

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

HOWARD INDUSTRIES, INC.

Petitioner,

v.

CAPSA SOLUTIONS LLC

Patent Owner.

U.S. Patent No. 7,594,668

Filing Date: August 18, 2008

Issue Date: September 29, 2009

U.S Patent No. 8,215,650

Filing Date: July 20, 2011

Issue Date: July 10, 2012

Case Nos. IPR2023-01274, IPR2023-01275

**DECLARATION OF PINHAS BEN-TZVI IN SUPPORT OF PATENT
OWNER'S RESPONSE TO '668 AND '650 IPR PETITIONS**

I, Pinhas Ben-Tzvi, declare as follows:

INTRODUCTION

1. I have been retained by Plaintiff Capsa Solutions LLC (or “Capsa”) as an independent expert for the above-identified inter partes review proceeding involving U.S. Patent Nos. 7,594,668 (“the ’668 Patent”) and 8,215,650 (“the ’650 Patent”) (collectively,

“the Patents-at-issue”).

I have personal knowledge of the facts stated herein, unless stated otherwise, and I would testify truthfully to those facts if called as a witness.

BACKGROUND AND QUALIFICATIONS

2. I received a BS degree in Mechanical Engineering (Summa Cum Laude) from the Technion - Israel Institute of Technology in 2000, a Master's degree in Mechanical Engineering from the University of Toronto in 2004, and a Ph.D. degree in Mechanical Engineering from the University of Toronto in 2008. Attached to this Declaration, as **Exhibit 1**, is a true and correct copy of my curriculum vitae (CV). I have authored numerous technical books and articles in the field. *See* **Exhibit 1**, CV. I've authored over 180 peer-reviewed articles in the field of engineering design and various mechanisms. I have also been retained as an expert in support of patent litigation. *See*, **Exhibit 2**, list of cases. I have prior expert witness experience, written expert reports, and testified in depositions, IPR and ITC proceedings related to patent infringement cases and validity issues also related to medical equipment.
3. I am currently a Professor in the Department of Mechanical Engineering at Virginia Tech University, Blacksburg, Virginia. I am a tenured Professor of Mechanical Engineering and Electrical and Computer Engineering, and Founder and the Director of the Robotics and Mechatronics Lab at Virginia Tech. I am also a licensed Professional Engineer (P.E.).
4. I am currently also a Program Director for the Established Program to Stimulate

Competitive Research (EPSCoR), Office of Integrative Activities (OIA), Office of the Director (OD), National Science Foundation (NSF), Alexandria, VA on an Intergovernmental Personnel Act (IPA) assignment as detail to NSF. My views in this declaration are my own, and do not represent the NSF in any way or form.

5. I am the named inventor on at least twelve U.S. patents and patent applications and a Canadian patent directed to various electromechanical devices.
6. My expertise includes mechatronics, robotics, automated control systems and automation, mechanical design, mechanism design, machine design, and product development and integration. I have additional knowledge in mobile robotics for military and police applications, human-robot interaction, microprocessor-based applications, and computer aided design (CAD).
7. In my many years of engineering, manufacturing, and product development experience, I have personally been involved in the design of many types of mechanical products, including many designs using drivers (e.g., gas pistons or springs, hydraulic drivers, electro-mechanical drivers/linear actuators). I am intimately familiar with the technology, and concepts utilized in the products at issue in this case. In my experience, I have seen the importance of understanding how a product will be used and how chosen performance features will determine the predominant final product application.
8. I am an experienced mechanical/electromechanical design engineer and technical expert with extensive experience with various types of drivers, linear motion control,

and ergonomic industrial design. I have over 24 years of combined industrial and academic experience in mechanical design, testing, prototyping, developing, and machine/mechanism design, synthesis, analysis, manufacturing and integration. I have industrial experience working for General Electric Medical Systems and other companies in product development that involved the use of height adjustment mechanisms that use drivers for various medical equipment. At General Electric Medical Systems, I designed and integrated various devices and related electronic components including height adjustment mechanisms and drivers used in conjunction with the development of two-degrees-of-motion beds for PET, CT and MRI machines.

9. I also teach courses at Virginia Tech in electro-mechanics that involve the design and construction of various drivers, actuators and linear motion control. I also frequently use and design drivers and linear motion control components in development of prototypes as part of my ongoing academic research funded by a variety of government agencies.

MATERIALS CONSIDERED

10. In forming my opinions, I have reviewed documents cited in the Petitioner's IPR Petitions to the '668 and '650 Patents. The descriptions of the '668 and '650 Patents are the same and the claims at-issue from the '650 and '668 Patents have the same dispositive limitations not found in the cited references. Therefore, citations to '650 and '668 Patent descriptions may be used interchangeably herein.

11. I have also reviewed and considered documents cited in Patent Owner's Responses to

the Petitioner's IPR Petitions to the '668 and '650 Patents.

SUMMARY OF LAW

12. Anticipation: To prove anticipation under 35 U.S.C. § 102, Petitioner must prove that “the four corners of a single, prior art document describe every element of the claimed invention” in the same specific “arrange[ment] as in the claim.” *See Net MoneyIN, Inc., v. Verisign, Inc.*, 545 F.3d 1359, 1371 (Fed. Cir. 2008). Petitioner has not made an argument relating to anticipation. All of Petitioner's invalidity arguments are based on alleged obviousness of the claims – not anticipation.
13. Obviousness: As to its obviousness grounds, Petitioner must prove under 35 U.S.C. § 103 that “the differences between the subject matter sought to be patented 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 person of ordinary skill in the art. *KSR Int'l Co. v. Teleflex Inc.*, 550 U.S. 398, 406 (2007). An obviousness determination must be based on four factual inquiries: (1) the scope and content of the prior art; (2) the differences between the claims and the prior art; (3) the level of ordinary skill in the art; and (4) objective indicia of nonobviousness. *Id.*, 406 (citing *Graham v. John Deere Co. Kan. City*, 383 U.S. 1, 17–18 (1996)). A party alleging obviousness is “required to place themselves in the minds of those of ordinary skill in the relevant art at the time the invention was made, to determine whether that which is now plainly at hand would have been obvious at such earlier time.” *Millennium Pharms., Inc. v. Sandoz Inc.*, 862 F.3d 1356, 1367 (Fed. Cir. 2017). Petitioner must “articulate specific reasoning, based

on evidence of record, to support the legal conclusion of obviousness.” *U.S. Well Servs., LLC v. Halliburton Energy Servs., Inc.*, IPR2022-01163, Paper 9 at 10 (PTAB Dec. 20, 2022) (quoting *Magnum Oil*, 829 F.3d at 1380). Petitioner cannot rely on conclusory statements or blanket assertions of common sense to fill gaps and missing limitations from the prior art. *Arendi S.A.R.L. v. Apple Inc.*, 832 F.3d 1355, 1362–63 (Fed. Cir. 2016). “It is not the Board’s job to cobble together assertions from different sections of a petition or citations of various exhibits in order to infer every possible permutation of a petitioner’s arguments.” *Microsoft Corp. v. FG SRC, LLC*, 860 Fed. App’x 708, 713 (Fed. Cir. 2021). Petitioner’s obviousness arguments “must be made with particularity, not opacity.” *Id.*

14. Petitioner also has the burden to show there would have been some motivation to combine the asserted prior art, and that the proposed combinations would render the patented claims obvious. “Obviousness requires more than a mere showing that the prior art includes separate references covering each separate limitation in a claim under examination.” *Unigene Labs., Inc. v. Apotex, Inc.*, 655 F.3d 1352, 1360 (Fed. Cir. 2011) (internal citation omitted). Petitioner must show a reasonable expectation of success in making a prior art combination. *See Intelligent Bio-Sys., Inc. v. Illumina Cambridge Ltd.*, 821 F.3d 1359, 1367 (Fed. Cir. 2016).

15. The Federal Circuit has found that, even for an obviousness challenge based on a single reference in view of the knowledge of a person of ordinary skill in the art, there must have been a motivation to make a modification of embodiments shown in that

reference and a reasonable expectation that such a modification would have been successful; otherwise a skilled artisan would not have arrived at the claimed combination. *In re Stepan Co.*, 868 F.3d 1342, 1345–46 (Fed. Cir. 2017). In other words, when a gap in a single prior art reference requires filling with the knowledge of one of ordinary skill, there must be a further showing that the skilled artisan would have arrived at the claimed invention. *Id.*

16. I have been instructed that independent claims stand on their own and dependent claims depend off the independent claims (dependent claims incorporate all the limitations of the independent claims). Because an independent claim is broader than the dependent claims that depend from it, if an independent claim is not obvious, then it follows that the claims that depend from it are also not obvious.

Summary of the Law of Claim Construction:

17. The purpose of claim construction is to give claim terms the meaning understood by a person of ordinary skill in the art at the time of invention. *Phillips v. AWH Corp.*, 415 F.3d 1303, 1312-14 (Fed. Cir. 2005) (en banc). The words of a patent claim are generally given their ordinary and customary meaning as understood by a person of ordinary skill in the art when read in the context of the patent description (i.e., specification) and prosecution history. *See Id.* at 1313. There is a heavy presumption that claim terms are to be given their ordinary and customary meaning. *Avlus Networks, Inc. v. Apple Inc.*, 856 F.3d 1353, 1358-59 (Fed. Cir. 2017). There are only two exceptions to this general rule: 1) when a patentee provides his or her own special

definition and acts as his own lexicographer, or 2) when the patentee disavows (or “disclaims”) the full scope of a claim term either in the specification or during prosecution. *Thorner v. Sony Comput. Entm't Am. LLC*, 669 F.3d 1362, 1365 (Fed. Cir. 2012), citing to *Vitronics Corp. v. Conceptronic, Inc.*, 90 F.3d 1576, 1580 (Fed. Cir. 1996).

18. To act as its own lexicographer, a patentee must “clearly set forth a definition of the disputed claim term” other than its plain and ordinary meaning. *Thorner*, 669 F.3d at 1365-66. It is not enough for a patentee to simply disclose a single embodiment or use a word in the same manner in all embodiments, the patentee must “clearly express an intent” to redefine the term. *Id.* For example, the patentee can show clear intent to redefine a term by putting the term in quotation marks, or otherwise making it clear the patentee is providing a special definition. *Tyco Fire Prods., L.P. v. Victaulic Co.*, No. 10-4645, 2012 U.S. Dist. LEXIS 42766, at *73 (E.D. Pa. Mar. 27, 2012) (finding a special definition where patent explicitly stated the claim term had a particular meaning).

19. The standard for disavowal of claim scope is similarly exacting. “The patentee may demonstrate intent to deviate from the ordinary and accustomed meaning of a claim term by including in the specification expressions of manifest exclusion or restriction, representing a clear disavowal of claim scope.” *Thorner*, 669 F.3d at 1366 (Fed. Cir. 2012); *see also Home Diagnostics, Inc. v. LifeScan, Inc.*, 381 F.3d 1352, 1358 (Fed. Cir. 2004) (“Absent a clear disavowal in the specification or the prosecution history,

the patentee is entitled to the full scope of its claim language."). "We do not read limitations from the specification into claims; we do not redefine words. Only the patentee can do that. To constitute disclaimer, there must be a clear and unmistakable disclaimer." *Id.* "Where an applicant's statements are amenable to multiple reasonable interpretations, they cannot be deemed clear and unmistakable." *3M Innovative Props. Co. v. Tredegar Corp.*, 725 F.3d 1315, 1326 (Fed. Cir. 2013).

20. The Federal Circuit has repeatedly cautioned against limiting the claimed invention to preferred embodiments or specific examples described in the patent specification. *Williamson v. Citrix Online, LLC*, 792 F.3d 1339, 1346-47 (Fed. Cir. 2015); *Liebel-Flarsheim Co. v. Medrad, Inc.*, 358 F.3d 898, 913 (Fed. Cir. 2004) ("[I]t is improper to read limitations from a preferred embodiment described in the specification—even if it is the only embodiment—into the claims absent a clear indication in the intrinsic record that the patentee intended the claims to be so limited."). "[I]t is the *claims*, not the written description, which define the scope of the patent right." *Laitram Corp. v. NEC Corp.*, 163 F.3d 1342, 1347 (Fed. Cir. 1998); *see also id.* ("[A] court may not import limitations from the written description into the claims.").
21. When engaged in the construction of claims, courts begin by looking to the words of the claims themselves to define the scope of the patented invention. *Vitronics Corp.*, 90 F.3d at 1582; *Innova/Pure Water, Inc. v. Safari Water Filtration Sys.*, 381 F.3d 1111, 1116 (Fed. Cir. 2004), ("[A] claim construction analysis must begin and remain centered on the claim language itself, for that is the language the patentee has chosen

‘to particularly point[] out and distinctly claim[] the subject matter which the patentee regards as his invention.’”

22. After reviewing the language of the claims, a subsequent step in claim construction is to review the patent specification. Claims must always be read in view of the specification, which is “highly relevant to the claim construction analysis.” *Vitronics Corp.*, 90 F.3d at 1582.

23. Third, the court may also consider the prosecution history of the patent, if in evidence. *Id.* However, general statements discussing the prior art, without more, should not be interpreted to disclaim every feature of every prior art device discussed in the patent. *Ventana Med. Sys. v. BioGenex Labs., Inc.*, 473 F.3d 1173, 1181 (Fed. Cir. 2006). In most situations, an analysis of the intrinsic evidence (i.e., patent description/specification and patent prosecution (file) history) alone will resolve any ambiguity in a disputed claim term. In such circumstances, it is improper to rely on extrinsic evidence, such as experts. *Vitronics*, 90 F.3d. at 1583.

Summary of Conclusions:

24. Challenged claims 3-4 of the '668 Patent and claims 1-3, 5-6, and 8 of the '650 Patent were rightfully allowed by the Office. Nothing provided or argued by Petitioner should disturb the USPTO's correct decision to issue the '668 and '650 Patents. For these and other reasons more fully set forth herein, Petitioner fails to carry its burden of proving obviousness of claims 3-4 of the '668 and claims 1-3, 5-6, and 8 of the '650 Patent.

Overview of the '650 Patent

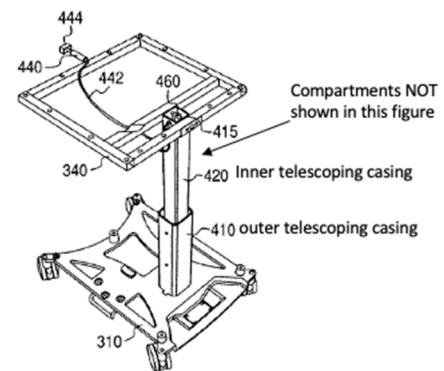
25. The claimed invention provides a mobile medical cart station with enhanced ergonomics for nurses and other medical staff. *E.g.*, '650 Patent, Abstract. Prior to the '650 and '668 patents, no one in the industry had invented a mobile medical cart with height adjustable compartments and work surface(s) as part of a unified, compact work platform as recited in the claims at-issue or knew how to realize the same. *See* '650 Patent, claim 1. Although carts with height adjustable work surfaces and keyboard trays (e.g., workstations for computers) were known, these known carts lacked enclosed storage compartments (e.g., for storing medications and medical supplies) that are also adjustable in height. Because these carts have to be mobile and light enough for nurses to easily move them around a hospital, nobody in the industry, prior to the '668 and '650 Patents, knew how to integrate relatively heavy compartments, and stored items within them, into a height adjustable work platform without sacrificing mobility, stability and weight constraints. In other words, the top-mounted (top-heavy) prior art carts do not have as much stability as the present invention for supporting compartments in a height adjustable workstation due to their higher center of gravity (COG).

26. The inventors of the '650 Patent were the first to successfully incorporate *compartment(s) into a height adjustable work platform while maintaining a stable configuration with a lower COG*, allowing the compartments to be adjustable in height so nurses and other healthcare providers do not have to constantly bend over to obtain

items stored in the compartments.

27. The height adjustment mechanism that allows the work platform, including compartments, to move up and down in height is described in one embodiment as a gas piston driver encased in a telescoping casing. See '650 Patent, col. 8:15-32, Figure 10b (perspective view showing inner telescoping casing 420 that moves in and out of the outer casing 410).

Fig. 10B



28. Instead of increasing the weight of the base portion (like the '061 Miller patent discussed above), the inventors of the '650 Patent were the first to solve the problems of the top-heavy prior art carts by configuring the cart so that the compartment is “*disposed in the portion of the work platform projecting from [or relative to] the height adjustment mechanism in the forward direction*” as recited in the claims at issue. Configuring the inventive cart in this specifically claimed fashion allows the cart to be more compact with a lower COG unlike the top-mounted carts of the Clark and Reeder references relied upon by Petitioner. The Patent Office agreed with this reasoning during the prosecution of the related '650 Patent in overcoming the Clark reference.

29. The only independent claim of the '650 Patent at-issue (claim 1) is reproduced below.

What is claimed is:

1. A cart comprising:

a work platform including a work surface and at least one compartment for containing an item within the compartment, wherein the work surface is disposed above a top of the at least one compartment;

a base configured to be movable in at least a rearward direction; and

a height adjustment mechanism for adjusting a height of the work platform relative to the base, wherein the height adjustment mechanism is configured to releasably position the work platform at a plurality of heights, the height adjustment mechanism comprising:

a driver configured to releasably position the work platform; and

an actuator for controlling the driver,

wherein the base includes a portion projecting, relative to the height adjustment mechanism, in a forward direction that is substantially opposite to the rearward direction,

wherein the work platform includes a portion projecting, relative to the height adjustment mechanism, in the forward direction, wherein the compartment is disposed in the portion of the work platform projecting in the forward direction, and the compartment is configured to permit a user facing in the rearward direction to access the item within the compartment,

wherein the actuator is disposed above the compartment and on the portion of the work platform projecting in the forward direction, and

wherein the work surface is movable relative to a remainder of the work platform from an extended position to a non-extended position.

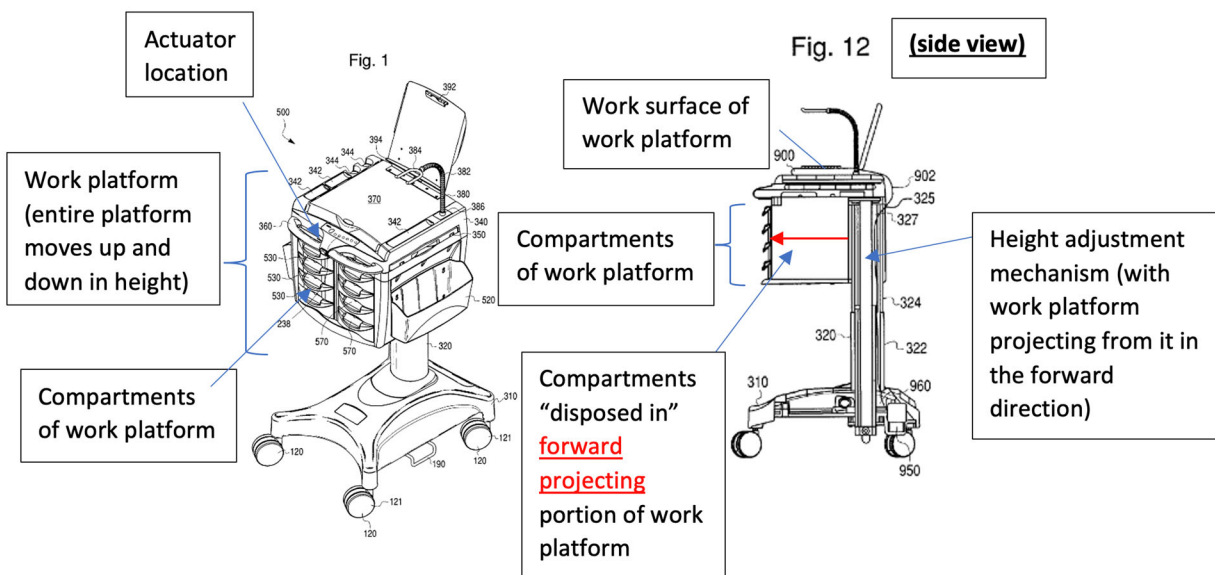
30. Claim 1 of the '650 Patent recites the phrase a compartment...disposed in the portion of the work platform *projecting [relative to the height adjustment mechanism]* in the forward direction”.

31. Both independent claims 3 and 4 of the related '668 Patent also recite the phrase to: “compartment(s)...disposed in the portion of the work platform that *projects from* the height adjustment mechanism in the forward direction”. '668 Patent, claims 3, 4 (claim 3 recites a plurality of “compartments” whereas claim 4 recites one “compartment” – similar to claim 1 of the '650 Patent).

32. These phrases at issue in the '650 and '668 Patents have the same scope (except

independent claim 1 of the '650 and independent claims 4 of the '668 Patent only recites one compartment, whereas independent claim 3 of the '668 Patent recites a plurality of compartments. For simplicity's sake, I will refer to these similar phrases from all of the independent claims at issue collectively as: "compartment(s)...disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction".

33. The challenged claims require, among other limitations, a height adjustable work platform that includes a compartment and a work surface. *E.g.*, '650 Patent, claim 1. The compartment(s) project in a forward direction from [or relative to] a height adjustment mechanism so that a medical provider may stand in front of the cart, "facing in the rearward direction", to access items stored within the compartment(s). *Id.*, see also *e.g.*, '650 Patent, col. 4 ll. 33-37. Exemplary figures with annotations from the '650 Patent in this regard are provided below to provide a generalized understanding of certain important claim features:

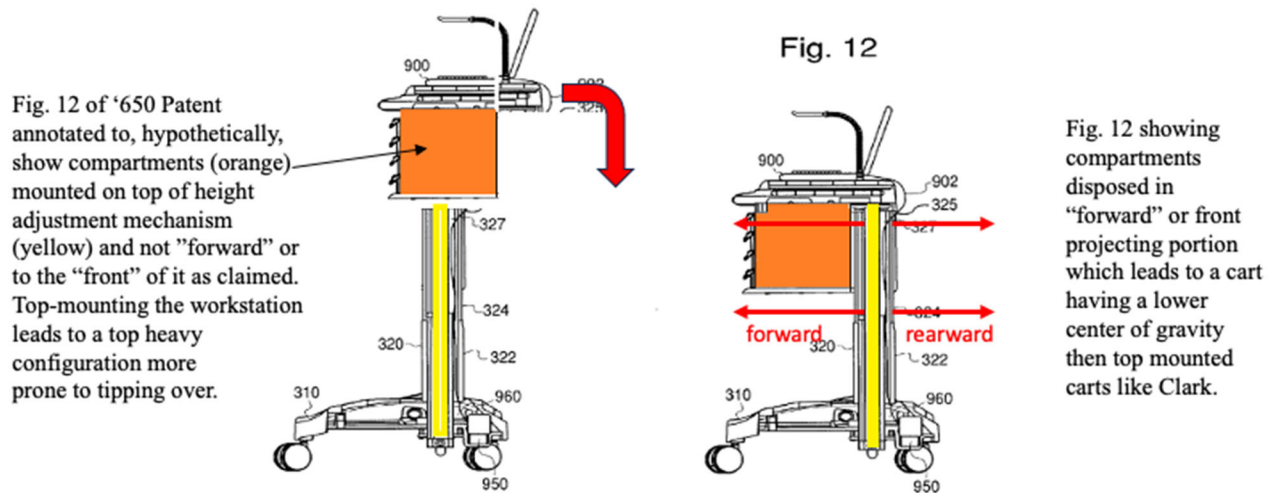


34. As particularly visible in the side view of Fig. 12 of the '650 Patent (annotated), the compartment(s) are “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction” (see annotated red arrow pointing in the forward (front) direction).¹ Placing the compartments in front of the height adjustment mechanism results in a more stable cart with a centralized, lower COG unlike the carts of Clark and Reeder that have workstations mounted entirely to the top of the height adjustment mechanism.

35. To demonstrate this advancement, an exemplary hypothetical embodiment of the cart from the '650 Patent, derived from Figure 12, is reproduced below with the compartments highlighted in orange and the height adjustment mechanism highlighted in yellow. If the cart from the '650 Patent were hypothetically configured to be top-heavy like the carts of Clark and Reeder, the resulting arrangement would resemble the depiction on the left, where the work platform, including compartments, is mounted on top of the centrally located height adjustment mechanism. In contrast, the inventive design of the '668 and '650 Patents, shown on the right, is more compact and balanced with a lower center of gravity (COG). In other words, the compartments of the patented '650 cart are contained in the portion of the work platform that projects in front of the height adjustment mechanism, positioning them lower on the cart. This lower position decreases the COG, providing more stability to the cart. The annotated

¹ There is no embodiment described in the '650 Patent where the compartments, or any part of the compartments, are disposed outside of a front-projecting portion of the work platform.

embodiment on the left has a higher COG and is more prone to toppling over, similar to the carts of Clark and Reeder, which mount the entire workstation on top of the centrally positioned height adjustment mechanism.



36. The figure above is for demonstration purposes and illustrates how the inventive cart of the '650 and '668 Patents would be top heavy if the workstation and compartments were mounted entirely on top of the height adjustment mechanism, as suggested by Clark and Reeder, which the Petitioner relies upon.

37. U.S. Patent No. 9,367,061 to Miller, another patent to a medical cart filed well *after* the '650 Patent, discussing problems with medical carts tipping over when maneuvered over uneven or slanted surfaces, and how "a lower center of gravity" can "enhance the stability of the cart and reduce the likelihood of the cart tipping over". *See, e.g., Ex. 2017, col. 18:4-24.* One solution to lower the COG of the cart proposed by this patent to Miller is to increase the weight of the base portion. *Id.* This is not an ideal solution as it increases the weight of the cart making it harder for nurses to push the cart around

the hospital. Notably, this patent also copies the invention of the '650 Patent in containing the compartments in a portion of the work platform projecting to the front of height adjustment mechanism 112 in order to lower the COG to increase stability of the cart.² Ex. 2017 at Figure 1 and 21a; col. 18:4-50.

Fig. 21a, Miller patent (filed well after the '650 and '668 Patents) showing compartments/drawers contained in front of the height adjustment column to lower COG and increase stability to prevent tipping of the cart when moving over uneven surfaces. Ex. 2017, col. 18:4-50.

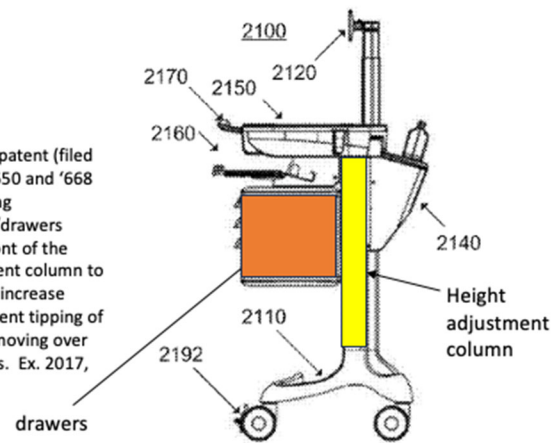


FIG. 21a

'650 File History:

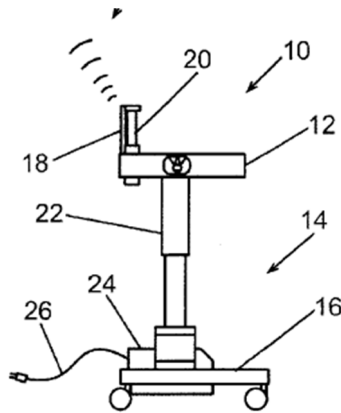
38. The file history is comprised of the correspondences between the patent applicant and examiner during the examination of the patent application at the U.S. Patent Office. These comments shed light on the meaning of claim terms and is part of the intrinsic record (as well as the patent description itself).
39. A review of the '650 File History³ demonstrates that the Petitioner makes substantially

² One difference between the Miller patent and the claimed invention of the '650/'668 Patents is that the compartments are not attached to the work platform in Miller like in the '650/'668 Patents.

³ I have been instructed by counsel that the file history comments discussed herein from the '650 file history also apply to the claims at-issue in the '668 Patent because:

1. The '650 and '668 patents are related and share the same description (the '650 Patent is a continuation of the '668 Patent);
2. They share the same dispositive claim limitations, including:
“compartment(s)...disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”;
3. The same patent examiner examined both the '668 and '650 Patents.

the same arguments made and overcome during the original prosecution of the '650 Patent. As discussed in more detail throughout this response, the Clark reference (relied upon Petitioner as a primary reference) was effectively cited during the original prosecution and was overcome. Clark is cited on the face of the '668 Patent and an equivalent⁴ was extensively discussed and overcome during prosecution of the related and co-challenged '650 Patent. Figure 1 below from Clark illustrates a side view of the workstation of Clark (work surface and keyboard tray **12**) centrally mounted to the top of a height adjustment column **22**.



40. During the original prosecution, the Applicant of the '650 Patent and the Examiner conducted an interview where the Applicant discussed proposed amendments to the pending claims as well as an argument that there were “structural compatibility” issues

⁴ Ex. 2002, US Pat. 6,721,178 to Clark, which is a continuation of the Clark reference cited by Petitioner. The claims at issue in the '650 IPR Petition filed concurrently with the '668 IPR are substantially similar to the claims at issue from the '668 Patent. Thus, Petitioner's arguments made in the '668 IPR are very similar to the arguments made in the '650 IPR. For example, the only independent claim at issue in the related '650 Patent also recites limitations to a cart having a height adjustable work platform, including compartments, where the compartments are disposed in a forward-projecting portion of the work platform. '650 Patent, claim 1.

with combining the teachings of the Clark and Ellefson references. See Ex. 1002, Interview Summary, 3/21/2012. In Examiner's summary of the interview, the Examiner noted that if the Applicant amended the claims as proposed and provided an argument "directed to the structural issues associated with the combination of Clark et al. and Ellefson" that these steps "would likely be persuasive in overcoming the rejections." *Id.* (see below excerpt).

Continuation of Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: The inventive cart was briefly discussed with a view to the specific elements constituting the various movable work surfaces at the top of the cart (elements 370 and 350). Further, applicant has tentatively proposed amending each of the independent claims to include:

a. [claim 1]: "wherein the work surface is disposed above a top of the at least one compartment...wherein the work surface is movable relative to a remainder of the work platform from an extended position to a non-extended position"

b. [claim 9]: "wherein the movable platform and the work surface are disposed above a top of the at least one compartment."

c. [claim 16]: "wherein the secondary work surface and the movable platform are positioned above a top of the at least one compartment."

The examiner commented that as regards the proposed amendment to claim 1, that the combined base and modifying references (e.g., Clark et al. and Rice et al.) would not reasonably meet a claim with these further limitations. As regards the claims initially including some recitations directed to movable work surfaces (which claim 1 initially did not include), the examiner noted that currently the critical modifying reference would be the reference to Ellefson, and there was some further discussion directed to the structural compatability of the Ellefson reference, with the examiner suggesting that in combination with the amendment, an argument directed to the structural issues associated with the combination of Clark et al. and Ellefson would likely be persuasive in overcoming the rejections as currently set forth.

41. In the next response, the Applicant amended the claims as proposed in the interview and made the arguments relating to the structural incompatibility of Clark with Ellefson and the other cited references. For example, the Applicant argued:

Furthermore, one of ordinary skill in the art would not incorporate the teachings of Rice, Murphy, and Ellefson into the workstation of Clark so as to arrive at a height-adjustable work platform with a movable work surface located above a compartment. For example, if one of ordinary skill in the art had tried to incorporate the pivotal trays 48, 50, and 52 of Ellefson into the workstation of Clark, the resulting work station would be top heavy if the trays were deployed. The result is that the deployed trays would make the workstation of Clark unstable so that it would be easily knocked over. The reason that the pivotal trays can work in the tool chest of Ellefson is that a tool chest contains heavy tools so as to prevent the instability, a condition that is lacking in Clark. In other words, the overall design of the tool chest of Ellefson (including its lower center of gravity) permits the use of pivotal trays while the workstation of Clark (with its higher center of gravity) does not. Accordingly, one of ordinary skill in the art would not combine the teachings of Clark, Rice, and Ellefson so as to arrive at a height-adjustable work platform with a movable work surface located above a compartment. Thus, claim 1 is allowable over Clark, Rice, and Ellefson.

Similarly, one of ordinary skill in the art would not have had a reason to incorporate any particular feature on Murphy into the workstation of Clark because Murphy is designed to be low to the ground (that is, a lower center of gravity) and modifying the workstation of Clark (with its high center of gravity) based on the teachings of Murphy would likely make the resulting workstation top heavy such that it would be easily knocked over. Accordingly, one of ordinary skill in the art would not combine the teachings of Clark, Rice, and Murphy so as to arrive at a height-adjustable work platform with a movable work surface located above a compartment. Thus, claim 1 is allowable over Clark, Rice, and Murphy.

See e.g., Ex. 2003, OAR of 3/28/2012 in '650 Patent File History at pgs. 8-12. The next action was a notice of allowance. *Id.*, *see* Ex. 2007, '650 File History, Notice of Allowance.⁵

⁵ These arguments made during original prosecution overcoming Clark provides evidence that the '650 Applicant disclaimed coverage over carts like Clark (and now Reeder) that have a workstation/components mounted entirely on top, and to the rear, of a height adjustment mechanism (e.g., disposed outside a forward-projecting portion of the work platform) because they have a COG and are not as stable (more easily knocked over). Petitioner ignores these arguments made by the '650 Applicant and attempts to invalidate the '650 Patent with the same art and arguments previously overcome.

42. The carts of Clark (and now Reeder) were overcome during prosecution because the Examiner accepted the argument that 1. the top-mounted workstation of Clark, with its higher COG, does not have the adequate stability to support additional components/”features” because it would become top heavy and more easily knocked over, and, thus 2. a PHOSITA, concerned about cart stability, would not be motivated to modify the cart of Clark, with its higher COG, to make it even more top-heavy by adding additional components (*e.g.*, pivotable trays of Ellefson or “any particular feature on Murphy”) into the workstation because the carts modified in this manner would be more unstable and would not work for their intended purposes (*e.g.*, they would be more susceptible to toppling over from the extra weight). In other words, prior to the ’650 invention, *conventional wisdom was to keep the top workstation portion as light and unencumbered as possible in order to keep the cart’s COG lower and more stable*. Because the inventive carts of the ’650 and ’668 patents have a lower COG, they are more stable and can support a heavier work platform that may also include extendable work surfaces and compartments. This is a distinction argued before the Office with regard to Clark in the related and co-challenged US Pat. No. 8,215,650 – an argument the Office rightfully agreed with.

43. The Petitioner ignores these findings by the original Examiner and now similarly argues that the ’650 Patent is obvious in view of modifying the workstation of Clark by adding alleged compartments into the height adjustable workstation of Clark. Thus, Petitioner essentially repeats the arguments that were already addressed during

the prosecution of the related '650 Patent. Specifically, the Petitioner's argument merely substitutes other alleged compartments for the pivotal trays and other components of the Ellefson/Murphy references cited by the patent Examiner during original prosecution. Both the Petitioner and Petitioner's expert overlook the previous arguments that successfully addressed the issues with Clark.

44. The remaining secondary references cited by the Petitioner do not address the fundamental distinctions at issue. Specifically, these additional references do not provide new arguments that resolve the higher center of gravity (COG) or instability issues previously identified with Clark. Moreover, the Petitioner does not cite these secondary references for the purpose of addressing these deficiencies.⁶ Consequently, since independent claim 1 is not considered obvious based on the alleged combinations, the dependent claims in question are also not obvious.

Level of Ordinary Skill in the Art

45. A PHOSITA in the 2003-2004 timeframe of the priority filing date of the '668 and '650 Patents would have had a bachelor's degree in a pertinent discipline involving mechanical product design, such as mechanical engineering, with 2-3 years of experience in in the design, manufacture, or analysis of mechanical devices. Alternatively, a POSITA would have been a person with a 2-year mechanical engineering diploma and had 4-6 years of experience in in the design, manufacture, or

⁶ *I.e.*, Petitioner relies on the secondary reference of Manner only for the limitation relating to the location of the actuator, Gillis for the arcuate work surface limitations, and Hartman for the gas spring only recited in dependent claim 6.

analysis of mechanical components and devices. Petitioner submits a somewhat different, and broader, definition. Petition at pg. 7. The difference is notable particularly as it supports fields, such as industrial design, that do not require the same level of hard sciences as Patent Owner's definition. In this regard, Petitioner's supplied expert testimony from Mr. Kemnitzer comes from an industrial designer. *E.g.*, Ex. 1004 at ¶ 4-6. Patent Owner's definition of a PHOSITA should be adopted. Notwithstanding, the Petition should be denied under either party's definition of a PHOSITA as Petitioner has failed to meet its burden of establishing a *prima facie* case of obviousness.

46. I understand that I must evaluate the '668 and '650 Patents from the perspective of a person of ordinary skill in the art. That is, the '668 and '650 Patents must be evaluated through the eyes of a person with ordinary skill in the relevant art at the time of the invention of this patent.

47. Based on my educational background and experience, I am qualified as at least a person of ordinary skill in the art with respect to the '668 and '650 Patents. I am familiar with the knowledge of a person of ordinary skill in the art at the time of the inventions of the '668 and '650 Patents. I am capable of providing an expert opinion on how a person of ordinary skill in the art (PHOSITA) would have understood the patent descriptions and claims of the Patents-at-issue, the descriptions of the prior art, the motivation to combine the prior art, and what combinations would have been obvious or not obvious to someone of ordinary skill in the art.

Claim Construction

48. Petitioner fails to expressly adopt or set forth any claim definitions. While certain claim construction briefing documents are provided for “reference”, it is unclear if Petitioner actually intends for the Board to adopt such definitions, aside from the “work surface” term. *E.g.*, Petition at pg. 7-9. Ironically, this is a term that need not be construed for purposes of this preliminary response. Patent Owner expressly sets forth appropriate definitions herewith for certain key claim terms below including the term “compartment(s)” which the Petitioner agreed to in the ongoing, parallel litigation. Ex. 2006; Ex. 2008, Report and Recommendations Regarding Claim Construction, pg. 15.⁷ Because Petitioner has agreed to the definition of “compartment(s)” in the ongoing, parallel litigation, this definition requiring “enclosure” should be applied for this IPR proceeding. *Id.*

49. I have been instructed that extrinsic evidence is not necessary in claim construction if the intrinsic evidence is clear. Thus, I have been instructed that the claim construction for the terms discussed below are based on the intrinsic evidence (e.g., patent descriptions, claims and file histories). Although my opinions are not needed (as it is extrinsic evidence), I have reviewed the claim construction sections of the submitted IPR Responses and I agree with the definitions as set forth and argued in the response. It is my opinion that a PHOSITA would define the claims as set forth in Patent Owner’s

⁷ This case was administratively closed prior to receiving a claim construction order from the District Court.

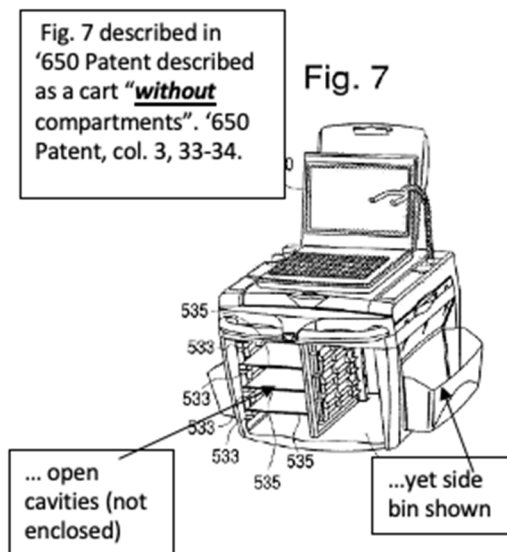
response brief based on the intrinsic evidence as summarized below.

Meaning of “Compartment(s)”:

50. Although extrinsic evidence is not needed to construe the term “compartment” as the term is not ambiguous in view of the intrinsic evidence, Plaintiff cites to the dictionary definitions that confirm the plain and ordinary meaning of the term as proposed by Capsa as an “enclosed” space. *See, e.g., “Compartment: 2. One of the parts into which an enclosed space is divided.” Merriam-Webster.com Dictionary, Merriam-Webster, <https://www.merriam-webster.com/dictionary/compartment>. Accessed Apr. 2023 and May 2023. See Ex. 2014 (dictionary excerpts); Ex. 2013, ¶2.*
51. Based on the foregoing, “compartment” should be afforded its plain and ordinary meaning, or as “an enclosed space for containing an item” as the definition that one of ordinary skill in the art would understand as the meaning of the term based on a review of the intrinsic evidence.
52. Alternatively, even assuming an ordinary meaning of “compartment” does not require enclosure, Patent Owner’s definition should be adopted because the term has been redefined by the ’650 Patent by implication and consistent usage throughout the ’650 Patent. *See SkinMedica, Inc. v. Histogen Inc.*, 727 F.3d 1187, 1203-04 (Fed. Cir. 2013) (finding redefinition can come from consistent usage of the term throughout the description in a manner consistent with only a single meaning and through implicit disclaimer by distinguishing the term from other terms). For example, the ’650 Patent never describes the compartments as anything but enclosed. The ’650 Patent teaches

that the “... compartments 530 enable a user (e.g., a nurse) to separately maintain medication for particular patients or for a particular room.” ’650 Patent, col. 7 ll. 34-36. The ’650 Patent goes on to explain, over and over, that the compartments may be lockable (e.g., col. 8 ll. 1-5), may be labeled drawers (e.g., col. 2 ll. 15, col. 7 ll. 30-35), and states the work platform “houses the at least one compartment”. (col. 2:38-39).

53. The description of the ’650 and ’668 Patents repeatedly distinguishes the claimed



“compartment” from unenclosed storage spaces. ’650 patent, Figure 1 (showing compartments 530 as pull-out enclosure-type containers or drawers); col. 3:14-15; 33-37; col. 4:30-34 (expressly distinguishing the “compartment” from other unenclosed storage spaces such as top bins 342, side bins 520, cup holders 344, and barcode scanner

holder 380). Similar to the *SkinMedica* case, the ’650 Applicant went even further to distinguish their disclaimed embodiment then using a disjunctive “or” by explicitly describing Figure 7 (reproduced here below) as a medical cart “without compartments” yet the unenclosed side bin 520 storage unit and unenclosed cavities are shown as part of the medical cart in Figure 7. *Id.* at col. 3:33-35. This unambiguous, explicit description confirms that unenclosed items like side bins and open cavities are

distinguishable and implicitly disclaimed from “compartments”.⁸

54. Based on the foregoing, the definition of “compartment” as **“an enclosed space for containing an item”** is the definition that one of ordinary skill in the art would understand as the meaning of the term based on a review of the intrinsic evidence.

Meaning of the claim phrase “[C]ompartment(s)...*disposed in* the portion of the work platform that projects from [or relative to] the height adjustment mechanism] in the *forward direction*, and the compartment(s) are configured to permit a user facing in the rearward direction to access an item within the compartment”⁹

55. Regardless of whether “compartment” is defined as “enclosed” or not, none of the cited references relied upon by Petitioner teach or suggest the claimed limitations of a compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”. The issues for the PTAB to decide in construing this claim phrase are:

1. whether this phrase at issue, particularly the terms “disposed in” means the compartment is partially in or is entirely in (i.e., “contained in”) the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction; and

⁸ In the *SkinMedica* case, the patentee used the distinctive phrase “as opposed to” when differentiating between bead and 3-dimensional cultures.

⁹ The claims at issue in the ’650 and ’668 IPR recite these claim limitations, or substantially the same limitations. The only minor differences are that some claims recite “a compartment” and some claim a plurality of “compartments”. Also, the ’650 patent recites that the work platform projects “*relative to*” height adjustment mechanism versus the ’668 patent that recites that the work platform projects “*from*” the height adjustment mechanism. Other than the number of compartments, it is my opinion that the meanings of these claim terms are the same.

2. whether the phrase at issue, particularly the term “forward direction” means in front of the height adjustment mechanism or whether it can include portions that are over or on top of the height adjustment mechanism.

56. It is my opinion that the Applicant of the '650 Patent, in the context of the rest of the claim terms, redefined the term “disposed in” to mean entirely within or “contained in” through clear, implicit redefinition or disclaimer. Additionally, the term “forward direction” means “in front,” either because this is its plain and ordinary meaning or, alternatively, by clear disclaimer, as the applicant disclaimed workstations that are mounted entirely on top of the height adjustment mechanism due to their high center of gravity (COG) and unstable design.

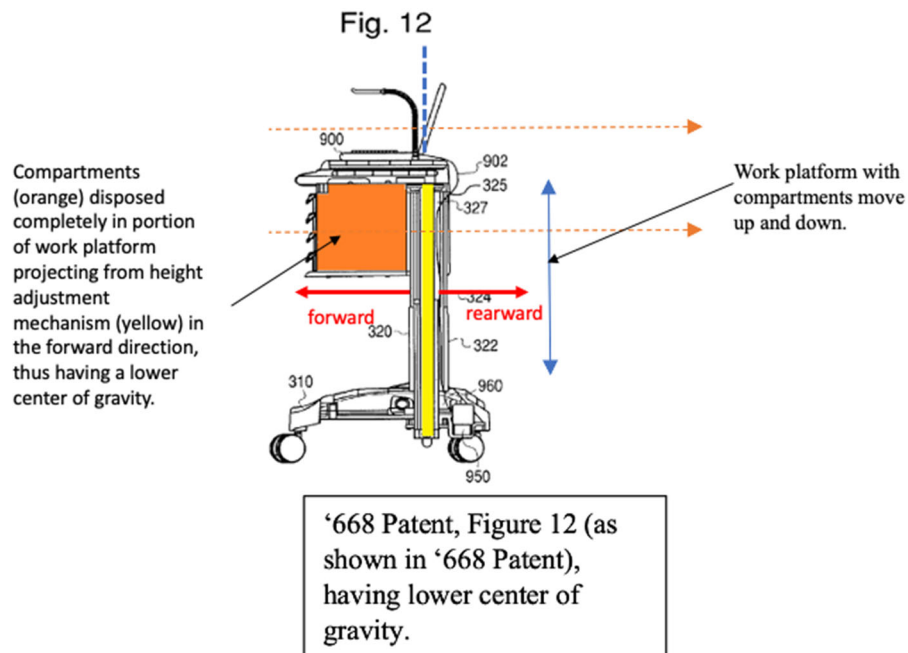
Implicit Redefinition/Disclaimer of “Disposed In” (in context of other claim terms):

57. There are multiple reasons supporting Patent Owner’s position that the phrase at issue means that the compartment is contained in (or is entirely in) the portion of the work platform projecting in the forward direction.

a. All embodiments described depict the compartments entirely in or contained in the forward projecting portion of the work platform

First, all embodiments described in the '650 and '668 Patents show that the compartments are disposed entirely in the portion of the work platform projecting from the height adjustment mechanism in the forward direction. In the '650 and '668 Patents, Figure 12 (annotated side view) illustrates that no part of the compartments (shown in orange) extends beyond the portion of the work platform that projects from

(or relative to) the height adjustment mechanism (shown in yellow) in the forward direction or to the front of the height adjustment mechanism.



There are no embodiments of the invention described in the '650 Patent where the compartments are disposed outside the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction. For example, there are no embodiments described in the '650 Patent having an enclosed compartment disposed on top of the height adjustment mechanism (as taught by Clark and Reeder) or that extends rearward or to the sides of the height adjustment mechanism.

b. Accepting Petitioner's argument would lead to an impossible result that is inconsistent with the other claim terms that require a user "facing in the rearward direction to access the item within the compartment"

In fact, it is impossible for the compartments in the cart of the '650 and '668 Patents to extend outside the forward (front) projecting portion of the work platform (e.g., to

the rearward direction from the height adjustment mechanism) because the height adjustment mechanism would be in the way, thus preventing a user from accessing items stored in the compartment as required by the claims at issue. Extending the compartments into the rearward-projecting portion of the work platform would necessitate boring a large hole through the middle of the compartments for the height adjustment mechanism to pass through. This would impede access to items stored in the compartments. For example, the compartments/drawers as shown in the annotated, hypothetical, Figure 12 below would not be functional as they could not be pulled open in such a configuration as the height adjustment mechanism goes through the middle of the drawers preventing them from being pulled out by the user. Additionally, if the drawers were extended, hypothetically, so that they projected in the rearward direction as shown below, users standing in front of the cart would not be able to access those items as the claims of the '650 Patent at-issue envision because the height adjustment mechanism would block access to that rearward portion.

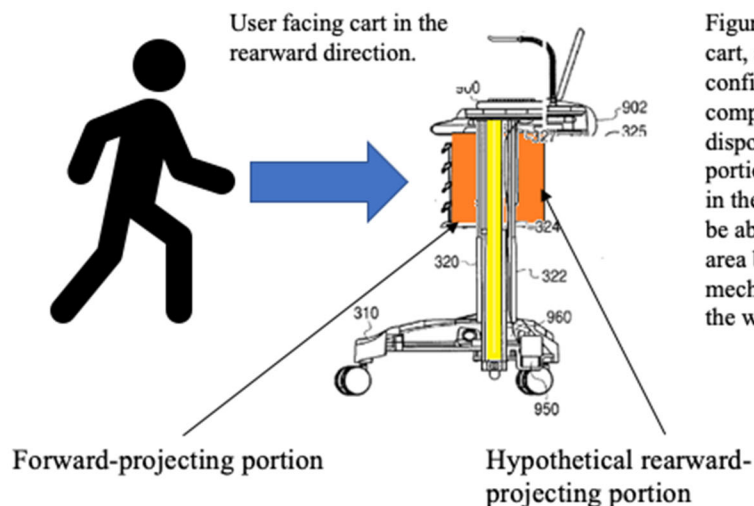


Figure 12, '650 Patent (side view of cart, altered to show impossible configuration). In other words, if the compartments (in orange) are disposed in a rearward-projecting portion here as shown, users facing in the rearward direction would not be able to access items stored in this area because the height adjustment mechanism (in yellow) would be in the way.

Petitioner's expert also concurred that Figure 12 of the '650 Patent depicts a cart where

it would be impractical for a user to access items positioned behind the height adjustment mechanism, as the mechanism itself would obstruct access. See Ex. 2010 at pg. 103:19-104:6; 134:15-135:7. Additionally, Petitioner's expert mentioned, while discussing Clark's cart, that a PHOSITA would interpret the drawers to be positioned in the forward location for accessibility by the user of the platform. *Id.*

Thus, the Applicant clearly disclaimed compartments that have portions extending outside the portion of the work platform projecting from the height adjustment mechanism in the forward direction. This is evidenced by the '650 description and claims that mandate the accessibility of stored items from the front of the cart. Based on the foregoing, it is clear from the intrinsic evidence that "disposed in" in the context of claim 1 means entirely in or "contained in".

"Forward" Means "in Front"

58. It is my opinion that the plain and ordinary meaning of "forward," interpreted as "in front," is applicable in this context. "Forward" defined as "to or toward what is ahead or in front". Merriam-Webster.com Dictionary, Merriam-Webster, <https://www.merriam-webster.com/dictionary/forward>; "Forward" defined as "toward the front: or toward what is ahead or in front". The Britannica Dictionary, <https://www.britannica.com/dictionary/forward>. Ex. 2010, at 105:7-21 (Petitioner's expert agreeing that "forward" means "towards the front").

59. Alternatively, if "in front" is not considered the plain and ordinary meaning of "forward", the Applicant clearly redefined the term as such by disclaiming

workstations that are mounted on top of or over the height adjustment mechanism. First, all embodiments disclosed in the '650 dispose the compartments in the portion of the work platform in front of the height adjustment mechanism.

60. Additionally, as discussed throughout this response, the Applicant of the '650 Patent consistently emphasized that a key aspect of the invention is achieving a lower center of gravity (COG). This is achieved (as discussed above) by positioning the compartments in the portion of the work platform projecting in front of the height adjustment mechanism, as opposed to mounting the workstation on top of it. Specifically, the Applicant overcame Clark during prosecution by criticizing Clark because it is “top-heavy” (i.e., the workstation of Clark, with keyboard tray, is mounted entirely on top of the height adjustment mechanism) resulting in a cart having a higher COG without adequate stability to support additional components without it being easily knocked over.¹⁰ It is my opinion that the file history arguments in overcoming Clark demonstrate that the '650 Patent Applicant explicitly disclaimed carts having workstations mounted entirely to the top of the height adjustment mechanism (e.g., carts like Clark and Reeder).

¹⁰ For the purposes of claim construction, it is not necessary to determine if the cart of Clark has a higher COG or is more top-heavy and more unstable than the present invention. It is enough that the '650 Applicant made those arguments for the purpose of determining the scope of the claim (e.g., the Applicant disclaimed coverage over carts like Clark that mount the workstation to the top of the height adjustment mechanism). The expert technical explanation of why the cart of Clark is top-heavy and more unstable when compared to the cart claimed in the '650 Patent will be explained in detail in a later section of this declaration discussing the motivation to combine/modify and the expectation of success.

61. Based on the foregoing, the claim phrase “compartment(s) [is/are] *disposed in* the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction” in the context of the other claim terms means **“compartment(s) [is/are] *contained in* the portion of the work platform projecting in front of the height adjustment mechanism”**.

GROUND 1 and 2: Petitioner Fails to Show that any Challenged Claim Is Unpatentable Under Grounds 1-2 (e.g., Because the primary reference of Clark does not teach or suggest all claim limitations)

62. The Petitioner fails to raise a *prima facie* case of obviousness as none of the cited references, including the primary references of Clark and Reeder, teach or suggest all of the limitations of the claims at-issue, because no articulated reasons are provided as to why a PHOSITA would modify the cited references to reach the claimed inventions, and because there would be no reasonable expectation of success in modifying the primary reference of Clark and Reeder as proposed. For example, Petitioner provides no reasons as to why a person having ordinary skill in the art (PHOSITA) would modify the carts of Clark or Reeder to position compartments entirely within (“contained in”) a forward-projecting portion of the height-adjustable work platform, nor any evidence suggesting there would be a reasonable expectation of success in this modification. Instead, Petitioner mistakenly argues that these references teach such claim elements based on overly broad claim interpretations.

None of the cited references, including Clark, discloses compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism] in the forward direction”

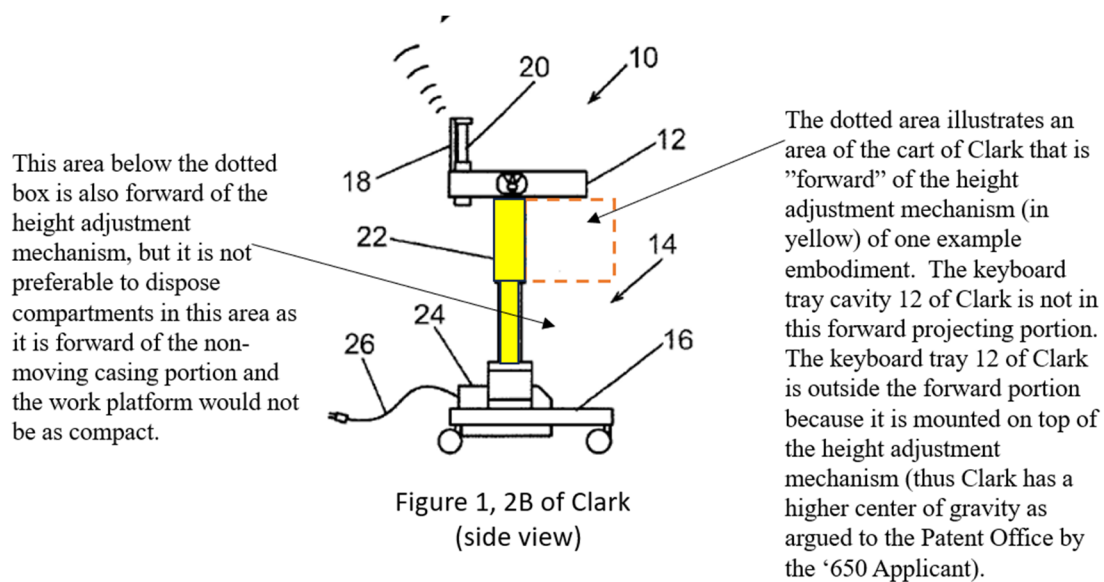
Even if we assume the keyboard tray cavity of Clark is a “compartment”, the keyboard tray is not contained in the portion of the work platform projecting in front of the height adjustment mechanism

63. The Petition fails to raise a *prima facie* case of obviousness as none of the cited references, including the primary reference of Clark, teaches or suggest a compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction” as required by claims at issue from the ’668 and ’650 Patents.

64. The side views of the cart of Clark illustrate that the keyboard tray of Clark (even assuming it is a “compartment”)¹¹ is mounted on top of the height adjustment mechanism and thus is disposed outside a portion that is forward (or in front) of the height adjustment mechanism.¹²

¹¹ *This open keyboard tray cavity does not meet the definition for the “compartment(s)” as “an enclosed space for containing an item” as agreed to by Petitioner in the ongoing, parallel litigation.* Clearly, this open keyboard cavity of Clark is not enclosed. Additionally, the keyboard cavity of Clark is not provided for the purpose of separately storing medical items as intended by the ’668 and ’650 Patents, *e.g.*, medications and medical supplies, because it is already occupied by a pull-out keyboard tray 70, 424 and computer keyboard.

¹² Even if the keyboard tray of Clark is considered to have a forward-projecting portion (which it does not as it is mounted entirely on top of the height adjustment mechanism), *it is not “disposed in” or entirely contained in a forward-projecting portion because the keyboard tray would also extend in the rearward direction.* In other words, only a minor part of the keyboard tray would be within the forward-projecting portion, rather than the entire tray or any significant functional part of it.



65. According to Ex. 2010 at 106:8-25, Petitioner's expert admitted that placing the compartments forward of the height adjustment mechanism would result in a lower center of gravity (COG) compared to a unit with compartments mounted entirely on top of the height adjustment mechanism. Additionally, at 94:17-23 and 95:5-96:9, the expert admitted that lowering the horizontal tray 12 of Clark would lower the COG and help make it more stable.

66. Based on the foregoing, the keyboard tray 12 of Clark, assuming it is an enclosed compartment, does not meet this limitation as it is not contained entirely in the portion of the work platform projecting in front of the height adjustment mechanism.

The vague, one-sentence, mention of a "drawer" in Clark does not specify that it is "disposed in the portion of the work platform projecting from [or relative to] the height adjustment mechanism in the forward direction"

67. As discussed in detail above, this claim phrase means the compartment is *contained* in the portion of the work platform projecting in front of the height adjustment mechanism. While Clark makes an unclear and passing reference to alternatively

moving the vertically mounted computer docking station 18 (and attached computer terminal 20) to a supporting drawer or pull-out tray, the details are vague, hypothetical, and aspirational.¹³ *E.g.*, '650 IPR Petition at pg. 22 (citing col. 10, ll. 30-33 of Clark). The drawer in question is not illustrated or described in any detail. *See id.* In *Tris Pharma Inc. v. Actavis Laboratories FL, Inc.*, No. 21-1495, 2022 U.S. App. LEXIS 18630 (Fed. Cir. July 7, 2022) (non-precedential), it was found that such aspirational and hypothetical references, without any data or explanations on why or how the claimed limitations could be accomplished, would be dismissed by a skilled artisan.

68. For example, this one sentence relied upon in Clark does not explain or suggest that such a hypothetical, aspirational, and unillustrated drawer be “disposed in” a *forward* projecting portion of a height adjustable work platform as claimed or how it would be configured or accomplished. *E.g.*, '650 IPR Petition at pg. 22 (citing col. 10, ll. 30-33 of Clark). Instead, this one sentence in Clark vaguely states that such a drawer could be located above or under the tray 12 (in other words “somewhere on the cart”). *Id.* Placing this alleged drawer over the keyboard tray 12 would not reach the claimed invention of the '650 Patent because the alleged tray would be above and outside the forward-projecting portion of the work platform (again top-heavy). As to being placed “under” the tray, Clark never explains specifically where or how such a drawer should be attached. In other words, this one sentence in Clark never explains how far under

¹³ For example, the docking station 18 supports a wireless computer terminal 20 which is displayed to the user, yet it is unclear why or how such a docking station would be placed into a drawer or how this would be accomplished.

the tray the drawer should be placed, or whether it is disposed in the alleged work platform as claimed, much less *contained in the portion of the work platform projecting in front of the height adjustment mechanism*. On the contrary, Clark states that the docking station 18 (*without* the drawer) can be mounted to the underside of the horizontal tray, but says nothing about the specific location of the alleged drawer. Clark at col. 10: 34-38. By explicitly stating that the docking station 18 (with attached computer terminal 20) can be mounted to the underside of the tray, but not a drawer, indicates that the inventors of Clark also appreciated that adding a drawer to the computer workstation of Clark was not feasible or desired.¹⁴

69. Petitioner's expert admits that this one sentence fails to explicitly state that the alleged drawer should be placed directly under/attached to the keyboard tray 12 as part of a compact work platform, and it fails to explicitly state the alleged drawer should be contained entirely in a forward-projecting portion of the workstation of Clark as required by the '650 claims at issue as properly construed. See Ex. 2010 at 132:1-

¹⁴ Additionally, on page 33 of the '650 IPR Petition, in discussing the claimed limitation of the actuator location, Petitioner draws in a red drawer at the bottom of the alleged work platform of Clark, but nowhere in Clark does it state or suggest that the drawer be disposed in this manner or location and nowhere does Petitioner provide any articulated reason why a PHOSITA would make such a modification or that there is a reasonable expectation of success. This amounts to a conclusory argument. For example, this vaguely described drawer could be placed under the horizontal tray but mounted entirely on top of the center height adjustment mechanism and not disposed in the portion projecting from the height adjustment mechanism in the forward direction. Or a PHOSITA, to maintain stability, could configure the cart similar to Figures 32 and 33 of Reeder where the compartments/drawers are placed as the stationary base of the cart that does not project from the height adjustment mechanism at all.

135:7 (e.g., admitting that the battery at the base of Clark described is “under” the tray 12 and that “under” can mean there is space in between the drawer and the horizontal tray).

70. Based on the foregoing, it is my opinion that Clark fails to teach or suggest a compartment contained in the portion of the work platform projecting in front of the height adjustment mechanism as required by the challenged claims.

Petitioner has failed to articulate a motivation to combine/modify Clark to reach the claimed invention (instead Petitioner wrongly assumes the forward-projecting compartment limitation is described in Clark)

71. Petitioner fails to provide any argument for why a PHOSITA would be motivated to modify the cart of Clark to include compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the *forward direction*” as claimed. Petitioner mistakenly argues that Clark teaches this limitation and thus completely fails to articulate a motivation to combine or modify Clark to reach this limitation or explain how there would be a reasonable expectation of success in doing so. *See* ’650 IPR Petition at 30-32, Kemnitzer, 80-81.

72. For example, no articulated reasons are provided as to why a PHOSITA would be motivated to dispose enclosed storage compartments in the workstation portion of Clark at all, much less contained in the portion of the work platform projecting in front of the height adjustment mechanism, or how such a modification would be successful in view of the fact that the workstation of Clark is mounted entirely on top of the height

adjustment mechanism resulting in a design with a higher center of gravity (“COG”).¹⁵

73. Because Petitioner fails to articulate any reasons for why a PHOSITA would modify Clark to include compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction” as claimed and properly construed, *Petitioner has failed to meet their burden to demonstrate a prima facie case of obviousness even if Patent Owner does not provide rebuttal arguments. Although a rebuttal argument is not required, counter arguments are provided below.*

Rebutting Motivation to Combine or Modify References (Clark)

74.A PHOSITA would not have been motivated to modify Clark to reach the claimed invention, especially the limitations to compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction” as claimed because:

¹⁵ This failure is even more glaring because the Examiner, during the original prosecution of the related ’650 Patent, found the workstation of Clark could not support additional components in the workstation while maintaining stability due to its top-heavy design (higher center of gravity).

1. the prior art or other appropriate evidence did not provide a basis for the modification (hindsight is improper);
2. the prior art relied upon by Petitioner did not recognize the unsolved problem or the solution in lowering COG and increasing stability (Petitioner and Petitioner's expert do not even mention stability or center of gravity anywhere in the filed Petitions);
3. there is no reasonable expectation of success in modifying the prior art to reach the claimed invention.

75. As discussed, Clark teaches the opposite of the claimed invention by mounting the workstation entirely on top of the height adjustment mechanism instead of in the forward/front direction. Thus, nowhere in Clark does it teach containing the compartment(s) in a front-projecting portion as claimed. Clark does not even recognize, or even mention, stability/higher COG of the cart as a problem, much less offer a solution.

76. Again, as previously discussed and as successfully argued in the '650 file history in overcoming Clark, a PHOSITA would not be motivated to modify the carts of Clark to reach the claimed invention because the entire workstation of Clark is mounted on top of the height adjustment mechanism. Adding relatively heavy compartments to the workstation of Clark (with its higher COG) would render the cart more unstable and more prone to being knocked over (e.g., thus unsatisfactory for its intended purpose). In other words, a PHOSITA, concerned with cart stability, would side with

conventional wisdom at the time and try to keep the top-mounted workstation of Clark, with its higher COG, as light and unencumbered as possible to maintain stability. Thus, not only does Clark fail to teach or suggest such limitations, but a PHOSITA would avoid modifying the top-mounted workstation of Clark with drawers/compartments to preserve balance and stability.

77. Again, Petitioner makes the same arguments relating to the Clark reference that were overcome during the original prosecution. The Clark reference was similarly overcome during the prosecution of the patents-at-issue in view of other secondary references (like the Ellefson reference) that allegedly taught pivotal trays. *See Ex. 2003, '650 file history, Applicant Response and Amendment dated 03/28/2012, pages 8-10, where the Applicant overcame the Clark reference by arguing that a PHOSITA would not modify Clark in this manner. The Applicant stated that adding an additional component (e.g., a pivotal tray) to the workstation of Clark, which has a higher center of gravity (COG), would make it top-heavy, unstable, and more susceptible to being knocked over.*

78. Mirroring the arguments made in the prosecution of the '650 Patent in overcoming Clark, if a PHOSITA had tried to incorporate compartments into the height adjustable workstation of Clark, the resulting workstation would be more unstable and top-heavy, resulting in a workstation of Clark that is more susceptible to being knocked over. The compartments can be located in the cart of the claimed invention because the cart has a lower COG, a condition that is lacking in Clark. Accordingly, a PHOSITA would

not be motivated to modify or combine the teachings of Clark so as to arrive at a height-adjustable work platform with compartment(s) “disposed in a portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”. *Id.* at para. 41.

79. As a sidenote, in its Order granting institution, the PTAB stated, in reference to Figure 2B of Clark, “the height adjustment mechanism, which supports the modified platform, is located closer to the frontward extended drawer providing a smaller moment arm than if the support is located at the rear of the modified platform. The smaller moment arm appears, based on the present record, to make the platform less susceptible to toppling/knocked over when the drawers are extended.” *See* IPR2023-01275 Decision re Institution, pg. 33 and IPR2023-01274 Decision re Institution, pg. 31. Even assuming this is true, this does not change the fact that Clark, with its workstation mounted entirely on top of the height adjustment mechanism, has a higher COG and is less stable when compared to the present invention which has the compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction.”

80. Furthermore, even assuming there is a shorter moment arm in the front, horizontal, direction, this results in a longer moment arm to the rearward direction which would cause the cart of Clark to be more susceptible to toppling over in the rearward direction which is undesirable. In other words, because these mobile medical cars are designed to roll/move in all directions, stability on all four sides of the cart is desired (not just

the front). Ex. 2010, pg. 90:4-22; 91:18-92:20 (Petitioner's expert also admitting this fact). Thus, the more relevant consideration here is not the horizontal moment arm as emphasized by the PTAB in its Decision re Institution, but the carts' relative COG and the lever arm through which *gravity* can exert force on the object which is relevant to the tipping angles of objects (e.g., carts) relative to the ground. In other words, as explained in detail below using technical formulas, by disposing the compartments in the forward-projecting portion (and not mounted on top) of the height adjustment mechanism, the COG of the '650 cart is lower, resulting in a smaller lever arm which increases stability of the '650 cart in all directions. Lowering an object's COG makes it more stable because it reduces the likelihood of tipping or falling over.

Technical Discussion

81. The stability of an object is closely related to its center of gravity (COG).

Center of Gravity (COG): The COG of an object is the point around which its mass is evenly distributed in all directions. For simple, symmetrical objects like a uniform rod or a sphere, the COG is easy to determine. However, for irregularly shaped objects, it may be more complex to pinpoint.

Stability: The stability of an object refers to its ability to resist tipping over (i.e., toppling/knocked over) when subjected to external forces or disturbances. Stability is influenced by factors such as the base area of the object, the mass distribution, and the position of the COG.

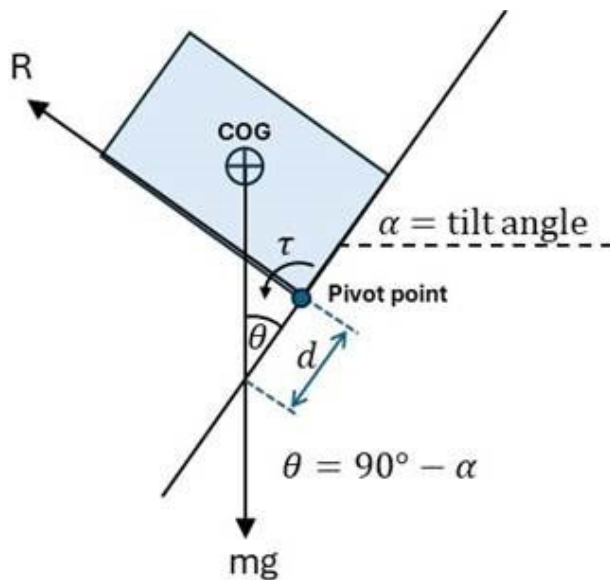
Stability and COG: The relationship between stability and the COG can be understood through the concept of torque. Torque is the tendency of a force to rotate an object about an axis, and it depends on both the magnitude of the force and the distance from the axis of rotation.

Torque Formula: The torque (τ) acting on an object is given by the formula:

$$\tau = mg * d * \sin (\theta)$$

where:

- **mg** is the gravitational force applied emanating from Center of Gravity (COG) location of the cart
- **d** is the distance from the pivot point to the point where the gravitational force is applied (see Figure below) –geometrical formulas can be generated for calculating **d** as a function of the tilt angle α and object geometry (width and height), if necessary
- **θ** is the angle between the gravitational force vector and the vector pointing from the pivot point to the point of application (the point where the gravitational force line of action intersects with the ground).



Technical Explanation:

82. The following provides a technical explanation of how COG relates to stability:

- When an object is disturbed or tilted, gravity exerts a torque (τ) on it, trying to rotate it further in the direction of the tilt.
- The greater the distance between the COG and the pivot (tipping) point, the greater the torque exerted by gravity.
- A lower COG means that the distance between the COG and the base of the object is reduced. Consequently, the torque produced by the force of gravity is minimized.
- With a lower COG, the object is less likely to tip over because it requires a larger external force to generate enough torque to overcome its stability.

83. *In essence, by lowering the COG, the lever arm through which gravity can exert a torque on the object is effectively decreased, making it more stable and resistant to tipping over.*

84. These principles can be illustrated through the tipping angles of automobiles. Ex.

2015, [https://www.schoolphysics.co.uk/age11-](https://www.schoolphysics.co.uk/age11-14/Mechanics/Statics/text/Stability_/index.html)

[14/Mechanics/Statics/text/Stability_/index.html](https://www.schoolphysics.co.uk/age11-14/Mechanics/Statics/text/Stability_/index.html). For example, racing cars have a lower COG than buses or truck so they can corner more rapidly without turning over.

Another way to increase stability

is to increase the area of the base

(i.e., the support polygon) - the

bigger the base area / support

polygon, the more stable the

object. A support polygon refers

to the area of contact between the

base of an object and the surface it rests on. It plays a role in determining the stability

of an object, as a larger support polygon provides greater stability by distributing

weight more evenly and reducing the risk of tipping over. If an object is tilted, it will

tip over if a vertical line from its COG falls outside the base (see illustration here

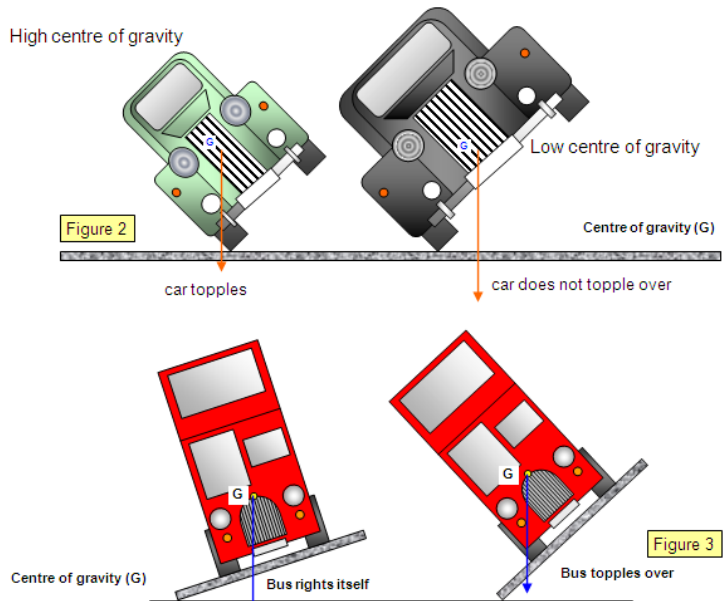
showing the point the bus will tip over). The diagrams show that the position of the

COG is important in tipping over. *Id.* The higher the COG, the more likely an object

is to tip over if it is tilted. For example, the car on the upper left, having a higher

COG, will tip easier than the car on the upper right. *Id.*; Ex. 2015; Ex. 2013, ¶3.

85. Another way of looking at this is by the article “Forces, centre of gravity, reactions and stability”, Royal Academy of Engineering. See **Exhibit 3**. This article describes

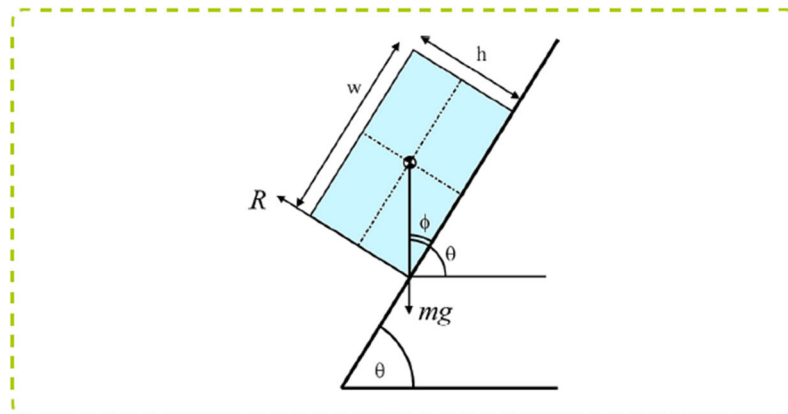


the tilt angle as a function of a *uniform* block having a height (h) and width (w). Several pages from this article have been reproduced below. It is evident that, for an object with a certain width (w), as the height of the object is lowered, the COG is lowered, causing the tilt angle (the angle that the object will tilt over) to increase, demonstrating that objects with a lower COG are more stable, and less likely to tip over. Similarly, for an object with a certain height (h), as the width (w) of the object is increased, the COG is lowered, causing the tilt angle to increase, demonstrating again that objects with a lower COG are more stable.

Background - Tipping angle

Many engineered objects, such as buses and pushchairs, require a physical tilt test to demonstrate adequate stability. However, it wouldn't be wise to build something as complex and expensive as a bus and then hope it passes such a test! During the design phase, engineers will have a good idea as to the expected stability by considering the location of the centre of gravity and where the limiting line of action lies. Indeed, many CAD packages will calculate the location of the centre of gravity.

Figure 3
An object on a rough plane at the tipping point



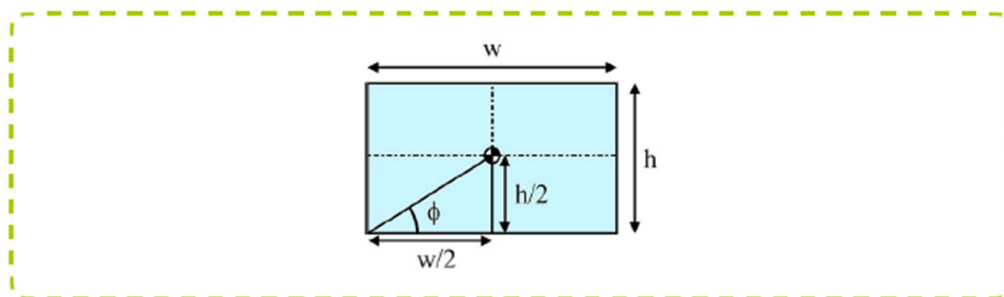
The diagram in **Figure 3** shows a uniform block of width w and height h , so that the centre of gravity is at the centre, at the point of tipping. Note, the plane is rough so the object does not slide. The tipping point is reached when the weight force acts through the corner of the object. At this point, angles θ and ϕ sum to 90° .

$$\theta + \phi = 90^\circ$$

The angle θ is the angle of the plane at which the object tips, i.e. $\theta = 90^\circ - \phi$

The angle ϕ is the angle between the bottom edge and the line joining the corner and the centre of gravity, as shown in **Figure 10** in the Appendix (page 11).

Figure 4



Using trigonometry

$$\tan \phi = \frac{h/2}{w/2} = \frac{h}{w}$$

so that the tipping angle is

$$\theta = 90^\circ - \tan^{-1}\left(\frac{h}{w}\right).$$

It can also be shown that (see Appendix)

$$\tan \theta = \frac{1}{\tan \phi} \Rightarrow \theta = \tan^{-1}\left(\frac{w}{h}\right).$$

Activity 3 - Finding the tipping angle

Values of the tipping angles for the shapes in **Table 1** are shown in **Table 2**.

Object	Width, w (cm)	Height, h (cm)	$\phi = \tan^{-1}\left(\frac{h}{w}\right)$	Calculated tipping angle	Tipping angle from interactive resource
				θ	θ
1	20	20	45°	45°	46°
2	20	12	30.96° (2 d.p.)	59.04° (2 d.p.)	60°
3	12	20	59.04° (2 d.p.)	30.96° (2 d.p.)	31°

Table 2

A comparison shows that the interactive resource gives larger values than the calculation. For shapes 2 and 3 this can be explained by the fact that the resource only allows you to select integer values for the angle θ . The nearest integer below the calculated tipping angle will not tip while the nearest one above it will definitely tip.

For shape 1 there appears to be a disagreement. This is because the calculated value of θ represents the angle at which the object is on the point of tipping. Technically, at this angle the object will not tip (as asserted by the interactive resource), however, any infinitesimal increase in angle beyond this will lead to tipping. Hence θ is an upper limit before tipping starts.

Activity 2 - Stability

1 The following observations are made

- Tilting the object moves the line of action of the normal reaction and the weight towards the corner.
- For angles up to 45° both the weight and the reaction fall within the base of the object there is no net moment about the lower corner of the object, and so it shows no tendency to tip, see **Figure 8**.

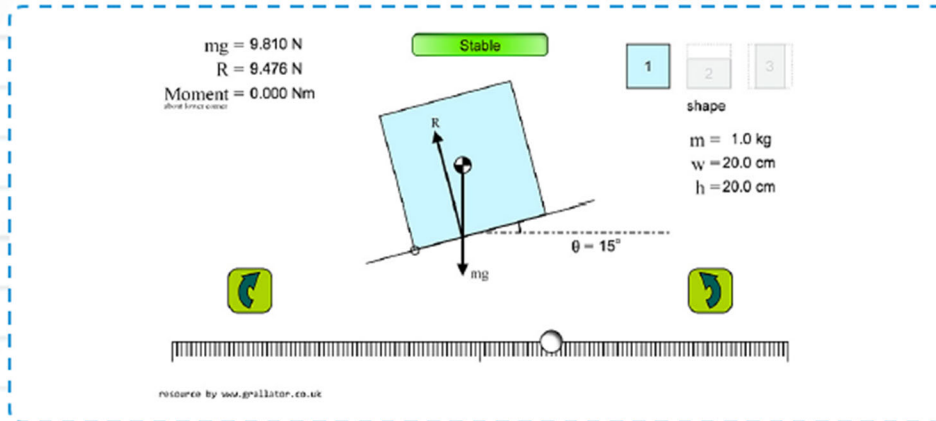


Figure 8
Screen shot
of resource
for a stable
configuration

- For angles above 45° , the weight force acts outside the base of the object. However, the normal reaction cannot do this - it can only exert a force where it is in contact with the surface.
- When the normal reaction is concentrated at the corner and the weight force acts outside the base of the object there is a net turning moment and the object tips, see **Figure 9**.

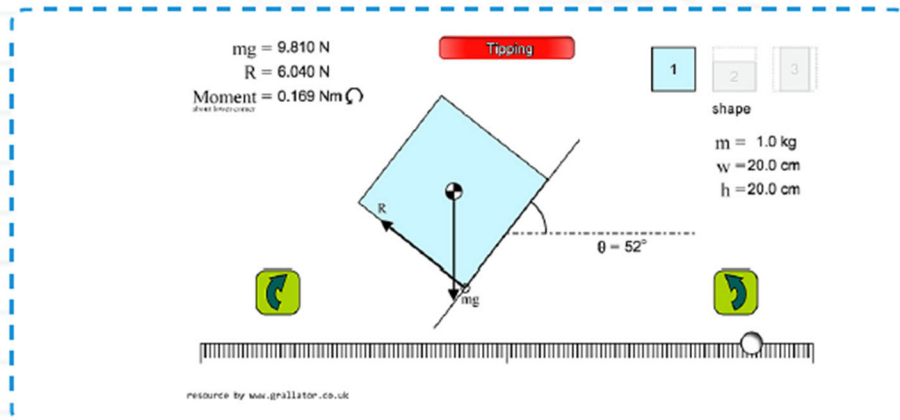


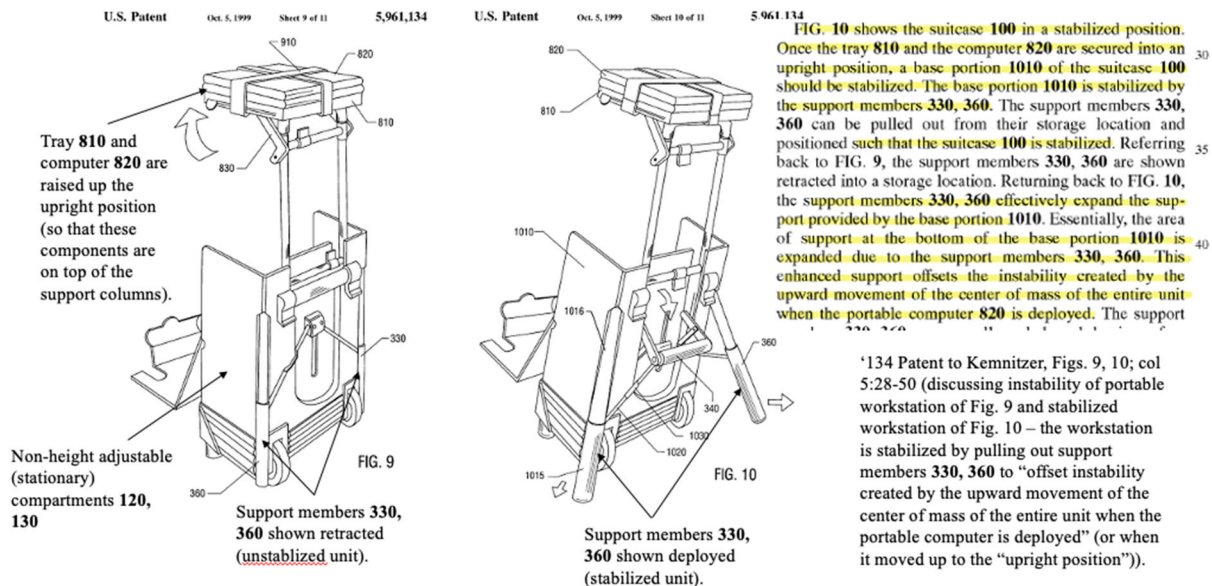
Figure 9
Screen shot of
resource for
an unstable
configuration

2 The flatter object (shape 2) has the same mass as the square object, but as it is flatter, has a lower centre of gravity. The result of this is that the object can be tilted much more before it tips over.

The narrower object (shape 3), also of the same mass, has its centre of gravity at the same height as the square block. However, because it is narrower, the weight acts outside the base at a lower angle, therefore the angle of tilt required before tipping over is less than the square block.

86. In fact, Petitioner's own expert Ronald Kemnitzer obtained a patent (U.S. Patent No.

5,961,134 to Kemnitzer) that recognizes the instability of a portable computer workstation when the height adjustable workstation is raised to an upright position and deployed. Ex. 2011; Ex. 2013, ¶5. The '134 Patent, filed in 1997 before the priority date of the '650 Patent at issue, envisions the use of support members **330**, **360** that fold out of the base in order to act as a sort of kickstand to “offset the instability” created by raising a height adjustable computer tray to its upright position (which causes an “upward movement of the center of mass of the entire unit”). *Id.* at col. 5:28-50.



87. Notably, like the Reeder reference relied upon by Petitioner, the enclosed compartments **120**, **130** are placed in a *stationary* base portion as far from the height adjustable workstation as possible while keeping the top-mounted workstation as light and unencumbered as possible in order to keep the COG lower. *Id.* at Figure 1; col. 3:27-33. This provides further evidence that at the time of the '650 invention, nobody in the industry knew how to incorporate enclosed compartments into a height

adjustable work platform while maintaining stability of the portable device. Mr. Kemnitzer expanded the base of his patented cart, and placed the compartments into the stationary base, to offset the instability caused by deploying the tray 810 “into an upright position”. *Id.* at col. 5:28-50. Thus, Petitioner’s own expert failed to come up with the solution of the ’650 Patent of increasing stability by disposing the compartments in a *forward*-projecting portion of the height adjustable work platform in order to lower the COG. Mr. Kemnitzer’s invalidity opinions and allegations in support of invalidity of the ’650 Patent are now based only on hindsight and by using the teachings of ’650 Patent as a blueprint to piece together his invalidity allegations.¹⁶

The Other Cited References of Manner, Gillis, and Hartman do not Cure the Deficiencies of Clark

88. For Grounds 1 and 2, the Petitioner only relies on the Clark reference as teaching the limitation of compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”. Petitioner relies on the secondary references of Manner, Gillis, and

¹⁶ Contrary to the incorrect statements of Petitioner, the Clark reference never states that the opening/cavity for the keyboard tray 70 can be *converted* to a drawer. *See* ’650 IPR Petition, pg. 24. Notwithstanding, a PHOSITA would not be motivated to make such a modification to the keyboard cavity of Clark as such a modification would render the Clark reference unsatisfactory for its intended purpose, *i.e.*, converting the keyboard tray cavity to a drawer for supporting a docking station 18 and computer 20 would leave no area for holding the keyboard, and, adding additional drawers to the already-top-heavy cart of Clark would cause it to be more susceptible to toppling over. *See* IPR2023-01275 Decision re Institution, pg. 24-25 and IPR2023-01274 Decision re Institution, pg. 31 (agreeing with this position).

Hartman for other limitations and/or other dependent claims and, therefore, these references do not cure the deficiencies of the Clark reference discussed above.

GROUND 3: Petitioner Fails to Show that any Challenged Claim Is Unpatentable Under Ground 3 (e.g., the primary reference of Reeder, like Clark, fails to teach all of the claim limitations of the claims at issue)

General Overview of Reeder

89. Reeder, like Clark, teaches a height adjustable computer *workstation*, but does not teach or suggest disposing enclosed compartments (e.g., drawers) in front of the height adjustable workstation or how it can be accomplished while maintaining stability of the cart. Reeder is generally directed to a patient monitoring cart/system. *E.g.*, Reeder, Abstract. While a large number of embodiments are provided in Reeder, only a select few are relied upon by Petitioner. *E.g.*, Petition (citing embodiments of figure 31, 45-46 of Reeder).
90. Exemplary figures from Reeder (annotated with color) are reproduced below for reference, showing work surface/workstation in orange and height adjustment mechanism in yellow. As illustrated, there are no enclosed compartments disposed in the height adjustable workstation of Reeder. The workstation of Reeder (in orange) is only comprised of a work surface (e.g., for a laptop) and a computer display.

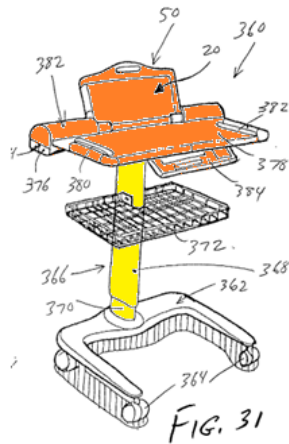
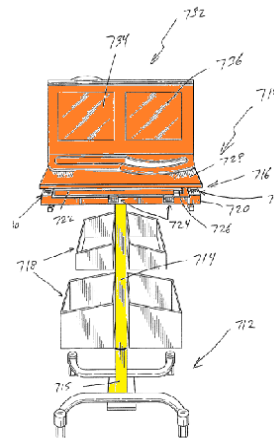


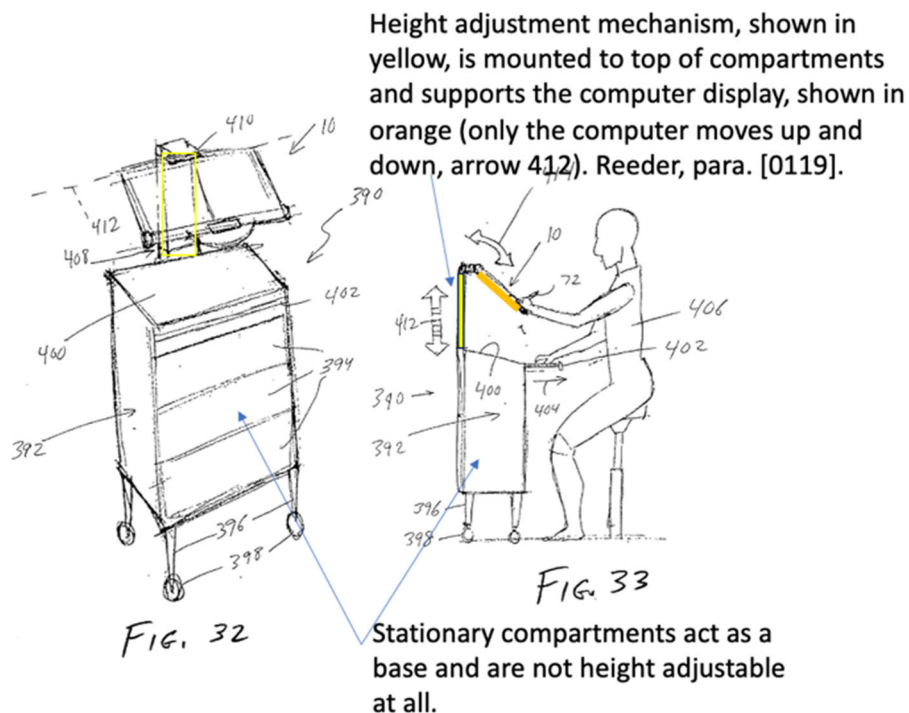
Fig. 45

91. These figures of Reeder, showing unenclosed wire trays and storage bins hanging off the support column significantly below the workstation demonstrates that Reeder did not envision or know how to dispose compartments in the height adjustable workstation portion of the device as claimed in the patents-at-issue.

92. Again, the cart of Reeder, like Clark, has a higher COG as compared to the '650 carts because it is also configured with a workstation/work surface mounted entirely on top of the height adjustment mechanism, and not in a forward-projecting portion. *See* Reeder, paras. [0118], [0147]-[0148], which describe the “center” vertical support member 714 with workstation 710 mounted entirely to the top of the center height adjustment mechanism. As previously discussed with respect to Clark, the '650 Applicant disclaimed carts with workstations that are mounted entirely on top of the height adjustment mechanism arguing they are less stable due to their higher COG.

93. Indeed, the only carts featuring enclosed compartments as described in Reeder (illustrated embodiments in Figures 32 and 33, reproduced here) utilize these compartments as the stationary base of the cart. Importantly, they lack any height

adjustment capability. Notably, the drawers in this particular embodiment of Reeder do not project from a height adjustment mechanism, as required by the claims of the '650 Patent. For instance, in Ex. 2010 at 142:15-143:20, the admission by the Petitioner's expert confirms that this particular embodiment of Reeder positions the compartments within a stationary base section that lacks height adjustability. The only component that projects forward from the height adjustment mechanism (annotated in yellow) in this embodiment of Reeder is the computer display (in orange) – not the compartments.¹⁷ *Id.*



94. Thus, Reeder teaches the exact opposite of what the '650 and '668 patents teach and

¹⁷ This embodiment of Reeder merely provides height adjustability to a computer 10 by way of a telescoping arm 408, such as highlighted in the annotated version of figure 33 shown here. *E.g., Id.* at para. [0119].

fails to solve the same problems in the art. In this embodiment, the height adjustment mechanism of Reeder is supported by the compartments, rather than the other way around as in the inventive carts of the '668 and '650 Patents. See arrow 412 in Figures 32, 33 of Reeder, Reeder at para. [0119]. Essentially, the compartments of Reeder do not extend forward from anything; instead, they serve as the base unit. Therefore, the embodiments of Figures 32 and 33 of Reeder do not teach or suggest the claim limitations of compartment(s) “*disposed in* the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”. Because the only embodiment of Reeder featuring enclosed compartments/drawers places them in a stationary base cabinet, far from the top-mounted workstation, this provides additional evidence that at the time of filing the '668 and '650 Patents, no one in the industry had integrated enclosed compartments into a height-adjustable work platform or knew how to achieve it while maintaining a lower center of gravity (COG) and sufficient stability.

None of the cited references, including Reeder, discloses compartments “disposed in” a height adjustable work platform

95. While Patent Owner disputes that Reeder teaches any height adjustable “compartments” when properly construed (as being “enclosed”), even if the Board finds that the unenclosed wire trays and side bins are “compartments”, they are not disposed in a height adjustable work platform – they merely hang off the support column far below the alleged work platform.

96. Reeder, akin to Clark, illustrates a height-adjustable computer workstation but does

not illustrate or suggest enclosed compartments, such as drawers, as part of the workstation or how such integration can be achieved. Petitioner identifies various other components of Reeder as alleged compartments, none of which fulfill the requirements of the challenged claims (in embodiments of Figures 31, 45-46 of Reeder). Specifically, Petitioner's references to the unenclosed wire storage tray 372 and/or storage containers 718 are not applicable as they do not meet the proper definition of "compartments". '650 IPR Petition at pg. 58 (citing figure 31 of Reeder).

97. Additionally, these wire trays and storage bins are not "disposed in" anything, let alone a height-adjustable work platform as specified in the claims at issue. *See* Ex. 2010 at 136:11-137:6, where Petitioner's expert agrees that there are no drawers in the workstation portion 378 of Reeder.

98. The only brief mention in Reeder of using compartments/drawers 346, 394 is with regard to the embodiment shown in figures 30 and 32-33, none of which are height adjustable. Reeder, Figs. 30, 32, 33, *e.g.*, para. [0117]-[0119].¹⁸ Thus, the only embodiment of Reeder disclosing enclosed compartments/drawers, dispose them in a stationary base cabinet and not in a height adjustable work platform as required by the '650 Patent claims at issue. In view of the foregoing, Reeder fails to teach or suggest compartment(s) disposed in a height adjustable work platform as claimed.

None of the cited references, including Reeder, discloses compartment(s)

¹⁸ Reeder fails to make any reference to use of drawers 346, 394 with respect to the top-mounted embodiments of figures 31 or 45-46. *See id.* Notably, while beginning with a discussion of figures 30-33, Reeder expressly move away from figure 31 in its discussion regarding the drawers 344, 392. *See id.*

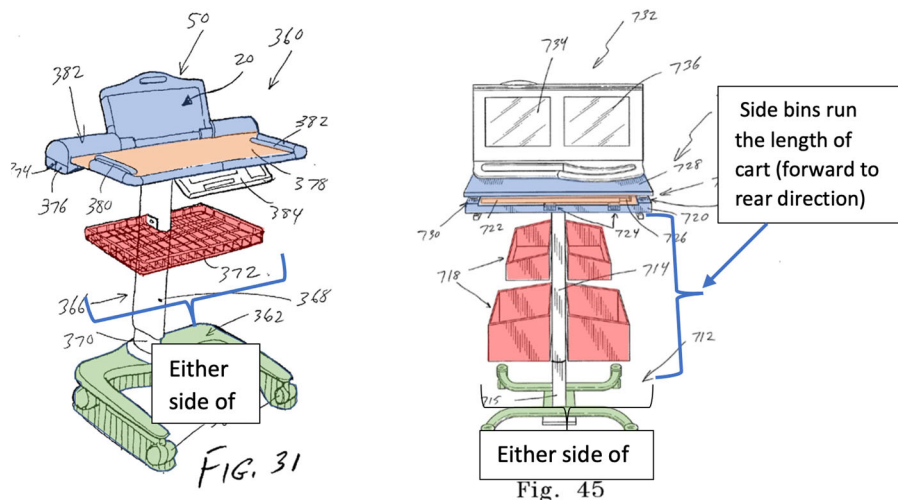
“disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”

99. As discussed in detail above, this claim phrase means that the compartment is *contained in* the portion of the work platform projecting in front of the height adjustment mechanism. A quick look at the figures of Reeder shows that there are no enclosed compartments disposed in the height adjustable workstation portion at all. Even assuming that Reeder teaches “compartments”, none of the cited wire storage tray 372 and storage containers 718 or drawers 394 are disposed in the alleged height adjustable work platform, much less contained in a portion of an alleged work platform projecting in front of the height adjustment mechanism. Petitioner incorrectly interprets the teachings of Reeder and wrongly assumes that Reeder teaches this limitation (relying on Figures 31, 45). *See* ’650 IPR Petition, pgs. 75-78, Kemnitzer, at 166-169.

100. Again, Petitioner takes an unreasonably broad and unsupported interpretation of the claim terms compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction.” For example, Petitioner essentially argues that a front area or front pocket of space of their alleged compartment meets this limitation because it is *partially* in the forward-projecting portion. *See* ’650 IPR Petition, pgs. 76-77 where they argue that the front space of the wire trays and side bins of Reeder meets this limitation. In an attempt to stretch Reeder’s teaching to meet the claims, Petitioner’s argument essentially divides the alleged compartments into separate, fractional pockets of

space/air. Again, such an interpretation is unsupported and contrary to a reasonable interpretation of the intrinsic evidence that demonstrates the '650 Applicant disclaimed embodiments where the compartments have portions disposed outside of the forward-projecting portion.

101. Inspection of the side view of the cart of Reeder illustrates that these wire trays and side bins of Reeder merely hang off the center support column and are not “disposed in” anything. Reeder at figures 31, 45-46. Additionally, the wire tray and side bins of Reeder hang off the sides and to the rear of the central support 714, and therefore are not contained in the portion of the work platform projecting in front of the height adjustment mechanism. The annotated versions of figures 31 and 45 from the Petition are reproduced below with further annotations to demonstrate this distinction. '650 IPR Petition at pgs. 76-77.



102. This distinction is better illustrated in the perspective view of Figure 46 of Reeder. As illustrated in the annotated Figure 46 of Reeder shown here, even if the wire tray and side bins of Reeder are considered “compartments” (which they are not as they are not enclosed in anything), they hang off the side of the height adjustment mechanism (center vertical support 714) and run the entire length (forward to rear) of the cart. Therefore, they are not contained in the portion of the work platform projecting in front of the height adjustment mechanism. In other words, these alleged compartments of Reeder are not disposed in a work platform at all and are clearly located outside the portion in front of the height adjustment mechanism. Thus, Reeder fails to identify the solution of the ’650 Patent of containing the compartment(s) entirely in the portion of the work platform projecting in front of the height adjustment mechanism in order to lower the COG of the cart for the purpose of increasing stability. Reeder fails to teach or suggest all of the claimed embodiments, alone or in combination.

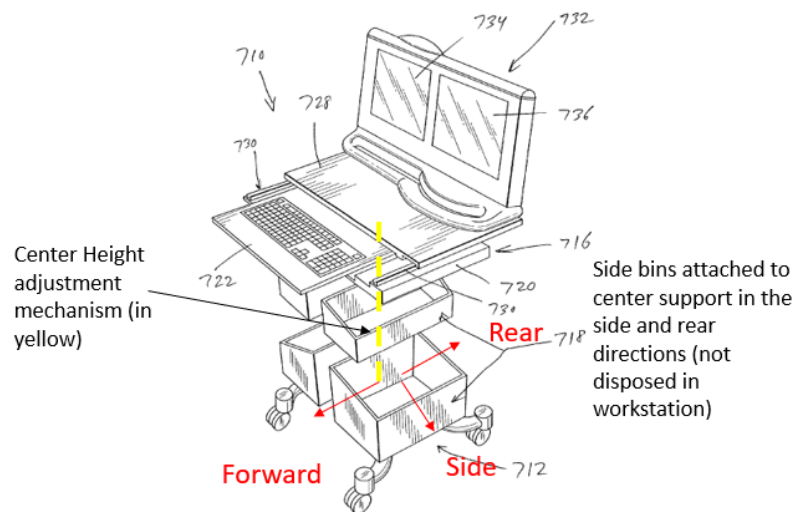


Fig. 46

Petitioner has failed to articulate a motivation to combine/modify Reeder to reach the claimed invention (Petitioner assumes the above limitation is described in Reeder)

103. Petitioner fails to articulate any basis for why a PHOSITA would be motivated to modify the cart of Reeder to include compartment(s) “disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the *forward direction*” as claimed. Petitioner instead mistakenly assumes that side bins and wire trays or substituted drawers¹⁹ of Reeder meet this limitation based on an incorrect claim construction, and thus Petitioner completely fails to articulate a motivation to combine or modify Reeder to reach this limitation.²⁰ See ’650 IPR Petition at 75-78, Kemnitzer, 166-169. For example, Petitioner generally alleges in conclusory fashion that a PHOSITA would know to add drawers to the “bottom side of the work platform” but never opines specifically that a PHOSITA would be motivated to contain the drawers in the portion of the work platform projecting in front of the height adjustment mechanism as required by the claims at issue. In *TQ Delta LLC v. Cisco Systems*, 942 F.3d 1352, 1360 (Fed. Cir. 2019), the court held that the petitioner must provide evidence explaining why a PHOSITA would combine references “in the way the claimed invention does.” This failure alone amounts to a basis for denying the Petitioner’s arguments as Petitioner has failed to demonstrate all

¹⁹ Petitioner states in conclusory fashion that a PHOSITA would know to substitute drawers for the side bins or trays shown in Reeder, yet this substitution, if even successful, would also not reach the invention as any substituted drawers, like the side bins and trays, would also be disposed outside the portion of the work platform projecting in front of the height adjustment mechanism ’668 IPR Petition, pg. 68.

²⁰ Petitioner cites to the Ellman reference for support, but Ellman does not teach height adjustable compartments at all much less *contained* in a portion of the work platform projecting in front of the height adjustment mechanism. ’668 IPR Petition, at pg. 68.

the required proof for meeting a *prima facie* case of obviousness.

Rebutting Motivation to Combine (Reeder):

104. As discussed, even though no rebuttal is necessary here as Petitioner has not met its burden, there is no motivation or reasonable expectation of success of modifying Reeder to include compartments in a forward-projecting portion of a height adjustable work platform for the same reasons provided against Clark (Grounds 1 and 2). For example, as successfully argued during the prosecution of the related '650 Patent in overcoming Clark, a PHOSITA would not be motivated to add additional, heavy components, such as storage compartments into the height adjustable workstation of Reeder (with its higher COG) as doing so would further destabilize the cart of Reeder, rendering the workstations more readily prone to toppling over. A PHOSITA would side with conventional wisdom at the time, and would keep the top-mounted workstation portion of Reeder as light and unencumbered as possible to keep the COG lower in order to maintain stability.

105. In fact, the prior art relied upon by Petitioner would have led a PHOSITA in a different direction than the claimed invention. In other words, both primary references of Clark and Reeder mount the workstation entirely on top of the height adjustment column without any description or detail of how to incorporate enclosed compartments into the top-mounted workstation. In fact, the only compartments disclosed in Reeder are located in a stationary base portion, as far away from the height adjustable work platform as possible. Thus, the state of the art at the time of the effective filing date

of the invention, as shown by the Clark and Reeder references, demonstrates that nobody in the industry had gone in the direction of the '650 Applicant who was the first to contain the compartment(s) entirely in the portion of the work platform projecting in front of the height adjustment mechanism. Accordingly, the state of the art at the time of the invention of the '650 and '668 patents would have pointed a PHOSITA in a different direction than that followed by the inventor. In other words, instead of following Clark and Reeder's lead of mounting the workstation entirely on top of the height adjustment mechanism, the '650 Applicant went in a different, novel, direction.

106. As discussed above in the context of Clark, Mr. Kemnitzer's (Petitioner's expert) own '134 patent acknowledges that to maintain the stability of a portable workstation, the compartments should be located at the *stationary* base portion (like in Reeder) while keeping the top-mounted workstation as light and unencumbered as possible. This configuration helps keep the COG lower. Petitioner's own expert opines that from a design perspective, it is desirable to keep the COG of a portable computer workstation lower in order to increase the stability of the cart. Ex. 2010, pg. 70:15-25; 72:1-17; 75:4-76-3.

107. Based on the foregoing, a PHOSITA would not be motivated to modify or combine the teachings of Reeder so as to arrive at a height-adjustable work platform with compartment(s) "disposed in a portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction". The inventor

of the '650 Patent was the first to solve the problem of how to incorporate compartments into a height adjustable work platform while maintaining stability of the cart. This was achieved by containing the compartments in the portion of the work platform projecting in front of the height adjustment mechanism, resulting in cart with a lower COG when compared to top-mounted carts like Clark and Reeder.

The Other Cited References of Manner and Gillis do not Cure the Deficiencies of Reeder

108. For Ground 3, the Petitioner only relies on the Reeder reference as teaching the limitation of compartment(s) disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction”. Petitioner relies on the secondary references of Manner, Gillis, and Hartman for other limitations and/or other dependent claims and, therefore, these references do not cure the deficiencies of the Clark reference discussed above.

Conclusion:

109. I have read the declaration of Craig Rydingsward (Ex. 2018) and I understand that his testimony supports the position that there are secondary considerations of nonobviousness that provide additional proof that the claims at issue are not obvious in view of the cited prior art. *See*, objective indicia of nonobviousness (factor 4 of the case of *Graham v. John Deere*). For example, there is evidence of commercial success and praise, copying and long felt need and failures of others to come up with the solution of the '668 and '650 Patents of containing the compartments in the portion of the work platform projecting from the height adjustment mechanism in the forward

direction. The evidence demonstrates that it is this inventive concept, and the stability it provides to the medical carts, is the reason customers buy Capsa's patented M38 and M48 carts.

110. In summary, none of Petitioner's cited references teach or suggest at least one element that is found in each of the independent claims of the subject patent, namely: the compartment(s) are "disposed in the portion of the work platform that projects from [or relative to] the height adjustment mechanism in the forward direction". This element provides the inventive cart of the '668 and '650 Patents with a lower COG, enhancing stability to support the height adjustable compartments. When properly defined, Petitioner's cited primary references do not have *enclosed* height adjustable compartments at all. Even with a broad interpretation of "compartment(s)", the carts in Petitioner's cited references do not contain the alleged compartment(s) entirely in a portion of an alleged work platform projecting in front of the height adjustment mechanism. Instead they place them on top of and/or outside of the front-projecting portion.

111. The '650 Applicant was the first to contain compartments in a forward-projecting (front) portion of the height adjustment mechanism in order to lower the COG of the cart to increase stability of the mobile medical cart. None of the prior art discloses this inventive feature. The Clark and Reeder references relied upon by Petitioner, as well as Petitioner's own expert's '134 Patent, all describe top-mounted workstations where the only enclosed compartments described with any specificity are

disposed in a stationary base cabinet as far from the height adjustable work platform as possible – presumably to preserve stability of the cart.

112. The patent examiner correctly rejected similar proposed modifications of Clark during the original prosecution, effectively agreeing that a PHOSITA would not have any reason to add additional components to the top-mounted workstation of Clark. Doing so would render it unstable due to its higher COG, making it more prone to being knocked over. For these and other reasons more fully set forth herein, Petitioner fails to carry its burden of prevailing on its challenge against the claims at-issue in the '650 Patent.

I declare under penalty of perjury that the foregoing is true and accurate.

Executed this 28 day of May, 2024.



Dr. Pinhas Ben-Tzvi

EXHIBIT 1

Pinhas Ben-Tzvi, Ph.D., P.E., FASME, SMIEEE
Professor of Mechanical Engineering
Professor of Electrical and Computer Engineering (by courtesy)
Director, VT Robotics and Mechatronics Laboratory (RMLab)
College of Engineering Faculty Fellow
Department of Mechanical Engineering, Virginia Tech
Tel/Cell: (202) 641-8011
Email: pinhas.bentzvi@gmail.com; Website: www.RMLab.org

Professional Experience

- 08/2022–Present: **Program Director**
Research Capacity and Competitiveness (RCC) Section
Established Program to Stimulate Competitive Research (EPSCoR)
Office of Integrative Activities (OIA), Office of the Director (OD)
National Science Foundation (NSF), Alexandria, VA
- 06/2020–Present: **Professor**
Department of Mechanical Engineering,
Virginia Tech, Blacksburg, VA
- 06/2020–Present: **Professor** (by courtesy)
Bradley Department of Electrical and Computer Engineering,
Virginia Tech, Blacksburg, VA
- 08/2015–05/2020: **Associate Professor**
Department of Mechanical Engineering,
Virginia Tech, Blacksburg, VA
- 05/2016–Present: **Associate Professor** (by courtesy)
Bradley Department of Electrical and Computer Engineering,
Virginia Tech, Blacksburg, VA
- 08/2014–08/2015: **Associate Professor**
Department of Mechanical & Aerospace Engineering,
George Washington University, Washington, DC
- 09/2008–08/2014: **Assistant Professor**, Department of Mechanical & Aerospace Engineering,
George Washington University, Washington, DC
- 09/2008–Present: **Founder and Director**, Robotics and Mechatronics Laboratory,
Virginia Tech, Blacksburg, VA: Aug 2015 - Present
George Washington University, Washington, DC: Sep 2008 – Aug 2015
- 2006 – 2008: **Lecturer**, Department of Mechanical & Industrial Engineering,
University of Toronto, Ontario, Canada
- 2006 – 2008: **Consultant**, Mobile Robots Division, Engineering Services Inc., Toronto, Canada
Design, Development and Integration of Mobile Robot Systems/Mechanisms
- 2002 – 2008: **Graduate Research Assistant**, Department of Mechanical Engineering,
University of Toronto, Ontario, Canada
Mobile robot mechanisms with hybrid mobility and manipulation (Ph.D.);
Dispensing systems for microdrops generation in medical applications (M.S.)

- 2002 – 2008: **Graduate Teaching Assistant**, Department of Mechanical Engineering, University of Toronto, Ontario, Canada
- 2000 – 2002: **R&D Mechanical Engineer**, General Electric Medical Systems, Haifa, Israel
Conducted research on design, development, and integration of mechanisms and mechatronic/robotic systems for medical imaging systems (CT, PET, MRI)
- 1998 – 2000: **Research Assistant**, Technion – Israel Institute of Technology, Haifa, Israel
Developed sensors and control system for a deep drawing mechanical process
- 1993 – 1996: **First Sergeant**, Israeli Air Force Academy

Professional Credential

2020–present **Licensed Professional Engineer (P.E.)**, Maryland

Other Professional Affiliations/Experience:

- 08/2015–Present: **Core Faculty Member**
Virginia Center for Autonomous Systems (VaCAS)
Virginia Tech, Blacksburg, VA
- 08/2015–Present: **Affiliate Faculty Member**
Center for Bioinspired Science and Technology (BIST)
Virginia Tech, Blacksburg, VA

Education

- | | |
|---|------|
| Ph.D., University of Toronto
Department of Mechanical Engineering (GPA 4.0/4.0) | 2008 |
| M.Sc., University of Toronto
Department of Mechanical Engineering (GPA 4.0/4.0) | 2004 |
| B.Sc. (<i>Summa Cum Laude</i>), Technion – Israel Institute of Technology
Department of Mechanical Engineering (GPA 4.0/4.0) | 2000 |
| Practical Engineer Diploma , ORT Vocational College, Haifa, Israel
Mechanical Engineering (<i>with Highest Honors</i> , GPA 4.0/4.0) | 1993 |

Research Expertise and Interests

My research and industrial experiences and expertise span the areas of mechanical/mechatronics design, electromechanical systems design, smart precision sensors and actuators, precision engineering design, mechanism/product design and system integration, intelligent autonomous systems and robotics, precision healthcare technologies, cyber-physical systems, machine learning and AI, human-machine interactions, industrial automation systems, feedback motion control systems, system dynamics.

Examples of research expertise include:

- Electromechanical Systems Design, Integration and Prototyping
- Linear Motion Control, Drivers, Actuators and Sensors
- Mechatronic and Robotic Systems - Design, Modeling, Simulation, Analysis, Integration
- Precision Mechanism and Machine Design, Analysis and Synthesis

- Sensing, Precision Actuation Devices and Measurement Modalities for Applications (vehicles, biomedical, industrial, etc.)
- Microprocessor-based Distributed and Modular Control Systems
- System Dynamics and Control
- Computer Aided Design/Engineering CAD/CAE
- Industrial Automation and Manufacturing Systems
- Ergonomic Industrial Design
- Intelligent Autonomous Systems
- Modular and Reconfigureable Robotic and Mechanical Systems
- Dexterous Robotic Manipulation - Tele-Operation, Autonomous Navigation/Function
- Rehabilitation and Medical Robotics
- Robotic Vision/Perception and Visual Servoing
- Bioinspired & Biomimetic Robotic Locomotion and Manipulation
- Continuum/Flexible Mechanisms and Structures
- Haptics Interfaces and Devices for Robotics Applications

Awards and Honors

Certificate of Recognition, Celebrating Innovation April 2024

Virginia Tech Senior Vice President for Research & Innovation

"In recognition of being awarded and issued patents in FY 2023, and important step in ensuring important discoveries reach the people who will benefit most".

Certificate of Recognition, Celebration Innovation April 2023

Virginia Tech Senior Vice President for Research & Innovation

"In recognition of being awarded and issued patents in FY 2022, and important Step in ensuring important discoveries reach the people who will benefit most".

Faculty Inventor Spotlight May 2022

Virginia Tech Center for Technology Commercialization

<https://vt.edu/link/license/faculty-inventors/pinhas-ben-tzvi.html>

Fellow, American Society of Mechanical Engineers (ASME) January 2022

Fellowship is bestowed upon members who have made significant contributions to mechanical engineering with less than 3400 of ASME's approximate 140,000 members receiving the honor

Certificate of Outstanding Professional Service November 2021

ASME Journal of Mechanisms and Robotics

In recognition of your dedicated service to the *Journal of Mechanisms and Robotics* and the Mechanisms and Robotics community at large (2018-2021)

Featured Journal Publication October 2021

Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, "Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves", *IEEE Sensors Journal*, Vol. 21, Issue 19, pp. 21120-21130, October 2021. DOI: 10.1109/JSEN.2021.3101143

*** Selected as a featured article**

Certificate of Outstanding Professional Service as Technical Editor January 2021

IEEE/ASME Transactions on Mechatronics

In grateful appreciation for, and recognition of, your dedicated service in advancing the science and art of mechatronics as Technical Editor (2016-2020)

- Certificate of Outstanding Service as Associate Editor** January 2021
International Journal of Control, Automation, and Systems (IJCAS)
In Grateful Recognition of Many Years of Dedicated Service to the Control Community as an Associate Editor of IJCAS (January 1, 2011 – December 31, 2020)
- Certificate of Appreciation in Outstanding Professional Service** August 2019
The Design Engineering Division, ASME
In Recognition of Outstanding Service as Program Co-Chair of the 43rd Mechanisms and Robotics Conference (MR) 2019
- Excellence in Teaching Award** May 2019
College of Engineering, Virginia Tech
In Recognition of Extraordinary Performance in Teaching
- IJCAS Academic Activity Award** January 2019
International Journal of Control, Automation, and Systems (IJCAS)
“In recognition of his outstanding service and dedicated work as an editorial board member of the IJCAS and for his exceptional contributions in the advancement of the journal.”
- Faculty Fellow, College of Engineering** April 2018
Virginia Tech
In Recognition of Extraordinary Performance in Research
- Keynote Speech Award** February 2018
International Conference on Mechatronics Systems and Control Engineering
“In honor of your excellent Keynote Speech and your significant contribution to the success of 2018 International Conference on Mechatronics Systems and Control Engineering (ICMSCE 2018), Amsterdam, Netherlands, Feb 21-23, 2018”
- Virginia Tech Inventor of the Month** August 2016
The Office of the Vice President for Research and Innovation recognizes Pinhas Ben-Tzvi as Inventor of the Month for August 2016 for his multiple inventions disclosed to Virginia Tech Intellectual Properties Inc.
- IJCAS Academic Activity Award** December 2013
International Journal of Control, Automation, and Systems (IJCAS)
“In recognition of his outstanding service and dedicated work as an editorial board member of the IJCAS and for his exceptional contributions in the development of the journal.”
- GW SEAS Outstanding Young Researcher Award** April 2013
<http://www.rmlab.org/honors.php>
"In recognition of his demonstrated and exceptional contributions to robotics, mechatronics, mechanism design and integration, systems dynamics and control, and sensing and actuation. Developing a very strong and externally sponsored program that covers both theoretical and applied research, Prof. Ben-Tzvi has quickly established himself as one of the leading researchers in the field of robotics, mechatronics, and controls. He founded the GW Robotics & Mechatronics Research Laboratory, and used both the lab and his research to help launch the GW robotics program."
- GW SEAS Outstanding Young Teacher Award** April 2013
<http://www.rmlab.org/honors.php>
"In recognition of his dedicated pursuit of innovative curricula and teaching methods, his efforts to develop the robotics program at SEAS, and his STEM-related mentoring and outreach activities to the local community. Prof. Ben-Tzvi works tirelessly to improve and promote robotics education, in particular, and STEM-related education in general. He has developed new courses and new labs for

students, initiated and spearheaded the development of a new robotics degree program option for undergraduate students, and created a variety of STEM-related educational outreach activities in robotics for the community beyond SEAS."

IEEE Senior Member (highest grade below fellow) April 2012

Winner of the Best Paper Award October 2011
for the paper entitled "MEMS-Based Microdroplet Generation with Integrated Sensing"
presented at the 2011 COMSOL Conference, Boston, MA, Oct 13–15, 2011
(with Doctoral Student William Rone)

Pi Tau Sigma November 2009
Faculty Honorary Membership (elected by the students)

Featured Journal Publication March 2009
Cover Article: "Design and Analysis of a Fast Steering Mirror for Precision Laser
Beams Steering"; *Sensors & Transducers Journal*, 5(3): 104–118 (2009)

The Robotdalen Scientific Award September 2008
Honorable Mention Recipient, Eskilstuna, Sweden

Governor General's Gold Medal Award of Canada - Finalist May 2008
Nominated by the Dept. of Mechanical Engineering at the University of Toronto
among 60 graduated Ph.D. students to honor academic excellence at the doctoral level

Winner of the Best Student Paper Award October 2007
for the paper entitled "Implementation of Sensors and Control Paradigm for
a Hybrid Mobile Robot Manipulator for Search and Rescue Operations" presented at the
2007 IEEE International Workshop on Robotic & Sensors Environments (ROSE 2007)

University of Toronto Open Fellowship (four awards) 2004 – 2008
Doctorate Research, University of Toronto

University of Toronto Open Fellowship (two awards) 2002 – 2003
Masters Research, University of Toronto

Summa Cum Laude, B.Sc. in Mechanical Engineering September 2000
Technion – Israel Institute of Technology (IIT)

President's Honors List Award (five awards) 1998 – 2000
Undergraduate Studies, Faculty of Mechanical Engineering, Technion – IIT

Dean's Honors List Award (two awards) 1996 – 1998
Undergraduate Studies, Faculty of Mechanical Engineering, Technion – IIT

Award for Outstanding Academic Achievements 1998
Undergraduate Studies at the Technion – Israel Inst. of Tech., Ministry of Education, Israel

Publications

Books

- [1] Kurdila, A.J., **Ben-Tzvi, P.**, Dynamics and Control of Robotic Systems. Wiley & Sons, Inc., December 2019, ISBN: 978-1-119-52483-0. (520 pages)

Peer-Reviewed Journal Publications (78 published, 0 accepted, 2 submitted/under review)

- [80] Liu, Y., **Ben-Tzvi, P.**, “Development and Experiments of a Novel Quadruped Robot with a Versatile Robotic Tail,” *IEEE Transactions on Robotics*, **Under review**, November 2023.
- [79] Guo, Y., Xu, W., **Ben-Tzvi, P.**, “Vision-Based Human-Machine Interface for a Robotic Exoskeleton Glove Designed for Patients with Brachial Plexus Injuries”, *Intelligent Service Robotics*, **Under review**, November 2023.
- [78] Feng, S., Pressgrove, I., Liu, Y., **Ben-Tzvi, P.**, “Autonomous Alignment and Docking Control for a Self-reconfigurable Modular Mobile Robotic System”, *Robotics Journal*, Vol. 13, Issue 5, pp. 1-17, May 2024. DOI: <https://doi.org/10.3390/robotics13050081>
- [77] Xu, W., Guo, Y., Liu, Y., **Ben-Tzvi, P.**, “Development of A Novel Compact Robotic Exoskeleton Glove with Reinforcement Learning Control”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 16, Issue 8, pp. 081016: 1-12, August 2024. DOI: <https://doi.org/10.1115/1.4064283>
- [76] Liu, Y., **Ben-Tzvi, P.**, “How a Serpentine Tail Assists Agile Motions of Kangaroo Rats: A Dynamics and Control Approach”, *Nonlinear Dynamics*, Vol. 111, pages 14783–14803, July 2023. DOI: [10.1007/s11071-023-08646-w](https://doi.org/10.1007/s11071-023-08646-w)
- [75] Xu, W., Guo, Y., Bravo, C.J., **Ben-Tzvi, P.**, “Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries”, *IEEE Transactions on Robotics*, Vol. 39, Issue 2, pp. 1637-1652, April 2023. DOI: [10.1109/TRO.2022.3220973](https://doi.org/10.1109/TRO.2022.3220973)
- [74] Han, X., Ren, H., Qi, J., **Ben-Tzvi, P.**, “Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and Robot Arm for First-Aid Airway Management”, *Journal of Medical Devices, Transactions of the ASME*, Vol. 17, Issue 1, pp. 014502: 1-9, March 2023. DOI: <https://doi.org/10.1115/1.4056505>
- [73] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, “Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove”, *Mechatronics Journal*, Vol. 83, pp. 102745:1-12, May 2022. DOI: [10.1016/j.mechatronics.2022.102745](https://doi.org/10.1016/j.mechatronics.2022.102745)
- [72] Sohal, S.S., Sebastian, B., **Ben-Tzvi, P.**, “Autonomous Docking of Hybrid-Wheeled Modular Robots With an Integrated Active Genderless Docking Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 14, Issue 1, pp. 011010: 1-15, February 2022. DOI: doi.org/10.1115/1.4051519
- [71] Njaka, T., Brizzolara, S., **Ben-Tzvi, P.**, “Design and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism”, *IEEE/ASME Transactions on Mechatronics*, Vol. 26, Issue 5, pp. 2339-2349, October 2021. DOI: [10.1109/TMECH.2020.3037887](https://doi.org/10.1109/TMECH.2020.3037887)

- [70] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, “Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves”, IEEE Sensors Journal, Vol. 21, Issue 19, pp. 21120-21130, October 2021. DOI:10.1109/JSEN.2021.3101143 * **Selected as a featured article**
- [69] Yang, J., Saab, W., Liu, Y., **Ben-Tzvi, P.**, “Reuleaux Triangle Based Two Degrees of Freedom Bipedal Robot”, Robotics Journal, Vol. 10, Issue 4, pp. 1-15, October 2021. DOI: 10.3390/robotics10040114
- [68] Liu, Y., **Ben-Tzvi, P.**, “Dynamic Modeling, Analysis, and Design Synthesis of a Reduced Complexity Quadruped with a Serpentine Robotic Tail”, Integrative and Comparative Biology, Vol. 61, Issue 2, pp. 464-477, August 2021. DOI: 10.1093/icb/icab083
- [67] Liu, Y., **Ben-Tzvi, P.**, “A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 13, Issue 3, pp. 031112: 1-7, June 2021. DOI: doi.org/10.1115/1.4050097
- [66] Feng, S., Sebastian, B., **Ben-Tzvi, P.**, “A Collision Avoidance Method Based on Deep Reinforcement Learning”, Robotics Journal, Vol. 10, Issue 2, pp. 1-19, May 2021.
- [65] Ren, H., Qi, J., **Ben-Tzvi, P.**, “Learning Flatness-Based Controller Using Neural Networks”, ASME Letters in Dynamic Systems and Control, Vol. 1, Issue 2, pp. 021003: 1-6, April 2021. DOI: 10.1115/1.4046776
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- [61] Wang, X., Ren, H., Kumar, A., **Ben-Tzvi, P.**, “Design and Analysis of a Variable Inertia Spatial Robotic Tail for Dynamic Stabilization”, Biomimetics, Vol. 5, Issue 4, pp. 1-16, November 2020. DOI: 10.3390/biomimetics5040055
- [60] Liu, Y., **Ben-Tzvi, P.**, “An Articulated Closed Kinematic Chain Planar Robotic Leg for High Speed Locomotion”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 4, pp. 041003: 1-15, August 2020. DOI: 10.1115/1.4045689
- [59] Liu, Y., **Ben-Tzvi, P.**, “Design, Analysis and Integration of a New Two-DOF Articulated Multi-link Robotic Tail Mechanism”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 2, pp. 021101: 1-9, April 2020. DOI: 10.1115/1.4045842
- [58] Ren, H., **Ben-Tzvi, P.**, “Advising Reinforcement Learning Towards Scaling Agents in Continuous Control Environments with Sparse Rewards”, Journal to Engineering Applications of Artificial Intelligence, Vol. 90, pp. 103515: 1-12, April 2020. DOI: 10.1016/j.engappai.2020.103515

- [57] Ren, H., **Ben-Tzvi, P.**, “Learning Inverse Kinematics and Dynamics of a Robotic Manipulator using Generative Adversarial Networks”, *Robotics and Autonomous Systems*, Vol. 124, pp. 103386: 1-12, February 2020. DOI: 10.1016/j.robot.2019.103386
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- [54] Williams, A., Sebastian, B., **Ben-Tzvi, P.**, “Review and Analysis of Search, Extraction, Evacuation, and Medical Treatment Field Robots”, *Journal of Intelligent and Robotic Systems*, Vol. 96, Issue 3, pp. 401-418, December 2019.
- [53] Budolak, D., **Ben-Tzvi, P.**, “Series Elastic Actuation for Improved Transparency in Time Delayed Haptic Teleoperation”, *Mechatronics Journal*, Vol. 63, pp. 102278:1-8, November 2019. DOI: 10.1016/j.mechatronics.2019.102278
- [52] Sebastian, B., **Ben-Tzvi, P.**, “Support Vector Machine Based Real-time Terrain Estimation for Tracked Robots”, *Mechatronics Journal*, Vol. 62, pp. 102260: 1-10, October 2019.
- [51] Liu, Y., Wang, J., **Ben-Tzvi, P.**, “A Cable Length Invariant Robotic Tail Using a Circular Shape Universal Joint Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 5, pp. 051005: 1-14, October 2019.
- [50] Kumar, P., **Ben-Tzvi, P.**, “Estimation of Wind Conditions Utilizing RC Helicopter Dynamics”, *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 5, pp. 2293-2303, October 2019.
- [49] **Ben-Tzvi, P.**, Saab, W., “A Hybrid Tracked-Wheeled Multi-Directional Mobile Robot”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 4, pp. 041008: 1-10, August 2019.
- [48] Rone, W., Saab, W., Kumar, A., **Ben-Tzvi, P.**, “Controller Design, Analysis and Experimental Validation of a Robotic Serpentine Tail to Maneuver and Stabilize a Quadrupedal Robot”, *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 141, Issue 8, pp. 081002: 1-9, August 2019.
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- [44] Saab, W., Rone, W., Kumar, A., **Ben-Tzvi, P.**, “Design and Integration of a Novel Spatial Articulated Robotic Tail”, *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 2, pp. 434-446, April 2019.
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- Tracked Vehicle Locomotion”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 2, pp. 021003: 1-12, April 2019.
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 - [41] Saab, W., Racioppo, P., Kumar, A., **Ben-Tzvi, P.**, “Design of a Miniature Modular Inchworm Robot with an Anisotropic Friction Skin”, *Robotica Journal*, Vol. 37, Issue 3, pp. 521-538, March 2019.
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*** **Winner of the Best Paper Award** ***
- [23] Moubarak, P., **Ben-Tzvi, P.**, "Design and Analysis of a New Piezoelectric MEMS Tilt Sensor", *Proceedings of the 2011 IEEE International Symposium on Robotic and Sensors Environments (ROSE 2011)*, Montreal, Quebec, Canada, pp. 83–88, Sep. 17-18, 2011.
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- [19] **Ben-Tzvi, P.**, Zhuk, M., "Real-time Dynamic Modeling and Virtual Prototype Simulation of Mechanical systems", *Proceedings of the 2010 ASME International Mechanical Engineering Congress and Exposition (IMECE 2010)*, Vancouver, British Columbia, Canada, November 12–18, 2010.

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- [16] **Ben-Tzvi, P.**, Xu, X., "An Embedded Feature-Based Stereo Vision System for Autonomous Mobile Robots", *Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010)*, Phoenix, Arizona, pp. 176–181, October 15-16, 2010.
- [15] **Ben-Tzvi, P.**, Charifa, S., Shick, M., "Extraction of 3D Images Using Pitch-Actuated 2D Laser Range Finder for Robotic Vision", *Proceedings of the 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2010)*, Phoenix, Arizona, pp. 140–145, October 15-16, 2010.
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- [12] **Ben-Tzvi, P.**, "Experimental Validation of a Hybrid Mobile Robot Mechanism with Interchangeable Locomotion and Manipulation", *Proceedings of the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2009)*, St. Louis, Missouri, pp. 420–421, October 11–15, 2009.
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- [10] Zhao, H., **Ben-Tzvi, P.**, Tingqi Lin, T., Goldenberg, A.A., "Two-layer Sliding Mode Control of Pneumatic Position Synchro System with Feedback Linearization Based on Friction Compensation", *Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008)*, Ottawa, ON, Canada, pp. 41–45, Oct 17–18, 2008.
- [9] Zhou, Q., **Ben-Tzvi, P.**, Fan, D., Goldenberg, A.A., "Design of Fast Steering Mirror Systems for Precision Laser Beams Steering", *Proceedings of the 2008 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2008)*, Ottawa, Ontario, Canada, pp. 144–149, October 17–18, 2008.
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- [7] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., "Design, Simulations and Optimization of a

Tracked Mobile Robot Manipulator with Hybrid Locomotion and Manipulation Capabilities”, *Proceedings of the 2008 IEEE International Conference on Robotics and Automation (ICRA2008)*, Pasadena, California, pp. 2307–2312, May 19–23, 2008.

- [6] **Ben-Tzvi, P.**, Goldenberg, A.A., “Mobile Robots for Hazardous Environments: New Technology for Mobility”, *ANS 2nd Int. Joint Topical Meeting on Emergency Preparedness & Response and Robotic & Remote Systems (12th Robotics & Remote Systems for Hazardous Environments)*, Albuquerque, NM, Mar 9–12, 2008.
- [5] Raoufi, C., **Ben-Tzvi, P.**, Goldenberg, A.A., and Kucharczyk, W., “A MR-Compatible Tele-Robotic System for MRI-Guided Intervention: System Overview and Mechanical Design”, *Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2007)*, San Diego, California, pp. 1975–1800, October 29 – Nov 2, 2007.
- [4] **Ben-Tzvi, P.**, Goldenberg, A.A., and Zu, J.W., “Implementation of Sensors and Control Paradigm for a Hybrid Mobile Robot Manipulator for Search and Rescue Operations”, *Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007)*, Ottawa, Ontario, Canada, pp. 92–97, October 12–13, 2007.
*** **Winner of the Best Student Paper Award** ***
- [3] **Ben-Tzvi, P.**, Ito, S., and Goldenberg, A.A., “Autonomous Stair Climbing with Reconfigurable Tracked Mobile Robot”, *Proceedings of the 2007 IEEE International Workshop on Robotic and Sensors Environments (ROSE 2007)*, Ottawa, Canada, pp. 104–109, October 12–13, 2007.
- [2] **Ben-Tzvi, P.**, Raoufi, C., Goldenberg, A.A., Zu, J.W., “Virtual Prototype Development and Simulations of a Tracked Hybrid Mobile Robot”, *Proceedings of MSC Software 2007 Virtual Product Development Conference*, Detroit, Michigan, October 10–12, 2007.
- [1] **Ben-Tzvi, P.**, Goldenberg, A.A., Zu, J.W., “A Novel Control Architecture and Design of Hybrid Locomotion and Manipulation Tracked Mobile Robot”, *Proceedings of the 2007 IEEE International Conference on Mechatronics and Automation (ICMA 2007)*, Harbin, China, pp. 1374–1381, August 5–8, 2007.

Magazine / Letter / Newsletter Publications

- [2] **Ben-Tzvi, P.**, Liu, Y., “Robots with Tails”, *Mechanical Engineering Magazine*, Vol. 143, Issue 6, pp. 32-37, October 2021.
- [1] **Ben-Tzvi, P.**, Rone, W., “Tiny Robots, Massive Potential”, *IEEE Nanotechnology Newsletter*, pp. 4-7, March 2011.

Peer-Reviewed Abstracts

- [8] Feng, S., **Ben-Tzvi, P.**, “A Modular Robotic System with Self-Reconfiguration Strategy”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.
- [7] Xu, W., **Ben-Tzvi, P.**, “Data Driven Calibration and Model-based Backlash Compensation of Compact Series Elastic Actuators for Robotic Exoskeleton Gloves”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.
- [6] Pressgrove, I., **Ben-Tzvi, P.**, “Development of a Compact and Easily Packageable Serpentine Robotic Tail System”, *Southeast Control Conference 2021 (SECC 2021)*, Blacksburg, VA, November 29-30, 2021.

- [5] Liu, Y., **Ben-Tzvi, P.**, "Towards Dynamic Locomotion of Legged Robots Using Biomimetic Articulated Robotic Tails", *2021 Annual Symposium of the Society for Integrative and Comparative Biology (SICB 2021)*, Washington, DC, January 3-7, 2021.
- [4] Fisher, N., Gilbert, G., German, S., **Ben-Tzvi, P.**, "Toward Robotic-Assisted Casualty Extraction in Multi-Domain Operations", *Military Health System Research Symposium (MHSRS 2019)*, Kissimmee FL, August 2019.
- [3] Rone, W.S., **Ben-Tzvi, P.**, "Design and Control of Bioinspired Articulated Robotic Tails for Stabilization and Maneuvering of Legged Robots", *Robotics Science and Systems (RSS 2018)*, Pittsburgh, PA, June 26–30, 2018.
- [2] Rone, W.S., Saab, W., **Ben-Tzvi, P.**, "Serpentine Robotic Tails for Maneuvering and Stabilizing Mobile Robots", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, pp. 5487, Sep. 24–28, 2017.
- [1] Kamidi, V., **Ben-Tzvi, P.**, "Experimental Validation of Dynamic Legged Locomotion Utilizing a Single-DOF Robotic Leg", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, pp. 5504, Sep. 24–28, 2017.

Monographs/Books

- [2] **Ben-Tzvi, P.**, Hybrid Mobile Robot Systems: Symbiosis of Locomotion and Manipulation. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8433-6890-2)
- [1] **Ben-Tzvi, P.**, A Dispensing System for Microdrops Generation in Medical Applications. Germany: LAP LAMBERT Academic Publishing, 2010 (ISBN-13: 978-3-8383-6000-3)

Book Chapters

- [1] **Ben-Tzvi, P.**, Moubarak, P., "A Mechatronic Perspective on Robotic Arms and End-Effectors" in Intelligent Mechatronics. Vienna, Austria: InTech Open Access Publisher, 28 Feb. 2011, pp. 3–20. (ISBN-13: 978-953-307-300-2, DOI: 10.5772/16234)
Note: this book chapter has been downloaded over 7197 times as of December 2016.

Refereed Conference Posters / Video Proceedings

- [6] Kamidi, V., **Ben-Tzvi, P.**, "Experimental Validation of Dynamic Legged Locomotion Utilizing a Single-DOF Robotic Leg", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, Sep. 24–28, 2017 – Poster Presentation.
- [5] Rone, W.S., Saab, W., **Ben-Tzvi, P.**, "Serpentine Robotic Tails for Maneuvering and Stabilizing Mobile Robots", *Proceedings of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2017)*, Vancouver, Canada, Sep. 24–28, 2017 – Poster Presentation.
- [4] Moubarak, P., Ma, Z., **Ben-Tzvi, P.**, "A Tri-state Rigid Reversible and Non-Back-Drivable Docking Mechanism for Modular Robotics Applications," *Proceedings of the 2012 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2012)*, 36th Mechanisms & Robotics Conference,

Chicago, IL, Aug. 12–15, 2012 – Poster Presentation.

***** Second place winner of the Graduate Robotics & Mechanisms Category*****

- [3] Moubarak, P., Barsky, D., **Ben-Tzvi, P.**, Zaghloul, M., “A Self-Calibrating Temperature Independent Model of a Bi-Axial Piezoelectric MEMS Tilt-Sensor,” *Proceedings of SPIE - Defense, Security, and Sensing, Micro- and Nanotechnology Sensors, Systems, & Applications IV Conf.*, Vol. 8373-93, Baltimore, MD, April 23-27, 2012 – Poster Presentation.
- [2] Rone, W., **Ben-Tzvi, P.**, "MEMS-Based Microdroplet Generation with Integrated Sensing", *COMSOL Conference*, Boston, MA, October 13-15, 2011 – Poster Presentation.
- [1] **Ben-Tzvi, P.**, Cole, K, Gilman, C., Goktas, H., Haque, S., Ma, Z., Moubarak, P., Ouellette, J., Rone, W., Sharathi, S., Torrey, J., Zambrana, E., “RAIL: Robotic Arm for Interactive Learning”, *Proceedings of the 2011 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2011)*, Washington, DC, Aug. 28–31, 2011 – Poster Presentation.
***** Third place winner of the Graduate Robotics & Mechanisms Category*****

Invited Keynote Lectures / Research Presentations and Seminars

- [29] *Novel Field Robots and Robotic Exoskeletons: Design, Control and Applications*, University of Virginia, Department of Mechanical and Aerospace Engineering, Charlottesville, VA, March 30, 2023. (Invited Research Presentation)
- [28] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Florida State University, Department of Mechanical Engineering, Tallahassee, FL, May 5, 2022. (Invited Research Presentation)
- [27] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Northeastern University, Department of Mechanical and Industrial Engineering, Boston, MA, February 28, 2022. (Invited Research Presentation)
- [26] Towards Dynamic Locomotion of Legged Robots Using Biomimetic Articulated Robotic Tails, *2021 Annual Symposium of the Society for Integrative and Comparative Biology (SICB 2021)*, Washington, DC, January 3-7, 2021. (**Invited Symposium Speaker**)
- [25] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, 2020 SPIE Smart Structures and Nondestructive Evaluation (EAPAD 2020) Conference, Anaheim, CA, April 26-30, 2020. (**Keynote Presentation**)
- [24] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Stevens Institute of Technology, Department of Mechanical Engineering, Hoboken, NJ, February 8, 2019. (Invited Research Presentation)
- [23] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, University of Waterloo, Department of Mechanical and Mechatronics Engineering, Waterloo, Ontario, Canada, January 18, 2019. (Invited Research Presentation)
- [22] *Design and Control of Bioinspired Articulated Robotic Tails for Stabilization and Maneuvering of Legged Robots*, Carnegie Mellon University, *Robotics Science and Systems Conference (RSS 2018)*, Pittsburgh, PA, June 26–30, 2018. (Invited Workshop Presentation on “Unusual Appendages: Novel, multi-modal, or multi-functional uses for limbs, tails, and other body parts”)

- [21] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, The Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA, March 4-6, 2018. (Invited Research Presentation)
- [20] *Recent Trends on Modeling and Integration of Novel Field Robots and Robotic Exoskeletons and Their Applications*, 2018 International Conference on Mechatronics Systems and Control Engineering (ICMSCE 2018), Amsterdam, Netherlands, February 21-23, 2018. (**Keynote Lecture**)
- [19] *Integrating Novel Field Robots and Robotic Exoskeletons of the Future*, Maxon Precision Motors, Inc. Annual Executive Meeting, Washington, DC, June 1, 2016. (Invited Research Presentation)
- [18] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, ON, Canada, February 26, 2016. (**Distinguished Seminar Series** – Research Presentation)
- [17] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Vanderbilt University, Department of Mechanical Engineering, Nashville, Tennessee, October 19, 2015. (Invited Research Presentation)
- [16] *Intelligent Biomimetic Flexible Robots for Stabilizing and Agile Maneuvering of Legged Robots*, Virginia Tech, Center for Bioinspired Science and Technology (BIST), Blacksburg, VA, October 9, 2015. (Research Presentation)
- [15] *Novel Field Robots and Robotic Exoskeletons: Design, Integration and Applications*, Virginia Tech, Virginia Center for Autonomous Systems (VaCAS), Blacksburg, VA, October 9, 2015. (Invited Research Presentation)
- [14] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, University of Maryland, Maryland Robotics Center, Department of Mechanical Engineering, College Park, MD, April 24, 2015. (Invited Research Presentation)
- [13] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, State University of New York at Buffalo (UB), Mechanical and Aerospace Engineering Department, Buffalo, NY, March 12, 2015. (Invited Research Presentation)
- [12] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, Worcester Polytechnic Institute, Mechanical Engineering Department, Robotics Engineering Department, Worcester, MA, March 9, 2015. (Invited Research Presentation)
- [11] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, Virginia Tech, Department of Mechanical Engineering, Blacksburg, VA, March 2, 2015. (Invited Research Presentation)
- [10] *Design and Integration of Novel Field Robots and Robotic Exoskeletons*, University of California, San Diego, Department of Mechanical & Aerospace Engineering, San Diego, CA, February 27, 2015. (Invited Research Presentation)
- [9] *Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain - Towards Modularity and Reconfigurability*, State University of New York at Buffalo (UB), Mechanical and Aerospace Engineering Department, Buffalo, NY, February 28, 2013. (Invited Research Presentation)

- [8] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, DARPA Defense Sciences Office Maximum Mobility and Manipulation (M3) Conference, Philadelphia, Pennsylvania, July 17-18, 2012. (Invited Research Presentation)
- [7] *STORM: Self-configurable and Transformable Omni-directional Robotic Modules for Rough Terrain Maximum Mobility and Manipulation*, Carnegie Mellon University (CMU), Robotics Institute, Pittsburgh, PA, March 5, 2012. (Invited Research Presentation)
- [6] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, DARPA Defense Sciences Office Maximum Mobility and Manipulation (M3) Conference, Miramar Beach, FL, January 24-25, 2012. (Invited Research Presentation)
- [5] *Symbiosis of Mobile Robotic Locomotion and Manipulation on Rough Terrain*, 2011 Symposium on Advanced Intelligent Systems, University of Waterloo, Waterloo, Canada, December 1-2, 2011. (**Keynote Lecture**)
- [4] *Sensor-Controlled Autonomous Compounded Manipulation and Locomotion of Mobile Robots*, Örebro University, School of Science and Technology, Centre for Applied Autonomous Sensor Systems (AASS), Sweden, September 10, 2008. (Research Talk)
- [3] *Autonomous Mobile Manipulation for Rough-Terrain Environments*, Mälardalen University, Intelligent Sensor Systems Division, Eskilstuna, Sweden, Sep. 11, 2008. (Research Talk)
- [2] *Hybrid Mobile Robot System for Field Operations: Interchanging Locomotion and Manipulation*, Robotdalen Day, Volvo CE Democenter, Eskilstuna, Sweden, Sep 10, 2008. (Research Presentation)
- [1] *Wireless Hybrid Mobile Robot system: Adaptive and Interchanging Locomotion and Manipulation*, The George Washington University, Washington, DC, March 2008. (Invited Research Presentation)

Outreach Presentations (in my role as Program Director at NSF)

- [1] *Navigating Research Funding Opportunities in the Research Capacity and Competitiveness (RCC) Section, NSF's Office of the Director, SC EPSCoR Annual State Conference*, Columbia, SC, April 9, 2024.
- [2] *Robotics Research Funding Opportunities in the Established Program to Stimulate Competitive Research (EPSCoR), Proceedings of the 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2023)*, Detroit, MI, October 1-5, 2023.
- [3] *Navigating Research Funding Opportunities in the Established Program to Stimulate Competitive Research (EPSCoR)*, Mississippi State University, National Science Foundation (NSF) Days, Starkville, Mississippi, November 21-22, 2022.

Other Conference /Scholarly/Technical Presentations

- [1] Guo, Y., Xu, W., **Ben-Tzvi, P.**, "Medical Robotic Exoskeleton Glove Designed for Patients with Hand Disabilities", *2022 Association for Uncrewed Vehicle Systems International (AUVSI) Ridge & Valley Conference: Partnerships for Autonomy*, Blacksburg, VA, October 25, 2022.
- [2] **Ben-Tzvi, P.**, "Field Performance of an Articulated Mobile Manipulator for Rough Terrain Applications", *Association for Unmanned Vehicle Systems International (AUVSI) Conference*, Denver, CO, August 24–27, 2010.

- [3] **Ben-Tzvi, P.**, "Mobile Robots for Security and Defense", *National Defense Industrial Association (NDIA) 2010 Ground Robotics Capabilities Conference & Exposition*, Miami, FL, March 16–18, 2010.
- [4] **Ben-Tzvi, P.**, "Demonstrations of a Mobile Robot with Compounded Mobility and Manipulation Capabilities", *Robotics Technology Consortium (RTC) Annual Meeting*, Miami, Florida, March 16, 2010.
- [5] **Ben-Tzvi, P.**, "Experimental Validation and Performance Metrics of a Hybrid Mechanism Mobile Robot", *Standard Test Methods for Response Robots Meeting, ASTM International Committee on Homeland Security Applications, National Institute of Standards and Technology (NIST), Intelligent Systems Division*, Gaithersburg, MD, June 8–10, 2009.
- [6] **Ben-Tzvi, P.**, "Field Performance Metrics of a Novel Hybrid Mobile Robot System", *National Institute of Standards and Technology (NIST), Intelligent Systems Division*, Gaithersburg, MD, March 16, 2009.
- [7] **Ben-Tzvi, P.**, "Swarms of Autonomously Self-Assembling Mobile Robots for Search & Rescue Missions", *National Science Foundation (NSF), Robust Intelligence Cluster, Information and Intelligent Systems*, Arlington, Virginia, February 27, 2009.
- [8] **Ben-Tzvi, P.**, "Proposal for Study on Autonomous Coupling of Navigation & Locomotion for a Hybrid Mechanism Mobile Robot", *Defense Advanced Research Projects Agency (DARPA), Information Processing Techniques Office (IPTO)*, Arlington, Virginia, Jan. 23, 2009.
- [9] **Ben-Tzvi, P.**, Goldenberg, A.A., "Mobile Robots with Hybrid Configuration for Military and Security Applications," *3rd Annual Conference on Robotics and Unmanned Systems*, Washington, DC, May 16-18, 2007.
- [10] **Ben-Tzvi, P.**, Ben Mrad, R., Goldenberg, A.A., "A Dispensing System for Microdrops Generation in Genomics and Proteomics Applications", *MMO Partnership Conference 2004*, Toronto Congress Centre, Toronto, Ontario, June 22, 2004.

Technical Reports

- [1] *Self-driving Modular AI-based Robot for Rough Terrain (SMARRT)*, Defense Advanced Research Projects Agency (DARPA), Contract # FA8100-19-P-0022, March 2021.
- [2] *Semi-Autonomous Victim Extraction Robot (SAVER) Design*, US Army Medical Research and Materials Command (USAMRMC/TATRC), Contract # W81XWH-16-C-0062, Sep 2018.
- [3] *Symbiosis of Locomotion and Manipulation with Hybrid Mechanisms Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-11-1-0012, July 2013.
- [4] *Autonomous Symbiosis of Mobile Robotic Locomotion and Manipulation*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-11-1-0012, July 2012.
- [5] *Field Experimental Results of a Hybrid Mechanism Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract # HR0011-09-1-0049, March 2011.
- [6] *Study on Autonomous Coupling of Navigation & Locomotion for a Hybrid Mechanism Mobile Robot*, Defense Advanced Research Projects Agency (DARPA), Contract HR0011-09-1-0049, Feb 2010.

- [7] *A Dispensing System for Microdrops Generation for Genomics and Proteomics Applications*, prepared for Materials & Manufacturing Ontario (MMO) Collaborative Project with Engineering Services Inc. (ESI), MMO Final Technical Report, July 2004.
- [8] *Survey on Droplet Generators – Assessment of Technologies and Applications*, MMO Technical Report, Toronto, Canada, September 2002.

Sponsored Research Funding

Total Extramural funding: \$4,225,471

Personal Share: \$2,445,286

Project title	Sponsor	PI	Funding Amount	Project Duration	Status
Robotic Hand Orthosis Providing Grasp Assistance for Patients with Brachial Plexus Injuries	NIH – National Institutes of Health Award # R21HD095027	Ben-Tzvi, P., Bravo, C (co-PI)	\$393,823	5/6/19 – 04/30/21	Complete
Closing the Loop between Robust Control of Agile Legged Robots and Bioinspired Robotic Tails: A Hybrid Systems Approach for Intrinsic Coupling	NSF – National Science Foundation Award # 1906727	Ben-Tzvi, P., Akbari (Co-PI)	\$396,036 (my portion \$244,366)	5/10/19-05/31/22	Complete
Collaborative Modular Robot Teammates for Shipboard Inspection and Maintenance	ONR – Office of Naval Research (DOD - Navy - SECNAV) Award # N00014-19-1-2026	Ben-Tzvi, P., Furukawa, T (PI for UVA)	\$416,924 (my portion \$58,497)	1/01/20 – 12/31/21	Complete
Phase I: Self-driving Modular AI-based Robot for Rough Terrain (SMARRT)	DARPA – Defense Advanced Research Projects Agency (Through Intelligent Automation Inc.) Contract # FA8100-19-P-0022	Ben-Tzvi, P. (VT), Charifa, S. (IAI)	\$225,000 (my portion \$90,000)	4/1/20-3/31/21	Complete
Phase II SBIR: Design of a Mobile Robot for LIFELINE-equipped Squad – Multipurpose Equipment Transport UGV	U.S. Army Medical Research and Material Command - Through RE2, Inc. Phase II SBIR Award # W81XWH-16-C-0062	Ben-Tzvi, P.	\$200,028	10/2016 - 09/2018	Complete

MRI: Development of a System for High-Resolution Uninterrupted Capture of Complex Animal Motions	NSF – National Science Foundation	R. Muller, Ben-Tzvi (Senior Personnel) +8 other SP	\$265,666 (my portion \$25,000)	10/2018-9/2020	Active/ Ongoing
Trawl-Resistant Self-Mooring Autonomous Underwater Vehicle (AUV)	NAVO – US Naval Oceanographic Office	Ben-Tzvi, P. (Co-PI), Stilwell, D. (PI)	\$379,057 (my portion \$71,373)	05/2017-05/2018	Complete
Active Dynamic Continuum Tails for Maneuvering and Stabilizing Legged Robots	NSF – National Science Foundation Award #1334227/1557312	Ben-Tzvi, P.	\$307,672	09/2013-08/2017	Complete
IRES: US-China Collaboration: Bats as Model Organisms for Bioinspired Engineering	NSF – National Science Foundation	R. Muller, Ben-Tzvi (Senior Personnel) +11 other SP	\$250,000 (my portion \$20,000)	02/2017-01/2020	Active/ Ongoing
Analysis of Ship Air Wakes with UAVs	ONR – Office of Naval Research Grant # N00014-15-1-2043	Ben-Tzvi, P. (Co-PI), Snyder, M.R (PI)	\$655,000 (my portion \$356,759)	01/2015-01/2018	Complete
Development of Two-Finger Haptic Glove Exoskeleton for Delivery of Somatosensory Stimuli for Measurement of Cortical Responses in Neurologically Impaired Children	NCH - Nationwide Children's Hospital Research Institute, Through National Institutes of Health (NIH)	Ben-Tzvi, P.	\$50,028	02/2016 - 10/2016	Complete
A Mechatronics Measurement System and Data Processing for Ship Air Wake Studies with UAVs	USN – United States Navy Grant # N00189-12-P-1183	Ben-Tzvi, P.	\$244,030	08/2012-02/2015	Complete
Autonomous Symbiosis of Robotic Locomotion & Manipulation	DARPA – Defense Advanced Research Projects Agency Grant #HR0011-11-1-0012	Ben-Tzvi, P.	\$100,000	09/2011-04/2013	Complete
Study on Autonomous Coupling of Navigation and Locomotion for a Hybrid Mechanism Mobile Robot	DARPA – Defense Advanced Research Projects Agency Grant #HR0011-09-1-0049	Ben-Tzvi, P.	\$299,707	07/2009-12/2010	Complete
Kinetic Universal Robotic	GWIBE – GW	Ben-Tzvi,	\$10,000	11/2010-	Complete

Assistive Joint	Institute for Biomedical Eng.	P.		07/2011	
A Precise Piezoceramic Actuated Dispensing Array for Microdrops Generation and a Vision Based Testing Setup	UFF/Dilthey Award – GWU Facilitating Fund	Ben-Tzvi, P.	\$20,000	07/2009-08/2010	Complete
Application of Electroactive Polymer (EAP) Artificial Muscles for Development of Bioinspired Walking Micro-Mobile Robot	COBRE – GW Center for Biomimetics and Bioinspired Engineering	Ben-Tzvi, P.	\$12,500	01/2009-12/2009	Complete

Other Awards and Recognitions

Awards of graduate students whose research I am directing

Torgersen Graduate Research Excellence Award, Finalist

May 2022

Prof. Ben-Tzvi's doctoral student, Mr. Yujiong Liu, was selected for an oral and poster presentation category of the Torgersen Graduate Research Award for the research entitled "Novel Legged Robots with a Serpentine Robotic Tail: Modeling, Control, and Implementations". He was one among the 3 selected from all PhD applicants in the College of Engineering.

Torgersen Graduate Research Excellence Award, Poster

May 2019

Prof. Ben-Tzvi's doctoral student, Mr. Bijo Sebastian, was selected for the poster presentation category of the Torgersen Graduate Research Award for the research entitled "Traversability Estimation Techniques for Improved Navigation of Tracked Robots". He was one among the 8 selected from 59 PhD applicants in the College of Engineering.

GW Research Day, 1st place

April 2014

Prof. Ben-Tzvi's doctoral student, Mr. Will Rone, won 1st place for the research entitled "Biomimetic Robotic Tails for Agile Maneuvering of Field Mobile Robots"

Article published by *GW Today* in Summer 2014 issue pg. 11 is available here: <http://bit.ly/1e87Gui>

ASME Graduate Mechanism & Robot Design Competition, 2nd place

August 2012

Prof. Ben-Tzvi's doctoral student, Mr. Paul Moubarak, presented his research project titled "A Tri-state Rigid Reversible and Non-Back-Drivable Docking Mechanism for Modular Robotics Applications" at the ASME IDETC/CIE 2012, August 12-15, Chicago, IL and won 2nd place

SEAS/GWU R&D Showcase, 3rd place

February 2012

for the research entitled "STORM: Self-configurable and Transformable Omni-directional Robotic Modules", Article available here: <http://bit.ly/yVNEXh>
(with Doctoral Student Paul Moubarak)

Mechanism & Robot Design Competition, 3rd place

August 2011

Students from my graduate robotics course presented their class project entitled "RAIL – Robotic Arm for Interactive Learning", at the ASME IDETC/CIE 2011, August 28-31, Washington, DC and won 3rd place
<https://sites.google.com/site/asmesmrdc/past-winners>

Recognitions & Media Coverage

Media Coverage, Research Profile Social Posts *LinkedIn/Instagram* October 2023
Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health, NIH/NICHD

Posts available at: [LinkedIn post 1/2](#); [LinkedIn post 2/2](#); [Instagram post 1/2](#); [Instagram post 2/2](#); [Twitter thread](#)

Media Coverage, Featured Article in *Virginia Tech News Daily* January 2023

Article titled “Pinhas Ben-Tzvi, a professor and researcher in mechanical engineering, is partnering with physician Cesar Bravo of Carilion Clinic to develop a new tool for those who have suffered a brachial plexus injury”, January 12, 2023 Issue.

Article available at: <https://tinyurl.com/52x5pmur>

Media Coverage, Featured Video in *Virginia Tech ME LinkedIn* December 2022

Article titled “Pinhas Ben-Tzvi teamed up with Carilion Clinic to create a robotic hand for use by those with brachial plexus injuries”, December 7, 2022.

Article available at: <https://tinyurl.com/2p9fcpwn>

Media Coverage, Featured Article in *Virginia Tech News Daily* September 2022

Article titled “Inventor Spotlight: Pinhas Ben-Tzvi, professor of mechanical engineering”, September 27, 2022 Issue.

Article available at: <https://www.vt.edu/link/license/faculty-inventors/pinhas-ben-tzvi.html>

Media Coverage, Cover Article Featured in *VT/ME Momentum Magazine* July 2022

Article titled “Pinhas Ben-Tzvi named Fellow of the ASME”,

Vol. 7, Issue 1, pp. 15, Spring 2022. Article available at: <https://bit.ly/3zFTjdh>

Media Coverage, Featured Article in *Virginia Tech News Daily* March 2022

Article titled “Pinhas Ben-Tzvi named fellow of the American Society of Mechanical Engineers”, March 15, 2022 Issue.

Article available at: <https://tinyurl.com/mu8zpv5j>

Media Coverage, Article Featured in *VT/ME Annual Report* Dec. 2021

Article titled “Robots with Tails”

December 2021 Issue. Article available at: <https://bit.ly/3Dw1I30>

Media Coverage, Article Featured in *Mechanical Engineering Magazine* Oct. 2021

Article titled “Robots with Tails”, Vol. 143, Issue 6, pp. 32-37, October/November 2021.

Article available at: <https://www.asme.org/topics-resources/content/engineers-could-put-tails-on-robots>

Media Coverage, Cover Article Featured in *VT/ME Annual Report* Dec. 2018

Article titled “Robotic Tails: High-Tech Tails May Provide Bio-Inspired Solution to Robot Stability”,

December 2018 Issue. Article available at: <https://vtechworks.lib.vt.edu/handle/10919/81207>

Media Coverage, Cover Article Featured in *VT/ME Momentum Magazine* June 2018

Article titled “Tails: The evolution of robots? Robotic tails facilitate robot movement”,

Vol. 3, Issue 2, pp. 10-15, Summer 2018. Article available at: <https://joom.ag/c9jY>

Media Coverage, Article Featured in *Roanoke Times* May 2018

Article titled “Virginia Tech animal-inspired robot tails”,

May 14, 2018 issue. Article available at: <https://bit.ly/2Gdi6rq>

- Media Coverage**, Article Featured in *VT/ME Momentum Magazine* June 2017
Article titled “UG lab gets students engaged in robotics”,
Vol. 2, Issue 2, pp. 23, Summer 2017. Article available at: <https://joom.ag/1sBW>
- Media Coverage**, Featured Article in *Virginia Tech News Daily* April 2017
Article titled “New robotics teaching lab enhances engineers' skills”, April 10, 2017 Issue.
Article available at: <https://vtnews.vt.edu/articles/2017/04/me-roboticsteachinglab.html>
- Media Coverage**, Featured Video and Article in *WDBJ-7 CBS-Affiliated TV Station* June 2016
Article titled “Exoskeleton glove developed at Virginia Tech could diagnose cerebral palsy in children”, June 17, 2016.
Video/Article available at: <http://www.wdbj7.com/content/news/love-modified-to--383468791.html>
- Media Coverage**, Featured Article in *Cerebral Palsy News Today* June 2016
Article titled “Cerebral Palsy Might Be Detected in Toddlers with Glove by Exoskeleton Engineer”, June 22, 2016 Issue.
Article available at: <http://bit.ly/2kOU0Mi>
- Media Coverage**, Featured Article in *3D Printer and 3D Printing News* June 2016
Article titled “VT engineer 3D prints robotic exoskeleton glove to help cerebral palsy diagnosis in children”, June 23, 2016 Issue.
Article available at: <http://bit.ly/28RVu3H>
- Media Coverage**, Featured Article in *Global News Connect* June 2016
Article titled “Engineer Modifies Robotic Exoskeleton Glove to Assistance Intelligent Palsy Diagnosis in Children”, June 13, 2016 Issue.
Article available at: <http://bit.ly/2fDTxf1>
- Media Coverage**, Featured Article in *ASEE* First Bell Magazine* June 2016
Article titled “Virginia Tech Engineer Develops Robotic Exoskeleton Hand to Diagnose Children”, June 21, 2016 Issue.
Article: <http://mailview.bulletinmedia.com/mailview.aspx?m=2016062101asee&r=2892555-5e40>
* ASEE – American Society of Engineering Education
- Media Coverage**, Article Featured in *VT/ME Momentum Magazine* July 2016
Article titled “Exoskeleton to help cerebral palsy diagnosis in children”,
Vol. 1, Issue 2, pp. 12, July 2016. Article available at: <http://bit.ly/2aytqSW>
- Media Coverage**, Featured Article in *Virginia Tech News Daily* June 2016
Article titled “Engineer modifies robotic exoskeleton glove to help cerebral palsy diagnosis in children”, June 10, 2016 Issue.
Article available at: <https://vtnews.vt.edu/articles/2016/06/me-roboticdiagnosticglove.html>
- Recognition**, Robotics and Mechatronics Laboratory (RML) December 2013
Cited on the newly published list of 99 Superb Sites on Mechatronics & Robotics Engineering,
<http://www.electricalengineeringschools.org/mechatronics>
- Media Coverage**, Featured Article in *GW Alumni Magazine* June 2013
Article titled “The Body Robotics”, Summer 2013 Issue, pp. 56-59.
Article available at: <http://magazine.gwu.edu/body-robotic>
- Media Coverage**, Featured Article in *GW Research Magazine* April 2013
Article titled “The Body Robotics: Form, function, and the future as seen through the eyes and handiwork of three GW roboticists”, Spring 2013 Issue, pp. 19-23.
Article available at: http://www.gwu.edu/~magazine/2013_research_spring/feature1.html

Media Coverage , television interview to CTV News (Canadian Television Network) Live interview on The Advancement of Robots Interview available at: http://bit.ly/1yU7DX2	Nov. 2012
Media Coverage , blog posting on the Scientific American Article titled "School Turns Engineering Faculty into Superheroes" Article available at: http://bit.ly/KzAADF	May 2012
Media Coverage , GW's Newspaper published by GW Today Article titled "Engineering Interest - New SEAS marketing campaign uses superheroes to highlight ground-breaking research" Article available at: http://bit.ly/KrooQr	April 2012
Newspaper Article , published by The GW Hatchet "SEAS shows off 'superhero' engineers", Vol. 108, Issue 56, pp. 3, Apr 16, 2012 Featured article on my research on modular and reconfigurable mobile robotics Article available at: http://bit.ly/HLUGJB	April 2012
Media Coverage , published by SEAS/GWU SEAS features Prof. Ben-Tzvi as a "superhero" – RobotronMan Article available at: http://bit.ly/1AfmE89	April 2012
Media Coverage , Featured Article by The GW Hatchet Robotics Workshop for GW's Science, Technology and Engineering Day Article available at: http://bit.ly/HHnTmz	April 2012
Media Coverage , GW's Newspaper published by GW Today For winning 3 rd place in the GWU SEAS R&D Showcase Article available at: http://bit.ly/yVNEXh	March 2012
Media Coverage , radio interview to China Radio International Live, hour-long panel discussion on Robot Revolution Interview available at: http://english.cri.cn/8706/2011/12/09/2861s670868.htm	December 2011
Media Coverage , Television interview for Voice of America Covered ongoing research activities in the Robotics and Mechatronics Lab Video and article available at: http://bit.ly/uHXKPz	August 2011
Media Coverage , Featured Video and Article at Loudoun Times Robotics Workshop for GW's Science, Technology and Engineering Day Article and video available at: http://bit.ly/e94yNk	April 2011
Media Coverage , Featured Article at Leesburg Today Robotics Workshop for Loudon county high school students as part of GW's Science, Technology and Engineering Day at the Virginia Science and Technology Campus Article available at: http://bit.ly/odlyXJ	April 2011
Media Coverage , radio interview on the show Today on Beyond Beijing Panel discussion featuring international experts on the future of robotics Interview available at: http://english.cri.cn/8706/2011/01/07/481s613923.htm	January 2011
Featured in GW's Newspaper published by GW Today Article titled " The Robot Revolution "	August 2010

Article available at: <http://gwtoday.gwu.edu/robot-revolution>

Featured in 2010 issue of SEAS *Synergy Magazine* (pg. 6) showcasing my research activities at the GW Robotics and Mechatronics Lab

July 2010

Featured in the [SEAS Video](http://www.rmlab.org/bentzvi) highlighting my research in the *Robotics & Mechatronics Lab in SEAS*
<http://www.rmlab.org/bentzvi> [GW video.php](http://www.rmlab.org/bentzvi)

May 2010

* Video used as a media content for various audiences including graduate and undergraduate recruiting, raising funds for SEAS from prospective donors and keeping alumni engaged

Featured photos of the Robotics and Mechatronics Lab
SEC (Science and Engineering Hall) Brochure highlighting students' research work in robotics and mechatronics

April 2010

Student Supervision

Graduated Ph.D. Students (12)

Dates	Degree	Candidate	Dissertation Title	Current Position
Dec. 2020 – Sep. 2023	Ph.D.	Yunfei Guo (ECE)	Vision-Based Force Planning and Voice-Based Human-Machine Interface of an Assistive Robotic Exoskeleton Glove for Brachial Plexus Injuries	Senior Robotics System Engineer, Futronics Corp., Pasadena, USA
Aug. 2019 – Sep. 2023	Ph.D.	Wenda Xu	Design, Development, and Control of an Assistive Robotic Exoskeleton Glove Using Reinforcement Learning-Based Force Planning for Autonomous Grasping	Senior Control and Manipulation Engineer, Futronics Corp., Pasadena, USA
Aug. 2017 – May 2022	Ph.D.	Yujiong Liu	Novel Legged Robots with a Serpentine Robotic Tail: Modeling, Control, and Implementations	Robotic System Engineer, Cornerstone Medical USA Inc.
May 2017 – Dec. 2021	Ph.D.	Shumin Feng	Design, Analysis, Planning, and Control of a Novel Modular Self-Reconfigurable Robotic System	Staff Robotics Engineer, DIMAAG-AI
Jan. 2018 – Dec. 2020	Ph.D.	Taylor Njaka	Design, Simulation, and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism	Postdoctoral Researcher at Virginia Tech
Sep. 2016 – Mar. 2020	Ph.D.	Hailin Ren	Human-Robot Interaction with Pose Estimation and Dual-Arm Manipulation Using Artificial Intelligence	Senior Software Engineer, MathWorks
Jan. 2016 – Sep. 2019	Ph.D.	Bijo Sebastian	Traversability Estimation Techniques for Improved Navigation of Tracked Mobile Robots	Assistant Professor, Indian Institute of Technology, Madras
Sep. 2012 – Mar. 2018	Ph.D.	Wael Saab	Design and Implementation of Articulated Robotic Tails to Augment the Performance of Reduced	Senior Research and Development Engineer,

			Degree-of-Freedom Legged Robots	SoftWear Automation
Jan. 2012 – Feb. 2018	Ph.D.	Anil Kumar	Estimation and Mapping of Ship Airwake Using RC Helicopters as a Sensing Platform	Senior Systems Integration Engineer, GM Cruise
Sep. 2010 – Dec. 2017	Ph.D.	William S. Rone	Hyperredundant Dynamic Robotic Tails for Stabilizing and Maneuvering Control of Legged Robots	Mechanical Engineer, US Airforce Nuclear Weapons Center
Sep. 2009 – May 2013	Ph.D.	Paul M. Moubarak	A Mobile Robot with Modular and Reconfigurable Mobility and Manipulation	Research Engineer, Ford Motor Company
Jan. 2010 – Dec. 2014	Ph.D.	Zhou Ma	Sensing and Force-Feedback Exoskeleton (SAFE) Robotic Glove Mechanism and Its Applications	Senior Robotics Engineer, US Medical Innovations Company

Graduated M.S. Students (20)

Dates	Degree	Candidate	Thesis Title
Aug. 2020 – May 2022 (VT)	M.S.	Isaac Pressgrove	A Systematic Design Methodology for Articulated Serpentine Robotic Tails to Assist Agile Robot Behaviors
Aug. 2019 – July 2021 (VT)	M.S.	Sarthak Pradhan	Design and Control of an Exoskeleton Glove Using a Neural Network Based Controller for Grasping Objects
Aug. 2019 – Dec. 2020 (VT)	M.S.	Yunfei Guo	Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove
Jan. 2019 – May 2020 (VT)	M.S.	Xiaoxue Han	Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and a Robotic Arm for First-Aid Airway Management
Aug. 2017 – July 2019 (VT)	M.S.	Teja Vanteddu	Grasp Stability with a Robotic Exoskeleton Glove
Aug. 2017 – May 2019 (VT)	M.S.	Shubhdildeep Singh Sohal	A Hybrid Tracking Approach for Autonomous Docking in Self-Reconfigurable Robotic Modules
Aug. 2017 – Dec. 2018 (VT)	M.S.	Jiteng Yang	A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism
May 2017 – Dec. 2018 (VT)	M.S.	Shumin Feng	Mobile Robot Obstacle Avoidance Based on Deep Reinforcement Learning
Sep. 2016 – May 2018 (VT)	M.S.	Adam Williams	A Robotic Head Stabilization Device for Post-Trauma Transport
Sep. 2016 – May 2018 (VT)	M.S.	Brielle Junghee Lee	Development of Intelligent Exoskeleton Grasping Through Sensor Fusion and Slip Detection
Jan. 2016 – Dec. 2017	M.S.	Vinaykarthik Kamidi	Design and Integration of Novel Single Degree of Freedom Leg For Fast Locomotion

(VT)			
Jan. 2016 – Dec. 2017 (VT)	M.S.	Peter Racioppo	Design and Control of a Modular, Cable-Driven Snake Robot
Jan. 2016 – Dec. 2017 (VT)	M.S. (ECE)	Eric Refour	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton
Sep. 2012 – May 2014 (GW)	M.S.	Jeffrey Phillips	Exoskeleton robotic arms for rehabilitation applications
Sep. 2012 – May 2014 (GW)	M.S.	Bohua Zhang	Robotic wrist exoskeleton device for debilitated patients
Sep. 2012 – May 2014 (GW)	M.S.	Yue Sun	Modeling and simulation of micro-droplet precision devices
Sep. 2010 – May 2012 (GW)	M.S.	Chad Gilman	Medical robotics – human wrist joint assist robot
Sep. 2013 – Aug. 2015 (GW)	M.S.	Xiaofan Liu	Non-Thesis
Sep. 2013 – Aug. 2015 (GW)	M.S.	Teng Long	Non-Thesis
Sep. 2012 – May 2015 (GW)	M.S.	Olugbenga Idowu	Non-Thesis

Visiting PhD Students

Date	Candidate	Originating Institution	Topic
09/01/2019 – 10/31/2020	Xiaoyun Lei	Nanjing University of Science and Technology	Dual-arm Cooperation Manipulation with Distance Constrains using Deep Reinforcement Learning

Postdoctoral Scientists

Employed	Student	Degree and Institution	Research Topic	Employment
May 2014– Apr. 2017	Dr. Lawrence Wong	Ph.D., University of Waterloo	Micromachined Ultrasonic Transducers for Non-destructive Testing Applications	Advanced Research Engineer at Thalmic Labs
Jan. 2012– Jan. 2013	Dr. Radu Robotin	Ph.D., Technical University of Cluj-Napoca	Vision Guided Autonomous Robotic Locomotion and Manipulation	Cloud Systems Engineer at National Cancer Institute (NCI)

Feb 2010– Feb. 2011	Dr. Xianxin Ke	Ph.D., Shanghai University	Dynamic Mobility of an Omni-wheel Robots	Associate Professor at Shanghai Univ.
Nov 2009– Jan. 2011	Dr. Samer Charifa	Ph.D., North Carolina Agricultural and Technical State Univ.	Volumetric Environment Mapping Using Multi-sensor Fusion for Robotic Vision	Research Scientist at Intelligent Automation, Inc.

Visiting Professors

Date	Candidate	Originating Institution	Topic
Sep. 2010 – Sep. 2012	Prof. Jae Weon Choi	Pusan National Univ., S. Korea	Navigation, Guidance, and Control for Autonomous Vehicles

Visiting Scholars Advising

Date	Candidate	Topic
Jul. 2010 – Sep 2011	Prof. Arif Ankarali	ANFIS* Inverse Kinematics and Precise Trajectory Tracking of a Dual Arm Robot (* <i>Adaptive Neuro Fuzzy Inference System</i>)
Oct. 2009 – Jan. 2010	Dr. Getachew Befekadu	Decentralized control and optimization of interconnected systems with applications to multiple robots coordination

Undergraduate Students Research Thesis/Projects Advising

Date	Candidate	Department	Research Topic
Aug. 2022 – Dec. 2022	Renrui Liu	ME/VT	Exoskeleton Robotic Glove Design for Hand Rehabilitation
May 2020 – Dec. 2021	Alex Broz	ME/VT	Design of a two-section robotic tail based on the Rigitail
May 2020 – Dec. 2021	Ruichang Chen	ECE/VT	Simulation environment development of modular and reconfigurable robots in V-Rep
Aug. 2019 – Dec 2020	Logan Stevenson	ME/VT	Upper extremity exoskeletons for robot control and rehabilitation therapy
Feb. 2019 – Dec 2020	Jonah Fike	AOE/VT	Omni-Direction Propulsion Mechanism for Underwater Vehicles
May 2019 – Dec 2020	Marco Brizzolara	Physics /VT	Omni-Direction Propulsion Mechanism for Underwater Vehicles
May 2019 – Dec 2020	Abdalla Diraz	ME/VT	Robotic Exoskeleton Glove Mechanism for Autonomous Grasping
Jan. 2019 – Dec 2020	Jingyuan Qi	Physics/VT	Machine learning application in human robot interaction and UAV
Sep. 2018 – Dec 2020	Samatar Jama	ME/VT	Semi-autonomous Robot Motion Planning
Sep. 2018 – Dec. 2018	Alex Rhee	ECE/VT	Design of Rotary SEA for Robotic Glove Exoskeleton Applications
May 2018 – Dec. 2018	Alina Voelker	ME/VT	Vision Based Localization Techniques for Ground Robots
Jan 2018 –	Kefan Li	ME/VT	Autonomous Grasping with a Robotic

May 2019			Exoskeleton
Nov 2017 – May 2018	Zhoubao Pang	ME/VT	Design and Integration of a Single-DOF Biped with a Rigid Robotic Tail
Nov 2017 – May 2018	Hongxu (Howard) Guo	ME/VT	Controller Design for a Single-DOF Biped Locomotion with a Robotic Tail
Jan 2017 – Dec. 2018	Nicole Gouhin	ME/VT	Review of Bio-inspired Robotic Tails
Jan 2017 – Dec. 2018	Xinran Wang	ME/VT	Suspension Design for a Search and Rescue Mobile Ground Robot
May 2017 – Aug 2017	Youssef Haridy	ME/VT	Docking Mechanisms for Modular Robotic Modules
Jan 2016 – May 2017	David Evans	CEC/VT	Design of Embedded Controllers for Reconfigurable Robotic Modules
Jan 2016 – May 2017	Brock Davis	ME/VT	Modeling and Controls of a Robotic Exoskeleton Mechanism for Rehabilitation
Jan 2016 – Dec 2016	Tommy Hutcheson	ME/VT	Design and Simulation of a 2-finger Robotic Exoskeleton Mechanism for Rehabilitation
Jan 2015 – Aug 2015	Timothy Wetzel	MAE/GWU	Simulation of Robotic Tails for Maneuvering Quadruped Robots
May 2013 – Aug 2015	Cyndi-Leigh Pine	MAE/GWU	Rehabilitation robotics and computer-aided design
Jan 2014 – May 2014	Robert Forcha	MAE/GWU	Simulation of Fingers Position for Hand Rehabilitation Application
May 2011 – May 2013	Eric Alvarez	MAE/GWU	Design of docking interface for reconfigurable mobile robotic system
Sep 2011 – May 2013	Jeff Birenbaum	MAE/GWU	Synergistic Piezo Actuation
Sep 2011 – Sep 2012	Jeffrey Phillips	MAE/GWU	Continuum Robotics for Rehabilitation
Jan – May 2012	Allison Hogarth & David Perry	MAE/GWU	Moving Side View Mirror for Blind Spot Detection
Sep 2011 – Dec 2011	Jimmy Gomez	MAE/GWU	Robotic exoskeleton device for augmenting wrist movement in debilitated patients
Sep. 2010 – Sep. 2012	Danielle Barsky	MAE/GWU	Modeling and Simulation of MEMS tilt sensor
May 2011 – Sep 2011	Gabriel Yessin	ECE/GWU	Optimization of algorithms for remote control operation of a mobile robot
Sep. 2009 – Jan. 2011	Michael Shick	CS/GWU	Algorithms for mobile robot autonomous functions
May 2009 – Aug. 2010	Will Rone	MAE/GWU	Piez-actuated dispensing system for micro-drops generation in microarray applications
May–Sep 2009	Sarah Beaver	MAE/GWU	Electroactive polymers applied toward biomimetic robots
May–Dec 2009	Tim Perkins	MAE/GWU	Smart materials for the development of biomimetic micro-robots
Dec. 2009 – June 2010	Marcus Hendricks	MAE/GWU	Mechanical and electrical design layout for a mobile robot remote controller
Mar. 2010 –	Hannah Stuart	MAE/GWU	Development of a operating control unit for a

April 2011			mobile robot
Mar. 2010 – April 2011	Micah Foster	MAE/GWU	Development of a operating control unit for a mobile robot
Mar. 2010 – Dec 2010	Nicholas Blanton	MAE/GWU	Detailed design layout of a operating control unit components
June – Sep 2010	Brandon Fix	MAE/GWU	Perform design layouts of mechanical parts using SolidWorks

Undergraduate Interns Supervision

Date	Candidate	Originating Institution	Topic
Oct – Dec. 2010	Gustavo Ruiz, B.Sc.	Polytechnic University of Chiapas, Mexico	Hardware-in-the-loop (HIL) simulations of dual arm mobile robotic system (<i>Funded by the Mexican government under the Governors' Internship Program</i>)
Jan–Apr. 2010	Mikhail Zhuk, MechE Senior	University of California, Irvine	Modeling and simulation of robotic systems using ADAMS and ATV ToolKit
Jun–Aug. 2010	Ari Schifftan, MechE Junior	University of Miami, FL	Modeling and analysis of mechanical parts for a hybrid mobile robot using ABAQUS FEA SW

Ph.D. Dissertation External Examiner

Student Name	Thesis Title	Defense date	Institution
So-Ra Chung	MEMS Demodulator Based on Electrostatic Actuator	July 6, 2012	University of Waterloo Dept. of Systems Design Engineering

PhD/MS Thesis Reader / Committee Member/Chair

Student Name	Thesis/Dissertation Title	Level	Defense date	Advisor	Role / Institution
Wenda Xu	Design, Development, and Control of an Assistive Robotic Exoskeleton Glove Using Reinforcement Learning-Based Force Planning for Autonomous Grasping	Ph.D.	Sep. 8, 2023	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Yunfei Guo	Vision-Based Force Planning and Voice-Based Human-Machine Interface of an Assistive Robotic Exoskeleton Glove for Brachial Plexus Injuries	Ph.D.	Sep. 12, 2023	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Shumin Feng	Design, Analysis, Planning, and Control of a Novel Modular Self-Reconfigurable Robotic System	Ph.D.	Dec. 2, 2021	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Michael Molzon	Development of a Mobile Robot System for the Visual Inspection of Railcar Undercarriage Equipment	Ph.D.	June 2022	Dr. Mehdi Ahmadian	Committee Member/ VT*
Sarthak Pradhan	Design and Control of an Exoskeleton Glove Using a Neural Network Based Controller for Grasping Objects	M.S.	July 23, 2021	Dr. P. Ben-Tzvi	Thesis Director/ VT*

Yunfei Guo	Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove	M.S.	Dec. 10, 2020	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Taylor Njaka	Design, Simulation, and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism	Ph.D.	Dec. 14, 2020	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Grant Carter	Adaptive Control of the Transition from Vertical to Horizontal Flight Regime of a Quad-Tailsitter UAV	M.S.	May 12, 2021	Dr. Andrea L'Afflitto	Committee Member/ VT*
Alfred Mayalu	Beyond LiDAR for Unmanned Aerial Event-Based Localization in GPS Denied Environments	Ph.D.	May 20, 2021	Dr. K. Kochersberger	Committee Member/ VT*
Kenneth E. Kroeger	Decentralized Task Allocation and Coordination of Heterogeneous UxVs Subjected to Spatiotemporally Evolving Environment	Ph.D.	TBD	Dr. K. Kochersberger	Committee Member/ VT*
Wael Saab	Design and Implementation of Articulated Robotic Tails to Augment the Performance of Reduced Degree-of-Freedom Legged Robots	Ph.D.	March 19, 2018	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Anil Kumar	Estimation and Mapping of Ship Air Wakes using RC Helicopters as a Sensing Platform	Ph.D.	Feb. 26, 2018	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
William S. Rone	Hyperredundant Dynamic Robotic Tails for Stabilizing and Maneuvering Control of Legged Robots	Ph.D.	Dec. 13, 2017	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Bijo Sebastian	Traversability Estimation Techniques for Improved Navigation of Tracked Mobile Robots	Ph.D.	Sep. 19, 2019	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Hailin Ren	Human-Robot Interaction with Pose Estimation and Dual-Arm Manipulation Using Artificial Intelligence	Ph.D.	March 23, 2020	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Shumin Feng	Path Planning Algorithms and Control of Modular Mobile Robots	Ph.D.	TBD	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Yujiong Liu	Dynamics Modeling and Control of Hybrid Robotic Tail-Bipedal Systems	Ph.D.	TBD	Dr. P. Ben-Tzvi	Dissertation Director/ VT*
Negin Nikafrooz	Design, fabrication, and control of an assistive glove for farmers with mobility limitations	Ph.D.	Spring 2021	Dr. A. Leonessa	Committee Member/ VT*
Murat Ambarkutuk	Development of a Non-Line-of-Sight Perception Technique with high-frequency short range RADAR for Deformation Measurements	Ph.D.	Fall 2020	Dr. T. Furukawa	Committee Member/ VT*
Murtaza Rangwala	Control and coordination of multi-agent systems/robots using deep reinforcement learning	Ph.D.	TBD	Dr. Ryan Williams	Committee Member/ VT*

Jiteng Yang	A Two-DOF Bipedal Robot Utilizing the Reuleaux Triangle Drive Mechanism	M.S.	Nov. 16, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Shumin Feng	Mobile Robot Obstacle Avoidance Based on Deep Reinforcement Learning	M.S.	Dec. 12, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Adam Williams	A Robotic Head Stabilization Device for Post-Trauma Transport	M.S.	May 9, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Brielle Junghee Lee	Development of Intelligent Exoskeleton Grasping Through Sensor Fusion and Slip Detection	M.S.	May 9, 2018	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Peter Racioppo	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton	M.S.	Dec. 11, 2017	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Vinaykarthik Kamidi	Design and Integration of Novel Single Degree of Freedom Leg For Fast Locomotion	M.S.	Dec. 19, 2017	Dr. P. Ben-Tzvi	Thesis Director / VT*
Eric Refour	Design and Integration of a Form-Fitting General Purpose Robotic Hand Exoskeleton	M.S.	Sep. 29, 2017	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Teja Vanteddu	Grasp Stability with a Robotic Exoskeleton Glove	M.S.	July 24, 2019	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Shubhdildeep Singh Sohal	A Hybrid Tracking Approach for Autonomous Docking in Self-Reconfigurable Robotic Modules	M.S.	May 9, 2019	Dr. P. Ben-Tzvi	Thesis Director/ VT*
Gordon Christie	Collaborative Unmanned Air and Ground Vehicle Perception for Scene Understanding, Planning and GPS-denied Localization	Ph.D.	Nov. 7, 2016	Dr. K. Kochersberger	Committee Member/ VT*
Hubert Kim	Joint Torque Feedback for Motion Training with an Elbow Exoskeleton	Ph.D.	Sep. 14, 2021	Dr. A. Asbeck	Committee Member/ VT*
Sebastien Corner	Modeling, Sensitivity Analysis, and Optimization of Hybrid, Constrained Mechanical Systems	Ph.D.	Feb. 14, 2018	Dr. Corina Sandu	Committee Member/ VT*
Adam Lowery	Enhanced Portability and Anti-Frosting Functionality of Cryostats for Synchrotron-Based X-ray Imaging	Ph.D.	June 21, 2022	Dr. Jonathan Boreyko	Committee Member/ VT*
Cong Chen	Robust Motion Tracking and Post Estimation of Combined Camera and Lidar 3D Shape	Ph.D.	TBD	Dr. T. Furukawa	Committee Member/ VT*
Mengyu Song	Specular Micro-texture Photometry for Circumferential Three-Dimensional Profiling	Ph.D.	May 19, 2020	Dr. T. Furukawa	Committee Member/ VT*
John Seminatore	Design of a Series Elastic Humanoid for the DARPA Robotics Challenge	M.S.	August 3, 2016	Dr. Al Wicks	Committee Member / VT*
Tom Ehrenzeller	Visual Servoing Using a Two Armed Robot	M.S.	TBD	Dr. T. Furukawa	Committee Member/ VT*
Chen Tang	Design of a Gravity Compensation Actuator for Arm Assistance	M.S.	Dec. 18, 2017	Dr. Alan Asbeck	Committee Member/ VT*

Yi Tian	Self-Powered Intelligent Traffic Monitoring Using IR Lidar and Camera	M.S.	Dec. 8, 2016	Dr. T. Furukawa	Committee Member/ VT*
Murat Ambarkutuk	A Grid-based Radiolocation Technique Based on Spatially Coherent Path Loss Model	M.S.	Sep. 1, 2017	Dr. T. Furukawa	Committee Member/ VT*
Bryan Todd	Comparison of the Role of Beamwidth in Biological and Engineered Sonar	M.S.	Sep. 29, 2017	Dr. R. Mueller	Committee Member/ VT*
Zhou Ma	Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove Mechanism for Rehabilitation	Ph.D.	Dec. 15, 2014	Dr. P. Ben-Tzvi	Dissertation Director/ GWU**
Paul M. Moubarak	A Mobile Robot with Modular and Reconfigurable Mobility and Manipulation	Ph.D.	March 15, 2013	Dr. P. Ben-Tzvi	Dissertation Director/ GWU**
Robert Cortesi	Modeling and Control of Joint-Actuated Buoys	Ph.D.	Feb. 15, 2012	Dr. D. Chichka	Committee Member/ GWU**
Kenan Cole	Design, Analysis, and Optimization of an Interferometer for Extreme Ultraviolet Interference Lithography	M.S.	Nov. 10, 2010	Dr. R. Ryan Vallance	Committee Member/ GWU**
Jaime Alba-Bohorquez	Design of a Robust Altitude-Hold Controller for UAVs Using Neural Networks	M.S.	Nov. 21, 2008	Dr. D. Chichka	Committee Member/ GWU**

* VT – Virginia Tech; ** GWU – George Washington University

High School Students Mentoring

Date	Candidate	School Name	Topic
Summer 2022	Phillipe Charalanis	Blacksburg Middle School	Camera System for Human Motion Detection and Tracking
May 2019 – Dec. 2020	Kye Gonino	James River High School	Omni-Direction Propulsion Mechanism for Underwater Vehicles
Sep 2013 – May 2015	Daniel Dulaney	School Without Walls (SWW)	Omni-directional mobile robots locomotion

Teaching

Courses Taught

Virginia Tech - Department of Mechanical Engineering

Controls Engineering I (ME 3534)	Spring 2022
Advanced Robotics and Automation (ME 5704/ECE 5704)	Fall 2021
Robotics & Mechatronics Seminar (ME 4734)	Fall 2021
Controls Engineering I (ME 3534)	Spring 2021
Engineering Design and Project II (ME4016)	Spring 2021
Mechanical Vibrations (ME 3524)	Fall 2020
Engineering Design and Project I (ME4015)	Fall 2020
Advanced Robotics and Automation (ME 5704/ECE 5704)	Spring 2020

Robotics Laboratory (ME 4584/ECE 4584)	Spring 2020
Robotics and Automation (ME 4524)	Spring 2020
Principles of Robotics Systems (ECE 4704)	Spring 2020
Advanced Robotics and Automation (ME 5704/ECE 5704)	Spring 2019
Robotics Laboratory (ME 4584/ECE 4584)	Spring 2019
Robotics and Automation (ME 4524)	Spring 2019
Principles of Robotics Systems (ECE 4704)	Spring 2019
Advanced Robotics and Automation (ME5704/ECE 5704)	Spring 2018
Robotics Laboratory (ME 4584/ECE 4584)	Spring 2018
Robotics and Automation (ME 4524)	Spring 2018
Principles of Robotics Systems (ECE 4704)	Spring 2018
Engineering Design and Project I (ME4015)	Fall 2017
Robotics and Automation (ME 4524)	Spring 2017
Principles of Robotics Systems (ECE 4704)	Spring 2017
Robotics and Automation (ME 4524)	Spring 2016
Principles of Robotics Systems (ECE 4704)	Spring 2016
Engineering Design and Project II (ME4016)	Spring 2016
System Dynamics (ME 3514)	Fall 2015
Engineering Design and Project I (ME4015)	Fall 2015

George Washington University - Department of Mechanical & Aerospace Engineering

Robotic Systems (MAE 6245)	Spring 2015
Mechatronics Design (MAE 4194)	Spring 2015
Electromechanical Control System Design (MAE 4182)	Fall 2014
Robotic Systems (MAE 6245)	Spring 2014
Mechatronics Design (MAE 4194)	Spring 2014
Analysis and Synthesis of Mechanisms (MAE 3190)	Fall 2013
Robotic Systems (MAE 6245)	Spring 2013
Mechatronics Design (MAE 4194)	Spring 2013
Analysis and Synthesis of Mechanisms (MAE 3190)	Fall 2012
Robotic Systems (MAE 6245)	Spring 2012
Mechatronics Design (MAE 4194)	Spring 2012
Electromechanical Control System Design (MAE 4182)	Fall 2011
Robotic Systems (MAE 6245)	Spring 2011
Mechatronics Design (MAE 4194)	Spring 2011
Electromechanical Control System Design (MAE 4182)	Fall 2010

Mechatronics Design (MAE 4194)	Spring 2010
Introduction to Vibration Analysis (MAE 3134)	Spring 2010
Electromechanical Control System Design (MAE 4182)	Fall 2009
Introduction to Vibration Analysis (MAE 3134)	Spring 2009

University of Toronto – Department of Mechanical & Industrial Engineering

Computer Aided Design (MIE441)	Winter 2006, 2007, 2008
Introduction to Computer Aided Design (Short Course)	Winter, Spring, Fall 2007, Winter 2008
Control Systems (MIE372)	Fall 2003, 2004
Co-Instructor (with Prof. A.A. Goldenberg)	

University of Toronto – Faculty of Applied Science and Engineering

Artificial Intelligence and Robotics	Fall 2006
Mechatronics and Artificial Intelligence	Summer 2005
Mechatronics Design and Operation	Fall 2004
Mechatronics	Summer 2004

Technion - Israel Institute of Technology

Instructor, Physics Courses – Mechanics	July 1999–July 2000
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Israeli Air Force Academy

Senior Instructor, Engineering Courses	May 1993–April 1996
Courses taught: Control Systems, Mechanics and Control Lab, Mechanical Machining Lab, Hydraulics Lab, Pneumatics Lab, CNC Lab, Engineering Drafting, Computer Aided Design Lab	

Teaching Expertise & Interests

The following is a selected list of my teaching experiences and interests:

System Dynamics and Control

- Analysis & Design of Feedback Control Systems
- Automatic Control Systems
- Linear & Nonlinear Control Systems
- Modeling and Simulation of Dynamic Systems

Mechatronics

- Mechatronic Systems Design
- Mechatronics Principles
- Microcontroller-based Systems Design
- Sensors, Actuators & Measurement

Core Courses

- Statics
- Dynamics and Vibrations
- Electrical Circuits

Robotics and Automation

- Industrial Automation Systems Design
- Robotic Systems Design
- Robot Kinematics, Dynamics & Control
- Design of Electromechanical Mobile Robots

Design and Manufacturing

- Precision Mechanism Analysis & Synthesis
- Electromechanical Machine Design
- Computer Aided Design (CAD)
- System Design & Analysis (FEA)

Service to Profession and Field

A. Professional Service

A1. Workshops Organized (in my role as Program Director at NSF)

- [1] *NSF EPSCoR Workshop on Quantum Computing, Information, Science, and Engineering*, National Science Foundation (NSF), Alexandria, VA, March 23-24, 2023.

A2. Conference General Chair

General Chair, IEEE International Symposium on Robotic and Sensors Environments – IEEE ROSE 2013, Washington, DC, 21-23 October 2013.

A3. Conference Technical Program Committees – Chair / Co-Chair

- **Chair** of the Technical Program Committee for the 44th Mechanisms and Robotics Conference at the 2020 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 2020, St. Louis, MO, USA.
- **Co-Chair** of the Technical Program Committee for the 43rd Mechanisms and Robotics Conference at the 2019 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 2019, Anaheim, CA, USA.
- **Chair** for Workshops, Tutorials and Special Sessions for the 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Co-Chair** of the Technical Program Committee for the 10th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2012, Magdeburg, Germany, 16-18 Nov. 2012.
- **Co-Chair** of the Technical Program Committee for the 7th IEEE International Workshop on Robotic and Sensors Environments – ROSE 2009, Lecco, Italy, 6-7 November 2009.

A4. Symposium Chair / Co-Chair

Symposium Co-Chair, Mobile Robotics Symposium, 42nd Mechanisms and Robotics Conference at the 2018 ASME International Design Engineering Technical Conferences (IDETC/CIE), August 26-29, 2018, Quebec City, Canada.

A5. Conference Technical Program Committees – Member

- **Member** of the Technical Program Committee for the 2019 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2019, Tianjin, China, 4-7 Aug. 2019.
- **Member** of the Technical Program Committee for the 2019 IEEE International Workshop on Robotic and Sensors Environments - ROSE 2019, Ottawa, Canada, 17-18 June 2019.
- **Member** of the Organizing Committee for the 2018 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2018, Amsterdam, Netherlands, 21-23 Feb. 2018.

- **Member** of the Technical Program Committee for the 2017 IEEE International Conference on Robotics and Biomimetics – ROBIO 2017, Macau SAR, China, 5-8 Dec. 2017.
- **Member** of the Technical Program Committee for the 2017 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2017, Takamatsu, Japan, 6-9 Aug. 2017.
- **Member** of the Organizing Committee for the 2017 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2017, Kayseri, Turkey, 2-4 Feb. 2017.
- **Member** of the Technical Program Committee for the 2016 IEEE International Conference on Robotics and Biomimetics – ROBIO 2016, Qingdao, China, 3-7 Dec. 2016.
- **Member** of the Technical Program Committee for the 2016 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2016, Harbin, China, 7-10 Aug. 2016.
- **Member** of the Technical Editorial Board for the 2016 CSME (Canadian Society for Mechanical Engineering) International Congress – Symposium on Control and Robotics, Kelowna, BC, Canada, 26-29 June 2016.
- **Member** of the Technical Program Committee for the 2015 IEEE International Conference on Robotics and Biomimetics – ROBIO 2015, Zhuhai, China, 6-9 Dec. 2015.
- **Member** of the Technical Program Committee for the 2014 IEEE International Conference on Robotics and Biomimetics – ROBIO 2014, Bali, Indonesia, 5-10 Dec. 2014.
- **Member** of the Technical Program Committee for the 12th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2014, Timisoara, Romania, 16-18 Oct. 2014.
- **Member** of the Technical Program Committee for the 2014 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2014, Takamatsu, Tianjin, China, 3-6 Aug. 2014.
- **Member** of the Technical Program Committee for the 2014 Robotics Science and Systems Conference – RSS 2014, Berkeley, CA, USA, July 12–16, 2014.
- **Member** of the Technical Program Committee for the 2013 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2013, Takamatsu, Kagawa, Japan, 4-7 Aug. 2013.
- **Member** of the Technical Program Committee for the 2012 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2012, Chengdu, Sichuan, China, 5-8 Aug. 2012.
- **Member** of the Technical Program Committee for the 9th IEEE International Symposium on Robotic and Sensors Environments – ROSE 2011, Montréal, Québec, Canada, 17-18 Sep. 2011.
- **Member** of the Technical Program Committee for the 7th ASME/IEEE Int. Conf. on Mechatronics & Embedded Systems & Applications – MESA 2011, Washington, DC, August 28-31, 2011
- **Member** of the Technical Program Committee for the 2011 IEEE International Conference on Mechatronics and Automation - IEEE ICMA 2011, Beijing, China, 7-10 August 2011.
- **Member** of the Technical Program Committee for the 8th IEEE International Workshop on Robotic and Sensors Environments - ROSE 2010, Phoenix, Arizona, 15-16 October 2010.
- **Member** of the Technical Program Committee for the 6th IEEE International Workshop on Robotic and Sensors Environments - ROSE 2008, Ottawa, Canada, 17-18 October 2008.

A6. Expert Panels Chair/Reviewer and Proposal Reviewer

- **Proposal Reviewer**, Czech Science Foundation, Czech Republic 2022
- **Panelist at a Study Section**, National Institutes of Health (NIH) 2021
SRO, Bioengineering, Technology, and Surgical Sciences (BTSS) Study Section
Surgical Sciences, Biomedical Imaging and Bioengineering IRG
- **Reviewer**, Mitacs, Canadian Network of Centres of Excellence, Canada 2019
- **Proposal Reviewer**, National Research Foundation, Prime Minister's Office, Singapore 2019
- **Proposal Reviewer**, Natural Sciences & Eng Research Council of Canada (NSERC) 2018
- **Proposal Reviewer**, Israeli Ministry of Science and Technology August 2018
Topic: Robotics, Medical Devices and Big Data
- **Panelist**, IIHCC Industry Roundtable – Virginia Tech Applied Research Corp. Nov. 2017
Intelligent Infrastructure for Human-Centered Communities (IIHCC)
- **Panelist**, Red Teaming Round Table – Virginia Tech Applied Research Corp. Nov. 2016
Fully-Autonomous Drone Swarms; Office of the Deputy Assistant Secretary of the Army R&T
- **Expert Reviewer**, Canada Foundation for Innovation (CFI) Jul – Oct 2016
2015 Innovation Fund (IF) Competition
- **Panelist**, National Science Foundation – National Robotics Initiative (NRI) June 2016
Division for Electrical, Communications and Cyber Systems (ECCS)
- **Panelist**, National Science Foundation – CISE/IIS/Robust Intelligence (NRI) May 2015
Division of Information and Intelligent Systems
- **Proposal Reviewer**, Canadian Institutes of Health Research (CIHR) December 2014
- **Panelist**, NSF CAREER – CMMI / Sensors, Dynamics & Control Programs Sep 2014
- **Chair of Expert Committee**, Canada Foundation for Innovation (CFI) Jul – Oct 2014
2015 Innovation Fund (IF) Competition
- **Panelist**, National Science Foundation – CMMI / Dynamical Systems May 2014
- **Proposal Reviewer**, National Science Foundation – CISE/Robust Intelligence Feb 2014
- **Proposal Reviewer**, Natural Sciences & Eng Research Council of Canada (NSERC) 2012-2014
- **Panelist**, U.S. Army Medical Robotics Product Line Review (PLR) Expert Panel October 2012
U.S. Army Telemedicine & Advanced Technology Research Center (TATRC)
- **Panelist**, National Science Foundation – National Robotics Initiative (NSF-NRI) June 2012
- **Panel Chair**, National Defense Science & Eng. Graduate (NDSEG) Fellowship Feb 2012
- **Panelist**, Air Force Summer Faculty Fellowship Program (AF SFFP) Jan 2010, 2011
- **Panelist**, NSF Graduate Research Fellowship Program (GRFP) Feb 2010, 2011, 2012, 2013
- **Panelist**, National Defense Science & Eng. Graduate (NDSEG) Fell. 2010, 2011, 2012, 2015

- **Panelist** , ONR Summer Faculty Research Program (ONR SFRP) Feb 2011, 2012
- **Panelist** , DOD Science, Mathematics & Research for Transformation (SMART) Defense Scholarship for Service Program 2011, 2012, 2015, 2016
- **Panelist** , NASA Aeronautics Scholarship Program (NASA ASP) Feb 2011, 2012, 2013
- **Panelist** , NSF East Asia and Pacific Summer Institutes (EAPSI) Jan 2010
- **Proposal Reviewer**, *India Science & Technology Partnership (INSTP)* April 2009
Invited by the Smithsonian Institution, INDO-US Science & Technology Forum, Washington, DC

A7. Technical Editorial and Reviewer

Associate Editor - Journal May 2021 – Aug. 2022
Robotics

Technical Editor - Journal July 2016 – April 2021
IEEE/ASME Transactions on Mechatronics

Guest Editor - Journal June 2020 – April 2021
ASME Journal of Mechanisms and Robotics (special issue)

Guest Editor - Journal June 2019 – April 2020
ASME Journal of Mechanisms and Robotics (special issue)

Associate Editor - Journal Jan. 2018 – Jan. 2021
ASME Journal of Mechanisms and Robotics

Associate Editor - Journal Oct. 2017 – Dec. 2021
IEEE Robotics and Automation Magazine

Associate Editor - Journal Jan. 2011 – Jan. 2021
International Journal of Control, Automation and Systems

Associate Editor – Conference

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2022)	2021–2022
IEEE International Conference on Robotics and Automation (ICRA 2018)	2017–2018
IEEE International Conference on Robotics and Automation (ICRA 2017)	2016–2017
ASME Dynamic Systems and Control Conference (DSCC 2017)	2017
IEEE International Conference on Robotics and Automation (ICRA 2016)	2015–2016
IEEE International Conference on Robotics and Automation (ICRA 2014)	2013–2014
IEEE International Conference on Robotics and Automation (ICRA 2013)	2012–2013

Journal Reviewer (2007 – current):

- IEEE Transactions on Robotics
- IEEE Robotics and Automation Letters
- IEEE/ASME Transactions on Mechatronics
- Transactions of the ASME, Journal of Mechanical Design

- Transactions of the ASME, Journal of Mechanisms and Robotics
- Transactions of the ASME, Journal of Dynamic Systems, Measurement and Control
- Journal of Field Robotics
- Journal of Robotics and Autonomous Systems
- Journal of Intelligent and Robotic Systems
- Robotica Journal
- Mechatronics Journal
- IEEE Sensors Journal
- IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems & Humans
- IEEE Transactions on Nanotechnology
- Journal of Intelligent Service Robots (ISR)
- Autonomous Robots
- Journal of Biomedical Microdevices

Conference Proceedings Reviewer (2004 – current):

- IEEE International Conference on Robotics and Automation (ICRA)
- IEEE International Conference on Intelligent Robots and Systems (IROS)
- IEEE International Workshop on Robotic and Sensors Environments (ROSE)
- IEEE International Conference on Mechatronics and Automation (ICMA)
- ASME International Mechanical Engineering Congress and Exposition (IMECE)
- Dynamic Systems and Control Conference (DSCC)
- IEEE Conference on Automation Science and Engineering (CASE)
- IEEE Conference on Decision and Control (CDC)
- IEEE RAS/EMBS Int. Conference on Biomedical Robotics and Biomechatronics (BioRob)
- IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)
- American Control Conference
- ASME International Design Engineering Technical Conferences (IDETC/CIE)
- ASME/IFTOMM International Conference on Reconfigurable Mechanisms and Robots
- IASTED Conference on Robotics and Applications

Book Proposals Reviewer

- Fundamentals and Applications of Nanopositioning Technologies Mar. 2014
Publisher: Springer; Edited by: Changhai Ru, Xinyu Liu, and Yu Su

A8. Professional Meetings, Workshops, Etc. Chaired or Organized

- **Session Chair**, Technical Session: “Prosthetics, exoskeletons and Rehabilitation”, *Proc. of the 2023 IEEE International Conference on Robotics and Automation (ICRA2023)*, London, UK, May 29-June 2, 2023.
- **Session Chair**, Technical Session: “Novel Mechanisms, Robots, and Applications”, Topic: TBD1”; *ASME IDETC/CIE 2021, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, Aug. 14-17, 2022.
- **Session Chair**, Technical Session: “Novel Mechanisms, Robots, and Applications”, Topic: TBD2”; *ASME IDETC/CIE 2021, 46th Mechanisms & Robotics Conference*, St. Louis, Missouri, Aug. 14-17, 2022.

- **Session Chair**, Technical Session: “Motion Planning”, Topic: “Dynamics, and Control of Robots”; *ASME IDETC/CIE 2021, 45th Mechanisms & Robotics Conference*, Virtual Conference, Aug. 17-19, 2021.
- **Session Chair**, Technical Session: “Ions, Hydrogels, LC Elastomers, and Coiled Artificial Muscle Heat Pumping”, *2020 SPIE Smart Structures and Nondestructive Evaluation (EAPAD 2020) Conference*, Anaheim, CA, April 26-30, 2020.
- **Session Chair**, Technical Session: “Autonomous Vehicle Navigation II”, *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Macau, China, November 4-8, 2019.
- **Session Organizer**, Technical Session: “Humanlike Robots - The Ultimate Challenge to Biomimetics”, *ASME IDETC/CIE 2018, 43rd Mechanisms & Robotics Conference*, Anaheim, CA, Aug. 18-21, 2019.
- **Session Chair**, Technical Session: “Motion Planning”, Topic: “Mobile Robotics”; *ASME IDETC/CIE 2018, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- **Session Co-Chair**, Technical Session: “Upper Extremity”, Topic: “Medical & Rehabilitation Robotics”; *ASME IDETC/CIE 2018, 42nd Mechanisms & Robotics Conference*, Quebec City, Canada, Aug. 26-29, 2018.
- **Session Chair**, Technical Session: “Robot Design and Development”, *2018 International Conference on Mechatronics Systems and Control Engineering – ICMSCE 2018*, Amsterdam, Netherlands, 21-23 Feb. 2018.
- **Session Co-Organizer**, Technical Session: “Design and Control of Robots, Mechanisms and Structures I”, Track: “Dynamics, Vibration, and Control”; Topic: “Design and Control of Robots, Mechanisms and Structures”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2017*, Tampa, FL, 3-9 Nov. 2017.
- **Session Co-Chair**, Technical Session: “Unmanned, Ground and Surface Robotics I”, 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Session Co-Chair**, Technical Session: “Unmanned, Ground and Surface Robotics III”, 2017 ASME Dynamic Systems and Control Conference – DSCC 2017, Tysons Corner, VA, 11-13 Oct. 2017.
- **Session Chair**, Technical Session: “Mobile Robots”, *2017 IEEE Conference on Control Technology and Applications*, Kohala Coast, Hawai'i, Aug. 27–30, 2017
- **Session Co-Chair**, Technical Session: “Assistive Devices”, Topic: “Medical & Rehabilitation Robotics”; *ASME IDETC/CIE 2017, 41st Mechanisms & Robotics Conference*, Cleveland, OH, Aug. 6-9, 2017.
- **Session Chair**, Technical Session: “Mobile Robots”, Topic: “Novel Mechanisms, Robots and Applications”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.
- **Session Organizer**, Technical Session: “Mobile Robots”, Topic: “Novel Mechanisms, Robots and Applications”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.

- **Session Co-Organizer**, Technical Session: “Modeling, Analysis, and Estimation”, Topic: “Mobile Robots, Motion Planning, Dynamics and Control”; *ASME IDETC/CIE 2016, 40th Mechanisms & Robotics Conference*, Charlotte, NC, Aug. 21-24, 2016.
- **Session Chair**, Technical Session: “Modeling and Control of Mobile Robots”, Topic: “Mobile Robots and Cable-Driven Systems”; *ASME IDETC/CIE 2015, 39th Mechanisms & Robotics Conference*, Boston, MA, Aug. 2-5, 2015.
- **Session Chair**, Technical Session: “Developments in sUAV: From Payload to Safety”, Topic: “Small Unmanned Aerial Vehicle Technologies and Applications”; *ASME IDETC/CIE 2015, ASME/IEEE International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, Boston, MA, Aug. 2-5, 2015.
- **Session Chair**, Technical Session: “Bioinspired Mechanisms and Robots II”, Topic: “Symposium on Biologically Inspired and Health Motivated Mechanisms and Robotics”; *ASME IDETC/CIE 2014, 38th Mechanisms & Robotics Conference*, Buffalo, NY, Aug. 17-20, 2014.
- **Session Co-Chair**, Technical Session: “Surgical and Rehabilitation Robotics”, Topic: “Symposium on Biologically Inspired and Health Motivated Mechanisms and Robotics”; *ASME IDETC/CIE 2014, 38th Mechanisms & Robotics Conf.*, Buffalo, NY, Aug. 17-20, 2014.
- **Session Chair**, Technical Session: “Collaborative Robotics & Distributed Sensing”, *IEEE International Symposium on Robotic & Sensors Environments – ROSE 2013*, Washington, DC, Oct. 21-23, 2013.
- **Session Chair**, Technical Session: “Robotic Dynamics”, Track: “Dynamic Systems and Control”; Topic: “Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress & Exposition – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Organizer**, Technical Session: “Biomedical Mechatronics”, Track: “Mechatronics & Intelligent Machines”; Topic: “Symposium on Biomedical Mechatronics”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Organizer**, Technical Session: “Robotics, Actuators and Sensors V”, Track: “Mechatronics & Intelligent Machines”; Topic: “Symposium on Robotics, Actuators and Sensors”; *ASME Int’l Mechanical Eng. Congress & Expo. – IMECE 2011*, Denver, CO, 11-17 Nov. 2011.
- **Session Chair**, Technical Session: “Localization Systems”, *IEEE International Symposium on Robotic & Sensors Environments – ROSE 2011*, Montreal, Quebec, Canada, Sep. 17-18, 2011.
- **Session Chair**, Technical Session: “Robot Control”, Track: “Dynamic Systems and Control”; Topic: “Symposium on Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2010*, Vancouver, BC, 12-18 November 2010.
- **Session Co-Chair**, Technical Session: “Robot Control II”, Track: “Dynamic Systems and Control”; Topic: “Symposium on Dynamics and Control of Mechanisms and Robots”; *ASME International Mechanical Engineering Congress and Exposition – IMECE 2010*, Vancouver, BC, 12-18 November 2010.
- **Session Chair**, Technical Session: “Wireless and Distributed Sensing Networks”, *IEEE International Workshop on Robotic and Sensors Environments – ROSE 2010*, Phoenix, Arizona, 15-16 October 2010.

- **Session Co-Chair**, Technical Session: “Vibration and Control of Mechanical Systems”, *ASME International Mechanical Engineering Congress and Exposition – IMECE 2009*, Lake Buena Vista, FL, 13-19 November 2009.

A9. Advisory/Technical Committee Memberships

- **Member**, IEEE Robotics and Automation Society, Mechanisms and Design Technical Committee (TC) 2017–Present
- **Elected Voting Member**, ASME Design Engineering Division, Mechanisms and Robotics Technical Committee (TC) 2018–2022
- **Program Advisory Committee**, Robotics & Mechatronics Systems Eng. Program 2011–Present
University of Detroit, Mercy

A10. Professional Memberships

- American Society of Mechanical Engineers (ASME) 2002 – Present
- Institute of Electrical & Electronics Engineers (IEEE) 2002 – Present
- IEEE Robotics and Automation Society (RAS) 2009 – Present
- Association for Unmanned Vehicle Systems International (AUVSI) 2008 – Present
- Society of Automotive Engineers (SAE) 2008 – Present
- The Israeli Robotics Association (IROB) 2018 – Present
- Robotics Technology Consortium (RTC) 2009 – 2014

B. Departmental Service and Administrative Assignments

Virginia Tech

- **Member**, RADS Major Subcommittee
Robotics, Autonomous, and Dynamical Systems (RADS)
Mechanical Engineering Department 2022 – 2022
- **Member**, Graduate Program Committee
Mechanical Engineering Department 2015 – 2022
- **Chair**, Faculty Search Committee (Dynamic Systems and Control)
Mechanical Engineering Department 2017 – 2018
- **Chair**, Faculty Search Committee (Robotics Perception)
Mechanical Engineering Department 2017 – 2018
- **Member**, Ad Hoc (P&T and TAC) Committee
Mechanical Engineering Department 2017 – 2019
- **Coordinator**, Thrust Area Committee (TAC)
Robotics, Autonomous, and Dynamical Systems (RADS)
Mechanical Engineering Department 2017 – 2018
- **Mentor for Junior Faculty**
Mechanical Engineering Department 2018 – 2019

- **Representative Member**, Thrust Area Committee (TAC) Robotics, Autonomous, and Dynamical Systems (RADS) Mechanical Engineering Department 2016 – 2019
- **Member**, Faculty Search Committee (Dynamic Systems & Control - Perception) Mechanical Engineering Department 2016 – 2017
- **Member**, Faculty Search Committee (Energy Area) Mechanical Engineering Department 2015 – 2016

George Washington University

- Member, Sub-Committee for the Undergraduate Design Curriculum 2009 – 2015
- ABET Design Subcommittee 2010 – 2015
- Member, Academic Standards Committee 2009 – 2015
- Member, Laboratory Committee 2009 – 2015
- Member, Steering Committee Center for Biomimetics & Bioinspired Engineering (COBRE) 2009 – 2015
- Member, Faculty Search Committee Dept. of Mechanical & Aerospace Engineering, GWU 2010 – 2011
- Member, Faculty Search Committee Dept. of Computer Science, GWU 2009 – 2010
- Departmental Secretary, MAE Faculty Meetings 2009 – 2010

C. School/College Service and Administrative Assignments

Virginia Tech

- Faculty Judge, 2022 Senior Design Competition Expo April 2022
- Faculty Judge, 2021 Senior Design Competition Expo April 2021
- Faculty Judge, Torgersen Graduate Research Award Competition May 2019
- Faculty Judge, 2019 Senior Design Competition Expo May 2018
- Faculty Judge, 2018 Senior Design Competition Expo May 2018
- Faculty Judge, 2017 Senior Design Competition Expo May 2017
- Faculty Judge, 2016 Senior Design Competition Expo May 2016

George Washington University

- Faculty Judge, 2015 R&D SEAS Showcase Feb 2015

- Faculty Judge, The Pelton Award for Outstanding Senior Project May 16, 2012
- Faculty Judge, 2012 R&D SEAS Showcase Feb 27, 2012
- Faculty Panelist, SEAS New Faculty Orientation August 24, 2011
- Faculty Panelist, SEAS New Faculty Orientation August 25, 2010
- Member, SEAS Biomedical Engineering (BME) Interest Group 2009 – 2015
- Member, Science and Engineering Hall (SEH) Planning Committee 2009 – 2015
- Member, SEAS Educational Initiatives (SEI) Committee Spring 2009
Undergraduate Programs in Robotics, and Energy & Sustainability
- Affiliate Member, GW Institute for Nanotechnology (GWIN) 2013 – 2015
- Affiliate Member, GW Institute for Biomedical Engineering (GWIBE) 2009 – 2015
- Participated in various School of Engineering & Applied Science recruiting events and orientations for Graduate and Undergraduate students, including:
 - Graduate / Undergraduate Open Houses
 - Undergraduate recruiting events and orientations
 As part of those activities, students tour the Robotics & Mechatronics Lab (RML) and I give talks about educational and research opportunities in SEAS through various demonstrations of research ongoing in RML.

D. University Service and Administrative Assignments

George Washington University

- Member, Faculty Governance Working Group on Appointment, Promotion & Tenure 2014–2015
- Member, Faculty Senate Committee on Professional Ethics & Academic Freedom 2012–2015
- Judging Team Member, GWU Research Day Apr 2014
- Judging Team Captain, GWU Research Day Apr 2013
- Reviewer, George Washington University Facilitating Fund UFF/Dilthey Award Jan. 2012, 2013
- Organizer, Robotics Workshops at the Science, Technology & Engineering Day Apr 2011, 2012, 2013, 2014
Virginia Science and Technology Campus, GWU
Workshop title: “Greater than the Sum of its Parts: Integrating a Robotic System”

Dr. Pinhas Ben-Tzvi, journal articles, books, patents

PEER-REVIEWED JOURNAL PUBLICATIONS:

- [80] Liu, Y., **Ben-Tzvi, P.**, “Development and Experiments of a Novel Quadruped Robot with a Versatile Robotic Tail,” *IEEE Transactions on Robotics*, Under review, November 2023.
- [79] Guo, Y., Xu, W., **Ben-Tzvi, P.**, “ Vision-Based Human-Machine Interface for a Robotic Exoskeleton Glove Designed for Patients with Brachial Plexus Injuries”, *Intelligent Service Robotics*, Under review, November 2023.
- [78] Feng, S., Pressgrove, I., Liu, Y., **Ben-Tzvi, P.**, “Autonomous Alignment and Docking Control for a Self-reconfigurable Modular Mobile Robotic System”, *Robotics Journal*, Vol. 13, Issue 5, pp. 1-17, May 2024. DOI: <https://doi.org/10.3390/robotics13050081>
- [77] Xu, W., Guo, Y., Liu, Y., **Ben-Tzvi, P.**, “Development of A Novel Compact Robotic Exoskeleton Glove with Reinforcement Learning Control”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 16, Issue 8, pp. 081016: 1-12, August 2024. DOI: <https://doi.org/10.1115/1.4064283>
- [76] Liu, Y., **Ben-Tzvi, P.**, “How a Serpentine Tail Assists Agile Motions of Kangaroo Rats: A Dynamics and Control Approach”, *Nonlinear Dynamics*, Vol. 111, pages 14783–14803, July 2023. DOI: 10.1007/s11071-023-08646-w
- [75] Xu, W., Guo, Y., Bravo, C.J., **Ben-Tzvi, P.**, “Design, Control, and Experimental Evaluation of a Novel Robotic Glove System for Patients with Brachial Plexus Injuries”, *IEEE Transactions on Robotics*, Vol. 39, Issue 2, pp. 1637-1652, April 2023. DOI: 10.1109/TRO.2022.3220973
- [74] Han, X., Ren, H., Qi, J., **Ben-Tzvi, P.**, “Autonomous Cricothyroid Membrane Detection and Manipulation using Neural Networks and Robot Arm for First-Aid Airway Management”, *Journal of Medical Devices, Transactions of the ASME*, Vol. 17, Issue 1, pp. 014502: 1-9, March 2023. DOI: <https://doi.org/10.1115/1.4056505>
- [73] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, “Personalized Voice Activated Grasping System for a Robotic Exoskeleton Glove”, *Mechatronics Journal*, Vol. 83, pp. 102745:1-12, May 2022. DOI: 10.1016/j.mechatronics.2022.102745
- [72] Sohal, S.S., Sebastian, B., **Ben-Tzvi, P.**, “Autonomous Docking of Hybrid-Wheeled Modular Robots With an Integrated Active Genderless Docking Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 14, Issue 1, pp. 011010: 1-15, February 2022. DOI: doi.org/10.1115/1.4051519

- [71] Njaka, T., Brizzolara, S., **Ben-Tzvi, P.**, “Design and Experimental Validation of a Novel High-Speed Omnidirectional Underwater Propulsion Mechanism”, IEEE/ASME Transactions on Mechatronics, Vol. 26, Issue 5, pp. 2339-2349, October 2021.
DOI: 10.1109/TMECH.2020.3037887

- [70] Guo, Y., Xu, W., Pradhan, S., Bravo, C.J., **Ben-Tzvi, P.**, “Data Driven Calibration and Control for Compact Lightweight Series Elastic Actuators for Robotic Exoskeleton Gloves”, IEEE Sensors Journal, Vol. 21, Issue 19, pp. 21120-21130, October 2021.
DOI:10.1109/JSEN.2021.3101143 * **Selected as a featured article**

- [69] Yang, J., Saab, W., Liu, Y., **Ben-Tzvi, P.**, “Reuleaux Triangle Based Two Degrees of Freedom Bipedal Robot”, Robotics Journal, Vol. 10, Issue 4, pp. 1-15, October 2021.
DOI: 10.3390/robotics10040114

- [68] Liu, Y., **Ben-Tzvi, P.**, “Dynamic Modeling, Analysis, and Design Synthesis of a Reduced Complexity Quadruped with a Serpentine Robotic Tail”, Integrative and Comparative Biology, Vol. 61, Issue 2, pp. 464-477, August 2021. DOI: 10.1093/icb/icab083

- [67] Liu, Y., **Ben-Tzvi, P.**, “A New Extensible Continuum Manipulator Using Flexible Parallel Mechanism and Rigid Motion Transmission”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 13, Issue 3, pp. 031112: 1-7, June 2021.
DOI: doi.org/10.1115/1.4050097

- [66] Feng, S., Sebastian, B., **Ben-Tzvi, P.**, “A Collision Avoidance Method Based on Deep Reinforcement Learning”, Robotics Journal, Vol. 10, Issue 2, pp. 1-19, May 2021.

- [65] Ren, H., Qi, J., **Ben-Tzvi, P.**, “Learning Flatness-Based Controller Using Neural Networks”, ASME Letters in Dynamic Systems and Control, Vol. 1, Issue 2, pp. 021003: 1-6, April 2021.
DOI: 10.1115/1.4046776

- [64] Wang, J., Liu, Y., **Ben-Tzvi, P.**, “Robust Adaptive Input-Output Control for a Class of Modular Robotic Systems via Inverse Optimality Theory”, International Journal of Control, Vol. 95, Issue 7, pp. 1898-1912, July 2022.
DOI:10.1080/00207179.2021.1885741

- [63] Liu, Y., **Ben-Tzvi, P.**, “Dynamic Modeling, Analysis, and Comparative Study of A Quadruped With Bio-Inspired Robotic Tails”, Multibody System Dynamics, Vol. 51, Issue 2, pp. 195-219, February 2021. DOI: 10.1007/s11044-020-09764-8

- [62] Vanteddu, T., **Ben-Tzvi, P.**, “Stable Grasp Control with a Robotic Exoskeleton Glove”, Journal of Mechanisms and Robotics, Transactions of the ASME, Vol. 12, Issue 6, pp. 061015: 1-14, December 2020.

- [61] Wang, X., Ren, H., Kumar, A., **Ben-Tzvi, P.**, “Design and Analysis of a Variable Inertia Spatial Robotic Tail for Dynamic Stabilization”, *Biomimetics*, Vol. 5, Issue 4, pp. 1-16, November 2020. DOI: 10.3390/biomimetics5040055
- [60] Liu, Y., **Ben-Tzvi, P.**, “An Articulated Closed Kinematic Chain Planar Robotic Leg for High Speed Locomotion”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 4, pp. 041003: 1-15, August 2020. DOI: 10.1115/1.4045689
- [59] Liu, Y., **Ben-Tzvi, P.**, “Design, Analysis and Integration of a New Two-DOF Articulated Multi-link Robotic Tail Mechanism”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 12, Issue 2, pp. 021101: 1-9, April 2020. DOI: 10.1115/1.4045842
- [58] Ren, H., **Ben-Tzvi, P.**, “Advising Reinforcement Learning Towards Scaling Agents in Continuous Control Environments with Sparse Rewards”, *Journal to Engineering Applications of Artificial Intelligence*, Vol. 90, pp. 103515: 1-12, April 2020. DOI: 10.1016/j.engappai.2020.103515
- [57] Ren, H., **Ben-Tzvi, P.**, “Learning Inverse Kinematics and Dynamics of a Robotic Manipulator using Generative Adversarial Networks”, *Robotics and Autonomous Systems*, Vol. 124, pp. 103386: 1-12, February 2020. DOI: 10.1016/j.robot.2019.103386
- [56] Chauhan, R., Sebastian, B., **Ben-Tzvi, P.**, “Grasp Prediction Towards Naturalistic Exoskeleton Glove Control”, *IEEE Transaction on Human-Machine Systems*, Vol. 50, Issue 1, pp. 22-31, February 2020. DOI: 10.1109/THMS.2019.2938139
- [55] Refour, E., Sebastian, B., Chauhan, R., **Ben-Tzvi, P.**, “A General Purpose Robotic Hand Exoskeleton with Series Elastic Actuators”, *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 6, pp. 060902: 1-9, December 2019.
- [54] Williams, A., Sebastian, B., **Ben-Tzvi, P.**, “Review and Analysis of Search, Extraction, Evacuation, and Medical Treatment Field Robots”, *Journal of Intelligent and Robotic Systems*, Vol. 96, Issue 3, pp. 401-418, December 2019.
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- [51] Liu, Y., Wang, J., **Ben-Tzvi, P.**, "A Cable Length Invariant Robotic Tail Using a Circular Shape Universal Joint Mechanism", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 5, pp. 051005: 1-14, October 2019.
- [50] Kumar, P., **Ben-Tzvi, P.**, "Estimation of Wind Conditions Utilizing RC Helicopter Dynamics", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 5, pp. 2293-2303, October 2019.
- [49] **Ben-Tzvi, P.**, Saab, W., "A Hybrid Tracked-Wheeled Multi-Directional Mobile Robot", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 4, pp. 041008: 1-10, August 2019.
- [48] Rone, W., Saab, W., Kumar, A., **Ben-Tzvi, P.**, "Controller Design, Analysis and Experimental Validation of a Robotic Serpentine Tail to Maneuver and Stabilize a Quadrupedal Robot", *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, Vol. 141, Issue 8, pp. 081002: 1-9, August 2019.
- [47] Sebastian, B., **Ben-Tzvi, P.**, "Physics Based Path Planning for Autonomous Tracked Vehicle in Challenging Terrain", *Journal of Intelligent and Robotic Systems*, Vol. 95, Issue 2, pp. 511-526, August 2019.
- [46] Racioppo, P., **Ben-Tzvi, P.**, "Design and Control of an Articulated Cable-Driven Modular Snake Robot", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 3, pp. 893-901, June 2019.
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- [44] Saab, W., Rone, W., Kumar, A., **Ben-Tzvi, P.**, "Design and Integration of a Novel Spatial Articulated Robotic Tail", *IEEE/ASME Transactions on Mechatronics*, Vol. 24, Issue 2, pp. 434-446, April 2019.
- [43] Sebastian, B., **Ben-Tzvi, P.**, "Active Disturbance Rejection Control for Handling Slip in Tracked Vehicle Locomotion", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 11, Issue 2, pp. 021003: 1-12, April 2019.
- [42] Williams, A., Sebastian, B., **Ben-Tzvi, P.**, "A Robotic Head Stabilization Mechanism for Medical Transport", *Robotics Journal*, Vol. 8, Issue 1, pp. 1-16, March 2019.
- [41] Saab, W., Racioppo, P., Kumar, A., **Ben-Tzvi, P.**, "Design of a Miniature Modular Inchworm Robot with an Anisotropic Friction Skin", *Robotica Journal*, Vol. 37, Issue 3, pp. 521-538, March 2019.

- [40] Saab, W., Racioppo, P., **Ben-Tzvi, P.**, "A Review of Coupling Mechanism Designs for Modular Reconfigurable Robots", *Robotica Journal*, Vol. 37, Issue 2, pp. 378-403, February 2019.
- [39] Rone, W., Liu, Y., **Ben-Tzvi, P.**, "Maneuvering and Stabilization Control of a Bipedal Robot with a Universal-Spatial Robotic Tail", *Bioinspiration and Biomimetics Journal*, Vol. 14, Issue 1, pp. 016014: 1-16, January 2019.
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- [37] Saab, W., Rone, W., **Ben-Tzvi, P.**, "Robotic Tails: A State-of-The-Art Review", *Robotica Journal*, Vol. 36, Issue 9, pp. 1263-1277, September 2018.
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- [33] Kumar, A., **Ben-Tzvi, P.**, "Novel Wireless Sensing Platform for Experimental Mapping and Validation of Ship Air Wake", *Mechatronics Journal*, Vol. 52, pp. 58-69, June 2018.
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- [29] Saab, W., **Ben-Tzvi, P.**, "A Genderless Coupling Mechanism with 6-DOF Misalignment Capability for Modular Self-Reconfigurable Robots", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 8, Issue 6, pp. 061014: 1-9, December 2016.
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- [27] Zhao, H., **Ben-Tzvi, P.**, "Synchronous Position Control Strategy for Bi-Cylinder Electro-pneumatic Systems", *International Journal of Control, Automation and Systems*, Vol. 14, Issue 6, pp. 1501-1510, December 2016.
- [26] Kumar, A., **Ben-Tzvi, P.**, "Spatial Object Tracking System Based on Linear Optical Sensor Arrays", *IEEE Sensors Journal*, Vol. 16, Issue 22, pp. 7933-7940, November 2016.
- [25] **Ben-Tzvi, P.**, Danoff, J., Ma, Z., "The Design Evolution of a Sensing and Force-Feedback Exoskeleton Robotic (SAFER) Glove for Hand Rehabilitation Application", *Journal of Mechanisms and Robotics, Transactions of the ASME*, Vol. 8, Issue 5, pp. 051019: 1-9, October 2016.
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- [23] Kumar, A., **Ben-Tzvi, P.**, Saab, W., Snyder, M.R., "Wireless Telemetry System for Real-time Estimation of Ship Air Wake with UAVs", *Mechatronics Journal*, Vol. 36, pp. 18-26, June 2016.
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EXHIBIT 2

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Expert Testimony List

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In the Matter of Certain Electronic Candle Products and Components Thereof (Investigation No. 337-TA-1195)

L&L Candle Company LLC and Sotera Tschetter, Inc. (Complainants) v. Sterno Products *et al.* (Defendants)*

Provide expert opinion on patentability/obviousness

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Technical Report

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Patent No. at Issue: 9,675,982

Declaration, Provide expert opinion on patentability/obviousness

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DFI Corporation (Plaintiff)* v. Sauer Danfoss, Inc. and Norcan Fluid Power Limited (Defendant),
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Site Inspection/Field Investigation, Expert Report

United States International Trade Commission (ITC)

In the Matter of Certain Hospital Beds and Components Thereof (Investigation No. 337-TA-987)
Stryker (Complainant)* v. Umano Medical Inc. and Umano Medical World Inc. (Defendants)

Two Declarations, Deposition

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Site Inspection/Field Investigation, Expert Report

EXHIBIT 3

Forces, centre of gravity, reactions and stability

Topic areas

Mechanical engineering:

- ✓ Centre of gravity
- ✓ Forces
- ✓ Moments
- ✓ Reactions
- ✓ Resolving forces on an inclined plane.

Mathematics:

- ✓ Angles
- ✓ Trigonometric identities

Prerequisites

It may be useful to look at the resource **'Centre of gravity of composite bodies'** to introduce the concepts of the centre of gravity and tipping.

Problem statement

Many engineered objects, such as buses, boats, diggers, pushchairs, furniture, etc. are required to be resistant to tipping over under normal use conditions. How can an engineer determine when an object will tip over?



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**MOTOROLA SOLUTIONS
FOUNDATION**

Capsa Solutions LLC Ex. 2012

Howard Industries, Inc. v. Capsa Solutions LLC IPR2023-01275 - Page 146 of 157



Background

The weight of an object is the force due to gravity acting between the earth and the object, and is measured in newtons (N). As the scale of the earth is large compared with many everyday objects, the weight force acting on an object, F , can be related to its mass, m , through the approximating expression

$$F = mg,$$

where g is the acceleration due to gravity, usually taken to be 9.81 ms^{-2} at the earth's surface.

When a force acts on a body the body will accelerate in the direction of the force unless there is a balancing force to oppose it.

For an object sitting on a plane, this balancing force is the normal reaction, R , which acts normally and upwards (or perpendicular) to the plane. If there is friction between the object and the plane which acts against any sliding tendencies, a frictional force acts upward along the plane.

Activity 1 - Discussion

Look at the following stationary block on a level plane (left) and an inclined plane (right).

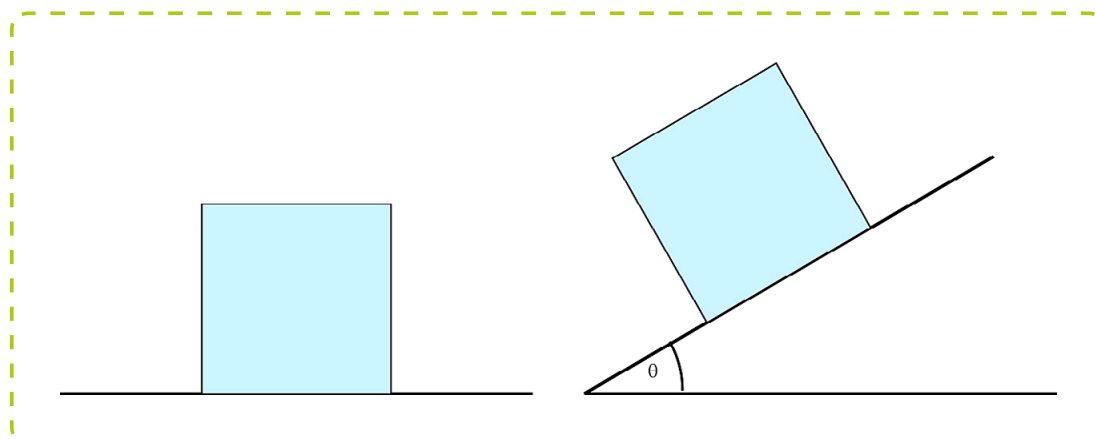


Figure 1
Stationary
blocks

Discuss what forces are acting and draw force arrows showing where they are acting. What assumptions do you make?

Activity 2 - Stability

The resource [tipping-1](#), shown in **Figure 2**, allows you to tilt an object with a uniform mass distribution and a mass of 1 kg. It is assumed that the friction between the object and the plane is large enough to prevent the object from sliding.

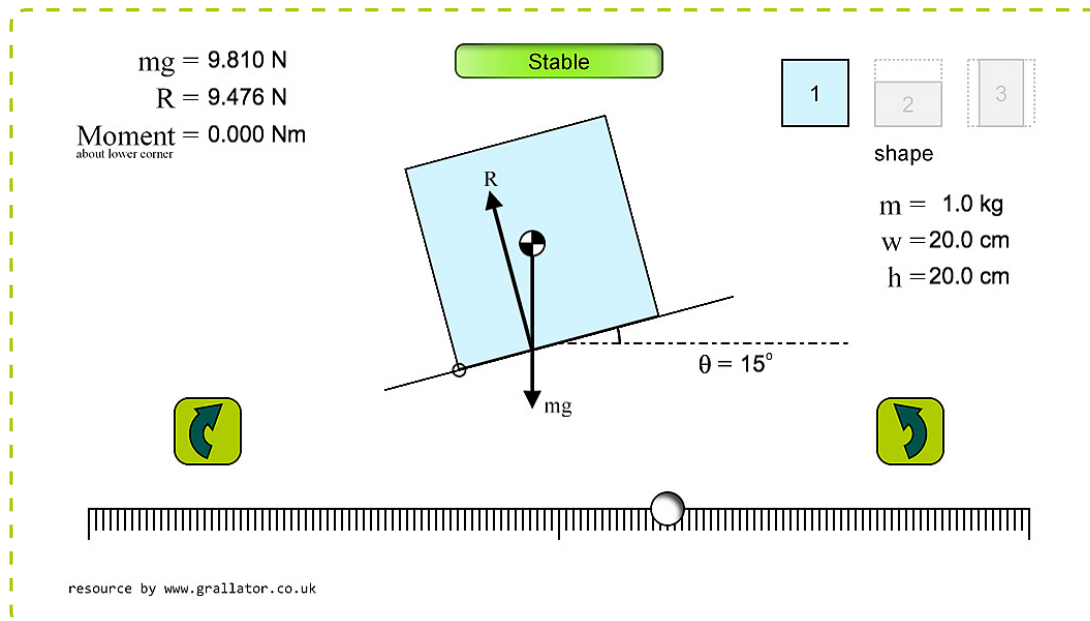
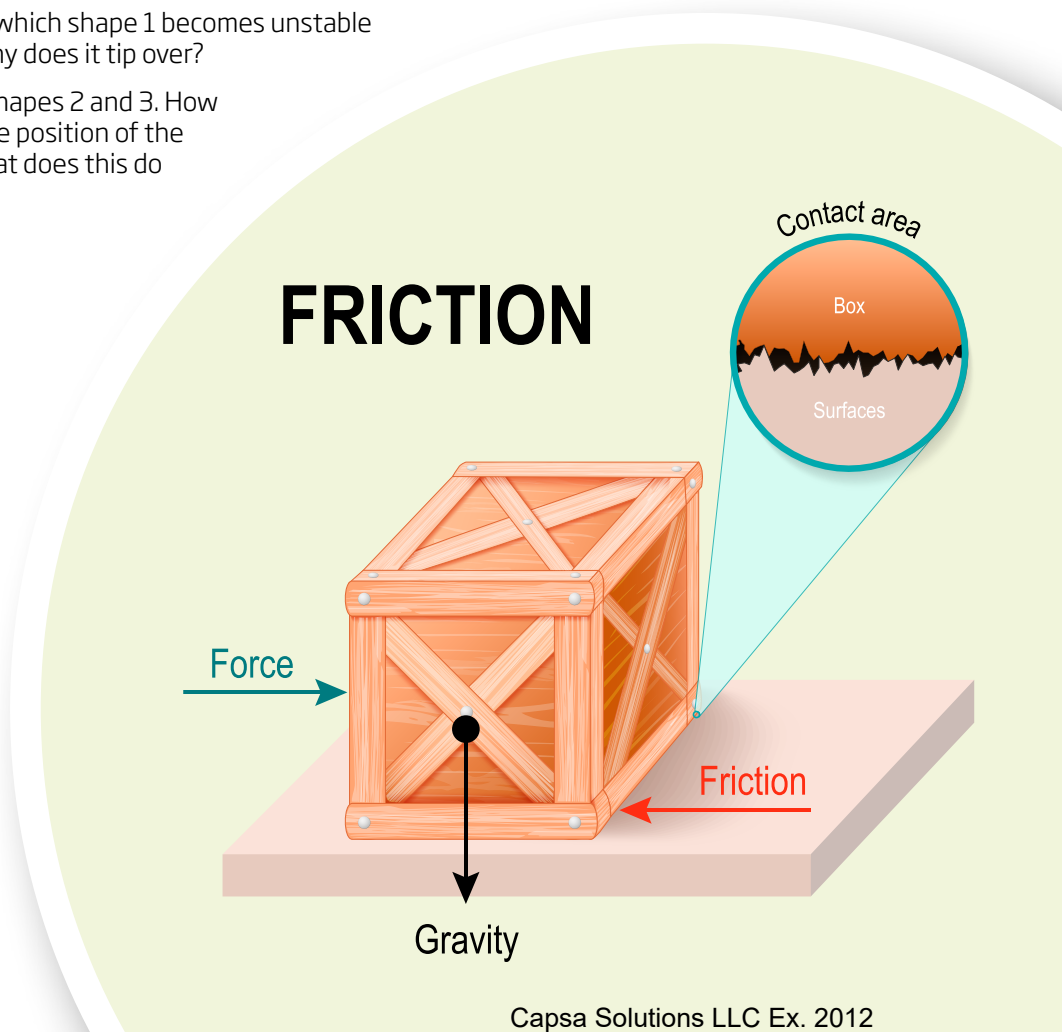


Figure 2
Screen shot of
resource

The object can be tilted by dragging the slider, or clicking/tapping to buttons for fine control. Additionally, the object can be changed for a one of the same mass but different dimensions (the outline of the original square and original centre of gravity are also shown).

- 1 Investigate the angle at which shape 1 becomes unstable and wants to tip over. Why does it tip over?
- 2 Repeat the above with shapes 2 and 3. How does the shape affect the position of the centre of gravity and what does this do to the stability?



Background - Tipping angle

Many engineered objects, such as buses and pushchairs, require a physical tilt test to demonstrate adequate stability. However, it wouldn't be wise to build something as complex and expensive as a bus and then hope it passes such a test! During the design phase, engineers will have a good idea as to the expected stability by considering the location of the centre of gravity and where the limiting line of action lies. Indeed, many CAD packages will calculate the location of the centre of gravity.

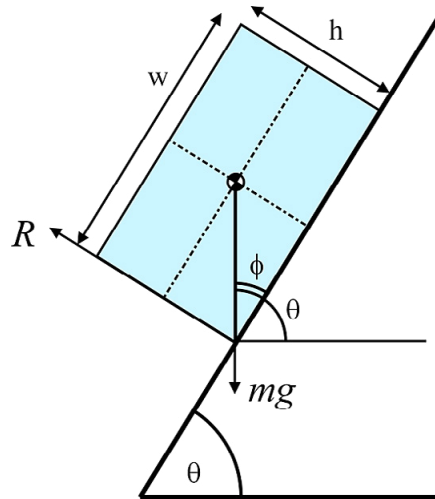


Figure 3
An object on a rough plane at the tipping point

The diagram in **Figure 3** shows a uniform block of width w and height h , so that the centre of gravity is at the centre, at the point of tipping. Note, the plane is rough so the object does not slide. The tipping point is reached when the weight force acts through the corner of the object. At this point, angles θ and ϕ sum to 90° .

$$\theta + \phi = 90^\circ$$

The angle θ is the angle of the plane at which the object tips, i.e. $\theta = 90^\circ - \phi$

The angle ϕ is the angle between the bottom edge and the line joining the corner and the centre of gravity, as shown in **Figure 10** in the Appendix (page 11).

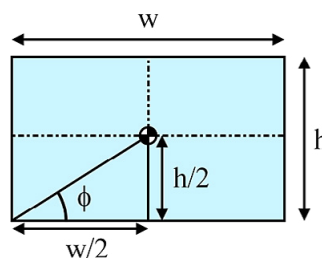


Figure 4

Using trigonometry

$$\tan \phi = \frac{h/2}{w/2} = \frac{h}{w}$$

so that the tipping angle is

$$\theta = 90^\circ - \tan^{-1} \left(\frac{h}{w} \right).$$

It can also be shown that (see Appendix)

$$\tan \theta = \frac{1}{\tan \phi} \Rightarrow \theta = \tan^{-1} \left(\frac{w}{h} \right).$$

Activity 3 - Finding the tipping angle

Calculate the tipping angle for the three objects considered in **Activity 2** and compare the results with the predictions of the resource [tipping-1](#). The dimensions of the objects are given in **Table 1**.

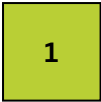
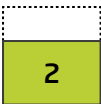
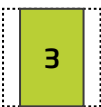
Object	Width, w (cm)	Height, h (cm)	$\phi = \tan^{-1}\left(\frac{h}{w}\right)$	Calculated tipping angle	Tipping angle from interactive resource
				θ	θ
	20	20			
	20	12			
	12	20			

Table 1

Stretch and challenge activity

The resource [Bus1.html](#), shown in **Figure 5**, allows you to tilt a bus that can be configured as

- ✓ A double decker (with and without upstairs passengers).
- ✓ A single decker
- ✓ Just the chassis

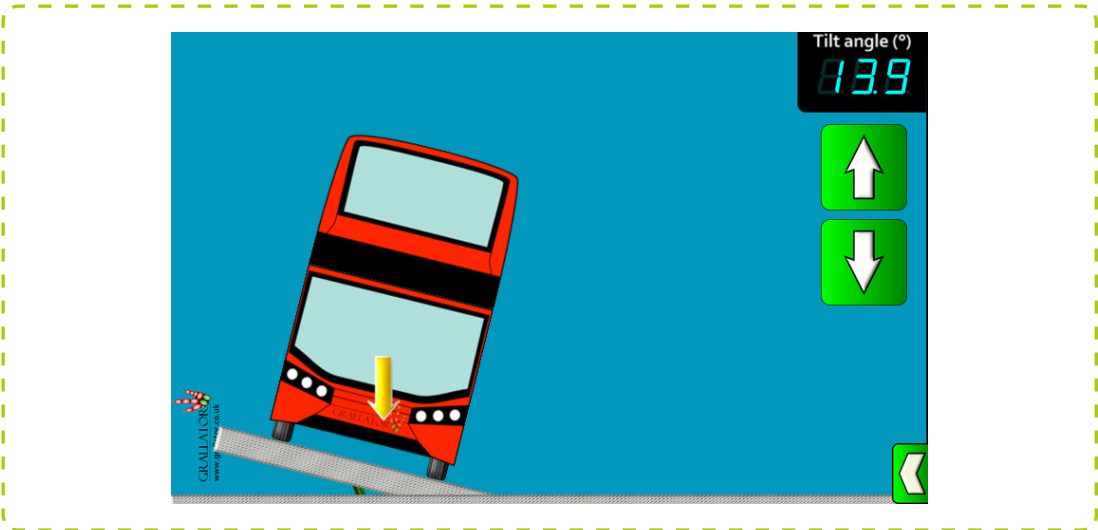
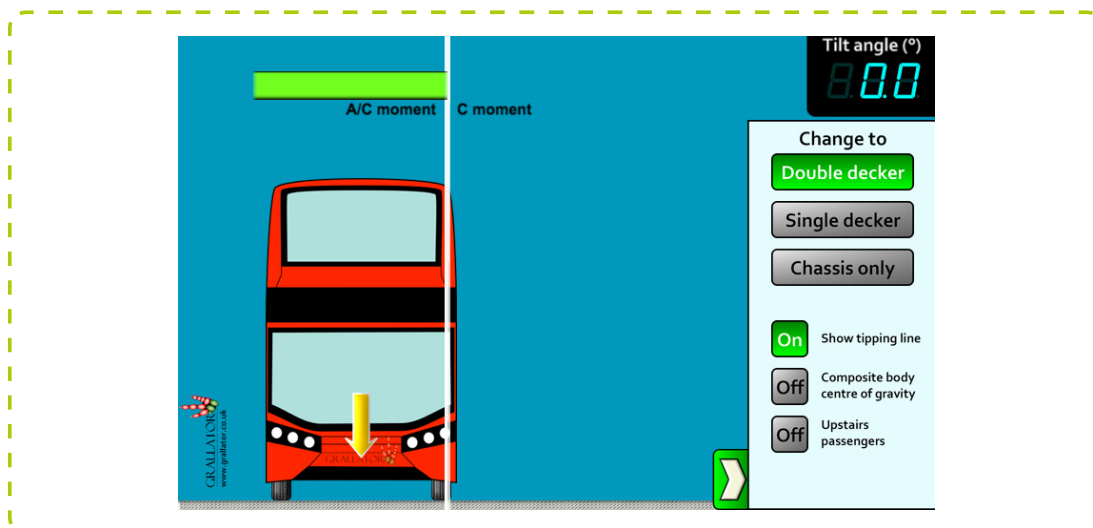


Figure 5
Screen shot of resource

The up and down arrows control the tilt angle of the bus. The left arrow at the bottom-right of the screen pulls out an options menu. The large yellow arrow shows the weight force acting from the centre of gravity of the bus.

Pull out the options menu and turn on the options for showing the tipping line, as shown in **Figure 6**.

Figure 6
The options menu



- 1 A bus is made of a number of components such as
 - A strong chassis that contains the heaviest items such as engine, cooling system, controls, suspension, wheels etc.
 - The internal fittings such as the seats.
 - The bodywork, which is usually made of relatively thin metal sheet.

Use the options menu to select the double decker, single decker and chassis only configurations and discuss the position of the centre of gravity of the bus for each.

- 2 Estimate the tipping angle for the three different configurations. Remember this will happen when the weight force acts outside the base of the object, which, in this case, is the wheel.
- 3 What effect does allowing for upstairs passengers have on the stability of the double decker configuration? (Check this by turning on the 'Upstairs passengers' option on the options menu.)



Notes and solutions

Activity 1

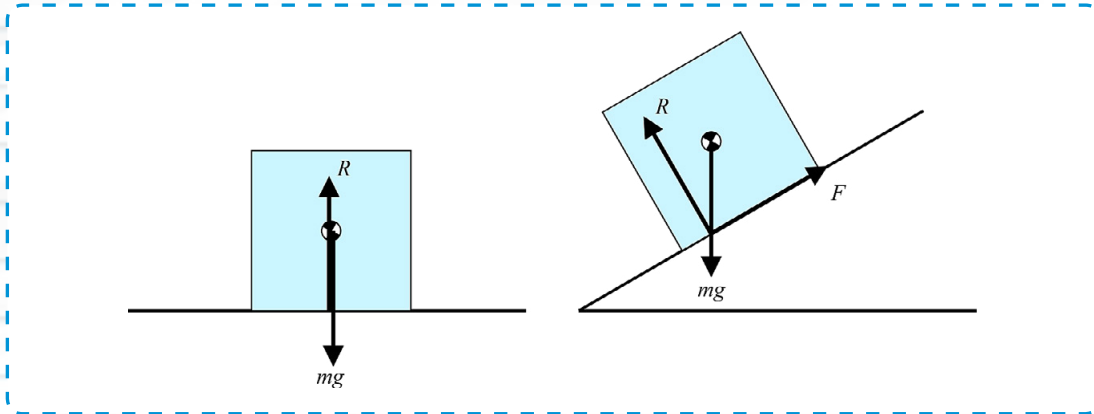


Figure 7
Force diagram

It is stated that the object is stationary, therefore there should be no net forces acting.

On the left-hand diagram, the weight force mg acts vertically downwards through the centre of gravity of the object. This is balanced by an equal and opposite normal reaction force, R . This force acts between the base of the object and the plane and through the centre of gravity.

On the right-hand diagram the weight force mg acts vertically downwards through the centre of gravity of the object. Again there is a normal reaction force, R , acting perpendicular to the plane. It is drawn acting at the base of the object where the line of action of the weight force intersects the base. As the object is stationary, there must also be a friction force acting along the plane to prevent sliding. This is also drawn on the base of the object acting from the same point as the normal reaction.

Activity 2 - Stability

1 The following observations are made

- Tilting the object moves the line of action of the normal reaction and the weight towards the corner.
- For angles up to 45° both the weight and the reaction fall within the base of the object there is no net moment about the lower corner of the object, and so it shows no tendency to tip, see **Figure 8**.

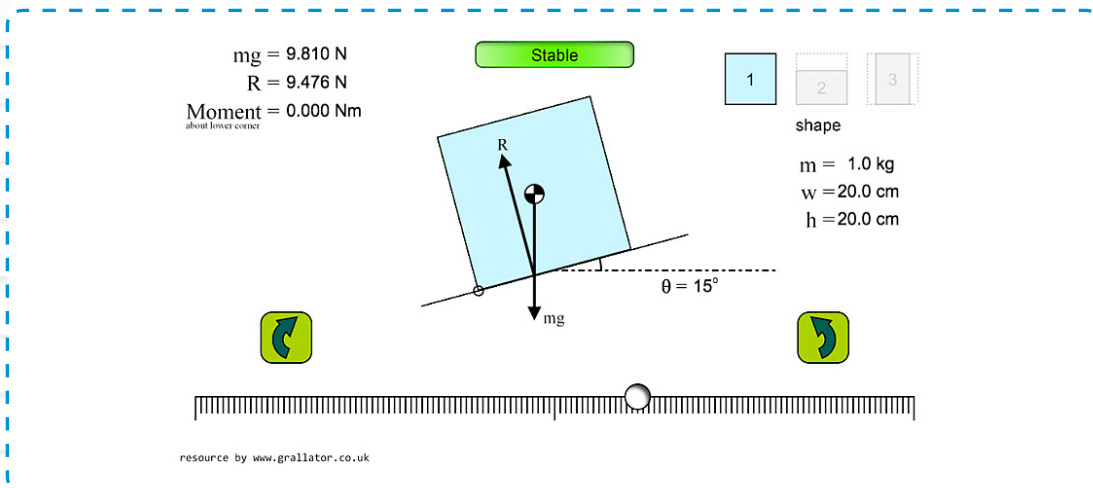


Figure 8
Screen shot
of resource
for a stable
configuration



- For angles above 45° , the weight force acts outside the base of the object. However, the normal reaction cannot do this - it can only exert a force where it is in contact with the surface.
- When the normal reaction is concentrated at the corner and the weight force acts outside the base of the object there is a net turning moment and the object tips, see **Figure 9**.

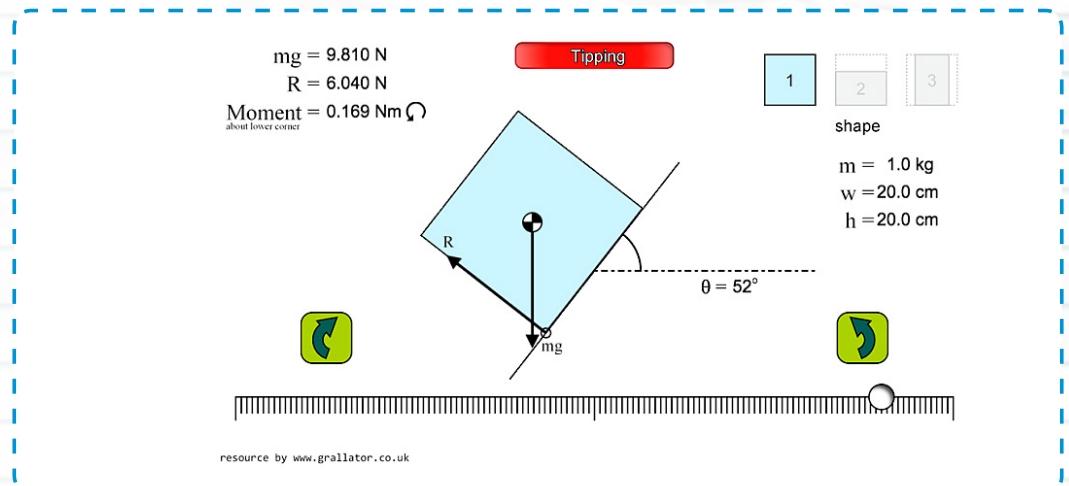


Figure 9
Screen shot of
resource for
an unstable
configuration

- 2 The flatter object (shape 2) has the same mass as the square object, but as it is flatter, has a lower centre of gravity. The result of this is that the object can be tilted much more before it tips over.

The narrower object (shape 3), also of the same mass, has its centre of gravity at the same height as the square block. However, because it is narrower, the weight acts outside the base at a lower angle, therefore the angle of tilt required before tipping over is less than the square block.

Activity 3 - Finding the tipping angle

Values of the tipping angles for the shapes in **Table 1** are shown in **Table 2**.

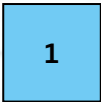
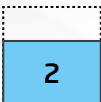
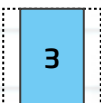
Object	Width, w (cm)	Height, h (cm)	$\phi = \tan^{-1}\left(\frac{h}{w}\right)$	Calculated tipping angle	Tipping angle from interactive resource
				θ	θ
	20	20	45°	45°	46°
	20	12	30.96° (2 d.p.)	59.04° (2 d.p.)	60°
	12	20	59.04° (2 d.p.)	30.96° (2 d.p.)	31°

Table 2

A comparison shows that the interactive resource gives larger values than the calculation. For shapes 2 and 3 this can be explained by the fact that the resource only allows you to select integer values for the angle θ . The nearest integer below the calculated tipping angle will not tip while the nearest one above it will definitely tip.

For shape 1 there appears to be a disagreement. This is because the calculated value of θ represents the angle at which the object is on the point of tipping. Technically, at this angle the object will not tip (as asserted by the interactive resource), however, any infinitesimal increase in angle beyond this will lead to tipping. Hence θ is an upper limit before tipping starts.

Stretch and challenge activity

- The bus is constructed using a strong chassis that contains the heaviest items such as engine, cooling system, controls, suspension, wheels etc. This has a centre of gravity reasonable close to the ground. On top of this sits the coachwork, including the seats. These add mass above the chassis and so raise the centre of gravity. However, the coachwork is light compared with the chassis so that the centre of gravity remains relatively low compared with the height of the bus, even when it is configured as a double decker. The individual contributions from the chassis, lower body work and upper body work can be viewed by turning on the "Composite body centre of gravity" option.
- The bus will tip at the point where the line of action of the combined weight passes through the outer corner of the lower tyre.
 - For the chassis only configuration, the tipping angle is estimated to be about 56.6°.
 - For the single decker configuration the tipping angle is estimated to be about 50.8°.
 - For the double decker configuration the tipping angle is estimated to be about 38.6°.
- When passengers are on the upper deck of a bus they add significant weight which moves the centre of gravity upwards. **Activity 3** showed that an object with a high centre of gravity is less stable than an object with a low centre of gravity. Adding upstairs passengers (use the pull-out menu option to do this) decreases the tipping angle to about 31.3°. In the UK it is legislation that a double decker which is fully loaded on the top deck bus must not tip when tilted at an angle of 28° (cited here www.publications.parliament.uk/pa/cm198990/cmhansrd/1990-06-05/Debate-1.html). The bus in this activity therefore passes!

Appendix

The main text states that it can also be shown that the tipping angle, θ is related to the angle ϕ through (refer to **Figures 3** and **4**).

$$\tan \theta = \frac{1}{\tan \phi} \Rightarrow \theta = \tan^{-1} \left(\frac{w}{h} \right).$$

This is an opportunity to use some angle formulae.

Approach 1

Taking the tangent of both sides of $\theta + \phi = 90^\circ$ gives $\tan(\theta + \phi) = \tan 90^\circ$. Using the angle sum formula for $\tan$

$$\begin{aligned} \tan(\theta + \phi) &= \tan 90^\circ \\ \frac{\tan \theta + \tan \phi}{1 - \tan \theta \tan \phi} &= \tan 90^\circ \end{aligned}$$

The right hand side may be considered to be a problem – a calculator will give an error if you try to find the $\tan$ of 90° . However, if you look at a plot of $\tan \theta$, you will see that $\tan \theta \rightarrow \infty$ as $\theta \rightarrow 90^\circ$.

Rearranging the above

$$\frac{\tan \theta + \tan \phi}{\tan 90^\circ} = 1 - \tan \theta \tan \phi$$

As $\tan 90^\circ$ is infinitely large, any finite number divided by this is zero, so that

$$\begin{aligned} \frac{\tan \theta + \tan \phi}{\tan 90^\circ} &= 0 = 1 - \tan \theta \tan \phi \\ \Rightarrow \\ 1 &= \tan \theta \tan \phi \\ \tan \theta &= \frac{1}{\tan \phi} \end{aligned}$$

Substituting $\tan \phi = \frac{h}{w}$ gives

$$\tan \theta = \frac{w}{h}$$



Approach 2

Consider the shape at a general angle as shown in **Figure 10**.

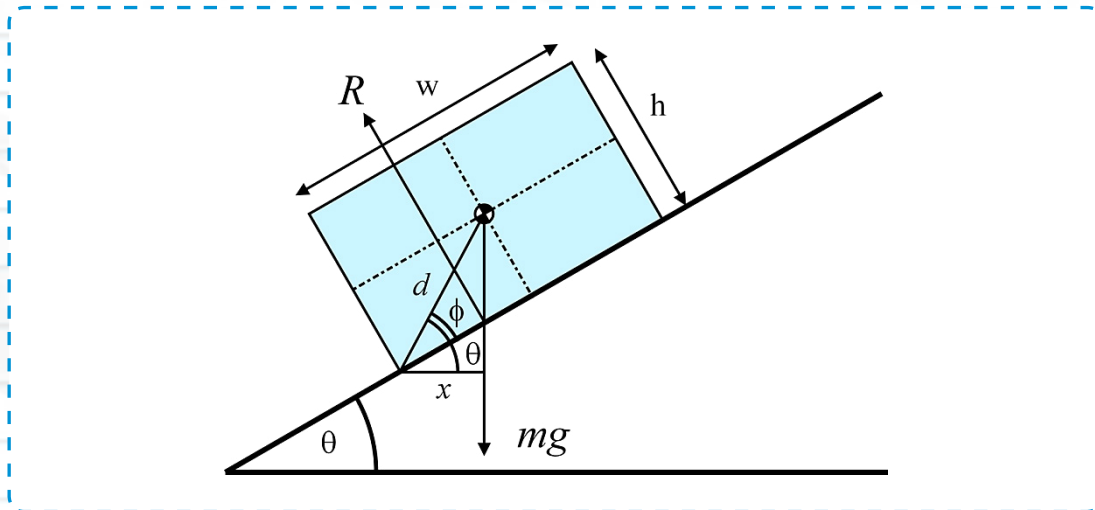


Figure 10

The horizontal distance from the corner to the line of action of the weight force is denoted x in the diagram. The distance from the corner to the centre of gravity is denoted d . The angle θ is the tilt angle and ϕ is the angle between the bottom edge and the line joining the corner and the centre of gravity. Its value is given by $\tan \phi = \frac{h/2}{w/2} = \frac{h}{w}$ (see solution for Activity 3, above). Using trigonometry

$$x = d \cos(\theta + \phi).$$

At the tipping point $x = 0$ as the line of action of the weight passes through the corner. Using this and the angle sum formula for cos

$$0 = d \cos(\theta + \phi)$$

$$0 = \cos(\theta + \phi) \quad (d \neq 0)$$

$$0 = \cos \theta \cos \phi - \sin \theta \sin \phi$$

$$\sin \theta \sin \phi = \cos \theta \cos \phi$$

$$\frac{\sin \theta}{\cos \theta} = \frac{\cos \phi}{\sin \phi}$$

$$\tan \theta = \frac{1}{\tan \phi} = \frac{w}{h}$$

i.e.

$$\tan \theta = \frac{w}{h}$$



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