

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

AXON ENTERPRISE, INC., DEDRONE HOLDINGS, INC., AND
SKYDIO, INC.
Petitioners,

v.

AIRSPACE SYSTEMS, INC.,
Patent Owner.

Case IPR2025-00629
Patent No. 10,514,711

DECLARATION OF DR. WILLIAM SINGHOSE

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I, Dr. William Singhose, hereby declare as follows:

I. INTRODUCTION & QUALIFICATIONS

1. My name is Dr. William Singhose. I make this declaration based upon my own personal knowledge and, if called upon to testify, would testify competently to the matters contained herein.

2. I have been asked to provide technical assistance in the *inter partes* review of U.S. Patent No. 10,514,711, which I may abbreviate as “the ’711 Patent” or refer to as the “Challenged Patent.” This declaration is a statement of my opinions on issues related to the unpatentability of claims of the ’711 Patent. I am being compensated at my normal hourly rate for my analysis, plus reimbursement for expenses. My compensation does not depend on the content of my opinions or the outcome of this proceeding.

3. In formulating my opinions, I have relied upon my knowledge, training, and experience in the relevant art. My qualifications are stated more fully in my curriculum vitae, which has been provided as Appendix A. My CV also lists publications on which I am a named author and identifies parties on behalf of whom I have previously provided expert testimony within the past four years. Here, I provide a brief summary of my qualifications.

4. Based on my education, research, and work experience, I am knowledgeable about the subject matter of the ’711 patent and the cited prior art.

Specifically, my knowledge at least stems from being an expert in the control of rotary aircraft, other similar machines, and the use of sensors in control systems stem from my prior work experience, as well as my experience as a Professor in the Woodruff School of Mechanical Engineering at Georgia Tech performing research, teaching, working, and consulting. I have hundreds of publications that are directed toward understanding and improving the control of machinery using sensor systems.

5. Regarding my education, I received a B.S. in Mechanical Engineering from the Massachusetts Institute of Technology (“MIT”) in 1990. I then received an M.S. in Mechanical Engineering from Stanford University in 1992. Finally, I received a Ph.D. in Mechanical Engineering from MIT in 1997. After receiving my Ph.D., I was a postdoctoral researcher at MIT before becoming a professor at Georgia Tech in 1998.

6. At Georgia Tech, I have taught a graduate-level course on advanced control system design and implementation since 2001. I have co-authored a textbook entitled “Command Generation for Dynamic Systems”, which focuses on designing control commands to move machines. The textbook presents numerous examples of various machines to which the theoretical concepts are applicable, including cranes, robots, and satellites. I have also developed a series of remote-operated experimental cranes and aerial lifts used extensively in educational activities.

7. My research focuses on the dynamics and control of a wide range of machines. However, I have researched, developed experimental platforms, and published numerous papers specifically relevant to aircraft and flight control. For example, I conducted research directed at controlling rotorcraft sling load operations which was sponsored by the National Rotorcraft Technology Center. This project involved researching the effects of suspended loads on the control of rotorcraft and techniques to reduce the swinging of the load and improve the response of such systems. The results of my research were presented in several papers. One such paper, “Dynamic Modeling and Simulation of a Remote-Controlled Helicopter with a Suspended Load”, studied the dynamic effects of loads suspended below the helicopter by cables and created a dynamic model of the loaded system. The paper documented the difficulty of maintaining a steady hover position after a horizontal movement of the helicopter while carrying a suspended load.

8. My paper “Input-Shaping and Model-Following Control of a Helicopter Carrying a Suspended Load” studied the effects of a heavy load suspended from a helicopter. The paper analyzed how the swinging of a suspended load can create challenges for model-following control architectures used in modern helicopter flight control systems due to the degradation of the tracking of the prescribed model dynamics, thereby degrading the control effectiveness. The paper described the use of input shaping with model-following control to reduce helicopter

payload swing and improve the tracking of the prescribed model. The paper illustrates the design of an attitude-command flight control system that combines input-shaping and model-following control using dynamic models of a Sikorsky S-61 helicopter. It also shows the simulation results of the system for longitudinal and lateral repositioning movements.

9. My paper “Reducing Swing of Model Helicopter Sling Load Using Input Shaping” studied techniques for suppressing the swinging of a load suspended beneath a helicopter to improve safety and productivity. Specifically, the paper discusses the formation of a dynamic model to characterize the translational response of a model helicopter and sling load to lateral control inputs in order to investigate the use of input shaping on helicopters.

10. I have listed the previously discussed textbook and papers below, in addition to select other papers that I have published on rotorcraft:

- W. Singhose and W. Seering, “Command Generation for Dynamic Systems,” 11th Edition, 2011, ISBN13: 9780984221004.
- J.J. Potter, R. Simpson, W. Singhose, “Dynamic Modeling and Simulation of a Remote-Controlled Helicopter with a Suspended Load,” *ASME Dynamic Systems and Control Conference*, Stanford, CA, March 6, 2014, DSCC2013-3998, V001T01A006.

- C. Adams, J.J. Potter, W. Singhose, “Input-Shaping and Model-Following Control of a Helicopter Carrying a Suspended Load,” *AIAA Journal of Guidance, Control, and Dynamics*, vol. 38, no. 1, pp. 94-105, January 2015, DOI:10.2514/1.G000326.
- J. J. Potter, W. Singhose, M. Costello, “Reducing Swing of Model Helicopter Sling Load Using Input Shaping,” 2011 9th IEEE International Conference on Control and Automation (ICCA), 19-21 December 2011, Santiago, Chile, DOI: 10.1109/ICCA.2011.6138048.
- J. J. Potter and W. Singhose, “A Planar Experimental Remote-Controlled Helicopter with a Suspended Load,” *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 5, pp. 2496-2503, 2015, doi: 10.1109/TMECH.2014.2386801.
- J. J. Potter, C. J. Adams, and W. Singhose, “An Experimental Remote Controlled Helicopter with Suspended Load,” in *2013 Int. Symp. on Mechatronics and its Applications*, Amman, Jordan, 2013.
- N. Johnson and W. Singhose, “Dynamics and Modeling of a Quadrotor with a Suspended Payload,” in *AIAA Aviation Forum Applied Aerodynamics Conference*, Atlanta, GA, 2018
- C. Adams, J. Potter, and W. Singhose, “Modeling and Input Shaping Control of a Micro Coaxial Radio-Controlled Helicopter Carrying a

Suspended Load,” in *Int. Conference on Control, Automation and Systems*, Jeju, Korea, 2012.

- S. Ichikawa, A. Castro, N. Johnson, H. Kojima, and W. Singhose, “Dynamics and Command Shaping Control of Quadcopters Carrying Suspended Loads,” in *14th IFAC Workshop on Time Delay Systems TDS (IFAC-PapersOnLine)*, Budapest, Hungary, 2018, vol. 51, no. 14, pp. 84 - 88.

11. In addition to conducting research on rotorcraft dynamics and control, I have also performed research on air traffic control that was sponsored by NASA. That research program produced several publications directed to optimizing flight paths and controlling speeds of aircraft, such as:

- Vela, A., J. P. Clarke, E. Feron and W. Singhose (2011). “The Relative Value of Trajectory Prediction and Conflict-Resolution Algorithms.” *IEEE/AIAA 30th Digital Avionics Systems Conference*, Seattle, WA, 2011.
- Vela, A., K. Feigh, S. Solak, W. Singhose and J.-P. Clarke (2012). “Formulation of Reduced-Taskload Optimization Models for Conflict Resolution.” *IEEE Trans. on Systems, Man, and Cybernetics* 42(6): 1552- 1561.

- Vela, A., S. Solak, E. Feron, K. Feigh, W. Singhose and J.-P. Clarke (2009). “A Fuel Optimal and Reduced Controller Workload Optimization Model for Conflict Resolution.” *Digital Avionics Systems Conference*, Orlando, Florida.
- Vela, A., S. Solak, W. Singhose and J.-P. Clarke (2009). “A Mixed Integer Program for Flight-Level Assignment and Speed Control for Conflict Resolution.” *IEEE Conference on Decision and Control*, Shanghai, China.
- Vela, A. E., E. Feron, W. Singhose and J.-P. Clarke (2010). “Control of Holding Patterns for Increased Throughput and Recovery of Operations.” *Digital Avionics Systems Conference*, Salt Lake City, UT.
- Vela, A. E., E. Salaun, E. Feron, W. Singhose and J.-P. Clarke (2011). “Bounds on Controller Taskload Rates at an Intersection for Dense Traffic.” *2011 American Control Conference*, San Francisco, CA.
- Vela, A. E., S. Solak, J.-P. Clarke, W. Singhose, E. Barnes and E. Johnson (2010). “Near Real-Time Fuel-Optimal En Route Conflict Resolution.” *IEEE Trans. on Intelligent Transportation Systems* 11(4): 826-837.

12. Finally, I am a named inventor on six US patents directed at improving control systems:

- Singhose, W., Singer, N., Rappole, W., Derezinski, S., and Pasch, K., “Methods and Apparatus for Minimizing Unwanted Dynamics in a Physical System,” U.S. Patent 5,638,267, granted June 10, 1997.
- R. Eloundou, W. Singhose, “Command Generation Combining Input Shaping and Smooth Baseline Commands,” U.S. Patent 6,920,378, granted July 19, 2005.
- K. L. Sorensen, W. Singhose, and S. Dickerson, “Combined feedback and command shaping controller for multistate control with application to improving positioning and reducing cable sway in cranes,” U.S. Patent 7,970,521, granted June 28, 2011.
- W. Singhose and D. Kim, “Methods and Systems for Double-Pendulum Crane Control,” U.S. Patent 8,235,229, granted August 7, 2012.
- W. Singhose and Joshua Vaughan, “Methods and Systems for Improving Positioning Accuracy,” U.S. Patent 8,975,853, granted March 10, 2015.
- W. Singhose and Chen Chih Peng, “Crane Control Systems and Method,” U.S. Patent 9,132,997, granted September 15, 2015. • Khalid Sorensen and W. Singhose, “Crane Motion Control”, U.S. Patent 9,776,838, granted Oct. 3, 2017.

13. Therefore, based on my education, professional experience of over 35 years, and scholarly publications, I am an expert in the relevant field of the '711 Patent and have been an expert in this field since before the '711 Patent was filed with the United States Patent and Trademark Office ("USPTO"). I am familiar with how a person having ordinary skill in the art would have understood and used the terminology found in the '711 Patent at the time of filing.

II. TASK SUMMARY AND MATERIALS REVIEWED

14. I have been asked to review the Challenged Patent and its prosecution history, to provide an understanding of the technology relevant to the Challenged Patent, to review certain prior-art references, and analyze whether or not those references disclose or teach limitations of claims from the Challenged Patent. The opinions stated in this declaration are from the perspective of a person of ordinary skill in the art (POSITA).

III. LIST OF EXHIBITS

15. In forming my opinions, I have reviewed the Challenged Patent, its prosecution history and references cited by the Examiner, the materials cited in the List of Exhibits, and the materials cited throughout my declaration.

Ex.	Description
1001	U.S. Patent No. 10,514,711 to Bar-Nahum <i>et al.</i> , "Flight Control Using Computer Vision" (the "'711 Patent")

1002	File History for U.S. Patent No. 10,514,711
1003	Declaration of Dr. William Singhose
1004	Complaint for Patent Infringement, <i>Airspace Systems, Inc. v. Dedrone Holdings, Inc.</i> , Case No. 1-24-cv-01625 (E.D. VA), September 13, 2024
1005	U.S. Patent Application Publication No. 2017/0160751 to Pierce <i>et al.</i> , “System and Method for Controlling Drone Movement for Object Tracking Using Estimated Relative Distances and Drone Sensor Inputs” (“Pierce”) filed December 5, 2016, published June 8, 2017
1006	U.S. Provisional Application No. 62/263,510 to Pierce <i>et al.</i> , “System and Method for Controlling Drone Movement for Object Tracking Using Estimated Relative Distances and Drone Sensor Inputs” (“Pierce Provisional”), filed December 4, 2015
1007	U.S. Patent Application Publication No. 2017/0161911 to Kumar <i>et al.</i> , “System and Method for Improved Distance Estimation of Detected Objects” (“Kumar”) filed December 5, 2016, published June 8, 2017
1008	U.S. Provisional Application No. 62/263,496 to Kumar <i>et al.</i> , “System and Method for Improved Distance Estimation of Detected Objects” (“Kumar Provisional”), filed December 4, 2015
1009	U.S. Patent No. 9,769,387 to Beard <i>et al.</i> , “Action Camera System for Unmanned Aerial Vehicle” (“Beard”) filed November 5, 2014, published September 19, 2017
1010	U.S. Patent Application Publication No. 2017/0059692 to Laufer <i>et al.</i> , “Mitigation of Small Unmanned Aircraft Systems Threats” (“Laufer”) filed August 26, 2016, published March 2, 2017
1011	U.S. Patent No. 8,874,283 to Cavote, “Drone for Inspection of Closed Space and Method Thereof” (“Cavote”) filed December 4, 2012, published October 28, 2014
1012	Internet Archive Wayback Machine screenshot of www.lauferradarsystems.com/technology , dated August 1, 2017

1013	Laufer Wind, Eagle Take Minimization System, Contract DE-EE0007884.0000, Final Technical Report, dated March 28, 2018
1014	U.S. Patent Application Publication No. 2003/0143524 to Lerner, “Method and System for Determining the Amount, Distribution and Confirmation of Genetic Material in a Cell” (“Lerner”) filed January 31, 2002, published July 31, 2003
1015	U.S. Provisional Application No. 62/405,972 to Bar-Nahum <i>et al.</i> , “Multimodal Sensor Empowered Awareness Engine for Target Recovery and Object Path Prediction” (“972 Provisional”), filed October 9, 2016
1016	Quadrotor Helicopter Flight Dynamics and Control: Theory and Experiment, Hoffmann <i>et al.</i> , American Institute of Aeronautics and Astronautics
1017	DJI Spreading Wings S1000+ User Manual, Version 1.4, dated January 2016
1018	Excerpts from <i>Control Theory for Humans</i> , Jagacinski and Flach, 2003
1019	Excerpts from <i>Control Systems Engineering</i> , Nise, 2015
1020	Excerpts from <i>Modern Control Systems</i> , Dorf and Bishop, 2005
1021	U.S. Patent Application Publication No. 2012/0106800 to Khan <i>at al.</i> , 3-D Model Based Method for Detecting and Classifying Vehicles in Aerial Imagery (“Khan”), filed October 28, 2010, published May 3, 2012
1022	PCT International Publication Number WO2017/123477 to Hogasten, Vehicle Based Radar Upsampling (“Hogasten”), filed January 6, 2017, published July 20, 2017, designating the U.S. and filed in English
1023	U.S. Provisional Application No. 62/277186 to Hogasten, “Vehicle Based Radar Upsampling” (“Hogasten Provisional”), filed January 11, 2016
1024	U.S. Patent Application Publication 2013/0301905 to Malecki <i>et al.</i> , “System and Method for Determining an Orientation and Position of an Object” (“Malecki”), filed April 10, 2013, published November 14, 2013

1025	U.S. Patent Application Publication 2012/0004844 to Sahasrabudhe et al., “Formation Flying Method and System” (“Sahasrabudhe”), filed June 29, 2011, published January 5, 2012
1026	Claim Listing of Challenged Claims
1027	Siemens SIMATIC VS72X Manual, 2005
1028	<i>Command Limiting in Reconfigurable Flight Control</i> , Bodson et al., Journal of Guidance, Control, and Dynamics, Vol. 21, No. 4, July-August 1998

IV. SUMMARY OF CONCLUSIONS AND GROUNDS FOR CHALLENGE

16. After reviewing the materials identified in the List of Exhibits, I have concluded that each of the Challenged Claims of the ‘711 Patent are unpatentable, based on the following grounds.

Ground	‘711 Claims	Basis for Challenge	Prior Art
1	1-3, 5, 6, 9, 10, 12, 14-16, 18-20	103	Beard, Laufer
2	4	103	Beard, Laufer, Khan
3	7, 8	103	Beard, Laufer, Kumar
4	11	103	Beard, Laufer, Malecki
5	13	103	Beard, Laufer, Sahasrabudhe

6	17	103	Beard, Laufer, Hogasten
7	1, 3, 5-9, 15, 19, 20	102	Pierce
8	1, 3, 5-9, 15, 19, 20	103	Pierce, Kumar
9	2, 12, 18	103	Pierce, Laufer
10	2, 12, 18	103	Pierce, Kumar, Laufer
11	4	103	Pierce, Khan
12	4	103	Pierce, Kumar, Khan
13	17	103	Pierce, Hogasten
14	17	103	Pierce, Kumar, Hogasten
15	1, 3, 5-9, 14-16, 19- 20	103	Pierce, Sahasrabudhe
16	1, 3, 5-9, 14-16, 19- 20	103	Pierce, Kumar, Sahasrabudhe
17	2, 12, 18	103	Pierce, Sahasrabudhe, Laufer
18	2, 12, 18	103	Pierce, Kumar, Sahasrabudhe, Laufer
19	4	103	Pierce, Sahasrabudhe, Khan
20	4	103	Pierce, Kumar, Sahasrabudhe, Khan

21	17	103	Pierce, Sahasrabudhe, Hogasten
22	17	103	Pierce, Kumar, Sahasrabudhe, Hogasten

V. LEGAL STANDARDS

A. LEVEL OF ORDINARY SKILL IN THE ART

17. When interpreting a patent, I understand that it is important to identify the relevant art pertaining to the patent-in-suit as well as the level of ordinary skill in that art at the time of the claimed invention. The “art” is the field of technology to which the patent is related.

18. I have been instructed by counsel that the person of ordinary skill in the art (“**POSITA**”) is a hypothetical person who is presumed to know the relevant prior art. I understand that the actual inventor’s skill is not determinative of the level of ordinary skill. I further understand that the factors that may be considered in determining the level of skill include: the types of problems encountered in the art; prior art solutions to those problems; rapidity with which innovations are made; sophistication of the technology; and educational level of active workers in the field. I understand that not all such factors may be present in every case, and one or more of them may predominate.

B. LEGAL STANDARD FOR CLAIM CONSTRUCTION

19. I understand that the first step in determining whether a patent claim would have been anticipated or obvious is to ascertain how a POSITA would have understood the claim terms.

20. I have been instructed by counsel on the law regarding claim construction and patent claims, and I understand that a patent may include two types of claims: independent claims and dependent claims. An independent claim stands alone and includes only the limitations it recites. A dependent claim can depend from an independent claim, or it can further depend from another dependent claim. I understand that a dependent claim includes all the limitations that it recites, in addition to all the limitations recited in the claim(s) from which it depends.

21. It is my understanding that in proceedings before the USPTO, the claims of a patent are to be construed under what is referred to as the “Phillips standard.” I understand that this means that claim terms of a patent are given the meaning the terms would have to a POSITA, in view of the description provided in the patent itself and the patent’s file history.

22. I understand that to determine how a person of ordinary skill would understand a claim term, one should look to those sources available that show what a person of skill in the art would have understood the disputed claim language to mean. I understand that, in construing a claim term, one looks primarily to the

intrinsic patent evidence, including the words of the claims themselves, the remainder of the patent, and the patent's prosecution history. I understand that extrinsic evidence, which is evidence external to the patent and the prosecution history, may also be useful in interpreting patent claims when the intrinsic evidence itself is insufficient.

23. I understand that words or terms should be given their ordinary and accepted meaning unless it appears that the inventors were using them to mean something else. In making this determination, the claims, the remainder of the patent, and the prosecution history are of paramount importance. Additionally, the patent and its prosecution history must be consulted to confirm whether the patentee has acted as its own lexicographer (i.e., provided its own special meaning to any disputed terms), or intentionally disclaimed, disavowed, or surrendered any claim scope.

24. In comparing the claims of the Challenged Patent to the prior art, I have considered the Challenged Patent and its file history in light of the understanding of a person of skill at the time of the alleged invention.

C. ANTICIPATION

25. It is my understanding that the claims of a patent are anticipated by a prior art reference if each and every element of the claim is found either explicitly or inherently in a single prior art reference or system. I understand that inherency

requires a showing that the missing descriptive matter in the claim is necessarily or implicitly present in the allegedly anticipating reference, and that it would have been so recognized by a POSITA. In addition, I understand that an enabling disclosure is a disclosure that allows a POSITA to make the invention without undue experimentation. Although anticipation typically involves the analysis of a single prior art reference, I understand that additional references may be used to show that the primary reference has enabling disclosure, to explain the meaning of a term used in the primary reference, and/or to show that a characteristic is inherent in the primary reference.

D. OBVIOUSNESS

26. I understand that the prior art may render a patent claim “obvious.” I understand that two or more prior art references (e.g., prior art articles, patents, or publications) that each disclose fewer than all elements of a patent claim may nevertheless be combined to render a patent claim obvious if the combination of the prior art collectively discloses all elements of the claim and one of ordinary skill in the art at the time would have been motivated to combine the prior art in such a way. I understand that this motivation to combine need not be explicit in any of the prior art, but may be inferred from the knowledge of one of ordinary skill in the art at the time the patent was filed. I also understand that one of ordinary skill in the art is not an automaton, but is a person having ordinary creativity. I further understand that

one or more prior art references, articles, patents or publications that disclose fewer than all of the elements of a patent claim may render a patent claim obvious if including the missing element would have been obvious to one of skill in the art (e.g., the missing element represents only an insubstantial difference over the prior art or a reconfiguration of a known system).

27. I understand that under the doctrine of obviousness, a claim may be invalid if the differences between the invention and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a POSITA to which the subject matter pertains.

28. To assess obviousness, I understand that I am to consider the scope and content of the prior art, the differences between the prior art and the claim, the level of ordinary skill in the art, and any secondary considerations to the extent they exist.

29. I understand that any evidence of secondary indicia of non-obviousness should be considered when evaluating whether a claimed invention would have been obvious to one of ordinary skill at the time of invention. These secondary indicia of non-obviousness may include, for example:

- a long felt but unmet need in the prior art that was satisfied by the claimed invention;
- commercial success of processes claimed by the patent;
- unexpected results achieved by the invention;
- praise of the invention by others skilled in the art;

- the taking of licenses under the patent by others; and
- deliberate copying of the invention.

30. I understand that there must be a nexus between any such secondary indicia and the claimed invention.

31. It is also my understanding that there are additional considerations that may be used as further guidance as to when the above factors will result in a finding that a claim is obvious, including the following:

- the claimed subject matter is simply a combination of prior art elements according to known methods to yield predictable results;
- the claimed subject matter is a simple substitution of one known element for another to obtain predictable results;
- the claimed subject matter uses known techniques to improve similar devices or methods in the same way;
- the claimed subject matter applies a known technique to a known device or method that is ready for improvement to yield predictable results;
- the claimed subject matter would have been “obvious to try” choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success;
- there is known work in one field of endeavor that may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations would have been predictable to a POSITA;
- there existed at the time of the invention a known problem for which there was an obvious solution encompassed by the patent’s claims; and

- there is some teaching, suggestion, or motivation in the prior art that would have led a POSITA to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed subject matter.

32. Finally, I understand that a claim may be deemed invalid for obviousness in light of a single prior art reference, without the need to combine references, if the elements of the claim that are not found in the reference can be supplied by the knowledge or common sense of one of ordinary skill in the relevant art.

VI. OVERVIEW OF THE CHALLENGED PATENT

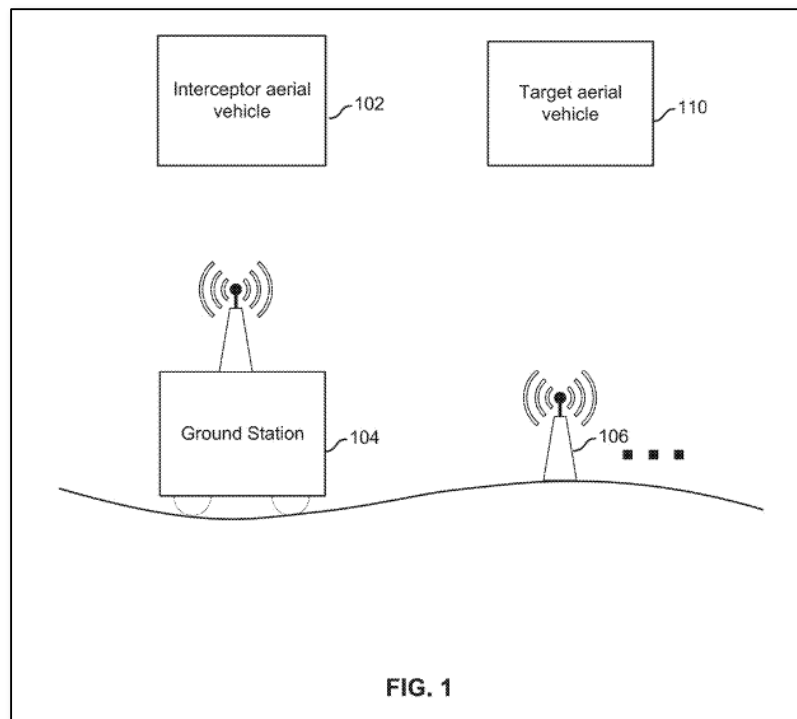
33. I have reviewed U.S. Patent No. 10,514,711 (“the ’711 Patent”), which is entitled “Flight Control Using Computer Vision.” I understand that the patent was filed on September 26, 2018, and that it was issued on December 24, 2019. The ’711 Patent purports to be a “[c]ontinuation-in-part of application No. 15/729,581, filed on October 10, 2017.” *Id.*, item (63). The ’711 Patent claims priority to provisional application No. 62/566,449, which was filed on October 1, 2017, and provisional application No. 62/405,972 (the “’972 Provisional”), which was filed on October 9, 2016. *Id.*, item (60).

A. THE SUBJECT MATTER OF THE CHALLENGED PATENT

34. The ’711 Patent generally relates to the “flight control operation of a reference aerial vehicle.” [EX1001, ’711 Patent, Abstract]. The ’711 Patent explains that unmanned aerial vehicles, such as drones, are typically “controlled using flight

controllers manually operated by a human user,” which “requires the human user to have a visual sight of the aerial vehicle and/or an image captured by the aerial vehicle.” *Id.*, 1:27-31. However, according to the ’711 Patent, “this may be challenging in circumstances where a trained human user is unavailable or unable to react quickly enough to perform a desired flight maneuver,” and “if communication between the aerial vehicle and the flight controller is lost or becomes unreliable, the aerial vehicle may be unable to complete a desired flight operation.” *Id.*, 1:31-37. Such issues can be prevalent when using an unmanned aerial vehicle to track another vehicle. Accordingly, the ’711 Patent purported to invent an aerial vehicle that was “able to autonomously track and fly to” a target “using machine vision based on images captured by a camera of the” aerial vehicle. *Id.*, 3:27-30.

35. Figure 1 of the ’711 Patent, reproduced below, shows an example system where interceptor aerial vehicle 102 tracks target aerial vehicle 110 to capture it.



[EX1001, '711 Patent, Fig. 1]

36. “Interceptor aerial vehicle 102 follows and/or navigates to a location associated with the target aerial vehicle (e.g., target aerial vehicle 110).” [EX1001, '711 Patent, 3:52-54]. A “detected location of target aerial vehicle 110 may be provided to interceptor aerial vehicle 102 to allow it to automatically and autonomously fly towards the direction of the detected location,” but “once interceptor aerial vehicle 102 is near target aerial vehicle 110, the location data from ground-based sensors may not be accurate or updated fast enough for interceptor aerial vehicle 102 to get close enough to the moving target aerial vehicle 110 to reliably deploy a capture mechanism.” *Id.*, 4:14-26. Interceptor aerial vehicle 102 is therefore provided with “one or more computer vision sensors and a processor that

can be used to dynamically detect the unauthorized aerial vehicle and autonomously navigate interceptor aerial vehicle 102 towards the target aerial vehicle.” *Id.*, 4:22-26. For example, the interceptor aerial vehicle includes a camera system to “visually detect a UAV” or “object” and “provide visual data (e.g., pixel data)” to a machine learning model, which can “determine whether the object is a UAV or not a UAV,” as well as “identify specific UAV models.” *Id.*, 5:21-23, 7:16-52, 8:48-57.

37. The ’711 Patent explains that a “relative location of the target is detected using the captured image,” and this location is used to control the interceptor aerial vehicle. [EX1001, ’711 Patent, 16:11-13, 16:41-55, 18:44-64]. For example, after the target is detected, “the relative location is specified by an azimuth angle and an altitude angle” and “[a] distance value to the target and/or desired speed/acceleration may also be specified for the relative location.” *Id.*, 16:37-44. The patent further notes that “[i]n some embodiments, the relative location is specific by a three-dimensional vector determined based on the detected image of the target” and “[f]or example, the three-dimensional vector is specified by values corresponding to three axial values” such as the “x-axis, y-axis, and z-axis.” *Id.*, 16:44-48, 18:44-49.

38. The ’711 Patent also explains that control of the interceptor aerial vehicle can include “modifying the speed and/or acceleration associated with the vector.” [EX1001, ’711 Patent, 19:4-8]. For example, the patent states that a “speed

and/or acceleration factor is multiplied by one or more scalar values that change in magnitude based on a directional deviation of the vector from a current direction of movement (e.g., deviation of the target in the image from the center of the image representing the current heading direction of the interceptor aerial vehicle).” *Id.*, 19:14-20.

B. THE CHALLENGED CLAIMS OF THE '711 PATENT

39. The Challenged Claims of the '711 Patent are set forth below.

#	Limitation
1[a]	A method of performing a flight control operation of a reference aerial vehicle, comprising:
1[b]	receiving an image captured by an image sensor of the reference aerial vehicle;
1[c]	detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;
1[d]	determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and
1[e]	performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.
3	The method of claim 1, wherein performing the flight control operation includes one or more of the following: turning the reference aerial vehicle

	towards the target, adjusting a speed of the reference aerial vehicle, or engaging a mechanism to capture the target.
4	The method of claim 1, wherein detecting the target in the image includes identifying a model type of the target.
5	The method of claim 1, wherein detecting the target in the image includes identifying a bounding box outlining a portion of the image that includes detected features of the target.
6	The method of claim 5, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on an area of the bounding box of the target within the image.
7	The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on a size of the target within the image and a physical size corresponding to an identified type for the target.
8	The method of claim 7 wherein performing the flight control operation includes determining a speed adjustment factor based on the determined distance to the target.
9	The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining a direction of the target with respect to the reference aerial vehicle.
10	The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining an azimuth angle and an altitude angle to the target from the reference aerial vehicle.
11	The method of claim 1, wherein determining the three-dimensional relative location of the target includes converting a two-dimensional vector to a three-dimensional vector representing the three-dimensional relative location.
12	The method of claim 1, further comprising: receiving a geographical location associated with the target detected at least in part using a ground-based sensor; autonomously navigating the reference aerial vehicle towards the

	received geographical location; and determining to allow image-based navigation.
13	The method of claim 1, wherein the speed adjustment factor is greater for a smaller magnitude of deviation as compared to for a greater magnitude of deviation.
14	The method of claim 1, wherein performing the flight control operation includes scaling a speed adjustment factor to smooth and limit a rate of change of a speed of the reference aerial vehicle.
15	The method of claim 1, wherein performing the flight control operation includes determining a direction adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.
16	The method of claim 15, wherein performing the flight control operation includes scaling the direction adjustment factor to smooth and limit a rate of change of a direction of the reference aerial vehicle.
17	The method of claim 1, wherein the distance to the target is determined based at least in part using a radar.
18	The method of claim 1, wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location.
19[a]	A reference aerial vehicle, comprising:
19[b]	an image sensor configured to capture an image;
19[c]	a processor configured to: detect a target in the image; and
19[d]	[the processor configured to:] determine a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image; and
19[e]	a flight controller configured to perform a flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein the flight controller is configured to perform

	the flight control operation including by being configured to determine a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.
20[a]	A computer program product for performing a flight control operation of a reference aerial vehicle, the computer program product being embodied in a non-transitory computer readable storage medium and comprising computer instructions for:
20[b]	receiving an image captured by an image sensor of the reference aerial vehicle;
20[c]	detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;
20[d]	determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and
20[e]	performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

C. PROSECUTION HISTORY OF THE '199 PATENT

40. The application leading to the '711 Patent was filed on September 26, 2018, as U.S. Application 16/142,452 (the "'452 Application"). [EX1001, '711 Patent, cover page, items (21), (22)]. On its face, the '711 Patent purports to be a "[c]ontinuation-in-part of application No. 15/729,581, filed on October 10, 2017." *Id.*, item (63). The '711 Patent claims priority to provisional application No.

62/566,449 (the “449 Provisional,” EX1016), which was filed on October 1, 2017, and provisional application No. 62/405,972 (the “972 Provisional,” EX1015), which was filed on October 9, 2016. *Id.*, item (60).

41. Prosecution of the ’452 Application involved two office actions and two applicant responses. EX1002, 104-115, 158-163, 165-176, 215-221. After receiving a first non-final office action, the applicant responded by amending independent Claims 1, 19, and 20. *Id.*, 104-115, 158-163. The Office then issued a final office action. *Id.*, 165-176.

42. In response, the applicant again amended Independent Claims 1, 19, and 20, deleting subject matter but also adding claim elements “based on [] allowable claim 12.” EX1002, 215-221. The added elements to claim 1 are shown below:

performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

43. In response, the Office issued a notice of allowance. EX1002, 222-229. The Office stated “[n]one of the prior art of record teaches or fairly suggests that image processing method that [sic] performing the flight control operation of a reference aerial vehicle based on the three-dimensional relative location of the target with respect to the reference aerial vehicle which is based on the image, wherein performing the flight control operation includes determining a speed adjustment

factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle, and together with combination of other claims elements” of the independent claims. *Id.*, 227.

D. PRIORITY DATE FOR THE CHALLENGED CLAIMS

44. As I noted above, the ’711 Patent purports to be a “[c]ontinuation-in-part of application No. 15/729,581, filed on October 10, 2017.” *Id.*, item (63). The ’711 Patent claims priority to provisional application No. 62/566,449, which was filed on October 1, 2017, and provisional application No. 62/405,972 (the “’972 Provisional”), which was filed on October 9, 2016. *Id.*, item (60).

45. In my opinion, the Challenged Claims should not be afforded priority to the October 9, 2016 filing date of ’972 Provisional.¹ [EX1001, ’711 Patent, cover page, item (60)]. Independent Claim 1 recites the following claim elements:

¹ I address support for the ’972 Provisional and assume that the earliest claimed priority date to which the ’711 Patent is entitled for purposes of this proceeding is October 1, 2017, the filing date of the ’449 Provisional. However, I do not concede that the Challenged Claims are actually entitled to this priority date or the October 10, 2017 filing date of U.S. Patent Application No. 15/729,581, or that the

1[d]: determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and

1[e]: performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle,

1[f]: wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

[EX1001, '711 Patent, Claim 1]; [EX1026, Claim Listing].

46. Independent Claims 19 and 20 include similar elements. The '972 Provisional does not provide adequate written description for at least these claim elements. Thus, Claim 1, its challenged dependent claims, and Claims 19 and 20 are not entitled to the '972 Provisional's filing date.

47. The '972 Provisional describes “predict[ing] the location of a target in the [video] frame” (EX1015, 15), “[o]nce a sensor package has detected an anomaly in the airspace, its location is communicated to the appropriate interceptor drone” (*Id.*, 17), and other general references to “location.” EX1015, 5, 14-18, 28-30. The '972 Provisional also describes that “a deep neural network [is] trained not only to identify the presence of a drone but also the position of that drone in the camera

Challenged Claims have adequate written description support within the '711 patent itself.

frame in real time” and that an interceptor drone “position[][s] itself in a predefined relative position to the target.” EX1015, 13, 17; *see also id.*, 16, 29. But none of these, or any other, portions of the ’972 Provisional describe “determining a ***three-dimensional relative location of the target with respect to the reference aerial vehicle,***” that such a determination is made “***based on the image,***” or that the determination “include[][es] by ***determining a distance to the target based at least in part on a size of the target detected within the image***” (element 1[d]) (emphasis added). *Id.*

48. The ’972 Provisional describes “trajectory estimation engines have a dynamic vector update rate to control the flight path,” where “vectors continuously correct the flight path, effectively controlling the trajectory of the interdiction drone,” (EX1015, 15), a “control network” and “instructions from a control server” (*Id.*, 17), “camera control signals” (*Id.*, 19), and other generalized references to “control.” *See also* EX1015, 10, 15, 17, 19. But neither these, or any other, portions of the ’972 Provisional describe “performing the ***flight control operation based on the three-dimensional relative location of the target*** with respect to the reference aerial vehicle” (element [1e]) (emphasis added). *Id.* And the ’972 Provisional is similarly silent as to any sort of control that “includes ***determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the***

reference aerial vehicle” (element 1[f])(emphasis added). Indeed, the ’972 Provisional does not describe any “speed adjustment factor,” let alone any “factor” that is “based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.” *See generally*, EX1015. The ’972 Provisional’s only reference to “speed” is in the context of computational speed (EX1015, 4, 10, 11, 13, 14) or general references drones that travel at a “high-speed” (*Id.*, 9, 15).

49. The ’972 Provisional thus does not provide written description support for elements 1[d], 1[e], or 1[f]. Claim 1, as well as its challenged dependent claims, are therefore not entitled to the ’972 Provisional’s October 9, 2016 filing date. Because independent Claims 19 and 20 include similar elements to Claim 1, they also are not entitled to this October 9, 2016 date.

VII. LEVEL OF ORDINARY SKILL IN THE ART

50. I understand that issues relating to the unpatentability of the ’711 patent must be judged from the perspective of a person of ordinary skill in the relevant art, as I discuss below. I have been asked to define the level of a “person of ordinary skill in the art” or “POSITA” at the time the alleged invention as claimed was made. In deciding the level of ordinary skill, I have considered at least the following factors, which I have been informed are relevant to the determination of ordinary skill in the art: levels of education and experience of persons working in the field;

types of problems encountered in the art; prior art solutions to these problems; rapidity with which innovations are made; and sophistication of the technology.

51. In addition to the commonly-used factors above, I have also considered when, and if, aspects of the claimed technology appear within the engineering curriculum. For example, in my opinion, the Challenged Claims related to subject matter that is normally taught in the junior or senior year of mechanical, aerospace, and electrical engineering.

52. In my opinion, a POSITA would have had either (1) at least a Bachelor of Science in Mechanical Engineering, Electrical Engineering, Aerospace engineering, or an equivalent field, as well as at least 2 years of academic or industry experience in the aerospace or avionics fields, or (2) at least four years of experience in any of the above industries.

53. I arrived at this definition by considering the various factors listed above.

54. I was at least a POSITA as of the priority date of the '711 patent because I received a B.S. in Mechanical Engineering in 1990, an M.S. in Mechanical Engineering from Stanford University in 1992, and a Ph.D. in Mechanical Engineering from MIT in 1997. I also have a significant amount of experience in the subject matter of the '711 patent, as demonstrated by the Introduction and Qualifications section herein and my attached CV.

VIII. CLAIM CONSTRUCTION

55. I have been informed by counsel for Petitioner that the challenged claims of the '711 Patent are to be given their ordinary and customary meaning as understood by one of ordinary skill in the art at the time of the invention in light of the specification and the prosecution history pertaining to the patent. I also understand, however, that a claim term will not receive its ordinary meaning if the patentee acted as his own lexicographer and clearly set forth a definition of the claim term in the specification. In this case, the claim term will receive the definition set forth in the patent. I have followed these principles in my analysis set forth in this Declaration.

56. To the extent the Applicant has expressly defined a claim term in the specification, I have used that definition. With respect to claim terms for which the applicant has not provided an express definition, I have applied the ordinary and customary meaning of the claim terms in light of the specification and the prosecution history in my analysis of the claims and the prior art herein.

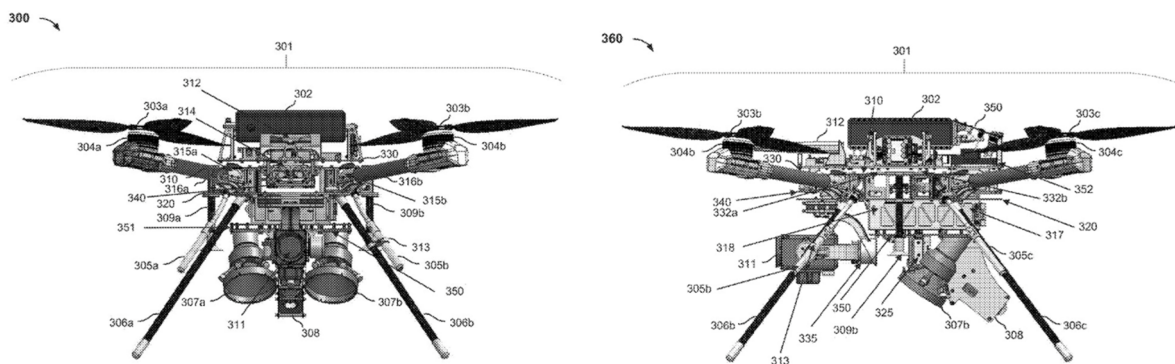
IX. TECHNOLOGY BACKGROUND AND STATE OF THE ART

57. Three main technologies described by the '711 patent related to the claims: i) autonomous flight control, ii) vision systems, and iii) machine learning. Relevant aspects of these three technologies are reviewed in the following subsections.

58. To illustrate relevant background, I will use the example unmanned aerial vehicle (UAV) shown in Figures 3A and 3B of the '711 patent. These two figures have been reproduced below for convenience.

A. AUTONOMOUS FLIGHT CONTROL

59. UAVs can be operated manually by a remote operator or flown by an autonomous control system. An autonomous control system requires sensing systems that are able to accurately measure the vehicle's states (usually positions and velocities.) The control systems use the state measurements, as well as desired vehicle states, to adjust the speed of the aircraft such that the actual vehicle states converge toward the desired states. For the case of the UAV shown below (from Figures 3A and 3B of the '711 patent), that would require adjusting the rotational speeds of the four (4) rotors.



[EX1001, '711 Patent, Figs. 3A, 3B]

60. Autonomous flight control is generally accomplished with feedback control that attempts to drive the error between the actual and desired states to zero, so the system is driven to the desired state. The desired state of a system is often referred to as the “reference” state and the actual state is often called the “output” state because it is the output of the system being controlled.

61. Such feedback control can be accomplished with three main steps: i) sensors measure the state of the UAV, ii) the sensor measurements are compared to the desired state of the UAV, and iii) the deviation (error) between the measured and desired states is used to issue corrective control signals to the UAV (such as adjusting the speed of the rotors.) Generally, as the magnitude of the state error increases, the larger the corrective control action becomes. However, UAVs become unstable if they are commanded to change state too quickly or outside of operational limits; therefore, feedback control systems on UAVs generally limit the speed of corrective actions, and can limit the corrective actions themselves. Such limits on the corrective actions are often referred to as rate limiting and can also be used to avoid saturation of the system’s actuators.

62. Feedback control, like that claimed in the ‘711 patent, was well-established engineering technology. For example, the textbook *Control Theory for Humans* (EX1018)² shows a simple feedback control block diagram in its FIG. 2.4,

² *Control Theory for Humans*, Jagacinski and Flach, 2003.

which is reproduced below. The textbook provides the following textual description of feedback control:

“This capacity to respond to the relation between reference input and outputs is called *feedback control*...The output in this system is fed back and subtracted (hence negative) from the input. The attender then operates on the difference between one set of inputs and the output. This difference is called the *error* and the inputs that are compared to the output are generally referred to as the *reference*, or *command*, *inputs*.”

[Control Theory for Humans, EX1018, page 5 (native page 10).]

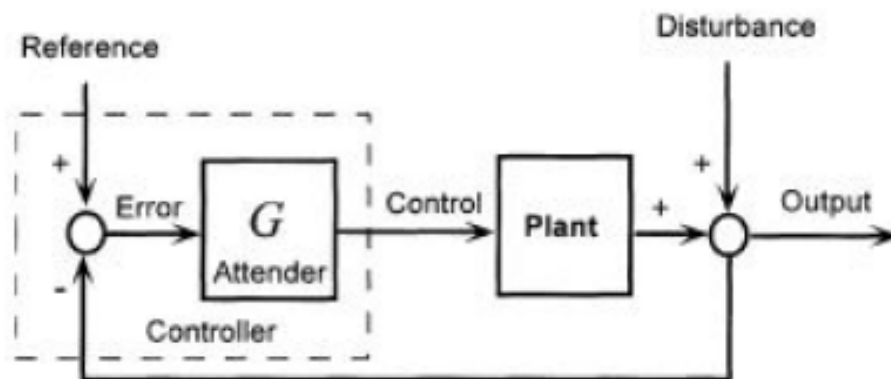


FIG. 2.4. The forward loop normally includes both the control function (G) and the dynamics of the controlled system or plant. The plant typically represents the physical constraints on action (e.g., limb or vehicle dynamics).

Feedback Control Loop Shown in FIG. 2.4 of Control Theory for Humans

(Control Theory for Humans, EX1018).

63. The textbook explains that the “Plant” in the above block diagram is the “controlled system”. [Control Theory for Humans, EX1018, page 6 (native page 14).] For example, it could be an aerial vehicle and the feedback control system could be an autopilot. [See e.g. “Control system designers can anticipate the changing dynamic properties and can program adjustments to the autopilot so that it behaves as a different servomechanism (e.g. different gain) depending on its current attitude.” [Control Theory for Humans, EX1018, page 7 (native page 15).]]. In such a case, the aircraft would often have a desired three-dimensional location (the “reference”). The sensors would measure the *output* states of the aircraft. Then, the feedback controller would calculate the deviation (error between the reference and the output states) and the magnitude of that error would be used to adjust the speed of the aircraft.

64. Another well-known textbook also uses a simple block diagram and textual description of feedback control. Figure 1.5(b) from *Control Systems Engineering* (EX1019)³ is reproduced below for convenience. This diagram shows

³ *Control Systems Engineering*, Nise, 2004.

how the output (controlled variable) is compared against (subtracted from) the reference to generate an error (deviation) signal.

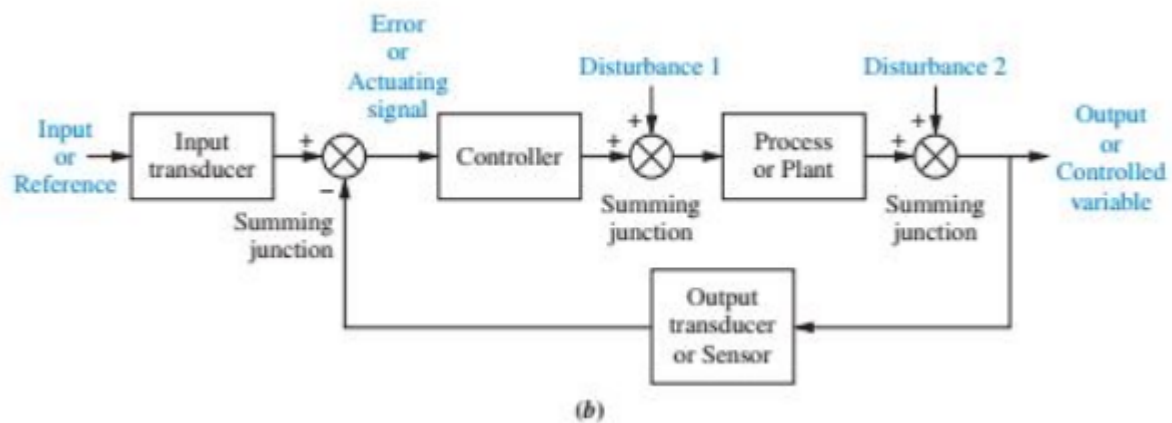


Figure 1.5(b) from Control Systems Engineering.

(Control Systems Engineering, EX1019, page 5 (native page 7))

65. The very first case study considered in this textbook is control of the azimuth angle of an antenna. An azimuth angle can also be referred to as a bearing or heading angle. The diagram showing the antenna and control components in Figure 1.8(b) is reproduced below.

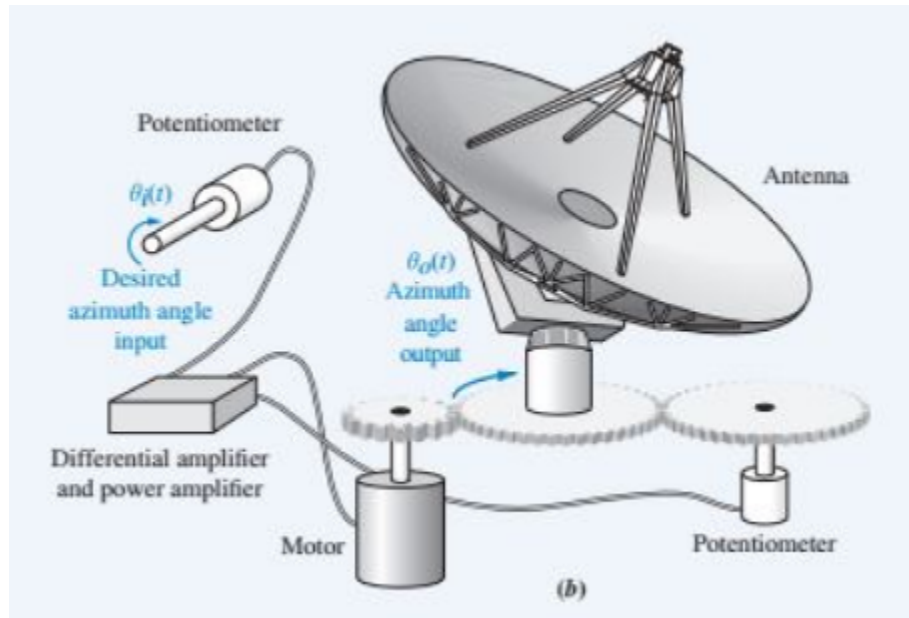


Figure 1.8(b) from Control Systems Engineering Illustrating Azimuth Control of an Antenna.

(Control Systems Engineering, EX1019, page 7 (native page 12))

66. The azimuth angle of the antenna is described as being adjusted by turning a motor that is geared to the base of the antenna. The resulting angular output motion of the antenna is measured with a potentiometer (angle sensor). As shown below in Figure 1.8(d), the feedback control system determines the amount of power sent to the motor based on the deviation between the angular input (reference) and the angular output of the antenna.

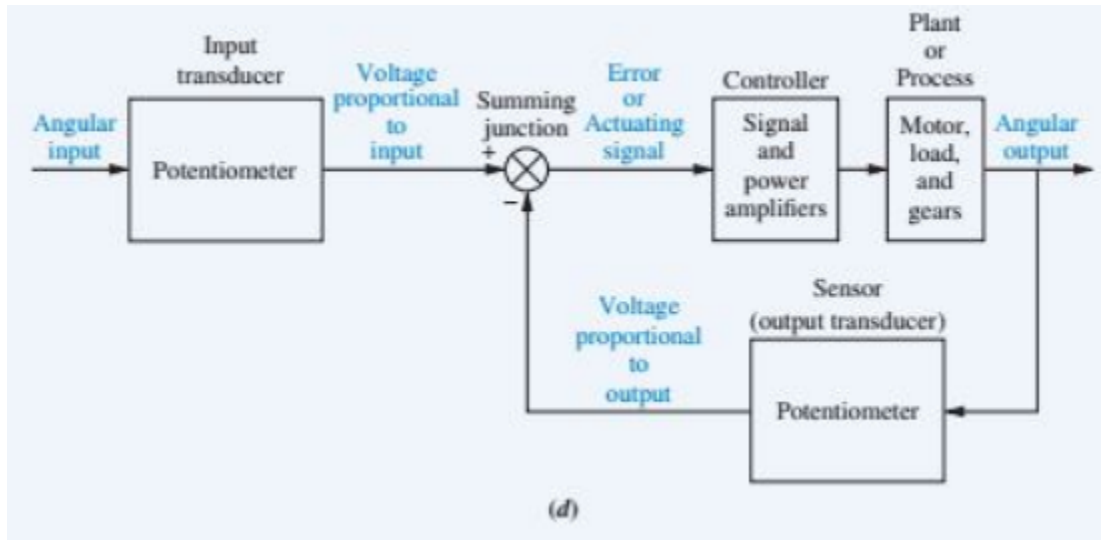
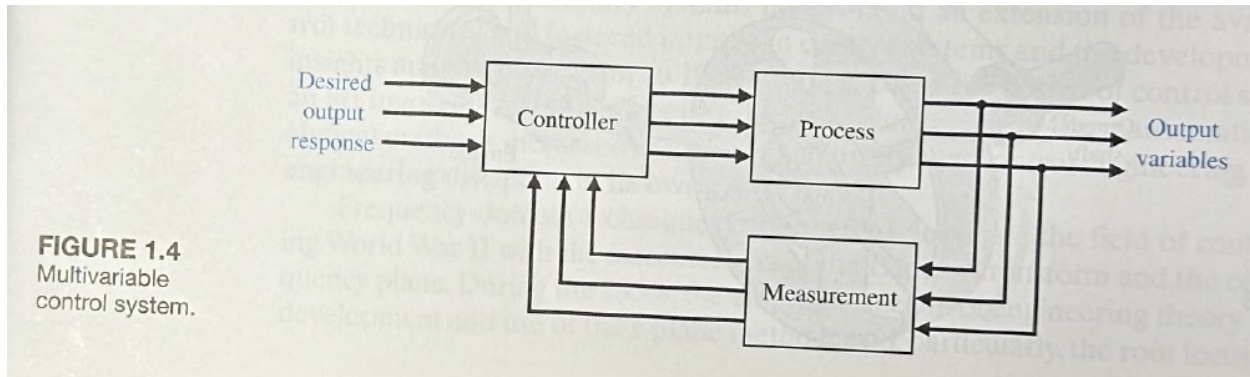


Figure 1.8(d) from Control Systems Engineering.

(Control Systems Engineering, EX1019, page 8 (native page 13))

67. While many of the basic block diagrams used to teach feedback control show a single “reference” and “output” line going into and out of the operational blocks, it was well known that multiple variables (such as X, Y, and Z positions, or azimuth, attitude, and distance) could be controlled with feedback control. One textbook that explicitly shows multiple lines for the reference and output variables is *Modern Control Systems* (EX1020)⁴. Figure 1.4 from this textbook is reproduced below to show such multi-variable control.

⁴ *Modern Control Systems*, Dorf and Bishop, 2005.

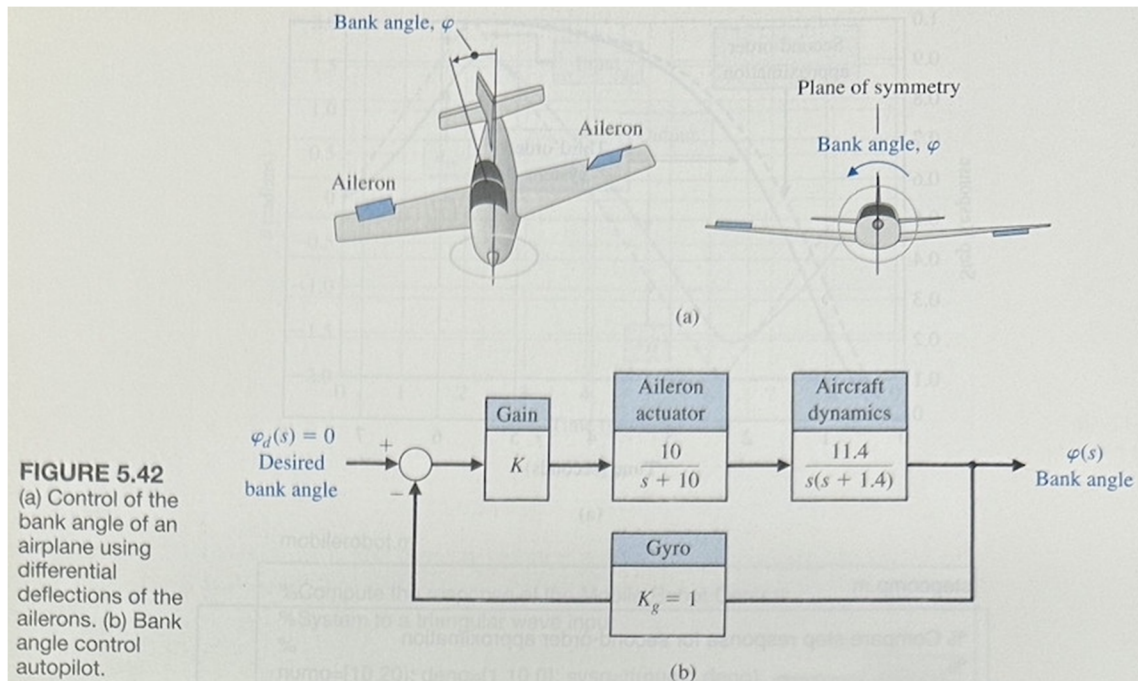


Modern Control Systems Figure 1.4 Showing Multi-Variable Feedback Control.

(Modern Control Systems, EX1020, page 3 (native page 3))

68. Feedback control systems can use any number of methods to convert the error signal into a control signal. One such method is to issue a corrective control signal that is proportional (P) to the magnitude of the error. When the control system drives the system very close to the desired state, then the corrective control action may decrease toward zero so that the actual system approaches the desired position smoothly.

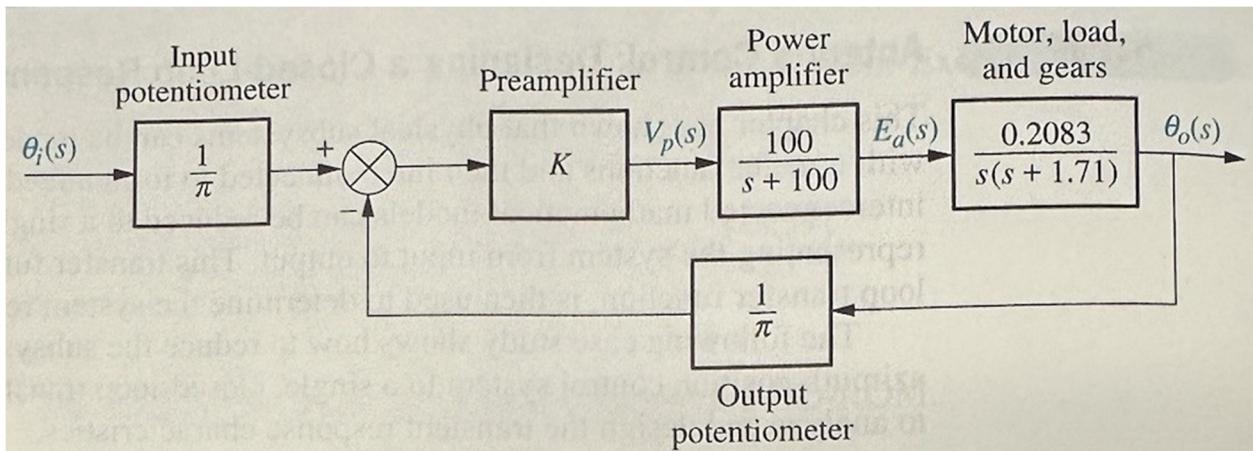
69. Proportional control was well known. For example, a proportional control action for aircraft is shown in Figure 5.42 of *Modern Control Systems*, which is reproduced below for convenience. Note that the deviation (Desired bank angle - Bank angle) is multiplied by the proportionality gain K in order to generate a control signal for the aircraft's aileron.



Modern Control Systems Figure 5.42 Showing Proportional Feedback Control of an Aircraft Bank Angle.

(Modern Control Systems, EX1020, page 4 (native page 288))

70. *Modern Control Systems* shows a proportional feedback control solution in Figure 5.34, which is reproduced below for convenience. Here again, the output is subtracted from the input to create an error signal. That deviation signal is multiplied by the preamplifier proportionality constant K to create a corrective control signal that is sent to the power amplifiers and then onto the azimuth-slewing motor.



Modern Control Systems Figure 5.34 Showing Proportional Feedback Control
the Azimuth Angle of an Antenna.

(Modern Control Systems, EX1020, page 5 (native page 294))

B. VISION SYSTEMS

71. UAVs are equipped with a range of sensors to provide the flight control systems with the measurements and information necessary to safely complete their missions. These sensors can include Inertial Measurement Units (IMUs), GPS, Pitot tubes, altitude sensors, radar, as well as other advanced sensor systems.

72. One very common sensor used on drones are vision sensors. In fact, one of the primary use cases for drones is aerial photography. In addition to simply acquiring image data, vision systems have had the ability, for decades, to analyze the image data to locate targets within the data and to extract information about those targets.

73. As an example, consider the SIMATIC vision sensor sold by Siemens approximately 20 years ago. The capabilities of that vision sensor are described in

its manual. Siemens SIMATIC VS 72X / SIMATIC Spectation Manual (“SIMATIC” or “the SIMATIC Manual”) (EX1027) is the product manual for the SIMATIC VS 720 series vision sensors. An image showing one of the SIMATIC vision sensors is shown below in SIMATIC Figure 1-1.



Figure 1-1: Member of the VS 720 Series: the SIMATIC VS 724 Vision Sensor

EX1027, p. 14 (native page 1-4)

74. The SIMATIC manual discloses numerous image-processing features available in the Spectation firmware that comes with the vision sensor [SIMATIC, EX1027, 54], including (1) detecting the position or location of “parts to be inspected” (i.e. targets) [SIMATIC, EX1027, 6, 112-114 (“Dealing with Part Movement”)]; (2) detecting the presence or absence of visual features “that make

the part being inspected different from the background” [SIMATIC, EX1027, 64, 61, 115 (“Presence/Absence Inspections”)]; and (3) recognizing the shape of parts and finding their edges, such as through “blob” detection [SIMATIC, 91-93 (“Blob Tools”)] or “fuzzy logic to detect gradient changes between pixels” [SIMATIC, 106 (“Segmentation SoftSensor”).]

75. The SIMATIC manual is a printed publication that was publicly accessible in the United States at least by June 1, 2005. I understand the SIMATIC manual was publicly accessible by June 1, 2005 based at least on the SIMATIC manual itself (e.g. the language “Edition 04/2005” on page 1) and on my own personal experience. Specifically, I received a number of Siemens SIMATIC VS 720 series cameras during the course of research projects starting in 2004, and was provided with a copy of the SIMATIC manual at least by June 1, 2005. The SIMATIC manual does not contain any confidentiality requirement and was not distributed under confidentiality agreements. In my experience and personal knowledge, the same manual would have been distributed to anyone who had purchased a Siemens SIMATIC VS 720 series camera, which, to my personal knowledge were on-sale in the United States before June 1, 2005.

C. MACHINE LEARNING

76. Machine learning is a phrase that refers to a large variety of methods that allow computers to improve data without being explicitly taught how to make

improvements. Machine learning generally uses algorithms that analyze large datasets to identify patterns. The patterns can then be used to predict relationships in other datasets that share similarities in structure and content. Neural networks are a specific type of machine learning that use a large number of mathematical relationships between input and output variables. The networks are trained on a sample dataset to adjust the values within the mathematical relationships. Once the network is trained, then its mathematical relationships can be used on new input data that is not within the training data to predict appropriate output data. Using machine learning to identify objects in images was well known. For example, the Siemens SIMATIC VS 720 manual (EX1027) describes how to “train” a camera to detect targets in the image data. The target is acquired in a Region of Interest (ROI). [SIMATIC VS 720 manual, EX1027, pages 86, 90, 122.].

X. OVERVIEW OF THE PRIOR ART

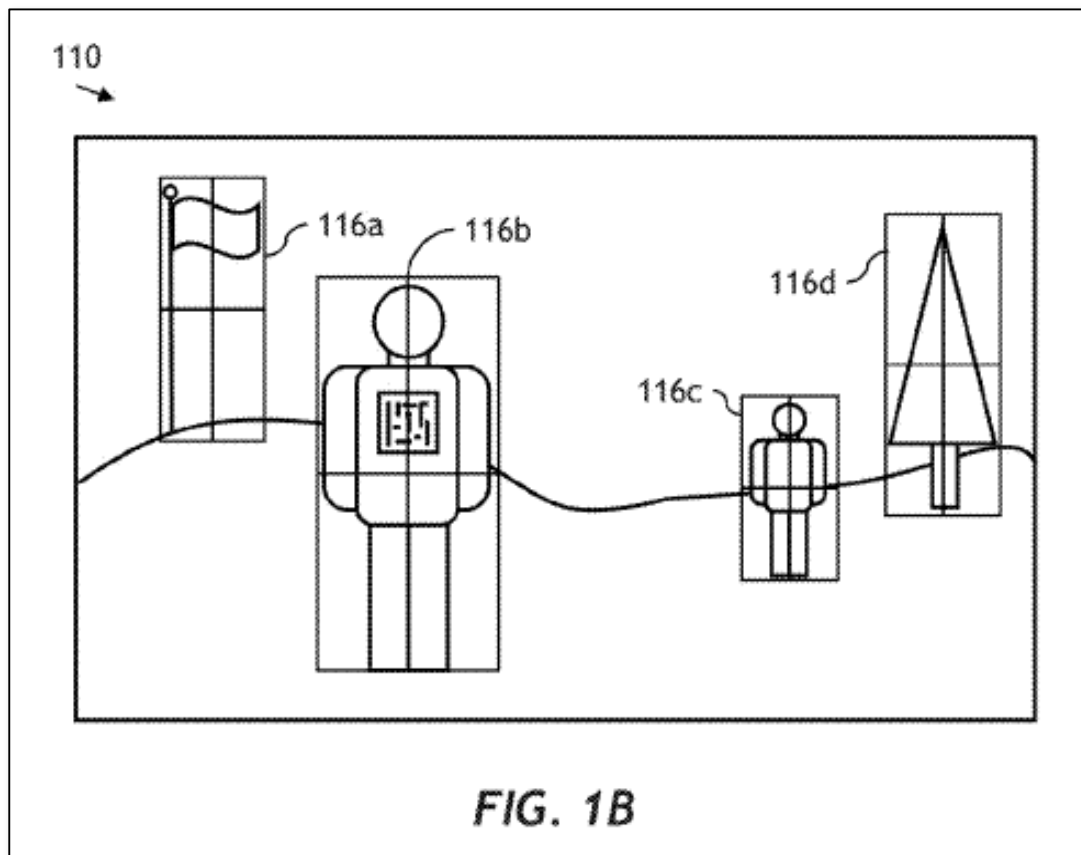
A. BEARD (EX1009)

1. Status of Beard

77. Beard is U.S. Patent No. 9,769,387, was filed on November 5, 2014, and issued on September 19, 2017. EX1009. Beard is thus prior art to the '711 Patent as of its November 5, 2014 filing date even if the '711 Patent is found entitled to the '972 Provisional's October 9, 2016 priority date (which it is not). And because the '711 Patent is entitled to a priority date no earlier than October 1, 2017, Beard is further prior art as of its September 19, 2017 issuance date.

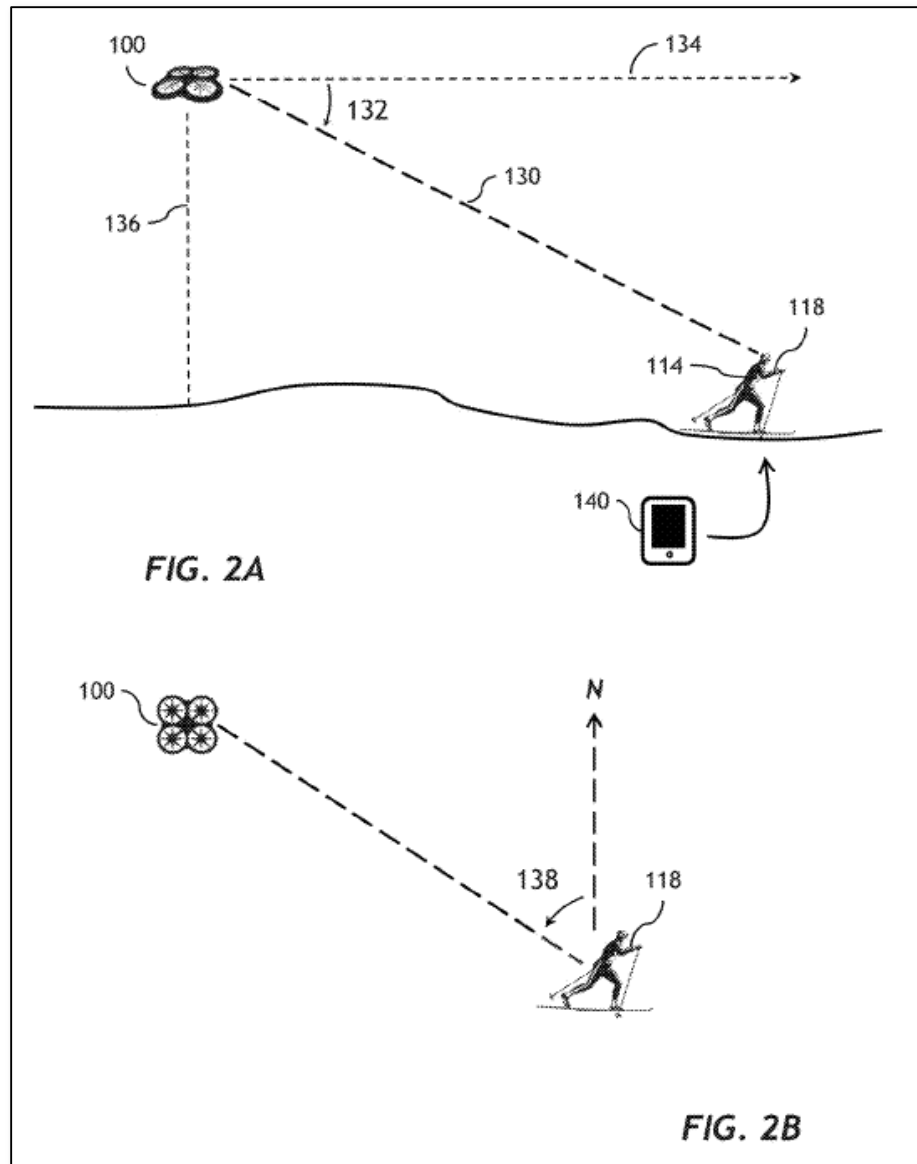
2. Overview of Beard

78. Like the '711 Patent, Beard describes a flight control system where an “unmanned aerial vehicle (UAV) selects a target based on a reference image captured by an onboard camera” and “image processing determines a desired orientation of the target to the UAV, by which the UAV can track the target and provide streaming video images from the desired orientation.” EX1009, Abstract, 1:19-23, 2:19-22, 3:9-39, 9:9-30. Beard’s system analyzes input images to “identify potential target objects...via bounding boxes” within the images. *Id.*, 3:9-4:21, 7:13-53, Figs. 1A-1F, 5.



EX1009, Fig. 1B

79. Moreover, Beard describes that it determines a relative location of the target to the drone by determining “at least one of a second distance [e.g., 130] between the UAV 100 and the at least one target 118, a second angle of elevation 132 between the UAV 100 and the at least one target 118, and a second bearing [e.g., 138] between the UAV 100 and the at least one target 118;” this distance and these angles are shown below in Figures 2A and 2B. EX1009, 3:9-39, 4:17-39, 5:30-6:3, 7:54-8:66, Figs. 2A, 2B.



EX1009, Figs. 2A, 2B

80. Beard then effectuates flight control based on this relative location, maintaining a desired orientation of the drone to the target by controlling rotor speed of the drone. *Id.*, 2:19-22, 9:9-30. Beard further explains that its drone body speed is adjusted to maintain the orientation. *Id.*, 2:33-38, 3:9-30, 4:60-63, 6:4-7:12.

81. Beard is analogous art to the '711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.*, how to detect targets from captured images and control an aircraft to track the targets). [EX1001, '711 Patent, Abstract, 3:27-45; EX1009, Abstract, 3:9-39].

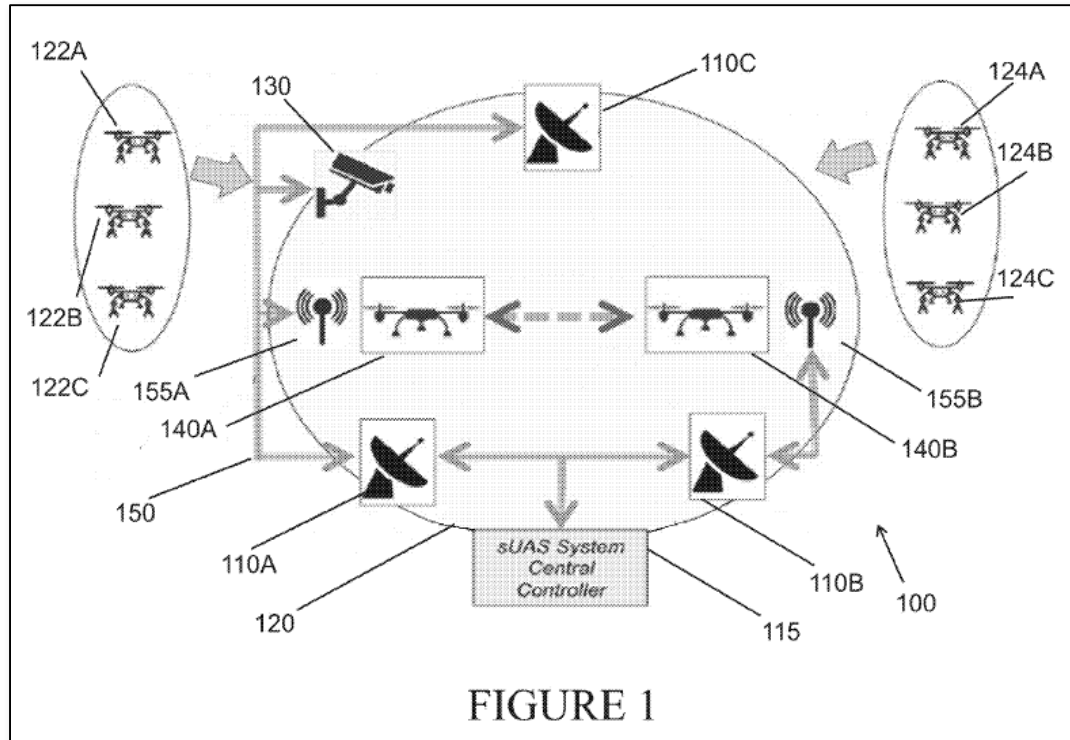
B. LAUFER (EX1010)

1. Status of Laufer

82. Laufer is U.S. Patent Application Publication No. 2017/0059692, was filed on August 26, 2016, and published on March 2, 2017. EX1010. Laufer is prior art to the '711 patent as of its August 26, 2016 filing date and as of its March 2, 2017 publication date.

2. Overview of the Disclosure of Laufer

83. Laufer teaches “systems and methods for drone interdiction.” EX1010, Abstract. The system includes “doppler radars 110A-110C” distributed throughout an area, which define a “surveillance zone 120” and are used along with fixed cameras to discriminate between targets in the zone that present a threat, such as drones 122A-122C and 124A-124C, and targets that do not present a threat, such as birds. *Id.*, 0022-0024, Fig. 1. The surveillance zone further includes interceptor aircraft 140A-140B, which can be quadcopter drones. *Id.*, 0024.



EX1012, Fig. 1

84. In operation, the real time tracking of targets is provided, where a drone identification module can use “video or image data from fixed camera 130...and/or data from radars 110A-110C to determine whether a detected target exhibits characteristics that would indicate it was a threat.” EX1010, 0031. “Machine learning algorithms, for example, Deep Convolutional Neural Network architectures such as those available from OpenCV or TensorFlow can be used” to “determine whether a target is a drone, and if the target is a drone, whether it is a threat.” *Id.*

85. Laufer further explains that its central controller 115 receives “signals reflected from an object and detected by” doppler radar 110A-110C to “generate a radar target state estimate 415” that includes “information about a detected object’s

position, velocity, and/or acceleration,” and that a radar stage estimate 415 is then used as part of a radar target model. EX1010, ¶¶0022, 0038-0039, Figs. 1, 4. The radar target model is used by the central controller 115 to determine an interception location 425, which is a location where an interceptor aircraft and a target will intercept. *Id.* The interceptor aircraft is then caused to “fly to interception location 425” using “autopilot aircraft commands” generated based on the interception location 425, *Id.*, ¶¶0022, 0038-0040, Figs. 1, 4. And then, when a target drone is “within a range of a camera mounted to the interceptor aircraft...the interceptor aircraft can be piloted according to the image or video data acquired by the on-board camera,” where “aircraft control commands [] based on” a “video target model” are calculated using a “video target state estimate” generated from video captured by the interceptor drone. *Id.*, 0042-0044.

86. Laufer is analogous art to the '711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.* how to detect targets from captured images and control an aircraft to track the targets). [EX1001, '711 Patent, Abstract, 3:27-45; EX1010, ¶¶0006, 0022-0031, 0038-0044].

C. KHAN (EX1021)**1. Status of Khan**

87. Khan is U.S. Patent Application Publication No. 2012/0106800, was filed on October 28, 2010, and published on May 3, 2012. EX1021. Khan qualifies as prior art as of its October 28, 2010 filing date and its May 3, 2012 publication date.

2. Overview of Khan

88. Khan teaches a computer vision system used by UAVs that detects vehicle target objects in captured images and classifies them by “vehicle model type.” EX1021, 0003-0004, 0009-0015, 0025, 0044-0045, 0048-0049, 0053-0062, Fig. 6.

89. Khan is analogous art to the '711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.* how to detect targets from captured images and control an aircraft to track the targets). [EX1001, '711 Patent, Abstract, 3:27-45; EX1021, ¶¶0003-0004, 0009-0015, 0025, 0044-0045, 0048-0049, 0053-0062, Fig. 6].

D. MALECKI (EX1024)**1. Status of Malecki**

90. Malecki is U.S. Patent Application Publication 2013/0301905, was filed one April 10, 2013, and published on November 14, 2013. Malecki qualifies as

prior art under §102(a)(2) as of its April 10, 2013 filing date and under §102(a)(1) as of its November 14, 2013 publication date.

2. Overview of Malecki

91. Malecki is directed to a system that “transform[s] the two dimensional position information of a UAV [target] into three dimensional positional information.” [EX1024, ¶0051]. It performs this transformation by utilizing the known positioning of position indicators on the UAV target. *Id.*, ¶¶ 0047-0061.

92. Malecki is analogous art to the '711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.* how to detect targets from captured images and control an aircraft to track the targets). [EX1001, '711 Patent, Abstract, 3:27-45; EX1024, Abstract, ¶¶0002, 0030-0035, 0047-0051].

E. SAHASRABUDHE (EX1025)

1. Status of Sahasrabudhe

93. Sahasrabudhe is U.S. Patent Application Publication 2012/0004844, was filed June 29, 2011, and published January 5, 2012. Sahasrabudhe qualifies as prior art under §102(a)(2) as of its June 29, 2011 filing date and under §102(a)(1) as of its January 5, 2012 publication date.

2. Overview of Sahasrabudhe

94. Sahasrabudhe is directed to a system that determines a “magnitude error” in positions between a follower aircraft and leader aircraft. It also determines

whether “low gain” or “high gain” corrective measures are needed to correct the error and return the aircraft to a desired relative orientation. EX1025, ¶0017.

95. Sahasrabudhe is analogous art to the ’711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.* how to detect targets from captured images and control an aircraft to track the targets). [EX1001, ’711 Patent, Abstract, 3:27-45]; [EX1025, ¶¶0011-0019, Fig. 1].

F. HOGASTEN (EX1022)

1. Status of Hogasten

96. Hogasten is International Publication Number WO2017/123477, was filed on January 6, 2017 in English, designated the U.S., and published on July 20, 2017. EX1022. Hogasten claims priority to U.S. Provisional Application No. 62/277186 (EX1023, “Hogasten Provisional”) filed on January 11, 2016. The portions of Hogasten on which I rely are supported by the Hogasten Provisional.⁵ Hogasten qualifies as prior art as of its January 11, 2016 effective filing date, as well

⁵ The Hogasten grounds include parallel citations showing where the relied upon subject matter of Hogasten (EX1022) is disclosed by the Hogasten Provisional (EX1023).

as its January 6, 2017 application filing date. Hogasten also qualifies as prior art as of its July 20, 2017 publication date.

2. Overview of Hogasten

97. Hogasten describes an “object detection system” for a vehicle such as an “aircraft.” EX1022, 0013, 0015, 0026, Figs. 1, 2; EX1023, 0012, 0014, 0025, Figs. 1, 2. The system includes a “distance sensor 106” that can be “radar” that “detect[s] one or more objects located at a distance from the distance sensor [] and/or determine[s] the distance that the one or more objects are located at relative to the distance sensor [].” EX1022, 0015, Fig. 1; EX1023, 0014, Fig. 1. The distance sensor is used in conjunction with a thermal imaging sensor to detect objects. EX1022, 0015, Fig. 1; EX1023, 0014, Fig. 1.

98. Hogasten is analogous art to the ’711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.* how to detect targets from captured images and control an aircraft to track the targets). [EX1001, ’711 Patent, Abstract, 3:27-45]; EX1022, ¶¶0013, 0015, 0026, Figs. 1, 2; EX1023, 0012, 0014, 0025, Figs. 1, 2.

G. PIERCE (EX1005)

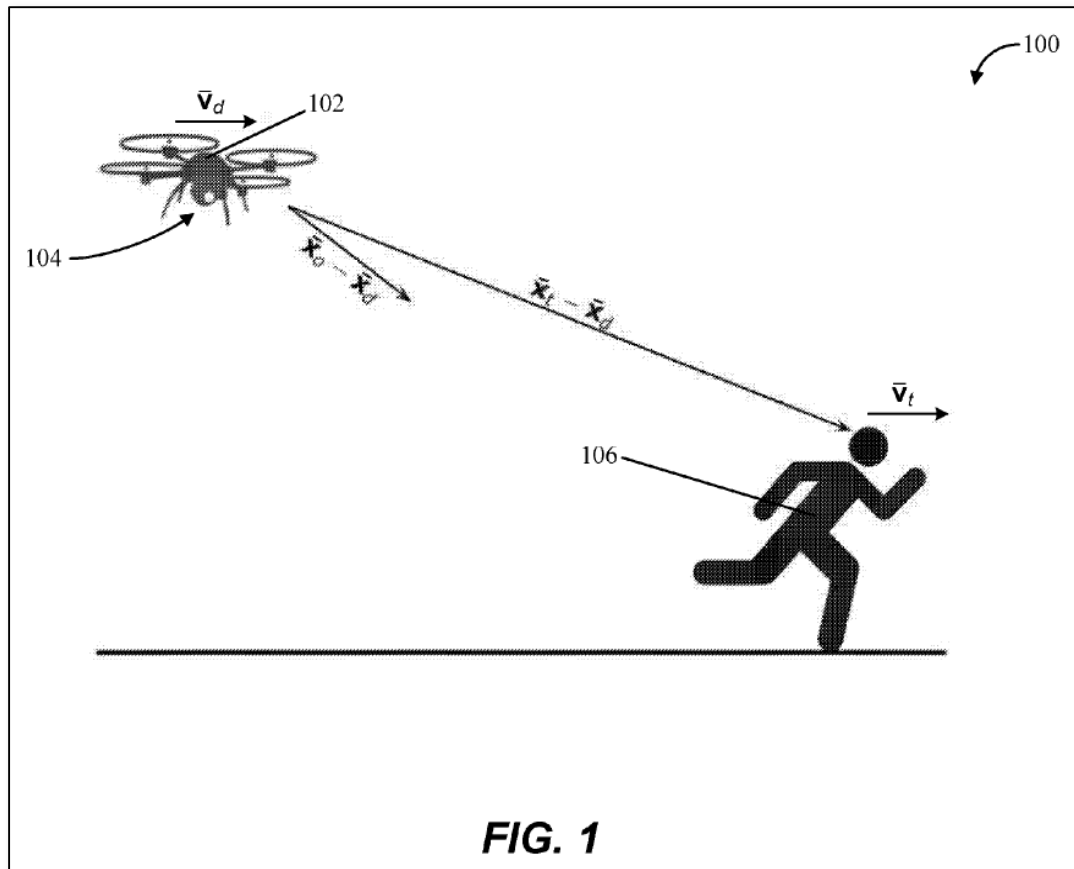
1. Status of Pierce

99. Pierce is U.S. Patent Application Publication No. 2017/0160751, was filed on December 5, 2016, and published on June 8, 2017. EX1005. Pierce claims priority to U.S. Provisional Application No. 62/263,510 (EX1006, “Pierce

Provisional”) filed on December 4, 2015. The portions of Pierce on which I rely are supported by the Pierce Provisional. Pierce qualifies as prior art as of its December 4, 2015 effective filing date, as well as its December 5, 2016 application filing date. Pierce also qualifies as prior art as of its June 8, 2017 publication date.

2. Overview of Pierce

100. Like the '711 Patent, Pierce describes “controlling drone movement for object tracking.” EX1005, Abstract; EX1006, ¶¶0001, 0004. For instance, Pierce explains that a “drone 102 includes a camera 104 to record images as input,” and those images are used by a “drone control algorithm” so that the drone can track or follow a moving target. EX1005, ¶¶0027-0031, Fig. 1; EX1006, ¶¶0026-0028, Fig. 1.



EX1005, Fig. 1; EX1006, Fig. 1

101. As part of its control, Pierce determines a “target’s position...relative to the drone.” EX1005, ¶0022; EX1006, ¶0019. Pierce implements its flight control based on this relative position as it determines a “linear velocity [] of the drone [] using the...position of the moving target,” and further implements the flight control by using a determined angular velocity. EX1005, Abstract, ¶¶0034, 0035; EX1006, ¶¶0004, 0019, 0030, 0031. The angular velocity is calculated according to the equation $\omega_d = (P(\alpha_t - \alpha_d), 0, 0)$, where “ α_t is the yaw angle of the target and α_d is the yaw angle of the drone” and P is “some constant value.” EX1005, ¶¶0023, 0034;

EX1006, ¶¶0019, 0023, 0030. The angular velocity that is calculated with the above equation is the angular velocity that the controller seeks to achieve as it changes the drone's velocity to automatically fly the drone toward the target. The "yaw velocity" of the drone is represented by the " $P(\alpha_t - \alpha_d)$ " portion of the equation, where P is "multiplied by the difference between the target's yaw angle and the drone's yaw angle." *Id.* The yaw velocity is therefore adjusted by how this difference changes—i.e., by the magnitude of deviation between the yaw angle of the target and the yaw angle of the drone. *Id.* Moreover, because that difference (represented by $(\alpha_t - \alpha_d)$) changes yaw velocity, it also adjusts the angular velocity (represented by ω_d in the equation above). EX1005, Abstract, ¶¶0023, 0034, 0035; EX1006, ¶¶0004, 0019, 0023, 0030, 0031.

102. Pierce is analogous art to the '711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.*, how to detect targets from captured images and control an aircraft to track the targets). [EX1001, '711 Patent, Abstract, 3:27-45]; EX1005, Abstract, ¶¶0023, 0027-0031, 0034-0035, Fig. 1; EX1006, ¶¶0001, 0004, 0019, 0023, 0026-0028, 0030-0031, Fig. 1.

H. KUMAR (EX1007)**3. Status of Kumar**

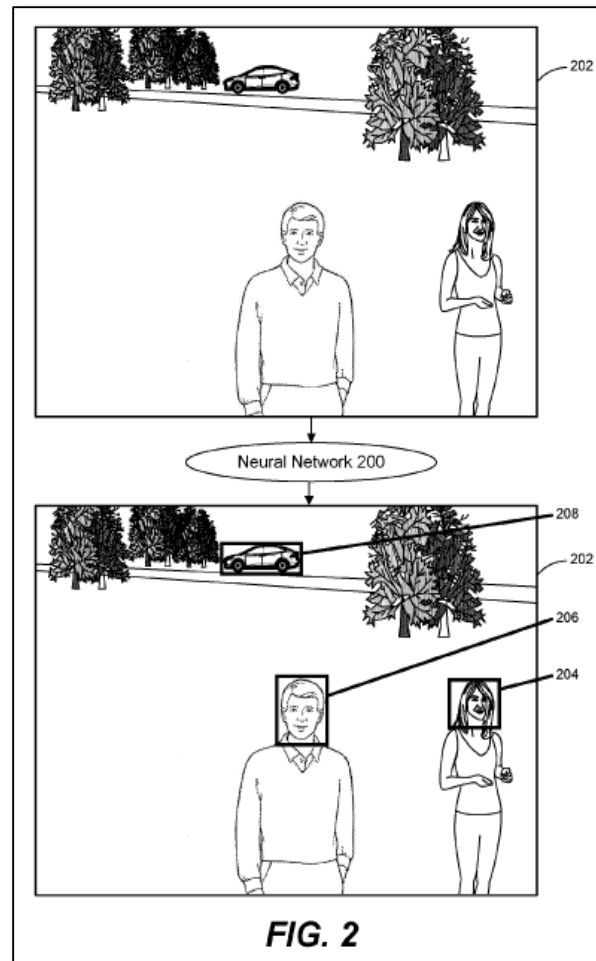
103. Kumar is U.S. Patent Application Publication No. 2017/0161911, was filed on December 5, 2016, and published on June 8, 2017. EX1007.⁶ Kumar claims priority to U.S. Provisional Application No. 62/263,496 (EX1008, “Kumar Provisional”) filed on December 4, 2015. The portions of Kumar on which I rely are supported by the Kumar Provisional. Kumar qualifies as prior art as of its December 4, 2015 effective filing date and its December 5, 2016 application filing date. Kumar also qualifies as prior art as of its June 8, 2017 publication date.

4. Overview of Kumar

104. Kumar is directed to a “method for distance and velocity estimation of detected objects.” EX1007, Abstract; EX1008, ¶0004. Kumar’s system obtains an image and detects an “object of interest” within the image by, for example, using a neural network. EX1007, ¶¶0005, 0019; EX1008, 0004, 0018. As shown in Figure 2 below, a “bounding box” is produced around the detected object of interest within the image. EX1007, ¶¶0019, 0035; EX1008, ¶¶0018, 0030.

⁶ The Pierce publication (EX1005) explicitly incorporates Kumar by reference.

EX1005, ¶0022.



EX1007, Fig. 2; EX1008, Fig. 2

105. Kumar determines “position estimates” for a target by calculating a “noisy estimate of the relative physical position (relative to the camera) of each object within the image (for all the bounding boxes that are given).” EX1007, ¶0021; EX1008, ¶0019. The “system computes the relative position” as (x_0, x_1, x_2) according to the following:

$$(x_0, x_1, x_2) = (\cos(\theta - \delta_h) * d, \sin(\delta_w) * d, -\sin(\theta - \delta_h) * d)$$

where δ_w and δ_h are the “horizontal and vertical position of the box center within the image (in pixels)” and d is the “straight-line distance [] between the object and

the camera.” EX1007, ¶¶0024-0025; EX1008, ¶¶0022-0023. Moreover, the straight-line distance d is calculated by the following equation:

$$d = s/2 * \tan(A/2 * \alpha/H)$$

where A is the “area of the box in pixels,” that is, the area of a bounding box around the object in the image, s is the “physical length of the diagonal across the box for an average instance of the object,” α is the field of view of the camera, and H is the height of the captured image in pixels. EX1007, ¶¶0021, 0024; EX1008, ¶¶0019, 0022.

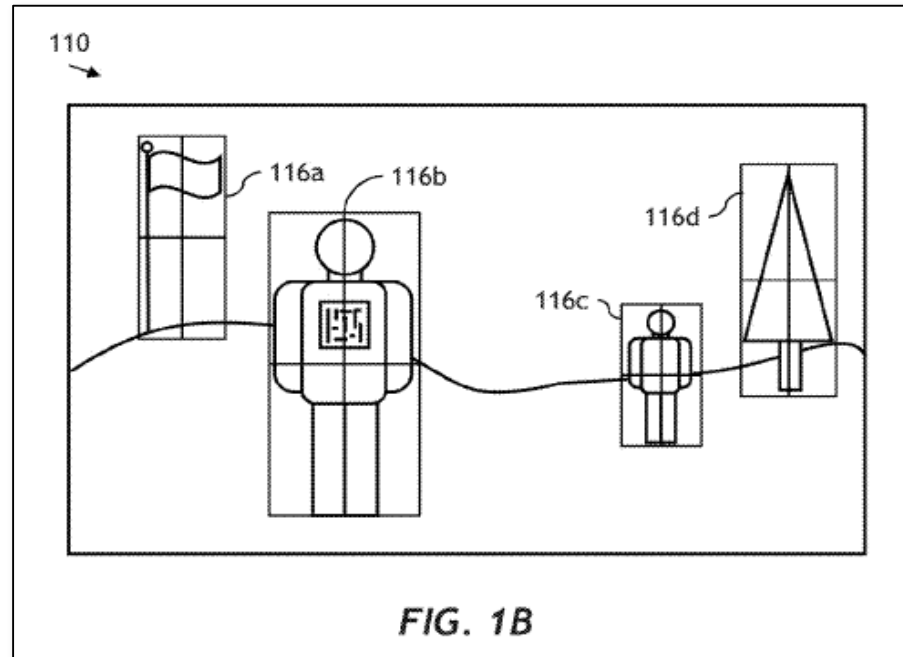
106. Kumar is analogous art to the ’711 patent, from the same field of endeavor as the patent, and reasonably pertinent to the particular problem the patent was trying to solve (*e.g.*, how to detect targets from captured images and control an aircraft to track the targets). [EX1001, ’711 Patent, Abstract, 3:27-45]; EX1007, ¶¶0019, 0024-0025, 0035; EX1008, ¶¶0018, 0022-0023, 0030.

XI. GROUND 1: BEARD AND LAUFER RENDER OBVIOUS CLAIMS 1-3, 5, 6, 9, 10, 12, 14-16, AND 18-20

A. MOTIVATION TO COMBINE BEARD AND LAUFER

107. Beard describes a flight control system where a UAV captures images of a target, uses image processing to identify the target, determines a desired orientation of the target to the UAV, and tracks the target at the desired orientation. EX1009, Abstract, 1:19-23, 2:19-22, 3:9-4:21, 7:13-53, 9:9-30, Figs. 1A-1F, 5.

Specifically, Beard's system analyzes the images to "identify potential target objects...via bounding boxes" within the images, as shown below. *Id.*



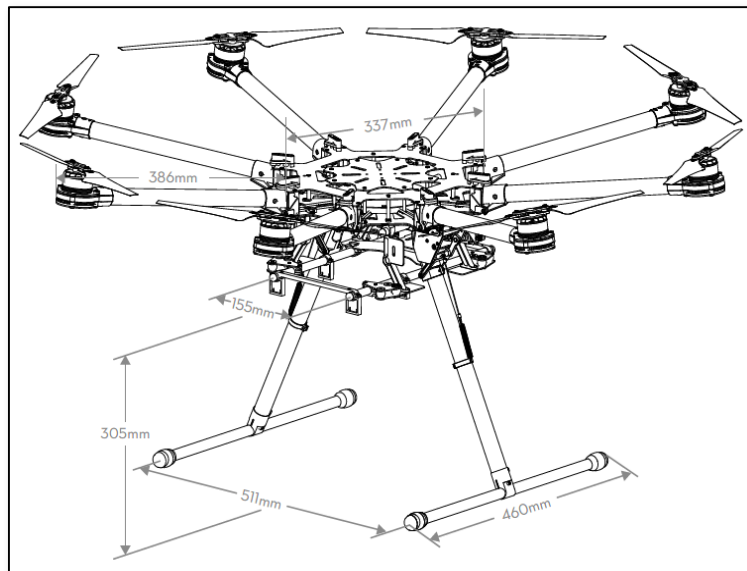
EX1009, Fig. 1B

Beard describes that potential targets include "human or animal subjects, natural features, or manmade landmarks." *Id.* 3:62-64.

108. Laufer's system includes doppler radars defining a surveillance zone, that are used along with fixed cameras to discriminate between targets in the zone that present a threat, such as aircraft (*e.g.*, small unmanned aircraft systems ("sUAS") drones), and targets that do not present a threat, such as birds. EX1010, ¶¶0001, 0022-0031, 0041-0049, Fig. 1. The system uses machine learning algorithms to analyze video or image data captured by the cameras and "determine

whether a target is a drone, and if the target is a drone, whether it is a threat.” *Id.*, ¶0031.

109. The surveillance zone further includes interceptor aircraft, such as quadcopter drones or the DJI S1000+ drone, that track targets. EX1010, ¶¶0025-0026, 0041, 0049, Fig. 1. Quadcopter drones were known to have four rotors, and the DJI S1000+ includes multiple rotors (shown below) and uses a “multi-rotor autopilot system.” EX1016, 1; EX1017, 1-2.



EX1017, 2

110. Doppler radar signals are used to determine an “interception location” where an interceptor aircraft and a target will intercept. *Id.*, ¶¶0022, 0038-0039, Figs. 1, 4. The interceptor aircraft flies to the interception location using “[a]utopilot aircraft commands.” *Id.*, ¶¶0022, 0038-0040, Figs. 1, 4. And when a target drone is “within a range of a camera mounted to the interceptor aircraft,” the interceptor

aircraft is controlled based on captured image or video data of the target. *Id.*, ¶¶0042-0044.

111. A POSITA would have been motivated to combine Beard with Laufer to implement Laufer's teachings on machine learning for object detection and on how a tracking drone is brought to be within an imaging range of an aircraft target. In the combination, Beard's image processor 234 of UAV 100 would use machine learning to detect aircraft targets in captured images, the UAV would be brought to within an imaging range of the target using a radar-generated interception location and autopilot commands, and the UAV would use image-based flight control when within the imaging range, as taught by Laufer. *Id.*

112. Beard describes "automatically" detecting targets within images, such as by placing bounding boxes around them, and using additional "recognition techniques" to determine a target. EX1009, 3:9-16, 3:57-4:21, Figs. 1A-1F. A POSITA would have been motivated to combine Beard with Laufer because Laufer furthers these aspects, specifying an automated technique of using machine learning to detect aircraft targets in captured images. EX1010, 0001, 0025-0031, 0041, 0049, Fig. 1. Indeed, Laufer provides known implementation details regarding Beard's described object detection. *Id.*

113. Beard also explains an example where when its UAV no longer has a "visual lock" of a target, the UAV may be directed to a location where it is "most

likely to re-establish visual contact” using data from a smartphone carried by the target. EX1009, 6:57-7:12. Laufer enhances Beard by providing a way of establishing visual contact with a target *without* smartphone data—i.e., by using data from doppler radar to determine an interception location and generating autopilot aircraft commands that bring the UAV to such a location; thereafter, when the target is within adequate visual range of the UAV, the UAV is controlled and tracks the target using imaging. EX1010, 0022-0031, 0038-0044, Figs. 1, 4. Laufer’s teachings therefore benefit Beard’s system by providing additional flexibility.

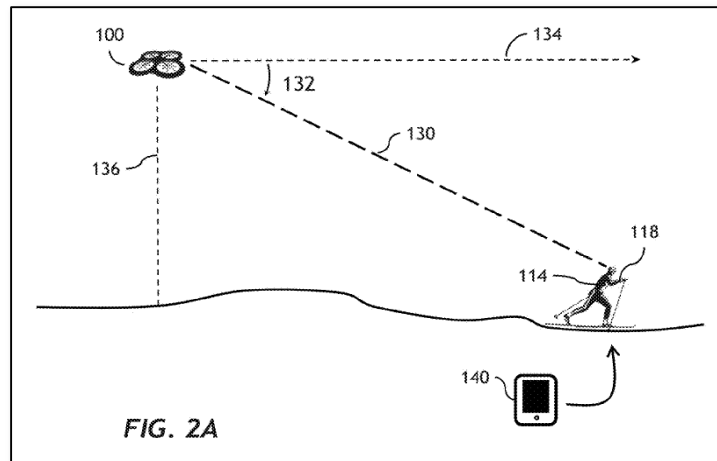
114. Enhancing Beard as discussed above would have been routine and straightforward. The combination simply would have entailed programming Beard’s UAV, including its image processor, such that its UAV implements the techniques discussed above. Effectuating this would have been well within the capabilities of a POSITA because machine learning object detection and radar were well-known. As such, enhancing Beard with Laufer’s teachings would have been nothing more than applying a known technique (Laufer’s machine learning object detection and use of radar) to improve similar devices (Beard’s drone flight control system) in the same way. The results of the combination would have been predictable: Beard’s UAV detecting target aircraft in captured images using machine learning and being navigable to a target using radar to establish visual contact, and using image-based flight control when within the imaging range. And for at least the same reasons

discussed above, a POSITA would have had a reasonable expectation of success in making the combination. [*Id.*] Further expectation of success would come from a POSITA knowing that radar was well understood and widely used for aerospace applications.

B. CLAIM 1

1. 1[a]: A method of performing a flight control operation of a reference aerial vehicle, comprising

115. To the extent the preamble is limiting, Beard describes an unmanned aerial vehicle (UAV) 100 “selects a target [118] based on a reference image captured by an onboard camera,” and “image processing determines a desired orientation of the target to the UAV, by which the UAV can track the target and provide streaming video images from the desired orientation,” and where “position and speed of the UAV” is adjusted to maintain the desired orientation (*A method of performing a flight control operation of a reference aerial vehicle*). EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 6:4-35, 9:9-30, Fig. 2A. An example of UAV tracking target 118 is shown below in Fig. 2A.



EX1009, Fig. 2A

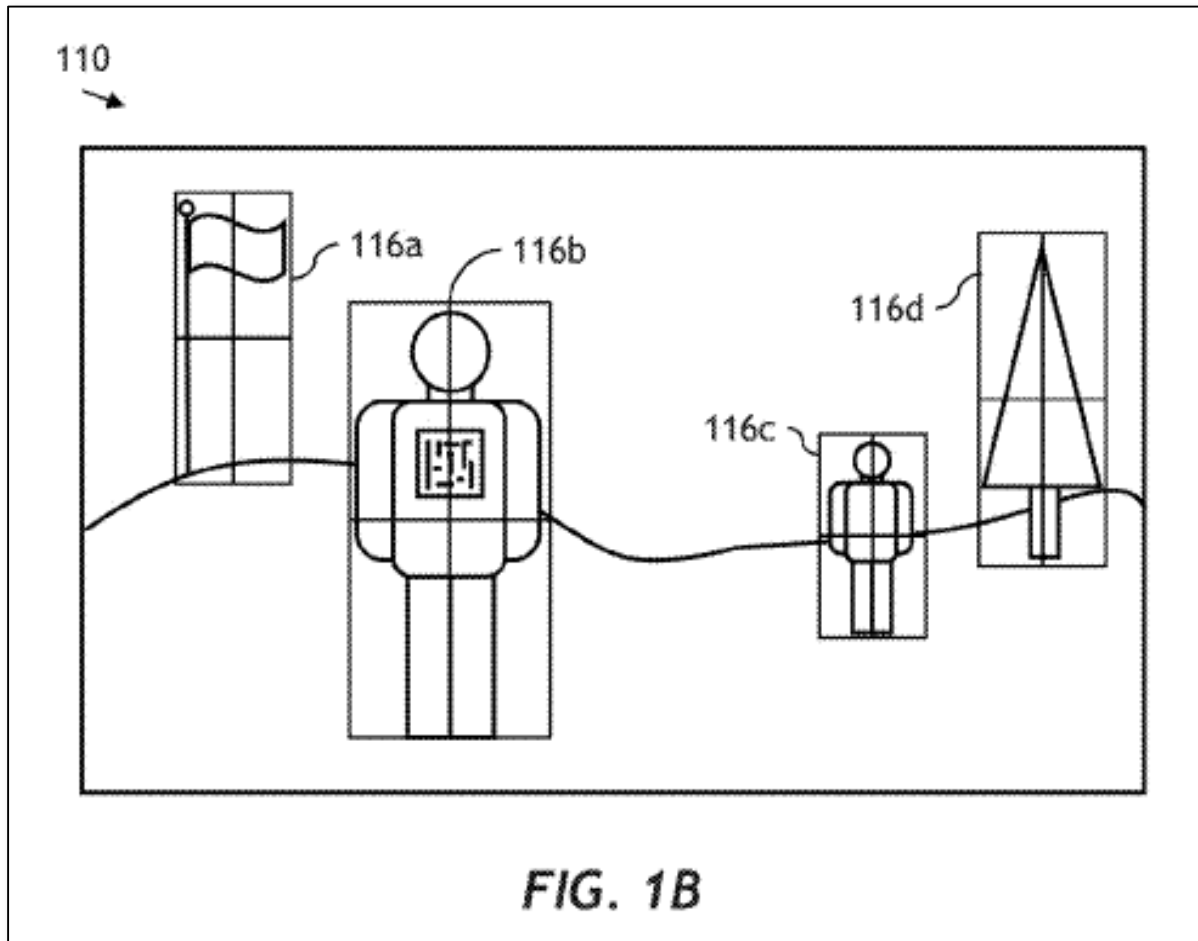
2. 1[b]: receiving an image captured by an image sensor of the reference aerial vehicle;

116. Beard describes an “action camera system 200” including “image sensor 212” is located aboard UAV 100 and captures image frames, including a reference image frame that includes potential target objects 112a, 112b, 112c, and 112d (*receiving an image captured by an image sensor of the reference aerial vehicle*). EX1009, 3:9-4:21, 2:2-8, 7:13-53, Figs. 1A, 1B, 5.

3. 1[c]: detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;

117. In the Beard-Laufer combination, image processor 234 of UAV 100’s action camera system 200 detects a target 118 in image frames by applying a machine learning algorithm to image frames to “identify potential target objects 112a, 112b, 112c, and 112d,” which can be aircraft, “via bounding boxes 116a, 116b,

116c, and 116d,” where a target object is selected as target object 118 (*detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target*). Section XI.A; EX1009, 3:9-4:21, 4:22-25, 2:2-8, 7:13-53, Figs. 1A-1C, 5.



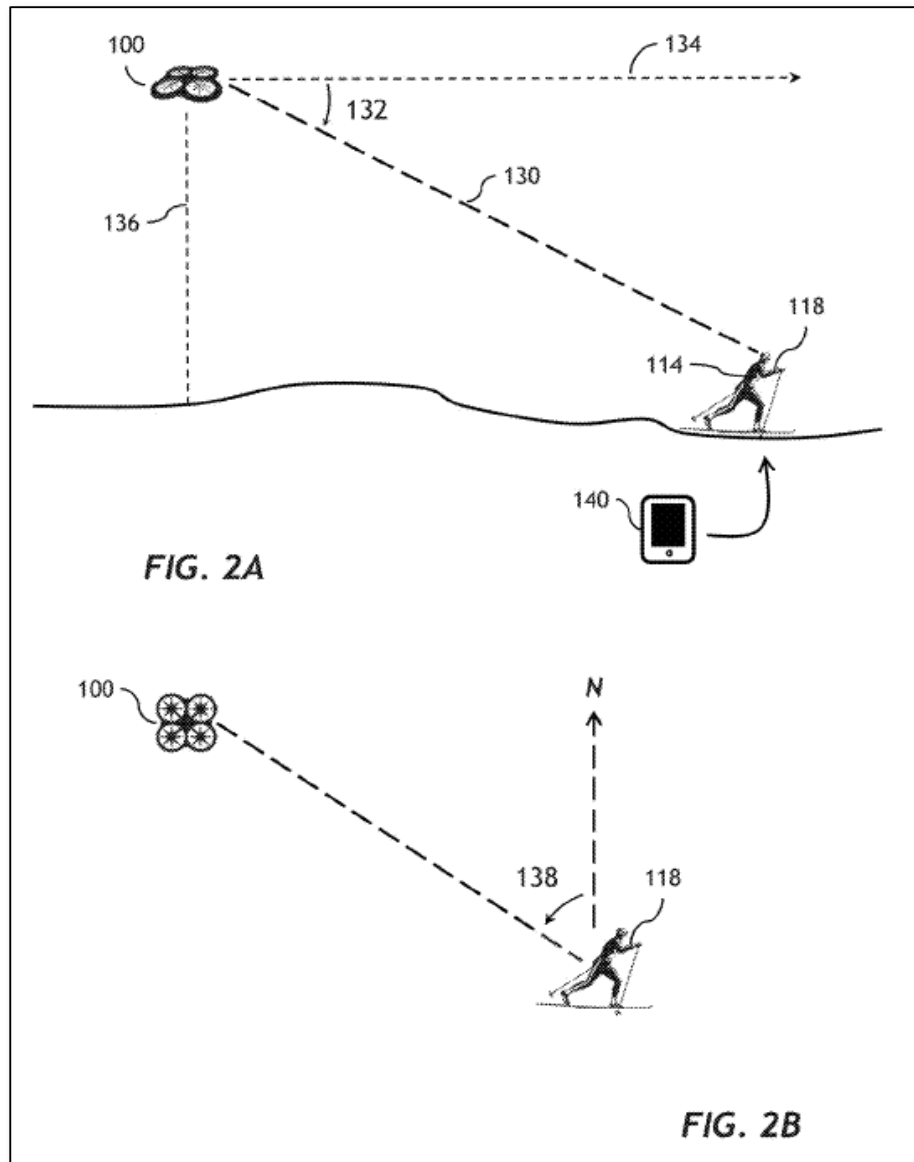
EX1009, Fig. 1B

118. In the combination, Laufer describes “[m]achine learning algorithms, for example Deep Convolutional Neural Network architectures such as those available from OpenCV or TensorFlow” analyze “video or image data” to

“determine whether a target is a drone, and if the target is a drone, whether it is a threat.” EX1010, ¶0031. Laufer therefore specifies to detect a target in Beard’s reference image frame by applying a machine learning algorithm to the image frame, to identify the portion of the frame including the target object, such as target objects 112a, 112b, 112c, or 112d, which can be aircraft. *Id.*; See Section XI.A (Motivation to Combine Beard and Laufer).

4. 1[d]: determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and

119. Beard describes that a target object, such as target object 112b, is selected as a detected target object 118. EX1009, 3:9-39, 4:22-25. Beard’s image processor 234 determines “second tracking parameters” including “at least one of a second distance [e.g., 130] between the UAV 100 and the at least one target 118, a second angle of elevation 132 between the UAV 100 and the at least one target 118, and a second bearing [138] between the UAV 100 and the at least one target 118,” shown below in figures 2A and 2B (*determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image*). EX1009, 1:66-2:38, 3:9-39, 4:17-39, 5:30-6:3, 7:27-8:66, 9:9-30, Figs. 2A-2B. This distance and these angles are shown in Figures 2A and 2B below.



EX1009, Figs. 2A, 2B

120. The *three-dimensional relative location* is provided by the distance between UAV 100 and target 118, the angle of elevation between UAV 100 and

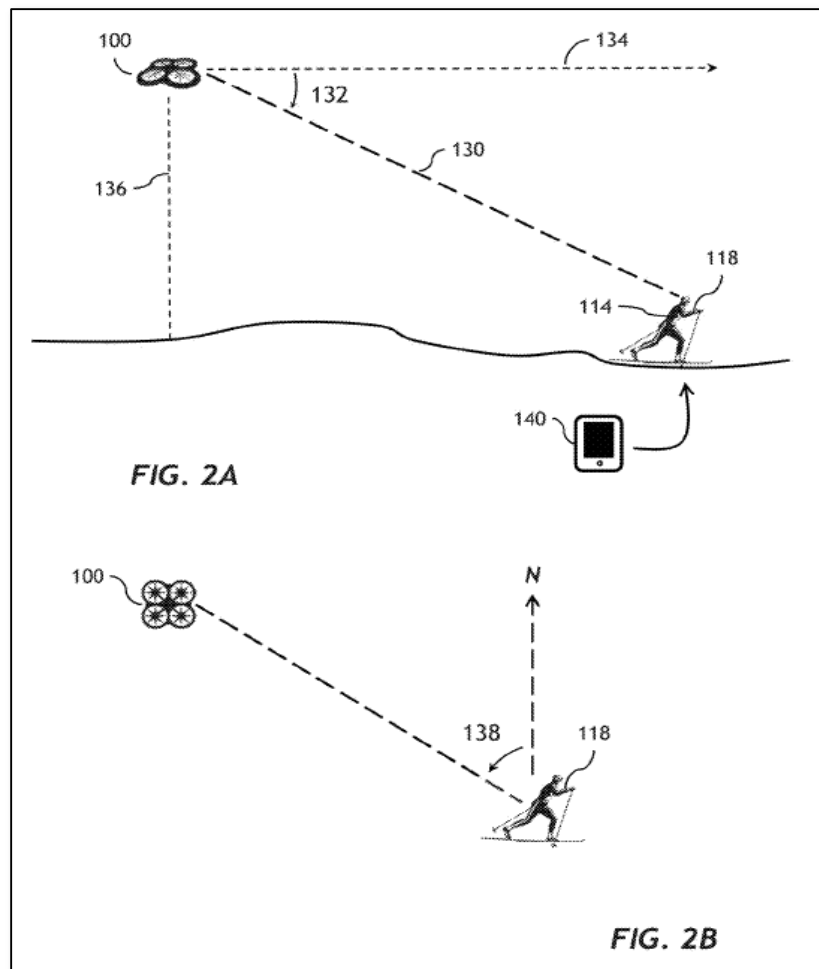
target 118, and the bearing between UAV 100 and target 118.⁷ *Id.* Beard further explains that its determined distance is “based on the pixel size of the target 118...relative to that of the frame” (*including by determining a distance to the target based at least in part on a size of the target detected within the image*). *Id.*

5. 1[e]: performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

121. Beard discloses or at least renders obvious element [1e]. Beard describes controlling the speed of one or more rotors of UAV 100 using attitude control system 232. EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6. This control maintains UAV 100’s orientation relative to a target and thereby adjusts the UAV’s

⁷ This comports with the ’711 patent, which explains, for example, that relative location includes the relative azimuth angle (*e.g.*, equivalent to Beard’s bearing angle), altitude angle (Beard’s angle of elevation), and distance (*e.g.*, Beard’s relative distance) between a drone and target. *See* [EX1001, ’711 Patent, 15:45-50, 16:41-44, 18:44-64].

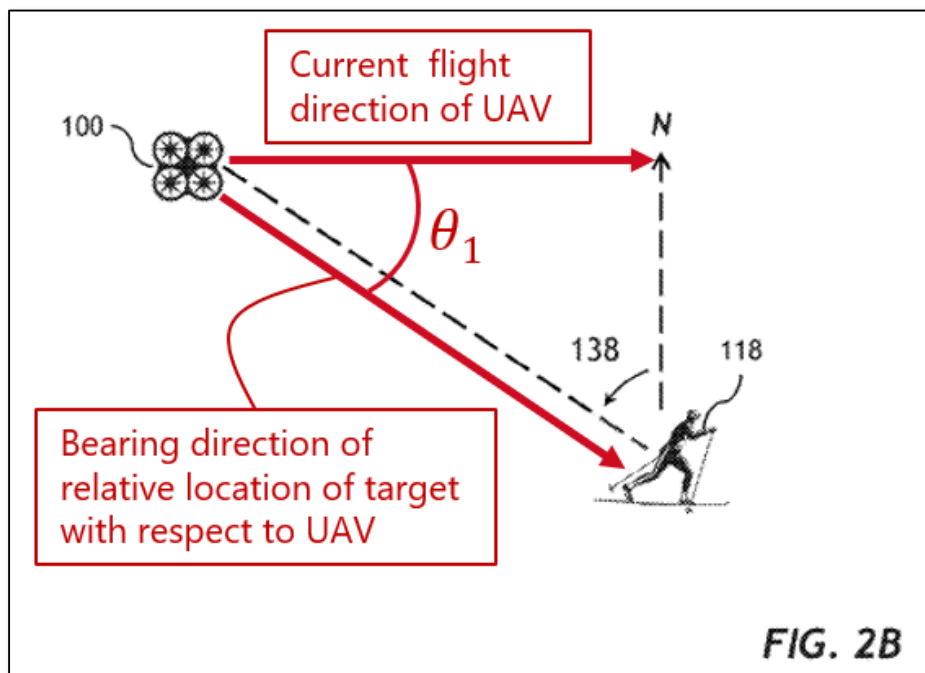
body speed, and is based on the second tracking parameters that are the second distance between the UAV 100 and the at least one target 118, the second angle of elevation 132 between the UAV 100 and the at least one target 118, and the second bearing 138 between the UAV 100 and the at least one target 118 (*performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle*). *Id.*; Section XI.B.4 (element 1[d]). Figures 2A and 2B below show this distance and these angles.



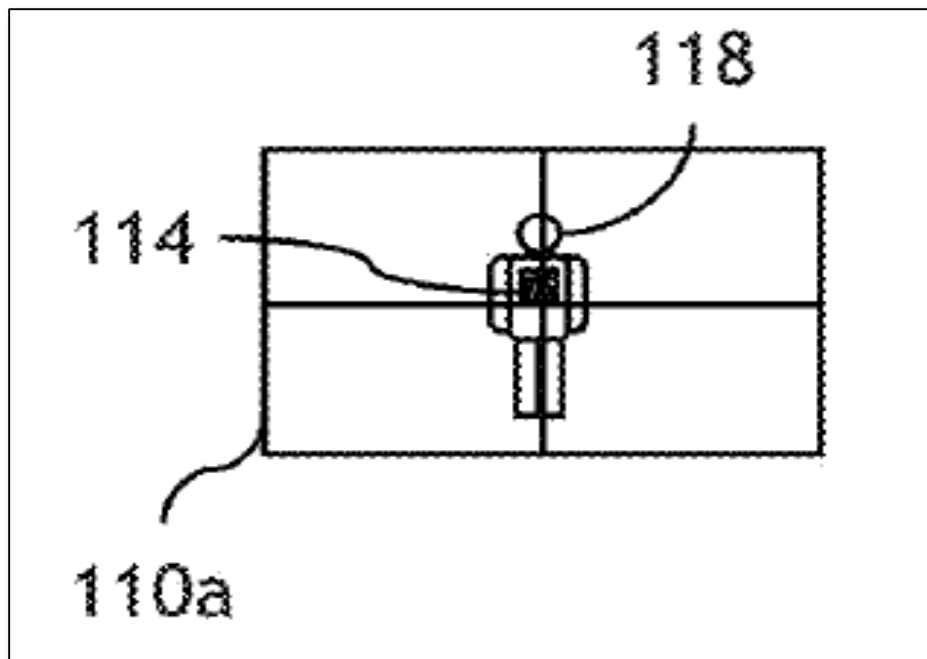
EX1009, Figs. 2A, 2B

122. A POSITA would have understood that the control determines an amount or factor by which rotor speed and/or body speed should be adjusted (*wherein performing the flight control operation includes determining a speed adjustment factor*). EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6. This is because the automatic flight control adjusts rotor speed of UAV 100, as well as the overall body speed of UAV 100, to maintain a particular orientation between UAV 100 and a target and keep target 118 in the center of an image frame. *Id.*; *see also* EX1009, 3:9-38 (“adjusting the position and speed of UAV 100 in order to maintain” the orientation of target 118 within an image frame). To adjust such speeds, a POSITA would have known that an amount or factor by which the speed is adjusted would have been determined so that the orientation is maintained, i.e., so the orientation is continually driven toward the desired orientation. *Id.* Examples of such feedback control factors from textbooks were provided above in the Technology Background section. Alternatively, it would have been obvious to a POSITA that the control determines an amount or factor by which rotor speed and/or body speed should be adjusted due to the same reasons noted above, and also because control systems were known to operate in this manner, as demonstrated by the review of autonomous flight control systems in the Technology Background section. *Id.*

123. Element 1[e]’s recitation of “*the three-dimensional relative location*” refers to the “*three-dimensional relative location of the target with respect to the reference aerial vehicle*” recited earlier in the element and in element 1[d]. Beard teaches that its system adjusts such speeds of UAV 100 based on the difference between (1) the bearing direction of the relative location of target 118 with respect to UAV 100 and (2) UAV 100’s current flight direction (*based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle*) as demonstrated with an example flight direction below on an annotated version of Beard’s Figure. 2B. EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6.



EX1009, Fig. 2B (annotated)

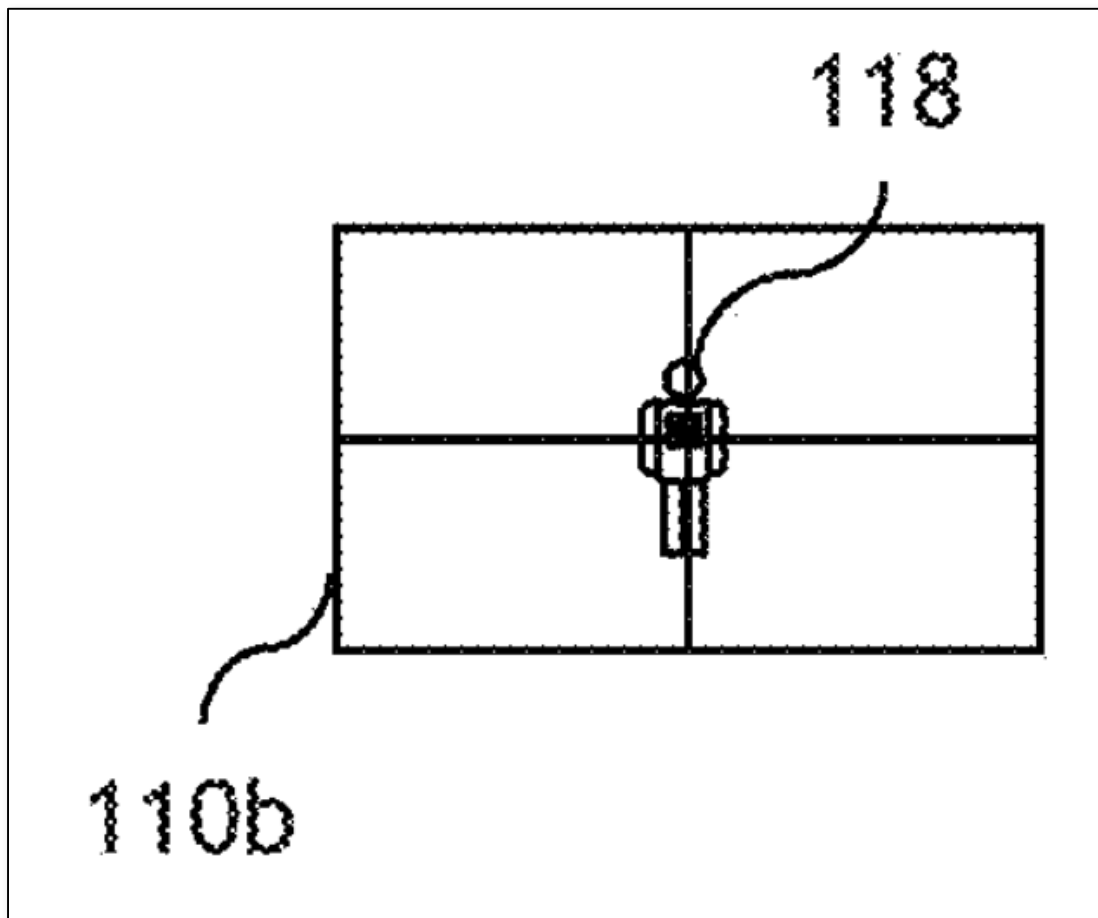


EX1009, Fig. 3 (in part)

124. UAV 100 includes a camera that is “fixed relative to [the] UAV,” meaning that UAV 100 must adjust its positioning or flight direction to change the camera’s field of view. EX1009, 5:54-59, 6:25-31. UAV 100 may initially track and follow target 118 at a desired orientation, such as that shown above in Fig. 2B, so that the target is located centrally within an image frame captured by the fixed camera, as shown by image frame 110a above. EX1009, 3:9-39, 5:9-30, 6:4-35, Figs. 2B, 3. UAV 100 “matches the initial speed” and follows the target, for example as it traverses downhill, so therefore has a current flight direction—an example of which is annotated in Figure 2B above. *Id.* The bearing direction of the relative location of target 118 with respect to UAV 100 and the current flight direction of

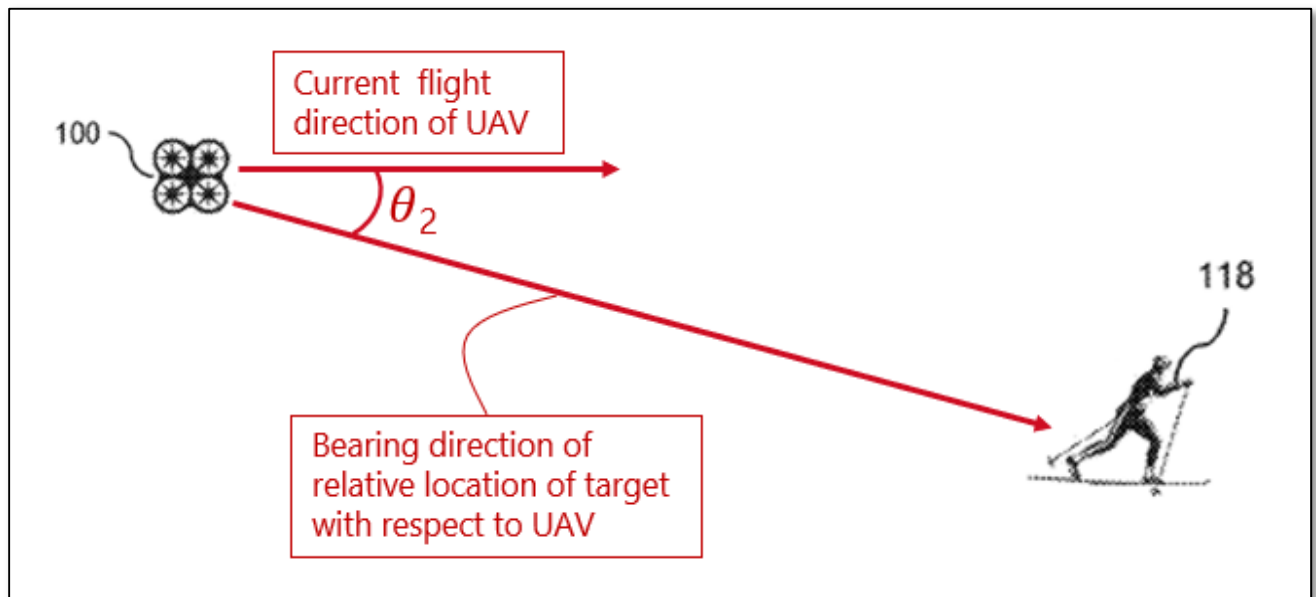
UAV 100 form an angle θ_1 between them, and an example of this is shown in annotated Fig. 2B above. EX1009, 6:4-17, Fig. 3.

125. The target then increases speed relative to UAV 100's speed, causing target 118 to appear smaller in the image frame, as shown by frame 110b. EX1009, 6:15-31, Fig. 3. A difference now exists between the orientation between UAV 100 and target 118, and the desired orientation between UAB 100 and target 118. *Id.*



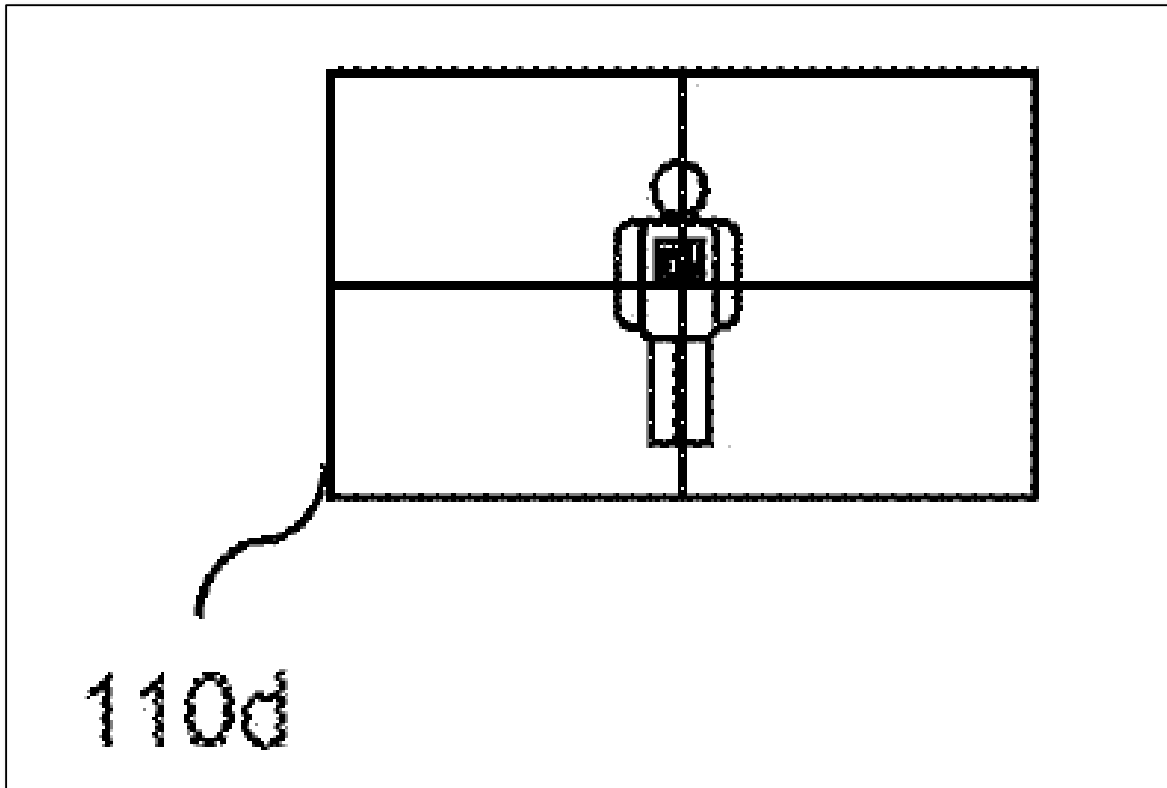
EX1009, Fig. 3 (in part)

126. Specifically, due to this increased speed, a deviation now exists between (1) the bearing direction of the relative location of target 118 with respect to UAV 100 and (2) the current flight direction of UAV 100, compared to when the directions resulted in image 110a. *Id.* This deviation is reflected by an increased distance between UAV 100 and target 118; indeed, because target 118 increased speed and is located further away from UAV 100, an angle θ_2 smaller than θ_1 is now formed between these two directions, as shown below. *Id.*



127. In order to recapture the desired orientation with respect to the target (e.g., θ_1), UAV 100 “responds” by increasing its speed to follow target 118 at the “desired distance and orientation,” so that its fixed camera can properly capture images of target 118. EX1009, 6:15-35, 3:9-39 (“adjusting the position and speed of UAV 100 in order to maintain” the orientation of target 118 within an image frame);

see also id., Abstract, 1:19-23, 1:66-2:38, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6. This speed adjustment is effectuated by adjusting the speed of UAV 100's rotors. EX1009, 4:60-63, 5:54-59, 6:15-35, 9:9-20. As such, based on the deviation between (1) the bearing direction from UAV 100 to the relative location of target 118 and (2) the current flight direction of UAV 100, the speed of UAV 100's rotors (as well as the body speed of UAV 100 itself) is adjusted to maintain the desired orientation between UAV 100 and the target (*wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle*). EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6. The resulting image shows target 118 having the correct size, an example of which is shown below. *Id.*



EX1009, Fig. 3 (in part)

128. As another example, if target 118 were to change direction—for example such that it is no longer centered in a captured image frame—UAV 100 can increase its speed (by changing rotor speed) to maintain the desired orientation (*e.g.*, θ_1) with respect to target 118 and keep the target centered in the frame. EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6.

129. These teachings from Beard are similar to the '711 patent's explanation that a tracking UAV's speed is adjusted based on a deviation of a target from the center of an image captured by the UAV. [EX1001, '711 Patent, 19:4-7, 14-20].

130. Moreover, I note that Beard renders limitation 1[e] obvious for at least the following reasons as well. A POSITA would have recognized that, to maintain a given orientation of Beard's UAV 100 to a target, speed and direction of travel are the only relevant variables under the control. If the position of the UAV starts to move away from the desired position, then the speed of the UAV has to be changed so that it can move back into the correct position. If the UAV starts drifting off in the wrong direction, then the direction of the UAV has to be changed to get it headed back in the correct direction. Therefore, a POSITA seeking to maintain the orientation between UAV 100 and the target would have adjusted and optimized the vehicle's speed and direction to achieve the desired orientation. Thus, the use of speed control is not an inventive feature; it is a well-known required operation for any autonomous flight control. Limitation [1e] does not reflect any inventive insight over the teachings Beard, and any alleged gaps between the teachings of Beard and limitation [1e] would have been obvious to a POSITA.

C. CLAIM 2

1. **The method of claim 1, wherein the reference aerial vehicle is a multirotor unmanned aerial vehicle and the target is an aerial vehicle.**

131. Beard describes UAV 100 includes “one or more rotors 208” (*wherein the reference aerial vehicle is a multirotor unmanned aerial vehicle*), and the Beard-Laufer combination teaches that a target tracked by Beard’s UAV 100 is an aircraft (*and the target is an aerial vehicle*). EX1009, 3:59-64, 4:60-63, 5:54-59, Fig. 5; EX1010, ¶¶0001, 0022-0031, 0041-0049, Fig. 1; Section XI.A. (Motivation to Combine Beard and Laufer).

D. CLAIM 3

1. **The method of claim 1, wherein performing the flight control operation includes one or more of the following: turning the reference aerial vehicle towards the target, adjusting a speed of the reference aerial vehicle, or engaging a mechanism to capture the target.**

132. Beard describes that the flight operation performed by UAV 100 includes controlling the speed of one or more rotors of UAV 100, adjusting the UAV’s body speed, to maintain UAV 100’s orientation relative to a target and thereby adjust the drone’s body speed (*wherein performing the flight control operation includes one or more of the following: ...adjusting a speed of the reference aerial vehicle...*). See Section XI.B.5 (element 1[e]).

E. CLAIM 5

1. **The method of claim 1, wherein detecting the target in the image includes identifying a bounding box outlining a portion of the image that includes detected features of the target.**

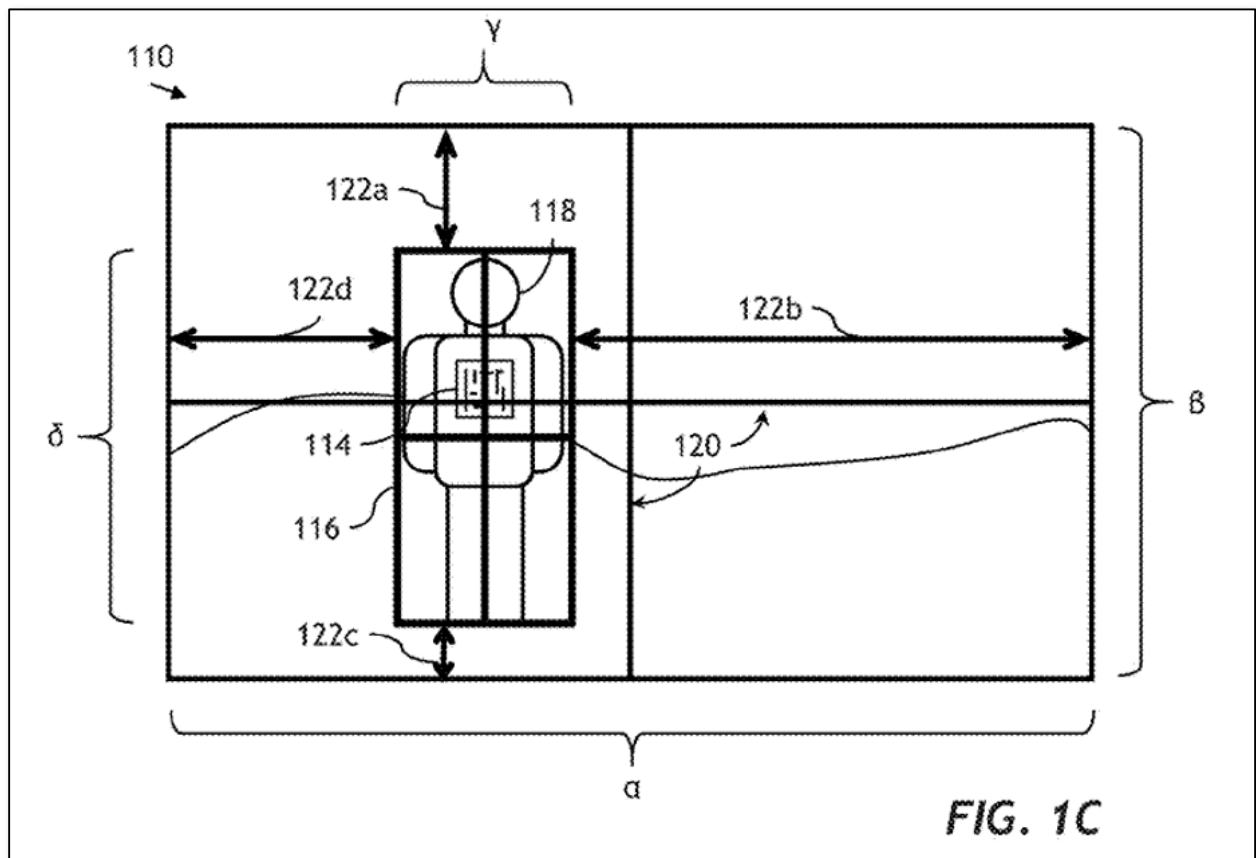
133. Beard describes that the image frame captured by UAV 100 includes potential target objects 112a, 112b, 112c, and 112d, and to “identify potential target objects 112a, 112b, 112c, and 112d via bounding boxes 116a, 116b, 116c, and 116d,” where “distinctive facial features of the target” are analyzed using “Viola-Jones or other facial recognition algorithms, pixel analysis, vote-matching, cascade recognition, or other visual recognition techniques” to isolate the target from the from its surroundings and determine position information regarding the target (*wherein detecting the target in the image includes identifying a bounding box outlining a portion of the image that includes detected features of the target*). EX1009, 3:9-4:63, 7:39-50, Figs. 1A-1F; Section XI.B.3 (element 1[c]).

F. CLAIM 6

1. **The method of claim 5, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on an area of the bounding box of the target within the image.**

134. The determined *three-dimensional relative location* is represented by the distance between UAV 100 and target 118, the angle of elevation between UAV 100 and target 119, and the bearing between UAV 100 and target 118. *See* Section XI.B.4 (element [1d]). Beard further describes that the determined distance between

UAV 100 and target 118 is based on the area of bounding box 116 around a target, calculated by multiplying the bounding box's width of " γ pixels" with the bounding box's height of " δ pixels" (i.e., " $\gamma * \delta$ "), as shown below in Figure 1C (*wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on an area of the bounding box of the target within the image*). EX1009, 4:22-39, Fig. 1C.

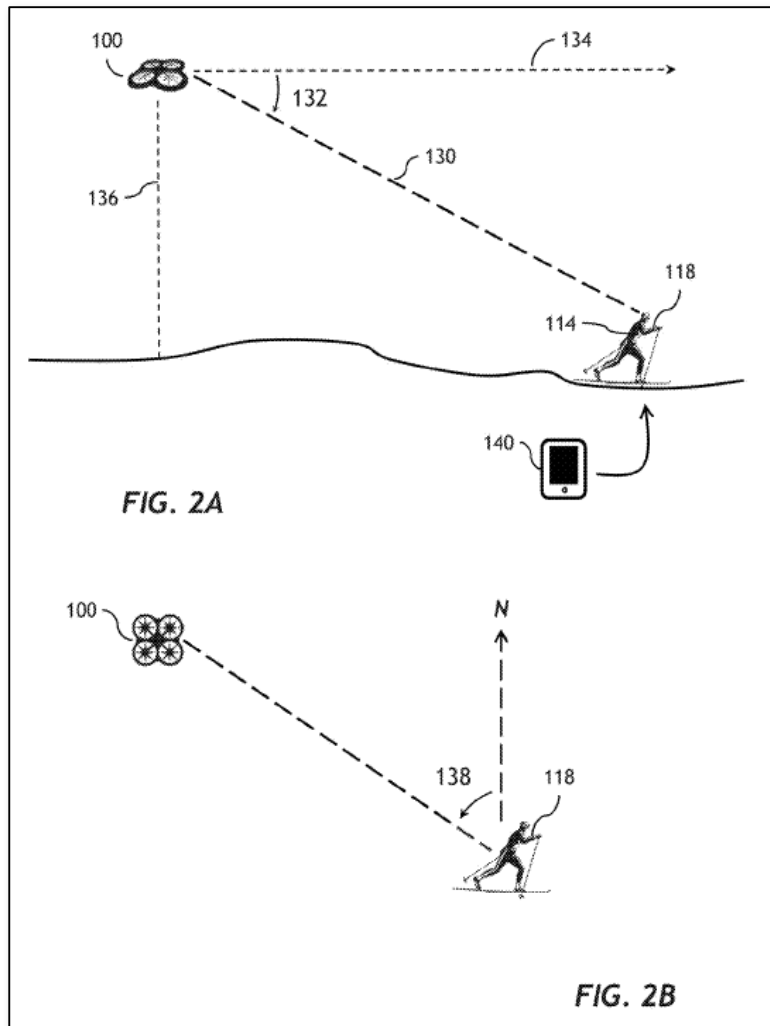


EX1009, Fig. 1C

G. CLAIM 9

- 1. The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining a direction of the target with respect to the reference aerial vehicle.**

135. The determined *three-dimensional relative location* of target 118 is represented by the distance between UAV 100 and target 118, the angle of elevation between UAV 100 and target 118, and the bearing between UAV 100 and target 118. Section XI.B.4 (element 1[d]). Thus, determining the location includes determining the angle of elevation 132 between the UAV 100 and target 118, as shown by Figure 2A below, which defines an elevation direction of target 118 with respect to UAV 100 (*wherein determining the three-dimensional relative location of the target includes determining a direction of the target with respect to the reference aerial vehicle*). *Id.*



EX1009, Figs. 2A, 2B

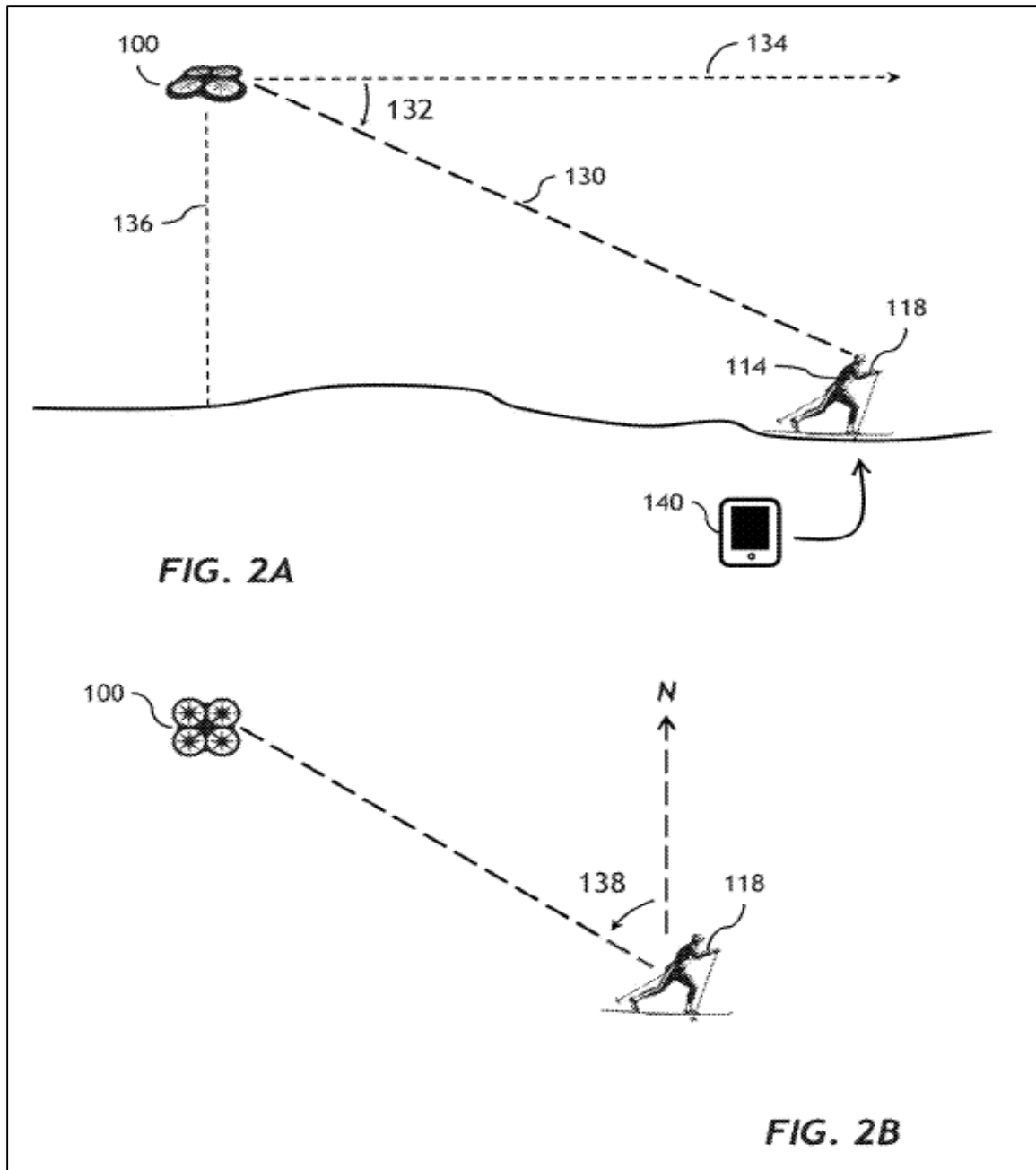
136. Moreover, determining the location includes determining the bearing 138 between UAV 100 and target 118, as shown by Figure 2B above, which defines the bearing direction of target 118 with respect to UAV 100. *Id.* And a POSITA would have understood as much or at least found as much obvious because it was well-known that a relative bearing or elevational angle between two items defines a

direction from one of those items to the other (and vice-versa). Put simply, the direction from one object to another is the relative angle between the two objects.

H. CLAIM 10

1. The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining an azimuth angle and an altitude angle to the target from the reference aerial vehicle.

137. The determined *three-dimensional relative location* of target 118 is the distance between UAV 100 and target 118, the angle of elevation 132 between UAV 100 and target 118, and the bearing 138 between UAV 100 and target 118. Section XI.B.4 (element 1[d]). The claimed *azimuth angle* is taught by Beard's determined bearing angle 138 as shown below in Figure 2B, and the claimed *altitude angle* is taught by Beard's determined angle of elevation 132 as shown in below in Figure 2A, providing that *determining the three-dimensional relative location of the target includes determining an azimuth angle and an altitude angle to the target from the reference aerial vehicle* as claimed. *Id.*



EX1009, Figs. 2A, 2B

I. CLAIM 12

1. **The method of claim 1, further comprising: receiving a geographical location associated with the target detected at least in part using a ground-based sensor; autonomously navigating the reference aerial vehicle towards the received geographical location; and determining to allow image-based navigation.**

138. In the Beard-Laufer combination, Laufer teaches that doppler radar signals generated by ground-based doppler radars (e.g., the “Laufer Wind MD-12”) are used to determine, and thereby receive, an “interception location” where UAV 100 and the target will intercept (*receiving a geographical location associated with the target detected at least in part using a ground-based sensor*). EX1010, ¶¶0001, 0022-0031, 0038-0049, Fig. 1; EX1012 (referring to “up-tower maintenance” of an MD-12 doppler radar, demonstrating the radar is on a tower attached to the ground); EX1013, 5-8, Fig. 5 (showing MD-12 radars mounted to a “man-lift” on the ground); Section XI.A (Motivation to Combine Beard and Laufer). In the combination, UAV 100 is brought to within an imaging range of the target using an interception location and autopilot commands (*autonomously navigating the reference aerial vehicle towards the received geographical location*). EX1010, ¶¶0022-0031, 0038-0040, Fig. 4; Section XI.A (Motivation to Combine Beard and Laufer). Then, when the target is within an adequate range of UAV 100’s camera, UAV 100 is controlled using captured image or video data to track the target (*and determining to allow*

image-based navigation). EX1010, ¶¶0022-0031, 0038-0044, Figs. 1, 4; Sections XI.A (Motivation to Combine Beard and Laufer), XI.B.5 (limitation 1e).

J. CLAIMS 14-16

139. Each of claims 14-16 describes a specific optimization of a known variable for maintaining the orientation between an aerial vehicle and a target, and would therefore have been obvious. XI.B.5 (element 1[e]).

K. CLAIM 18

- 1. The method of claim 1, wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location**

140. *See* Section XI.I (claim 12). Moreover, as combined with Laufer, Beard's UAV 100 implements its image-based flight control to track the target when the target is determined to be within imaging range of UAV 100, the range being a threshold distance away from the interception location with the target (*wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location*). *Id.*; EX1010, ¶¶0040-0044; Section XI.A (Motivation to Combine Beard and Laufer).

L. CLAIM 19

- 1. 19[a]: A reference aerial vehicle, comprising**

141. *See* Section XI.B.1.

2. **19[b]: an image sensor configured to capture an image;**
142. *See* Section XI.B.2.
3. **19[c]: a processor configured to: detect a target in the image; and**
143. *See* Section XI.B.3.
4. **19[d]: [the processor configured to:] determine a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image; and**
144. *See* Section XI.B.4.
5. **19[e]: a flight controller configured to perform a flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein the flight controller is configured to perform the flight control operation including by being configured to determine a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.**
145. *See* Section XI.B.5.

M. CLAIM 20

1. **20[a]: A computer program product for performing a flight control operation of a reference aerial vehicle, the computer program product being embodied in a non-transitory computer readable storage medium and comprising computer instructions for;**
146. *See* Section XI.B.1; EX1009, 9:42-64.
2. **20[b]: receiving an image captured by an image sensor of the reference aerial vehicle;**
147. *See* Section XI.B.2.

3. **20[c]: detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;**

148. *See* Section XI.B.3.

4. **20[d]: determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and**

149. *See* Section XI.B.4.

5. **20[e]: performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle**

150. *See* Section XI.B.5.

XII. GROUND 2: BEARD, LAUFER, AND KHAN RENDER OBVIOUS CLAIM 4

A. MOTIVATION TO COMBINE BEARD, LAUFER, AND KHAN

151. The Beard-Laufer combination teaches Beard's UAV detects target aircraft in captured images using machine learning. *See* Sections XI.A (Motivation to Combine Beard and Laufer), XI.B.3 (element 1[c]). Khan teaches a computer vision system used by UAVs that detects vehicle target objects in captured images by classifying them according to "vehicle model type." EX1021, 0003-0004, 0009-0025, 0044-0049, 0053-0062, Fig. 6.

152. A POSITA would have been motivated to combine Beard, Laufer, and Khan. In the combination, the detection of targets in captured images by Beard's UAV 100 would include identifying a model type of each target, as taught by Khan. *Id.*

153. Beard teaches that the detection of target objects in images includes analyzing characteristics of the object (e.g., "features") to help "isolate" the object from image surroundings. EX1009, 7:40-50. Laufer similarly teaches analyzing characteristics of a target in images, such as those indicating whether a target is a threat. EX1010, ¶0031. A POSITA would have been motivated to combine Beard, Laufer, and Khan because Khan furthers these aspects of both Beard and Laufer, teaching that the detection of an object (e.g., a vehicle) in images include identifying and classifying it by model type (e.g., vehicle model type). EX1021, ¶¶0003-0004, 0009-0025, 0044-0049, 0053-0062, Fig. 6. Khan enhances the flexibility of the Beard-Laufer combination by providing an additional characteristic (i.e., model type) of an object that can be analyzed in object detection. *Id.*

154. Moreover, Khan explains that "the problem of object classification has received considerable attention from both the computer vision and machine learning communities." EX1021, ¶0004. As noted, the Beard-Laufer combination describes Beard's UAV detecting target aircraft in captured images using machine learning. Sections XI.A (Motivation to Combine Beard and Laufer), XI.B.3 (element 1[c]).

Thus, a POSITA would have looked to enhance the Beard-Laufer combination with Khan's model-type object classification teachings, so that the Beard-Laufer system identifies model types when detecting target objects.

155. Enhancing the Beard-Laufer combination as discussed above would have been routine and straightforward. The combination simply would have entailed programming the Beard-Laufer system such that its UAV implements the detection techniques discussed above. Effectuating this would have been well within the capabilities of a POSITA because object classification was well-known and such algorithms were widely available, as indicated by Khan. The results of the combination would have been predictable: the target detection by Beard's UAV 100 including model type identification and classification. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination.

B. CLAIM 4

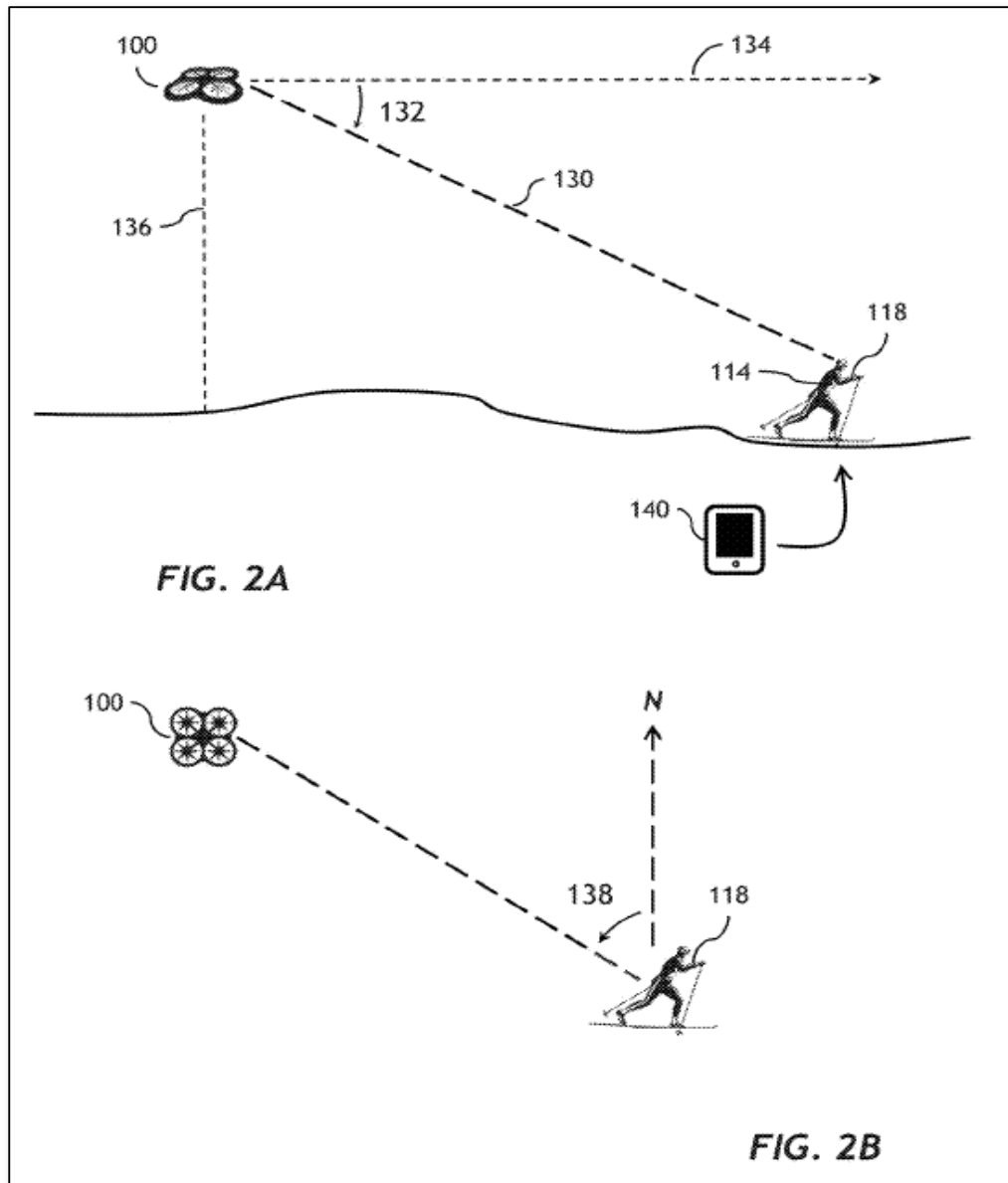
1. The method of claim 1, wherein detecting the target in the image includes identifying a model type of the target.

156. The Beard-Laufer-Khan combination teaches the detection of targets in captured images by Beard's UAV 100 includes identifying a model type of each target (*wherein detecting the target in the image includes identifying a model type of the target*). Section XII.A (Motivation to Combine Beard, Laufer, and Khan).

XIII. GROUND 3: BEARD, LAUFER, AND KUMAR RENDER OBVIOUS CLAIMS 7 AND 8

A. MOTIVATION TO COMBINE BEARD, LAUFER, AND KUMAR

157. The Beard-Laufer combination teaches an image-based target tracking system that determines “a second distance between the UAV 100 and the at least one target 118” using captured images to determine the three-dimensional relative location of target 118 to UAV 100, and that generates bounding boxes around targets in such images. Section XI.B.4 (element [1d]).



EX1009, Figs. 2A, 2B

158. Kumar similarly describes a target tracking system that recognizes a target in captured images and produces a bounding box around the target. EX1007, ¶¶0020, 0035, Fig. 2; EX1008, ¶¶0018, 0030, Fig. 2. Kumar’s system determines the relative position of a target to the camera capturing the images based on the “known physical [bounding] box size of the object of interest’s type of object” and

the “physical length of the diagonal across the [bounding] box for an average instance of the object.” EX1007, ¶¶0019-0025, 0037, Fig. 3A; EX1008, ¶¶0018-0023, 0032, claims 4-5, claims 14-15; claims 24-25, Fig. 3A.

159. A POSITA would have been motivated to combine Beard, Laufer, and Kumar. The combination would have specified that the distance determination taught by Beard and Laufer is, in addition to being based on target size within an image, also based on a bounding box corresponding to a known physical size of a type of a target present in an image and the physical length of the diagonal across the box for an average instance of the target, as taught by Kumar.

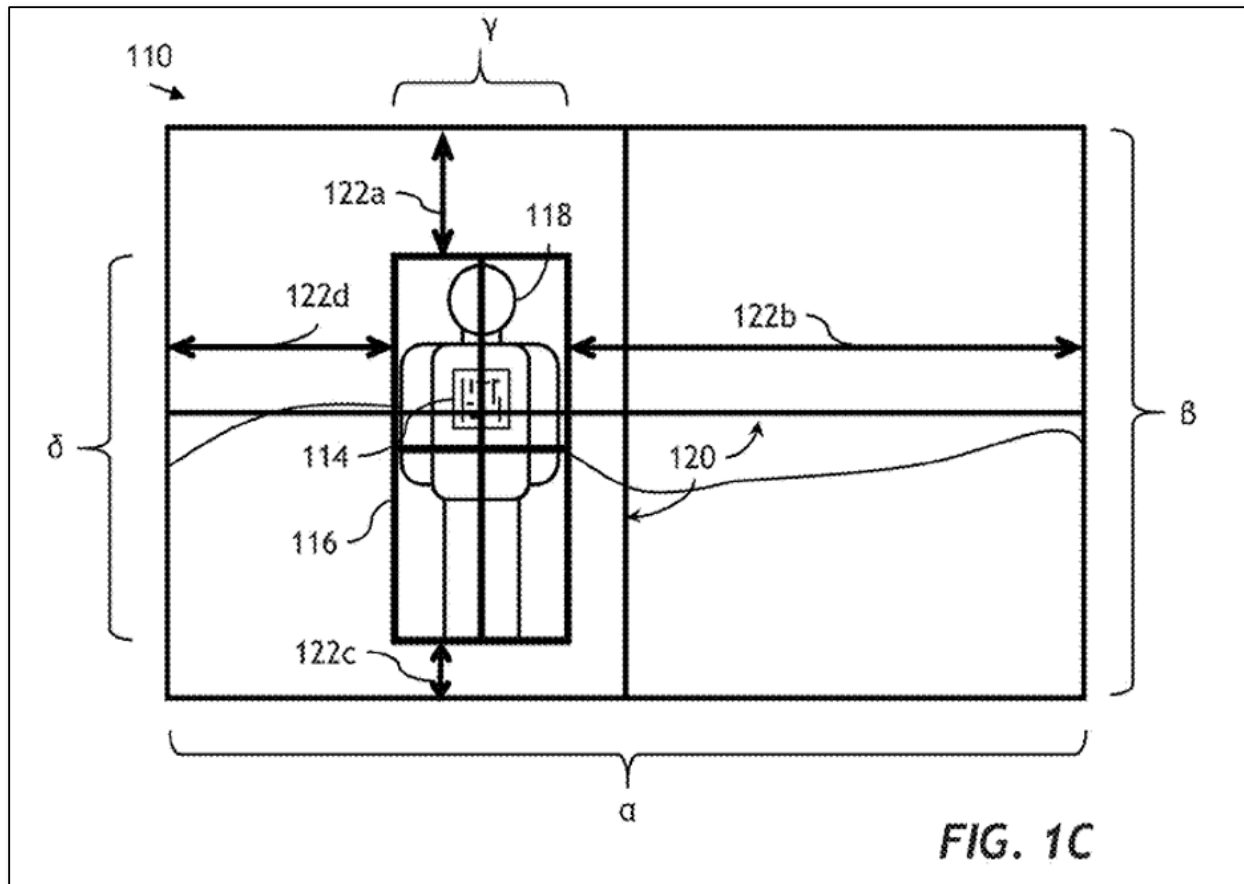
160. A POSITA would have been motivated to combine Beard, Laufer, and Kumar in this manner to improve the accuracy of target detection within captured images and the distance information obtained by the image analysis. Kumar’s teachings address a “need for distance estimation of an object no matter how far the object is from the observer, as long as the object appears in the camera used by the observer,” improving accuracy over prior techniques that “may not be accurate.” EX1007, ¶0003; EX1008, ¶0002. Kumar’s teachings thus would have similarly improved the object detection of the Beard-Laufer combination, providing more information (i.e., information on known physical size of a type of target and physical length of the diagonal for average instances) upon which the Beard-Laufer system can base its distance determinations. *Id.*; Section XI.B.4 (element 1[d]).

161. Enhancing the Beard-Laufer combination as discussed above would have been routine and straightforward. The combination would have entailed programming the Beard-Laufer system so it based distance determinations on the known physical size of object types and average bounding box diagonals, as discussed above. And the results of the combination would have been predictable: the distance determination taught by Beard and Laufer, in addition to being based on target size within an image, is also based on a bounding box corresponding to a known physical size of a type of a target object present in an image and the physical length of the diagonal across the box for an average instance of the target object. *Id.* And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination. Additional expectation of success would arise from a POSITA knowing that it is easy to estimate the average size of common objects such as a person's head or the tire of a car. EX1007, ¶¶0019-0025, 0037, Fig. 3A; EX1008, ¶¶0018-0023, 0032, claims 4-5, claims 14-15; claims 24-25, Fig. 3A.

B. CLAIM 7

1. **The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on a size of the target within the image and a physical size corresponding to an identified type for the target.**

162. The determined *three-dimensional relative location* is the distance between UAV 100 and target 118, the angle of elevation between UAV 100 and target 118, and the bearing between UAV 100 and target 118. *See* Section XI.B.4 (element 1[d]). Beard further describes that determining the distance between UAV 100 and target 118 is based on the size of the bounding box around the target, defined by a height of δ pixels and a width of γ pixels, within the captured image frame as shown in Figure 1C below (*wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on a size of the target within the image*). EX1009, 4:22-39, Fig. 1C.



EX1009, Fig. 1C

163. The Beard-Laufer-Kumar combination teaches that the distance between Beard's UAV 100 and target 118 would further have been based on a physical size of the type of target object identified in a captured image (*a physical size corresponding to an identified type for the target*). EX1007, ¶¶0019-0025, 0037, Fig. 3A; EX1008, ¶¶0018-0023, 0032, claims 4-5, claims 14-15; claims 24-25, Fig. 3A; Section XIII.A (Motivation to Combine Beard, Laufer, and Kumar).

C. CLAIM 8

- 1. The method of claim 7 wherein performing the flight control operation includes determining a speed adjustment factor based on the determined distance to the target.**

164. The Beard-Laufer combination teaches *performing the flight control operation includes determining a speed adjustment factor* as discussed in Section XI.B.5 (element 1[e]). Moreover, in the Beard-Laufer-Kumar combination, Beard teaches that its system adjusts the speed of UAV 100 based on the determined distance between UAV 100 and target 118, to maintain an orientation between UAV 100 and target 118 and keep target 118 “centrally framed at a fixed distance” within image frames captured by UAV 100 (*includes determining a speed adjustment factor based on the determined distance to the target*). EX1009, Abstract, 1:19-23, 1:66-2:38, 3:9-39, 4:22-5:4, 5:31-6:35, 7:13-53, 7:65-8:62, 9:9-41, claim 1, Figs. 1, 2A, 2B, 3, 6; *see* Section XI.B.5 (element 1[e]).

XIV. GROUND 4: BEARD, LAUFER, AND MALECKI RENDER OBVIOUS CLAIM 11**A. MOTIVATION TO COMBINE BEARD, LAUFER, AND MALECKI**

165. The Beard-Laufer combination teaches determining a *three dimensional relative location* by determining the second distance between the UAV 100 and target 118, second angle of elevation 132 between the UAV 100 and target 118, and second bearing between the UAV 100 and target 118. [Section XI.B.4

(element 1[d]).] Malecki teaches that a detection device, which may be located on a moving vehicle, detects an azimuth and an altitude of a UAV target. [EX1024, Abstract, ¶¶0002, 0030-0035, 0047-0061.] This two-dimensional positional information of the UAV target is then “mathematically transform[ed]” into “three dimensional positional information,” with “the third dimension being the distance of the UAV from the detection device, or range.” [*Id.*] Malecki performs this transformation by utilizing the known positioning of position indicators on the UAV target. [*Id.*]

166. A POSITA would have been motivated to combine Beard, Laufer, and Malecki. In the combination, Beard’s second angle of elevation and second bearing would have been transformed into Beard’s three-dimensional location of the second angle of elevation, second bearing, and second distance, as taught by Malecki.

167. A POSITA would have been motivated to combine Beard, Laufer, and Malecki in this manner to improve the efficiency of Beard’s three-dimensional location calculation. Malecki explains that such calculations “can be a complicated mathematical task” and “require a correspondingly large amount of processing power” using computers that are “often inherently heavy” and “can be a hinderance.” [EX1024, ¶¶0003-0004.] Malecki’s teachings thus would have improved efficiencies of the Beard-Laufer system, reducing the need for a processing-intensive and heavy computing device to calculate relative location of a target. [*Id.*] This

benefit would have been especially helpful for Beard's UAV, as such vehicles often do not have the capability to carry excess weight. [*Id.*; EX1024, ¶¶0033-0034.] Malecki also explicitly suggests its techniques being incorporated into a UAV localization and control system. [EX1024, ¶¶0061-0062, 0104.]

168. Enhancing the Beard-Laufer combination as discussed above would have been routine and straightforward. The combination simply would have entailed programming the Beard-Laufer system such that its UAV implements the location calculation techniques of Malecki discussed above, utilizing azimuth, altitude, and known positioning information to calculate a distance and generate a three-dimensional location of distance, azimuth, and altitude. Effectuating this would have been well within the capabilities of a POSITA because determining a distance from azimuth and altitude, and other known positioning information, was well-known. The results of the combination would have been predictable: Beard's UAV 100 transforming its determined second angle of elevation and second bearing into a three-dimensional location of the second angle of elevation, second bearing, and second distance. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination.

169. There would also have been an expectation of success because the elements used by Malecki to implement his method are well known components that

a POSITA would have understood had been in use for a long period of time and had proven successful in related applications.

B. CLAIM 11

- 1. The method of claim 1, wherein determining the three-dimensional relative location of the target includes converting a two-dimensional vector to a three-dimensional vector representing the three dimensional relative location.**

170. The Beard-Laufer-Malecki combination teaches that Beard's determining the second distance between the UAV 100 and target 118, second angle of elevation 132 between the UAV 100 and target 118, and second bearing between the UAV 100 and target 118 (*wherein determining the three-dimensional relative location of the target*) includes converting a two-dimensional vector of the angle of elevation and the bearing into a three-dimensional vector of the distance, angle of elevation, and bearing noted above (*includes converting a two-dimensional vector to a three-dimensional vector representing the three dimensional relative location*).

[Section XIV.A (Motivation to Combine Beard, Laufer, and Malecki).]

XV. GROUND 5: BEARD, LAUFER, AND SAHASRABUDHE RENDER OBVIOUS CLAIM 13

A. MOTIVATION TO COMBINE BEARD, LAUFER, AND SAHASRABUDHE

171. The Beard-Laufer combination teaches an image-based target tracking system. [Section XI.B.4 (element 1[d]).] Sahasrabudhe similarly describes a flight control system that allows a follower aircraft to track a lead aircraft. [EX1025,

¶¶0002-0003.] The follower aircraft determines a relative range (distance), azimuth, and elevation between the lead aircraft and follower aircraft using captured image data. [EX1025, ¶¶0011-0019, Fig. 1.] This relative position is then compared to a selected position of a desired position envelope, and based on the magnitude error between these positions, either high gain or low gain corrective measures are taken to move the follower aircraft. [*Id.*, Fig. 3.] The high gain 48 and low gain 50 options in the control system are shown in Fig. 3, which has been reproduced below for convenience. The high gain option is a part of the control system that uses a larger speed adjustment factor than the low gain option.

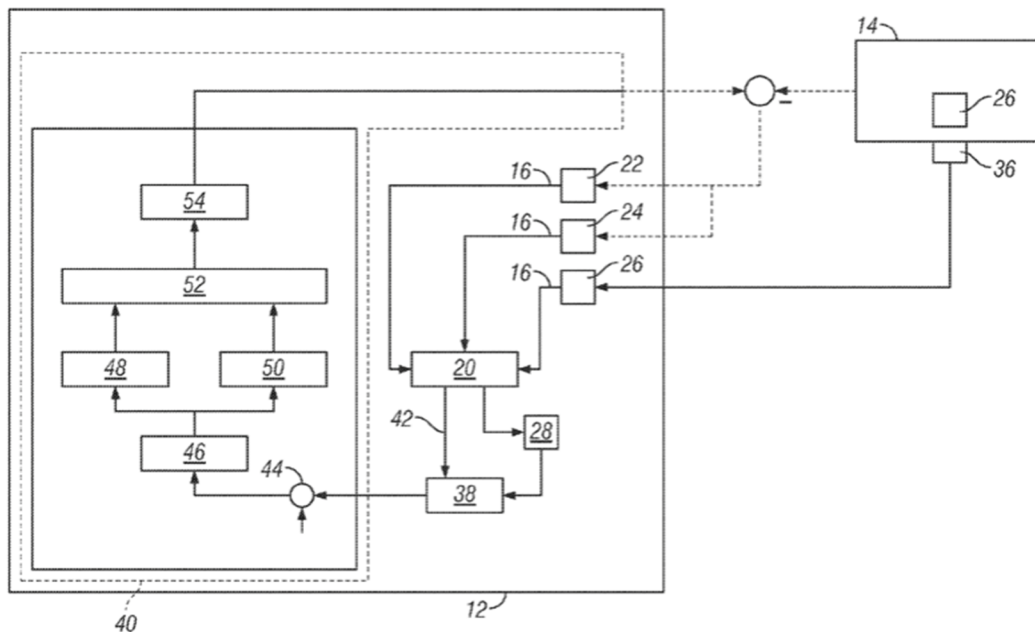


FIG. 3

172. Sahasrabudhe teaches that when the relative position is a great distance away from the selected relative position, the flight control computer might prescribe “harsh” corrections to the path of the follower aircraft to return the follower aircraft to the desired position envelope. Therefore, when the magnitude of the relative error is large, the speed adjustment factor of the control computer might be too large and lead to “harsh” control actions that “might endanger the aircraft.” [EX1025, ¶¶0011-0019, Figs. 1-3.] In addition to choosing the low gain options for such cases, Sahasrabudh also teaches a correction limiter 54 that limits the speed adjustment factor so as to avoid the “harsh” control actions that might damage the aircraft. The corrective limiter “limits the amount of correction available, limits specific commands such as roll, pitch, etc., and also limits the rate of such commands to preserve safety of the aircraft and nearby aircraft.” *Id.* Given this function of reducing the speed adjustment factor for larger deviations, Sahasrabudhe teaches the use of greater speed adjustment factors for smaller deviations (which would not trigger “harsh” conditions) as compared to greater magnitude deviates (which would trigger “harsh” conditions). *Id.*

173. A POSITA would have been motivated to combine Beard, Laufer, and Sahasrabudhe. The combination would have specified that Beard’s speed adjustment factor of UAV 100 is smaller, using low gain or limited commands, when large deviations with target 118 exists. However, the speed adjustment factor is larger,

using high gain commands, when small deviations exist. A POSITA would have been motivated to combine Beard, Laufer, and Sahasrabudhe in this manner so that the UAV is returned to a desired position without inducing harsh conditions that could damage the aircraft. Sahasrabudhe's teachings thus would have benefited the Beard-Laufer system by providing an additional technique by which UAV 100 maintains an orientation with a target. [*Id.*; Section XI.B.5.]

174. Enhancing the Beard-Laufer combination as discussed above would have been routine and straightforward. The combination simply would have entailed programming the Beard-Laufer system such that its UAV implements the positional correction techniques discussed above. Effectuating this would have been well within the capabilities of a POSITA because switching between high and low gains, as well as limiting commands,^{8,9} was well-known. The results of the combination would have been predictable: Beard's speed adjustment factor of UAV 100 being smaller, using low gain or limited commands, when large deviations exist and being larger using high gain correction, when smaller deviations exists. And for at least the same reasons discussed above, a POSITA would have had a reasonable

⁸ Gain switching is also called "gain scheduling" because the changes in gain can be scheduled to occur for various reasons. The method is available to students and engineers in commonly-used control system design tools such as MATLAB. See e.g. www.mathworks.com/help/control/gain-scheduled-controller-tuning.html.

⁹ See e.g. M. Bodson and W. A. Pohlchuck, "Command Limiting in Reconfigurable Flight Control," *Journal of guidance, control, and dynamics*, vol. 21, no. 4, pp. 639-646, 1998, doi: 10.2514/2.4283 (EX1028).

expectation of success in making the combination. Additional expectation of success would exist because the gain-switching and command-limiting techniques taught by Sahasrabudhe were available in commonly-used control system design tools.

B. CLAIM 13

1. The method of claim 1, wherein the speed adjustment factor is greater for a smaller magnitude of deviation as compared to for a greater magnitude of deviation.

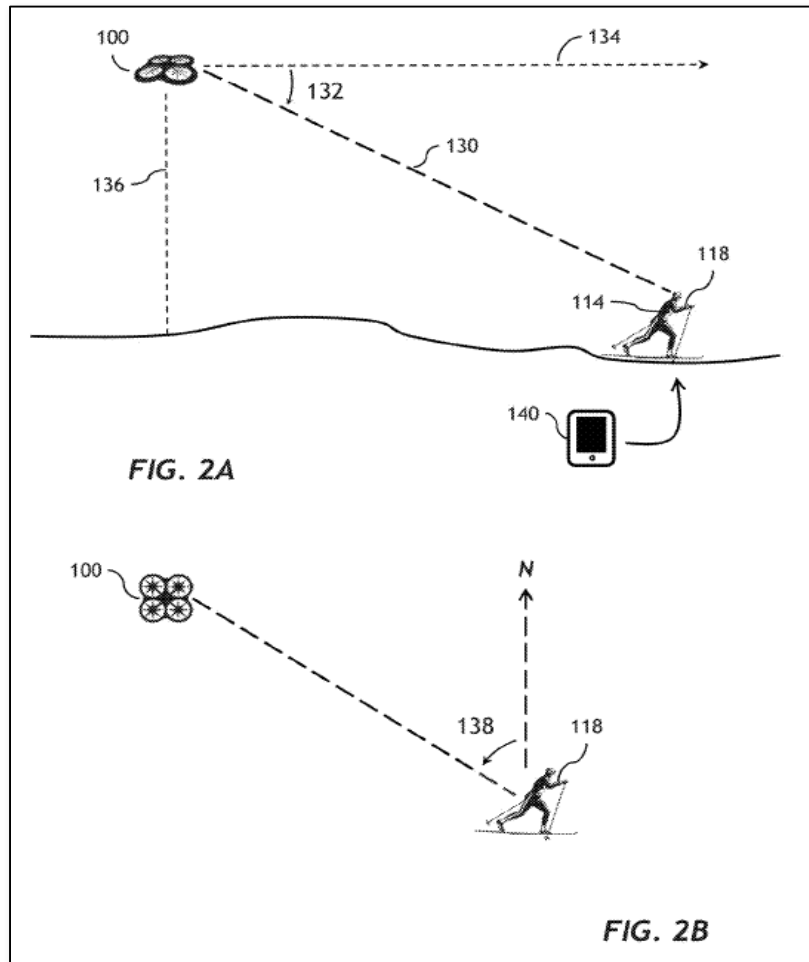
175. The Beard-Laufer-Sahasrabudhe combination teaches that the speed adjustment factor applied to UAV 100 may be larger, using high gain correction when a deviation between UAV 100 and target 118 is small (*wherein the speed adjustment factor is greater for a smaller magnitude of deviation*), but the speed adjustment factor is smaller, using a lower gain correction, when a deviation between UAV 100 and target 118 is larger (*as compared to for a greater magnitude of deviation*). Section XV.A (Motivation to Combine Beard, Laufer, Sahasrabudhe). Additionally, speed is a known variable for maintaining the orientation between a moving vehicle and another object. [Section XI.B.5.] Claim 13 describes a specific optimization of a known variable and is, therefore, obvious.

XVI. GROUND 6: BEARD, LAUFER, AND HOGASTEN RENDER OBVIOUS CLAIM 17

A. MOTIVATION TO COMBINE BEARD, LAUFER, AND HOGASTEN

176. The Beard-Laufer combination teaches an image-based target tracking system that determines “a second distance between the UAV 100 and the at least one

target 118” using captured images to determine the three-dimensional relative location of target 118 to UAV 100. A representation of the UAV and target is shown below. The combination also generates bounding boxes around targets in such images. [Section XI.B.4 (element 1[d]).]



EX1009, Figs. 2A, 2B

177. Hogasten similarly describes an “object detection system” for a vehicle such as an “aircraft.” [EX1022, ¶¶0013, 0015, 0026, 0039, Figs. 1, 2; EX1023, ¶¶0012, 0014, 0025, 0038, Figs. 1, 2.] The system includes a “distance sensor 106”

that can be “radar” that “detect[s] one or more objects located at a distance from the distance sensor [] and/or determine[s] the distance that the one or more objects are located at relative to the distance sensor [].” [EX1022, ¶0015, Fig. 1; EX1023, ¶0014, Fig. 1.] The distance sensor is used in conjunction with a thermal imaging sensor to detect objects. [EX1022, ¶0015, Fig. 1; EX1023, ¶0014, Fig. 1.]

178. A POSITA would have been motivated to combine Beard, Laufer, and Hogasten. The combination would have specified that Beard’s UAV 100 calculates the second distance between UAV 100 and the at least one target 118 using radar and its output radar distance measurements as taught by Hogasten. [*Id.*] A POSITA would have been motivated to combine Beard, Laufer, and Hogasten in this manner to allow for “quickly and accurately determin[ing] an environment around” Beard’s UAV 100. [*Id.*; EX1022, ¶0003; EX1023, ¶0002.] Indeed, Hogasten explains that providing such quick and accurate determinations is “particularly desirable” for autonomous vehicles, such as UAV 100. [*Id.*] Thus, by using Hogasten’s radar and its output distance measurements, the Beard-Laufer system would have had increased speed and accuracy in target detection and distance determinations within captured images. [*Id.*; Section XI.B.4 (element 1[d]).]

179. Hogasten also already suggests such a combination, teaching that its radar is used in conjunction with thermal imaging sensors to effectuate object detection. [EX1022, ¶0015, Fig. 1; EX1023, ¶0014, Fig. 1.] Combined with Beard

and Laufer, Hogasten's radar would have similarly complemented the camera of Beard's UAV 100 to effectuate object detection and improve accuracy. [*Id.*; Section XI.B.4 (element 1[d]).]

180. Enhancing the Beard-Laufer combination as discussed above would have been routine and straightforward. The combination would have entailed providing Beard's UAV 100 in the Beard-Laufer system with radar capabilities and the ability to use radar distance measurements, which would have been readily performed by a POSITA because radar was well-known and widely used for object detection applications. And the results of the combination would have been predictable: Beard's UAV 100 would have calculated the second distance between UAV 100 and the at least one target 118 using radar and its output radar distance measurements as taught by Hogasten. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination. [*Id.*]

B. CLAIM 17

1. The method of claim 1, wherein the distance to the target is determined based at least in part using a radar.

181. The Beard-Laufer-Hogasten combination teaches that Beard determines the second distance between the UAV 100 and the at least one target 118 based on using a radar and its output radar distance measurements (*wherein the distance to the target is determined based at least in part using a radar*). [Section

XI.B.4 (element 1[d]); Section XVI.A (Motivation to Combine Beard, Laufer, and Hogasten).]

XVII. GROUNDS 7 AND 8: PIERCE ANTICIPATES CLAIMS 1, 3, 5-9, 15, 19, AND 20 (GROUND 7); PIERCE AND KUMAR RENDER OBVIOUS CLAIMS 1, 3, 5-9, 15, 19, AND 20 (GROUND 8)

I note that anticipation ground 7 is based on Pierce's incorporation by reference of Kumar, and obviousness ground 8 treats them as separate references.

A. MOTIVATION TO COMBINE PIERCE AND KUMAR

182. Pierce describes “controlling drone movement for object tracking.” [EX1005, Abstract; EX1006, ¶¶0001, 0004.] Pierce’s drone 102 uses an attached camera 104 to capture images of a target object 106 for tracking, where the target is recognized within captured images by image recognition techniques that produce a bounding box around the target. [EX1005, ¶¶0002, 0028, 0031, Fig. 2; EX1006, ¶¶0001, 0027, 0028, Fig. 2.] Pierce’s tracking algorithm uses a value x_t that represents a “target’s position...relative to the drone.” [EX1005, ¶0022; EX1006, ¶0019.] Pierce does not specify how this relative position x_t is calculated, but explicitly incorporates Kumar (and the Kumar provisional) by reference for this calculation, stating that “the position and velocity of the moving target may be calculated by a position estimation system” as described by Kumar. [EX1005, ¶0022.]

183. Like Pierce, Kumar describes a target tracking algorithm that recognizes a target in captured images using image recognition techniques that produce a bounding box around the target. [EX1007, ¶¶0020, 0035, Fig. 2; EX1008, ¶¶0018, 0030, Fig. 2.] Kumar’s algorithm determines a relative position of a target to the camera by generating “position estimates” that include calculating a “noisy estimate of the relative physical position (relative to the camera) of each object within the image (for all the bounding boxes that are given).” [EX1007, ¶0021; EX1008, ¶0019.] Kumar’s “system computes the relative position” as (x_0, x_1, x_2) according to the following equation:

$$(x_0, x_1, x_2) = (\cos(\theta - \delta_h) * d, \sin(\delta_w) * d, -\sin(\theta - \delta_h) * d)$$

where δ_w and δ_h are the “horizontal and vertical position of the box center within the image (in pixels)” and d is the “straight-line distance [] between the object and the camera.” [EX1007, ¶¶0024-0025; EX1008, ¶¶0022-0023.] Moreover, the straight-line distance d is calculated by the following equation:

$$d = s/2 * \tan(A/2 * \alpha/H)$$

where A is the “area of the box in pixels,” that is, the area of a bounding box around the object in the image, s is the “physical length of the diagonal across the box for an average instance of the object,” α is the field of view of the camera, and H is the height of the captured image in pixels. [EX1007, ¶¶0021, 0024; EX1008, ¶¶0019, 0022.]

184. A POSITA would have been motivated to combine Pierce and Kumar such that Pierce's system determines the relative position (x_0, x_1, x_2) of a target with respect to drone 102 as taught by Kumar. The combination would have provided that Pierce's system determines this relative position (x_0, x_1, x_2) of the target using Pierce's captured image having a bounding box around the target, where a "straight-line distance" value d and "area of the bounding box" value A would have been utilized to calculate the relative position as taught by Kumar. [*Id.*] A POSITA would have been motivated to combine these teachings for several reasons.

185. First, Pierce provides an express motivation to utilize Kumar's teachings. As noted, Pierce already describes a value x_t that represents a "target's position...relative to the drone." [EX1005, ¶0022; EX1006, ¶0019.] The Pierce publication (EX1005) then explicitly incorporates Kumar and its provisional by reference, stating that "the position and velocity of the moving target may be calculated by a position estimation system as described" by Kumar and the Kumar provisional. [EX1005, ¶0022; EX1007; EX1008, page 1 (filing receipt).] Therefore, Pierce at least provides a teaching, suggestion, or motivation to use the "position estimation" system of Kumar, and as such, a POSITA would have been motivated to look to Kumar's teachings.

186. Second, both Pierce and Kumar are directed to target object tracking using image recognition techniques. [EX1005, ¶¶0002, 0028, 0031, Fig. 2; EX1006,

¶¶0001, 0027, 0028, Fig. 2; EX1007, ¶¶0020, 0035, Fig. 2; EX1008, 0018, 0030, Fig. 2.] Even aside from Pierce's incorporation of Kumar, a POSITA seeking to implement the tracking techniques of Pierce would have looked to other references that describe such techniques, such as Kumar, due to these similarities and the complimentary nature of their teachings.

187. Third, enhancing Pierce's drone control system with Kumar's teachings would have been nothing more than applying a known technique (Kumar's relative position determining techniques for tracking target objects in images) to improve similar devices (Pierce's drone control system that tracks target objects in images) in the same way. The combination would further merely have been combining prior art elements (Kumar's relative position determining techniques for tracking target objects in images and Pierce's drone control system that tracks target objects in images using relative position) according to known methods (known software and programming methods to enhance Pierce's drone control system, that already utilizes the relative position of a detected target, with Kumar's teachings that specify how to determine such a relative position) to yield predictable results. [*Id.*] Under both rationales, the results of the combination would have been predictable: determining a relative position of a target object using a captured image (as taught by Kumar) in a drone control system that uses such a position to track the target (as taught by Pierce). And for at least the same reasons, and because the enhancements

to Pierce's system would have required only routine adjustments to Pierce's drone control algorithm, POSITA would have had a reasonable expectation of success in making the combination. [*Id.*]

B. CLAIM 1

1. 1[a]: A method of performing a flight control operation of a reference aerial vehicle, comprising:

188. To the extent the preamble is limiting, Pierce describes a “drone 102” (*a reference aerial vehicle*) is controlled using a “method for controlling drone movement for object tracking,” which includes controlling drone movement to track a moving target using determined angular velocity 407 and linear velocity 411 (*A method of performing a flight control operation of a reference aerial vehicle*). [EX1005, Abstract, ¶¶0027, 0035, Fig. 1; EX1006, ¶¶0004, 0019, 0026, 0031, Fig. 1.]

2. 1[b]: receiving an image captured by an image sensor of the reference aerial vehicle;

189. Pierce describes that “drone 102 includes a camera 104 to record images as input” (*an image sensor of the reference aerial vehicle*). [EX1005, ¶0027, Fig. 1; EX1006, ¶0026, Fig. 1.] Images captured by the camera 104 are received and used by a “drone control algorithm” that allows drone 102 to track or follow a moving target (*receiving an image captured by an image sensor of the reference aerial vehicle*). [EX1005, ¶¶0027-0031; EX1006, ¶¶0026-0028.]

3. 1[c]: detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;

190. Pierce describes that a captured camera 104 captures an “input image 200” that “is passed through a neural network to produce a bounding box 208 around the head 206 of person 202” and further explains that vehicles such as cars can be detected and bounded with a box (*detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target*). [EX1005, ¶¶0002, 0028, 0030-0031 (Input image 200 “may be recorded by a camera 204” and “camera 204 may be camera 104 on drone 102.”), Fig. 2; EX1006, ¶¶0001, 0027, 0028, Fig. 2.] A POSITA would have understood that a “neural network” is a type of machine learning model. [EX1005, ¶0002; EX1006, ¶0001.] The 711 patent itself notes that “machine learning models [] may be configured to implement one or more machine learning algorithms” such as a “neural network.” [EX1001, ’711 Patent, 7:27-32, 3:31-36]. Moreover, an example of a “machine learning model” is a “neural network,” and “[m]achine learning algorithms” include “Deep Convolutional Neural Network architectures.” [EX1014, ¶0039; EX1010, ¶0031.]

4. 1[d]: determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and

191. Pierce discloses element 1[d]. Pierce incorporates Kumar by reference and describes that its system determines the relative position (x_0 , x_1 , x_2) of the target 106 with respect to drone 102 (as explained by incorporated Kumar) based on Pierce's processed image having a bounding box around the target (*determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image*). [Section XVII.A (Motivation to Combine Pierce and Kumar).]

192. The combination of Pierce and Kumar also renders obvious element 1[d]. The Pierce-Kumar combination teaches that Pierce's system determines the relative position (x_0 , x_1 , x_2) of the target 106 with respect to drone 102 based on Pierce's processed image having a bounding box around the target (*determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image*). [Section XVII.A (Motivation to Combine Pierce and Kumar).]

193. A POSITA would have understood that (x_0 , x_1 , x_2) is a *three-dimensional relative location* because it is defined in three dimensions, using three measure numbers: x_0 , x_1 , and x_2 . [EX1007, ¶¶0024-0025; EX1008, ¶¶0022-0023.] The first measure number, x_0 , indicates how far away the object is along

one axis of the coordinate system, such as left-right. The other two measure numbers, x_1 , and x_2 , indicate how far away the object is along the other two axes, such as forward-backward and up-down. Moreover, the determination of (x_0, x_1, x_2) uses the “straight-line distance” value d , and this value d is determined using (1) a value A that represents the “area of the bounding box in pixels,” specifying the area of a bounding box of a target object that is detected and tracked in the processed image, and (2) a value s that represents the “physical length of the diagonal across the box for an average instance of the object.” (*including by determining a distance to the target based at least in part on a size of the target detected within the image*). [See Section XVII.A; EX1007, ¶¶0021, 0024-0025; EX1008, ¶¶0019, 0022-0023.] These teachings are similar to the ’711 patent’s description. [See, e.g., [EX1001, ’711 Patent, 17:39-18:11].]

5. 1[e]: performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

194. Pierce (incorporating Kumar) discloses element 1[e]. The combination of Pierce and Kumar also renders obvious element 1[e]. Pierce controls movement of its drone to track a moving target by “[u]sing a determined angular velocity 407 and linear velocity 411” (*performing the flight control operation*). [EX1005,

Abstract, ¶0035; EX1006, ¶¶0004, 0019, 0031.] Pierce further explains that “determining the linear velocity 411 of the drone includes using the...position of the moving target.” [EX1005, ¶0034; EX1006, ¶¶0019, 0030.] As noted for element 1[d], Pierce (incorporating Kumar) and the combination of Pierce and Kumar each provide that Pierce’s position of the target is the (x_0, x_1, x_2) relative position, teaching the *three-dimensional relative location*. [See Section XVII.B.4 (element 1[d]); Section XVII.A.] As such, Pierce (incorporating Kumar) and the combination of Pierce and Kumar each teach performing Pierce’s control of a drone to track a moving target based on the (x_0, x_1, x_2) relative position, which is the relative position of the target with respect to the drone (*performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle*). [*Id.*]

195. As noted above, Pierce controls drone movement using a determined angular velocity 407 and linear velocity 411. [EX1005, Abstract, ¶0035; EX1006, ¶¶0004, 0019, 0031.] Angular velocity 407 is calculated according to the following equation: $\omega_d = (P(\alpha_t - \alpha_d), 0, 0)$ where “ α_t is the yaw angle of the target and α_d is the yaw angle of the drone.” [EX1005, ¶¶0023, 0034; EX1006, ¶¶0019, 0023, 0030.] The “yaw velocity” is represented by the “ $P(\alpha_t - \alpha_d)$ ” portion of the equation, where P is “some constant value” that is “multiplied by the difference between the target’s yaw angle and the drone’s yaw angle.” [EX1005, ¶0023; EX1006, ¶0023.] As such,

Pierce describes that by controlling drone movement using determined angular velocity, such control includes determining the difference between the target's yaw angle and the drone's yaw angle, represented by $(\alpha_t - \alpha_d)$ (*wherein performing the flight control operation includes determining a speed adjustment factor*). [EX1005, Abstract, ¶¶0023, 0034, 0035, 0037; EX1006, ¶¶0004, 0016, 0019, 0023, 0030-0031.] Pierce's difference between the target's yaw angle and the drone's yaw angle, represented by $(\alpha_t - \alpha_d)$, forms a *speed adjustment factor* because this difference in yaw angle is a factor that multiplies the constant P and thereby adjusts the yaw velocity represented by the " $P(\alpha_t - \alpha_d)$." [Id.] Additionally, or alternatively, Pierce's difference between the target's yaw angle and the drone's yaw angle, represented by $(\alpha_t - \alpha_d)$, forms a *speed adjustment factor* because this difference in yaw angle adjusts the yaw velocity represented by the " $P(\alpha_t - \alpha_d)$ " as noted, which in turn adjusts the angular velocity 407 of Pierce's drone, that is calculated according to the following equation: $\omega_d = (P(\alpha_t - \alpha_d), 0, 0)$. [Id.]

196. Moreover, Pierce's difference between the target's yaw angle and the drone's yaw angle, represented by $(\alpha_t - \alpha_d)$ —the *speed adjustment factor*—is determined based on an amount of difference in the α_t yaw angle of the target, located at the (x_0, x_1, x_2) relative position described by Kumar, and the α_d yaw angle of the drone (*based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial*

vehicle). [EX1005, Abstract, ¶¶0023, 0034-0035, 0037; EX1006, ¶¶0004, 0019, 0023, 0030-0031; Sections XVII.B.4 (element 1[d]), XVII.A.] A POSITA would have understood that the yaw angle of the target (represented by α_t) indicates the direction of the target at its relative position, thereby corresponding to “a direction of the three-dimensional relative location” (x_0, x_1, x_2) under one reading of the claims, and the yaw angle of the drone (represented by α_d) indicates a current flight direction of the drone—i.e., a current direction of the drone during flight. [*Id.*; Section XVII.B.4 (claim 1[d]).] Indeed, yaw indicates angular direction, and the yaw direction of a drone is a flight direction of the drone. [*Id.*; see also EX1011, 9:17-21 (referring to “flight directions” of a drone as including the “yaw” direction).]

197. This analysis is consistent with the '711 patent's disclosure. For example, the '711 patent states that “[i]n some embodiments, the speed and/or acceleration factor is multiplied by one or more scaler values that change in magnitude based on the directional deviation of the vector [of a target] from a current direction of movement [of an interceptor drone].” [EX1001, '711 Patent, 18:44-49, 19:14-20]. Here, the described scaler value corresponds to the claimed *speed adjustment factor*. [*Id.*] This is similar to Pierce, where a constant P that impacts angular velocity is multiplied by a scaler value ($\alpha_t - \alpha_d$), which is thus a *speed adjustment factor*, and the scaler ($\alpha_t - \alpha_d$) changes in magnitude based on the

deviation or difference of the target's yaw direction (α_t) from a current direction of movement that is the drone's yaw direction (α_d).

C. CLAIM 3

- 1. The method of claim 1, wherein performing the flight control operation includes one or more of the following: turning the reference aerial vehicle towards the target, adjusting a speed of the reference aerial vehicle, or engaging a mechanism to capture the target.**

198. Pierce describes that movement of its drone flight is controlled to track a moving target by “[u]sing a determined angular velocity 407 and linear velocity 411,” where control of the drone provides that it can “slow down [] in real-time and not overshoot the moving target if the moving target suddenly stops moving” (*performing the flight control operation includes one or more of the following:...adjusting a speed of the reference aerial vehicle....*). [EX1005, Abstract, ¶¶0035, 0037; EX1006, ¶¶0004, 0016, 0019, 0031.]

D. CLAIM 5

- 1. The method of claim 1, wherein detecting the target in the image includes identifying a bounding box outlining a portion of the image that includes detected features of the target.**

199. Pierce describes that an “input image 200 is passed through a neural network to produce a bounding box 208 around the head 206 of person 202” and further explains that vehicles such as cars can be detected and bounded with a box, where detected features of the head (e.g., mouth, eyes, etc.) and car (wheels, doors)

are outlined by the box (*detecting the target in the image includes identifying a bounding box outlining a portion of the image that includes detected features of the target*). [EX1005, ¶¶0002, 0028, 0031, Fig. 2; EX1006, ¶¶0001, 0027, 0028, Fig. 2; Section XVII.B.3 (element 1[c]).]

E. CLAIM 6

1. The method of claim 5, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on an area of the bounding box of the target within the image.

200. Pierce (incorporating Kumar) and the Pierce-Kumar combination each teach determining the relative position (x_0 , x_1 , x_2) of the target 106 with respect to drone 102 based on an image having a bounding box around the target (*determining the three-dimensional relative location of the target*), where the determination of (x_0 , x_1 , x_2) uses the “straight-line distance” value d , and this value d is determined using a value A that represents the “area of the box in pixels,” representing the area of a bounding box of a target object being tracked (*includes determining the distance to the target based on an area of the bounding box of the target within the image*). [EX1007, ¶¶0021, 0024-0025; EX1008, ¶¶0019, 0022-0023; Sections XVII.B.4 (element 1[d]), XVII.A.]

F. CLAIM 7

- 1. The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining the distance to the target based on a size of the target within the image and a physical size corresponding to an identified type for the target.**

201. Pierce (incorporating Kumar) and the Pierce-Kumar combination each teach determining the relative position (x_0 , x_1 , x_2) of the target 106 with respect to drone 102 based on an image having a bounding box around the target (*determining the three-dimensional relative location of the target*), where the determination of (x_0 , x_1 , x_2) uses the “straight-line distance” value d , and this value d is determined using a value A that represents the “area of the box in pixels,” representing the size of a target within the image in pixels (*includes determining the distance to the target based on a size of the target within the image*). [EX1007, ¶¶0021, 0024-0025; EX1008, ¶¶0019, 0022-0023; Section XVII.B.4 (element 1[d]).] Moreover, the value A is also based on “the approximate physical, diagonal size of [the] object[] within the box[]” that is told to the system so that a bounding box can identify objects (EX1007, ¶0019; EX1008, ¶0018); as such, the “straight-line distance” value d , which is determined using the value A , is determined based on physical size of the object corresponding to the type of target identified by the system (*and a physical size corresponding to an identified type for the target*).

[EX1007, ¶¶0019, 0021, 0024-0025; EX1008, ¶¶0018, 0019, 0022-0023; Section XVII.A.]

G. CLAIM 8

2. The method of claim 7 wherein performing the flight control operation includes determining a speed adjustment factor based on the determined distance to the target.

202. Pierce controls movement of its drone to track a moving target by “[u]sing a determined angular velocity 407 and linear velocity 411” (*performing the flight control operation*). [Section XVII.B.5 (element 1[e]).] Pierce further explains that “determining the linear velocity 411 of the drone includes using the...position of the moving target.” [EX1005, ¶0034; EX1006, ¶¶0019, 0030.] The following formula is used to calculate the linear velocity 411:

$$_ (v_d) = _ (v_t) + P * (_ x_t - _ (x_d))$$

where $_ (v_d)$ is the linear velocity of the drone, $_ (v_t)$ is the target’s estimated linear velocity, P is a constant, $_ (x_d)$ is the drone’s position, and $_ (x_t)$ is the target’s position. [EX1005, ¶¶0022-0025;¹⁰ EX1006, ¶¶0023-0025.] Pierce thus describes

¹⁰ Pierce also indicates use of an “offset position” $_ x_0$ is used to determine linear velocity but does not show this value as part of the $_ (v_d)$ equation; Pierce explains that linear velocity calculation uses distance to a target. [EX1005, ¶0034; EX1006, ¶¶0019, 0030.]

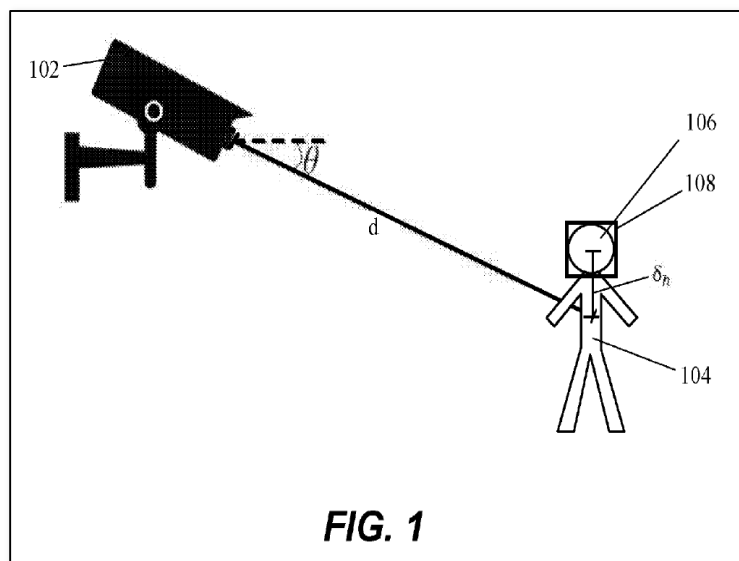
that by controlling drone movement using determined linear velocity, such control includes determining the difference between the target's and drone's positions, represented by $(x_t - x_d)$ (*wherein performing the flight control operation includes determining a speed adjustment factor*). [*Id.*] Pierce's $(x_t - x_d)$ value forms a *speed adjustment factor* because it is a factor that multiplies the constant P and thereby adjusts the linear velocity represented by $v_d = v_t + P(x_t - x_d)$. [*Id.*] And Pierce (incorporating Kumar) and the combination of Pierce and Kumar each provide that Pierce's position of the target x_t is the (x_0, x_1, x_2) relative position calculated using the "straight line distance" to the target object. [*See* Section XVII.B.4 (element 1[d]), XVII.F (claim 7); XVII.A.] Thus, the determined $(x_t - x_d)$ *speed adjustment factor*, which uses x_t , is, therefore, based on the determined straight-line distance to the target object (*determining a speed adjustment factor based on the determined distance to the target*). [*Id.*] Additionally, the value " $P(x_t - x_d)$ " is a *speed adjustment factor* as it too adjusts the v_d linear velocity of the drone, and it also uses x_t so is, therefore, based on the determined straight-line distance to the target object (*determining a speed adjustment factor based on the determined distance to the target*). [EX1005, ¶¶0022-0025; EX1006, ¶¶0023-0025.]

H. CLAIM 9**3. The method of claim 1, wherein determining the three-dimensional relative location of the target includes determining a direction of the target with respect to the reference aerial vehicle.**

203. Pierce (incorporating Kumar) and the Pierce-Kumar combination each teach determining a relative position (x_0, x_1, x_2) of the target 106 with respect to drone 102 using the following equation:

$$(x_0, x_1, x_2) = (\cos(\theta - \delta_h) * d, \sin(\delta_w) * d, -\sin(\theta - \delta_h) * d)$$

where θ is the “angle of the camera with the ground” (or more specifically, to the target as shown by Figure 1 below), and represents the direction of the target being tracked with respect to the camera, where the camera is located on the drone as taught by Pierce. [EX1005, ¶0027, Fig. 1; EX1006, ¶0026, Fig. 1; EX1007, ¶0024, Fig. 1; EX1008, ¶0022, Fig. 1. *See* Sections XVII.A, XVII.B.2, XVII.B.4.]



EX1007, Fig. 1; EX1008, Fig. 1

204. This target direction value θ is determined at least because it is obtained and used as an input to the equation above for calculating (x_0, x_1, x_2) . [*Id.*] Moreover, for the same reasons, it would have been obvious to a POSITA that the value θ is determined. [*Id.*] Indeed, to use the value, it would have been calculated or otherwise defined so that it can be used for calculating (x_0, x_1, x_2) , and so that such a calculation is accurate. [*Id.*]

205. Pierce (incorporating Kumar) and the Pierce-Kumar combination each teach that determining the relative position (x_0, x_1, x_2) of the target 106 with respect to drone 102 includes determining the angle θ that represents the direction of the target with respect to the drone's camera (*wherein determining the three dimensional relative location of the target includes determining a direction of the target with respect to the reference aerial vehicle*). [*Id.*]

I. CLAIM 15

4. The method of claim 1, wherein performing the flight control operation includes determining a direction adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.

206. Pierce describes that its flight control operation determines angular velocity (ω_d) which is determined based on yaw, pitch, and roll. [EX1005, ¶0023; EX1006, ¶0023; Section XVII.B.5 (element 1[e]).] The difference in target yaw angle and drone yaw angle ($\alpha_t - \alpha_d$) is a *speed adjustment factor* as discussed in

Section XVII.B.5. This difference in target yaw angle and drone yaw angle ($\alpha_t - \alpha_d$), along with the setting of the drone's pitch and roll to zero, further forms a determined *direction adjustment factor* because it defines the degree or factor of directional adjustment for the drone. [EX1005, ¶0023; EX1006, ¶0023.] The difference in target yaw angle and drone yaw angle ($\alpha_t - \alpha_d$) and zero pitch and roll values are *based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle* for the same reasons discussed in XVII.B.5. Moreover, direction is a known variable for maintaining the orientation between a moving vehicle and another object; Claim 15 thus describes a specific optimization of a known variable and is, therefore, obvious. [XVII.B.5.]

J. CLAIM 19

1. 19[a]: A reference aerial vehicle, comprising:

207. *See* Section XVII.B.1.

2. 19[b]: an image sensor configured to capture an image;

208. *See* Section XVII.B.2.

3. 19[c]: a processor configured to: detect a target in the image; and

209. *See* Section XVII.B.3. Pierce describes that its functionality can be implemented by “one or more processors” (*a processor configured to...*). [EX1005, ¶¶0006, 0007, 0017, 0038; EX1006, ¶0005, 0006, 0015, 0032, claims 11-30.]

4. **19[d]: [the processor configured to:] determine a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image; and**

210. See Section XVII.B.4. Pierce describes that its functionality can be implemented by “one or more processors” (*the processor configured to...*). [EX1005, ¶¶0006-0007, 0017, 0038; EX1006, ¶¶0005-0006, 0015, 0032, claims 11-30.]

5. **19[e]: a flight controller configured to perform a flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein the flight controller is configured to perform the flight control operation including by being configured to determine a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle.**

211. See Section XVII.B.5. Pierce’s system uses a “drone controller” to implement its described drone flight control to track a target using angular velocity 407 and linear velocity 411 (*a flight controller configured to...*). [EX1005, ¶¶0019, 0026-0028; EX1006, ¶¶0019, 0025-0027, claims 11-30.]

K. CLAIM 20

1. **20[a]: A computer program product for performing a flight control operation of a reference aerial vehicle, the computer program product being embodied in a non-transitory computer readable storage medium and comprising computer instructions for:**

212. *See* Section XVII.B.1. [EX1005, ¶¶0006, 0007; EX1006, ¶¶0005, 0006, claims 11-30.]

2. **20[b]: receiving an image captured by an image sensor of the reference aerial vehicle;**

213. *See* Section XVII.B.2.

3. **20[c]: detecting a target in the image including by applying a machine learning model to the image to identify a portion of the image that includes the target;**

214. *See* Section XVII.B.3.

4. **20[d]: determining a three-dimensional relative location of the target with respect to the reference aerial vehicle based on the image including by determining a distance to the target based at least in part on a size of the target detected within the image; and**

215. *See* Section XVII.B.4.

5. 20[e]: performing the flight control operation based on the three-dimensional relative location of the target with respect to the reference aerial vehicle, wherein performing the flight control operation includes determining a speed adjustment factor based on a magnitude of deviation of a direction of the three-dimensional relative location with respect to a current flight direction of the reference aerial vehicle

216. See Section XVII.B.5.

XVIII. GROUND 9 AND 10: PIERCE AND LAUFER RENDER OBVIOUS CLAIMS 2, 12, AND 18 (GROUND 9); PIERCE, KUMAR, AND KUMAR RENDER OBVIOUS CLAIMS 2, 12, AND 18 (GROUND 10)

A. MOTIVATION TO COMBINE PIERCE AND LAUFER/PIERCE, KUMAR, AND LAUFER

217. Pierce (incorporating Kumar) and the Pierce-Kumar combination teaches a drone control system that uses camera imaging to determine a relative position of a target and track the target. [See Section XVII.A (Motivation to Combine Pierce and Kumar).] Laufer teaches a system as described in Section XI.A (Motivation to combine Beard and Laufer).

218. A POSITA would have been motivated to combine Pierce and Laufer, as well as Pierce, Kumar, and Laufer. In the combinations, Pierce's drone 102 would have been brought to within an imaging range of a target aircraft using a radar-generated interception location and autopilot commands, and the drone would use image-based flight control when within the imaging range, as taught by Laufer. Drone 102 would also be specified as a multirotor drone.

219. Pierce’s system addresses a “need for better and more efficient drone tracking systems that provide smooth object tracking.” [EX1005, ¶0003; EX1006, ¶0002.] Kumar’s teachings address a “need for distance estimation of an object no matter how far the object is from the observer, as long as the object appears in the camera used by the observer,” improving accuracy over prior techniques that “may not be accurate.” [EX1007, ¶0003; EX1008, ¶0002.] Laufer furthers both of these aspects by teaching a technique for tracking a target when an object *does not* appear in a camera frame—i.e., by using data from doppler radar to determine an interception location and generating autopilot aircraft commands that bring the drone to such a location and allow it to track the target using imaging—improving efficiency of the Pierce/Pierce-Kumar combined system and providing additional flexibility. [EX1010, ¶¶0022-0031, 0038-0044, Figs. 1, 4.] Indeed, instead of the Pierce/Pierce-Kumar system inefficiently attempting the use of imaging to track a target when the target is not visible, Laufer teaches a technique by which the drone can move to a location so it regains visibility of the target, overcoming these inefficiencies. [*Id.*] Moreover, the combination allows Pierce’s drone to track a target over a much larger volume of space, including when it loses visibility of a target. [*Id.*]

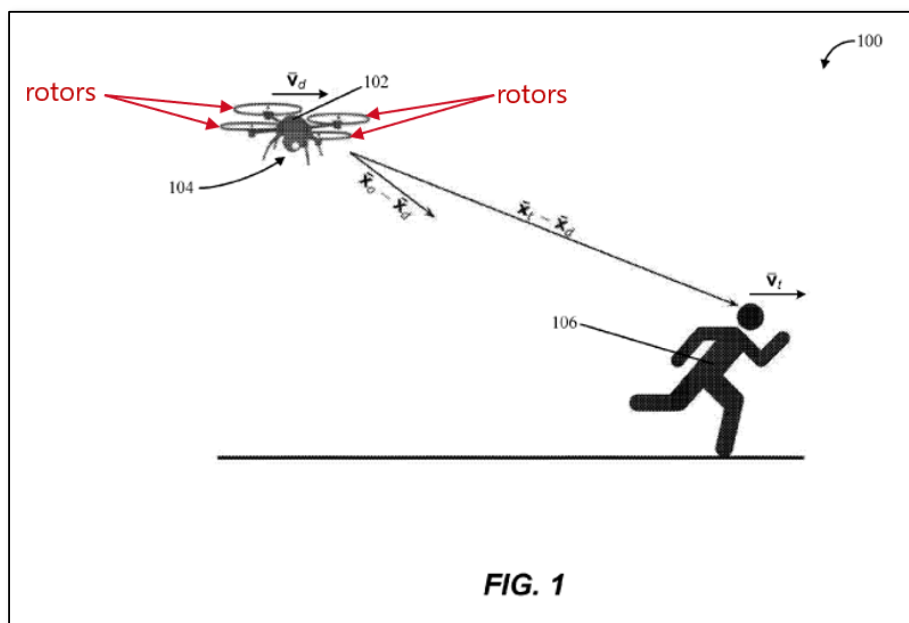
220. Moreover, while Pierce also arguably shows that its drone 102 is a multirotor drone in Figure 1, Laufer simply specifies implementation details that the

drone is a “quadcopter drone[,]” or a multi-rotor drone such as the DJI S1000+. [EX1010, ¶0025.] Pierce further suggests Laufer’s teaching of tracking a drone aircraft, noting that objects for tracking include vehicles. [EX1005, ¶¶0003, 0031, Fig. 1; EX1006, ¶¶0002, 0028, Fig. 1.]

221. Enhancing Pierce/the Pierce-Kumar combination, as discussed above, would have been routine and straightforward. Indeed, the combination simply would have entailed programming Pierce’s system such that its drone implements the techniques discussed above, and specifying that the drone is a multicopter drone. Effectuating this would have been well within the capabilities of a POSITA because radar and quadrotor drones were well-known. The results of the combination would have been predictable: Pierce’s drone 102 would be a multicopter drone, and would be brought to within an imaging range of a target aircraft using a radar-generated interception location and autopilot commands. Furthermore, the drone would use image-based flight control when within the imaging range. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination. [*Id.*] Further expectation of success would come from a POSITA knowing that radar was well understood and widely used for aerospace applications.

B. CLAIM 2**6. The method of claim 1, wherein the reference aerial vehicle is a multirotor unmanned aerial vehicle and the target is an aerial vehicle.**

222. As shown by annotated Figure 1 below, Pierce teaches that drone 102 includes four rotors (*wherein the reference aerial vehicle is a multirotor unmanned aerial vehicle*). [EX1005, Fig. 1; EX1006, Fig. 1.]



EX1005, Fig. 1; EX1006, Fig. 1 (annotated)

223. The Pierce-Laufer/Pierce-Kumar-Laufer combinations further teach that Pierce's drone 102 is a drone having multiple rotors (e.g., a quadcopter drone) (*wherein the reference aerial vehicle is a multirotor unmanned aerial vehicle*), and that the target tracked by drone 102 is an aircraft (*and the target is an aerial vehicle*).

[Section XVIII.A (Motivation to Combine Pierce and Laufer/Pierce, Kumar, and Laufer).]

C. CLAIM 12

7. The method of claim 1, wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location.

224. In the Pierce-Laufer/Pierce-Kumar-Laufer combinations, Laufer teaches that doppler radar signals generated by ground-based doppler radars (e.g., the “Laufer Wind MD-12”) are used to determine, and thereby receive, an “interception location” where drone 102 and the target will intercept (*receiving a geographical location associated with the target detected at least in part using a ground-based sensor*). [EX1010, ¶¶0001, 0022-0031, 0038-0049, Fig. 1; EX1012 (referring to “up-tower maintenance” of an MD-12 doppler radar, demonstrating the radar is on a tower attached to the ground); EX1013, 5-8, Fig. 5 (showing MD-12 radars mounted to a “man-lift” on the ground); Section XVIII.A (Motivation to Combine Pierce and Laufer/Pierce, Kumar, and Laufer).] In the combinations, drone 102 is brought to within an imaging range of the target using an interception location and autopilot commands (*autonomously navigating the reference aerial vehicle towards the received geographical location*). [EX1010, ¶¶0022-0031, 0038-0040, Fig. 4; Section XVIII.A (Motivation to Combine Pierce and Laufer/Pierce, Kumar, and Laufer).] Then, when the target is within an adequate range of drone 102’s

camera, drone 102 is controlled using captured image or video data to track the target *(and determining to allow image-based navigation)*. [EX1010, ¶¶0022-0031, 0038-0044, Figs. 1, 4; Section XVIII.A (Motivation to Combine Pierce and Laufer/Pierce, Kumar, and Laufer), XVII.B.5 (element 1[e]).]

D. CLAIM 18

8. The method of claim 1, wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location

225. See Section XVIII.C (claim 12). Moreover, as combined with Laufer, the drone 102 of the Pierce-Laufer/Pierce-Kumar-Laufer combinations implements its image-based flight control to track the target when the target is determined to be within imaging range of drone 102, the range being a threshold distance away from the interception location with the target *(wherein it is determined to allow the image-based navigation based on whether the reference aerial vehicle is within a threshold distance away from the received geographical location)*. [*Id.*; EX1010, ¶¶0040-0044; Section XVIII.A (Motivation to Combine Pierce and Laufer/Pierce, Kumar, and Laufer).]

XIX. GROUNDS 11 AND 12: PIERCE AND KHAN RENDER OBVIOUS CLAIM 4 (GROUND 11); PIERCE, KUMAR, AND KHAN RENDER OBVIOUS CLAIM 4 (GROUND 12)

A. MOTIVATION TO COMBINE PIERCE AND KHAN/PIERCE, KUMAR, AND KHAN

226. Pierce (incorporating Kumar) and the Pierce-Kumar combination teaches Pierce’s drone detects target vehicles captured in images using a neural network. [Section XVII.B.3 (element 1[c]).] Khan teaches a computer vision system used by UAVs that classifies detected vehicles by “vehicle model type.” [EX1021, 0003-0004, 0009-0015, 0025, 0044-0045, 0048-0049, 0053-0062, Fig. 6.]

227. A POSITA would have been motivated to combine Pierce and Khan, as well as Pierce, Kumar, and Khan. In the combination, the detection of target vehicles in captured images by Pierce’s drone 102 would include identifying a model type of each vehicle, as taught by Khan. Pierce already suggests the combination, explaining that its system detects vehicle targets. [EX1005, ¶¶0002, 0028, 0030-0031, Fig. 2; EX1006, ¶¶0001, 0027, 0028, Fig. 2.] Khan thus comports with Pierce, specifying how such vehicles should be classified (i.e., by vehicle model type) during detection. [EX1021, 0003-0004, 0009-0015, 0025, 0044-0045, 0048-0049, 0053-0062, Fig. 6.]

228. Moreover, Khan explains that “the problem of object classification has received considerable attention from both the computer vision and machine learning communities.” [EX1021, ¶0004.] As noted, Pierce (incorporating Kumar) and the Pierce-Kumar combination describes Pierce’s drone detecting target vehicles in

captured images using a neural network. [Section XVII.B.3 (element 1[c]).] Thus, a POSITA would have looked to enhance Pierce/the Pierce-Kumar combination with Khan's model-type object classification teachings, providing that Pierce/the Pierce-Kumar combined system identifies model type when detecting target objects.

229. Enhancing Pierce/the Pierce-Kumar combination as discussed above would have been routine and straightforward. The combination simply would have entailed programming Pierce/the Pierce-Kumar system such that its drone implements the detection techniques discussed above. Effectuating this would have been well within the capabilities of a POSITA because object classification was well-known. The results of the combination would have been predictable: the detection of target vehicles in captured images by Pierce's drone 102 would include identifying a model type of each vehicle, as taught by Khan. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination.

B. CLAIM 4

1. The method of claim 1, wherein detecting the target in the image includes identifying a model type of the target.

230. The Pierce-Khan/Pierce-Kumar-Khan combinations teach the detection of target vehicles in captured images by Pierce's drone 102 includes identifying a model type of each target vehicle (*wherein detecting the target in the image includes*

identifying a model type of the target). [Section XIX.A (Motivation to Combine Piece and Khan/Pierce, Kumar, and Khan).]

XX. GROUND 13 AND 14: PIERCE AND HOGASTEN RENDER OBVIOUS CLAIM 17 (GROUND 13); PIERCE, KUMAR, AND HOGASTEN RENDER OBVIOUS CLAIM 17 (GROUND 14)

A. MOTIVATION TO COMBINE PIERCE AND HOGASTEN/PIERCE, KUMAR, AND HOGASTEN

231. In Pierce (incorporating Kumar) and the Pierce-Kumar combination, Kumar describes determining “straight-line distance [] between the object and the camera.” Section XVII.B.4 (element 1[d]). Hogasten teaches a system as described in Section XVI.A (Motivation to Combine Beard, Laufer, and Hogasten).

232. A POSITA would have been motivated to combine Pierce and Hogasten, as well as Pierce, Kumar, and Hogasten. The combination would have specified that Pierce’s drone 102 calculates its distance to a target utilizing radar and associated output radar distance measurements as taught by Hogasten. [Section XVII.B.4 (element 1[d]).] A POSITA would have been motivated to combine Pierce and Hogasten/Pierce, Kumar, and Hogasten in this manner to allow for “quickly and accurately determin[ing] an environment around” Pierce’s drone 102. [*Id.*; EX1022, ¶0003; EX1023, ¶0002.] Hogasten explains that providing such quick and accurate determinations is “particularly desirable” for autonomous vehicles, such as drone 102. [*Id.*] Thus, by using Hogasten’s radar and its output distance measurements, the Pierce/Pierce-Kumar systems would have had increased speed and accuracy in target

detection and distance determinations within captured images. [*Id.*; XVII.B.4 (element 1[d]).]

233. Hogasten also already suggests such a combination, teaching that its radar is used in conjunction with thermal imaging sensors to effectuate object detection. [EX1022, ¶0015, Fig. 1; EX1023, ¶0014, Fig. 1.] Combined with Pierce/Pierce and Kumar, Hogasten's radar would have similarly complemented the camera of Pierce's drone 102 to effectuate object detection and improve accuracy. [*Id.*; XVII.B.4 (element 1[d]).]

234. Enhancing Pierce/the Pierce-Kumar combination as discussed above would have been routine and straightforward. The combination would have entailed providing Pierce's drone 102 with radar capabilities and the ability to use radar distance measurements, which would have been readily performed by a POSITA because radar was well-known. And the results of the combination would have been predictable: Pierce's drone 102 calculates its distance to a target utilizing radar and associated output radar distance measurements as taught by Hogasten. And for at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success in making the combination. Further expectation of success would come from a POSITA knowing that radar was well understood and widely used for aerospace applications.

B. CLAIM 17**1. The method of claim 1, wherein the distance to the target is determined based at least in part using a radar.**

235. The Pierce-Hogasten/Pierce-Kumar-Hogasten combinations teach that Pierce's drone 102 calculates its distance to a target based on utilizing radar and associated output radar distance measurements (*wherein the distance to the target is determined based at least in part using a radar*). [XVII.B.4 (element 1[d]); Section XX.A (Motivation to Combine Pierce and Hogasten/Pierce, Kumar, and Hogasten).]

XXI. GROUND 15 AND 16: PIERCE AND AND SAHASRABUDHE RENDER OBVIOUS CLAIMS 1, 3, 5-9, 14-16, AND 19-20 (GROUND 15); PIERCE, KUMAR, AND SAHASRABUDHE RENDER OBVIOUS CLAIMS 1, 3, 5-9, 14-16, AND 19-20 (GROUND 16)

A. MOTIVATION TO COMBINE PIERCE AND SAHASRABUDHE/PIERCE, KUMAR, AND SAHASRABUDHE

236. Pierce controls movement of its drone to track a moving target using linear velocity 411 and angular velocity 407. [Section XVII.B.5 (element 1[e]).] Angular velocity 407 is calculated according to $\omega_d = (P(\alpha_t - \alpha_d), 0, 0)$, where ω_d is the "angular velocity vector of the drone," " α_t is the yaw angle of the target and α_d is the yaw angle of the drone," and P is a constant; "yaw velocity" is represented by " $P(\alpha_t - \alpha_d)$." [Section XVII.B.5 (element 1[e]).] The angular velocity is defined by a difference in target yaw angle and drone yaw angle ($\alpha_t - \alpha_d$), along with the setting of the drone's pitch and roll values to zero. [*Id.*; Section XVII.I (Claim 15).]

237. Linear velocity 411, which is $\underline{(v_d)}$, is scaled or modified by the value $\underline{(v_t)}$, the target's estimated linear velocity, as this value is added to $P^*(\underline{x_t} - \underline{(x_d)})$. [See XVII.G (claim 8); EX1001, 18:65-19:7 (referring to “scaling” as including “modifying”); EX1005, ¶¶0003, 0020, 0025-0026, 0036, Fig. 4B; EX1006, ¶¶0002, 0021, 0025, 0031, Fig. 4B.]

238. Sahasrabudhe teaches the system discussed in Section XV.A (Motivation to Combine Beard, Laufer, and Sahasrabudhe). Sahasrabudhe further explains that determined flight corrections may impose “overaggressive inputs” and “harsh corrections” that might endanger an aircraft. [EX1025, ¶0019.] Thus, Sahasrabudhe teaches to apply a limit to determined flight corrections and the “rate” of such corrections to ensure that aircraft safety is preserved. [*Id.*]

239. A POSITA would have been motivated to combine Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe. First, the combinations would have provided that Pierce's angular velocity $\underline{(\omega_d)}$, yaw velocity $P(\alpha_t - \alpha_d)$, and/or pitch and roll values are compared to a correction limit and limited if they exceed the limit, and that the rate of such commands is limited, as taught by Sahasrabudhe. Second, the combinations would have provided that Pierce's linear velocity 411 $\underline{(v_d)}$ is scaled or modified by the value $\underline{(v_t)}$ and similarly compared to a correction limit and limited if it exceeds the limit, thereby ensuring that Pierce's drone control is smooth and subject to a correction limit that limits a “rate” of changing speed.

[EX1005, ¶¶0003, 0020, 0025-0026, 0036, Fig. 4B; EX1006, ¶¶0002, 0021, 0025, 0031, Fig. 4B; EX1025, ¶0019.] A POSITA would have been motivated to make this combination because Sahasrabudhe explains that its correction limits “limit the amount of correction available” and also “limit[] the rate of such commands,” to “preserve safety of the aircraft” and avoid flight corrections that are “harsh” and “might endanger the aircraft.” [EX1025, ¶0019.] Sahasrabudhe’s teachings, therefore, benefit Pierce, ensuring its flight control using determined angular and linear velocities does not operate too aggressively and jeopardize aircraft safety. [*Id.*] Moreover, Pierce explains that its drone’s linear velocity $_ (v_d)$ is modified by the target’s linear velocity $_ (v_t)$ so the drone does not exhibit “‘jumpy’ behavior” and “movement of the drone relative to the target” is “smoother.” [EX1005, ¶¶0003, 0020, 0025-0026, 0036, Fig. 4B; EX1006, ¶¶0002, 0021, 0025, 0031, Fig. 4B.] Enhancing Pierce with Sahasrabudhe’s correction limiting teachings would have furthered Pierce’s goal of smooth drone movement, ensuring that the drone does not initiate harsh or overaggressive velocity and/or directional corrections. [EX1025, ¶¶0017-0019.]

240. These combinations discussed above would have been routine and straightforward. They would have entailed programming Pierce/the Pierce-Kumar system such that the control parameters discussed above are limited as taught by Sahasrabudhe. Effectuating this would have been well within the capabilities of a

POSITA because preventing control parameters from exceeding safety or operational limits was well-known. The results of the combination would have been predictable: Pierce's angular velocity (ω_d), yaw velocity $P(\alpha_t - \alpha_d)$, and/or pitch and roll values being compared to a correction limit and limited if they exceed the limit, and that the rate of such commands being limited; and Pierce's linear velocity 411 (v_d) being scaled or modified by the value v_t , and being compared to a correction limit and limited if it exceeds the limit. *See* EX1028. For at least the same reasons discussed above, a POSITA would have had a reasonable expectation of success.

B. CLAIMS 1, 19, AND 20

241. Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe teach elements 1[a]-1[e], 19[a]-19[e], and 20[a]-20[e] for the reasons discussed in Section XVII.B.1-XVII.B.5 (elements 1[a]-1[e]), XVII.J.1-XVII.J.5, and XVII.K.1-XVII.K.5. Further regarding elements 1[e], 19[e], and 20[e], Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe teaches that the yaw velocity $P(\alpha_t - \alpha_d)$ is compared to a correction limit and limited if it exceeds the limit. Section XXI.A (Motivation to Combine Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe). This provides that the limited yaw velocity $P(\alpha_t - \alpha_d)$ is a *speed adjustment factor* as claimed because (1) it reflects the determined yaw velocity $P(\alpha_t - \alpha_d)$ that has been limited, and (2) the limited yaw velocity $P(\alpha_t - \alpha_d)$ adjusts the

angular velocity (ω_d) of Pierce's drone. [Sections XXI.A; XVII.B.5 (element 1[e])]. This limited yaw velocity is consistent with the '711 Patent's description of one example of the "factor used to control speed" that includes limiting its value. EX1001, 19:36-44.

C. CLAIMS 3, 5-9, AND 15

242. Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe teach claims 3, 5-9, and 15 for the same reasons discussed in Sections XVII.C-I.

D. CLAIM 14

- 1. The method of claim 1, wherein performing the flight control operation includes scaling a speed adjustment factor to smooth and limit a rate of change of a speed of the reference aerial vehicle.**

243. The Pierce-Sahasrabudhe/Pierce-Kumar-Sahasrabudhe combination teaches scaling or modifying Pierce's linear velocity 411 (v_d) by the value v_t and a correction limit that is applied to the linear velocity; using v_t in the calculation of linear velocity v_d ensures smooth movement of drone 102 and that the drone does not exhibit "jumpy" behavior", and applying the correction limit to the linear velocity provides that the "rate" of changing speed is limited to preserve aircraft safety (*performing the flight control operation includes scaling a speed adjustment factor to smooth and limit a rate of change of a speed of the reference aerial vehicle*). [See Section XXI.A (Motivation to Combine Pierce and

Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe).] Moreover, Claim 14 describes a specific optimization of a known variable and is therefore obvious. [Section XI.B.5.]

E. CLAIM 16

- 1. The method of claim 15, wherein performing the flight control operation includes scaling the direction adjustment factor to smooth and limit a rate of change of a direction of the reference aerial vehicle.**

244. In the Pierce-Sahasrabudhe/Pierce-Kumar-Sahasrabudhe combinations, drone movement is smooth and correction limits are applied to the determined difference in target and drone yaw values, pitch value, and roll value to limit the rate of such commands and preserve aircraft safety (*wherein performing the flight control operation includes scaling the direction adjustment factor to smooth and limit a rate of change of a direction of the reference aerial vehicle*). [See Sections XXI.A (Motivation to Combine Pierce and Sahasrabudhe/Pierce, Kumar, and Sahasrabudhe); XVII.B.5 (element 1[e]); XVII.I (Claim 15).] Moreover, Claim 16 describes a specific optimization of a known variable and is therefore obvious. [Sections XI.B.5; XVII.I (Claim 15).]

XXII. GROUNDS 17-22

245. Pierce, Sahasrabudhe, and Laufer (Ground 17)/ Pierce, Kumar, Sahasrabudhe, and Laufer (Ground 18) render obvious Claims 2, 12, and 18 for the same reasons discussed in Section XVIII.A-D.

246. Pierce, Sahasrabudhe, and Khan (Ground 19)/ Pierce, Kumar, Sahasrabudhe, and Khan (Ground 20) render obvious Claim 4 for the same reasons discussed in Section XIX.A-B.

247. Pierce, Sahasrabudhe, and Hogasten (Ground 21)/Pierce, Kumar, Sahasrabudhe, and Hogasten (Ground 22) render obvious Claim 17 for the same reasons discussed in Section XX.A-B.

XXIII. SECONDARY CONSIDERATIONS

248. I am not aware of any evidence of secondary considerations that would support a finding of non-obviousness of the '711 Patent. Should the Patent Owner put forth any alleged evidence of secondary considerations, I reserve the right to consider such evidence, to consider whether any such evidence has a nexus to any claims of the '711 Patent, and to update my analysis.

XXIV. CONCLUSION

249. All statements made herein of my own knowledge are true, and all statements made on information and belief are believed to be true. I further understand that willful false statements and the like are punishable by fine or imprisonment, or both under Section 1001 of Title 18 of the United States Code. I declare under penalty of perjury that the foregoing is true and correct.

Executed on February 23, 2025.

A handwritten signature in black ink, appearing to read "William Singhose", written over a horizontal line.

Dr. William Singhose

APPENDIX A

Professor William Singhose, PhD

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I. Earned Degrees

1997, Ph.D. Mechanical Engineering, Massachusetts Institute of Technology
1992, M.S. Mechanical Engineering, Stanford University
1990, B.S. Mechanical Engineering, Massachusetts Institute of Technology

II. Employment History

Georgia Institute of Technology (8/98 – present) Atlanta, GA
Professor of Mechanical Engineering (2014-Present). Associate Professor (2004-2014). Assistant Professor (1998-2004). Director of Crane Safety Research Center (2023-Present). Head of Automation and Mechatronics Group (2006-2010). Develop curriculum and teach courses in mechanical design, dynamics, controls, and rehabilitation engineering. Develop research programs and proposals. Direct research of graduate students, undergraduate students, and postdoctoral researchers in the areas of dynamics, vibration suppression, robotics, spacecraft, crane control, flight control, active seating technology, and product design. Advise SME, ASME, and CanSat student groups. Held visiting appointments at MIT, Stanford, the Tokyo Institute of Technology, and Polytechnic University of Madrid.

InVekTek, Inc. (12/15 – present) Atlanta, GA
Co-Founder and CTO. Develop and commercialize control systems for robotic and industrial material-handling systems. The control systems are embedded in motor drives to reduce unwanted machine motion.

Google, Inc. (9/17 – 12/19) Mountain View, CA
Pennington Advisor mechanical engineer to Google's augmented reality (Daydream) and Advanced Technology and Projects (ATAP) facilities. Performed mechanical design and analysis of hand-held consumer electronic products and wearable devices. Performed failure and hazard analyses. Directed and performed research activities on human-motion measurement, human-machine interactions, actuation system design, and activity monitoring.

Stanford University (3/18 – 7/19) Stanford, CA
Visiting Professor in the Department of Mechanical Engineering. Delivered lectures on product design, safety analysis, and sensors. Advised student design teams.

CAMotion Cranes, Inc. (9/08 – 11/2013) Atlanta, GA
Co-Founder and Board Member. Developed and commercialized crane-control technology. Controllers improve crane safety, throughput, and ease of operation. Sold company to PaR Systems in Nov. 2013.

Massachusetts Institute of Technology (9/10 – 6/11) Cambridge, MA
Taught graduate-level controls course. Supervised research projects. Developed textbook on command-shaping control methods.

Polytechnic University of Madrid (5/10 – 8/10) Madrid, Spain
Taught course in manufacturing controls. Supervised construction of experimental equipment. Developed international collaborative research projects.

Tokyo Institute of Technology (10/05 – 4/06) Tokyo, Japan
Visiting Associate Professor in Center of Excellence in Robotics. Taught advanced control course. Conducted experiments with robotic crane. Developed research proposals with Japanese collaborators.

Massachusetts Institute of Technology (6/97 – 7/98) Cambridge, MA
Postdoctoral Fellow in the NSF Center for Innovation in Product Development. Directed the development of an internet-controlled machine. Conducted research in design process optimization. Taught senior-level design course.

Convolve, Inc. (4/92 - 8/94) Armonk, NY
Managed NSF sponsored project investigating techniques for inspecting manufactured parts using measurement robots. Developed computer simulations of manufacturing robots, coordinate measuring machines, car seats, and NASA weather balloons. Designed control systems for automated machines. Designed data acquisition system using a laser interferometer.

Apple Computers, Inc. (6/91 - 3/92) Santa Clara, CA
Designed and performance evaluation tests for the Audio-Visual 14" Monitor. Designed and constructed test equipment. Organized, interpreted and reported test results produced by product evaluation team. Made design recommendations based on test results and dynamic simulations.

Walt Disney World (5/90-8/90) Orlando, FL
Designed components for the Space Mountain rehabilitation project. Performed failure analysis and developed design changes for Star Tours and Body Wars simulators. Performed stress analysis of the Star Jets base plate and specified welds. Designed IR sensor mount and cable management for the Norway Pavilion water ride. Formulated repair procedures for Pirates of the Caribbean roller bearings.

Artificial Intelligence Laboratory (12/87 - 6/90) Cambridge, MA
Developed computer simulations of flexible robots. Performed research on command-shaping methods to eliminate vibration in computer controlled machines. Performed robotic experiments to verify controller's robustness to modeling errors and changing configurations. Verified new control theory by performing simulations of the space shuttle's robotic arm. The control methods were tested on-orbit in Space Shuttle Endeavour.

Cable News Network (Summer '89) Atlanta, GA
AAAS Mass Media Science and Engineering Fellow. Wrote several stories for CNN Science and Technology. Field producer on stories covering the Starship 1 aircraft and

an international climate study. Produced a story reporting on a car seat that lowers impact forces during head-on collisions.

Riverside Cement Company (Summer '88) Riverside, CA
Cement lab technician. Designed and performed experiments to test mechanical properties of cement. Operated a wide range of equipment including forklifts, cement pumps, sand sifters, trucks, climatic test chambers, and compression testing machines.

Bill's Asphalt Repair (8/85-8/87) Springfield, OR
Developed bids and executed construction projects involving asphalt and concrete structures. Operated heavy machinery including: dump trucks, paving machines, steam rollers, and compactors.

III. Honors and Awards

Academic

- 2015 Asian Control Conference, Best Application Paper Finalist
- 2013 Zeigler Woodruff School Outstanding Educator Award
- 2009 Georgia Tech SAIC Student Paper Contest Winner, Graduate Division
- 2006 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 2004 CETL Educational Partnership Award
- 2003 SME Jiri Tlustý Outstanding Young Manufacturing Engineer Award
- 2002 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 2002 CETL/BP Junior Faculty Teaching Excellence Award
- 2002 Japan Society for the Promotion of Science Invitation Fellowship
- 2001 Georgia Tech SAIC Student Paper Contest Winner, Undergraduate Division
- 1996 Massachusetts Space Grant Fellowship
- 1990 Office of Naval Research Fellowship
- 1990 Phi Beta Kappa
- 1989 AAAS Mass Media Science and Engineering Fellowship
- 1989 Tau Beta Pi
- 1989 Pi Tau Sigma

Academic and Athletic

- 1990 The GTE Academic All-American, Collegiate Division (only one award nationally each year)
- 1990 NCAA Postgraduate Scholarship
- 1990 NACDA/Walt Disney Scholar-Athlete Award

Athletic

- 1989 NCAA Division III National Decathlon Champion
- 1990 New England Division III Athlete of the Year
- 1990 All New England Field Athlete of the Year
- 1988-1990 NCAA Division III All-American (8-Times)

IV. Research, Scholarship, and Creative Activities

A. Published Books, Book Chapters, and Edited Volumes

- [1] J. Vaughan and W. Singhose, "Advances in Delays and Dynamics at Springer," in *The Influence of Time Delay on Crane Operator Performance*. 2014
- [2] W. Singhose, "Trajectory Planning for Flexible Robots," in *CRC Robotics and Automation Handbook*, T. Kurfess, Ed.: CRC Press, 2004.
- [3] W. Singhose and W. Seering, "Control of Flexible Manipulators with Input Shaping Techniques," in *Flexible Robot Manipulators: Modelling, Simulation and Control*, M. O. Tokhi and A. K. M. Azad, Eds. Stevenage, UK: The Institution of Engineering and Technology, 2008, pp. 235-257.
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- [6] W. Singhose and W. Seering, *Command Generation for Dynamic Systems*: www.lulu.com/content/621219, 978-0-9842210-0-4, 2010.
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B. Refereed Publications and Submitted Articles

Journal Articles

- [1] W. Singhose, W. Seering, and N. Singer, "Residual Vibration Reduction Using Vector Diagrams to Generate Shaped Inputs," *ASME J. of Mechanical Design*, vol. 116, no. June, pp. 654-659, 1994.
- [2] W. Singhose, K. Bohlke, and W. Seering, "Fuel-Efficient Pulse Command Profiles for Flexible Spacecraft," *AIAA J. of Guidance, Control, and Dynamics*, vol. 19, no. 4, pp. 954-960, 1996.
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- [6] L. Y. Pao and W. E. Singhose, "Verifying Robust Time-Optimal Commands for Multi-Mode Flexible Spacecraft," *AIAA J. of Guidance, Control, and Dynamics*, vol. 20, no. 4, pp. 831-833, 1997.
- [7] W. Singhose, A. Banerjee, and W. Seering, "Slewing Flexible Spacecraft with Deflection-Limiting Input Shaping," *AIAA J. of Guidance, Control, and Dynamics*, vol. 20, no. 2, pp. 291-298, 1997.
- [8] W. Singhose and L. Pao, "A Comparison of Input Shaping and Time-Optimal Flexible-Body Control," *IFAC Control Engineering Practice*, vol. 5, no. 4, pp. 459-467, 1997.
- [9] W. Singhose, L. J. Porter, T. D. Tuttle, and N. C. Singer, "Vibration Reduction Using Multi-Hump Input Shapers," *ASME J. Dynamic Systems, Measurement, and Control*, vol. 119, no. June, pp. 320-326, 1997.
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- [15] N. C. Singer, W. E. Singhose, and W. P. Seering, "Comparison of Filtering Methods for Reducing Residual Vibration," *European Journal of Control*, vol. 5, no. 2, pp. 208-219, 1999.
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- [399] D. Frakes and W. Singhose, "Geometrically Constrained Optical-flow Based Tracking for the Extraction of Kinematic Data from Video," in *Fifth Int. Symp. on Computer Methods in Biomechanics and Biomedical Engineering*, Rome, Italy, 2001.
- [400] K. Kozak, I. Ebert-Uphoff, P. A. Voglewede, and W. Singhose, "Concept Paper: On the Significance of the Lowest Linearized Natural Frequency of a Parallel Manipulator as a Performance Measure for Concurrent Design," in *Workshop on Fundamental Issues and Future Research Directions for Parallel Mechanisms and Manipulators*, Quebec City, Quebec, Canada, 2002.
- [401] E. Ooten-Biediger and W. Singhose, "Command Generation for Trajectory Planning of Coordinating Satellites," in *University Space Systems Symposium*, Honolulu, HI, 2002.
- [402] M. Robertson and W. Singhose, "Deflection-Limiting Control of Flexible Spacecraft Using On-Off Thrusters," in *University Space Systems Symposium*, Honolulu, HI, 2002.
- [403] E. Biediger and W. Singhose, "Formation Flying Satellite Control Utilizing Input Shaping," in *AIAA/AAS Astrodynamics Specialist Conf.*, Big Sky, Montana, 2003.
- [404] E. Biediger, W. Singhose, D. Frakes, M. Kashiwa, and S. Matunaga, "An Investigation of Video Tracking on a Formation Flying Satellite Testbed," in *AIAA/AAS Astrodynamics Specialist Conf.*, Big Sky, Montana, 2003.
- [405] W. Singhose, M. Robertson, T. Watanabe, H. Kojima, and A. Banerjee, "Tether-Based Actuators for Space Applications," in *2003 International Workshop on Advanced Sensors, Structural Health Monitoring, and Smart Structures*, Yokohama, Japan, 2003.
- [406] T. Watanabe, T. Makida, H. A. Fujii, H. Kojima, and W. Singhose, "An Application of Input Shaping for Electrodynamic Tether System," in *AIAA/AAS Astrodynamics Specialist Conference*, Providence, Rhode Island, 2004.

- [407] A. Banerjee, W. Singhose, and D. Blackburn, "Orbit Boosting of an Electrodynamic Tethered Satellite with Input-Shaped Current," in *AAS/AIAA Astrodynamics Specialist Conference*, Lake Tahoe, CA, 2005.
- [408] W. Singhose and D. Kim, "Robustness of Command-Shaping Control on Flexible Systems," in *Spring Research Conference on Statistics in Industry and Technology*, Chicago, IL, 2011.

D. Presentations

Keynote and Plenary Lectures

6/8/23 "Hazard Analysis of Mobile Juvenile Products," International Forum on Automotive and Mechanical Engineering (MECHFORUM2023)

9/23/15 "Dynamics and Control of Crane Payload Lift-off and Lay-Down Operations," XXI Triennial Int. Conference on Material Handling, Constructions, and Logistics, Vienna, Austria

10/27/14 "Using Mechatronics to Improve Human Operation of Complex Dynamic Systems," International Conference on Mechanics and Control Engineering, Asheville, NC

10/18/12 "Improving Human Operation of Oscillatory Dynamic Systems," International Conference on Control, Automation and Systems, Jeju, South Korea

10/19/06 "Crane Oscillation Control: Applications and Educational Uses," International Conference on Material Handling, Constructions, and Logistics, Belgrade, Serbia

Other Invited Lectures

3/2/20 "Legal Considerations of Sensor use in Emerging Technology," Google, Mountain View, CA

4/24/19 "Ethical Considerations of Sensor Use," Stanford University, Palo Alto, CA

11/29/18 "Killer Robots: Why You Will not be Owning a Self-Driving Car," Stanford University, CA

10/12/18 "Georgia Tech ARLISS Team", University of Oregon, Eugene, OR

2/26/18 "Command Generation for Flexible Systems," University of California, Berkeley, Berkeley, CA

10/3/16 "Oscillation Control Using Input Shaping Technology," Hankyong University, Anseong, South Korea

9/29/16 "Input Shaping Control Technologies", Shanghai Jiao Tong University, Shanghai, China

4/21/16 "Improving Manufacturing Machines with Command Shaping," Mercedes Manufacturing Facilities, Vance, AL

1/25/16 "Commercialization of University-Developed Technology," University of Chicago Booth School of Business, Chicago, IL

9/25/15 "Applications of Input Shaping Control Methods," Czech Technical University, Prague, Czech Republic

3/25/15 "Oscillation Control of Suspended Loads Using Command Shaping," Boeing BR&T – Vertical Lift, Mesa, AZ

1/22/15 "Building a Culture of Active Learning in Mechatronics," Kumoh National Institute of Technology, Gumi, South Korea

1/19-1/23/15 "Special Lectures on Mechatronics by Foreign Distinguished Professor," Kumoh National Institute of Technology, Gumi, South Korea

9/26/14 "Building a Culture of Active Learning", Georgia Tech Zeigler Lecture

8/4/14 "NI myRIO Design Real Systems, Fast: 2014 Student Project Success", Panelist, NI Week, Austin, TX

3/19/14 "Input Shaping for Oscillation Reduction in the Digital World", Auburn University

11/16/13 "Improving Machine Motion with Command Shaping", Wuxi Zhong Ding Logistics, Wuxi, China

11/14/13 "Improving Manufacturing Machines with Command Shaping", HUST-Wuxi Research Institute, Wuxi, China

11/13/13 "Analyzing Accident Videos of Inverted-Pendulum Human Transporters", Huazhong University of Science and Technology, Wuhan, China

4/15/13 "Control of Large Flexible Spacecraft, Robots, and Cranes", Budapest University of Technology and Economics, Budapest, Hungary

4/15/13 "Recue Robot: An International Student Design Collaboration", University of Patras, Patras, Greece

10/17/12 "Active Learning Methods for Mechanical Engineering", Yeungnam College, Daegu, South Korea

6/26/12 "Command-Shaping Control of Flexible Aerospace Systems", Beijing Institute of Technology Beijing, China

6/18-21/12 "Introductory Creative Decision and Design Tools for Mechatronics", Huazhong University of Science and Technology, Wuhan, China

11/8/11 "Advanced Crane Control to Improve Safety and Ergonomics", Boeing Research and Technology Ergonomics Road Show, Everett, WA

5/6/11 "Creative Decisions and Design: An Innovative Design Course at Georgia Tech", Aalto University, Helsinki, Finland

4/25/11 "Creative Decisions and Design: An Innovative Design Course at Georgia Tech", Chosun University, Gwangju, Korea

4/21/11 "Controlling Large Flexible Structures with Command Shaping", Konkuk University, Seoul, Korea

4/19/11 "Command Shaping Control of Large Flexible Structures", Shanghai Maritime University, Shanghai, China

4/18/11 "Creative Decisions and Design: An Innovative Design Course at Georgia Tech", Huazhong University of Science and Technology, Wuhan, China

4/18/11 "Controlling Large Flexible Structures with Command Shaping", Huazhong University of Science and Technology, Wuhan, China

4/1/11 “Command Shaping Control of Large Flexible Systems”, University of Parma, Parma, Italy

7/12/10 “Command Shaping Control of Large Flexible Systems”, University Carlos III, Madrid, Spain

6/18/10 “Advanced Crane Control Lab at Georgia Tech”, KoneCranes, Hyvinkää, Finland

5/3/10 “Command Shaping Control of Flexible Systems”, University Castilla-La Mancha, Ciudad Real, Spain

12/16/09 “Control of Cranes and Spacecraft using Command Shaping”, University of Sydney, Sydney, Australia

11/25/09 “The ASU Experience: Interfacing with the Machines“, Arizona State University, Tempe, AZ

11/25/09 “Interfaces and Control Systems for Intuitive Crane Control”, Arizona State University, Tempe, AZ

10/6/09 “Using Competitions in Mechatronics Engineering Education at Georgia Tech”, Chosun University, Kwangju, Korea

4/20/09 “Advanced Command Shaping Control of Cranes, Robots, and Spacecraft”, Instituto Automatico de Industriales, Madrid, Spain

11/25/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Kyung Hee University, Suwon, Korea.

11/24/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Seoul National University, Seoul, Korea.

11/21/08 “Command Shaping Control of Cranes, Robots, and Spacecraft”, Korean Atomic Energy Research Institute, Deajon, Korea.

11/20/08 “Control of Tip-Over Instability”, Kumoh National Institute of Technology, Gumi, Korea.

8/10/08 “Engineering Teaching Methods at Georgia Tech”, Shandong Jianzhu University, Jinan, China.

8/10/08 “Using Command Shaping to Control Robots, Spacecraft, and Cranes”, Shandong Jianzhu University, Jinan, China.

8/8/08 “Control of Robots, Spacecraft, and Cranes Using Command Shaping”, Northeastern Forest University, Harbin, China.

8/7/08 “Engineering Teaching Methods at Georgia Tech”, Northeastern Forest University, Harbin, China.

8/4/08-8/8/08 “Command Shaping for Dynamic Systems”, Harbin Institute of Technology, Harbin, China.

5/28/07, "A Design Course at Georgia Tech: Creative Decisions & Design", Center of Excellence in Robotics, Kumoh National Institute of Technology, Gumi, Korea.

5/24/07, "Making Robots and Cranes Move Very Fast with Command Shaping", Northwest Forest University, Harbin, China.

5/23/07, "Making Robots and Cranes Move Very Fast with Command Shaping", Harbin Institute of Technology, Harbin, China.

3/19/07, "Crane Dynamics and Control: Applications and Educational Uses", Center of Excellence in Robotics, Tokyo Tech, Tokyo, Japan.

9/1/2006, "Crane Oscillation Control by Command Shaping", Ishikawajima Harima Heavy Industries, Yokohama, Japan.

4/20/06, "High-Speed Motion Control Using Command Shaping", Toshiba Corporate Research & Development Center, Tokyo, Japan.

1/25/2006, "Command Shaping for Cranes and Other Flexible Systems", University of Tokyo, Tokyo, Japan.

1/18/06, "Research Topics for Gantry Robots", Kumoh National Institute of Technology, Gumi, South Korea.

12/13/05, "An Introduction to Command Shaping for Flexible Systems", Center of Excellence in Robotics, Tokyo Tech, Tokyo, Japan.

8/12/05, "Advanced Command Shaping for Nonlinear Systems and On-Off Actuators", Kumoh National Institute of Technology, Gumi, South Korea.

8/11/05, "An Introduction to Command Shaping for Flexible Systems", Kumoh National Institute of Technology, Gumi, South Korea.

8/10/05, "An Introduction to Command Shaping for Flexible Systems", Korea Institute of Machinery & Materials, Deajon, South Korea.

8/9/05, "Command Shaping for Flexible Systems", Pusan National University, Busan, South Korea.

11/29/04, "Improving Machine Speed and Accuracy by Command Shaping", Metz, France.

10/27/04 – "Improving the Speed of Cranes, Robots, and Micro Mills by Command Shaping", Instituto Automatico de Industriales, Madrid, Spain

4/15/04 – "Undergraduate Research in Mechanical Engineering", Meeting of Congressional Staffers, Georgia Tech Conference Center, Atlanta, GA.

3/10/04 – "Design of Physical Mechanisms to Reduce Unwanted Dynamics", Nihon University, Tokyo, Japan.

1/29/04 – "Georgia Tech CanSat Team", Southeastern Space Grant Consortia Director's Meeting, Atlanta, GA.

10/23/03 - "Control of Flexible Spacecraft Using Command Shaping ", Georgia Tech IEEE meeting Atlanta, GA.

8/7/02 - "Rapid Motion of Crane-Like Structures", Tsukuba University, Tsukuba, Japan.

10/15/02 - "Designing Commands to Reduce Vibration in Mechanical Systems", ETSII de Madrid, Madrid, Spain.

10/14/02 - "Designing Commands to Reduce Vibration in Mechanical Systems", University of Vigo, Vigo, Spain.

8/13/02 - "Command Shaping for Flexible Structures", Tokyo Metropolitan Institute of Technology, Tokyo, Japan.

7/29/02 - "Controlling Flexible Spacecraft through Command Shaping", ISAS Astrodynamics Symposium Invited Speaker, Sagamihara, Japan.

7/13/02- "Using Input Shaping with On/Off Actuators", Laboratory for Space Systems, Tokyo Institute of Technology, Tokyo, Japan.

7/6/02- "Tutorial on Input Shaping for Moving Flexible Structures", Laboratory for Space Systems, Tokyo Institute of Technology, Tokyo, Japan.

3/18/02 - "Command Shaping Overview and Application to Hard Disk Drive Servo Control", Hitachi Corporation, Odawara, Japan.

3/15/02 - "Command Shaping for Vibration Reduction: Overview and Application to Hard Disk Drive Servo Control", IEE Committee Meeting for Mass Storage Servo, Nagoya, Japan.

10/27/00 - "Robotics Research at Georgia Tech." Waseda University, Tokyo, Japan.

10/24/00 - "Robotics Research at Georgia Tech." Tokyo Institute of Technology, Tokyo, Japan.

10/23/00 - "Robotics Research at Georgia Tech." Kyushu University, Fukuoka, Japan.

10/16/00 - "How to Properly Motivate Robots." MIT Club of Atlanta, Georgia Tech.

2/27/99 - "Making Machines Move Very Fast With Command Generation." American University in Cairo, Cairo, Egypt.

E. Grants and Contracts

A. As PI or Co-PI

Private Sources

"Crane Safety Research Center", Wang-Wong Foundation, December, 2023, \$5,000,000.

Government Sources

"Input Shaping Mobile Crane Controllers", Georgia Research Alliance, October 2018, \$49,965.

"I-Corps: Reducing Oscillation of Systems Driven by Stepper Motors and On-Off Actuators", National Science Foundation, April 2016, \$50,000.

"Rocket Rescue Robot", Georgia Space Grant Consortium, August 2014, \$6,000.

"Designing a Rocket-Launched Target-Seeking Rescue Robot", Georgia Space Grant Consortium, May 2013, \$3,762.

"Hopping Rotochute Micro Satellite Design Project", Georgia Space Grant Consortium, July 2012, \$2,275.

"International DDEP: Control of Complex Tower Crane Motion Using Low-Cost Cameras", National Science Foundation, September 2011-December 2012, \$13,930.

"Input Shaping for Rotorcraft Sling Load Operation", National Rotorcraft Technology Center (NRTC), Jan. 2011 – May 2013, \$120,000. **Co-PI (Singhose: \$56,875)**

"Georgia Tech Student CanSat Team", Georgia Space Grant Consortium, Jan. 2006 - May 2010, \$19,708.

"International DDEP: Development of Aircraft Conflict Resolution Algorithms", National Science Foundation, May 2008-September 2008, \$9,950.

"Approaches to Traffic Flow Management in the Presence of Uncertainty", NASA, October 2006-September 2008, \$706,366. **Co-PI (Singhose: \$120,056)**

"International DDEP: Experimental Evaluation of a Mobile Tower Crane", National Science Foundation, November 2006-March 2007, \$10,800.

"International DDEP: Experimental and Educational Research with Remotely Operated Cranes", National Science Foundation, December 2005-March 2006, \$8,100.

"Planning Visit: Large Flexible Space Structures", National Science Foundation, December 2005, \$12,412.

"Application of Command Generation Techniques to the Control of Space Tether Systems", NASA/Marshall Space Flight Center, July 2005-July 2006, \$24,000.

"Ph.D. Dissertation Enhancement Project: Experimental Evaluation of Low-Contact-Force Machining", National Science Foundation, January 2004-May 2004, \$9,700.

Support for International Workshop on Advanced Sensors, Structural Health Monitoring, and Smart Structures, Yokohama, Japan, National Science Foundation, November 2003, \$1,334.

"Command Generation and Control of Momentum Exchange Electrodynamic Reboost Tethered Satellite", NASA/Marshall Space Flight Center, August 2003-July 2005, \$48,000.

"Georgia Tech CanSat Development", Georgia Space Grant Consortium, December 2002 - December 2005, \$20,851.

"Experimental Evaluation of Coordinated Flexible Satellite Control", National Science Foundation, November 2002, \$7,995.

"Trajectory Planning for Coordinating Satellites Using Command Generation",
NASA/ Goddard Space Flight Center, August 2002-July 2005, \$72,000.

Industry Sources

"Evolution of Novel Haptic Actuation, Implementation and Test Systems"

Google Inc., Jan. 2022, \$249,869.

"Steady Hoist Swing-Damping Control for Rotocraft Operations," Atlas Devices Inc., March, 2021, \$100,000.

"Development of Advanced Haptic Actuation Structures and Control Methods,"

Google Inc., Jan. 2021, \$246,042.

"Development of Novel Haptic Actuation," Google Inc., Jan. 2020, \$258,488.

"Dynamic Model and Control System Design for Cable-Driven Crane,"

ConcertLab, Jan. 2020, \$27,088.

"Steady Hoist for Rotocraft Operations," Atlas Devices, LLC, Dec. 2019, \$10,000.

"Mobile Vision GT Singhose SOW 5", Google Inc., Nov, 2017, \$105,650.

"Mobile Vision GT Singhose SOW 4", Google Inc., Jan, 2017, \$95,922.

"Development Kits and myRIO Controllers for Undergraduate Controls",

National Instruments, October 2016, \$8,814.

"Mobile Vision GT Singhose SOW 3", Google Inc., August, 2016, \$80,193.

"Mobile Vision GT Singhose SOW 2", Google, Inc. Jan, 2016, \$112,309.

"Automated Large-Area Sanding", Boeing Research and Technology, Jan, 2016, \$50,000.

"Mobile Vision - Design and Evaluation of a Mobile Vision-Based Device for Interactive Writing", Google Inc., June, 2015, \$79,794.

"Automated Large-Area Painting", Boeing Research and Technology, May, 2015, \$50,000.

"Hardware Integration for Large-Area Sensing", Boeing Research and Technology, July, 2014, \$141,632.

"ME6404 Pneumatics project", National Fluid Power Association, November 2014, \$4,520.

"PLC Programming Curriculum for Georgia Tech", Siemens, August 2014, \$27,500.

"Use of Pneumatic Systems in Introductory Mechanical Design Projects",
National Fluid Power Association, November 2013, \$4,720.

“Development of Mechatronics and Robotics Educational Platforms Using Compact Control Units”, National Instruments, May 2013, \$117,000.

“Integration of Zurich University of Applied Sciences Bridge Crane into Georgia Tech Research and Educational Activities”, Siemens, May 2013, \$15,920.

“Manufacturing Technologies for the 21st Century”, Boeing Research and Technology, Jan. 2013, \$185,700.

“Multi-National Collaborative Design of Target-Seeking Robots”, Boeing Research and Technology, Nov. 2012, \$60,864.

“Multi-National Collaborative Design Tools”, Boeing Research and Technology, Nov. 2012, \$62,711.

“Input Shaping Analysis and Design Support”, Space Systems Loral, August 2012, \$47,086.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2012, \$100,000.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2011, \$100,000.

“A Balloon Hoist Experimental Setup to Evaluate National Instruments Products”, National Instruments, March 2011, \$38,665.

“Design & Development of a Pediatric Personal Transporter for Children with Disabilities”, International Diversified Products, December 2010, \$5,500. **Co-PI (Singhose: \$2,750)**

“Siemens Automation – Cherrypicker Crane Project”, Siemens Industry, August 2010, \$44,732.

“Investigation of Commercial Personal Transporters”, International Diversified Products, June 2010, \$6,000. **Co-PI (Singhose: \$3,000)**

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2010, \$100,000.

“Sponsorship of Georgia Tech Curriculum Improvements”, British Petroleum, Nov. 2009, \$7,500.

“Development of a Cherrypicker Aerial Lift for Use in Local and Remote Laboratories”, Siemens Energy and Automation, Sept. 2009, \$38,000.

“Pneumatic Powered Advertisement Dispenser”, Diastone Corporation, May 2009, \$8,800.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2009, \$100,000.

“Integrating Pneumatics Into Introductory Mechanical Design”, National Fluid Power Association, May 2008, \$4,960.

“Material Handling Dynamic Load Oscillation Suppression”, Boeing Research and Technology, Jan. 2008, \$75,000.

“Expansion of Pneumatic Systems in ME2110: Creative Decisions and Design”, National Fluid Power Association, March 2006, \$4,000.

“Pneumatic Equipment and Supplies for ME2110: Creative Decisions and Design”, Festo Corporation, March. 2005, \$6,898.

“Introduction of Pneumatic Systems into ME2110: Creative Decisions and Design”, National Fluid Power Association, Nov. 2004, \$5,000.

“Feedback and Command Shaping Control of Bridge Cranes”, CAMotion, Inc. Jan. 2004 - August 2008, \$98,168.

“Prototype Controller for Elastic Spacecraft”, Northrop Grumman, January 2004 – December 2004, \$44,415.

Support for University Space System Symposium, Jet Propulsion Laboratory, November 2002-5, \$5,528.

“Control of Sloshing Liquid Demonstration Unit”, National Instruments, March 2001, \$1,500.

International Sources

“International Design and Construction of Quadrotors”, Kumoh National Institute of Technology, December 2015, \$6,000.

“International Cooperative Education in Engineering Design”, Chosun University, November 2013, \$9,000.

“Development of Educational Tasks in an Introductory Design Course”, Chosun University, November 2011, \$9,600.

“Development of a Mobile Mechatronic Device”, Chosun University, June 2011, \$9,600.

“Development of Educational Tasks in an Introductory Design Course”, Chosun University, November 2010, \$2,400.

“Research on Mobile Mechatronics Machine”, Chosun University, November 2010, \$3,600.

“Mechanical Manipulators Control, Education and Research”, Ministerio de Ciencia e Innovacion de España, Dec. 2009, 18,000 Euro (\$25,767).

“Environmentally-Friendly Automotive Parts - Human Resources Development Center”, Chosun University, Dec. 2009, \$6,000.

“Versatile Command Shaping Controllers for Industrial Cranes”, Kumoh National Institute of Technology, June 2006, \$50,829

“Development of Vibration Reduction Scheme for XY Stages Using Input Shaping”, Top Engineering Co., Center for Nano and Precision Technology, Kumi, Korea, December 2005, \$5,000.

“Command Generation for Flexible Systems”, Kumoh National Institute of Technology and Pusan National University, August 2005, 3300000 Won (\$3,210).

“Enhanced Trajectory Tracking of Flexible Systems Using Command Generation”, Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT), and Tokyo Metropolitan Institute of Technology (TMIT), \$11,500 **Co-PI** (Singhose: \$5,750).

“Generación De Órdenes De Movimiento Que No Inducen Vibración En Maquinas Con FaltaDe Rigidez”, University of Vigo, October 2002, 900 Euros.

“Experimental Investigation of Deflection-Limiting Satellite Thruster Control for Multiple Flexible Satellites”, Japan Society for the Promotion of Science, June 2002, \$17,245.

Internal Sources

“An International Collaborative Student Space Robot Design Initiative”, Denning Global Engagement Seed Fund, 2014, \$15,000.

GTRC travel grant to Serbia, July, 2014, \$1,458.

“Interactive Tablet Computers for Introductory Mechanical Design”, Georgia Tech Technology Fee Grant, 2013, \$22,896.

“Power Analyzer for Energy-Efficient Student Design Projects”, Georgia Tech Technology Fee Grant, 2013, \$17,104.

GTRC travel grant to Turkey, July, 2013, \$1,500.

GTRC travel grant to Lithuania, July, 2012, \$750.

“Siemens Cherrypicker and Conference Paper Support” Manufacturing Research Center, July 2010, \$6,750.

GTRC travel grant to Egypt, July, 2010, \$750.

“Siemens Conference Paper Support” Manufacturing Research Center, September 2009, \$3,200.

GTRC travel grant to Spain, April, 2009, \$1,500.

“The Influence of Input Shaper Duration on Bridge Crane Operator Performance” Aayush Daftari, President's Undergraduate Research Travel Award, August 2008, \$1,000.

“Dynamics of Orbit Boosting of an Electrodynamic Tethered Satellite with Input-Shaped Current” Adrit Lath, President's Undergraduate Research Award, July 2008, \$1,500.

“Robustness of Negative Input Shaping” Aika Yano, President's Undergraduate Research Travel Award, May 2008, \$1,000.

“Generator for Mobile Boom Crane”, Materials, Supplies, & Travel Grants for Undergraduate Research, April. 2008, \$1,500.

GTRC travel grant to Turkey, April, 2008, \$1,500.

“Comparison of Command Filtering Methods for Vibration Reduction in Mechanical Systems”, Anderson Smith, President's Undergraduate Research Awards, March. 2008, \$1,500.

“Development of Input Shapers for Mobile Cranes”, Adrit Lath, President's Undergraduate Research Awards, Nov. 2007, \$1,500.

“Effect of Input Shaper Duration on Crane Operator Performance”, Aayush Daftari, President's Undergraduate Research Awards, Nov. 2007, \$1,500.

“Robust Input Shaper Evaluation”, Aika Yano, President's Undergraduate Research Awards, May 2007, \$1,500.

GTRC travel grant to China, May, 2007, \$1,500.

“Conference Travel Funding: Reduction of Double Pendulum Crane Oscillations”, Dooroo Kim, President's Undergraduate Research Awards, August 2006, \$1,000.

GTRC travel grant to Serbia, October, 2006, \$1,278.

“Reduction of Double Pendulum Crane Oscillations”, Dooroo Kim, President's Undergraduate Research Awards, December 2005, \$1,500.

“Development and Testing of a Command Shaping Compensator for Nonlinear Drives”, Jon Danielson, President's Undergraduate Research Awards, December, 2005, \$1,000.

“Space Tethered Satellite Control”, Andrew Timm, President's Undergraduate Research Awards, May, 2005, \$1,500.

GTRC travel grant to IFAC (Czech Republic) & REM (France), June, 2005, \$1,500.

“Use of Fluid Power to Cancel Low Frequency Vibrations”, Varun Sharma,

President's Undergraduate Research Awards, Jan. 2005, \$1,500.

"The Effects of Input Shaping on a Flexible Nonlinear Robotic Arm with Backlash", Matthew Falkenberg, President's Undergraduate Research Awards, Jan. 2005, \$1,500.

"Study of Operator Behavior and Performance Using an Input-Shaped Bridge Crane", Attir Khalid, President's Undergraduate Research Awards, April 2004, \$1,000.

"Fluid Power Control of a Hyper-Active Seat for Low-Frequency Vibration Suppression", Earl Lewis, President's Undergraduate Research Awards, December 2003, \$960.

GTRC travel grant to IEEE CCA (Turkey) & IEEE MED (Greece), June, 2003, \$1,500.

"Vibration Reduction for High-Rise Elevators", Vlad Patrangenaru, President's Undergraduate Research Awards, April 2003, \$800.

"Experimental Verification of Input Shaping Combined with Vibration Absorbers for Oscillatory Systems", President's Undergraduate Research Awards, April 2003, \$900.

"Experimental Investigation of Input Shaping with Friction on a Solder Cell Machine", President's Undergraduate Research Awards, December 2002, \$900.

"CanSat Project", President's Undergraduate Research Awards, December 2002, \$500.

Georgia Tech Foundation Travel Grant to Spain, October 2002, \$764.

GTRC travel grant to NCOLS 2001 (Russia), April 2001, \$1,406.

"Experimental Apparatus for Input-Shaped Cam Profiles", President's Undergraduate Research Awards, July 2001, \$1,250.

GTRC travel grant for Japan lecture tour, October 2000, \$1,231.

GTRC travel grant to Advanced Motion Control 2000, February 2000, \$1,250.

Other Sources

SURE & SHARP student support (Marie Cox, April Pritchard, Nathan Mauch, Adam Vela, Dwayne Bobb, Timothy Melano, Rory Thomas, Kimberly Sheafe)
May 1999 – August 2004, \$4,000.

B. As Investigator

RERC on Wheeled Mobility in Everyday Life. PI Dr. Stephen Sprigle. Funding for salary, graduate student support, materials and supplies. November 2003 - October 2008. \$134,725. Total project budget \$4,750,000.

In-Line Optical Measurement of MicroElectroMechanical Systems (MEMS) Devices During Production. PI Dr. Thomas Kurfess. Funding provided to train high school teacher for mechatronics curriculum transfer from Georgia Tech to Cedar Grove High School. June 2003-August 2003. \$6,000.

MARC Siemens - Automation and Drives. PI Dr. Steven Danyluk. Funding provided for graduate and undergraduate student support, hardware development, installation of oscillation controller on the MARC crane and development of portable bridge and tower cranes. August 2002 – August 2012, \$889,429.

HUSCO/Ramirez Laboratories for Fluid Power and Motion Control. PI Dr. Wayne Book. Funding for graduate student support, hardware development, and travel. August 2002-July 2004. \$42,775.

F. Other Scholarly and Creative Accomplishments

Patents

- [1] W. Singhose, N. Singer, W. Rappole, S. Derezinski, and K. Pasch, "Methods and Apparatus for Minimizing Unwanted Dynamics in a Physical System," US Patent US 5,638,267, June 10, 1997, 1997.
- [2] R. Eloundou and W. Singhose, "Command Generation Combining Input Shaping and Smooth Baseline Commands," Patent US 6,920,378, July 19, 2005, 2005.
- [3] K. L. Sorensen, W. Singhose, and S. Dickerson, "Combined feedback and command shaping controller for multistate control with application to improving positioning and reducing cable sway in cranes " Patent US 7,970,521, June 28, 2011, 2011.
- [4] W. Singhose and D. Kim, "Methods and Systems for Double-Pendulum Crane Control," Patent US 8,235,229, August 7, 2012, 2012.
- [5] W. Singhose and K. Peng, "Crane Control Systems and Method," US Patent US9,132,997 Patent Appl. 13/642,075, Sept. 15, 2015.
- [6] W. Singhose and J. Vaughan, "Methods and Systems for Improving Positioning Accuracy," US Patent US 8,975,853 B2 Patent Appl. 2011/0298409 A1, 2015.
- [7] K. L. Sorensen, W. Singhose, and S. Dickerson, "Crane Motion Control," Patent US 9,776,838, October 3, 2017, 2017.

G. Other Professional

Conferences Organized

NSF Planning Visit: Large Flexible Space Structures, Tokyo Japan, 12/11-12/15/2005.

Siemens Automation and Drives Conference at Georgia Tech Lorraine, 11/29-11/30/04.

Conference Sessions Organized

“Command Shaping in Mechatronics.” 7th Mechatronics Forum International Conference, 2000, Atlanta, GA.

“Tutorial: Input Shaping and Time Delay Control of Maneuvering Flexible Structures.” 2002 American Controls Conference, Anchorage, AK.

Conference Sessions Chaired

2007 American Control Conference, New York, NY

2006 ICAMEM, Tunis, Tunisia

2004 Japan-USA Symposium on Flexible Automation, Denver, CO.

2004 American Control Conference, Boston, MA.

2003 American Control Conference, Denver, CO.

2002 2nd IFAC Conference on Mechatronic Systems, Berkeley, CA.

2002 6th International Conference on Motion and Vibration Control, Saitama, Japan

2002 Japan-USA Symposium on Flexible Automation, Hiroshima, Japan.

2002 American Control Conference, Anchorage, AK.

1999 IEEE Conference on Control Applications, Kona, HA.

1998 IEEE Conference on Control Applications, Trieste, Italy.

1995 IFToMM Ninth World Congress on the Theory of Machines and Mechanisms, Milan, Italy.

V. Education

B. Individual Student Guidance

B1. Ph.D. Students

B1.a. Graduated Ph.D. Students

- 1) Kris Kozak. Started Fall '99. Passed qualifier examination Fall '00. Ph.D. awarded May '03, "Investigation of Input Shaping for Parallel Manipulators." Currently at Southwestern Research Institute. (coadvised with Dr. Ebert-Uphoff).
- 2) Erika Biediger-Ooten. Started Fall '98. M.S. Dec. '00. Passed qualifier examination Fall '01. Ph.D. awarded May '05, “Vibration Reduction Using Command Generation in Formation Flying Satellites.” Currently Engineer at Exxon-Mobil.
- 3) Mike Robertson. Started Fall '98. M.S. May '01. Passed qualifier examination Spring '02. Ph.D. awarded May '05, “Command Generation for Tethered Satellite Systems”. Currently Professor at the Naval Academy
- 4) Joel Fortgang. Started Fall '99. M.S. May '02. Passed qualifier examination Spring '02. Ph.D. awarded May '06. “Combined Mechanical and Command Design for Micro-Milling Machines”.

- 5) John Huey. Started Fall '01. M.S. August '03. Passed qualifier examination Fall '03. Ph.D. awarded August '06. "Concurrent Design of Feedback and Command Shaping Control". Currently Controls Engineer - GE Aviation.
- 6) Jason Lawrence. Started Fall '00. M.S. August '02. Passed qualifier examination Fall '03. Ph.D. awarded August '06. "Control of Tower Cranes", Currently Mechanical Engineer at Lexmark.
- 7) Joshua Vaughan. Started Fall '02. M.S. May '04, Ph.D. awarded August '08 "Dynamics and Control of Mobile Cranes". Currently professor at University of Louisiana-Lafayette.
- 8) Khalid Sorensen. Started Fall '03. M.S. May '05, Ph.D. awarded August '08. "Combined Feedback Control and Command Shaping of a Bridge Crane."
- 9) Adan Vela. Started Fall '06. Ph.D. awarded Dec. '11. "Bounds on Controller Taskload Implementing Conflict-Resolution Algorithms in an Airspace."
- 10) Kelvin Peng, Started Spring '08, Ph.D. awarded Dec. '13, "Methods for Improving Crane Performance and Ease of Use."
- 11) Ehsan Maleki, Started Fall '08, Ph.D. awarded Dec. '13, "Control of Human-Operated Machinery with Flexible Dynamics."
- 12) James Potter, Started Fall '09, Ph.D. awarded Dec. '13, "Input-Shaped Manual Control of Helicopters with Suspended Payloads."
- 13) Arto Kivila, Started Fall '13, Ph.D. awarded Aug. '17, "Modeling, Estimation and Control for Serial Flexible Robot Arms."
- 14) Daichi Fujioka, Started Fall '10, Ph.D. awarded Aug. '17, "Input-Shaped Model Reference Control for Flexible Systems."
- 15) Christopher Adams, Started Fall '12, Ph.D. awarded Dec. '18, "Modeling and Control of Backdrivable Flexible Systems"
- 16) Ali AlSaibie, Started Fall '12, Ph.D. awarded Dec. '18, "Mechatronic Design of Micro Autonomous Underwater Vehicles for Confined Spaces"
- 17) Arnolando Castro, Started Spring '16, Ph.D. awarded Dec. '19, "Dynamics and Control of Self-Balancing Transporters"

B1.b. In Process Ph.D. Students

- 1) Alison Jenkins, Started Spring '20, Passed Quads Fall 2021
- 2) Tyler Rome, Started Spring '21, Passed Quads Fall 2022

B2. M.S. Students (Indicate Thesis Option for Each Student)

B2.a. Graduated M.S. Students

- 1) Mike Kenison. Graduated Dec. '99 - "Command Generation in Control System Design for Systems with Parameter Variations." Currently Development Engineer, Schlumberger.
- 2) Karen Grosser. Graduated May '00 - "Input Shaping for Telerobotic Manipulators." Currently Development Engineer, Schlumberger.

- 3) Erika Ooten. Graduated Dec. '00 - "Command Generation for Flexible Systems Using Numerator Dynamics and Sliding Mode Control." Currently Engineer at Exxon-Mobil.
- 4) Kris Kozak. Graduated Aug. '01 - "Dynamic Analysis of Parallel Manipulators and Digital Input Shaper Computation Using Linear Optimization." Currently a Post-doc at Tsinghua University.
- 5) Mike Robertson. Graduated May '01. "Methods for Generating Deflection-Limiting Commands." Currently Post-doc at Air Force Research Lab.
- 6) Joel Fortgang. Graduated May '02 - "Concurrent Design of Input Shaping and Vibration Absorbers."
- 7) Jason Lawrence. Graduated August '02 - "Using Input Shaping to Optimize Point-to-Point Motions in PD Controlled Systems with Coulomb Friction."
- 8) Raynald Eloundou. Graduated August '02 - "Investigation of Various Reference Commands for Vibration Reduction." Currently Mechanical Engineer at Hitachi.
- 9) John Huey. Graduated August '03. "Dynamics and Vibration Control of Large Area Manipulators."
- 10) Sam Klooster. Graduated Spring '04. "Design of an Active Safety Seat." Currently mechanical engineer at Lockheed Martin.
- 11) Joshua Vaughn. Graduated Spring '04. "Active and Semi-Active Control to Counter Vehicle Payload Variation." (coadvised with Dr. Nader Sadegh)
- 12) Khalid Sorensen. Graduated Spring '05. "A Combined Feedback and Command Shaping Controller for Improving Positioning and Reducing Cable Sway in Cranes"
- 13) Vlad Patrangenaru. Graduated Spring '06. "Design of Active Wheelchair Seats to Compensate for Extensor Tone in Children."
- 14) Azeem Meruani, Spring '06. "Tweel Technology Tires for Wheelchairs and Instrumentation for Measuring Everyday Wheeled Mobility"
- 15) David Blackburn. Graduated Summer '06. "Control of Space Tethers."
- 16) Jim Kitchen. Graduated Summer '06. "Design of an Dynamic Wheelchair Seat."
- 17) Ray Manning. Graduated Spring '08 "Improving the Control of Two-Mode Flexible Systems with Input Shaping"
- 18) Jon Danielson. Graduated Summer '08 "Mobile Boom Crane Dynamics and Control"
- 19) Andreas Rauch, Graduated Summer '08 "Stability Analysis of Mobile Boom Cranes"
- 20) Daichi Fujioka, Graduated Summer '10, "Dynamic Stability of Mobile Boom Cranes"
- 21) Kelvin Peng, Graduated Fall '09, "Interfaces and Control Systems for Intuitive Crane Control"
- 22) Ehsan Maleki, Graduated Summer '10, "Dynamics and Control of a Small-Scale Mobile Boom Crane"

- 23) Brice Pridgen, Graduated May '11, "Comparison of Polynomial Profiles and Input Shaping for Industrial Applications"
- 24) Arnolando Castro, Graduated Summer '12, "Modeling and Dynamic Analysis of a Two-Wheeled Inverted-Pendulum"
- 25) Christopher Adams, Graduated Summer '12, "Modeling and Control of Helicopters Carrying Suspended Loads"
- 26) Eileen Hernandez, Graduated Fall '12, "Dynamic Characterization and Analysis of Aerial Lifts"
- 27) Arto Kivila, Graduated Aug. '13, "Touchscreen Interfaces for Machine Control and Education"
- 28) Alex Miller, Graduated Dec. '13, "Dynamics and Control of Dual-Hoist Cranes Moving Distributed Payloads"
- 29) Athony Garcia, Graduated Dec. '14, "Improved Friction, Contact and Dynamic Simulation Model to Study the Behavior of Payloads During Off-Centered Crane Lifts"
- 30) John Harber, Graduated May '16, "A Dual Hoist Robot Crane for Large Area Sensing"
- 31) Sima Rishmawi, Graduated May '16, "Tip-Over Stability Analysis of Crawler Cranes in Heavy Lifting Applications"
- 32) Yujia Yang Graduated May '17, "Automated Longitudinal Payload Lift-up Using Bridge Cranes"
- 33) Nickolas Johnson, Graduated May'17, "Control of a Folding Quadrotor with a Slung Load Using Input Shaping."
- 34) Franziska Schlagenhauf, Graduated Aug. '17, "A Kinematic Upper Body Model for Evaluating Clothing"
- 35) Xiaoshu Liu, Graduated Dec. '17, "Numerical Investigation of Affordable 2D Lidar Sensors for Autonomous Driving Under a Specially-Structured Driving Environment"
- 36) Luk, Henry, Graduated May '20, Non-thesis Master's, Project: Dynamics of LRA Devices Within Wrist Bands
- 37) Lyman, Colin, Graduated August '21, Non-thesis Master's, Project: Development of Multi-LRA Devices
- 38) Ravishankar, Praveen, Graduated August '21, Non-thesis Master's, Project: Development of Haptic Signals for Multi-LRA Devices
- 39) Schmidt, Ryan, Graduated August '22, Non-thesis Master's, Project: Sensing of LRA Back EMF

B2.b. In Process M.S. Students

- 1) William Barclay
- 2) Eemil Harkonen
- 3) Sae Sholapurkar

B3. Undergraduate Students

Kanako Abe, Hafeez Alam, Ulf Andresen, Derek Bastien, Fernando Bazerghi, Esteban Benero (SURE), Dustin Bergman, Dwayne Bobb (SURE - Morehouse College), Carrie Boles, Justis Brogan, Jeff Clement, Maria Cox (SURE), Jon Danielson, Chuck Devane, Raynald Eloundou, Adrian Erb (Swiss), Matthew Falkenberg (PURA), Brian Fatkin, Jonathon Fonseca, Craig Forest, Damien Gaudry, Terry Hall, Samir Idnani, Walker Inman, Taft Jones (SURE), Paul Jurek, Attir Khalid, Dooroo Kim, Jae-Hyung Kim, Nathan Knight, Prerana Kumar, Bumsoo Lee, Caitlyn Leksana, Earl Lewis, Alan Martin, Timothy Melano (SURE – Berkeley), Ben Myers, Chad Nicholson, Noav Nossenson (SURE), Patrick Opdenbosch, Adnan Pandjou, Tejan Poage, Jessica Powell, April Pritchard (SURE), Devshan Renganathan, Caroline Rhee, Nathan Ritz, Nick Sabogal, Prachi Sahoo, Dushyant Sharma, Varun Sharma (PURA), Kimberly Sheafe (SURE – Stanford), Anderson Smith (PURA), Jonathon Smith, Josh Spiers, Christoph Stäheli (Swiss), Lee Stokes, Ethan Stone (PURA), Art Terdpravat, Brandon Terrell, Rory Thomas (SURE – John Hopkins), Andrew Timm, Adam Vela (SURE), Rolf Weiss (Swiss), Amber Welsh, Kevin Yang, Aika Yano, Jieun Yoo.

B5. Mentorship of Postdoctoral Fellows or Visiting Scholars

B5.a. Postdoctoral Fellows

- 1) Dr. Kris Kozak. June 2003-Dec. 2003, “Development of a Hyperactive Seat.”
- 2) Dr. Joshua Vaughan. Jan. 2010–August 2012, “Development of an Aerospace Manufacturing Center.”
- 3) Dr. Christopher Adams. Jan. ’19-present, “Input Shaping Mobile Crane Controllers”

B5.b. Visiting Scholars

- 1) Prof. Seong-Wook Hong, Kumoh National University, Kumi, Korea, Feb. 2004-Feb. 2005.
- 2) Prof. Juan de Juanes Marquez, Escuela Tecnica Superior de Ingenieros Industriales (ETSII), Madrid, Spain, June 2005-Dec. 2005.
- 3) Prof. Yoon-Gyeong Sung, Chosun University, Gwangju, Korea, July 2006-August 2007.
- 4) Prof. Mingxiao Dong, Shandong Jianzhu University, China, Dec 2007-May 2008
- 5) Ji Sup Joon, Division Director, Advanced Fuel Cycle System Eng., Korea Atomic Energy Research Institute, Korea, September 2008-September 2009
- 6) Prof. Zhang Yizhuo, North East Forestry University, Harbin, China, Dec. 2009 – Dec. 2010
- 7) Prof. Youmin Hu, Huazhong University of Science & Technology, Wuhan, China, Jan. 2010-Jan 2011

- 8) Prof. Kyoungseok Park, Kumoh National Institute of Technology, Gumi, Korea, June 2010-June 2011
- 9) Prof. Jie Huang, Beijing Institute of Technology, August 2014-July 2015
- 10) Prof. Dongjoo Kim, Kumoh National Institute of Technology, Gumi, Korea, Feb. 2016 - Feb. 2017
- 11) Stanislao Grazioso, Università degli Studi di Napoli "Federico II", Napoli, Italy, August 2016-Dec. 2016
- 12) Dr. Ali AlSaibie, Kuwait University, July-August 2023

C. Educational Innovations and Other Contributions

a) New Course Development

ME 6404 - Advanced Control System Design and Implementation. Course was completely overhauled, updated, and expanded for the Fall of 2001. The result was essentially a new course. A book, *Command Generation for Dynamic Systems*, was written to compliment the course curriculum. A portable robotic bridge crane was constructed so that this course could be taught at Georgia Tech Lorraine in the fall of 2004. Siemens sponsored the crane construction and also a two-day conference at GTL that centered on the crane and the associated curriculum development: <http://singhose.marc.gatech.edu/SiemensGTL/>. A portable tower crane was also constructed for the course. The tower crane was used at Tokyo Tech for 2 years. Students conducted remote operation tests via the internet. The course was also taught at MIT during the fall of 2010 in conjunction with Professor Warren Seering of MIT. The course was expanded in the fall of 2011 to include a distance learning curriculum that uses remote-operated labs.

ME 4863 – Emerging Technology Law. Course was designed to educate engineering students about legal constructs that effect engineering activities in the area of emerging technology. The course is cross listed as BME4853. The course has two main components: Product Liability and Intellectual Property. In addition to weekly lectures, the course includes weekly studio sessions and mock trials.

b) Laboratory Experiments Developed: The new version of Advanced Control System Design and Implementation has a major laboratory component. An entire sequence of laboratory projects were developed for the course using the large bridge crane in the MARC building and hardware in the Love Building hydraulics laboratory. The crane in the MARC building has been equipped with oscillation-reducing technology that is taught in ME6404. The crane was also used as a testbed in the senior-level experimental engineering course, ME4055. Several laboratory projects were developed for ME2110, Creative Decisions and Design. A paper describing these developments was presented at the 2nd IFAC Conference on Mechatronic Systems. A

two-week curriculum on PLC programming was developed along with PLC workstations to conduct laboratory activities. Hands-on control experiments for ME4452 (Control Systems) were developed to utilize the NI MyRIO controller along with a flexible-beam experimental setup.

c) Interactive Instructional Materials Developed: Dr. Singhose has developed interactive textbooks for both introductory mechanical design (with an emphasis on mechatronics) and advanced control system implementation (with an emphasis on command-shaping control). Features of interactive textbooks include: embedded videos that can be viewed with the tap of a finger, picture slideshows, user-controlled simulations, and interactive charts that accept user input and provide immediate feedback. Dr. Singhose has also developed a series of remote-operated experimental cranes and aerial lifts that have been used extensively in educational activities.

VI. Service

A. Professional Contributions

Journals

Int. Journal of Control, Automation, and Systems (IJCAS), Editorial Board Member, 2005-Present

Mechatronics, Associate Editor, 2008

Control Engineering Practice, Designated Editor, 2007-2010

Conferences

Asian Control Conference, Associate Editor of Contributed Papers, 2017

Int. Symposium on Flexible Automation, Program Chair, 2008

IEEE/ASME Int. Conference on Advanced Intelligent Mechatronics, Program Committee, 2007

Int. Symposium on Flexible Automation, Program Committee, 2006

Advanced Intelligent Mechatronics Program Committee, member, 2005

International Conference on Motion and Vibration Control Program Committee, member, 2004

American Control Conference Program Committee, member, 2004

Japan-USA Symposium on Flexible Automation Program Committee, member, 2004

Reviews

National Science Foundation, Division of Design Manufacturing and Industrial Innovation, proposal reviewer

National Science Foundation, Sensors and Sensor Systems, proposal reviewer

AIAA Journal of Guidance, Control, and Dynamics, reviewer

AIAA Journal of Spacecraft and Rockets, reviewer

AIAA Guidance, Navigation, and Control Conference, reviewer

American Control Conference, reviewer

ASME Journal of Dynamic Systems, Measurement, and Control, reviewer

ASME Design Engineering Technical Conferences, reviewer
ASME Journal of Vibration and Acoustics, reviewer
Automatica, reviewer
Control Engineering Practice, reviewer
Control Systems Technology, reviewer
IEEE/ASME Transactions on Mechatronics, reviewer
IEEE Transactions on Systems, Man, and Cybernetics, reviewer
IEEE Conference on Control Applications, reviewer
IEEE Int. Conference on Robotics and Automation, reviewer
Industrial & Engineering Chemistry Research, reviewer
Journal of the Franklin Institute, reviewer
Journal of Sound and Vibration, reviewer
Mechatronics, reviewer
Mechatronics 2000, Panel reviewer
Industrial Project Advising
Milliken Summer Faculty Challenge – 2000

B. Public and Community Service

Standards Committees

IEEE Virtual Reality and Augmented Reality Standards Working Group, 2018-2019
ASTM F15.18 - Cribs, Toddler Beds, Play Yards, Bassinets, Cradles and Changing Tables, 2018-2019
ASTM D13-Textiles, D13.66 – Sewn Product Automation subcommittee member, 2017-2019
ASTM F08.52, F08.67 - Pole Vault Pole Testing and Pole Vault Landing Pads subcommittee, member, 2000-2006
USA Track & Field Pole Vault Equipment Task Force, member.

Legislative Testimony

Washington State Legislature, Senate Labor & Commerce Committee, SB5900 – Construction Crane Safety, 1/11/24
Washington State Legislature, House Labor and Workplace Standards Meeting, HB2022 – Construction Crane Safety, 1/12/24

C. Institute Contributions

Organized and supervised Georgia Tech Rescue Robot Team, 2013-present
Organized and supervised Georgia Tech CanSat Team, 2002-2012
ASME Student Group, Faculty Advisor, 2007-2012
SME Student Group, Faculty Advisor, 2001-2007
Pole vault coach for Georgia Tech track and field team (1998-2000)
2009 Chair of Director of Design Search Committee

2015 Chair of Zeigler Woodruff School Outstanding Educator Award Committee

Woodruff School Committee member:

2023 Zeigler Outstanding Educator Award Committee

2022 Zeigler Outstanding Educator Award Committee

2021-23 RPT

2019-21 Graduate Student Development

2015-16 RPT

2016-17 PPR

2013-16 Undergraduate

2012 Director of Design Search Committee

2008 HR Director Search Committee

2006-07 Undergraduate

2003-04 Faculty Awards

2001-03 Undergraduate

2000 Faculty Recruiting

1999 Graduate

1998 Undergraduate

APPENDIX B

Dr. William Singhose
Expert Witness Testifying Experience
2020-2025

1. Wong et al. v. Morrow Equipment et al.
7/2019-3/2022
Civil Action No. 19-2-33286-7 SEA
Swanson, Gardner, and Meyers
Depositions: 1/3/22, 1/31/22
Court Testimony: 1/31-2/1/22, 3/2/22
2. Guntert and Zimmerman v. Gomaco
5/20-10/21
C.A. No. 5:20-cv-4007
Finnegan Henderson
Analysis of construction machines and patents
Deposition: 8/21/20
3. Coleman Co. vs. Team Worldwide Corp.
5/2020-1/23
Civil Action No. 2:20cv351-RGD-RJK
Meunier Carlin & Curfman LLC
Analysis of air mattresses and patents
Deposition: 8/18/21
4. Gamevice v. Nintendo
6/20-12/20
Certain Portable Gaming Console Systems with Attachable Handheld Controllers and Components Thereof
ITC Investigation No. 337-TA-1197
Finnegan Henderson
Analysis of gaming consoles and patents
Depositions: 9/29/20, 10/2/20; Trial Testimony: 12/10/20, 12/14/20
5. Gomaco v. Guntert and Zimmerman
9/2020-7/2021
IPR2020-01698, IPR2021-00050, IPR2021-00136, IPR2021-00234
Finnegan Henderson
Analysis of construction machine patents US9,708,020 & US10,196,101 & US10,029,749 & US9,908,57
Deposition: 7/21/21 & 7/23/21
6. Unicorn Global v. GoLabs
11/2020-7/2021
Civil Action No. 3:20-cv-02023
Offit Kurman, P.A.

Analysis of hoverboards and patents
Deposition: 3/31/21

7. Courkamp v. Fisher Price

2/26/20-10/22

No. CV-19-02689-PHX-GMS

US District Court for the Northern District of Arizona

Goldberg & Osborne LLP

Analysis of infant incline sleepers

Deposition: 9/14/21, 9/27/21

8. iRobot v. SharkNinja

6/20-1/21

Certain Robotic Floor Cleaning Devices and Components Thereof

ITC Investigation No. 337-TA-1252

Finnegan Henderson

Analysis of robotic cleaners and patents

Deposition: 10/6/21

Court Testimony: 1/10-1/12/22

9. DJI v. Textron

9/21-10/22

IPR2022-00162 and IPR2022-00162

Finnegan Henderson

Analysis of drone patents

Deposition: 8/11/22, 10/7/22

10. Caterpillar Paving Products v. Wirtgen America

12/21-7/23

IPR2022-01264, IPR2022-01277, IPR2022-01278, IPR2022-01310

Finnegan Henderson

Analysis of construction machine patent US9879390, US9879391, US8424972

Deposition: 4/6/23, 4/12/23

11. Opex v. HC Robotics

1/22-12/22

Certain Automated Put Walls and Automated Storage and Retrieval Systems, Associated Vehicles, Associated Control Software, and Component Parts Thereof

ITC Investigation No. 337-TA-1293

Desmarais

Analysis of factory automation and mobile robot patents

Deposition: 9/22/22

Court Testimony: 12/1/22

12. Bissell v. Tineco

- 2/22-12/22
Certain Wet Dry Surface Cleaning Devices
ITC Investigation No. 337-TA-1304
Quinn Emanuel
Analysis of wet/dry cleaning devices and patents
Deposition: 10/27/22
Court Testimony: 12/5/22 and 12/9/22
13. LightGuide v. Amazon
3/23-12/23
IPR2023-01423
Hueston Hennigan LLP
Analysis of assembly system patents US10528036, US9658614, and US7515981
Deposition: 10/20/23
14. Juul v. NJOY
9/23-Present
ITC Investigation No. 337-TA-1368
IPR2024-00223
Weil, Gosthal and Manges
Analysis of vaporizer patent US10709173
Deposition: 2/27/24
Court Testimony: 5/3, 5/8/24
15. Lenovo v. Asus
2/24-Present
ITC Investigation No. 337-TA-1382
DLA Piper
Analysis of computer hinges and US8687354
Deposition: 7/9/24
Court Testimony: 9/21, 9/22, 9/24
16. Juul v. NJOY
6/24-Present
IPR2024-00160, IPR2024-00161
Weil, Gosthal and Manges
Analysis of vaporizer patents 11,497,864 and US10,334,881
Deposition: 10/24/24
17. US Conec v. Senko
7/24-8/24
ITC Inv. No. 33-TA-1399
Certain Fiber-Optic Connectors, Adapters, Jump Cables, Patch Cords, Products Containing
The Same, and Components Thereof
Alston & Bird
Analysis of Fiber-Optic Equipment and Patents

Deposition: 8/6/24