equilibrium, all forces and moments sum to zero. In the case of a hydrofoil, that means that:

$$L = W$$

$$T = D$$

$$M = 0$$

That is, lift force L equals weight W, thrust T equals drag D, and pitch moment M equals zero. A person having ordinary skill in the art often refers to equilibrium as "trim."

8. A particular equilibrium may be stable. If an equilibrium is stable, there is a restoring force that seeks to return the system back to its equilibrium after a disturbance. Stability is commonly described in terms of <u>static</u> stability *(i.e.*, the initial tendency to return to equilibrium after a disturbance) and <u>dynamic</u> stability *(i.e.*, the effects of a disturbance decay to zero over time). A system that is statically stable may (but not necessarily) be dynamically stable. However, a system that is dynamically stable must also be statically stable. Stable systems tend to be easier for humans to operate. As an example, consider the difference between balancing a broomstick upright on the palm of your hand [an unstable arrangement] versus allowing it to hang downwards as you grip the top end between your thumb and

fingers [a stable arrangement]. That is, you may be able to find an equilibrium as you balance the broomstick upright on the palm of your hand, but any small disturbance *(e.g.,* a gust of air) will cause the broomstick to tip over. However, a system may be too stable, in which case it will be very difficult or impossible for the human steering inputs to be able to overcome the system's inherent stability.

9. Independent claim 1 of the '044 Patent recites a "hydrofoil having no movable surface and designed to provide passive static stability controlled solely by weight shift of the user". Similarly, independent claim 1 of the `659 Patent recites a "passively stable, weight-shift controlled personal hydrofoil watercraft." In view of these patents (which share a specification), a POSITA would understand that "passively stable" means that stability is achieved without the need for active control systems or mechanisms. Moreover, "weight-shift controlled" would be understood to mean that steering is achieved by shifting the weight of the rider, resulting in a change of direction or speed (or both).

10. Passive stability is achieved by satisfying certain conditions in the equations that govern the dynamics of a system. In the case of a hydrofoil, the conditions governing longitudinal stability can be summarized as:

$$C_{M\alpha} < 0$$

$$C_{Mq} < 0$$

That is, $C_{M\alpha}$ (the derivative of pitching moment coefficient with respect to angle of attack) is less than zero. In simple terms, this means, for example, that a disturbance that causes it to nose-up (increasing the angle of attack) will result in a negative pitch moment, which will push nose-down (reducing the angle of attack) – this is static pitch stability. When also considering dynamic stability, C_{Mq} (the derivative of pitching moment coefficient with respect to pitch rate) is also less than zero (i.e., a disturbance that causes an increase in the rate of pitch will result in a negative restoring moment). In addition, the existence of a stable *equilibrium* further requires that:

$$C_{M0} > 0$$

That is, C_{M0} (the pitching moment coefficient at zero angle of attack and zero pitch rate) is greater than zero. *Id*. Thus, mathematically:

$$C_{M\alpha} = - C_{L\alpha} (h_{NP} - h) \quad \text{[Equation 7]}$$

where h is the location of the center of gravity and h_{NP} is the neutral point. The neutral point is defined as the location of the center of gravity location the hydrofoil becomes unstable. If the center of gravity is forward of the neutral point, then the hydrofoil will be stable, whereas, if the center of gravity is aft of the neutral point, then the hydrofoil will be unstable.

11. One might conclude that stability is therefore achieved solely by placing the center of gravity ahead of the neutral point. However, for passively

stable, weight-shift controlled personal hydrofoil watercraft to be functional, it is important to provide a range of stable equilibria so that the rider can choose (and change in real time) the riding condition, while maintaining stability. Consider a desired equilibrium at some nominal speed v_0. If we assume that this desired equilibrium is at a constant pitch angle, the pitch rate q will equal 0. Therefore, mathematically, we must first satisfy the following (see Equations 1 and 2 in paragraph 5, as well as the equilibrium conditions noted in paragraph 11 above):

$$W = \tfrac{1}{2}\rho v_0^2 S C_L = \tfrac{1}{2}\rho v_0^2 S(C_{L0} + C_{La}a) \quad \text{[Equation 8]}$$

A desired speed v_0 thus results in a desired angle of attack α_0. At that desired angle of attack, we must also satisfy $M = 0$ (from the conditions in paragraph 11 above). Hence:

$$0 = C_{M0} + C_{M\alpha}\alpha_0 \quad \text{[Equation 9]}$$

Because the weight-shift controlled personal hydrofoil watercraft as recited in claim 1 does not have moveable control surfaces, we can only satisfy the above Equation 9 by adjusting C_{Ma} by changing the location of the center of gravity with respect to the neutral point. Substituting for C_{Ma} (from Equation 7), we get the following equation, which is rearranged in the subsequent lines below to yield Equation 10. That equation solves for h_0, which is the location of the center of gravity that results in an equilibrium at a desired angle of attack α_0 (and thus a desired speed v_0):

$$0 = C_{M0} - C_{L\alpha}(h_{NP} - h)\alpha_0$$

$$(h_{NP} - h_0) = C_{M0} / C_{L\alpha}\alpha_0$$

$$h_0 = h_{NP} - C_{M0} / C_{L\alpha}\alpha_0 \quad \text{[Equation 10]}$$

Thus, the rider can change h_0 to change the desired speed, and a small adjustment in thrust then counteracts any change in drag. As noted previously, C_{M0} and $C_{L\alpha}$, are dependent on design of the hydrofoil, and the location of the neutral point h_{NP} is similarly dependent on design of the hydrofoil. To be functional, the hydrofoil must be designed so that it is passively stable over a wide range of operating speeds, so that the user has sufficient control over the craft.

12. In addition to the above complexity in ensuring that the center of gravity is appropriately positioned with respect to the neutral point, there are further complications involved in achieving a functional, personal hydrofoil watercraft that is stable, all without the use of active control surfaces. Specifically, an additional complication results from the rider being positioned above the board ("flotation device" in the claims), as that results in the center of gravity being far above the hydrofoil that supports the weight of the vehicle, since the hydrofoil is submerged below the board and interconnected with the recited "strut." That positioning thus results in the system as a whole being dynamically equivalent to an inverted pendulum, which is unstable (as with the broomstick being balanced on the palm of your hand, as discussed above). That is in contrast to a hang glider, for example, which is another type of weight-shift controlled personal "craft" (specifically an

aircraft), since a hang glider positions the center of gravity below the wing, which results in what is known as "pendulum stability."

13. A further complication arises from the fact that the thrust line (from the submerged "propulsor") is also spaced far below the center of gravity. That results in a strong nose-up pitching moment. Note that thrust contributes to positive C_{M0}, which contribution varies with the amount of thrust, which in turn varies with drag, which varies with lift, which varies with speed and angle of attack. The resulting effect is that strong disturbances are imposed on the vehicle, since what was a helpful condition *(i.e.,* contribution to positive C_{M0}*)* has become destabilizing because its magnitude is large and varies with thrust.

14. Thus, the hydrofoil must be designed to be stable in the presence of the strong inverted pendulum instability, as well as the strong disturbances that result from having the thrust line so far from the center of gravity. In addition, the hydrofoil must be designed so that changes in the location of the center of gravity (resulting from the weight shift of the rider) result in changes in operating condition, such as speed and/or turn rate. Even further, the hydrofoil must be designed so that it remains stable over a wide range of locations of the center of gravity, so that that the watercraft is stable for all desired operating conditions.

15. A significant constraint on designing a hydrofoil that is stable over a wide range of locations of the center of gravity, despite the presence of the different

instabilities noted above, is the fact that the claimed invention is "passively stable" and "weight-shift controlled," with the hydrofoil having "no movable surface" and the watercraft having "no movable steering system." Such passive stability with no movable control surfaces imposes a significant design constraint on the developer that conflicts with other constraints: mathematically, there would be "missing terms" in the equations that describe the system dynamics. At the time of the invention, therefore, a POSITA would have concluded that no feasible design exists, given the constraints. The literature that existed at the time of the invention would have further reinforced the conclusion that no feasible design for a passively stable, weight shift controlled personal watercraft exists, because of its focus on active control systems. The functioning watercraft of the present invention thus achieves results that would have been unexpected to a person having ordinary skill in the art at the time of the invention. Moreover, even if such a person were to try to achieve the invention as claimed, it would have involved undue experimentation to achieve a functioning watercraft without outside guidance.

16. The primary function of a hydrofoil is to improve vehicle performance, not stability. In particular, by creating lift that raises the main body of the watercraft above the surface of the water, the drag through the water that would have otherwise resulted from moving that body through the water is reduced. As relevant here, that reduces the power required to operate the watercraft at meaningful speeds, so that

range and endurance are improved. For the hydrofoil to be useful, it must also be stable and controllable. As described above, achieving stability and controllability in a hydrofoil without moveable control surfaces and without an active control system is difficult and would not have been obvious to a POSITA.

WOOLLEY

17. I have been asked by counsel to provide commentary regarding U.S. Patent No. 6,234,856 ("Woolley"). I understand that Woolley is being asserted in combination with the Evolo Report or certain Evolo videos by Foil Boarding Company in the pending IPRs (IPR2024-00085; IPR2024-00086) as rendering the '044 Patent and the '659 Patent as obvious.

18. Woolley discloses a "flying ski" that is pulled behind a motorboat by a tow rope, similar to a water ski, except that it "flies" above the surface of the water by means of a planing blade 38. Consistent with the general function of a hydrofoil, Woolley's planing blade 38 is primarily used in that reference for elevating the rider and board above the surface of the water to provide a flying experience (see col. 1, ln. 10-28 of Wooley, which refer to earlier disclosures of the flying ski by the same inventor, and which are improved upon in Woolley). Woolley mentions stability but does not teach how stability can be achieved. Perhaps more importantly, in Woolley an external force (the tow rope) is used by the rider as a means of providing active control over the pitch degree of freedom, thus providing an active control system

that may aid in any alleged stability (see paragraph 20). This is in contrast to the '044 and '659 Patents, which specifically provide passive stability over a wide range of operating conditions.

19. As noted above in paragraph 16, the function of a hydrofoil is to lift the main body of the watercraft above the surface of the water to reduce drag, and, once that objective is achieved, then the hydrofoil can be designed to provide desired stability characteristics to the lifted watercraft in operation. Therefore, in view of Woolley, a person having ordinary skill in the art would not incorporate a hydrofoil into a watercraft with an integrated propulsion system below the center of gravity, such as illustrated in the Evolo Report/Videos, for the purpose of improving stability.

20. Woolley is different from the claimed invention in at least three important respects. First, the propulsion in Woolley is provided by a tow rope held by the rider at one end and connected to a motorboat at the other end. Second, in addition to being a source of the propulsion, the tow rope is used to aid in control. That is, the rider can move the tow handle up, down, left, and right in order to provide steering and control moments. Third, the propulsive force provided by the tow rope goes roughly through the center of gravity of the vehicle (i.e., the rider plus board), and therefore it does not contribute to destabilizing the system in a way that a propulsor would if it were located relatively far below the center of gravity (such that it would remain submerged when the body of the board is raised above the

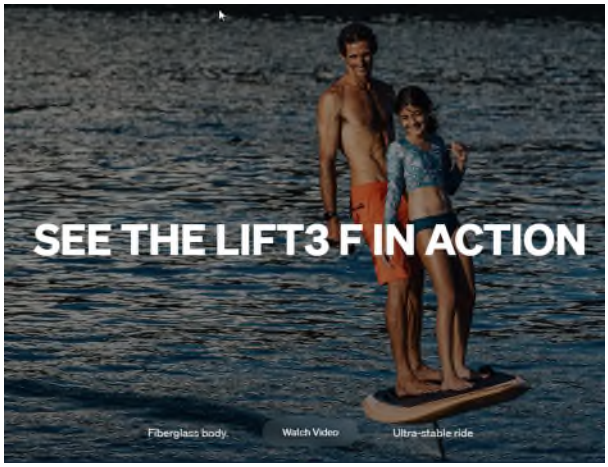
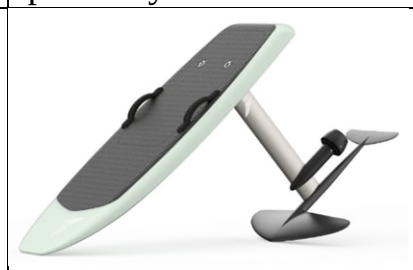
surface of the water). In that regard, consider the difference between pulling someone on roller skates by a rope tied around their waist versus a rope tied around their ankles. In the former case, the rope would be roughly aligned with the center of gravity of the person, and therefore pulling the person would not induce a destabilizing moment that could cause them to fall. In contrast, in the latter case, pulling the person by their ankles (far below the center of gravity) is most likely to result in pulling the person's feet out from under them and causing them to fall over.

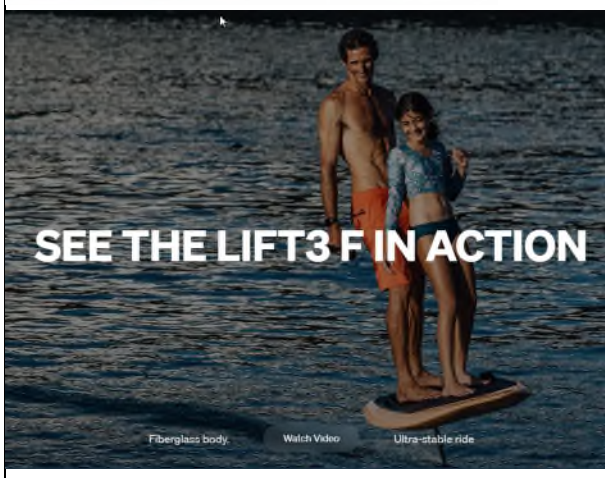
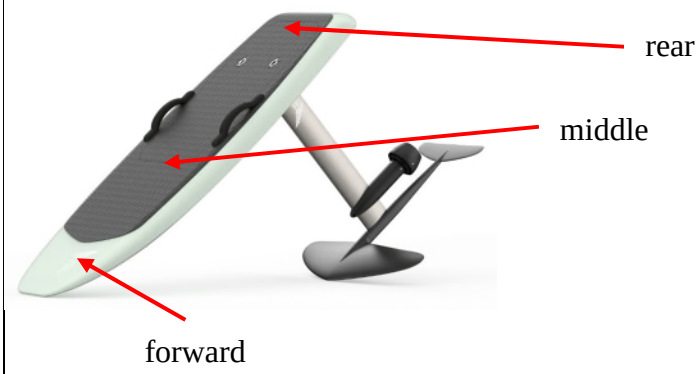
21. Due to the above differences between Woolley and the claimed invention, significant instabilities would be induced by simply adding Woolley's hydrofoil to the Evolo device (Report or Videos), as outlined in the Petitions. Shifting the location of the thrust away from the center of gravity in that manner (as in Woolley) would destabilize the watercraft of Evolo by imparting a large nose-up pitching moment on the watercraft. Neither Woolley nor Evolo (Report or Videos) suggest how one would counteract such a destabilizing torque because, as discussed above, Woolley's propulsion is roughly aligned with the center of gravity via the tow rope, and therefore Woolley does not experience anything like the torque that would result from making that modification. Moreover, Woolley certainly does not suggest how to achieve stability in such a modified watercraft without, at least, the capability for active control as provided by the tow rope.

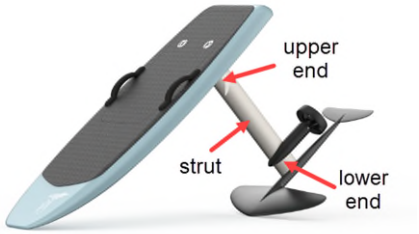
22. In view of the above, one of ordinary skill in the art would have concluded that the destabilizing effect of a propulsor spaced well below the center of gravity would have required the use of movable steering systems and/or movable control surfaces in combination with active control systems or mechanisms, which would be contrary to the explicit requirements of the claims of the ‘044 Patent and the ‘659 Patent. In fact, this is exactly what persons having ordinary skill in the art have done in the past: hydrofoils have traditionally incorporated moveable surfaces to provide stability (through active control) and for control of direction and height of the hull above water (i.e., steering).

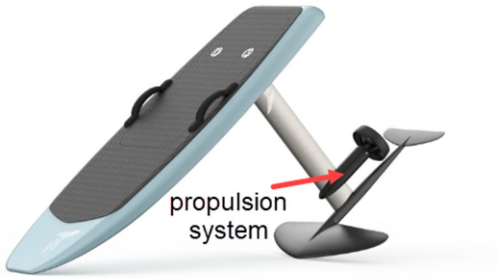
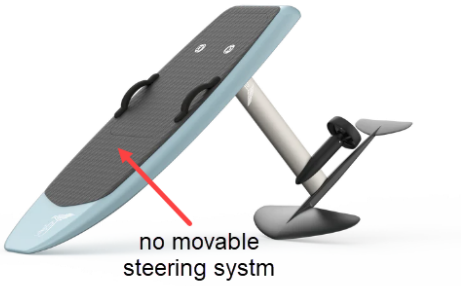
DISCUSSION RELATING TO SECONDARY CONSIDERATIONS

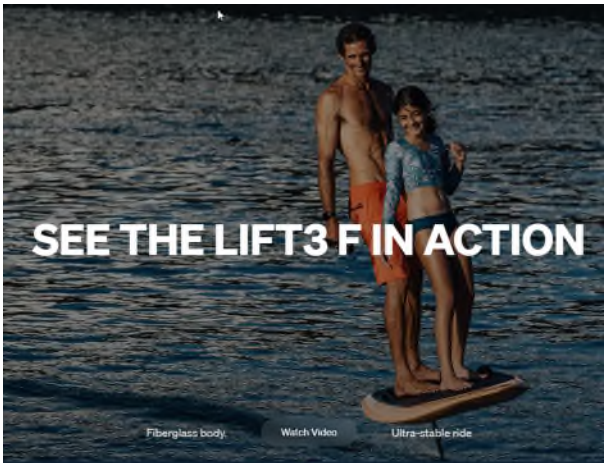
23. A sufficient nexus exists between the Patent Owner’s products the ‘044 Patent and the ‘659 Patent. As set forth in the following table, each element of the asserted independent claims is found in the LIFT3 eFoil product. While I demonstrate the LIFT3 below, the other generations of this product likewise embody the claims of the ‘044 Patent and ‘659 Patent.

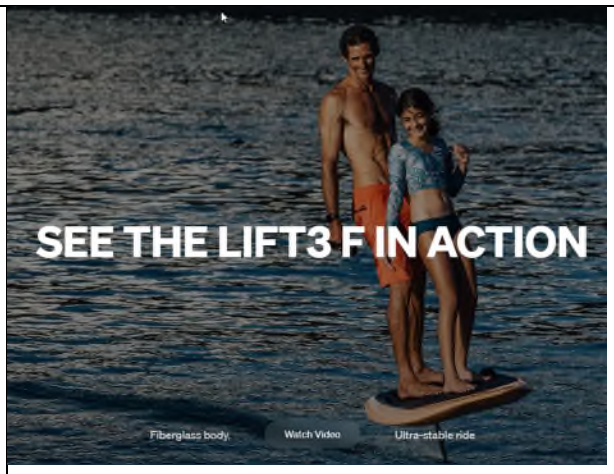
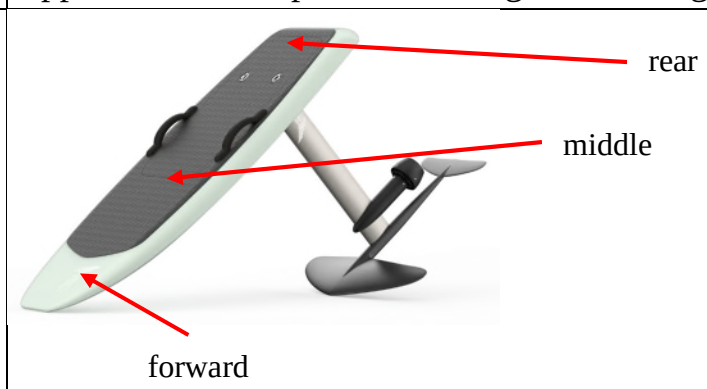
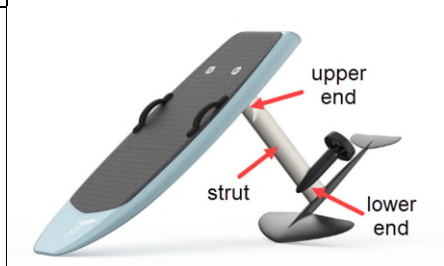
US 9,359,044 Claim Elements	LIFT3 F Product
1. A passively stable, weight-shift controlled personal hydrofoil watercraft, comprising:	  The LIFT3 F is a passively stable, weight shift controlled personal hydrofoil watercraft. Users can maneuver the passively stable watercraft solely by weight-shift.
a flotation device that has a fore-aft length greater than a lateral width,	 The fore-aft length of the flotation device is seen to be greater than a lateral width of the flotation device.

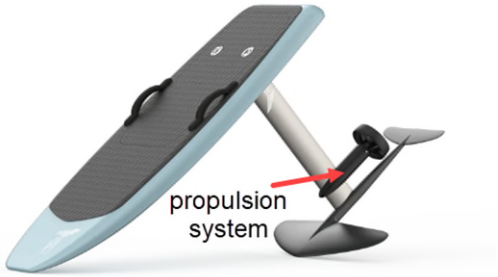
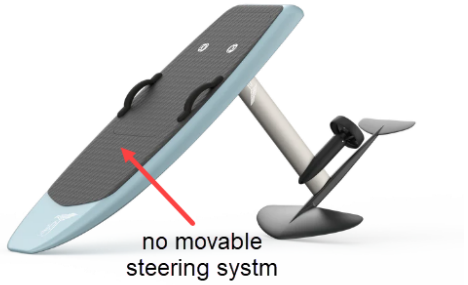
wherein a user can be disposed on the top surface of the flotation device in a prone, kneeling, or standing position	  The top surface of the flotation device is configured to support a user in a prone, kneeling, or standing position.
the flotation device having a forward section, a middle section, and a rear section;	 The flotation device can be divided into a forward section, a middle section, and a rear section.

and the flotation device being controlled via weight shift of the user;	 The flotation device is controlled via weight shift of the user on the device.
a strut having an upper end and a lower end, the upper end fixedly interconnected with the flotation device between the middle section and the rear section of the flotation device;	 The strut extends between an upper end that is fixedly interconnected with the flotation device and a lower end. Further, the strut is seen to be interconnected between a middle section of the flotation device and a rear section of the flotation device.
a hydrofoil fixedly interconnected with the lower end of the strut, the hydrofoil having no movable surface and designed to provide passive static stability controlled solely by weight shift of the user;	 The hydrofoil is fixedly interconnected with the lower end of the strut. The hydrofoil has no movable surface. The hydrofoils is designed to provide passive static stability and is controlled solely by the weight shift of the user.

a propulsion system for propelling the watercraft in a body of water, wherein the propulsion system is connected to the hydrofoil; and	 A propulsor of a propulsion system is connected to the hydrofoil via the strut and is configured to propel the watercraft in a body of water.
the watercraft having no movable steering system.	 The watercraft has no movable steering system, such as rudders.

US 9,586,659 Claim Elements	LIFT3 F Product
1. A passively stable, weight-shift controlled personal hydrofoil watercraft, comprising:	  The LIFT3 F is a passively stable, weight shift controlled personal hydrofoil watercraft. Users can maneuver the passively stable watercraft solely by weight-shift.
a flotation device that has a fore-aft length greater than a lateral width,	 The fore-aft length of the flotation device is seen to be greater than a lateral width of the flotation device.

wherein a user can be disposed on the top surface of the flotation device in a prone, kneeling, or standing position	 The top surface of the flotation device is configured to support a user in a prone, kneeling, or standing position.
the flotation device having a forward section, a middle section, and a rear section;	 The flotation device can be divided into a forward section, a middle section, and a rear section.
a strut having a upper end and a lower end, the upper end fixedly interconnected with the flotation device between the middle section and the rear section of the flotation device;	 The strut extends between an upper end that is fixedly interconnected with the flotation device and a lower end. Further, the strut is seen to be interconnected between a middle section of the flotation device and a rear section of the flotation device.

a hydrofoil fixedly interconnected with the lower end of the strut, the hydrofoil having no movable surface;	 A hydrofoil is connected to the lower end of the strut via a fuselage. The hydrofoil is also seen to include a unitary wing with no movable surfaces such as ailerons, elevators, rudders, etc.
a propulsion system for propelling the watercraft in a body of water, wherein the propulsion system is connected to the hydrofoil; and	 A propulsor of a propulsion system is connected to the hydrofoil via the strut and is configured to propel the watercraft in a body of water.
the watercraft having no movable steering system.	 The watercraft has no movable steering system, such as rudders.

I declare under penalty of perjury that the foregoing is true and correct, and that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I understand that willful false statements are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001.

Date: September 14, 2024

JACOB W. LANGELAAN

EXHIBIT A

Jack W. Langelaan PH.D.

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Education

Stanford University, Stanford, CA
Ph.D., Department of Aeronautics and Astronautics, March 2006.
Dissertation title: State Estimation for Autonomous Flight in Cluttered Environments
Advisor: Professor Stephen Rock, Department of Aeronautics and Astronautics

University of Washington, Seattle, Washington
Master of Science in Aeronautics and Astronautics, December 1994.
Thesis title: Design Oriented Structural Analysis for Shape Optimization of Isotropic and Composite Fuselage Structures
Advisor: Professor Eli Livne, Department of Aeronautics and Astronautics

Queen's University, Kingston, Ontario.
Bachelor of Science, Engineering Physics (Mechanical Option), with Honors, May 1992.

Research and Professional Experience

2020–present: Professor, Aerospace Engineering, The Pennsylvania State University, University Park, Pennsylvania. Director of Graduate Program, 2017–present.

2012–2020: Associate Professor, Aerospace Engineering, The Pennsylvania State University, University Park, Pennsylvania. Director of Graduate Program, 2017–present.

2006–2012: Assistant Professor, Aerospace Engineering, The Pennsylvania State University, University Park, Pennsylvania.

2000–2006: Research Assistant, Aerospace Robotics Laboratory, Department of Aeronautics and Astronautics, Stanford University, Stanford, California.

1995–2000: Engineer, Bombardier Aerospace (formerly de Havilland Inc.), Downsview, Ontario Canada.

1994–1995: Research Assistant, Department of Aeronautics and Astronautics, University of Washington, Seattle, Washington.

Professional Memberships and Service

Professional Engineer, Association of Professional Engineers of Ontario since 1996.

Associate Fellow (2011), American Institute of Aeronautics and Astronautics. Member of Guidance, Navigation and Control Technical Committee (2005-2014 and 2018-present). Chair of Education sub-committee, 2007-2010.

Member, Vertical Flight Society. Member of Unmanned Vertical Flight Technical Committee, (2014-present) and eVTOL Provisional Technical Committee (2019-present)

Member, Institute for Electrical and Electronics Engineers. Session organizer and co-chair (Autonomous Vehicles), 2006 and 2007 IEEE Aerospace Conference, Big Sky, MT.

Associate Editor, Journal of Guidance, Control and Dynamics (2017-present).

Reviewer: AIAA Journal of Guidance, Control and Dynamics; International Journal of Robotics Research; IEEE Transactions on Control System Technology; IEEE Transactions on Robotics; Journal of Intelligent Robots and Systems; IEEE Conference on Decision and Control; AIAA Guidance, Navigation and Control Conference; IEEE/RSJ International Conference on Intelligent Robots and Systems; IEEE Conference on Robotics and Automation; IEEE Multi-Conference on Systems and Control; American Control Conference.

Grant Proposal Peer Review: National Science Foundation Robust Intelligence Cluster "small proposals" panel, 2009, 2008, 2007; Army Research Office, 2009, Office of Naval Research, 2010.

Conference Organization: Technical Area co-chair, 2008 AIAA Guidance, Navigation and Control Conference; Technical Area Chair, 2009, 2010, 2011, 2020 AIAA Guidance, Navigation and Control Conference; Technical co-Chair, 2012 AIAA Guidance, Navigation and Control Conference; Organizing Committee, 2010 National Academy of Engineering United States Frontiers of Engineering (USFOE) Conference.

Honors and Awards

2014: Winner of OSTIV Diploma for best paper presented at the XXXI OSTIV Congress and published in the Journal of Technical Soaring, vol. 37, no. 3, July 2013. (OSTIV is the Organization Scientifique et Technique International du Vol à Voile).

2011: Winner of a NASA Centennial Challenge. Team Leader of Pipistrel-USA.com, winner of the Green Flight Challenge. Our four seat, electric powered aircraft flew 403 passenger miles per gallon over a 195 mile course at 107 miles per hour. The prize of $1.35Million is the largest ever awarded for an achievement in aviation.

2011: Associate Fellow, American Institute of Aeronautics and Astronautics.

2010: PSEAS Outstanding Teaching Award (awarded by the Penn State Engineering Alumni Society).

2008: National Science Foundation Faculty Early Career Development Program (CAREER) award.

2006-2008: Dorothy Quiggle Professor in Engineering, The Pennsylvania State University.

2001-2004: Alyce B. and Henry J. Ramey Jr. Fellow, Stanford University.

2000: Department Fellowship, Department of Aeronautics and Astronautics, Stanford University.

Teaching

AERSP 306 (Introduction to Aeronautics): Spring 2024, Spring 2018, Spring 2012, Spring 2010.

AERSP 397 (Aerospace Design Studio): Spring 2018

AERSP 402A (Aircraft Design, Preliminary): Fall 2020-2016, 2012-2014.

AERSP 402B (Aircraft Design, Detailed): Spring 2021-2017, 2012-2015.

AERSP 413 (Aircraft Stability and Control): Fall 2023, 2022, 2008.

AERSP 460 (Control of Aerospace Systems): Fall 2021-2018, 2012, 2010, 2009, 2007, 2006.

AERSP 497D/597D (AUV Design): Fall 2013, Spring 2014, Fall 2014

AERSP 518 (Dynamics and Control of Aerospace Vehicles): Spring 2021

AERSP 597 (Advanced Air Mobility): Spring 2022-Spring 2024

AERSP 597E (Estimation Theory): Spring 2013, Spring 2011, Spring 2008.

AERSP 597G (Theory and Application of Global Navigation Satellite Systems): Fall 2011, Spring 2009, Spring 2007.

Patents

Names in **BOLD SMALL CAPS** denote students supervised by Langelaan.

[P3] Stroman, Richard, Daniel J. Edwards, Daniel S. Newton, **JOHN J. BIRD**, Jack W. Langelaan, Vladimir Dobrokhodov, *Method for identifying optimal vehicle paths when energy is a key metric or constraint*, US Patent Application Publication 2019/0107408 A1, April 11, 2019.

[P2] Langelaan, Jacob Willem, *Powered hydrofoil board*, US Patent 9,586,659 B2, March 7, 2017.

[P1] Langelaan, Jacob Willem, *Weight-shift controlled personal hydrofoil watercraft*, US Patent 9,359,044 B2, June 7, 2016.

Jack W. Langelaan PH.D.

Invited Publications

[1] Langelaan, Jack W. and Nicholas Roy, "Enabling New Missions for Robotic Aircraft," *Science*, vol. 326, no. 5960, December 18, 2009, pp. 1642-1644, DOI: 10.1126/science.1182497

Refereed Journal Publications

Names in **BOLD SMALL CAPS** denote students supervised by Langelaan.

[J26] Hendrick, Christopher M.; **JAQUES, EMMA R.**; Horn, Joseph F.; Langelaan, Jack W.; Sydney, Anish J. "Model-Scale Evaluation of Autonomous Ship Landing Guidance and Control Modes," Journal of the American Helicopter Society, available on-line January 2024

[J25] **OPAZO, TOMAS I.,** Raja Akif Raja Zahirudin, Jose Palacios, Sven Schmitz, and Jack W. Langelaan, "Analytical and Experimental Power Minimization for Fixed-Pitch Coaxial Rotors in Hover," *Journal of Aircraft*, vol. 60, no. 2, December 2022. DOI: 10.2514/1.C036807

[J24] **GENG, JUNYI,** Puneet Singla, & Jack W. Langelaan. "Load-Distribution-Based Trajectory Planning and Control for a Multilift System," *Journal of Aerospace Information Systems*, January 2022. DOI: 10.2514/1.I011067

[J23] **GENG, JUNYI** and Jack W. Langelaan, "Mass and Center of Mass Location Estimation for a Multi-lift Slung Load," *AIAA Journal of Guidance, Control, and Dynamics*, November 2020. DOI: 10.2514/6.2020-2067

[J22] Yan, Sihong, **TOMAS I. OPAZO**, Jack W. Langelaan, and Jose L. Palacios, "Experimental Evaluation and Flight Simulation of Coaxial-rotor Vehicles in Icing Clouds," *Journal of the American Helicopter Society*, 65(2), April 2020. DOI: 10.4050/JAHS.65.022011

[J21] **GENG, JUNYI** and Jack W. Langelaan, "Cooperative transport of a slung load using load-leading control," *AIAA Journal of Guidance, Control, and Dynamics*, 43(7), March 2020. DOI: 10.2514/1.G004680

[J20] **BIRD, JOHN J.** and Jack W. Langelaan, "Optimal Speed Scheduling with Arrival Time Constraints for Solar Augmented Aircraft," *AIAA Journal of Guidance, Control, and Dynamics*, 43(7), May 2020. DOI: 10.2514/1.G004430

[J19] **BIRD, JOHN J.,** Scott J. Richardson, and Jack W. Langelaan, "Estimating the Vertical Structure of Weather-Induced Mission Costs for Small UAS," *Sensors* 2019, 19, 2770; DOI:10.3390/s19122770

[J18] **DEPENBUSCH, NATHAN T., JOHN J. BIRD** and Jack W. Langelaan, "The AutoSOAR Autonomous Soaring Aircraft Part 1: Autonomy Algorithms," *Journal of Field Robotics,* available online March 2018. DOI: 10.1002/rob.21782

[J17] Enciu, J., Joseph F. Horn and Jacob W. Langelaan, "Formation control of a rotorcraft multilift system," *Journal of the American Helicopter Society*, vol. 62, No. 4, October 2017.

[J16] **DEPENBUSCH, NATHAN T., JOHN J. BIRD** and Jack W. Langelaan, "The AutoSOAR Autonomous Soaring Aircraft Part 2: Hardware Implementation and Flight Results," *Journal of Field Robotics*, online October 3, 2017. DOI: 10.1002/rob.21747

[J15] **YOMCHINDA, THANAN**, Jack W. Langelaan and Joseph F. Horn, "Modified Dubins Parameterization for Aircraft Emergency Trajectory Planning," *Proceedings of the Institution of Mechanical Engineers Part G: Journal of Aerospace Engineering* 03/2016. DOI:10.1177/0954410016638869

[J14] **GRANDE, NICHOLAS, SHANE TIERNEY**, Joseph F. Horn and Jack W. Langelaan, "Safe Autorotation through Wind Shear via Backwards Reachable Sets," *Journal of the American Helicopter Society*, vol. 61, no. 2, April 2016.

[J13] Mandell, Jason G., Jack W. Langelaan, Andrew G. Webb, and Steven J. Schiff, "Volumetric brain analysis in neurosurgery: Part I. Particle filter segmentation of brain and cerebrospinal fluid growth dynamics from MRI and CT images," *Journal of Neurosurgery: Pediatrics,* vol. 15, no. 2, February 2015, pp 113-124. DOI: 10.3171/2014.9.PEDS12426

[J12] **BIRD, JOHN J.** and Jack W. Langelaan, "Spline Mapping to Maximize Energy Exploitation of Non-Uniform Thermals," *Journal of Technical Soaring*, vol. 37, no. 3, July-September 2013. Winner of 2014 OSTIV Diploma.

[J11] Langelaan, Jack W., **ANJAN CHAKRABARTY**, Aijun Deng, Kirk Miles, Vid Plevnik, Jure Tomazic, Tine Tomazic, Gregor Veble, "Green Flight Challenge: Aircraft Design and Flight Planning for Extreme Fuel Efficiency," *Journal of Aircraft*, vol. 50, no. 3, May 2013, pp 832-846. DOI: 10.2514/1.C032022

[J10] Tomažič, Tine, Vid Plevnik, Gregor Veble, Jure Tomažič, Franc Popit, Sašo Kolar, Radivoj Kikelj, Jacob W Langelaan, Kirk Miles, "Pipistrel Taurus G4: on Creation and Evolution of the Winning Aeroplane of NASA Green Flight Challenge 2011," *Strojniški vestnik-Journal of Mechanical Engineering*, vol. 57, no. 12, 2012, pp 869-878.

[J9] **CHAKRABARTY, ANJAN** and Jack W. Langelaan, "Energy-based Long-Range Path Planning for Soaring-capable UAVs," *Journal of Guidance, Control and Dynamics*, vol. 34, no. 4, 2011, pp 1002-1015.

[J8] Langelaan, Jack W., Nicholas J. Alley, and James Neidhoefer, "Wind Field Estimation for Mini- and Micro-Unmanned Aerial Vehicles," *Journal of Guidance, Control and Dynamics*, vol. 34, no. 4, 2011, pp 1016-1030.

[J7] Langelaan, Jack W., "A Gust Soaring Controller for Small Gliders," *Journal of Technical Soaring*, vol. 35, no. 2, 2011.

[J6] **MARLOW, SEAN Q.** and Jack W. Langelaan, "Local Terrain Mapping for Obstacle Avoidance using Monocular Vision," *Journal of the American Helicopter Society*, vol. 56, no. 2, April 2011.

[J5] **CORBETS, JEFFREY B.** and Jack W. Langelaan, "Real Time Trajectory Generation for Target Localization using Micro Air Vehicles," *Journal of Aerospace Computing, Information and Communications*, vol. 7, August 2010, pp 223-240. DOI: 10.2514/1.47834.

[J4] Langelaan, Jack W., "Gust Energy Extraction for Small- and Micro- Uninhabited Aerial Vehicles," *Journal of Guidance, Control and Dynamics,* vol. 32, no. 2, 2009, pp 464-473.

[J3] Langelaan, Jack W., "State Estimation for Autonomous Flight in Cluttered Environments," *Journal of Guidance, Control and Dynamics,* vol. 30, no. 5, 2007.

[J2] Langelaan, Jack, ed.: "Special Issue on Aircraft Design and Development," *Canadian Aeronautics and Space Journal* vol. 46, no. 2 June 2000.

[J1] Langelaan, Jack W. and E. Livne: "Analytic Sensitivities and Design Oriented Structural Analysis for Airplane Fuselage Shape Synthesis," *Computers and Structures*, vol. 62, no. 3, pp. 505–519, 1997.

Book Chapters

[B1] Langelaan, Jack W., "Power Generation and Energy Management," in *Encyclopedia of Aerospace Engineering: UAS*, online June 13, 2016. DOI: 10.1002/9780470686652.eae1113

Conference Publications

Names in **BOLD SMALL CAPS** denote Langelaan's students.

[C67] **YUAN, KAIL J.**, Damaris R. Zachos, Jack W. Langelaan, Eric Greenwood and Kenneth Brentner, "Flight Path Planning for Minimization of Total Noise Exposure in Urban Air Mobility Operations," *AIAA SciTech Forum*, January 2024. https://doi.org/10.2514/6.2024-2881

[C66] **KIMMEL, NATHAN K** and Jack W. Langelaan, "UAS Data retrieval in large-scale sensor networks," *AIAA SciTech Forum*, January 2024. https://doi.org/10.2514/6.2024-2891

[C65] Habas, Bryan, Jack W. Langelaan, and Bo Cheng, "Inverted Landing in a Small Aerial Robot via Deep Reinforcement Learning for Triggering and Control of Rotational Maneuvers," *IEEE International Conference on Robotics and Automation,* May 2023.

[C64] Hendrick, Christopher M., **EMMA R. JAQUES**, Joseph F. Horn, and Jack W. Langelaan, "Evaluation of Autonomous Ship Landing Systems at the Maneuvering and Seakeeping Basin," *Vertical Flight Society 79th Annual Forum*, West Palm Beach, FL, May 2023

[C63] **GONZALEZ, BIANCA**, Muhammad J. H. Zahed, Alan R. Wagner, and Jack W. Langelaan, "Scalable Collision Avoidance in High-density Airspaces," *Vertical Flight Society 79th Annual Forum*, West Palm Beach, FL, May 2023

[C62] Hendrick, C., **NICHOLSON, D., JACQUES, E.,** Horn, J. F., Langelaan, J., & Sydney, A. "Scaled Experiments in Flight Control Design for Autonomous Landing in High Sea States," *AIAA Aviation Conference,* June 2022.

[C61] **NICHOLSON, D.,** Hendrick, C., **JACQUES, E.,** Horn, J. F., Langelaan, J., & Sydney, A. "Scaled Experiments in Vision-Based Approach and Landing in High Sea States," *AIAA Aviation Conference*, June 2022.

[C60] Habas, B., Al Attar, B., Davis, B., Langelaan, J., & Cheng, B. "Optimal Inverted Landing in a Small Aerial Robot with Varied Approach Velocities and Landing Gear Designs," *IEEE International Conference on Robotics and Automation,* May 2022.

[C59] Langelaan, J., Schmitz, S., Adams, D. S., & Lorenz, R. D. (2021). Conceptual design of the Dragonfly lander. Vertical Flight Society 77th Annual Forum.

[C58] **GENG, JUNYI**, Puneet Singla and Jack W. Langelaan, "Trajectory Planning and Control for a Multilift System Based on Load Distribution," *Proceedings of the 2021 AIAA SciTech Forum,* virtual event, January 11-15 and 19-21, 2021. DOI: 10.2514/6.2021-0980

[C57] **GENG, JUNYI** and Jack W. Langelaan, "Mass and Center of Mass Location Estimation for a Multi-lift Slung Load," *Proceedings of the 2020 AIAA SciTech Forum*, Orlando, Florida, January 7-11, 2020. DOI: 10.2514/6.2020-2067

[C56] **BIRD, JOHN J.** and Jack W. Langelaan, "A Multi-Armed Bandit Approach to Atmospherically Aware Altitude Optimization," *Proceedings of the 2020 AIAA SciTech Forum*, Orlando, Florida, January 7-11, 2020. DOI: 10.2514/6.2020-1089

[C55] **LI, ZHENDA** and Jack W. Langelaan, "Parameterized Trajectory Planning for Dynamic Soaring," *Proceedings of the 2020 AIAA SciTech Forum*, Orlando, Florida, January 7-11, 2020. DOI: 10.2514/6.2020-0856

[C54] **OPAZO, TOMAS I.** and Jack W. Langelaan, "Longitudinal control of transition to powered flight for a parachute-dropped multirotor," *Proceedings of the 2020 AIAA SciTech Forum*, Orlando, Florida, January 7-11, 2020. DOI: 10.2514/6.2020-2072

[C53] Kinzel, Michael P., Jason K. Cornelius, Sven Schmitz, Jose L. Palacios, Jack W. Langelaan, Douglas Adams, and Ralph Lorenz, "An Investigation of the Behavior of a Coaxial Rotor in Descent and Ground Effect," *Proceedings of the 2019 AIAA SciTech Forum*, San Diego, California, January 7-11, 2019. doi: 10.2514/6.2019-1098

[C52] Yan, Sihong, David Getz, Jose L. Palacios, Michael P. Kinzel, Sven Schmitz and Jack W. Langelaan, "Design, Fabrication and Preliminary Testing of an Experimental Measurement Rig for Co-Axial Rotors," *Proceedings of the 2019 AIAA SciTech Forum*, San Diego, California, January 7-11, 2019. doi: 10.2514/6.2019-1096

[C51] **GENG, JUNYI** and Jack W. Langelaan, "Implementation and Demonstration Of Coordinated Transport Of A Slung Load By A Team Of Rotorcraft," *Proceedings of the 2019 AIAA SciTech Forum*, San Diego, California, January 7-11, 2019. doi: 10.2514/6.2019-0913

[C50] **BIRD, JOHN J.** and Jack W. Langelaan, "Optimal Speed Scheduling for Hybrid Solar Aircraft with Arrival Time Condition," *Proceedings of the 2019 AIAA SciTech Forum*, San Diego, California, January 7-11, 2019. doi: 10.2514/6.2019-1421

[C49] Yan, Sihong, **TOMAS OPAZO**, Jose Palacios, Jack W. Langelaan and Louis-David Germain, "Experimental evaluation of multi-rotor UAV operation under icing conditions," *Proceedings of the American Helicopter Society 74th Annual Forum,* Phoenix, Arizona, May 2018.

[C48] Lakhmani, Sagar, Jack W. Langelaan, and Alan Wagner, "Human-intuitable collision avoidance for autonomous and semi-autonomous aerial vehicles," *Proceedings of the American Helicopter Society 74th Annual Forum,* Phoenix, Arizona, May 2018.

[C47] McGee, Timothy G., Douglas S. Adams, Kenneth E. Hibbard, Elizabeth P. Turtle, Ralph D. Lorenz, Farzin Amzajerdian, and Jack W. Langelaan, "Guidance, Navigation, and Control for Exploration of Titan with the Dragonfly Rotorcraft Lander," *AIAA Guidance, Navigation, and Control Conference*, Kissimee, Florida, January 8-12, 2018.

[C46] **BIRD, JOHN J.** and Jack W. Langelaan, "Design Space Exploration for Hybrid Solar/Soaring Aircraft," *Proceedings of the AIAA Aviation Technology, Integration, and Operations Conference*, Denver, Colorado, June 5-7, 2017.

[C45] Langelaan, Jack W., Sven Schmitz, Jose Palacios and Ralph D. Lorenz, "Energetics of rotary-wing exploration of Titan," *IEEE Aerospace Conference*, Big Sky, Montana, March 6-10, 2017.

[C44] **GENG, JUNYI** and Jack W. Langelaan, "A Quasi Polar Local Occupancy Grid Approach for Vision-based Obstacle Avoidance," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, Grapevine, Texas, January 9-13, 2017.

[C43] **HOLMES, W. K.** and Jack W. Langelaan, "Autonomous Ship-board Landing using Monocular Vision," *Proceedings of the American Helicopter Society 72nd Annual Forum*, West Palm Beach, Florida, May 2016.

[C43] Jerath, Kshitij and Jack W. Langelaan, "Simulation framework for incorporating sensor systems in UAS conceptual design," *Proceedings of the AIAA Modeling and Simulation Technologies Conference*, San Diego, California, January 4-8, 2016.

[C42] Enciu, Jacob, Joseph F. Horn, and Jack W. Langelaan, "Formation control of a rotorcraft multi-lift system," *41st European Rotorcraft Forum*, September 1-4, 2015.

[C41] **DEPENBUSCH, NATHAN T.,** Constantino Lagoa, and Jack W Langelaan, "Random Geometric Graphs as a Model for Bounding the Endurance of Soaring Aircraft," *IEEE Conference on Decision and Control*, Los Angeles, California, December 2014.

[C40] **CHENG, KWOK** and Jack W. Langelaan, "Guided Exploration for Coordinated Autonomous Soaring Flight," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, National Harbor, Maryland, January 13-17, 2014.

[C39] **LI, ZUQUN,** Jack W. Langelaan and Joseph F. Horn, "Coordinated Transport of a Slung Load by a Team of Autonomous Rotorcraft," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, National Harbor, Maryland, January 13-17, 2014.

[C38] **MAKOVKIN, DMITRIY** and Jack W. Langelaan, "Optimal Persistent Surveillance using Coordinated Soaring," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, National Harbor, Maryland, January 13-17, 2014.

[C37] **BIRD, JOHN J.,** Jack W. Langelaan, Corey Montella, John Spletzer, Joachim Grenestedt, "Closing the Loop in Dynamic Soaring," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, National Harbor, Maryland, January 13-17, 2014.

[C36] **DAUGHERTY, SHAWN** and Jack W. Langelaan, "Improving Autonomous Soaring via Energy State Estimation and Extremum Seeking Control," *Proceedings of the AIAA Guidance, Navigation and Control Conference*, National Harbor, Maryland, January 13-17, 2014.

[C35] **DEPENBUSCH, NATHAN T.** and Jack W. Langelaan, "Minimum Risk Planning for Teams of Unmanned Air Vehicles," *Proceedings of the 2013 Infotech@Aerospace Conference*, Boston, Massachusetts, August 19-22, 2013. (invited paper).

[C34] **CHAKRABARTY, ANJAN** and Jack W. Langelaan, "UAV Flight Path Planning in Time Varying Complex Wind Fields," *American Control Conference*, Washington, DC, June 2013.

[C33] **GRANDE, NICHOLAS** and Jack W. Langelaan, "Safe Autonomous Flare and Landing during Autorotation through Wind Shear," *Proceedings of the AHS 69th Annual Forum*, Phoenix, Arizona, May 21-23, 2013.

[C32] **TRUSKIN, BENJAMIN** and Jack W. Langelaan, "Vision-based Deck State Estimation for Autonomous Ship-board Landing," *Proceedings of the AHS 69th Annual Forum*, Phoenix, Arizona, May 21-23, 2013.

[C31] Song, Y., Joseph F. Horn, **ZUQUN LI,** and Jack W. Langelaan, "Modeling, Simulation, and Non-linear Control of a Rotorcraft Multi-Lift System," *Proceedings of the AHS 69th Annual Forum*, Phoenix, Arizona, May 21-23, 2013.

[C30] **QUINDLEN, JOHN F.** and Jack W. Langelaan, "Flush Air Data Sensing for Soaring-capable UAVs," *51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, January 7-10, 2013. DOI: 10.2514/6.2013-1153.

[C29] **BIRD, JOHN J.** and Jack W. Langelaan, "Spline Mapping to Maximize Energy Exploitation of Non-uniform Thermals," *Proceedings of the XXXI OSTIV Congress*, Uvalde, Texas, August 8-13, 2012.

[C28] Langelaan, Jack W., J. Spletzer, C. Montella and J. Grenestedt, "Wind field estimation for autonomous dynamic soaring," *2012 IEEE International Conference on Robotics and Automation*, St. Paul, Minnesota, May 14-18, 2012.

[C26] **YOMCHINDA, THANAN,** Joseph F. Horn and Jack W. Langelaan, "Autonomous Control and Path Planning for Autorotation of Unmanned Helicopters," *American Helicopter Society 68th Annual Forum*, Fort Worth, Texas. May 1-3, 2012.

[C26] **MARLOW, SEAN Q.** and Jack W. Langelaan, "Population of a Range Bearing Map for Local Obstacle Avoidance Using Monocular Vision," *American Astronautical Society Guidance and Control Conference*, Breckenridge, Colorado, 2012.

[C25] **YOMCHINDA, THANAN**, Joseph F. Horn and Jack W. Langelaan, "Flight Path Planning for Descent-phase Helicopter Autorotation," *AIAA Guidance, Navigation and Controls Conference*, Portland, Oregon, August 7-11, 2011.

[C24] **NATHAN T. DEPENBUSCH** and Jack W. Langelaan, "Coordinated Mapping and Exploration for Autonomous Soaring," *AIAA Infotech@Aerospace Conference*, St. Louis, Missouri, March 29-31, 2011.

[C23] Jack W. Langelaan, Nicholas Alley and James Niedhoefer, "Wind Field Estimation for Small Unmanned Aerial Vehicles," *AIAA Guidance, Navigation and Controls Conference*, Toronto, Canada, August 2-5, 2010.

[C22] **DEPENBUSCH, NATHAN T.** and Jack W. Langelaan, "Receding Horizon Control for Atmospheric Energy Harvesting by Small UAVs," *AIAA Guidance, Navigation and Controls Conference*, Toronto, Canada, August 2-5, 2010.

[C21] **CHAKRABARTY, ANJAN** and Jack W. Langelaan, "Flight Path Planning for UAV Atmospheric Energy Harvesting Using Heuristic Search," *AIAA Guidance, Navigation and Controls Conference*, Toronto, Canada, August 2-5, 2010.

[C20] **MARLOW, SEAN Q.** and Jack W. Langelaan, "Dynamically Sized Occupancy Grids for Obstacle Avoidance," *AIAA Guidance, Navigation and Controls Conference*, Toronto, Canada, August 2-5, 2010.

[C19] Dean, Adam J., Jack W. Langelaan, and Sean N. Brennan, "Improvements in Terrain-Based Road Vehicle Localization by Initializing an Unscented Kalman Filter Using Particle Filters." *2010 American Control Conferenc*e, Baltimore, Maryland, June 30-July 2, 2010.

[C18] **TIERNEY, SHANE** and Jack W. Langelaan, "Autorotation Path Planning Using Backwards Reachable Sets and Optimal Control," *American Helicopter Society 66th Annual Forum*, Phoenix, Arizona, May 2010.

[C17] Jemmott, Colin W., Lee J. Culver, and Jack W. Langelaan, "Comparison of Particle Filter and Histogram Filter for Passive Sonar Localization," *Proceedings of Meetings on Acoustics*, vol. 8, issue 1, December 22, 2009. http://dx.doi.org/10.1121/1.3292596

[C16] Dean, Adam J., Jack W. Langelaan, and Sean N. Brennan, "Initializing an Unscented Kalman Filter using a Particle Filter," Dynamic Systems and Control Conference, Hollywood, California, October 2009.

[C15] **CHAKRABARTY, ANJAN** and Jack W. Langelaan, "Energy Maps for Long Range Path Planning for Small- and Micro- UAVs," *AIAA Guidance, Navigation and Controls Conference*, Chicago, Illinois, August, 2009.

[C14] **MARLOW, SEAN Q.** and Jack W. Langelaan, "Local Terrain Mapping for Obstacle Avoidance using Monocular Vision," *AHS International Specialist's Meeting on Unmanned Rotorcraft*, Scottsdale, Arizona, January 2009.

[C13] **SARFRAZ, SANA** and Jack W. Langelaan, "Autonomous Ground-Based Tracking of Migrating Raptors using Vision," *AIAA Guidance, Navigation and Controls Conference (invited paper)*, Honolulu, Hawaii, August 18-21, 2008.

[C12] Jack W. Langelaan, "Biologically Inspired Flight Techniques for Small and Micro Unmanned Aerial Vehicles," *AIAA Guidance, Navigation and Controls Conference*, Honolulu, Hawaii, August 18-21, 2008.

[C11] Jack W. Langelaan, "Tree-based Trajectory Planning to Exploit Atmospheric Energy," *American Control Conference,* Seattle, Washington, June 11-13, 2008.

[C10] **JEFFREY B. CORBETS** and Jack W. Langelaan, "Parameterized Trajectories for Target Localization using Small- and Micro- Unmanned Aerial Vehicles," *American Control Conference,* Seattle, Washington, June 11-13, 2008.

[C9] Jack W. Langelaan and Goetz Bramesfeld, "Gust Energy Extraction for Small and Micro Uninhabited Aerial Vehicles," *46th AIAA Aerospace Sciences Meeting*, Reno, Nevada, January 7-10, 2008.

[C8] Jack W. Langelaan, "Long Distance/Duration Trajectory Optimization for Small UAVs," *AIAA Guidance, Navigation and Controls Conference*, Hilton Head, South Carolina, August 20-23, 2007.

[C7] Eric W. Frew, Jack Langelaan, Maciej Stachura, "Adaptive Planning Horizon Based on Information Velocity for Vision-Based Navigation and Active Sensing," *invited to AIAA Guidance, Navigation and Controls Conference*, Hilton Head, South Carolina, August 20-23, 2007.

[C6] **JEFFREY B. CORBETS** and Jack W. Langelaan, "Parameterized Optimal Trajectory Generation for Target Localization," *invited to AIAA Guidance, Navigation and Controls Conference*, Hilton Head, South Carolina, August 20-23, 2007.

[C5] Eric Frew, Jack Langelaan and Sungmoon Joo, "Adaptive Receding Horizon Control for Vision-Based Navigation of Small Unmanned Aircraft," *invited to American Controls Conference*, Minneapolis, Minnesota, June 14-16, 2006.

[C4] Jack Langelaan and Steve Rock, "Towards Autonomous UAV Flight in Forests," *AIAA Guidance, Navigation and Control Conference*, San Francisco, California, August 15-18, 2005.

[C3] Jack Langelaan and Steve Rock, "Passive GPS-Free Navigation for Small UAVs," *IEEE Aerospace Conference*, Big Sky, Montana 2005.

[C2] Jack Langelaan and Steve Rock, "Navigation of Small UAVs Operating in Forests," *AIAA Guidance, Navigation and Control Conference*, Providence, Rhode Island, August 16-19, 2004.

[C1] Jack W. Langelaan and Leo J. J. Kok: "Damage Tolerance Modelling of Fibre/Metal Laminate Fuselage Structures," AIAA Paper 97-1400*, 38th Structures, Structural Dynamics and Materials Conference*, Kissimmee, Florida, April 7-10, 1997.

Funded research

August 15, 2023 – July 31, 2026, "Collaborative Research: Omnidirectional Perching on Dynamic Surfaces: Emergence of Robust Behaviors from Joint Learning of Embodied and Motor Control," National Science Foundation. Total requested: $700,021, co-PI (50%).

May 1, 2022 – April 30, 2025, "Design, characterization, and control of compound CAT-HR unmanned aircraft (or: Vindicator only slightly Defiant)," Office of Naval Research. Total requested: $905,163, co-PI (50%)

April 15, 2022 – March 31, 2027, "IUCRC Phase I Pennsylvania State University: Center for Autonomous Air Mobility and Sensing (CAAMS)," National Science Foundation. Total requested: $503,438, PI (100%)

October 1, 2021 – September 30, 2026, "Penn State Vertical Lift Research Center of Excellence (VLRCOE)," U.S. Army Contracting Command, Total requested: $7,172,443, co-I (12%)

December 1, 2019 – August 31, 2022, "Characterization and scaling of coaxial unmanned rotorcraft," Office of Naval Research, Federal Agencies. Total requested: $90,095.00, PI (100%)

December 1, 2019 – May 31, 2023, "Experimental Analysis of Advanced Control and Estimation Systems for Autonomous Ship Landing," Office of Naval Research, Federal Agencies. Total requested: $577,616.00, co-PI (50%)

February 3, 2021–April 30, 2026, "Dragonfly: PSU Phase C and D," Johns Hopkins University Applied Physics Lab, under negotiation, expected $2,000,000, PI (20%). (Pending)

September 1, 2019–February 2, 2021, "Dragonfly: PSU Bridge Phase and Phase B," Johns Hopkins University Applied Physics Lab, $751,000, PI (20%). (Pending)

June 1, 2018–May 31, 2020, "Sensor networks on Greenland Glaciers (Phase 1)," Heising-Simons Foundation, $489,327, co-PI (20%).

May 1, 2018–April 30, 2019, "Dragonfly: PSU Phase A," Johns Hopkins University Applied Physics Lab, $294,766, PI (34%).

February 28, 2017–December 31, 2019, "Energy Management and Adaptation to the Changing Atmosphere for Hybrid Soaring/Solar/Fuel Cell Aircraft," Naval Research Laboratory, $349,318, PI (100%).

November 30, 2016–October 30, 2021, "High-speed carriage of external loads," U.S. Army Combat Capabilities Development Command (CCDC) through the Vertical Lift Research Center of Excellence. Total requested: $611,032 (plus $636,454 cost share). Total awarded: $611,032 (plus $636,454 cost share), co-PI (29%).

November 30, 2016–October 30, 2021, "Slung load state and parameter estimation for autonomous multi-lift systems," U.S. Army Combat Capabilities Development Command (CCDC) through the Vertical Lift Research Center of Excellence. Total requested: $588,881 (plus $366,454 cost share). Total awarded: $588,881 (plus $366,454 cost share), PI (67%).

September 1, 2016–September 30, 2017, "Energy management and flight planning for hybrid soaring/solar/fuel cell aircraft," Naval research Laboratory, $24,713, PI (100%).

August 1, 2015–July 31, 2017, "Efficient Reconfigurable Cockpit Design and Fleet Operations using Software Intensive, Networked and Wireless Enabled Architecture (ECON)," National Aeronautics and Space Administration, $21,000, PI (100%).

June 1, 2015–December 31, 2015, "Competitive and cooperative autonomous soaring flight demonstrations," Naval Research Laboratory, $21,968, PI (100%).

March 23, 2015–March 22, 2017, "Product Architectures, Design, and Manufacturing for Operational Responsiveness," Naval Sea Systems Command, $1,237,264, co-PI (10%).

March 1, 2012–November 30, 2012, "Reactive Controller for Harvesting Gust Energy (RECHARGE)," Office of Naval Research STTR Phase 2 Option 1, $82,500, PI (100%)

December 1, 2012–November 30, 2013, "Reactive Controller for Harvesting Gust Energy (RECHARGE)," Office of Naval Research STTR Phase 2 Option 2, $225,000, PI (100%)

September 1, 2011–August 31, 2016, "Autonomous shipboard take-off and landing," U.S. Army Combat Capabilities Development Command (CCDC) through the Vertical Lift Research Center of Excellence. Total requested: $370,804 (plus $327,140 cost share). Total awarded: $370,804 (plus $327,140 cost share). PI (100%).

September 1, 2011–August 31, 2016, "Autonomous multi-lift systems," U.S. Army Combat Capabilities Development Command (CCDC) through the Vertical Lift Research Center of Excellence. Total requested: $370,804 (plus $327,140 cost share). Total awarded: $438,335 (plus $371,551 cost share). co-PI (50%).

April 1, 2011–March 21, 2014, "Low Altitude Persistence via Bio-inspired Flight: Cooperative Autonomous Soaring for sUAS," Office of Naval Research award number N00014-11-1-0656, $506,312, PI (100%).

March 1, 2011–February 28, 2014, "Collaborative Research: RI: Medium: Towards Perpetual Flight of a Gliding Unmanned Aerial Vehicle in the Jet Stream," National Science Foundation, $242,365, PI, (100%). This is a collaborative research submission done in conjunction with Lehigh University, Langelaan is a co-PI on full proposal with total budget $1,038,584

August 1, 2010–February 29, 2012, "Reactive Controller for Harvesting Gust Energy (RECHARGE)," Office of Naval Research STTR Phase 2 Base Award, $165,000, PI (100%)

May 15, 2010–December 31, 2012, "Aided/Automated Flare and Landing during Autorotation (AutoFLARE)", Vertical Lift Consortium, $350,000, Co-PI (50%)

April 30, 2010–August 30, 2010, "Robust Autonomous Maneuvering of Unmanned Air Systems in Challenging Environmental/Weather Conditions for Safety, Mission Effectiveness, and Endurance," Office of Naval Research STTR N09A-025-0019 in conjunction with Area-I, Inc, $15,000, PI (100%) (Phase 1 option complete).

July 1, 2009–April 30, 2010, "Robust Autonomous Maneuvering of Unmanned Air Systems in Challenging Environmental/Weather Conditions for Safety, Mission Effectiveness, and Endurance," Office of Naval Research STTR N09A-025-0019 in conjunction with Area-I, Inc, $50,000, PI (100%) (Phase 1 complete).

May 15, 2009–May 14, 2010, "REU: Development of a Small Autopilot Module for Mini- and Micro-Uninhabited Aerial Vehicles," National Science Foundation supplement to IIS-0746655, $6000, PI (100%).

January 1, 2008–May 15, 2012, "Local Terrain Mapping for Obstacle Avoidance using Monocular Vision," Applied Research Lab Exploratory and Foundational Research Program, $204,875, PI (100%)

June 15, 2008–May 31, 2013, "CAREER: Theory and Practice of Autonomous Soaring for Aerial Robots," National Science Foundation award number IIS-0746655, $439,750, PI (100%).