UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

MARKFORGED INC.,
Petitioner,

v.

CONTINUOUS COMPOSITES, INC.,
Patent Owner

IPR2022-01218

IPR2022-01220

U.S. Patent No. 9,987,798

Issue Date: June 5, 2018

Title: METHOD AND APPARATUS FOR CONTINUOUS COMPOSITE THREE-DIMENSIONAL PRINTING

DECLARATION OF DAVID ROSEN, PH.D. IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW OF U.S. PATENT NO. 10,744,798

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I, David Rosen, Ph.D., declare as follows:

I. QUALIFICATIONS

1. I make this Declaration based upon my own personal knowledge, information, and belief, and I would and could competently testify to the matters set forth in this Declaration if called upon to do so.

2. Attached hereto as Exhibit ("Ex.") 1015 is a true and correct copy of my Curriculum Vitae (CV).

3. I have over 24 years of experience in the field of additive manufacturing, also known as three-dimensional (3D) printing.

4. I am currently a professor at the George W. Woodruff School of Mechanical Engineering at Georgia Institute of Technology, and have been teaching at the school in some capacity since 1992. I was first employed at the George W. Woodruff School of Mechanical Engineering as an instructor, then as an assistant professor, associate professor, and currently hold the title of full professor.

5. During my tenure at the George W. Woodruff School of Mechanical Engineering I have studied, researched, and advised in the field of additive manufacturing, including teaching the following courses: Introduction to Additive Manufacturing, Rapid Prototyping in Engineering, Finite Element Method,

Computing Techniques, and Design Across Disciplines.

6. I am also the research director for the Digital Manufacturing and Design Center at the Singapore University of Technology and Design, and have been since 2016.

7. I was a visiting professor in the Department of Mechanical and Manufacturing Engineering at Loughborough University in the United Kingdom from 2005 to 2011.

8. I was also a visiting professor in the School of Mechanical and Aerospace Engineering at Nanyang Technological University in Singapore.

9. I am currently the director of the Rapid Prototyping and Manufacturing Institute, and my responsibilities include, but are not limited to, directing and formulating educational and research programs, coordinating laboratory operations, and supervising student projects in the field of additive manufacturing.

10. I hold a Ph.D. from the University of Massachusetts in Mechanical Engineering. I also hold a Bachelor's and a Master's degree from the University of Minnesota in Mechanical Engineering.

11. While studying at the University of Massachusetts, I was a visiting research scientist at the Ford Scientific Research Laboratory.

12. I have two years of experience in software development while working on mechanical computer-aided design systems at Computervision Corporation, before starting my Ph.D. studies.

13. As detailed in my CV, I have received numerous awards for my work, including awards from the 3-D Systems North American User Group, the Solid Freeform Fabrication Symposium, the American Society of Mechanical Engineers (ASME) Design Theory and Methodology Conference, and the ASME Computers and Information in Engineering Division. I have also been awarded numerous grants and contracts, as principal or co-principal investigator, relating to, among other things, additive manufacturing, design guidance systems for additive manufacturing, and design for manufacturing.

14. I have published three books, and contributed to chapters in numerous other books, on additive manufacturing technologies. I have authored hundreds of publications and presented at hundreds of conferences in the fields of additive manufacturing, engineering design, design for manufacturing, computer-aided design, and geometric modeling.

15. I am an inventor on five patents related to medical devices, fabrication techniques, and haptic interface devices.

16. I have founded two companies, AlpZhi, Inc. and Additive

Manufacturing Technologies Inc., both related to stereolithography and 3-D printing software.

17. I have guided dozens of students through their Ph.D. and Master's theses, and served on dozens of thesis and dissertation committees.

18. A copy of my curriculum vitae, including a list of scientific publications and presentations, is attached as Ex. 1016 to this Declaration.

A. Materials Considered

19. The analysis that I provide in this Declaration is based on my education and experience in the field of additive manufacturing, as well as the documents I have considered, including the '798 patent [Ex. 1001] and its prosecution history [Exs. 1003-1005, 1011 and 1012]. The '798 patent states on its face that it issued from U.S. Application Ser. No. 15/267,956, which was filed on September 16, 2016 and is a Continuation of U.S. Application Ser. No. 13/975,300, which was filed on August 24, 2013 and claims priority from U.S. Provisional Application No. 61/694,253 filed on August 29, 2012. For the purposes of this Declaration, I have assumed August 29, 2012 as the effective filing date for the '798 patent. I have cited to the following documents in my analysis below:

Exhibit No.	Description
Ex. 1001	U.S. Patent No. 9,987,798 ("the '798 Patent")
Ex. 1003	Non-Final Rejection mailed on December 12, 2017
Ex. 1004	Response to Non-Final Rejection filed on December 20, 2017
Ex. 1005	Final Rejection mailed on March 12, 2018
Ex. 1006	U.S. Patent No. 6,153,034 ("Lipsker")
Ex. 1007	Ma Dissertation Thesis ("Ma")
Ex. 1008	U.S. Patent No. 5,121,329 ("Crump")
Ex. 1009	Nikzad Dissertation Thesis ("Nikzad")
Ex. 1010	U.K. Patent Application GB2213793 ("Wohrl")
Ex. 1011	U.S. Patent No. 5,134,569 ("Masters")
Ex. 1012	Notice of Allowance mailed on April 27, 2018
Ex. 1013	Declaration of Dr. Sylvia Hall-Ellis
Ex. 1014	Information Disclosure Statement filed on September 16, 2016
Ex. 1015	Curriculum Vitae of David Rosen, Ph.D.
Ex. 1016	Pang *et al.*, A hollow fibre reinforced polymer composite encompassing self-healing and enhanced damage visibility (Composites Science and Technology, Vol. 65, pp. 1791–1799, 2005)
Ex. 1017	Zhong *et al*., Short fiber reinforced composites for fused deposition modeling (Materials Science and Engineering, A301, pp. 125–130, 2001)
Ex. 1020	Response to Final Rejection filed on March 16, 2018

II. LEGAL PRINCIPLES

20. I am not an attorney. For purposes of this declaration, I have been informed by counsel for MarkForged Inc., about certain aspects of the law that are

relevant to my analysis and opinions, as set forth below.

A. Prior Art

21. I understand that the prior art to the '798 patent includes patents and printed publications in the relevant art that predate the '798 patent's priority date. As I explained previously, I have been instructed to assume for purposes of my analysis that August 29, 2012 is the relevant date for determining what is "prior art." In other words, I should consider as "prior art" anything publicly available prior to August 29, 2012. I further understand that, for purposes of this proceeding in the United States Patent Trial and Appeal Board, only patents and documents that have the legal status of a "printed publication" may be relied on as prior art.

B. Claim Construction

22. I understand that under the legal principles, claim terms are generally given their ordinary and customary meaning, which is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention, *i.e.*, as of the effective filing date of the patent application. I further understand that the person of ordinary skill in the art is deemed to read the claim term not only in the context of the particular claim in which a claim term appears, but in the context of the entire patent, including the specification.

23. I am informed by counsel that the patent specification, under the legal

principles, has been described as the single best guide to the meaning of a claim term, and is thus highly relevant to the interpretation of claim terms. I understand for terms that do not have a customary meaning within the art, the specification usually supplies the best context of understanding the meaning of those terms.

24. I am further informed by counsel that other claims of the patent in question, both asserted and unasserted, can be valuable sources of information as to the meaning of a claim term. Because the claim terms are normally used consistently throughout the patent, the usage of a term in one claim can often illuminate the meaning of the same term in other claims. Differences among claims can also be a useful guide in understanding the meaning of particular claim terms.

25. I understand that the prosecution history can further inform the meaning of the claim language by demonstrating how the inventors understood the invention and whether the inventors limited the invention in the course of prosecution, making the claim scope narrower than it otherwise would be. Extrinsic evidence may also be consulted in construing the claim terms, such as my expert testimony.

26. I have been informed by counsel that, in *inter partes* review (IPR) proceedings, a claim of a patent shall be construed using the same claim

construction standard that would be used to construe the claim in a civil action filed in a U.S. district court (which I understand is called the "*Phillips*" claim construction standard), including construing the claim in accordance with the ordinary and customary meaning of such claim as understood by one of ordinary skill in the art and the prosecution history pertaining to the patent.

27. I have been instructed by counsel to apply the "*Phillips*" claim construction standard for purposes of interpreting the claims in this proceeding, to the extent they require an explicit construction. The description of the legal principles set forth above thus provides my understanding of the "*Phillips*" standard as provided to me by counsel.

28. I understand that some claims are independent, and that these claims are complete by themselves. Other claims refer to these independent claims and are "dependent" from those independent claims. The dependent claims include all of the limitations of the claims on which they depend.

C. Anticipation

29. I understand that a patent claim is anticipated if a single prior art document describes every element of the claim such that a person of ordinary skill in the art ("POSITA") could practice the claimed method without undue experimentation.

30. I understand that anticipation may be by express disclosure in the prior art. I also understand that if the prior art reference does not expressly set forth a particular claim element, the prior art may still anticipate a patent claim if that element is "inherent" in its disclosure—that is, if it is necessarily found in the reference. A property is inherent even if a POSITA would not have appreciated that property as of the date of that prior art.

D. Obviousness

31. I understand that obviousness is a determination of law based on various underlying determinations of fact. In particular, these underlying factual determinations include (1) the scope and content of the prior art; (2) the level of ordinary skill in the art at the time the claimed invention was made; (3) the differences between the claimed invention and the prior art; and (4) the extent of any proffered objective indicia of non-obviousness. I understand that the objective indicia which may be considered in such an analysis include commercial success of the patented invention (including evidence of industry recognition or awards), whether the invention fills a long-felt but unsolved need in the field, the failure of others to arrive at the invention, industry acquiescence and recognition, initial skepticism of others in the field, whether the inventors proceeded in a direction contrary to the accepted wisdom of those of ordinary skill in the art, and the taking

of licenses under the patent by others, among other factors.

32. To ascertain the scope and content of the prior art, it is necessary to first examine the field of the inventor's endeavor and the particular problem for which the invention was made. The relevant prior art includes prior art in the field of the invention, and also prior art from other fields that a person of ordinary skill in the art would look to when attempting to solve the problem.

33. I understand that a determination of obviousness cannot be based on the hindsight combination of components selectively culled from the prior art to fit the parameters of the patented invention. Instead, it is my understanding that in order to render a patent claim invalid as being obvious from a combination of references, there must be some evidence within the prior art as a whole to suggest the desirability, and thus the obviousness, of making the combination in a way that would produce the patented invention.

34. I further understand that in an obviousness analysis, neither the motivation nor the purpose of the patentee dictates. Rather, any problem known in the field can provide a reason for combining the prior art in the manner claimed.

III. LEVEL OF ORDINARY SKILL IN THE ART

35. I understand that an assessment of claims of the '798 patent should be undertaken from the perspective of a person of ordinary skill in the art as of the

earliest claimed priority date, which, as I explained above, I assumed to be August 29, 2012. I have also been advised that to determine the appropriate level of a person having ordinary skill in the art, the following factors may be considered: (1) the types of problems encountered by those working in the field and prior art solutions thereto; (2) the sophistication of the technology in question, and the rapidity with which innovations occur in the field; (3) the educational level of active workers in the field; and (4) the educational level of the inventor.

36. In my opinion, a person of ordinary skill in the art at the time of the alleged invention of the '798 patent is a person who would have had at least (1) a master's degree in mechanical engineering, materials science, or a related degree, and at least 3-5 years of experience in composite materials or additive manufacturing; or (2) a bachelor's degree in mechanical engineering, materials science, or a related degree, and at least 5-6 years of experience in composite materials or additive manufacturing.

37. My opinions regarding the level of ordinary skill in the art are based on, among other things, my experience in research and teaching additive manufacturing. Although my qualifications and experience exceed those of the hypothetical person having ordinary skill in the art, my analysis and opinions regarding the '798 patent have been based on the perspective of a person of

ordinary skill in the art as of August 29, 2012.

IV. THE ’798 PATENT

A. Overview of the ’798 Patent

38. The ’798 patent is titled “Method and apparatus for continuous composite three-dimensional printing.” (Ex. 1001, Title.) It issued from U.S. Application Ser. No. 15/267,956, which was filed on September 16, 2016. (Ex. 1001, face page.)

39. The ’798 patent is directed to “A Method and Apparatus for the Additive Manufacturing of Three-Dimensional Objects.” (*Id.*, Title.) The method of ’798 patent involves “[t]wo or more materials [] extruded simultaneously as a composite, with at least one material in liquid form and at least one material in a solid continuous strand completely encased within the liquid material.” (*Id.*) The liquid material is cured after the extrusion to produce a hardened composite. (*Id.*)

40. The ’798 patent purportedly addresses shortcomings of existing additive processes that build parts in a layer-by-layer fashion. According to the ’798 patent, existing additive processes are slow and produce parts with vulnerable joints. (*Id.*, 1:56-61.) Further, the ’798 patent states that “the materials used [in the existing additive processes] are mostly homogeneous plastic or resin, with a minority of manufacturers adding reinforcing particles. Theses [sic] materials have

much room for improvement with regard to strength and efficiency." (*Id.*, 1:61-64.)

41. The extruder housing used by the '798 patent is shown in Figure 4 below.

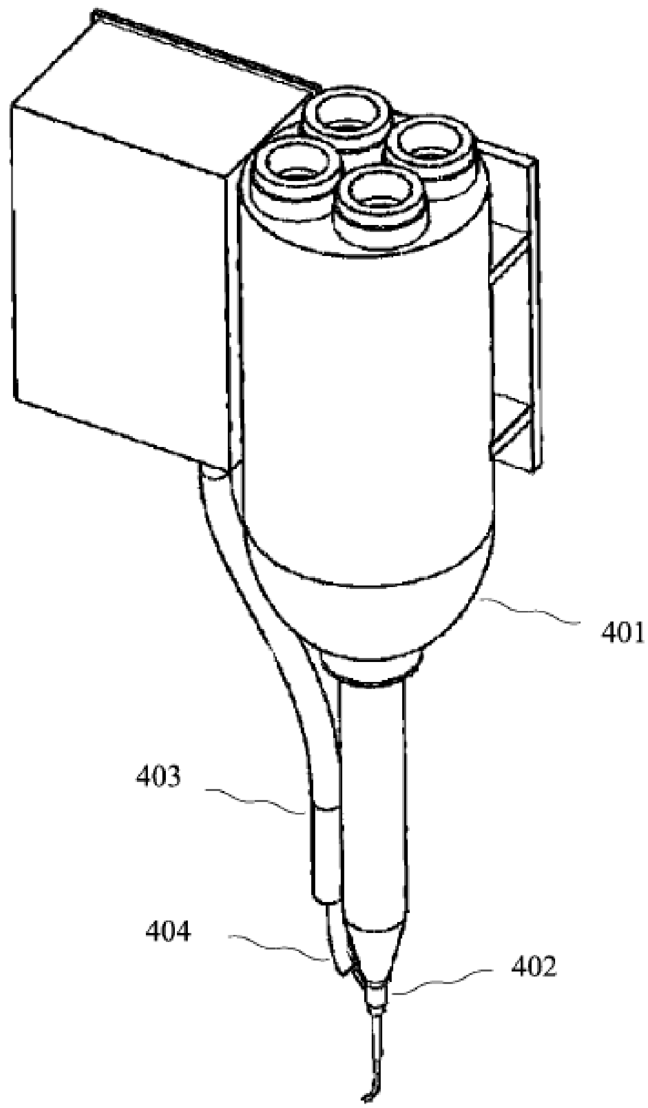


Fig. 4

(*Id.*, Figure 4.) The liquid primary material is collected in extruder 401 prior to being extruded out of the nozzle. (*Id.*, 5:18-19.) According to the '798 patent, "[t]he nozzle is the actual point of extrusion for the composite material 402." (*Id.*, 5:22-23.) The nozzle, which is not labeled in Figure 4 or in any successive Figures of the '798 patent, "is circular, with a diameter of 2 mm," or may have any shape or size based on the part to be fabricated. (*Id.*, 5:23-28.)

42. "The extruder housing also contains a feeder 403 … [that] directs the secondary material to the extruder." (*Id.*, 5:35-37.) The '798 patent explains that "[t]he feeder connects to the extruder prior to the nozzle, and feeds the secondary material into the extruder. The secondary material is extruded through the nozzle with the primary material, creating a composite material path." (*Id.*, 5:37-40.)

43. Once the composite material is extruded, it is cured preferably "immediately after the extrusion" to create a solid path. (*Id.*, 5:55-57.) The '798 patent mentions "possible means of curing," such as "light, heat, and chemical." (*Id.*, 5:59-60.) According to the '798 patent, the means for curing can be attached to the extruder housing, like ultraviolet light 501 shown in Figure 5 below. (*Id.*, 5:61-63.)

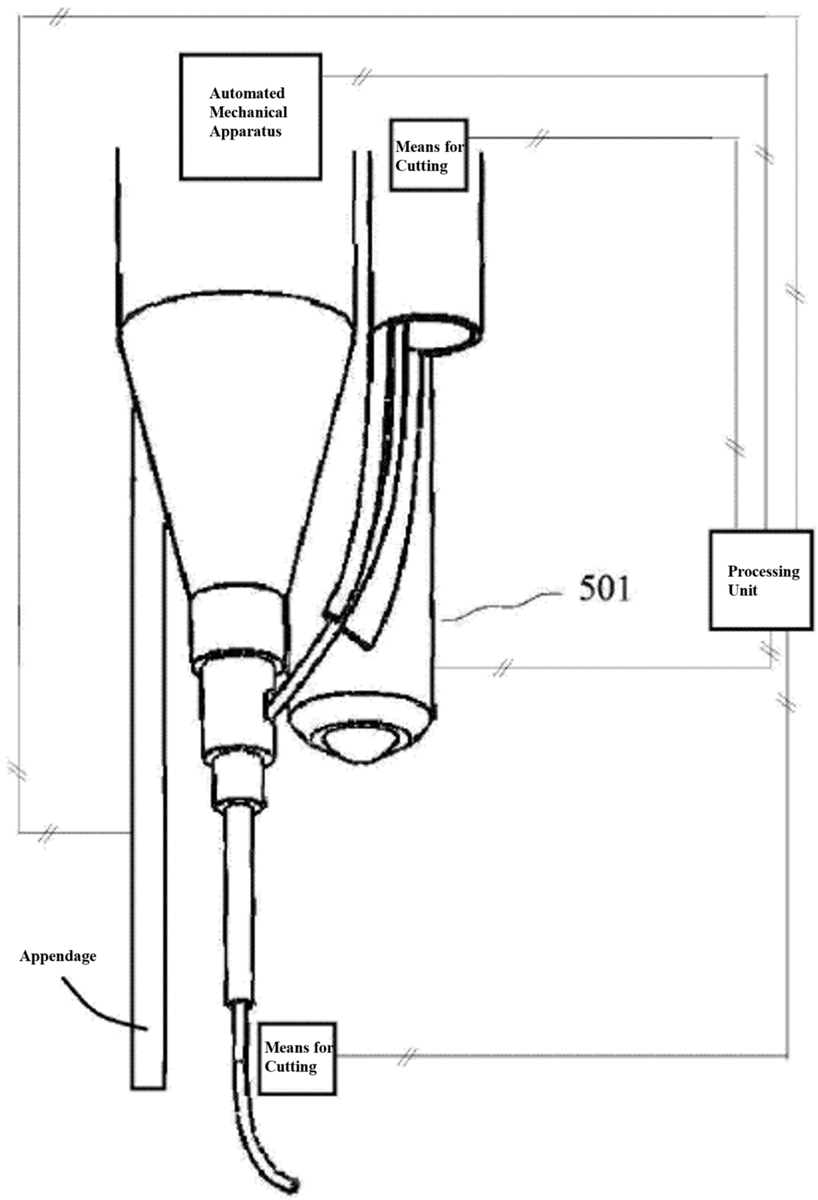


Fig. 5

(*Id*., Figure 5.)

44. "When a composite material path is complete, the path is cut at the point of extrusion. … Possible means include mechanical blades or lasers." (*Id*.,

6:19-23.) Preferably, "the apparatus will have two means of cutting, one for the secondary material at some point prior to the feeder flap, and one just after the nozzle." (*Id*., 6:24-26.)

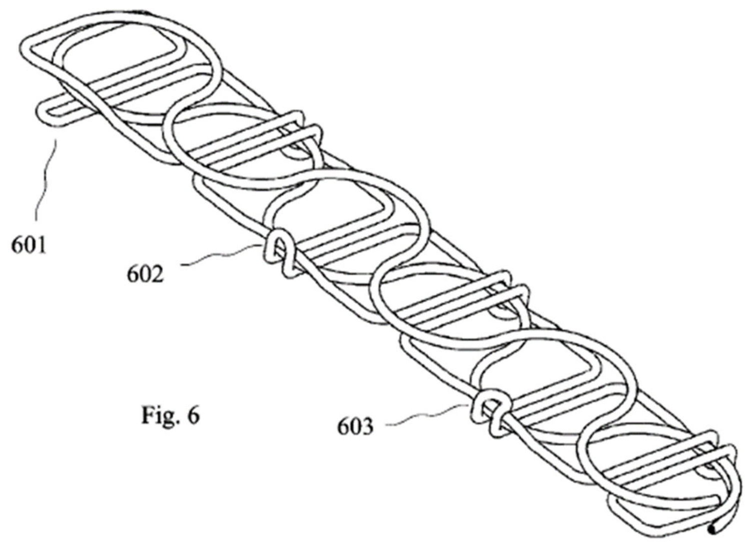
45. The apparatus of the '798 patent is allegedly able to extrude, cure, and cut, multiple paths on top of one another until the entire part is formed. (*Id*., 6:32-37.) The '798 patent explains:

> Once the origin is located, the numerical control processing unit positions the nozzle so that the point of extrusion is at the origin. The primary material processing unit pumps the primary material from its reservoir through a hose, filling the extruder housing with the primary material. Simultaneously, the secondary material processing unit feeds the secondary material to the nozzle. The energy curing processing unit activates the ultraviolet light, and the composite material is extruded as the numerical control maneuvers along the first path. When the first path reaches its endpoint, the path termination processing unit cuts the path, and the numerical control positions the nozzle for the start of the next path in the sequence according to the G-code. Paths are continuously extruded and cured until the sequence and the part is complete.

(*Id*., 8:37-52.) In addition, paths may be created with or without the secondary material if desired. (*Id*., 6:38-40.)

46. According to the '798 patent, "[t]he energy curing processing unit will

cure portions of the path upon extrusion, but leave some portions of the path uncured, or partially cured[]" so that "[t]he uncured portions are physically manipulated to interact with a cured portion of the part, creating … 'locking paths.'" (*Id*., 9:10-14.) An example is provided in Figure 6 below.



(*Id*., Figure 6.)

47. Finally, the '798 patent indicates that "[c]ertain embodiments create composite paths with tension, which will naturally pull the secondary material out through the nozzle. Other embodiments create paths without tension, and require a motor to control the feed rate." (*Id*., 5:46-49.) According to the '798 patent, the pulling action is made possible via the formation of a tension path between an anchor point and the extruder that allows the second material to be pulled out from the extruder when the extruder moves in relation to the anchor point. In reference

to anchor points the '798 patent states:

> Prior to manufacturing a part, the manufacturer designates an origin. The origin may be any point on any surface suitable for anchoring the part during manufacturing. This point of contact is called an anchor. Some parts may require multiple anchor points to support a part during manufacturing.

(*Id*., 8:31-36.) And in reference to the tension path, the '798 patent recites:

> FIG. 9 shows a tension path 901. The composite path is first extruded onto an anchor 903. Any surface or point may provide an anchor point. In FIG. 9, the anchor is a vertical plane. The origin of the path adheres to the anchor, allowing the extruder to pull on the secondary material during the extrusion.

(*Id*., 9:65-10:3.)

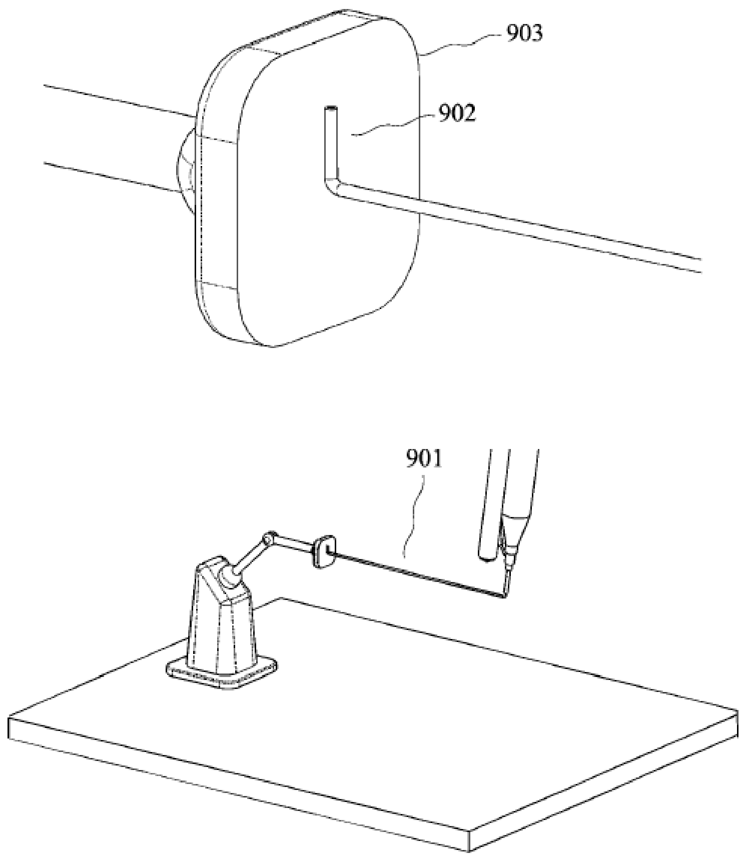


Fig. 9

(*Id.*, Figure 9.)

B. Prosecution History

48. The ’798 patent issued from U.S. Application Ser. No. 15/267,956, which was filed on September 16, 2016. (Ex. 1001, face page.)

49. The Examiner issued a Non-Final Rejection on December 12, 2017 in which claims 1-5, 7-9, 11-12, and 15-20 were rejected as being anticipated by Jang (U.S. Pub. Pat. Appl. No. 2003/0236588), and claims 1, 6-7, 10-14, and 18 were rejected under pre-AIA 35 U.S.C. § 102(b) as being anticipated by Crump (U.S.

Pat. Appl. No. 5,340,433.) (Ex. 1003 pp. 2 and 3.)

50. In a response filed on December 20, 2017, Applicant amended claim 13 to recite "exposing the curable liquid material … to a cured energy" as opposed to "curing the curable liquid material," and claim 19 to recite "mechanically interlocking" portions as opposed to "overlapping" portions. (Ex. 1004, pp. 4 and 5.)

51. With respect to Jang, Applicant argued that: (i) Jang fails to disclose "the 'pulling' feature of independent claim 1" (*id*., p. 9); (ii) with respect to independent claim 15, Jang "fails to disclose any use of a filler" (*id*., p. 10); (iii) with respect to independent claim 16, Jang "does not teach 'aiming a curing device at the path of composite material' or 'moving the curing device together with the nozzle'" (*id*); (iv) with respect to independent claim 17, Jang "does not teach cutting a continuous strand material before the continuous strand material reaches a nozzle" (*id*., p. 12; emphasis in the original); (v) with respect to independent claim 18, Jang "fails to disclose any trajectory being adjusted after discharge or any curing after trajectory adjusting" (*id*; emphasis in the original); and (vi) with respect to independent claim 19, Jang "fails to disclose any mechanical interlocking of an uncured path of composite material with a cured path" (*id.,* p. 13).

52. With respect to Crump, Applicant argued that: (i) with respect to independent claim 1, "Crump does not teach 'moving [a] nozzle away from the anchor during discharging to pull the path of composite material out of the nozzle'" or a composite material (*id*; emphasis in the original); (ii) with respect to independent claim 13, Crump "does not teach or suggest exposing anything to a cure energy to cause it to harden" (*id*., p. 15); and (iii) with respect to independent claim 18, Crump "fails to disclose any trajectory being adjusted after discharge or any curing after trajectory adjusting" (*id*., p. 16; emphasis in the original).

53. On March 12, 2018, the Examiner issued a Final Rejection in which claims 15-16 were rejected under pre-AIA 35 U.S.C. § 102(b) as being anticipated by Jang, and claims 1-14 and 17 were allowed. (Ex. 1005, pp. 2 and 3.)

54. In a response filed on March 16, 2018, Applicant amended independent claim 16 to recite "aiming a curing device at the path of composite material at a location outside of the nozzle to cure the curable liquid material," and substantially amended independent claim 19 to introduce a first cured portion and second uncured portion of the first path and mechanically interlocking the second uncured portion of the first path with the cured second path. (Ex. 1020, pp. 4-6.)

55. With respect to Jang, Applicant argued that, contrary to the Examiner's reasoning, Jang's description makes no "mention of a filler material

being discharged together with a continuous strand material and a curable liquid material, as required by independent claim 15." (*Id.*, p. 8.) Additionally, Applicant argued that Jang's heating elements (the alleged curing device) "are not aimed at a path of composite material at a location outside of a nozzle" as recited in independent claim 16. (*Id.*)

56. With respect to Crump, Applicant argued the "[b]ecause the strand (180) of CRUMP solidifies in space as it is dispensed, no opportunity exists for the post-discharge adjustment recited in independent claim 18." (*Id.*, p. 9.) With respect to independent claim 19, Applicant argued that Crump "does not disclose leaving a portion of a discharged path at least partially uncured, subsequently mechanically interlocking the portion with another already cured path, and thereafter curing the portion, as required by independent claim 19."

57. A notice of allowance mailed on April 27, 2018 included an Examiner's amendment in which: (i) independent claim 15 was amended to recite "flakes of fiber," (ii) independent claim 16 was amended to recite "aiming a curing device at the path of discharged composite material," and (iii) independent claim 18 was amended to recite "discharging," "adjusting," and "curing" the "path of uncured composite material." (Ex. 1012, pp. 2-3.)

C. The Challenged Claims

58. This Declaration addresses claims 1-20 of the ’798 patent. Claims 1, 13-19 are the independent claims.

59. Independent Claim 1 recites:

1[pre]	A method of manufacturing of a three-dimensional object, comprising:
1[a]	directing a curable liquid material to a nozzle;
1[b]	directing a continuous strand material to the nozzle;
1[c]	discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;
1[d]	bonding an end point of the path of composite material to an anchor; and
1[e]	moving the nozzle away from the anchor during discharging to pull the path of composite material out of the nozzle.

60. Independent Claim 13 recites:

13[pre]	A method of manufacturing of a three-dimensional object, comprising:
13[a]	directing a curable liquid material to a nozzle;

13[b]	directing a continuous strand material to the nozzle;
13[c]	discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;
13[d]	bonding an end point of the path of composite material to an anchor;
13[e]	moving the nozzle during discharging to cause the path of composite material to extend away from the anchor; and
13[f]	exposing the curable liquid material in the path of composite material to a cure energy while the nozzle is moving such that the path of composite material is hardened at a fixed location in three-dimensional space without support at locations between the anchor and the nozzle.

61. Independent Claim 14 recites:

14[pre]	A method of manufacturing of a three-dimensional object, comprising:
14[a]	directing a curable liquid material to a nozzle;
14[b]	directing a continuous strand material to the nozzle;

14[c]	discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;
14[d]	curing the curable liquid material in the path of composite material; and
14[e]	moving the nozzle during discharging to create tension in the continuous strand material that remains after curing of the composite material.

62. Independent Claim 15 recites:

15[pre]	A method of manufacturing of a three-dimensional object, comprising:
15[a]	directing a curable liquid material to a nozzle;
15[b]	directing a continuous strand material to the nozzle;
15[c]	directing flakes of fiber to the nozzle;
15[d]	discharging from the nozzle a path of composite material containing the continuous strand material and the flakes of fiber at least partially coated with the curable liquid material;

15[e]	moving the nozzle during discharging to create the three-dimensional object; and
15[f]	curing the curable liquid material in the path of composite material.

63. Independent Claim 16 recites:

16[pre]	A method of manufacturing of a three-dimensional object, comprising:
16[a]	directing a curable liquid material to a nozzle;
16[b]	directing a continuous strand material to the nozzle;
16[c]	discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;
16[d]	aiming a curing device at the path of discharged composite material to cure the curable liquid material;
16[e]	moving the nozzle during discharging to create the three-dimensional object; and
16[f]	moving the curing device together with the nozzle.

64. Independent Claim 17 recites:

17[pre]	A method of manufacturing of a three-dimensional object, comprising:
17[a]	directing a curable liquid material to a nozzle;
17[b]	directing a continuous strand material to the nozzle;
17[c]	discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;
17[d]	curing the curable liquid material in the path of composite material;
17[e]	moving the nozzle during discharging to create the three-dimensional object; and
17[f]	selectively cutting the continuous strand material before the continuous strand material reaches the nozzle such that at least one portion of the path discharging from the nozzle contains only the curable liquid material.

65. Independent Claim 18 recites:

18[pre]	A method of manufacturing of a three-dimensional object, comprising:
18[a]	directing a curable liquid material to a nozzle;

18[b]	directing a continuous strand material to the nozzle;
18[c]	discharging from the nozzle a path of uncured composite material containing the continuous strand material at least partially coated with the curable liquid material;
18[d]	adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle; and
18[e]	curing the curable liquid material in the path of uncured composite material at the new location after adjusting.

66. Independent Claim 19 recites:

19[pre]	A method of manufacturing of a three-dimensional object, comprising:
19[a]	discharging from a nozzle a first path of composite material;
19[b]	curing a first portion of the first path of composite material, leaving a second portion of the first path of composite material at least partially uncured;
19[c]	discharging a second path of composite material adjacent the first path of composite material,

19[d]	wherein the composite material of each of the first and second paths contain a continuous strand material at least partially coated with a curable liquid material;
19[e]	curing the second path of composite material;
19[f]	mechanically interlocking the second portion of the first path of composite material with the cured second path of composite material; and
19[g]	curing the second portion of the first path of composite material while the second portion of the first path of composite material is mechanically interlocked with the cured second path of composite material.

67. I have added indices of the form 1[a], 1[b], 1[c], *etc.* to each of the claim elements for ease of reference, and to match the indices used in the Petition.

V. APPLICATION OF THE PRIOR ART TO ASSERTED CLAIMS

68. I have reviewed and analyzed the prior art references and materials listed in Part I.A. above. In my opinion, the claims of the ’798 patent are rendered unpatentable based on the following prior art:

Ground	References	Claim(s)
1	Ma [Ex. 1007]	1, 2, 6-11, 14, 18
2	Ma [Ex. 1007] in view of Lipsker [Ex. 1006]	3, 5, 12, 16, 17, 19
3	Ma [Ex. 1007] in view of Lipsker [Ex. 1006] and Masters [Ex. 1011]	4
4	Ma [Ex. 1007] in view of Lipsker [Ex. 1006] and Crump [Ex. 1008]	20
5	Ma [Ex. 1007] in view of Crump [Ex. 1008]	13
6	Ma [Ex. 1007] in view of Nikzad [Ex. 1009]	15
7	Lipsker [Ex. 1006]	16-19
8	Lipsker [Ex. 1006] in view of Crump [Ex. 1008]	13, 20
9	Lipsker [Ex. 1006] in view of Nikzad [Ex. 1009]	15
10	Lipsker [Ex. 1006] in view of Ma [Ex. 1007]	1-3, 5-12, 14
11	Lipsker [Ex. 1006] in view of Ma [Ex. 1007] and Masters [Ex. 1011]	4

Ground	References	Claim(s)
12	Wohrl [Ex. 1010]	1, 2, 11, 12, 16, 18
13	Wohrl [Ex. 1010] in view of Lipsker [Ex. 1006]	3, 5, 17
14	Wohrl [Ex. 1010] in view of Ma [Ex. 1007]	6-10, 14
15	Wohrl [Ex. 1010] in view of Nikzad [Ex. 1009]	15

69. I am informed by counsel that each reference listed above qualifies as prior art to the challenged claims because each reference was filed and/or published before the earliest claimed priority date of the ’798 patent. I reserve the right to respond in the future to any arguments or positions that the Patent Owner may raise, taking account of new information as it becomes available to me.

A. Brief Summary of Prior Art

1. Lipsker [Ex. 1006]

70. Lipsker, U.S. Patent No. 6,153,034, titled “Rapid Prototyping,” was filed on August 3, 1988 and issued on November 28, 2000. (Ex. 1006, face page.) I am informed that Lipsker qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because its issue date of November 28, 2000 predates the earliest priority date of the ’798 patent, August 29, 2012, by more than a year.

71. Lipsker was cited in an Information Disclosure Statement (IDS; Ex. 1014) during the original prosecution of the '798 patent. However, careful review of the prosecution history reveals that the Examiner did not rely on Lipsker for the rejections presented therein, and for this reason Lipsker should not be dismissed.

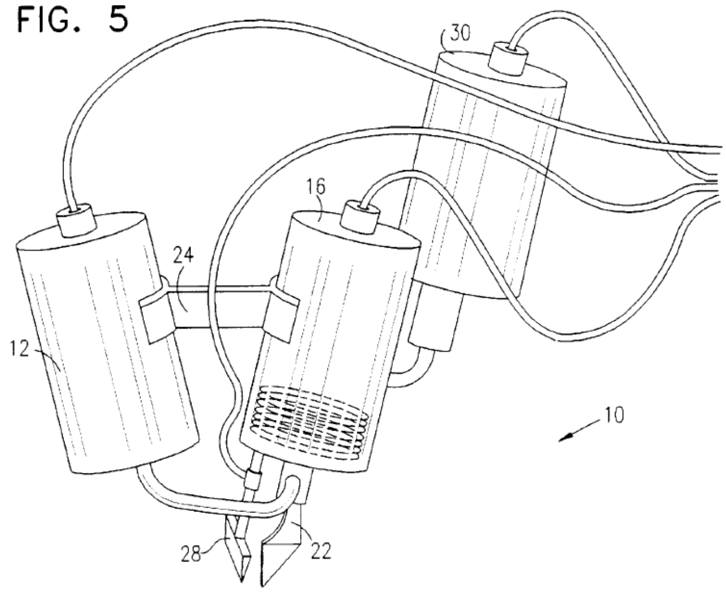
72. Lipsker is directed to "improved rapid prototype deposition modeling techniques and apparatus, wherein a building material is added layer by layer to build an accurate replica of a given object, without having to remove building material to arrive at the finished prototype." (Ex. 1006, 1:52-56.) Further, Lipsker discloses a process in which "the adhesive dispenser may be located so as to dispense the adhesive into the wire dispenser such that the wire is dispensed from the wire dispenser pre-coated with the adhesive." (*Id.*, 2:14-17.) According to Lipsker, "the term 'wire' encompasses any slender, dispensable building element, such as, but not limited to, wire, rod, bar, string, rope, thread, yarn, cord, filament, fiber, twine, strand, chain, cable, or wire twist." (*Id.*, 2:18-22.) Lipsker lists a wide range of wire materials that can be used in its embodiments. (*Id.*, 2:23-28 and 4:38-43.)

73. Lipsker further discloses a cutter, which is "provided for cutting the wire after being dispensed by the wire dispenser." (*Id.*, 2:34-36.) As Lipsker explains, "[t]he cutter is particularly useful in forming discrete or non-continuous

portions of the object." (*Id.*, 2:36-38.) Lipsker also discloses that a cutter may be integrated with a wire feeder so that the wire is cut before it reaches the nozzle. Figures 4C and 4D of Lipsker show and demonstrate how the wire feeder / cutter operates. (*See also id.*, 4:25-32.)

74. Figure 5 of Lipsker shown below illustrates a rapid prototype apparatus that precoats the wire inside the rapid prototype apparatus while the wire is being dispensed according to one of the preferred embodiments.

FIG. 5



(*Id.*, Figure 5.) Lipsker explains:

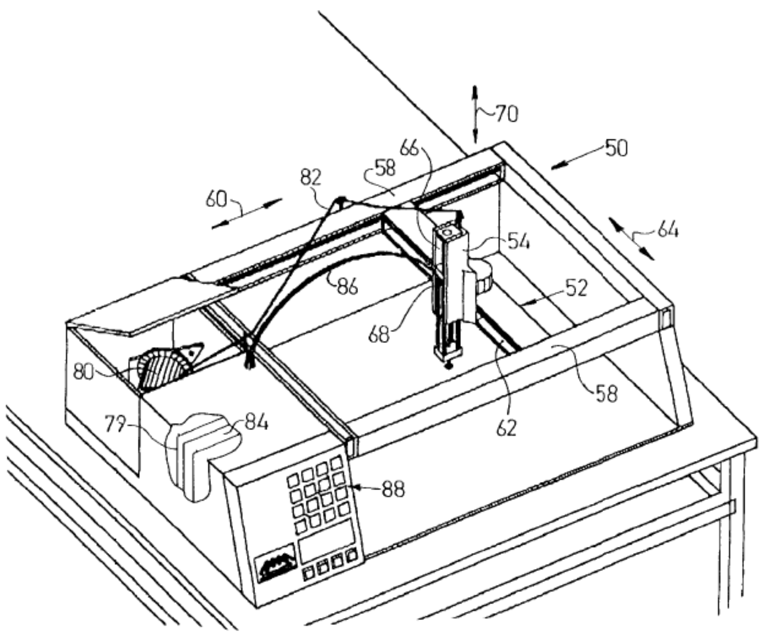
> Reference is now made to FIG. 5 which illustrates an alternative method of applying adhesive 14 to wire 18, in accordance with a preferred embodiment of the present invention. Adhesive dispenser 12 may be located so as to dispense adhesive 14 into nozzle 22 such that wire 18 is dispensed from wire dispenser 16 pre-coated with

adhesive 14.

(*Id*., 5:53-60.)

75. Lipsker further discloses that its rapid prototype apparatus is attached to an actuator 50 that includes a three-dimensional motion system controlled by a computer. (*Id*., 6:10-20.) Actuator 50 is illustrated in Figure 6 shown below.

FIG. 6

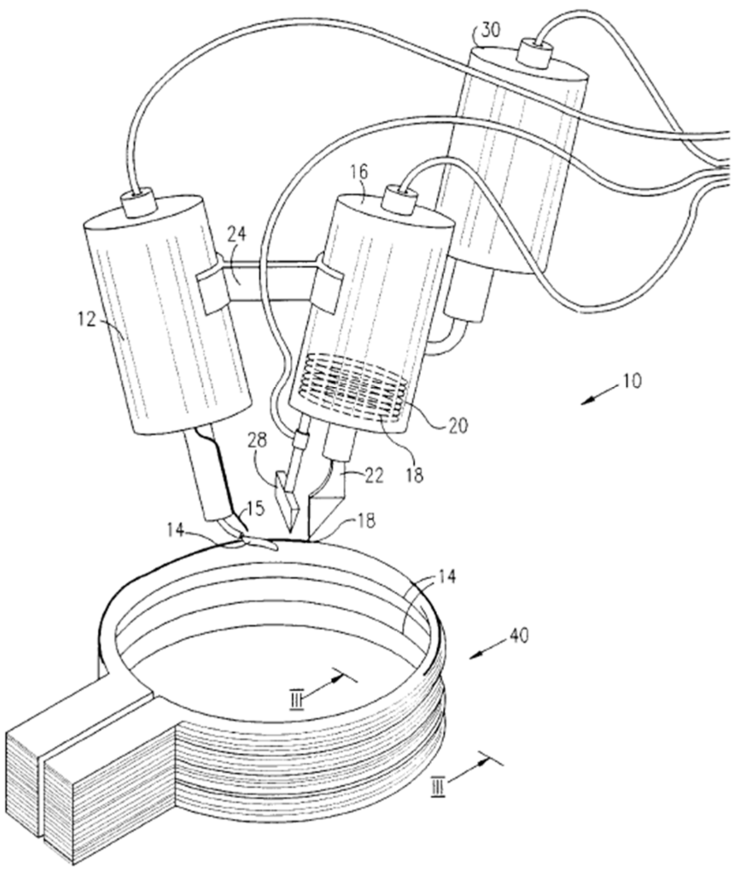


(*Id*., Figure 6.) Lipsker explains that "actuator 50 is capable of moving an adhesive dispenser and a wire dispenser in at least one of six degrees of freedom in accordance with a geometry of an object." (*Id*., 6:35-38.) Further, "[a] UV [ultraviolet] lamp 84 may be provided which transmits UV light via an optic fiber 86 to the vicinity of motion head 54 to cure the layers of adhesive." (*Id*., 6:38-40.)

76. Lipsker discloses that a prototype, like prototype 40 shown in Figure 2

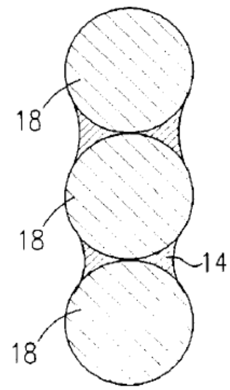
below, "may be produced by only dispensing layers of adhesive 14 in at least one of six degrees of freedom … in accordance with the geometry of object 34, and thereafter curing the layers of adhesive 14. Preferably a previously dispensed portion of adhesive 14 is bonded to a presently dispensed portion of adhesive 14. A successive layer of adhesive 14 may be dispensed one on top of a previous layer." (*Id.*, 5:62-6:3.)

FIG. 2



(*Id.*, Figure 2.) Figure 3 of Lipsker "illustrates a portion of prototype 40 formed with wire 18 and adhesive 14." (*Id.*, 5:42-44.)

FIG. 3



(*Id.*, Figure 3.) Lipsker discloses that "[a]dhesive dispenser 12 may control application of adhesive 14 to control the degree of covering of wire 18 and, to some extent, the finished appearance of the surface of prototype 40." (*Id.*, 5:45-48.)

77. Finally, Lipsker discloses that combinations of disclosed embodiments and features are possible and proper. More specifically, Lipsker discloses:

> It is appreciated that various features of the invention which are, for clarity, described in the contexts of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment may also be provided separately or in any suitable subcombination.

(*Id.*, 6:56-62.)

2. Ma [Ex. 1007]

78. Ma, is a dissertation titled "Solid Freeform Fabrication of Continuous Fiber Reinforced Composite Material," published in 2001. (Ex. 1007, introductory pp. 2 and 4.) I am informed that Ma qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because it was made available for public review no later than November 15, 2001 (Ex. 1013, ¶¶31 and 40), which predates the earliest priority date of the '798 patent, August 29, 2012, by more than one year.

79. According to Ma, Solid Freeform Fabrication (SFF) process is an emerging rapid prototyping and manufacturing technology (*see* Ex. 1007, at p. 1) described as "[a] novel computer-controlled composite layer manufacturing (CLM) process … capable of building a three-dimensional object of a complex shape from a high-strength fiber reinforced composite material." (*Id.*, p. iv.) Ma discloses that the CLM process is capable of building a continuous fiber reinforced composite part on a point-by-point and layer-by-layer basis. "This computer-automated process converts a computer-aided design file of a part directly into a 3-D physical object of a complex shape and good mechanical integrity." (*Id.*, p. 218.) According to Ma, CLM "takes advantages of the SFF technology (its flexibility in 3D forming) and the superior mechanical properties of composite materials." (*Id.*, p. 14.)

80. Ma studies two prevailing dispensing methods for its fiber reinforced composite material. Namely, the active supplying method and the passive supplying method. (*See id*., pp. 36 and 68.) According to Ma, in the active supplying method "[t]he material is affected by the pressure inside the nozzle that pushes the fluent material out of the orifice and propels the dispensed material toward the object with a certain speed." (*Id.*, p. 37.) In contrast, in the passive supplying method, "the forming material is passively moved out by the object's pulling force and not squeezed actively by its pressure." (*Id*., p. 38.) Ma provides a list of advantages and shortcomings for each method on pp. 66 and 68.

81. Concluding the study, Ma states that "[t]wo CLM forming methods," the "self-anchoring" and the "automatic-extrusion," have been designed and developed based on the selection and evaluation of various "forming theories." (*Id*., p. 219.) And further that:

> The two primary forming methods in CLM have been tested and proven very effective in forming a part layer by layer. The self-anchoring method and the required system have been developed. Composite parts have been successfully made by using this method.

(*Id.*, 220.)

82. Figure 2-5 of Ma shows an exemplary multi-components matrix composite apparatus capable of receiving and impregnating a fiber tow with a

mixture of components A and B in a mixing chamber prior to extruding the composite material via a nozzle to form a three-dimensional object.

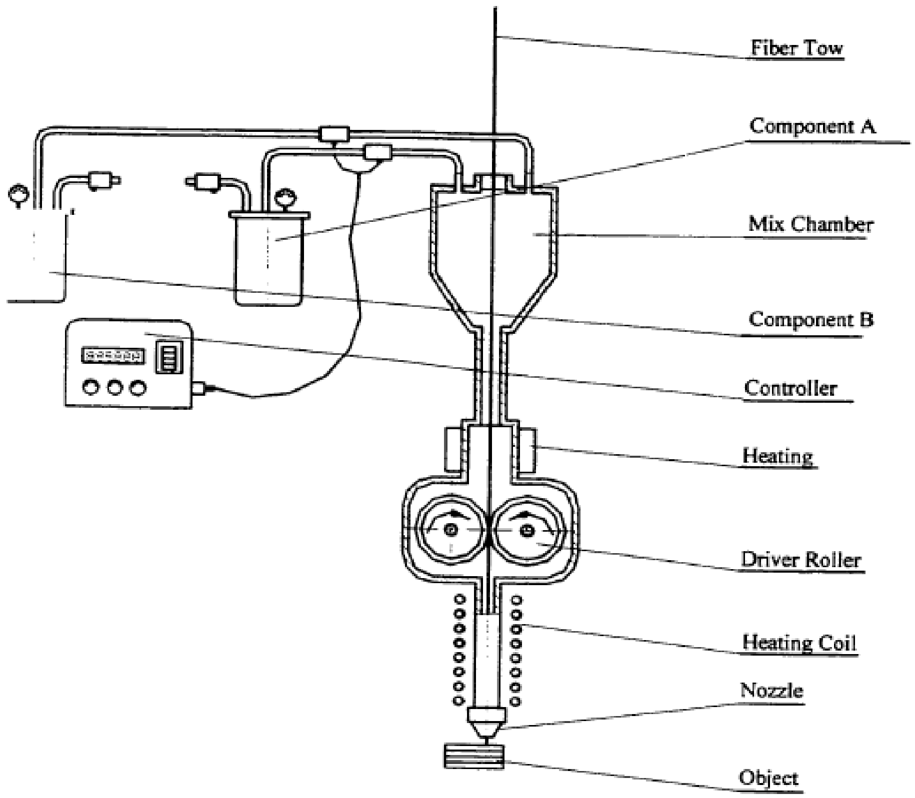


Fig. 2-5 Multi - components matrix composite.

(*Id*., Figure 2-5.) For example, Ma discloses that "the component A is a thermosetting material, and component B is a curing agent." (*Id*., p. 50)

83. "Component A and component B" are mixed together and "the mixture is used to impregnate the fiber tow to make a towpreg." (*Id*.) Then "the towpreg is pushed or pulled out of the nozzle and deposited on the top layer of an object by some means." (*Id*.) "The deposited towpreg is heated or treated in way

so as to solidify and adhere it to the previous layer" to form a three-dimensional object. (*Id*.) For example, Ma discloses that a towpreg containing a matrix material that is photocurable or includes a photo-initiator can be hardened when exposed to light. (*See id*., at pp. 26, 41, and 44).

84. The apparatus of Figure 2-5 is a one-step impregnation system (*e.g.*, impregnation of the fiber tow is achieved within the extrusion head and prior to the extrusion) and uses an active or a passive material supplying method to dispense the composite material—*e.g.*, to push or to pull the composite material out of the nozzle.

85. A two-step passive material method system is provided in Figure 2-18 at p. 69. In this system, the fiber tow impregnation process (*e.g.*, the formation of the towpreg) occurs in a previous step not shown. Once the towpreg is formed, "[t]he towpreg is driven to pass a heating pipe by a couple of driving rollers, and then is heated by the radiation of the heating pipe to a molten state." The towpreg is then pulled through "an alignment ring i.e. nozzle." (*See id.*, p. 68.)

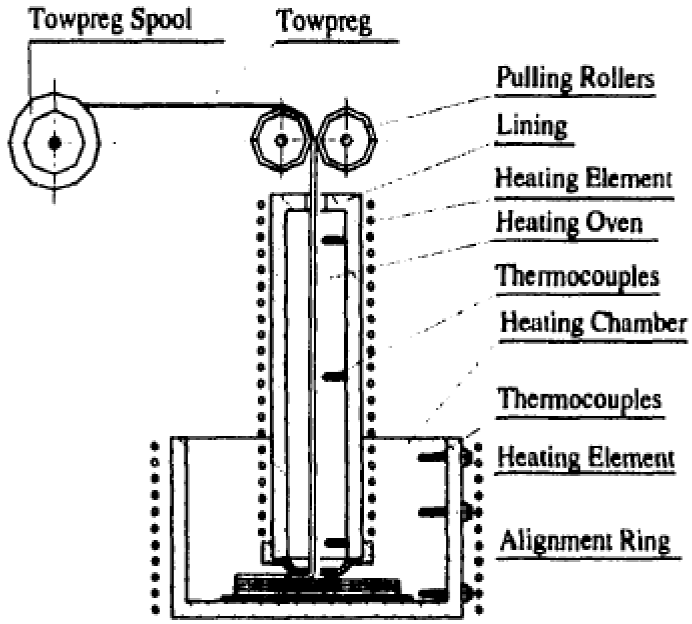


Fig. 2-18B The deposition roller is replaced by an alignment ring.

(*Id.*, Figures 2-18B.) Ma discloses the principles of the Passive material method with the help of Figure 2-19 on p. 70. Ma explains:

> During the deposition step, the nozzle is pressed on the molten towpreg to help it adhere to the previous layer. The forming mechanism is depicted in Figure 2-19. When the molten towpreg is deposited on the previous layer, under the surrounding temperature, the towpreg is solidified and glued to the previous layer immediately. The towpreg forms a series of anchor points. Because the anchor points adhered to the object, the towpreg should be pulled automatically out from the nozzle when the nozzle is continuously moved relative to the object. Then the deposition procedures are

repeated to form successive layers of an object.

(*Id.*, pp. 68 and 72.)

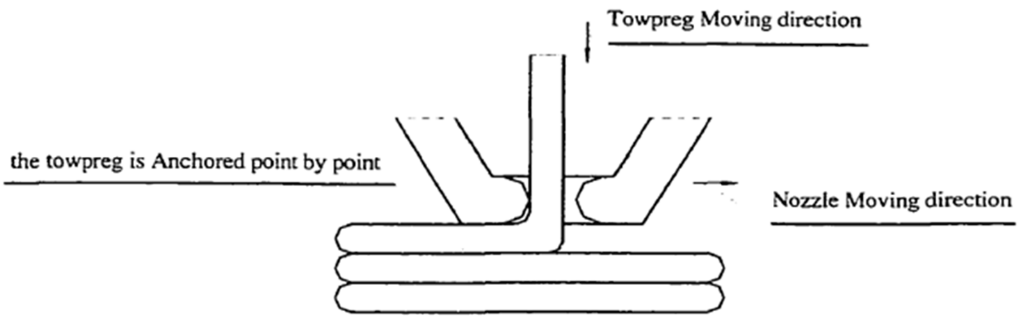


Fig. 2-19 the passive material supply mechanism.

(*Id.*, Figure 2-19.) Later, Ma discloses:

> In the self-anchoring forming method a towpreg made of a thermoplastic matrix is re-melted and deposited onto an object; the towpreg could be solidified to a certain degree and glued to a corresponding point of the base or the previous layer immediately to form a point of anchoring. Then, with the nozzle being moved forward the anchored point of towpreg serves as a stationary point to pull the towpreg out of the nozzle. Thus, more towpreg could be deposited into the object. The sequence "towpreg deposited □ solidified □ anchored □ pulled out □ deposited again" is the basic procedural steps of the self-anchoring process, which is also called Deposited and Anchored At Once forming principle.

(*Id.*, pp. 124-125.) The forming mechanism for the self-anchoring process is shown in Figures 4-1A and 4-1B.

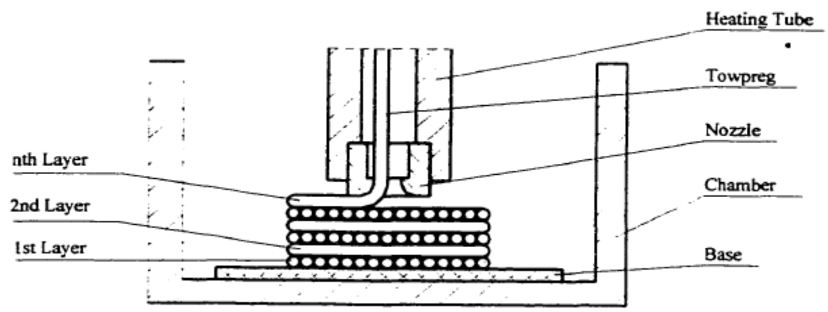


Fig. 4-1A

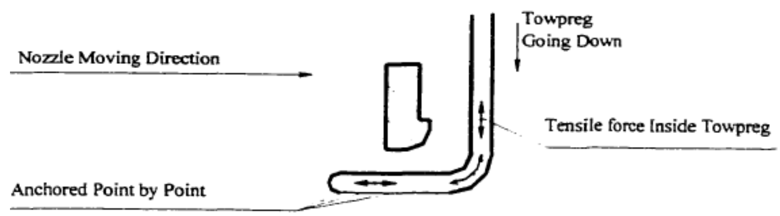


Fig. 4-1B

(*Id.*, Figures 4-1A and 4-1B.)

86. In the "Software Development Considerations" section (*id.*, p. 115), Ma discusses the importance of cutting off the towpreg. Ma discloses:

> the function of cutting is important in the CLM system, and the function of the cutting device should be a simple and reliable design. A monitoring sensor should be used to ensure that cutting is finished completely. … After an intermittent cut-off, a towpreg must be re-attached to a spot in a different region of a layer or in a different layers, and a dwell time may be required to accomplish this function.

(*Id.*, pp. 115-116.)

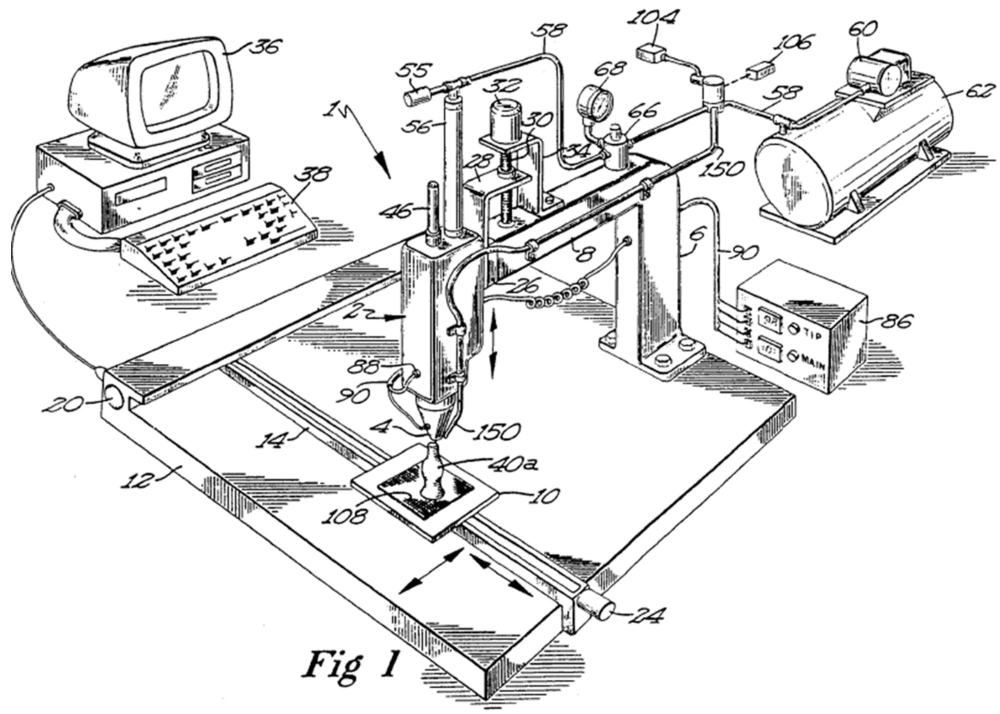
87. As part of its study, Ma tests different impregnation and deposition devices, as shown in Figures 4-15 and 4-16 on pp. 153 and 154.

3. Crump [Ex. 1008]

88. Crump, U.S. Patent No. 5,121,329, titled "Apparatus and Method for Creating Three-Dimensional Objects," was filed on October 30, 1989 and issued on June 9, 1992. (Ex. 1008, face page.) I am informed that Crump qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because its issue date of June 9, 1992 predates the earliest priority date of the '798 patent, August 29, 2012, by more than a year.

89. Crump discloses that "[t]hree-dimensional objects may be produced by depositing repeated layers of solidifying material until the shape is formed." (Ex. 1008, Abstract.) Crump further discloses that "[t]his invention relates to an apparatus and process for forming a three-dimensional object of predetermined design, and in particular to the making of a model or article by depositing multiple layers of a material in a fluid state onto a base." (*Id.*, 1:6-10.)

90. Crump also discloses that "[a] rod of solid material may also be used as the material-supply medium on the dispensing head." (*Id.*, 3:53-54.) Figure 1 of Crump illustrates an exemplary apparatus for making a three-dimensional article.



(*Id*., Figure 1.) According to Crump, the base plate 10 moves in the x and y directions while dispensing head 2 moves in the z direction. (*Id*., 10:64-66.) However, Crump indicates that independent movement of the base plate or the dispensing head in all directions is also possible. (*Id*., 10:67-11:2.)

91. In the case of Figure 1 above, "the working material is supplied in the form of a solid rod 46, heated to its melting point in dispensing head 2 and dispensed from nozzle 4 as a flowable fluid." (*Id*., 6:1-3.)

92. Figure 4 of Crump shows how "the supply material is dispensed in a fluid state from the dispensing head 2 or 112 through a dispensing outlet onto sandpaper 108 to form and build up multiple layers of material." (*Id*., 11:3-6.)

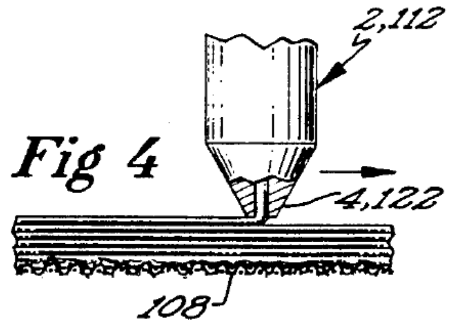


Fig 4

(*Id*., Figure 4.) Crump explains the "[m]ultiple passes of the dispensing head are made, with each pass taking place in a controlled pattern as dictated by the layering software 42 for multiple cross sections of the article being produced in accordance with design data inputted to computer 36." (*Id*., 11:6-11.)

93. Crump, among other configurations, discloses in Figure 11 a plurality of dispensing orifices 127 arranged in a circular pattern on a dispensing head 112.

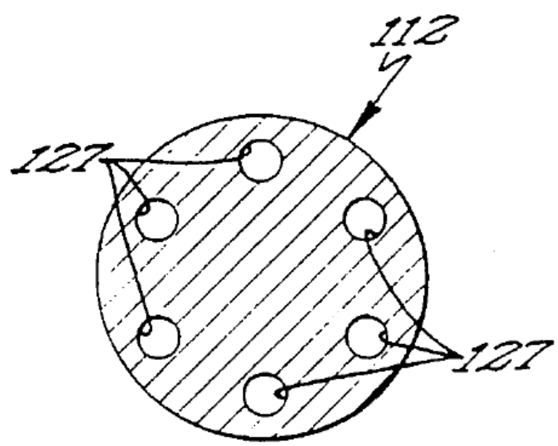


Fig 11

(*Id*., Figure 11.) According to Crump, dispensing head 112 features multiple supply passages, as shown in Figure 6, into which building materials with different composition and colors may be directed. (*Id.*, 14:37-43.)

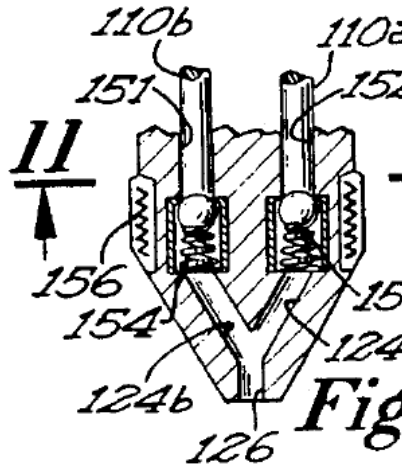


Fig 6

(*Id.*, Figure 6.) Accordingly, dispensing orifices 127 "permit discharge of material from any desired number of orifices by selective control of the separate supply materials." (*Id.*, 14:49-51.)

94. In addition, Crump discusses the formation of free-standing structures, such as wire frame segments, anchored to a substrate with the help of an ultrasonic vibrator attached to the dispensing head. (*See id.*, Figures 10 and 12.) The ultrasonic energy generated by the vibrator increases locally the pressure and keeps the dispensed material in liquid form even when the material is dispensed at a temperature slightly below its ambient solidification temperature. This allows the material to solidify immediately upon discharge. (*Id.*, 15:1-10.)

4. Nikzad [Ex. 1009]

95. Nikzad, is a dissertation titled "New metal/polymer composites for fused deposition modelling applications," published in May, 2011. (Ex. 1009, front page.) I am informed that Nikzad qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because its publication date of September 28, 2011 (Ex. 1013, ¶¶ 37 and 40) predates the earliest priority date of the '798 patent, August 29, 2012, by more than one year.

96. Nikzad discloses that "[t]he principal objective of this research is to develop new metal/polymer composite materials for direct use in the current Fused Deposition Modelling rapid prototyping platform" (Ex. 1009, Abstract.)

97. According to Nikzad "[t]he new metal/polymer composite material developed in this research work involves use of iron particles and copper particles in a polymer matrix of [Acrylonitrile Butadiene Styrene] ABS material, which offers much improved thermal, electrical and mechanical properties enabling current fused deposition modelling [FDM] technique to produce rapid functional parts and tooling." (*Id.)* Nikzad states that the FDM process is one of the rapid prototyping (RP) processes, which are recognized as additive manufacturing processes. *(See id.*, pp. 1 and 4.)

98. Nikzad discloses that short iron fiber fillers are selected due to their "reasonably good mechanical and thermal properties." (*Id.*, p. 68.) Further,

Nikzad discloses that the short iron fiber fillers are in the form of flakes with a size of about 45 µm. (*See id,* Table 3-3.)

Table 3-3: Types of fillers used in metal-polymer composite

Particulate	Purity	Size (µm)	Shape	Density (g/mL)	Melting point (^{0}C)
Carbonyl-Iron	≥99.5%	6-9	Spherical	7.86	1535
Iron	97%	~45	Flake	7.86	1535

(*Id.*, Table 3-3.) The iron fiber flakes are added to the ABS matrix to increase the modulus and strength of the resulting composite polymer-metal material, which is subsequently used in the FDM process to form three-dimensional objects. Nikzard explains:

> Orientation and reinforcement of polymeric chains can significantly increase **tensile modulus and tensile strength** by increasing the interchain forces. **Reinforcing fillers** can very well be used in accordance with the macromolecular mixtures to **increase the modulus and strength** of polymeric matrices.

(*Id.*, p. 64.)

5. Wohrl [Ex. 1010]

99. Wohrl, U.K. Patent Application GB2213793, titled “Method for Manufacturing a Three-Dimensionally Twisted Rotor Blade Airfoil,” was published on August 23, 1989, filed on November 10, 1988, and claims priority to

a German Application DE3743485 filed on December 22, 1987. I am informed that Wohrl qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because its publication date of August 23, 1989 (Ex. 1019 at ¶¶ 39-40) predates the earliest priority date of the ’798 patent, August 29, 2012, by more than one year.

100. Wohrl discloses a filament winding process, which is an additive manufacturing process like the rapid prototyping process, and “relates to a method for the manufacture of a fibre reinforced component, particularly a three-dimensionally twisted rotor blade airfoil, by wrapping a core with a resin-impregnated fibre material.” (Ex. 1010, 1:1-4.) According to Wohrl, the disclosed method “permits selective manipulation of components properties by selective routing of the fibres and more particularly so as to permit ready application of fibres also to concave surfaces.” (*Id*., 2:13-16.)

101. Wohrl discloses that its resin impregnated fibre material is made of fibre strands wetted with a resin matrix and pressed against the core by a nip roller. (*Id*., 2:21-23.) “[T]he resin matrix precured immediately thereafter, preferably by a precuring facility such as an infrared radiator coupled to the nip roller.” (*Id*., 2:23-26.) According to Wohrl “[f]ibres can be applied [] in each and every direction and on any shape of airfoil surface and so that they will then adhere and not subsequently become dislodged.” (*Id*., 2:27-3:2.) Wohrl discloses that

"[p]recuring the matrix material causes it to gel to a point where the fibre is cemented in place before the fibre matrix mixture still is fully cured. Thereafter the wrapped component is pressed to final size in a mould and cured in a furnace." (*Id.*, 3:7-9.) Wohrl claims that the disclosed process overcomes prior limitations, such as the ability to apply the fibres to concave surfaces. (*Id.*, at 1:18-23, 2:10-16, and 3:14-18.)

102. The fibre laying device (8) disclosed by Wohrl is shown in Figure 2 below.

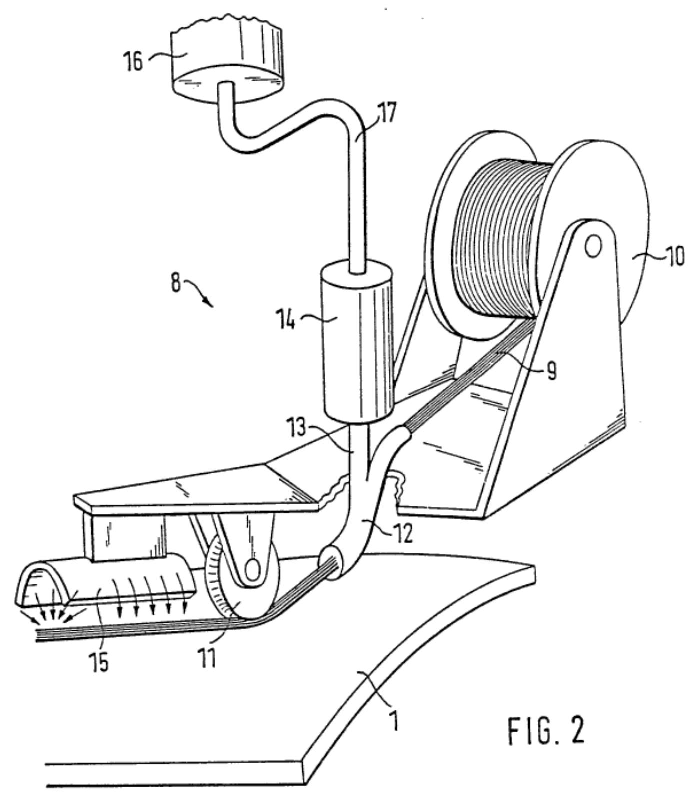


FIG. 2

(*Id.*, Figure 2.) As shown in Figure 2, the fibre laying device comprises "a fibre drum 10, a fibre feed duct 12 leading to a fibre nip roll 11, and a precuring facility

15." (*Id*., 4:20-23.) Wohrl explains:

> The matrix material is supplied from a storage container 16 to the matrix metering unit 14 through a flexible feed line 17. The volume of matrix fed per unit length of fibre can be adjusted, preferably to suit the fibre throughput. Having been wetted in this manner the fibres are accurately laid on to the component in the desired track under the fibre nip roll 11 and are precured (gelled) by means of the precuring device 15, causing the surface to dry and stick. In this manner, the fibre is fixed to a point where it can be laid on to radiused tracks. Thereafter, further fibre layers can be deposited in any desired orientation over the precured fibres.

(*Id*., 4:27-5:10.)

103. In referring to Figure 3, Wohrl indicates that fibre laying device 8 "is connected to the 'wrist' of a six-axis portal robot 7 and can thus - under computer control - deposit the fibre strand 9 on the component core fully automatically along precalculated tracks. This makes for very accurate reproducibility (<0.2 mm) of the fibre laying process." (*Id*., 5:11-17.)

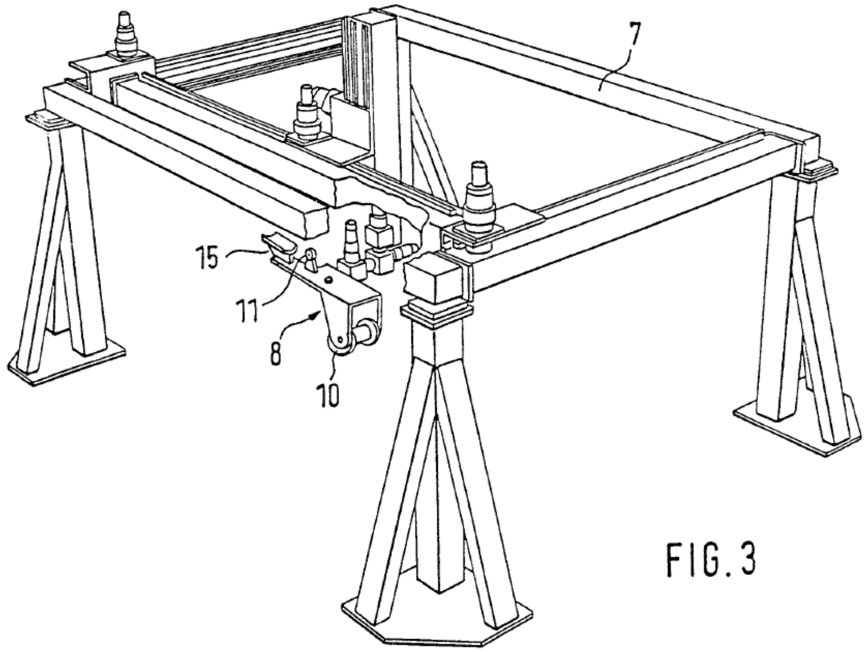


FIG. 3

(*Id.*, Figure 3.)

6. Masters [Ex. 1011]

104. Masters, U.S. Patent No. 5,134,569, titled "System and method for computer automated manufacturing using fluent material," was filed on June 26, 1989 and issued on July 28, 1992. (Ex 1011, face page.) I am informed that Masters qualifies as prior art under at least pre-AIA 35 U.S.C. § 102(b) because its issue date of July 28, 1992 predates the earliest priority date of the '798 patent, August 29, 2012, by more than a year.

105. Masters discloses a system and method for constructing a three-dimensional object. (Ex. 1011, Abstract.) More specifically, Masters discloses that "a polymeric material is extruded in a fluent state and is subjected to a

radiation beam for transition into the solid three-dimensional object." (*Id*., 2:53-56.) According to Masters, the polymeric building material is solidified after being exposed to an energy beam of UV light. (*Id*., at Abstract and 4:45-47.)

106. The system disclosed by Masters is shown in Figure 2. A more detailed representation is shown in Figures 3 and 4, which are reproduced below.

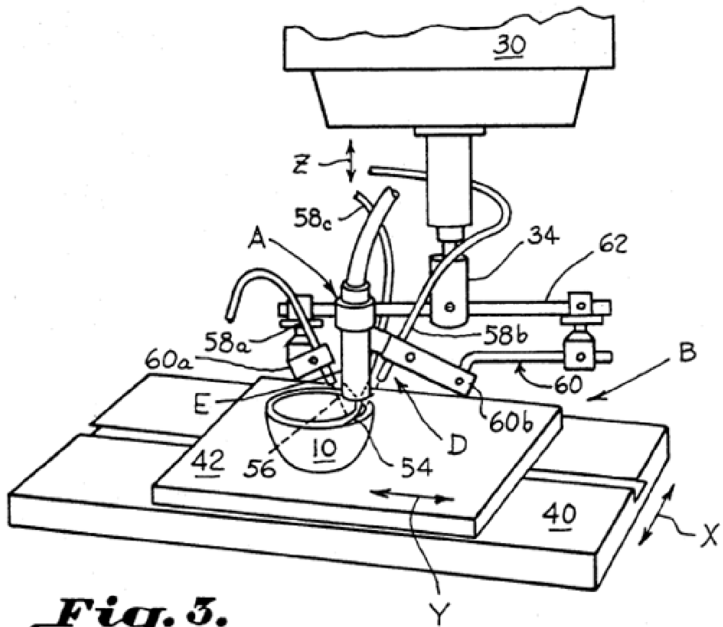


Fig. 3.

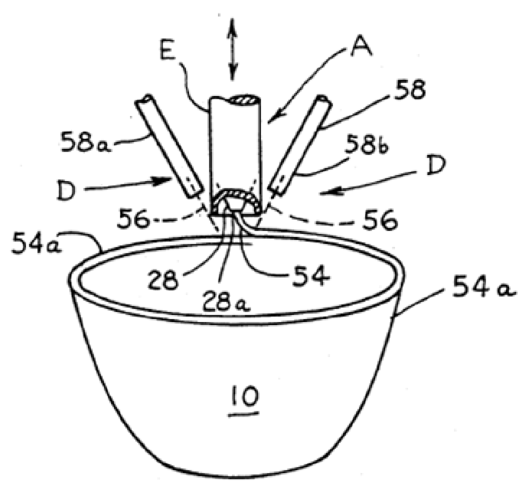


Fig. 4.

(*Id.*, Figures 3 and 4.) Masters discloses that a plurality of light beams is emitted from respective light tubes, which are radially arranged around the dispensing means. Masters explains:

As can best be seen in FIGS. 3 and 4, material treatment means D

> includes a plurality of ultraviolet light beams 56 emitted from a plurality of light tubes 58 which, preferably, are equally angularly spaced around dispensing means A.

(*Id.*, 4:53-57.)

107. Masters discloses several examples of its UV light arrangement. For example, Masters discloses:

> ultraviolet light tubes approximately 10 degrees from the vertical, 480 degrees apart at the XY plane at 40 degrees from the Z-axis.

(*Id.*, 6:14-16.)

> ultraviolet light tubes approximately 180 degrees apart from the XY axis and 10 degrees from the vertical axis.

(*Id.*, 6:28-30.)

> ultraviolet light tubes 58a, 58b, 58c with 58c 10 degrees from vertical, 58b 15 degrees from vertical, and 58a 5 degrees from vertical; lights 58b and 58a in the XY plane approximately 120 degrees apart.

(*Id.*, 6:45-49.)

B. Ground 1: Ma Renders Obvious Claims 1, 2, 6-11, 14, and 18

1. Independent Claim 1

108. It is my opinion that Ma discloses each and every limitation of Claim 1.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 1[pre])

109. To the extent the preamble is limiting, it is disclosed by Ma. Ma discloses "[a] novel computer-controlled composite layer manufacturing (CLM) process" (Ex. 1007, p. iv), and further that "[t]his computer-automated process converts a computer-aided design file of a part directly **into a 3-D physical object of a complex shape** and good mechanical integrity" (*id*., p. 218; emphasis added[1].) Therefore, a POSITA would have understood that Ma's disclosed method is "[a] method of manufacturing of a three-dimensional object" as recited in the preamble of Claim 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 1[a])

110. In the "Research Objectives" section, Ma discloses that "[t]he proposed process included impregnating a fiber tow with **a matrix material in a liquid state (e.g., melt)** and laying up the impregnated tow (towpreg) point-by-point and layer-by-layer according to a computer-aided design file." (Ex. 1007, p. 29.)

111. According to Ma, the matrix material is **a curable substance** whose "phase change speed must be sufficiently high, no matter what kind of energy is applied[.]" (*Id*., p. 41.) Ma further discloses that "a curing agent and other

[1] In the citations below, emphasis is added unless indicated otherwise.

ingredients are added into the matrix material with a catalyst and/or photo-initiator **to cure and solidify the material resin**. Such a chemical method is applied to increase phase change speed as illustrated in Figure 2-5." (*Id.*, 44.)

112. Figure 2-5 of Ma shows an exemplary multi-components matrix composite apparatus **that receives and impregnates a fiber tow with a mixture of components A and B** (collectively "curable liquid material") in a mixing chamber **prior to extruding the impregnated towpreg through a nozzle** to form a three-dimensional object.

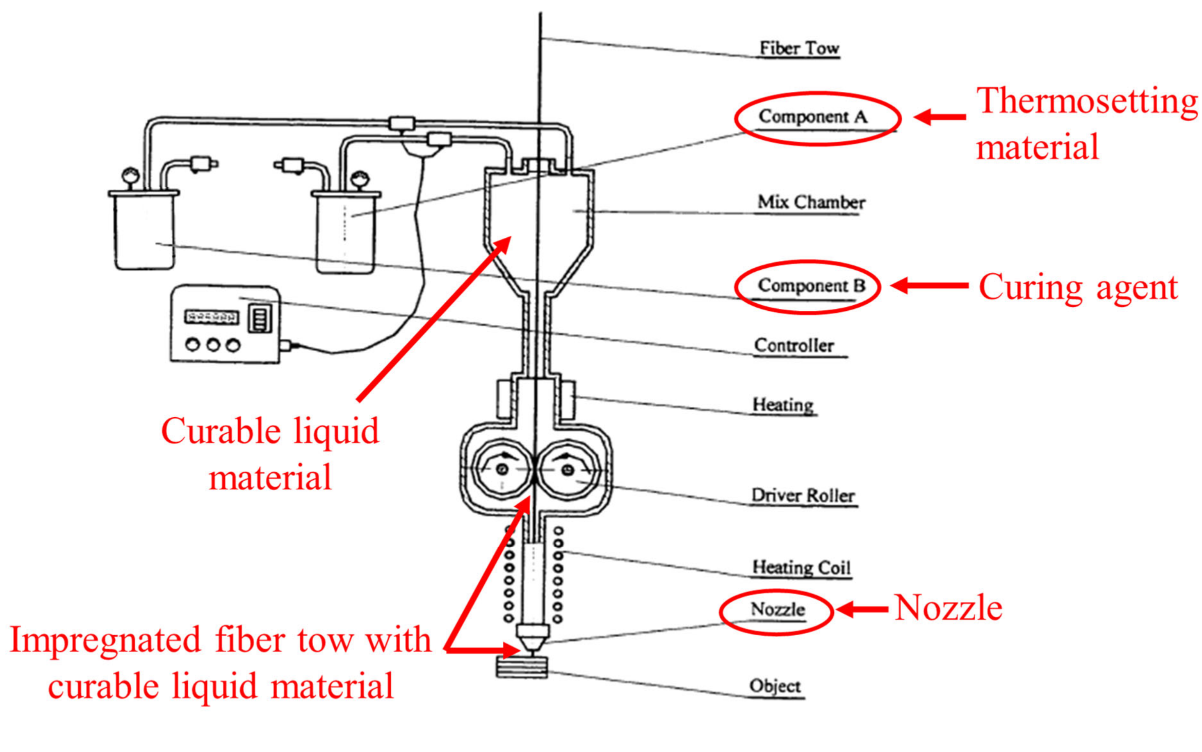


Fig. 2-5 Multi - components matrix composite.

(*Id.*, Figure 2-5; annotated.) Ma explains:

> As shown in the Figure 2-5, the component A is a thermosetting material, and component B is a curing agent. First component A and component B are mixed together and the mixture is used to impregnate the fiber tow to make a towpreg. Then the towpreg is pushed or pulled out of the nozzle and deposited on the top layer of an object by some means. On the current forming layer, the deposited towpreg is heated or treated in way so as to solidify and adhere it to the previous layer.

(*Id*., p. 50.) Thus, in the apparatus shown in Figure 2-5, the mixture of components A and B ("curable liquid material") is carried by/with the impregnated towpreg to the nozzle.

113. Accordingly, Ma discloses "directing a curable liquid material to a nozzle" as recited in Claim Element 1[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 1[b])

114. As shown in Figure 2-5 above, the fiber tow ("a continuous strand material") is directed to the nozzle after being impregnated with the mixture of components A and B ("curable liquid material"). Accordingly, Ma discloses Claim Element 1[b].

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 1[c])

115. As discussed in Claim Elements 1[a] and 1[b], the fiber tow ("the continuous strand") is impregnated ("at least partially coated") with the mixture of components A and B ("the curable liquid material") to form a towpreg ("composite material") that is subsequently discharged from the nozzle of the apparatus shown in Figure 2-5 to form "a path of composite material." Accordingly, Ma discloses Claim Element 1[c].

e. "bonding an end point of the path of composite material to an anchor; and" (Claim Element 1[d])

116. Ma discloses that the impregnated towpreg ("the composite material") is laid **point by point** and layer by layer. (Ex. 1007, p. 29.) Ma further discloses that "[w]hen the molten towpreg is deposited on the previous layer, under the surrounding temperature, the towpreg **is solidified and glued to the previous layer immediately**." (*Id.*, p. 72.) As a result "[t]he towpreg forms a series of **anchor points**." (*Id.*) For example, "the towpreg could be solidified to a certain degree **and glued to a corresponding point** of the base or the previous layer immediately **to form a point of anchoring**." (*Id.*, p. 124.) Ma **explicitly demonstrates** bonding the towpreg ("the path of composite material") on multiple locations (anchors) when discussing Figure 2-4.

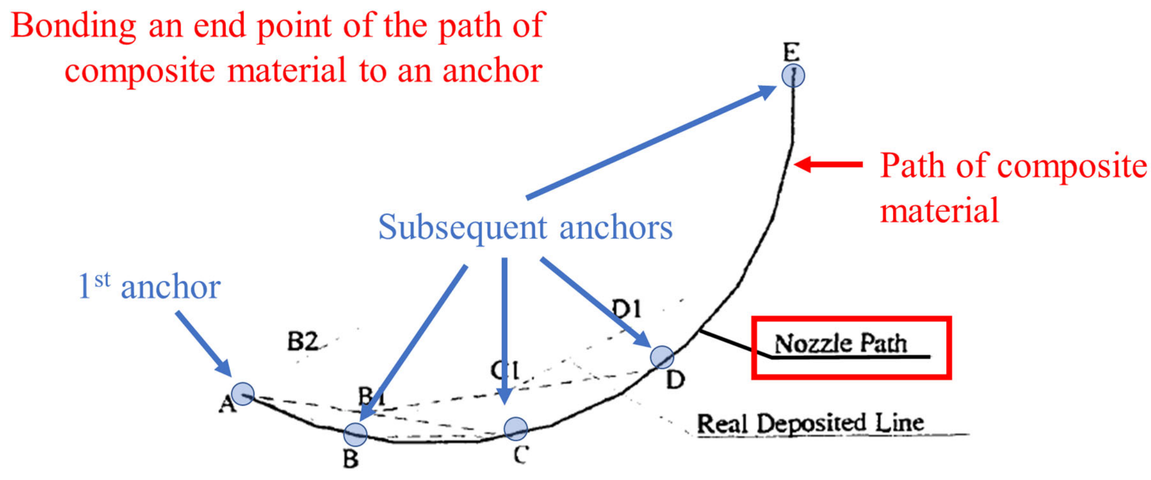


Fig. 4-2 An error is generated by the mechanism of the forming process.

(*Id.,* Figure 4-2; annotated.) Ma discloses:

> An arc toolpath is shown in Figure 4-2, and the nozzle is programmed to move along the arc toolpath from point A to points B, C, and D. Ideally, the towpreg is firmly anchored at point A. When the nozzle arrives at point B, the towpreg is supposed to be deposited and anchored at once to form a new anchoring point at B. Then the nozzle is moved to point C and so on to deposit the towpreg be following the path indicated with the broken line ABCDE

(*Id*., p. 127.) A POSITA would have understood from the above that points A through E are anchor point locations, and further, that point B is where **an end point** of the towpreg ("the path of composite material") is anchored after the "first" anchor location A. Subsequently, point C is where **a new end point** of the towpreg is anchored after the "second" anchor point location B, and so on. In other words, **a new end point of the towpreg is anchored to a new anchor point location as the nozzle advances forward**.

117. Accordingly, Ma discloses Claim Element 1[d].

f. "moving the nozzle away from the anchor during discharging to pull the path of composite material out of the nozzle." (Claim Element 1[e])

118. In discussing the passive material supplying method, Ma discloses that "when the **object moves relative to the nozzle during the forming process**, the towpreg is **pulled out by the object** instead of being pushed out by nozzle pressure. In the nozzle, the forming material is **passively** moved out by the object's **pulling force** and not squeezed out actively by its pressure." (Ex. 1007, p. 38.) Ma further discloses that the anchor points are used **to pull the towpreg** ("the path of composite material") **out of the nozzle during discharging**:

> When the molten towpreg is deposited on the previous layer, under the surrounding temperature, the towpreg is solidified and glued to the previous layer immediately. **The towpreg forms a series of anchor points. Because the anchor points adhered to the object, the towpreg should be pulled automatically out from the nozzle when the nozzle is continuously moved relative to the object.**

(*Id*., p. 72.) Also, Ma discloses:

> [W]ith the nozzle being moved forward **the anchored point of towpreg servers as a stationary point to pull the towpreg out of**

> **the nozzle**. … The sequence "towpreg deposited □ solidified □ **anchored** □ **pulled out** □ deposited again" is the basic procedural steps of the self-anchoring process, which is also called Deposited and Anchored At Once forming principle.

(*Id.*, pp. 124-125.) Based on the above disclosure and Figure 4-2 discussed in Element 1[d], a POSITA would have understood that moving the nozzle away from anchor point location B towards anchor point location C ("moving the nozzle away from the anchor during discharging") pulls the towpreg out of the nozzle ("pull the path of composite material out of the nozzle"). Further, a POSITA would have understood that this specific example is generalizable to any successive anchor point locations.

119. Accordingly, Ma discloses Claim Element 1[e].

2. Claim 2

120. Claim 2 depends from Claim 1, which Ma discloses. It is my opinion that Ma also discloses each and every limitation of Claim 2.

a. "wherein bonding the end point of the path of composite material to the anchor includes: placing the end point of the path of composite material on the anchor; and" (Claim Element 2[a])

121. A POSITA would have understood that "placing the end point of the path of composite material on the anchor" corresponds to placing the path of composite material to a selected point location ("the anchor") on which the path

will be attached. This is consistent with the description in the '798 patent[2] As discussed above in Claim Element 1[d], Ma explicitly discloses attaching (anchoring) the impregnated towpreg ("path of composite material") to a selected point location ("the anchor"). Accordingly, Ma discloses Claim Element 2[a].

b. "aiming a curing device at the path of composite material on the anchor." (Claim Element 2[b])

122. As discussed above in Claim Element 1[d], Ma discloses that "the towpreg **could be solidified to a certain degree and glued** to a corresponding point of the base or the previous layer immediately to form a point of anchoring." (Ex. 1007, p. 124.) In other words, the impregnated towpreg ("the path of composite material") is attached to the corresponding point location ("on the anchor") when it solidifies.

123. Ma further discloses that the deposited towpreg solidifies when it is exposed to **heat or energy by other means**:

> When needed to do a forming process, a towpreg is heated or is exposed to energy by other means during the depositing movement and is quickly solidified and allowed to adhere to the previous layer.

[2] "The origin may be any point on any surface suitable for anchoring the part during manufacturing. This point of contact is called an anchor." (Ex 1001 at 8:32-34.)

(*Id.*, p. 42.) Exposure to energy **by other means** includes, for example, light when photosensitive matrix materials are used. Ma explains:

> In the earliest developed [stereolithography] SL system a laser system and photosensitive epoxy were applied. The laser beam spot can be focused to become very small, and the energy can be **concentrated upon a small area to solidify the thermosetting material in a twinkling**.

(*Id.*) A POSITA would have ascertained that a device that emits heat or light for the purpose of solidifying the matrix material by initiating polymerization reactions in the matrix material is "a curing device," and that the "curing device" **is aimed** at the towpreg ("the path of composite material") **over a location on which the towpreg will be attached** ("on the anchor").

124. Indeed, Figure 2-7B shows a source of heated air ("curing device"; highlighted red) aimed directly at the towpreg ("path of composite material"; highlighted yellow). The heated air solidifies the towpreg ("path of composite material") at any desired location, such as an anchor location ("on the anchor"), to form an anchor point.

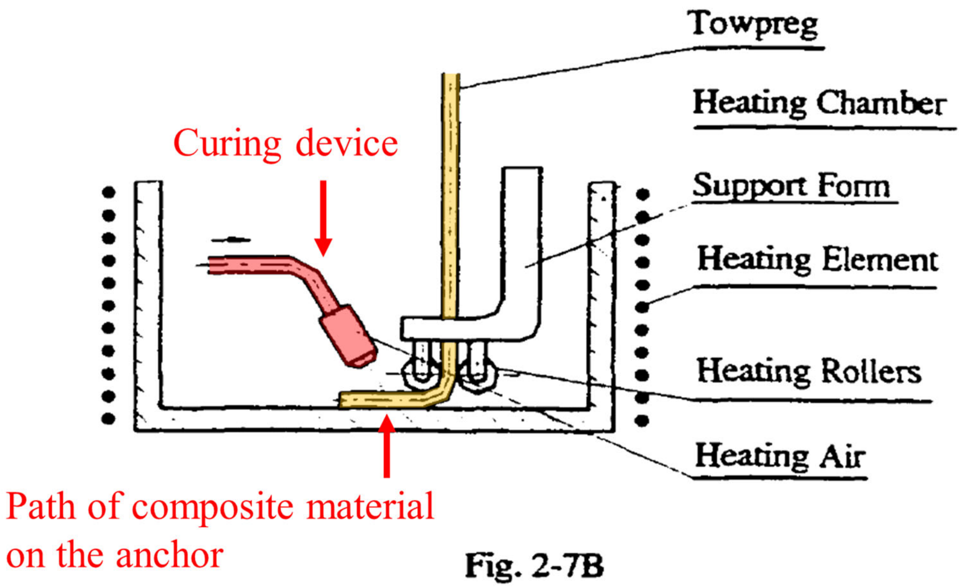


Fig. 2-7B

Step 2: the towpreg is deposited.

(*Id*., Figure 2-7B; annotated.)

125. Accordingly, Ma discloses Claim Element 2[b].

3. Claim 6: "wherein discharging from the nozzle the path of composite material includes discharging the path of composite material through a nozzle orifice having a diameter of about 2 mm."

126. Claim 6 depends from Claim 1, which Ma discloses. It is my opinion that Ma discloses or renders obvious Claim 6. Ma recognizes that "in the case of Passive Material Supply, the diameter of the nozzle bore **should be larger** than the diameter of towpreg. Otherwise, a frictional force between the orifice and the towpreg will be large and the force that is needed to pull the towpreg out of the nozzle will correspondingly be larger." (Ex. 1007, 79-80.) Ma goes in great

lengths to characterize the errors in the path's trajectory (*e.g.*, manifested by the deviation of the path's actual trajectory compared to its theorical desirable trajectory) as a function of the difference between the diameter of the nozzle's bore *R* and the diameter *r* of the towpreg (*e.g.*, *R-r*). (*See*, *e.g.*, *id.*, pp. 80-107.) Ma concludes that errors are primarily driven by the difference, *R-r*,—*e.g.*, when *R-r* is larger, the error is bigger. (*Id.*, pp. 91 and 106.) Therefore, a POSITA would have understood that to minimize or eliminate errors in the path's trajectory, the towpreg's diameter **dictates the selection of the nozzle's diameter**. Therefore, the nozzle's diameter is **a design choice** based on the towpreg's diameter.

127. Although a nozzle's diameter value is not provided in the above-noted study, Ma informs a POSITA of several nozzle sizes used to study how the diameter of the nozzle bore ϕ impacts the flow of the liquid matrix material in the extrusion head for the Active material supply method (*Id.*, p. 161.) A POSITA would have understood that the diameter of the nozzle bore ϕ is the diameter of the recited "nozzle orifice."

128. In one simulation experiment, the diameter of the nozzle bore ϕ is fixed at 2 mm while other parameters vary. Ma explains:

> 1. The h effect: the tapering head is used with a nozzle of **ϕ=2 mm**. Figure 4-19 shows a pressure distribution diagram near the nozzle exit for h = 1. 2, 3, 5 mm, respectively.

(*Id.*, p. 162.)

129. Subsequently, Ma discloses another experiment in which different nozzle bore diameters are investigated; namely, ϕ equal to 4 mm, 2.5 mm, **2 mm**, and 1 mm. Ma explains:

> 5. The minimum diameter of the nozzle: In this experiment, the nozzle bore diameter ϕ was selected at ϕ = 4 mm, ϕ = 2.5 mm, **ϕ = 2**, and ϕ = 1 mm, respectively. If ϕ > 2 mm, with the different depth of the nozzle and the ratio R not smaller than 0.5, a stable flow is observed.

(*Id.*, p. 191.)

130. Based on the above, a POSITA would have ascertained that a nozzle orifice of "about 2 mm" would be a common option at the time and an obvious design choice for towpregs with a diameter less than about 2 mm, which is within the realm of possibility. Accordingly, Ma discloses or renders obvious "a nozzle orifice having a diameter of about 2 mm" as recited in Claim 6.

4. Claim 7: "wherein the continuous strand material includes a plurality of strands arranged in at least one of a tow, a roving, and a weave."

131. Claim 7 depends from 6, which Ma discloses. It is my opinion that Ma discloses Claim 7. Ma in discussing pultrusion (*i.e.*, a continuous process used to produce fiber-reinforced plastic structures of a constant cross-sectional shape)

discloses:

> The process involves feeding **collimated bundles** [“a plurality of strands”] **of reinforcement fibers** [“continuous strand material”] through a resin bath, allowing the **fiber tows** [“a plurality of strands arranged in at least one of a tow”] to be impregnated with the matrix resin.

(Ex. 1007, p. 10-11.) In other words, Ma discloses that the reinforcement fibers (“the continuous strand material”) are collimated bundles (“a plurality of strands”) arranged as a fiber tow (“arranged in at least one of a tow”).

132. Therefore, a POSITA would have understood that a fiber (“the continuous strand material”) used in a process, like the one described in Ma, is generally available in the form of collimated bundles arranged in a tow. Therefore, Ma discloses Claim 7.

5. Claim 8: “wherein directing the curable liquid material to the nozzle includes directing a filler material at least partially coated in the curable liquid material to the nozzle.”

133. Claim 8 depends from Claim 1, which Ma discloses. It is my opinion that Ma also discloses Claim 8. The use of fillers in curable epoxies or resins (“curable liquid material”) was a known practice in the art well before the priority date of the ’798 patent. Ma discloses that “[f]iller components are added into epoxy to decrease the laser scan time [*i.e.*, reduce the curing time], reduce the

shrinkage, and improve mechanical properties." (Ex. 1007, item 2(a) at p. 22.) In the "Effects of Fibers and the Selection of Fibers for CLM" section, Ma discloses:

> In some RPT processes, which use a UV curable epoxy, some fiber like cotton thread may be pre-mixed with the epoxy during the forming process in order to save the expensive photosensitive epoxy. The fiber is not only the forming process carrier but is also the filler material that is required to be inexpensive, soft, and has good affinity with the epoxy.

(*Id*., p. 47.)

134. A POSITA would have understood from the above, that **filler materials** can be pre-mixed with the curable liquid material to, for example, reduce the curing time of the curable liquid material, to reduce the amount of curable liquid material used, and/or to improve the mechanical properties of the resulting structure.

135. And because the filler material is pre-mixed and has good affinity with the epoxy ("the curable liquid material"), the filler material is "at least partially coated in the curable liquid material" and will be carried to the nozzle by/with the curable liquid material. Accordingly, Ma discloses Claim 8.

6. Claim 9: "wherein the filler material includes pieces of fibers."

136. Claim 9 depends from Claim 8, which Ma discloses. It is my opinion

that Ma discloses or renders obvious Claim 9. As discussed above in Claim 8, Ma discloses that "some fiber like cotton thread may be pre-mixed with the epoxy[.]" (Ex. 1007, p. 47.) A POSITA would have understood, based on Ma's disclosure and his/her own knowledge, that fiber threads include "pieces of fibers" or, at the very least, the fiber threads are added as "pieces of fibers". For example, in 2001, Zhong *et al.* ("Zhong") in "Short fiber reinforced composites for fused deposition modeling" (Ex. 1017)[3] discusses the addition of **short fibers** in Acrylonitrile–butadiene–styrene (ABS) copolymer (*e.g*., a matrix material corresponding to Ma's resin) to form composites for rapid prototyping manufacturing. (*Id.*, Abstract.) According to Zhong, a filament used in a fused deposition modeling (FDM) process "may be composed of a **short fiber** or particulate reinforcement **dispersed in a matrix** (e.g. a thermoplastic such as nylon[or ABS])." (*Id*., p. 126.) In other words, Zhong discloses that **filler materials in the form of short fibers** ("pieces of fibers") can be mixed with a matrix material. Hence, a POSITA would have understood based, for example on Zhong, that the threads disclosed by Ma are also added in Ma's resin as "pieces of fibers" to ensure uniform mixing.

137. Accordingly, and as would be understood by a POSITA, Ma discloses

[3] Zhong *et al*., Short fiber reinforced composites for fused deposition modeling (Materials Science and Engineering, A301, pp. 125–130, 2001).

or renders obvious Claim 9.

7. Claim 10: "wherein the continuous strand material is hollow."

138. Claim 10 depends from Claim 1, which Ma discloses. It is my opinion that Ma renders Claim 10 obvious for the following reasons.

139. Ma discloses that the fiber material can be made of carbon, **glass**, Kevlar, metal, or cotton thread. (*See*, *e.g.*, Figure 2-4.) Therefore, a POSITA would have understood that glass fibers were a widely-used material in Rapid Prototyping processing and a candidate material for Ma's CLM process. Additionally, a POSITA would have realized, based on the disclosures from Ma and others, that hollow glass fibers are a viable option for the continuous strand material, and further that hollow glass fibers can be filled with other materials.

140. For example, a POSITA would have known that hollow fibers were readily available and used well before the priority date of the '798 patent. For example, in 2005, Pang *et al.*, ("Pang") in "A hollow fibre reinforced polymer composite encompassing self-healing and enhanced damage visibility" (Ex. 1016) explains that hollow fibres, such as hollow glass fibres, can be filled with functional components and subsequently incorporated into structures as structural elements to help identify or repair damages induced to the structures. (*See*, *e.g.*, *id*., at Abstract, and p. 1792.) Pang discloses that "[h]ollow glass fibres were seen

to provide a good combination of storage function and mechanical reinforcement[.]" (*Id.*, towards the end of p. 1792.) Based on work from others, Pang acknowledges that:

> Hollow glass fibre is an ideal medium for storing healing components as it can simultaneously act as structural reinforcement and potentially offers many other benefits to composite materials[].

(*Id.*, p. 1793.)

141. Therefore, a POSITA, who is apprised with all the recent developments in the continuous strand material arena, would have envisioned that readily available hollow glass fibers can be either filled and used as an ideal medium for storing other components in the final structure, or be used as-is (*e.g.*, hollow) to produce a light-weight final structure. Accordingly, a POSITA, in view of Ma and his/her own knowledge, would consider Claim 10 obvious.

8. Claim 11

142. Claim 11 depends from Claim 1, which Ma discloses. It is my opinion that Ma discloses each and every limitation of Claim 11.

a. "curing a first portion of the path of composite material;" (Claim Element 11[a])

143. Ma discloses that a dispensed portion of the towpreg ("a first portion of the path of composite material") is anchored (*i.e.*, solidified as a result of a curing process). For example, Ma explains:

> In the self-anchoring forming method, a towpreg made of a thermoplastic matrix is re-melted and deposited onto an object; the towpreg could be **solidified to a certain degree and glued to a corresponding point** of the base or the previous layer immediately to form a point of anchoring.

(Ex. 1007, p. 124.) And as discussed in Claim Element 2[b], the towpreg "is quickly solidified" when "is heated or [] exposed to energy by other means [*e.g.*, when cured] during the depositing movement." (*Id.*, p. 42.) Thus, Ma discloses "curing a first portion of the path of composite material."

b. "overlapping the first portion of the path of composite material with a second portion of the path of composite material that is uncured; and" (Claim Element 11[b])

144. Ma also discloses that once the dispensed towpreg is cured and secured, the nozzle advances to dispense a fresh portion of uncured towpreg ("a second portion of the path of composite material that is uncured"), which then solidifies as a result of the curing process described above in Claim Element 11[a]. Ma explains:

> Then, with the nozzle being moved forward the anchored point of towpreg servers [sic] as a stationary point to pull the towpreg out of the nozzle. **Thus, more towpreg** ["a second portion of the path of composite material that is uncured"] **could be deposited into the object. The sequence 'towpreg deposited □ solidified □ anchored □**

> **pulled out □ deposited again**' is the basic procedural steps of the self-anchoring process, which is also called Deposited and Anchored At Once forming principle.

(Ex. 1007, pp. 124-125.) Ma's Figure 4-1A shows overlapping portions of cured (highlighted red) and uncured (highlighted blue) towpreg according to the above forming process.

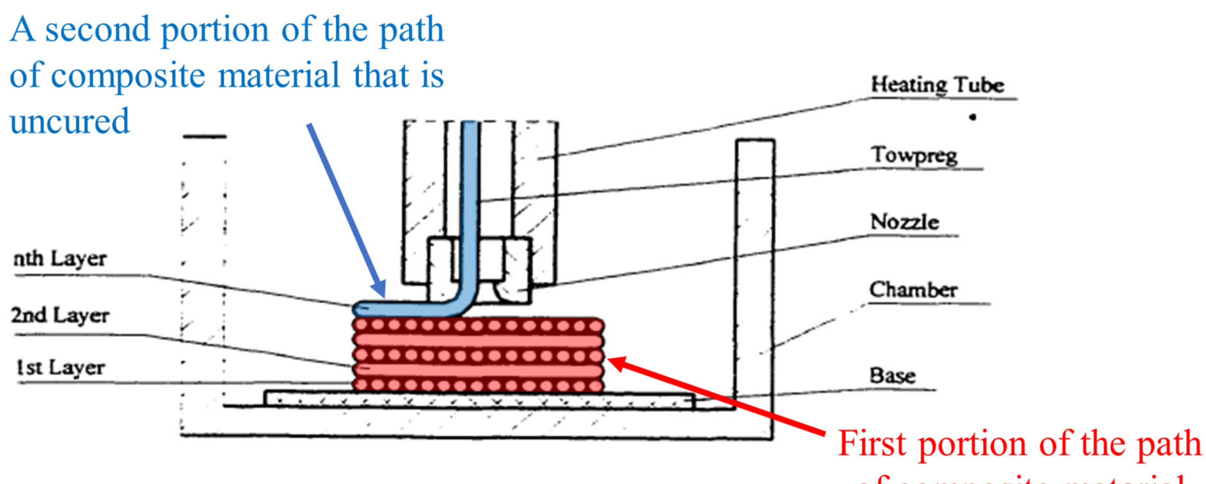


Fig. 4-1A

(*Id.*, Figure 4-1A; annotated.)

145. Accordingly, Ma discloses Claim Element 11[b].

c. "curing the second portion of the path of composite material while the first and second portions of the path of composite material are overlapped." (Claim Element 11[c]

146. A POSITA would have understood that Ma discloses Claim Element 11[c] as a result of the formation process discussed in Claim Elements 11[a] and 11[b]. For example, the freshly deposited second portion will be cured—"while

the first and second portions of the path of composite material are overlapped"—as "[t]he sequence 'towpreg deposited □ solidified □ anchored □ pulled out □ deposited again' " (Ex. 1007, p. 125) is repeated continuously to form the object[4].

9. Independent Claim 14

147. It is my opinion that Ma discloses each and every limitation of Claim 14.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 14[pre])

148. To the extent the preamble is limiting, it is disclosed by Ma. For example, the preamble of Claim 14 is identical to the preamble of Claim 1, which Ma discloses as discussed above.

b. "directing a curable liquid material to a nozzle;" (Claim Element 14[a])

149. Ma discloses Claim Element 14[a] because Claim Element 14[a] is identical to Claim Element 1[a], which Ma discloses as discussed above.

c. "directing a continuous strand material to the nozzle;" (Claim Element 14[b])

150. Ma discloses Claim Element 14[b] because Claim Element 14[b] is identical to Claim Element 1[b], which Ma discloses as discussed above.

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[4] "It is expected that these steps can occur immediately, continuously, repeatedly, and simultaneously." (Ex. 1007, p. 125.)

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 14[c])

151. Ma discloses Claim Element 14[c] because Claim Element 14[c] is identical to Claim Element 1[c], which Ma discloses as discussed above.

e. "curing the curable liquid material in the path of composite material; and" (Claim Element 14[d])

152. It is my opinion that Ma discloses Claim Element 14[d]. As discussed in Claim 11[5], Ma discloses curing freshly dispensed portions of the towpreg ("the path of composite material") as part of the object's formation process. And because the towpreg ("the path of composite material") is impregnated with the matrix material ("the curable liquid material"), which solidifies when cured[6], a POSITA would have understood that Ma discloses "curing the curable liquid material in the path of composite material" as recited in Claim Element 14[d].

f. "moving the nozzle during discharging to create tension in the continuous strand material that remains after curing of the composite material." (Claim Element 14[e])

153. It is my opinion that Ma discloses Claim Element 14[e]. As discussed in Claim Element 1[e], Ma discloses using the anchor points to **pull** the towpreg

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[5] *See*, *e.g.*, Claim Elements 11[a] and 11[c].

[6] *See*, *e.g.*, analysis for Claim Element 1[a].

out of the nozzle. In referring to Figure 4-1B below, Ma further discloses that tensile forces develop in the towpreg ("create tension in the continuous strand material") when the nozzle moves relative to the anchor points ("moving the nozzle during discharging").

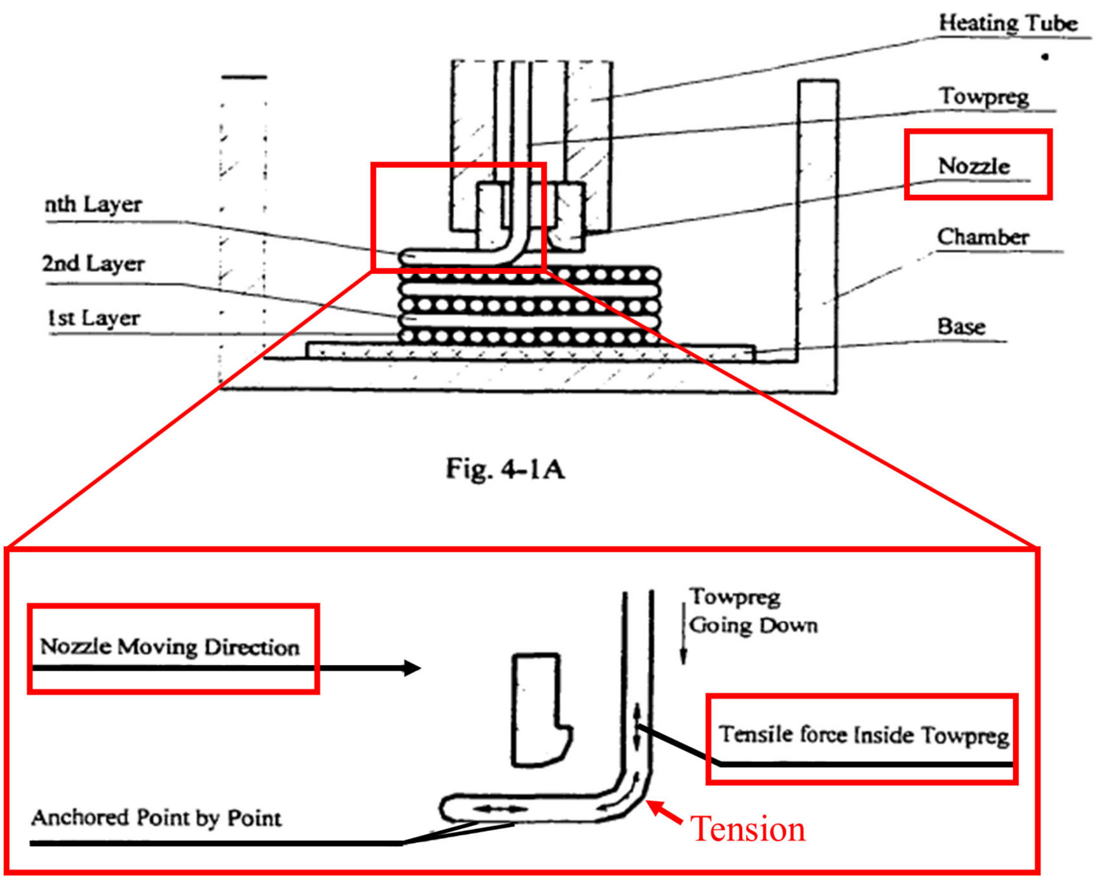


Fig. 4-1B

(Ex. 1007, Figures 4-1A and 4-1B; annotated.) A POSITA would have therefore understood that tension (as evidenced by the tensile forces within the towpreg) is the **immediate result** of the pulling action on the towpreg due to the movement of the nozzle relative to the stationary anchor points. Indeed, Ma discloses that the towpreg is pulled (and therefore tension develops in the towpreg) **as a result of the nozzle's movement relative to the anchored points when the towpreg is passively supplied through the nozzle**. Ma discloses:

> The definition of **Passive Material Supplying** is that, when **the object is moved relative to the nozzle** during the forming process, the **towpreg is pulled out by the object** instead of being pushed out by nozzle pressure. In the nozzle, **the forming material is passively moved out by the object's pulling force** [*e.g.*, the tension] and not squeezed out actively by its pressure.

(*Id.*, p. 38.) According to Ma "[t]he force [*e.g.*, the tension] acting on anchored points lies on the nozzle-moving plane" (*id.*, p. 125), as shown in Figure 4-1B.

154. And because Ma secures/anchors the towpreg during the forming process by hardening uncured portions of the towpreg, as discussed in Claim 11, a POSITA would have understood that the tension in the towpreg **remains** after the completion of the curing process. In other words, the towpreg ("the path of composite material") **is hardened while being under tension** since "the matrix material ["the curable liquid material"] can receive the energy quickly and cause it to change its physical state **as soon as possible**." (Ex. 1007, p. 41.)

155. Accordingly, Ma discloses Claim Element 14[e].

10. Independent Claim 18

156. It is my opinion that Ma discloses each and every limitation of Claim

18.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 18[pre])

157. To the extent the preamble is limiting, it is disclosed by Ma. This is because the preamble of Claim 18 is identical to the preamble of Claim 1, which Ma discloses as discussed above.

b. "directing a curable liquid material to a nozzle;" (Claim Element 18[a])

158. Ma discloses Claim Element 18[a] because Claim Element 18[a] is identical to Claim Element 1[a], which Ma discloses as discussed above.

c. "directing a continuous strand material to the nozzle;" (Claim Element 18[b])

159. Ma discloses Claim Element 18[b] because Claim Element 18[b] is identical to Claim Element 1[b], which Ma discloses as discussed above.

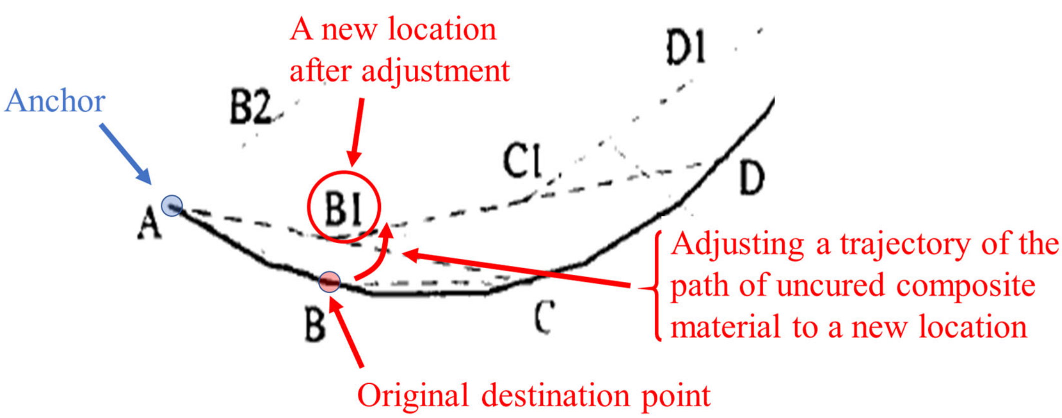
d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 18[c])

160. Ma discloses Claim Element 18[c] because Claim Element 18[c] is identical to Claim Element 1[c], which Ma discloses as discussed above.

e. "adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle; and" (Claim Element 18[d])

161. It is my opinion that Ma discloses Claim Element 18[d]. In discussing

error generation during the object's forming process, Ma discloses that in an ideal scenario, the towpreg is first anchored to point A, then to point B, and so on until a path ABCD is complete as shown in the magnified portion of Figure 4-2 below. (Ex. 1007, p. 127.)



(*Id.*, magnified portion of Figure 4-2; annotated.)

162. However, in the event that the towpreg is not properly anchored (or not anchored at all) at point B, point B can no longer serve as stationary point to pull the towpreg out of the nozzle. (*Id.*, p. 127.) Consequently, as the nozzle continues to move towards point C, point B **skids to a new location B1**. Thus, a POSITA would have understood that if the towpreg does not cure at location B (and is therefore not anchored at point B), the trajectory of the towpreg **can be adjusted to a new location B1** by moving the nozzle forward towards point C, as shown in Figure 4-2 above. The above example demonstrates that an uncured path

of the towpreg ("the path of uncured composite material") can be easily **relocated** "to a new location after discharge from the nozzle" by simply moving the nozzle and adjusting the towpreg's trajectory. A POSITA would have found this feature desirable when correcting an error during the fabrication process or when fabricating elaborate three-dimensional structures.

163. Accordingly, Ma discloses "adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle."

f. "curing the curable liquid material in the path of uncured composite material at the new location after adjusting." (Claim Element 18[e])

164. It is my opinion that Ma discloses Claim Element 18[e]. As discussed in Claim Element 18[d] (*see also* Claim Element 1[d]), Ma discloses that once the towpreg is located on a desired location—*e.g.*, on an anchor ("at the new location after adjusting")—the towpreg is bonded (anchored) to that location. Further, as discussed in Claim 2, Ma discloses that anchoring the towpreg is accomplished by curing the "curable liquid material in the path of uncured composite material." Accordingly, Ma discloses Claim Element 18[e].

C. Ground 2: The Combination of Ma and Lipsker Renders Obvious Claims 3, 5, 12, 16, 17, and 19

1. Claim 3: "wherein aiming the curing device includes aiming at least one UV light."

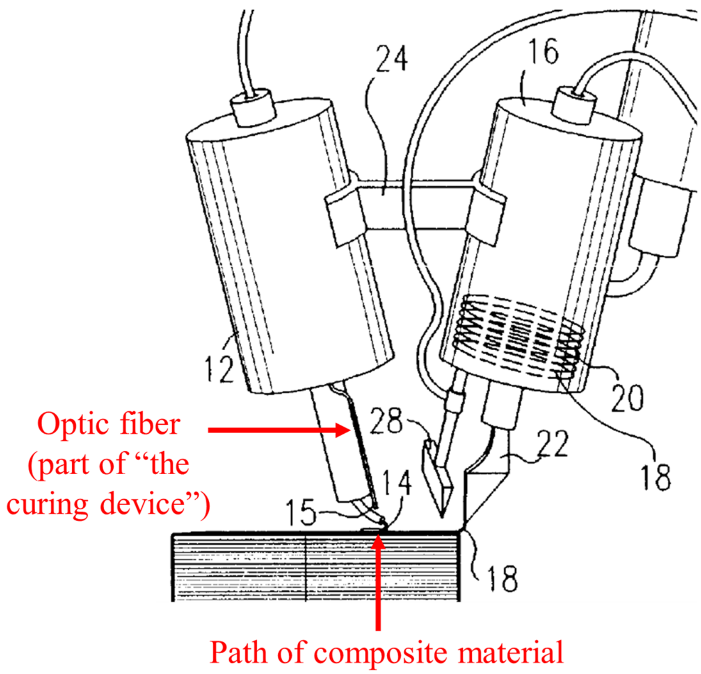
165. Claim 3 depends from Claim 2, which Ma discloses in Ground 1. It is

my opinion that Ma in combination with Lipsker discloses Claim 3.

166. Ma acknowledges that UV photo-curable materials are commonly used as matrix materials in rapid prototyping and are highly desirable (*see*, *e.g.*, Ex. 1007, at pp. 16, 26, 41-42, 47, and Figure 2-4). At the same time, Ma recognizes that the UV photo-curable materials can be expensive (*id*., 42) and for this reason proposes mixing photo-curable additives to the matrix material to reduce their cost (*id*., p. 44). Based on the above, a POSITA would have understood that the use of a UV-photocurable material in rapid prototyping requires a UV light source ("at least one UV light") for curing purposes. Although Ma studies many aspects of the CLM process, its focus is not on curing device equipment. For example, Ma discloses the notion of UV light curing but provides sparse details about the curing equipment used in the art. (*See*, *id.* at pp. 16 and 26.) Thus, a POSITA apprised with the benefits of UV photo-curable materials and looking to find additional information on UV curing would be inclined to look into Lipsker, which also discloses a rapid prototyping method and discloses such information.

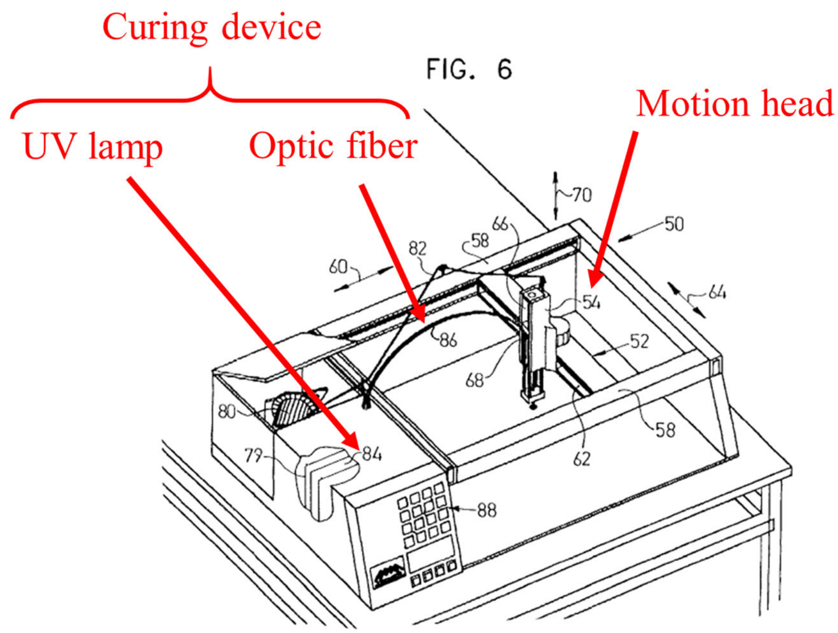
167. For example, Lipsker discloses aiming UV light from a UV lamp ("curing device") on the composite material path made from a wire 18 ("continuous strand") encased in an adhesive 14 ("curable liquid material"). (Ex.

1006, 3:41-45, 6:38-40.) More specifically, and in referring to the rapid prototype apparatus 10 in the annotated portion of Figure 1 below, Lipsker shows exposing adhesive 14 ("curable liquid material") to **UV light** from optic fiber 15—which a POSITA would understand to be an integral part of the recited "curing device"—to cure the composite material path (*i.e.*, wire 18 encased in the adhesive 14).



(Ex. 1006, portion of Figure 1; annotated.)

168. In referring to annotated Figure 6 below, Lipsker discloses that a UV lamp 84 is provided which "**transmits UV light via an optic fiber 86 to the vicinity** of motion head 54 to **cure the layers of adhesive**." (*Id.*, 6:38-42.)



(*Id.*, Figure 6; annotated.) A POSITA would have understood that optic fiber 86 of Figure 6 corresponds to optic fiber 15 of Figure 1, and further, that UV lamp 84 and optic fiber 86 collectively form the recited "curing device." This is because Lipsker discloses that **combinations of embodiments and features are possible and proper**. More specifically, Lipsker discloses:

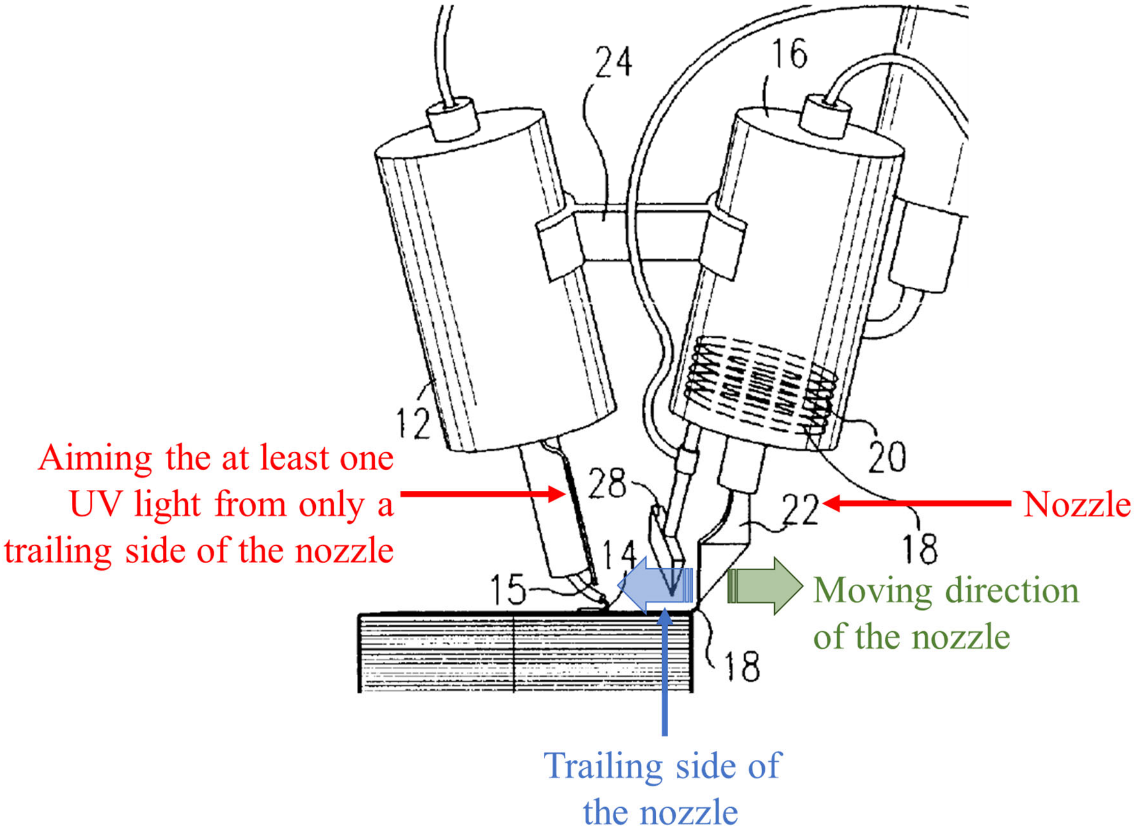
> It is appreciated that **various features** of the invention which are, for clarity, described in the contexts of separate embodiments **may also be provided in combination in a single embodiment**. Conversely, **various features of the invention** which are, for brevity, described in the context of a single embodiment may also be provided separately or **in any suitable subcombination**.

(*Id.*, 6:56-62.) Therefore, Lipsker discloses "aiming the curing device includes aiming at least one UV light" as recited in Claim 3.

169. Thus, a POSITA familiar with the known benefits of UV-curable materials, as described by Ma, would have a good reason to pursue the known options within his/her technical grasp and apply Lipsker's UV light arrangement to Ma with high expectation of success. Accordingly, Ma in combination with Lipsker discloses Claim 3.

2. Claim 5: "wherein aiming the at least one UV light includes aiming the at least one UV light from only a trailing side of the nozzle."

170. Claim 5 depends from Claim 3, which Ma in combination with Lipsker discloses. It is my opinion that Ma in combination with Lipsker also discloses Claim 5. As shown in Figure 1 of Lipsker below, the UV light, via optic fiber 15, trails (*e.g.*, follows) the nozzle's movement from left to right.



(Ex. 1006, portion of Figure 1; annotated.) In other words, the UV light is positioned so that it does not advance ahead of the nozzle but instead follows (*e.g.*, trails) the moving nozzle. A POSITA would have understood that positioning the UV light on the trailing side of the nozzle ensures that the path is properly cured once dispensed from the nozzle. Accordingly, Ma in combination with Lipsker discloses Claim 5.

3. Claim 12: "wherein the overlapping includes wrapping the second portion of the path of composite material around the first portion of the path of composite material."

171. Claim 12 depends from Claim 1, which Ma in combination with

Lipsker discloses. It is my opinion that Ma in combination with Lipsker also discloses Claim 12.

172. Ma discloses "[a] novel **computer-controlled** composite layer manufacturing (CLM) process" (Ex. 1007, p. iv), and further that "[t]his computer-automated process converts **a computer-aided design file of a part directly into a 3-D physical object of a complex shape** … ." (*Id*., p. 218.) Based on the above, a POSITA would have understood that Ma's **computer-automated process** can be implemented with the use of a three-dimensional motion device—such as a robot arm, a gantry system, or a moving stage—that would translate the instructions from the computer-aided design file into a physical movement for the extruder according to the design of the three-dimensional object. For example, Ma discloses an apparatus with a 3-D moving stage as shown in Figure 2-20.

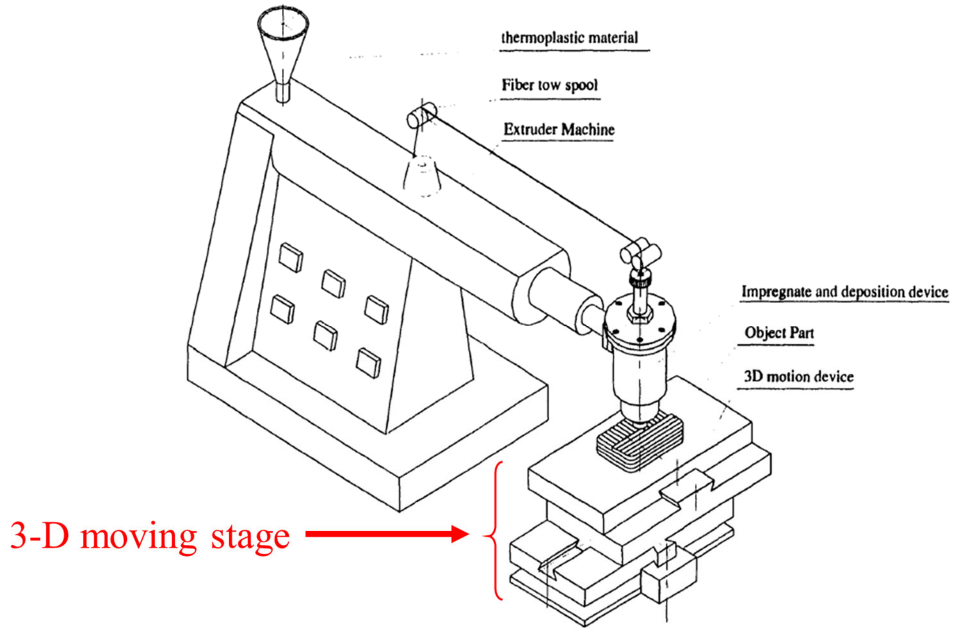
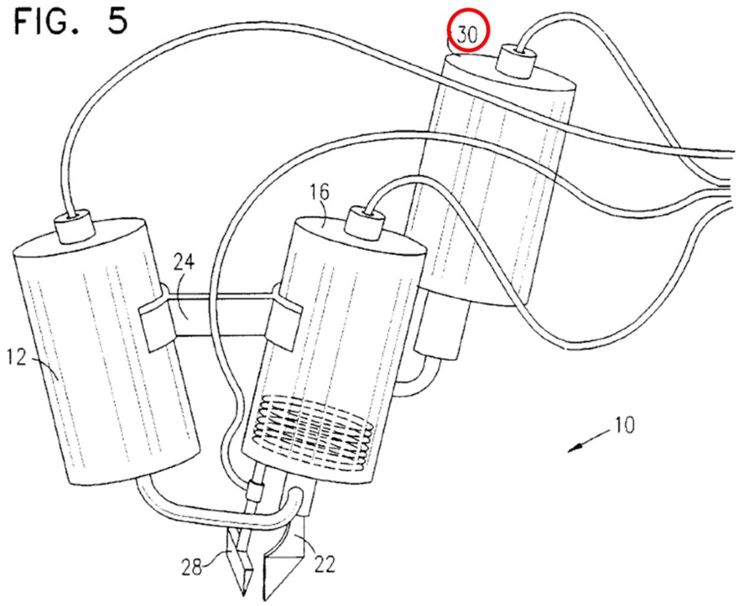


Fig. 2-20 the Active Material Supply method, a one-step forming process.

(*Id*., Figure 2-20; annotated.) However, a POSITA would have realized that the complexity of the structures produced by the apparatus shown in Figure 2-20 would be limited by the total degrees of freedom allowed by its three-dimensional moving stage. In the case of stage shown in Figure 2-20, the allowable number of degrees of freedom is no more than 3 (*e.g.*, up-down, left-right, forward-backward). A POSITA would have realized that alternative systems that are able move in more than three degrees of freedom would be capable of producing more elaborate and complex designs, which can be highly desirable for some applications. For this reason, a POSITA would be inclined to look beyond the teachings of Ma to identify such systems.

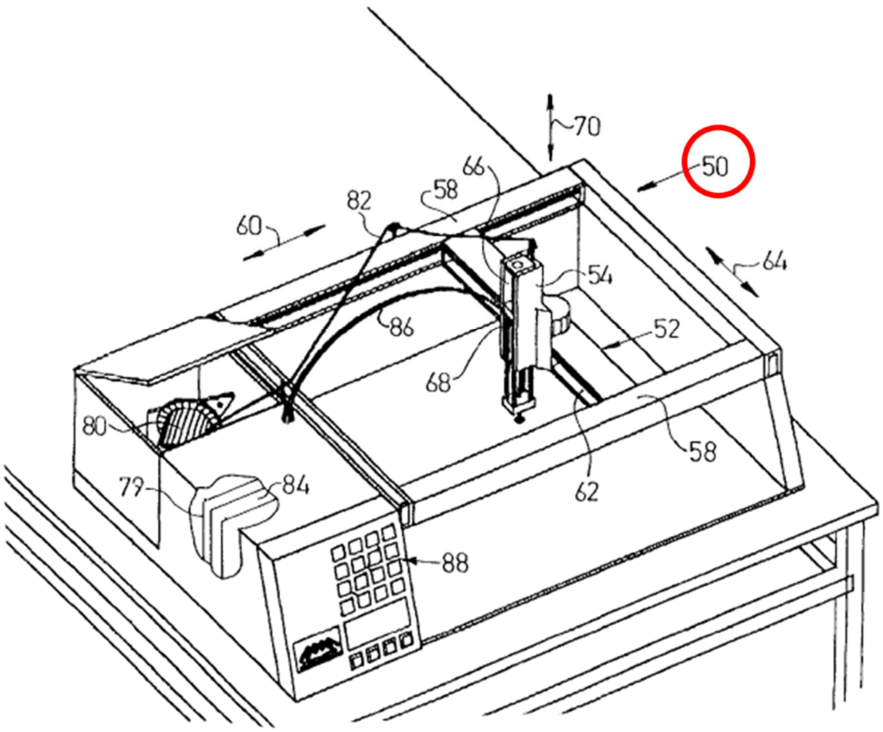
173. Lipsker discloses that actuator 30 of apparatus 10 shown, for example, in Figure 5 "moves adhesive dispenser 12 and wire dispenser 16 in at least one of **six degrees of freedom** (preferably in at least four degrees of freedom, **and most preferably in six degrees of freedom**)." (Ex. 1006, 4:60-63.)

FIG. 5

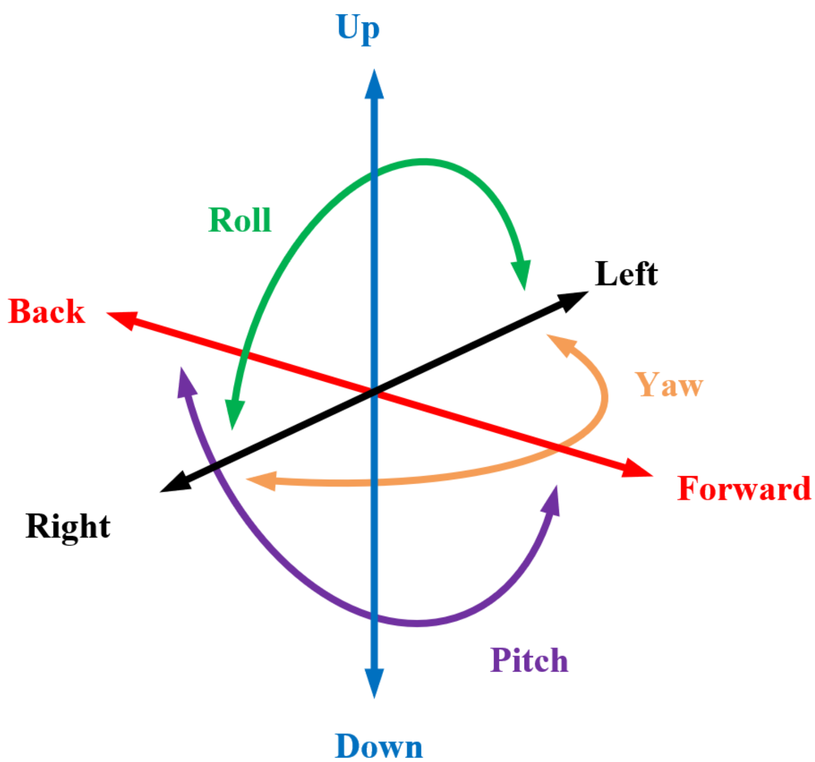


(*Id*., Figure 5; annotated.) Similarly, actuator 50, shown in Figure 6, "is capable of moving an adhesive dispenser and a wire dispenser **in at least one of six degrees of freedom** in accordance with a geometry of an object." (*Id.*, 6:35-38.)

FIG. 6



(*Id*., Figure 6; annotated.) This means that the actuators disclosed by Lipsker are designed to perform **any of the following movements or any combination of the following movements**.



(Movements representing six degrees of freedom.)

174. Accordingly, a POSITA would have realized that such movement flexibility allows Lipsker's wire and adhesive dispensers to move so that "the overlapping includes **wrapping the second portion of the path of composite material around the first portion of the path of composite material**," as recited in Claim 12. In addition, a POSITA would have understood that Lipsker's actuator could produce movements that result in deposited shapes with interlocking paths as illustrated in Figures 6 and 7 of the '798 patent. And because Lipsker's actuator includes **a commercially available** three-dimensional motion system (*id.*, 6:9-17) that can be used with any apparatus capable of producing three-dimensional

objects, such as Ma's equipment, Ma in combination with Lipsker discloses Claim 12.

4. Independent Claim 16

175. It is my opinion that Ma in combination with Lipsker discloses each and every limitation of Claim 16.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 16[pre])

176. To the extent the preamble is limiting, it is disclosed by Ma and Lipsker, alone and in combination.

177. For example, Ma discloses the preamble of Claim 16 because it is identical to the preamble of Claim 1, which Ma discloses in Ground 1.

178. Lipsker also discloses the preamble of Claim 16. Lipsker provides "improved rapid prototype deposition modeling techniques and apparatus, wherein a building material is added layer by layer to build an accurate replica of a given object, without having to remove building material to arrive at the finished prototype." (Ex. 1008, 1:52-56.) More specifically, Lipsker discloses:

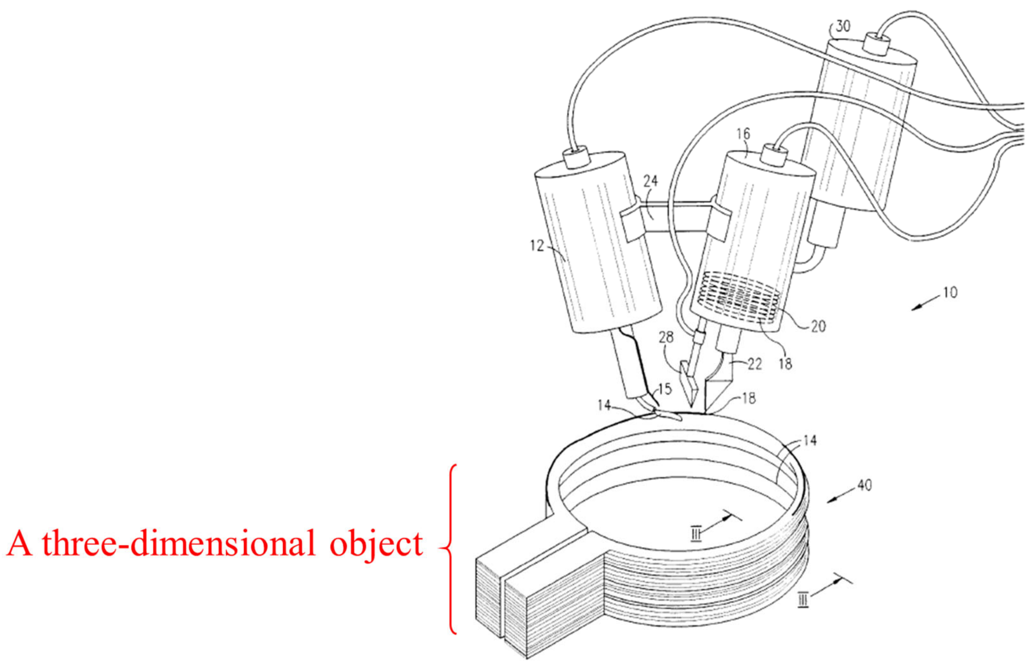
> **a method for producing a rapid prototype** including dispensing layers of a wire in at least four degrees of freedom **in accordance with a geometry of an object**, applying adhesive to the wire so as to bond a previously dispensed portion of wire to a presently dispensed portion of wire, and curing the adhesive so that **the layers**

of the wire form a prototype of the object.

(Ex. 1006, 2:50-60.)

179. Figure 2 shows an example of a three-dimensional object formed by Lipsker's method and apparatus.

FIG. 2



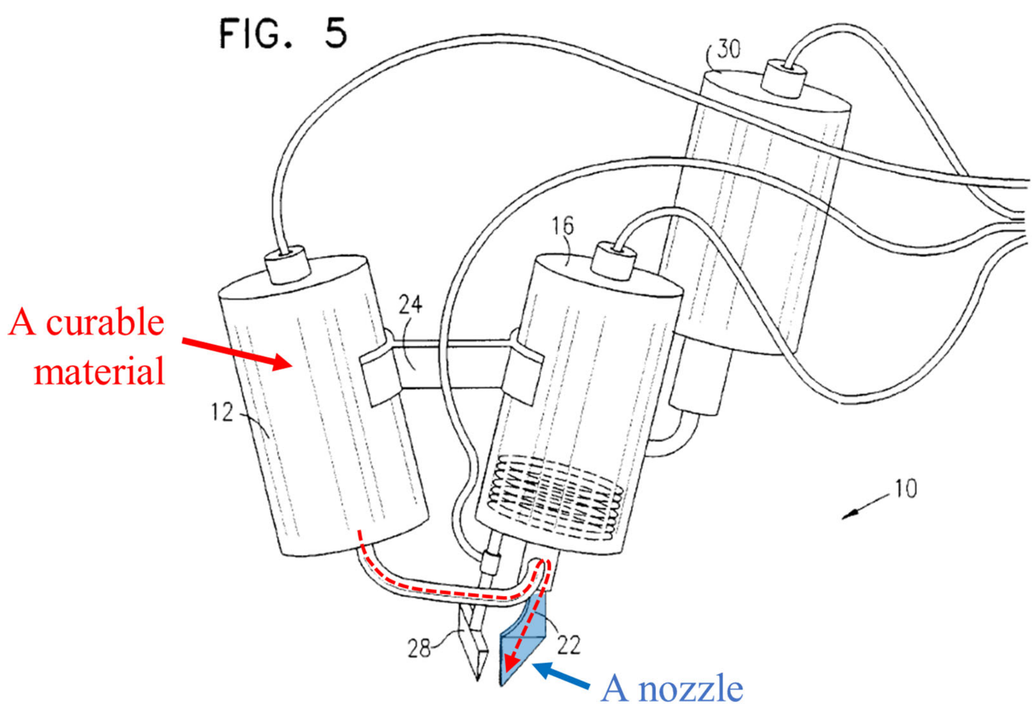
(*Id*., Figure 2; annotated.) Accordingly, Lipsker discloses the preamble of Claim 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 16[a])

180. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 16[a].

181. Claim Element 16[a] is identical to Claim Element 1[a], which Ma discloses in Ground 1. Accordingly, Ma discloses Claim Element 16[a].

182. Lipsker also discloses Claim Element 16[a]. Lipsker's rapid prototype apparatus 10 shown in Figure 2 above is equipped with an adhesive dispenser 12 for dispensing an adhesive 14, which according to Lipsker "is preferably a **quick curing** adhesive." (*See* Ex. 1006, 3:27-28; and 3:33-34.) As shown in annotated Figure 5, adhesive 14 ("the curable [] material") **is directed via a feeder**, as shown by the red dashed arrow, **through nozzle 22** (highlighted blue).



(*Id.*, Figure 5; annotated.)

183. In addition to being **a curable material**, adhesive 14 is also **a liquid**. Lipsker discloses that adhesive 14 **flows**. (*See id.*, 3:53-54.) Elsewhere, Lipsker

discloses:

> Adhesive dispenser 12 may control application of adhesive 14 **to control the degree of covering of wire 18** and, to some extent, the finished appearance of the surface of prototype 40. Adhesive 14 generally **wicks by capillary action between successive layers of wire 18.**

(*Id*., 5:45-50.) And because the adhesive is applied to the wire to "at least partially cover[] a perimeter of wire 18" (*id*., 5:44-45) and later bonded as a result of a curing process, a POSITA would have ascertained that adhesive 14 is a **liquid curable material** with an appropriate viscosity, since "wicks by capillary action" means that the adhesive flows.

184. Accordingly, Lipsker discloses Claim Element 16[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 16[b])

185. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 16[b].

186. It is noted that Claim Element 16[b] is identical to Claim Element 1[b], which Ma discloses in Ground 1. Accordingly, Ma discloses Claim Element 16[b].

187. Lipsker also discloses Claim Element 16[b]. First, Lipsker's rapid prototype apparatus 10 (shown in Figure 5 above) is also equipped with a wire

dispenser that dispenses wire 18 into nozzle 22. (Ex. 1006, 3:47-50.) Second, Lipsker discloses that wire 18 can be "spooled off from the bobbin … in a manner similar to that of a sewing machine," which means that wire 18 is stored and dispensed as a continuous strand material. (*See id.*, 3:60-66.) Indeed, Lipsker discloses:

> It is noted that throughout the specification and the claims **the term "wire" encompasses any slender, dispensable building element, such as,** but not limited to, **wire**, rod, bar, **string**, rope, **thread**, yarn, cord, filament, fiber, twine, **strand**, chain, **cable**, or wire twist.

(*Id*., 2:18-22.) A POSITA would have understood from the above that the aforementioned list of materials is **either in the form of a continuous strand or can be presented in the form of a continuous strand**. Accordingly, Lipsker discloses Claim Element 16[b].

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 16[c])

188. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 16[c].

189. Claim Element 16[c] is identical to Claim Element 1[c], which Ma discloses in Ground 1. Accordingly, Ma discloses Claim Element 16[c].

190. Lipsker also discloses Claim Element 16[c]. In referring to Figure 5,

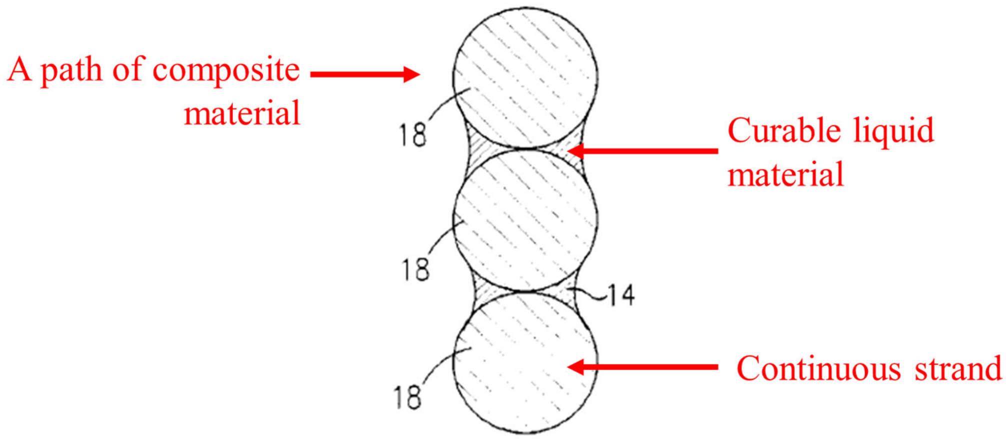
Lipsker discloses that the wire ("the continuous strand") is pre-coated ("at least partially coated") with the adhesive ("the curable liquid material") in the vicinity of the nozzle prior to being discharged from the nozzle ("discharging from the nozzle"):

> Reference is now made to FIG. 5 which illustrates an alternative method of applying adhesive 14 to wire 18, in accordance with a preferred embodiment of the present invention. Adhesive dispenser 12 may be located so as to dispense adhesive 14 into nozzle 22 such that wire 18 is dispensed from wire dispenser 16 pre-coated with adhesive 14. Indeed application of the wires and adhesive may be synchronized in any desired manner.

(Ex. 1006, 5:53-60.) A POSITA would have understood that: (i) wire 18 pre-coated with adhesive 14 is the "composite material," and (ii) the term *pre-coated*, as used in Lipsker, means **coating the wire with adhesive in the vicinity of the nozzle prior to dispensing the wire from the nozzle**.

191. The cross-section of the formed "composite material" is shown in Figure 3.

FIG. 3



(*Id*., Figure 3; annotated.) Accordingly, Lipsker discloses Claim Element 16[c].

e. "aiming a curing device at the path of discharged composite material to cure the curable liquid material;" (Claim Element 16[d])

192. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 16[d].

193. As discussed in Claim Element 2[b], the analysis of which is incorporated herein, Ma discloses "aiming a curing device at the path of composite material" with the purpose of curing the matrix material ("the curable liquid material") in the impregnated towpreg ("the path of discharged composite material") to form an anchor point. Accordingly, Ma discloses Claim Element 16[d].

194. Lipsker also discloses Claim Element 16[d]. For example, as discussed in Claim 3, the analysis of which is incorporated herein, Lipsker

discloses aiming UV light from a UV lamp via an optic fiber ("aiming a curing device") at the dispensed composite path ("at the path of discharged composite material") to cure the adhesive ("the curable liquid material") in the composite path. Accordingly, Lipsker discloses Claim Element 16[d].

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 16[e])

195. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 16[e].

196. As discussed for Claim Elements 1[c], 1[d], and 1[e] in Ground 1, Ma discloses a three-dimensional object forming process in which the nozzle is advanced ("moving the nozzle during discharging") relative to previously formed stationary anchor points to lay down fresh impregnated towpreg and to form additional anchor points until the entire three-dimensional object is complete ("to create the three-dimensional object"). *See*, *e.g.*, Figures 2-5, 4-1A, and 4-1B in the analysis presented above for Claim Elements 1[c], 1[d], and 1[e] in Ground 1. Accordingly, Ma discloses Claim Element 16[e].

197. Lipsker also discloses Claim Element 16[e]. In referring to Figure 5, Lipsker discloses that "[a]dhesive dispenser 12 may be located so as to dispense adhesive 14 into nozzle 22 such that wire 18 is dispensed from wire dispenser 16 pre-coated with adhesive 14." (Ex. 1006, 5:56-58.) Later, and in referring to

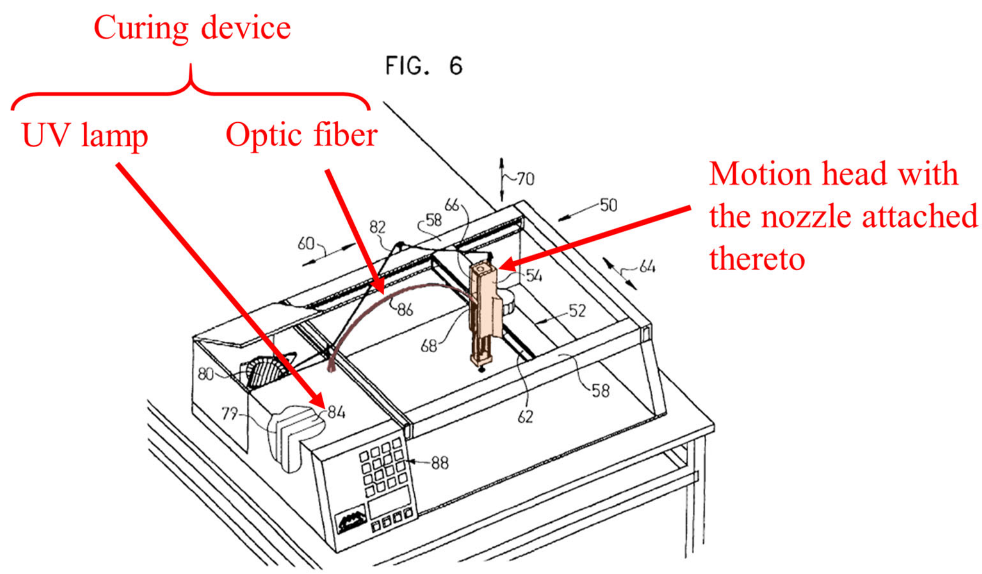
actuator 50 shown in Figure 6, Lipsker discloses that "actuator 50 is capable of moving an adhesive dispenser and a wire dispenser in at least one of six degrees of freedom in accordance with a geometry of an object." (*Id*., 6:35-38.) Accordingly, a POSITA would have understood from the above that the wire pre-coated with the adhesive ("the path composite material") is discharged from the nozzle while actuator 50 moves the nozzle according to the geometry of the three-dimensional object. Therefore, Lipsker discloses Claim Element 16[e].

g. "moving the curing device together with the nozzle." (Claim Element 16[f])

198. It is my opinion that Ma in combination with Lipsker discloses Claim Element 16[f].

199. As discussed in Claim 3, Ma studies many aspects of the CLM process but its focus is not on curing device equipment. Thus, a POSITA apprised with the benefits of UV photo-curable materials and looking to find additional information on UV curing equipment and related configurations would be motivated to look into Lipsker. A POSITA would have understood that Lipsker's UV lamp 84 and optic fiber 86 collectively form a "curing device." And because, as shown in Figure 6, optic fiber 86 (highlighted red) **is attached to and moves with** motion head 54 (highlighted orange)—on which the nozzle (not shown) is also attached to (*see* Ex. 1006, at 6:33-35)—it follows that "**the curing device" is**

attached to and moves with the nozzle.



(*Id*., Figure 6; annotated.) A POSITA would have found that this configuration allows Lipsker to cure the discharged material **on demand and at any point during the formation process with minimal interruptions**. Therefore a POSITA would be motivate to apply Lipsker's configuration to Ma to take advantage of such benefits.

200. Accordingly, Ma in combination with Lipsker discloses Claim Element 16[f].

5. Independent Claim 17

201. It is my opinion that Ma in combination with Lipsker discloses each and every limitation of Claim 17.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 17[pre])

202. To the extent the preamble is limiting, it is disclosed by Ma and Lipsker, alone and in combination, because the preamble of Claim 17 is identical to that of Claim 16, which Ma and Lipsker disclose, alone and in combination.

b. "directing a curable liquid material to a nozzle;" (Claim Element 17[a])

203. Ma and Lipsker, alone and in combination, disclose Claim Element 17[a] because Claim Element 17[a] is identical to Claim Element 16[a], which Ma and Lipsker disclose, alone and in combination.

c. "directing a continuous strand material to the nozzle;" (Claim Element 17[b])

204. Ma and Lipsker, alone and in combination, disclose Claim Element 17[b] because Claim Element 17[b] is identical to Claim Element 16[b], which Ma and Lipsker disclose, alone and in combination.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 17[c])

205. Ma and Lipsker, alone and in combination, disclose Claim Element 17[c] because Claim Element 17[c] is identical to Claim Element 16[c], which Ma and Lipsker disclose, alone and in combination.

e. "curing the curable liquid material in the path of composite material;" (Claim Element 17[d])

206. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 17[d]. For example, Ma discloses Claim Element 17[d] because Claim Element 17[d] is identical to Claim Element 14[d], which Ma discloses in Ground 1.

207. Lipsker also discloses Claim Element 17[d]. As discussed extensively in Claim 3 and Claim Element 16[d], the analyses of which are incorporated here, Lipsker discloses exposing the path of the adhesive-coated wire ("the path of composite material") to UV light to cure the adhesive ("the curable liquid material").

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 17[e])

208. Ma and Lipsker, alone and in combination, disclose Claim Element 17[e] because Claim Element 17[e] is identical to Claim Element 16[e], which Ma and Lipsker disclose, alone and in combination.

g. "selectively cutting the continuous strand material before the continuous strand material reaches the nozzle such that at least one portion of the path discharging from the nozzle contains only the curable liquid material." (Claim Element 17[f])

209. It is my opinion that Ma in combination with Lipsker discloses Claim Element 17[f].

210. Ma recognizes that "it is difficult and also unnecessary to form any complicated-shaped parts by only one continuous line of composite material" (Ex. 1007, p. 37) and "[i]f a machine for CLM process is to be designed properly, the cutting function [of the composite material] should be considered and this function need to be reliable and durable" (*id.*, p. 38). For this reason "[t]he towpreg must be readily cut off **where necessary**." (*Id.*, p. 47.) In other words, the towpreg can be cut off **at any convenient instance** during the object formation process. Although Ma studies many aspects of the CLM process, its focus is not on the cutting equipment. Thus, a POSITA familiar with the benefits of cutting the "continuous strand material" and looking to find additional information on the cutting process and the equipment involved, would be inclined to look into Lipsker which discloses additional information and variations.

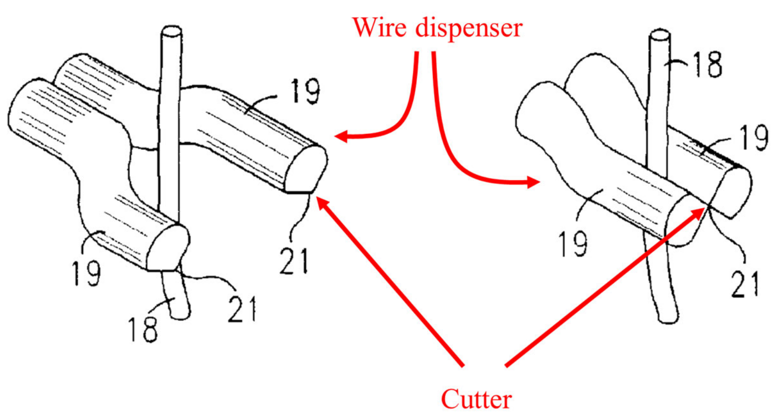
211. For example, Lipsker discloses a cutter 28 for cutting the wire ("the continuous strand material") to form discrete or non-continuous portions of an object. Lipsker also discloses that cutter 28 can be placed **in any suitable location within the apparatus**. Lipsker explains:

> In accordance with a preferred embodiment of the present invention, a cutter 28 is provided for cutting wire 18 after being dispensed by wire dispenser 16. Cutter 28 is particularly useful in forming discrete or non-continuous portions of an object. Cutter 28 is illustrated as an

> electrically operated and controlled knife, but it is appreciated that cutter 28 may comprise other cutting instruments, such as a laser or water jet. Cutter 28 is illustrated disposed intermediate adhesive dispenser 12 and wire dispenser 16, however, it is appreciated that cutter 28 may be placed in any other suitable location.

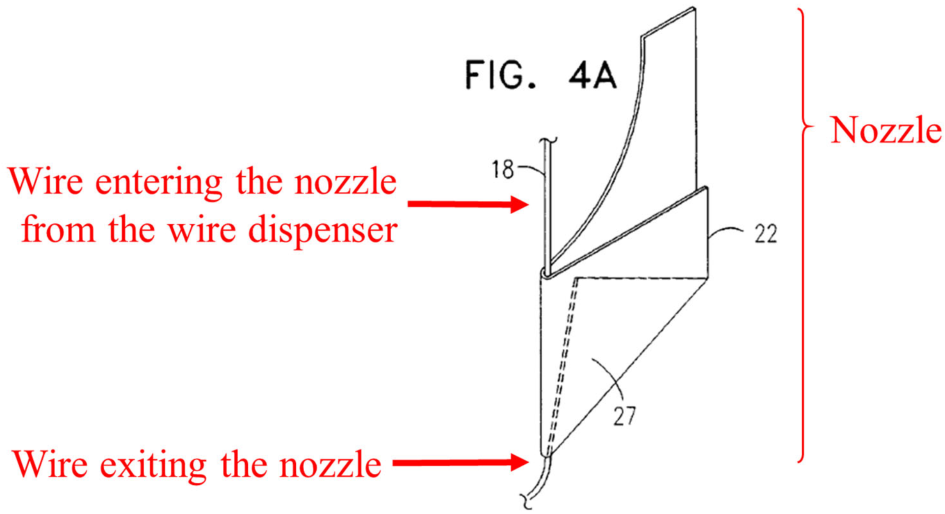
(Ex. 1006, 4:49-59.) For example, Lipsker discloses an embodiment in which the blades of a cutter **are integrated with the wire dispenser**, like cutter 21 on wire dispenser 19 shown in Figures 4C and 4D.

FIG. 4C FIG. 4D



(*Id.*, Figures 4C and 4D; annotated.) A POSITA would have understood that wire dispenser 19 shown in Figures 4C and 4D is located **upstream of the nozzle** since **the wire dispenser feeds the wire into the nozzle**[7] as shown in Figure 4A.

[7] "Wire dispenser preferably has a storage receptacle 20 for storing therein wire 18 which may be dispensed through a nozzle 22." (Ex. 1006, 3:47-49.)



(*Id.*, Figure 4A; annotated.) This configuration enables Lipsker to dispense the adhesive ("the curable liquid material") without the wire ("the continuous strand material") when the wire is cut prior to entering the nozzle so that "at least one portion of the path discharging from the nozzle contains only the curable liquid material." (*See id.*, 5:61-67.) A POSITA would have appreciated that selective sections of an article may not require wire. Therefore, **having the option to build these sections without the wire to reduce the cost and the weight of the resulting structure would be highly desirable**. Therefore, a POSITA would have a good reason to pursue the known options within his/her technical grasp and apply Lipsker's method to Ma to take advantage of such benefits.

212. Therefore, Ma in combination with Lipsker discloses Claim Element 17[f].

6. Independent Claim 19

213. It is my opinion that Ma in combination with Lipsker discloses each and every limitation of Claim 19.

a. "A method of manufacturing a three-dimensional object comprising:" (Claim Element 19[pre])

214. To the extent that the preamble of Claim 19 is limiting, it is disclosed by Ma and Lipsker, alone and in combination. For example, the preamble of Claim 19 is substantially similar, if not identical, to that of Claim 16, which both Ma and Lipsker disclose, alone and in combination.

b. "discharging from a nozzle a first path of composite material;" (Claim Element 19[a])

215. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 19[a]. For example, as discussed in connection to Claim 16[c] above, Ma and Lipsker, alone and in combination, disclose in part "**discharging from the nozzle a path of composite material**," which encompasses "discharging from a nozzle a **first** path of composite material" recited in Claim Element 19[a], as would be understood by a POSITA.

c. "curing a first portion of the first path of composite material, leaving a second portion of the first path of composite material at least partially uncured;" (Claim Element 19[b])

216. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 19[b] for the reasons set forth below.

217. As discussed in connection to Claim Element 2[b] in Ground 1, Ma discloses "aiming a curing device at the path of composite material." Such curing device is, for example, the source of heated air shown in Figure 2-7B. For the purposes of manufacturing flexibility, a POSITA would have understood that the heated air is **activated in a controlled manner to cure any desired portion of the dispensed towpreg** ("the path of composite material"). Otherwise, if the heated air was continuously flowing, the **entire** towpreg would be hardened immediately once discharged from the nozzle since Ma acknowledges the need for a matrix material that hardens **immediately** after extrusion—*e.g.*, within 0.1 and 0.01 seconds (see Ex. 1007, p. 44). Operating in this *continuous-flow* manner prevents one from manipulating or correcting the towpreg's trajectory and makes the formation process inefficient.

218. Consequently, and as shown in Figure 2-7B below, a POSITA would have anticipated that the heated air is activated **in a controlled manner** for "curing a first portion of the first path of composite material, leaving a second portion of the first path of composite material at least partially uncured."

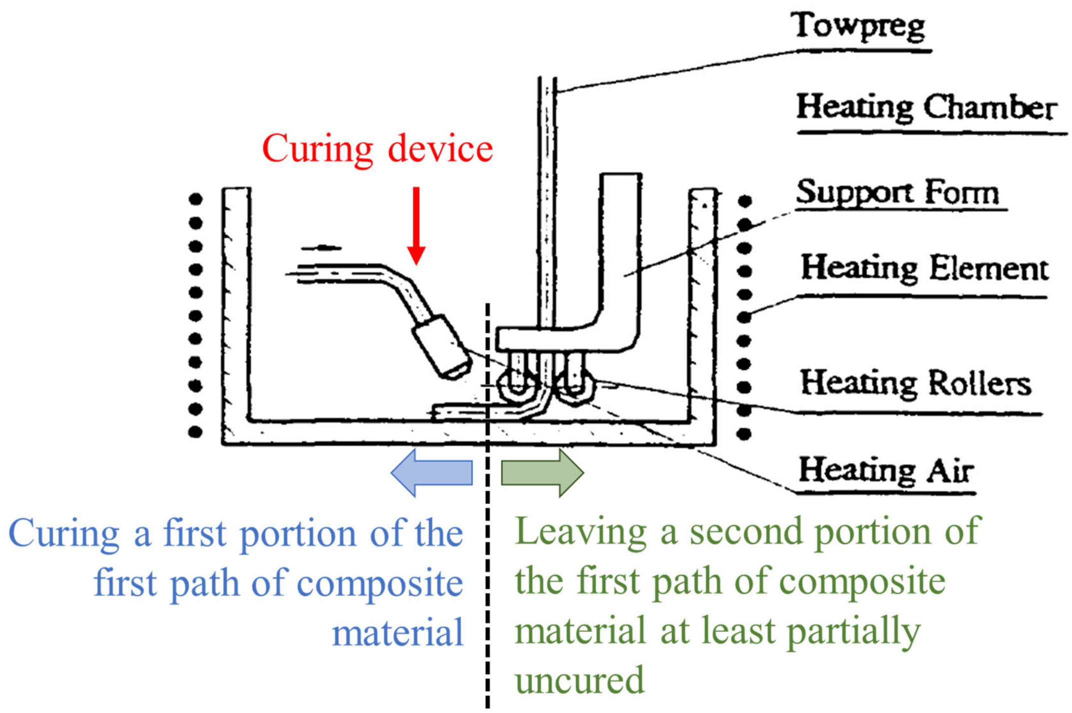
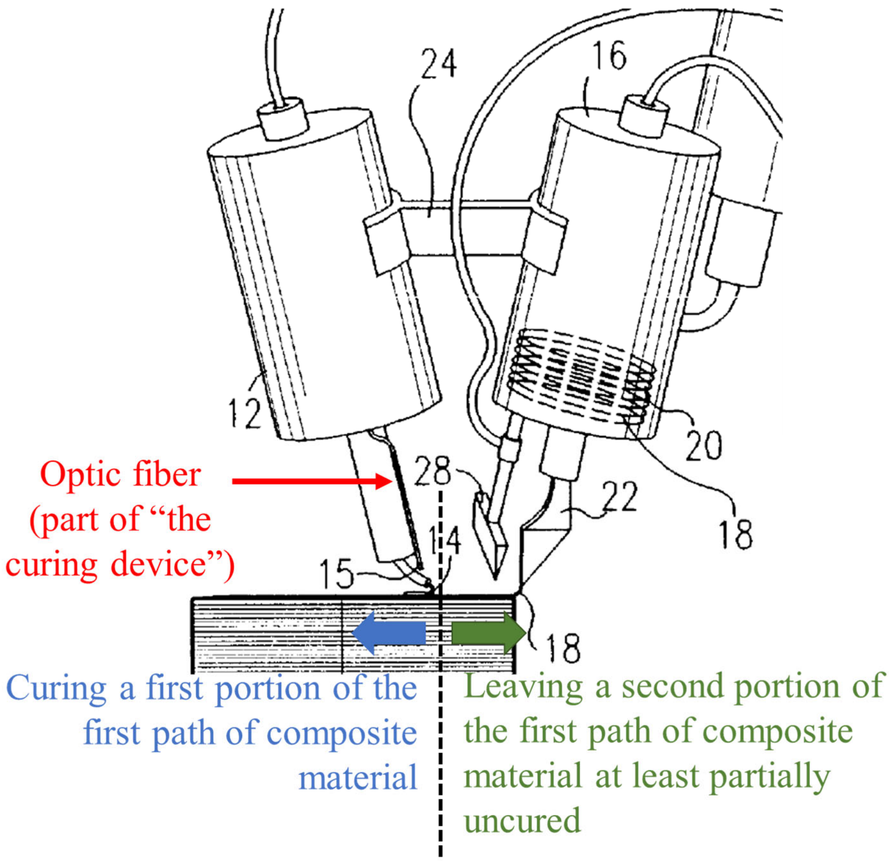


Fig. 2-7B
Step 2: the towpreg is deposited.

(Ex. 1007, Figure 2-7B; annotated.) Accordingly, Ma discloses Claim Element 19[b].

219. Lipsker discloses a similar notion. For the same reasons discussed above with respect to Ma, a POSITA would have understood that Lipsker's UV light emitted from optic fiber 15 in Figures 1 and 2, and from optic fiber 86 in Figure 6, is **activated in a controlled manner to cure any desired portion of the dispensed adhesive-coated wire** ("the path of composite material"). For instance, the UV light can be activated for "curing a first portion of the first path of

composite material, leaving a second portion of the first path of composite material at least partially uncured," as shown in Figure 1 below.



(Ex. 1006, portion of Figure 1; annotated.) Accordingly, Lipsker discloses Claim Element 19[b].

d. "discharging a second path of composite material adjacent the first path of composite material," (Claim Element 19[c])

220. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 19[c]. For example, Ma demonstrates in Figure 4-1A that

several paths of a towpreg ("composite material") are disposed laterally next to each other.

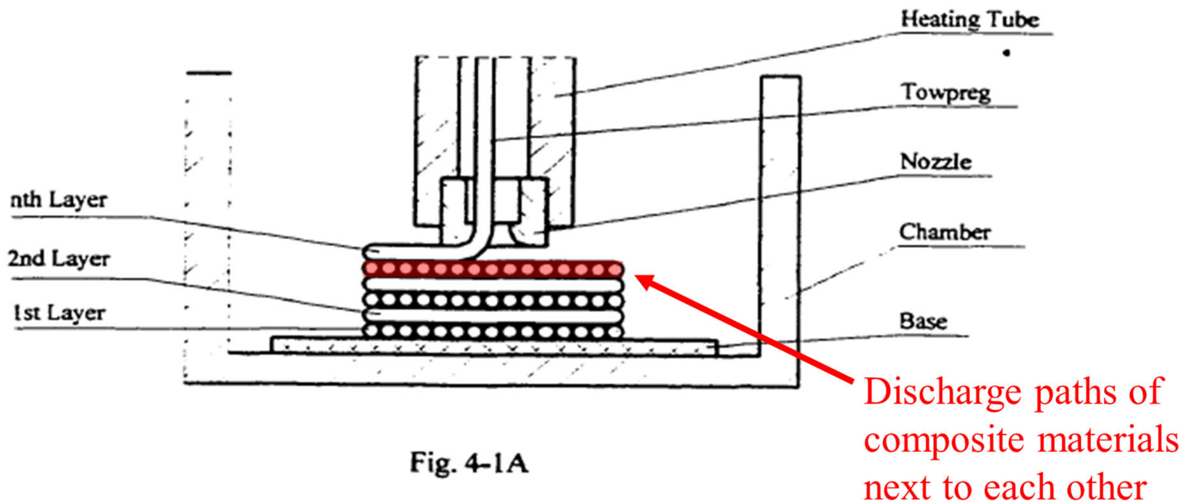
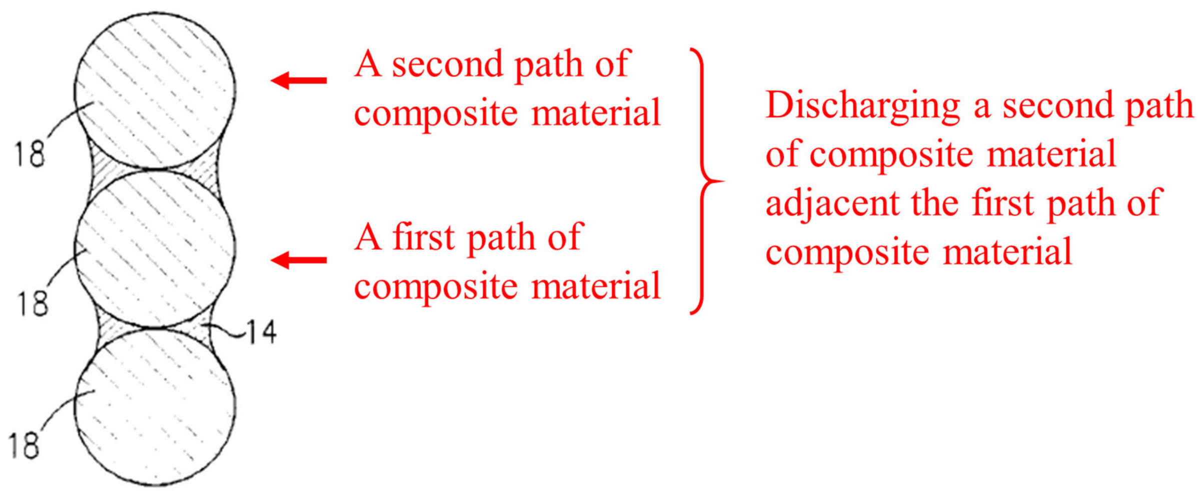


Fig. 4-1A

(Ex. 1007, Figure 4-1A; annotated.) Hence, a POSITA would have anticipated that Ma can discharge with ease "a second path of composite material adjacent the first path of composite material," as shown in Figure 4-1A.

221. Lipsker, similar to Ma, also discloses paths of adhesive-coated wire ("the composite material") discharged next to each other as shown, for example, in Figure. 3 below.

FIG. 3



(Ex. 1006, Figure 3; annotated.) Accordingly, Lipsker, like Ma, discloses Claim Element 19[c].

e. "wherein the composite material of each of the first and second paths contain a continuous strand material at least partially coated with a curable liquid material;" (Claim Element 19[d])

222. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 19[d]. For example, as discussed in Claim Element 16[c], Ma and Lipsker, alone and in combination, disclose "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material," which a POSITA would have understood to encompass Claim Element 19[d]. Accordingly, Ma and Lipsker, alone and in combination, disclose Claim Element 19[d].

f. "curing the second path of composite material;" (Claim Element 19[e])

223. It is my opinion that Ma and Lipsker, alone and in combination, disclose Claim Element 19[e]. For example, a POSITA would have ascertained that at some point during the forming process both Ma and Lipsker cure selective portions of the composite material with their respective curing devices according to the object's design. (*See*, *e.g.*, discussion in Claim Elements 16[d] and 19[b].) Accordingly, both Ma and Lipsker, alone and in combination disclose "curing the second path of composite material."

g. "mechanically interlocking the second portion of the first path of composite material with the cured second path of composite material; and" (Claim Element 19[f])

224. It is my opinion that Ma in combination with Lipsker discloses Claim Element 19[f].

225. As discussed in Claim 12, Lipsker's apparatus is capable of dispensing paths of adhesive-coated wire (*e.g.*, paths of composite material) **in any desirable direction in the three-dimensional space**. For example, Lipsker may dispense overlapping paths of composite material so that a first portion of the path is wrapped around a second portion of the path. It then follows that a POSITA would have also understood that Lipsker dispenses paths of composite material that

are mechanically interlocked—for example, "mechanically interlocking the second portion of the first path of composite material with the cured second path of composite material," as recited in Claim Element 19[f]. And because Lipsker's actuator includes a commercially available three-dimensional motion system (*id*., 6:9-17) that can **be used with any apparatus capable of producing three-dimensional objects**, such as Ma's equipment, a POSITA would have been motivated to incorporate Lipsker's motion system into Ma's configuration to take advantage of its six degrees of freedom movement capabilities. Accordingly, Ma in combination with Lipsker discloses Claim Element 19[f].

h. "curing the second portion of the first path of composite material while the second portion of the first path of composite material is mechanically interlocked with the cured second path of composite material." (Claim Element 19[g])

226. It is my opinion that Ma in combination with Lipsker discloses Claim Element 19[g] for at least the reasons discussed above in connection to Claim Element 19[e].

7. Motivation to Combine Ma and Lipsker

227. A POSITA would have been motivated to combine Ma and Lipsker for the following reasons.

228. First, a POSITA would have recognized that both Ma and Lipsker are

directed to **the same field of endeavor**—*i.e.*, to rapid prototyping manufacturing methods for fabricating accurate replicas of three-dimensional objects by dispensing a fiber-reinforced composite material. (*See*, *e.g.*, Ex. 1007, at p. iv and Ex. 1008, at 1:52-56 and 2:10-17.) Second, both Ma and Lipsker are responding to shortcomings arising from the use of **monolithic** building materials (*i.e.*, single-type building materials) in rapid prototyping processes—such as, the lack of rigidity and strength in fabricated three-dimensional products. For example, Ma mentions the need for "high strength-to-weight ratio" structures for aerospace and medical applications (market forces) (Ex. 1007 at p. 14) and Lipsker highlights the fabrication of three-dimensional objects without supporting structures (design incentives) (Ex. 1008, at 1:32-35).

229. Therefore, a POSITA who is eager to address the aforementioned shortcomings, expand his/her own knowledge on rapid prototyping methods, and get informed about the equipment options and materials used in rapid prototyping, would be highly motivated to seek Lipsker and Ma.

230. Further, a POSITA would have found that although Lipsker and Ma disclose **similar operating principles** and use **comparable baseline equipment**, they do not necessarily overlap in their focus. For example, Lipsker focuses more on the equipment side (*e.g.*, cutting and curing equipment) and motion system,

while Ma elaborates and studies in greater detail the dispensing mechanics. Therefore, a POSITA would have found that Lipsker and Ma are complimentary to one another and would have been motivated to combine them so as to benefit from their respective teachings.

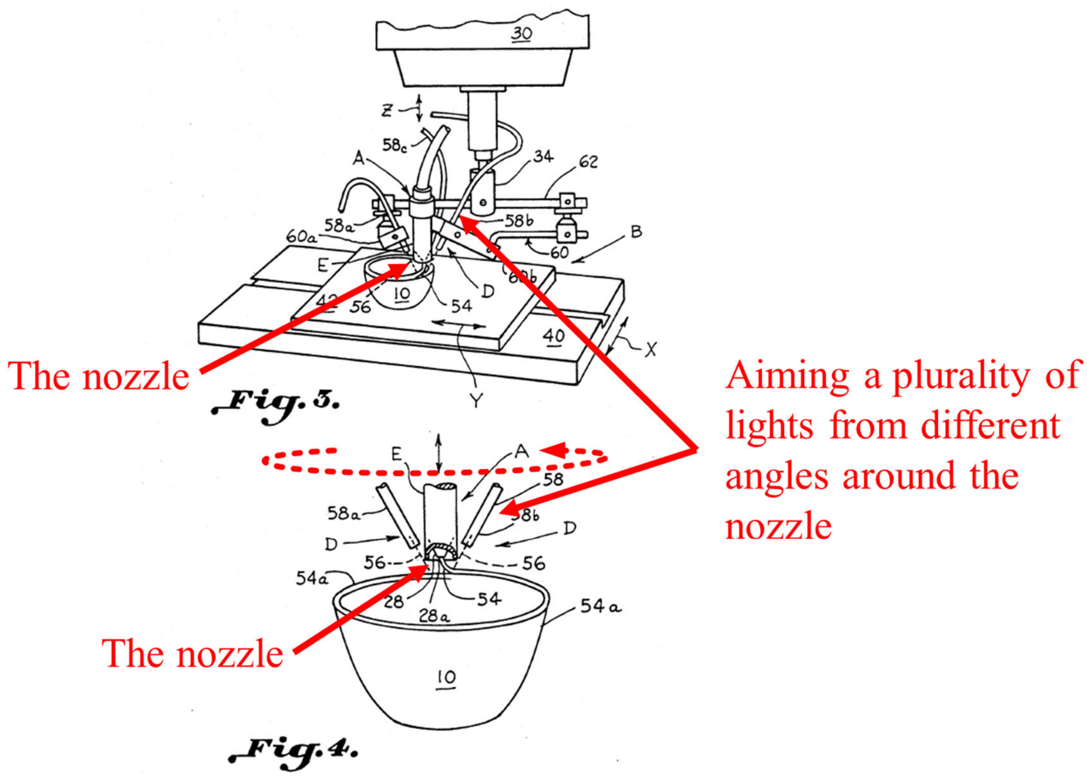
231. Finally, a POSITA would have considerable expectation of success when combining these teachings because such combination would amount to (i) a mere substitution of one known element for another, (ii) applying a known technique to a known device (method, or product) ready for improvement, and/or (iii) use of known techniques to improve similar devices (methods, or products), as discussed in more detail for the claims in Ground 2 above. Therefore, the teachings and considerations of Lipsker would allow a POSITA to improve on Ma's methods effortlessly (and vice versa), and for at least these reasons, a POSITA would be motivated to seek and combine Lipsker and Ma.

D. Ground 3: The Combination of Ma, Lipsker, and Masters Renders Obvious Claim 4

1. Claim 4: "wherein aiming the at least one UV light includes aiming a plurality of lights from different angles around the nozzle."

232. Claim 4 depends from Claim 3, which Ma in combination with Lipsker discloses. It is my opinion that Ma in combination with Lipsker and Masters discloses Claim 4.

233. As discussed for Claim 3 in Ground 2, Ma discloses the notion of UV light curing but provides sparse information about the curing equipment used. (*See*, Ex. 1007 at pp. 16 and 26). Meanwhile, Lipsker discloses aiming "at least one UV light" via optic fiber 15 in Figures 1 and 2, and via optic fiber 86 in Figure 6. Therefore, a POSITA aspired to improve the curing process as part of the normal course of his/her own research would be inclined to look further into other publicly available references in the same field of endeavor that are more focused on the subject of UV curing. Masters, for example, in referring to Figures 3 and 4, discloses a plurality of UV light beams emitted from a plurality of light tubes ("aiming a plurality of lights") positioned around the dispensing means ("around the nozzle") at an equal angular spacing ("from different angles").



(Ex. 1011, Figures 3 and 4; annotated.) Specifically, Masters discloses:

> As can best be seen in FIGS. 3 and 4, material treatment means D includes a plurality of ultraviolet light beams 56 emitted from a plurality of light tubes 58 which, preferably, are equally angularly spaced around dispensing means A.

(*Id.*, 4:53-57.)

234. A POSITA would have immediately recognized the similarities between Masters and Lipsker. For example, both Masters and Lipsker use fiber optics (*see*, *e.g.*, Masters' light tubes 58) to deliver UV light from a remote UV lamp to the curable material. Additionally, a POSITA would have appreciated that

Masters' UV light arrangement is particularly beneficial **for reducing the curing time and improving the curing uniformity** of the curable material. Thus, a POSITA would have a good reason to pursue the known options within his/her technical grasp and apply Masters' UV light arrangement to Ma and Lipsker to take advantage of such benefits. And because both Ma and Lipsker disclose the use of at least one UV light beam, adding additional UV light beams would be easily implemented and yield predictable results.

235. Accordingly, Ma in combination with Lipsker and Masters discloses Claim 4.

2. Motivation to combine Ma, Lipsker, and Masters

236. As discussed in Ground 2, a POSITA would be motivated to combine Ma and Lipsker. It is my opinion that a POSITA would be further motivated to combine Ma and Lipsker with Masters for the following reasons.

237. As discussed in the motivation to combine section in Ground 2, the disclosures from Lipsker and Ma have a different focus. Consequently, a POSITA looking to improve aspects of Ma and Lipsker as part of the normal course of his/her own research, would be motivated to look beyond their disclosures. Additionally, it is a common practice in research that a POSITA would explore references that are within the wider field of rapid prototyping. This means that a

POSITA would be inclined to seek references which are not limited to the disclosure of fiber-reinforced building materials, but nevertheless cover important aspects of the rapid prototyping process in great granularity. In my opinion, such reference is Masters.

238. Masters, like Ma and Lipsker, discloses a system and method for constructing a three-dimensional object by dispensing and subsequently solidifying **a polymeric material**. (Ex. 1011, Abstract.) However, a POSITA would have appreciated that Masters discloses a UV curing configuration that **reduces the curing time and improves the curing uniformity**, which are both highly desirable features for a rapid prototyping process. Accordingly, a POSITA would have **a good reason to pursue the known options within his/her technical grasp and apply Masters' teachings to Ma and Lipsker to take advantage of such benefits**.

239. Finally, a POSITA would have considerable expectation of success when combining these teachings. This is because the combination would amount to applying a known technique to a known device (method, or product) ready for improvement and/or use of known techniques to improve similar devices (methods, or products) in the same way. (*See* discussion in Claim 4 above.) Therefore, the teachings and considerations of Masters would allow a POSITA to improve on

Ma's and Lipsker's methods with high expectation of success, and for at least these reasons, a POSITA would be motivated to combine Ma and Lipsker with Masters.

E. Ground 4 The Combination of Ma, Lipsker, and Crump Renders Obvious Claim 20

1. Claim 20: "wherein discharging from the nozzle the first path of composite material and the second path of composite material includes simultaneously discharging the first and second paths of composite material."

240. Claim 20 depends from Claim 19, which Ma in combination with Lipsker discloses. It is my opinion that Ma in combination with Lipsker and Crump discloses Claim 20.

241. A POSITA who is aspired to improve the efficiency of the fabrication process would be inclined to look beyond the teachings of Ma and Lipsker to identify alternative or improved configurations in additional references within the same field of endeavor as part of the normal course of his/her own research. For example, Crump discloses in Figure 11 a plurality of dispensing orifices 127 arranged in a circular pattern on a dispensing head 112.

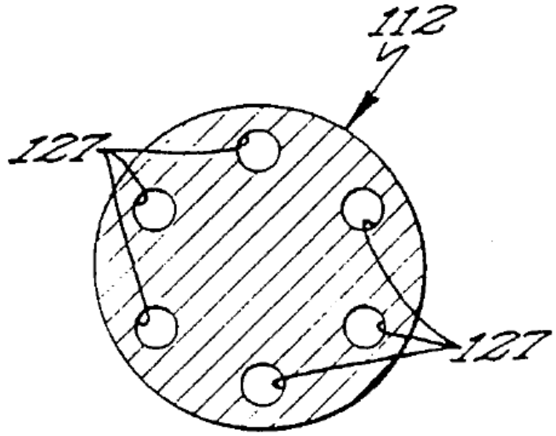


Fig 11

(*Id*., Figure 11.) According to Crump, dispensing head 112 features multiple supply passages, as shown in Figure 6, into which building materials with different composition and colors may be directed. (*Id.*, 14:37-43.)

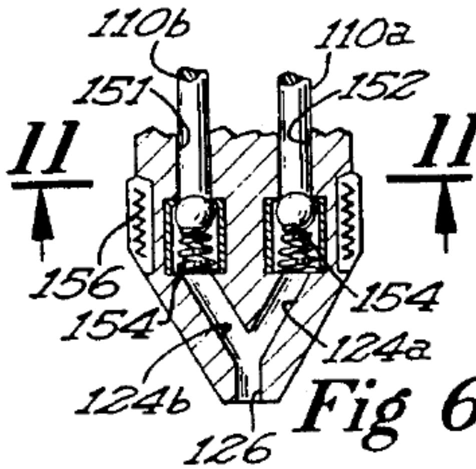


Fig 6

(*Id*., Figure 6.) Accordingly, dispensing orifices 127 "permit discharge of material from any desired number of orifices by selective control of the separate supply materials." (*Id.*, 14:49-51.)

242. Although Crump discloses dispensing single-composition material paths as opposed to fiber-based composite paths, a POSITA would have realized that Crump's orifice configuration achieves simultaneous discharging of multiple paths, which **substantially reduces the fabrication time, improves the efficiency of the entire fabrication process, and reduces the associated cost**. Additionally, a POSITA would have recognized that **discharging multiple paths in any desirable sequence permits seamless switching between dispensing materials with no down time, which in turn allows the fabrication of complex multi-material structures not possible with Ma and Lipsker**. Therefore, and in view the aforementioned compelling benefits of cost reduction, process yield improvement, and product innovation, a POSITA would have strong reasons to pursue the known options within his or her technical grasp to improve on the teachings of Ma and Lipsker based on the teachings disclosed or suggested by Crump.

243. Accordingly, Ma in combination with Lipsker and Crump, discloses Claim 20.

2. Motivation to Combine Ma, Lipsker, and Crump.

244. A POSITA would be motivated to combine Ma and Lipsker for the

reasons discussed above in Ground 2. It is my opinion that a POSITA would be further motivated to combine Ma and Lipsker with Crump for the following reasons.

245. A POSITA who is aspired to improve the efficiency of the fabrication process disclosed by Ma and Lipsker would be inclined to look beyond the teachings of these references to identify improved configurations in references within the same field of endeavor as part of the normal course of his/her own research. This means, that a POSITA would be inclined to seek references which are not limited to the disclosure of fiber-reinforced building materials, but nevertheless cover important aspects of the rapid prototyping process in great granularity. In my opinion, such reference is Crump.

246. A POSITA would have recognized that Crump, like Ma and Lipsker, discloses a rapid prototyping method for manufacturing three-dimensional objects from a three-dimensional digital file "by depositing repeated layers of [a] **solidifying material** until the shape is formed." (Ex. 1008 at Abstract and 5:44-46.) However, a POSITA would have appreciated that Crump discloses aspects of the rapid prototyping process that **reduce the fabrication time, improve the efficiency of the entire fabrication process, and reduce the associated cost**—all of which are **highly** desirable outcomes.

247. For example, a POSITA would have found that Crump discloses hardware configurations that would benefit both Ma and Lipsker in terms of functionality, fabrication time, and cost. More specifically, Crump discloses numerous nozzle arrangements (*see*, *e.g.*, Ex. 1008, Figures 6 and 7) and considerations that would allow Ma and Lipsker to dispense multiple paths of composite material simultaneously and to fabricate three-dimensional objects at a faster pace, which in turn reduces the fabrication cost and improves the fabrication efficiency.

248. A POSITA would realize that applying these teachings to Ma and Lipsker does not require substantial changes and would yield predictable results because such changes amount to a simple substitution of known parts.

249. For at least these reasons, it is my opinion that a POSITA would have been motivated to combine Ma and Lipsker with Crump.

F. Ground 5: The Combination of Ma and Crump Renders Obvious Claim 13

1. Independent Claim 13

250. It is my opinion that Ma in combination with Crump discloses each and every limitation of Claim 13.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 13[pre])

251. To the extent the preamble is limiting, it is disclosed by Ma and

Crump, alone and in combination. For example, the preamble of Claim 13 is identical to the preamble of Claim 1, which Ma discloses in Ground 1.

252. Crump also discloses the preamble of Claim 13. For example, Crump discloses "an apparatus and **process for forming a three-dimensional object** of predetermined design, and **in particular to the making of a model or article** by depositing multiple layers of a material in a fluid state onto a base." (Ex. 1008, 1:6-10.)

b. "directing a curable liquid material to a nozzle;" (Claim Element 13[a])

253. Claim Element 13[a] is identical to Claim Element 1[a], which Ma discloses in Ground 1. Therefore, Ma in combination with Crump discloses Claim Element 13[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 13[b])

254. Claim Element 13[b] is identical to that of Claim Element 1[b], which Ma discloses in Ground 1. Therefore, Ma in combination with Crump discloses Claim Element 13[b].

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 13[c])

255. It is my opinion that Ma in combination with Crump discloses Claim

Element 13[c]. For example, Claim Element 13[c] is identical to that of Claim Element 1[c], which Ma discloses in Ground 1. Therefore, Ma in combination with Crump discloses Claim Element 13[c].

e. "bonding an end point of the path of composite material to an anchor; and" (Claim Element 13[d])

256. It is my opinion that Ma in combination with Crump discloses Claim Element 13[d]. It is noted that Claim Element 13[d] is identical to Claim Element 1[d], which Ma discloses in Ground 1.

257. A POSITA would have come to realize that although Crump does not necessarily discuss a fiber-based material path, it discloses the **concept** of bonding selected portions of its dispensed path, such as "bonding an end point of the path," to one or more anchor locations ("to an anchor.) For example, as shown in annotated Figure 12 below, the discharged path is attached to and originates from a first anchor 180b.

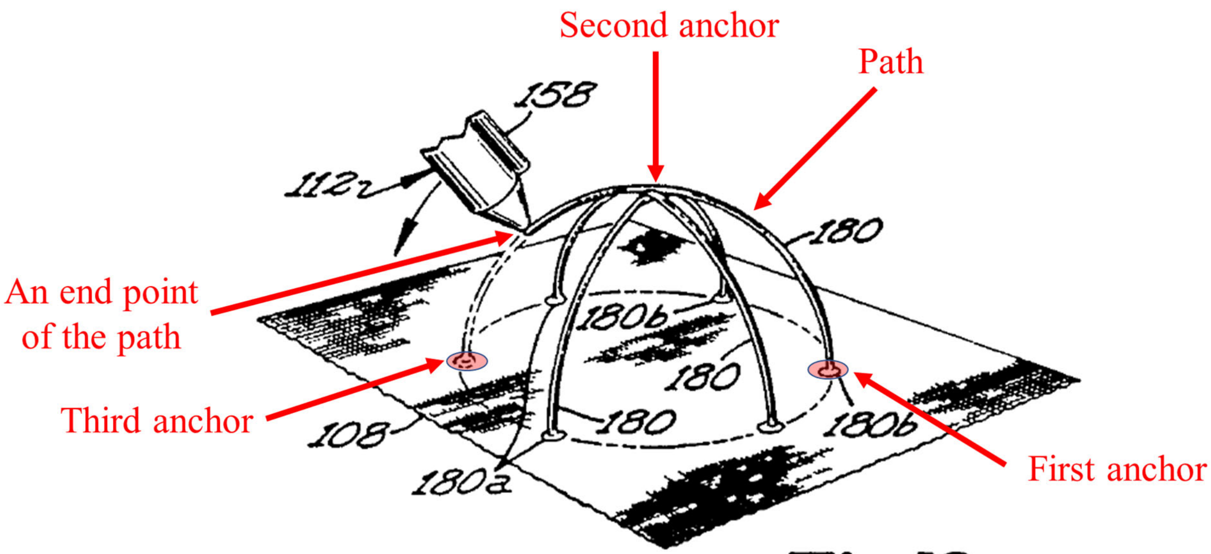


Fig 12

(*Id.*, Figure 12; annotated.) As additional path 180 is discharged along the intendent path trajectory, a second anchor is formed at a desired location (*e.g.*, at the apex of the path's trajectory). The end point of the path continues to follow the intended trajectory until it reaches the base where it is anchored again on a third anchor. Hence, a POSITA would have understood that there is always "an end point of the path" that is bonded to a respective anchor point.

258. Consequently, and irrespective of the fact that Crump does not discuss fiber-based materials, a POSITA would have found that the concept of "bonding an end point of the path to [] an anchor" is neither new nor novel, as demonstrated by Crump. And because Ma discloses the same concept with Crump and explicitly discloses a "path of composite material," Ma in combination with Crump discloses

Claim Element 13[d].

f. "moving the nozzle during discharging to cause the path of composite material to extend away from the anchor; and" (Claim Element 13[e])

259. It is my opinion that Ma in combination with Crump discloses Claim Element 13[e]. For example, Figure 4-2 shows that, under proper conditions, the towpreg path ("the path of composite material") coincides with the nozzle path. Figure 4-2 further shows that as the nozzle moves from one anchor point location to the next—*e.g.*, from anchor point A to anchor point location B—the towpreg ("the path of composite material") **extends away** from anchor point A ("the anchor").

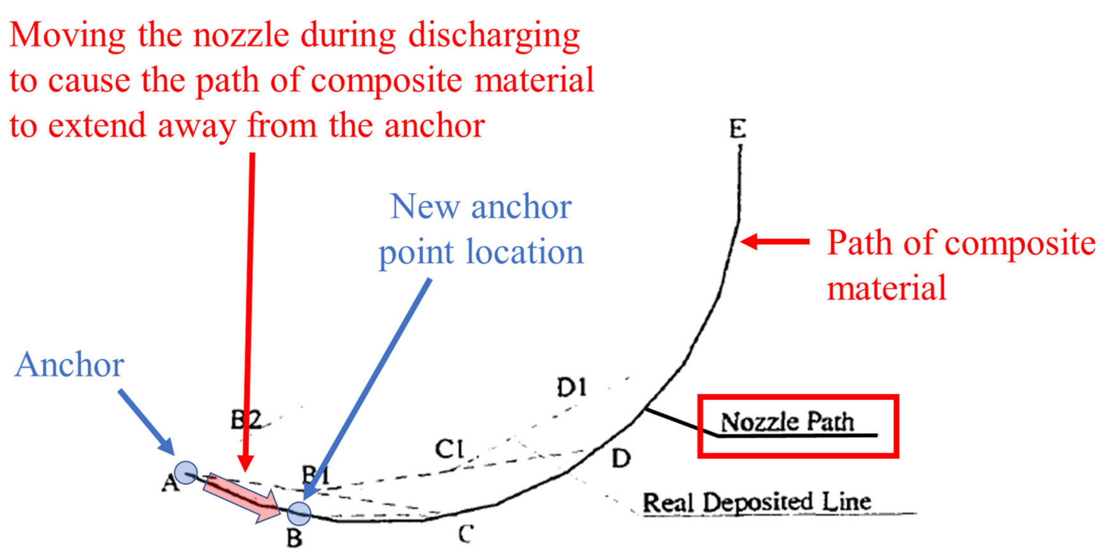
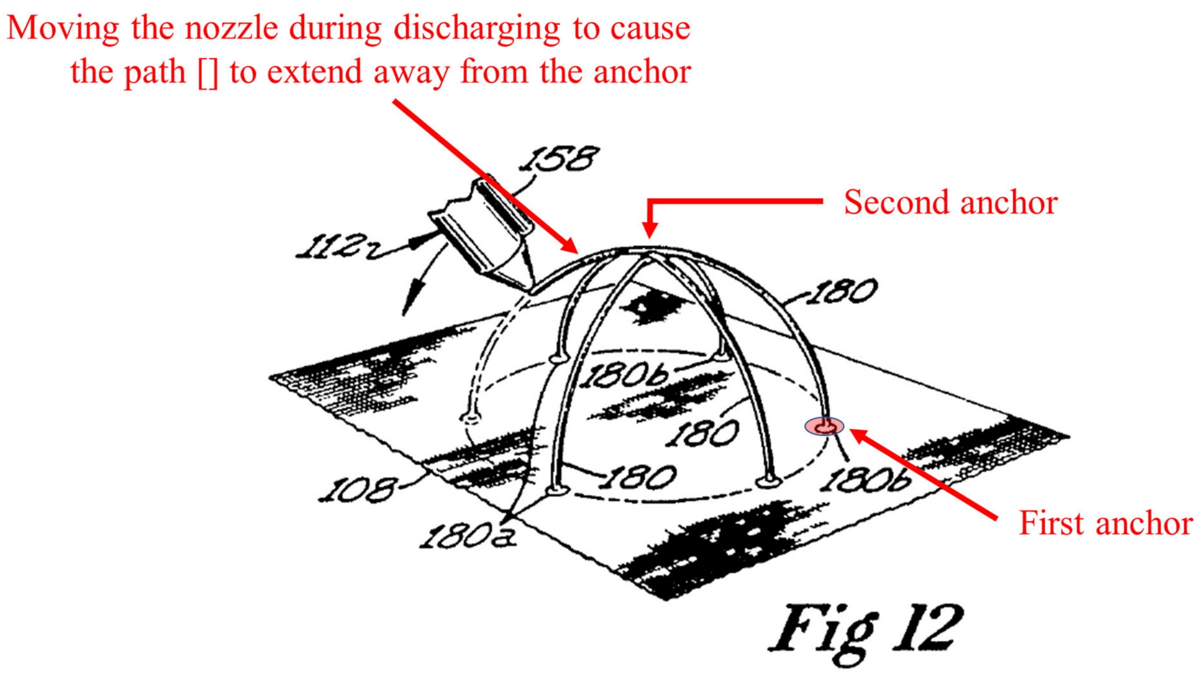


Fig. 4-2 An error is generated by the mechanism of the forming process.

(Ex. 1007, Figure 4-2; annotated.) Accordingly, Ma discloses Claim Element

13[e].

260. Based on the analysis presented above in Claim Element 13[d], a POSITA would have found that Crump also discloses the concept of "moving the nozzle during discharging to cause the path [] to extend away from the anchor," as shown in Figure 12 below.



(Ex. 1008, Figure 12; annotated.) And because Ma discloses the same concept as Crump, and additionally, explicitly discloses a "path of composite material," Ma in combination with Crump discloses Claim Element 13[e].

g. "exposing the curable liquid material in the path of composite material to a cure energy while the nozzle is moving such that the path of composite material is hardened at a fixed location in three-dimensional

space without support at locations between the anchor and the nozzle." (Claim Element 13[f])

261. It is my opinion that Ma in combination with Crump discloses Claim Element 13[f]. For example, and as discussed in reference to Claim Element 2[b] in Ground 1, Ma discloses that:

> When needed to do a forming process, a towpreg is heated or is exposed to energy by other means during the depositing movement and is quickly solidified and allowed to adhere to the previous layer.

(*Id.*, p. 42.) And because it is the matrix material ("the curable liquid material") in the towpreg ("in the path of composite material") that solidifies as a result of the exposure to the cure energy, Ma discloses "exposing the curable liquid material in the path of composite material to a cure energy while the nozzle is moving such that the path of composite material is hardened."

262. A POSITA who is looking to find ways to fabricate more complex and elaborate three-dimensional objects, such as free-standing three-dimensional structures, would be inclined to look beyond the teachings of Ma, as part of the normal course of his/her own research. For example, a POSITA would have been motivated to look into the work of others, such as the work from Crump who forms **free-standing** strands 180 extending from substrate anchor points 180a and 180b as shown in Figure 12 below.

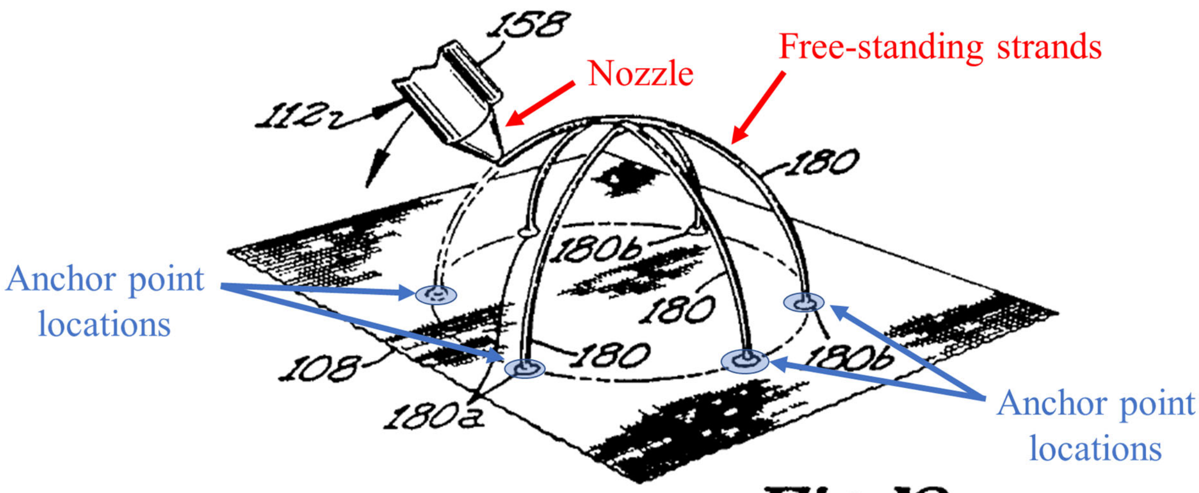


Fig 12

(Ex. 1008, Figure 12; annotated.) According to Crump, the extruded liquid material solidifies **instantly** when exposed to the ambient temperature or to a coolant. (*Id.*, 15:21-51.)

263. A POSITA would have understood from Crump that free-standing structures are made possible because Crump selects a building material that **solidifies rapidly** when exposed to an ambient temperature slightly lower than its melting temperature. A POSITA would have envisioned that Ma would be able to fabricate free-standing structures if **a matrix material** ("a curable liquid material") is appropriately selected so that it **hardens rapidly** when exposed to **a curing energy** (*e.g.*, to UV energy or heat). A POSITA would have also found that Ma is consistent with this notion because Ma acknowledges the need for a matrix material that hardens **immediately after extrusion**—*e.g.*, **within 0.1 and 0.01**

seconds (*see* Ex. 1007, p. 44), which is practically instantaneous. Additionally, a POSITA would have realized, contrary to Crump, that Ma's fiber tow can provide additional rigidity and support to a free-standing structure **without the need to rely exclusively on the curing characteristics of the matrix material**. Further, Ma discloses a 3-D moving stage (*see* Figure 2-20) which allows Ma to construct free-standing structures. Therefore, a POSITA would have ascertained that Ma **is perfectly capable and equipped to form free-standing structures by virtue of its fast-curing matrix material, the use of a fiber tow** (*e.g*., a metal wire, *see* Figure 2-4 at p. 43), and its 3-D moving stage.

264. Therefore, Ma in combination with Crump discloses Claim Element 13[f].

2. Motivation to combine Ma and Crump

265. A POSITA would have been motivated to combine Ma and Crump for at least the reasons discussed above in Ground 4, section V.E.2.

G. Ground 6: The Combination of Ma and Nikzad Renders Obvious Claim 15

1. Independent Claim 15

266. It is my opinion that Ma in combination with Nikzad discloses each and every limitation of Claim 15.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 15[pre])

267. To the extent the preamble is limiting, it is disclosed by Ma and Nikzad, alone and in combination.

268. The preamble of Claim 15 is identical to that of Claim 1, which Ma discloses in Ground 1.

269. Nikzad also discloses "a method of manufacturing of a three-dimensional object." For example, Nikzad discloses **a fused deposition modelling (FDM)** process, which "is **an extrusion based rapid prototyping process**." (Ex. 1009, p. 25.) Nikzad explains:

> Rapid prototyping (PR) describes the physical modelling of a design using digital data-driven, additive processes. Also recognized as additive manufacturing (AM), it is a solid freeform manufacturing process that allows users to fabricate a real physical part ["a three-dimensional object"] directly from a CAD (computer aided design) model.

(*Id.*, p. 1.) In Figure 7-2, Nikzad discloses an apparatus for the FDM process used to form a three-dimensional object.

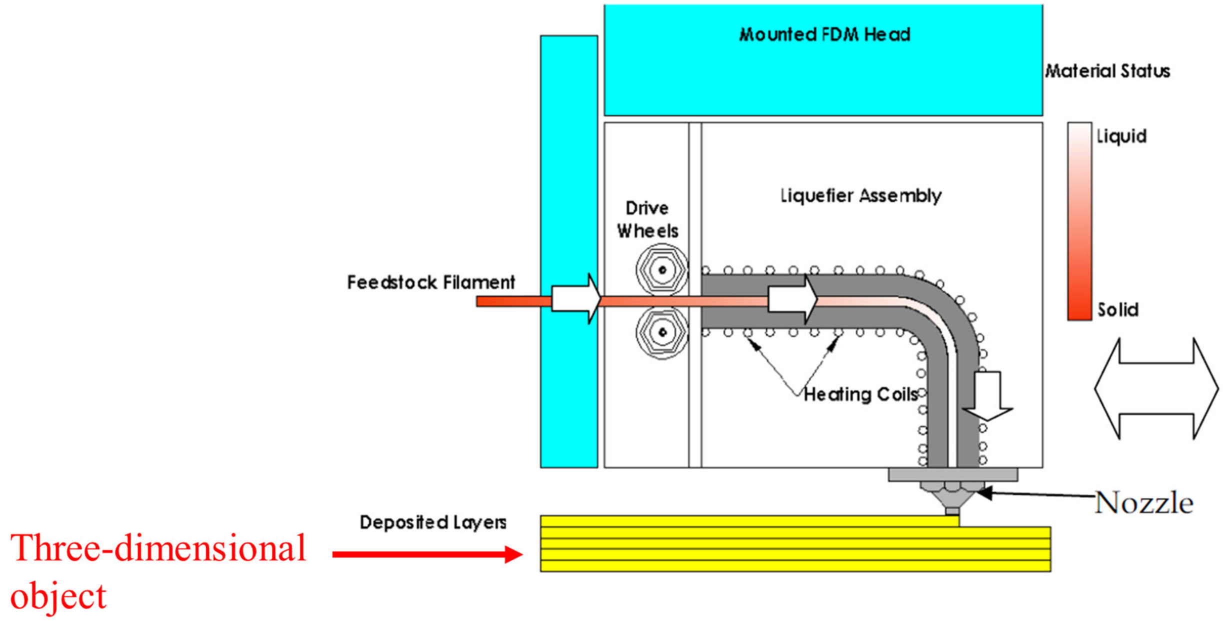


Figure 7-2: Fused Deposition Modelling process in FDM3000

(*Id*., Figure 7-2; annotated.) Thus, Nikzad discloses the preamble of Claim 15.

b. "directing a curable liquid material to a nozzle;" (Claim Element 15[a])

270. Claim Element 15[a] is identical to Claim Element 1[a], which Ma discloses in Ground 1. Accordingly, Ma in combination with Nikzad discloses Claim Element 15[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 15[b])

271. Claim Element 15[b] is identical to Claim Element 1[b], which Ma discloses in Ground 1. Accordingly, Ma in combination with Nikzad discloses Claim Element 15[b].

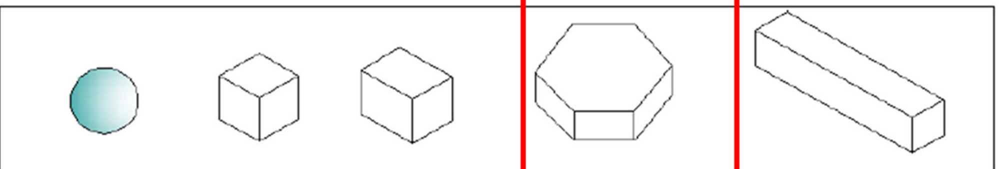
d. "directing flakes of fiber to the nozzle;" (Claim Element 15[c])

272. It is my opinion that Ma in combination with Nikzad discloses Claim Element 15[c].

273. As discussed above for Claim 8 in Ground 1, Ma discloses the use of filler materials in the matrix material ("curable liquid material") to reduce the curing time of the matrix material, reduce the amount of material used, and/or to improve the mechanical properties of the resulting structure. Ma further discloses that the filler material can be pieces of fiber. (*See*, *e.g.*, my analysis for Claim 9 in Ground 1.) However, Ma discloses limited information on filler materials and a POSITA looking into capitalizing on the aforementioned benefits would be motivated to look into other rapid prototyping references that provide additional information on fillers and types of fillers used in the art.

274. Such reference is Nikzad. According to Nikzad, "[s]election of fillers is primarily determined by the particle size distribution and **the particle shape** and, as a consequence of both, the way in which the particles pack together." (Ex. 1009, at p. 65.) Nikzad discloses that fillers can be shaped like **flakes**, as shown by Table 3-2 below.

Table 3-2: Particulate Filler Geometry (Harry 1987)

Idealised Shape Class					
Particle Class	sphere	cube	Block	Flake	Fibre
Descriptor	spheroidal	cubic prismatic rhombohe-dral	tabular prismatic pinacoid irregular	platy flaky	acicular elongated fibrous
Surface area equivalent	1	1.24	1.26-1.5	1.5-9.9	1.87-2.3

(*Id*., Table 3-2.)

275. For example, "iron powder as short fibre fillers" are introduced in Acrylonitrile Butadiene Styrene (ABS) to form a **metal-polymer composite filament material** (*id.*, pp. 68-77), which is subsequently emitted from an extruder's nozzle to form three-dimensional objects (*id.*, Figure 7-2). According to Nikzad, the short iron fiber fillers are shaped like flakes, as shown in Table 3-3.

Table 3-3: Types of fillers used in metal-polymer composite

Particulate	Purity	Size (μm)	Shape	Density (g/mL)	Melting point (^{0}C)
Carbonyl-Iron	≥99.5%	6-9	Spherical	7.86	1535
Iron	97%	~45	Flake	7.86	1535

(*Id.*, Table 3-3.)

276. Nikzad discloses that iron fiber flakes are added to the ABS to increase the modulus and strength of the resulting composite filament material. Nikzad explains:

> Orientation and reinforcement of polymeric chains can significantly increase **tensile modulus and tensile strength** by increasing the interchain forces. **Reinforcing fillers** can very well be used in accordance with the macromolecular mixtures to **increase the modulus and strength** of polymeric matrices.

(*Id.*, p. 64.)

277. A POSITA would have understood that fiber flakes, **based on the teachings and suggestions by Nikzad**, can be added to the matrix material ("curable liquid material") disclosed by Ma to **reduce the curing time of the matrix material, reduce the amount of the matrix material used, and/or to improve the mechanical properties of the resulting structure**. And because Ma discloses "directing a filler material at least partially coated in the curable liquid material to the nozzle," as discussed in Claim 8, it follows that Ma in combination with Nikzad discloses "directing flakes of fiber to the nozzle" as recited in Claim Element 15[c].

e. "discharging from the nozzle a path of composite material containing the continuous strand material

and the flakes of fiber at least partially coated with the curable liquid material;" (Claim Element 15[d])

278. For at least the reasons discussed above in Claim Element 15[c], Ma in combination with Nikzad discloses Claim Element 15[d].

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 15[e])

279. It is my opinion that Ma and Nikzad, alone and in combination, disclose the additional limitation of Claim Element 15[e].

280. For example, the limitation of Claim Element 15[e] is identical to that of Claim Element 16[e], which Ma discloses in Ground 2. Accordingly, Ma discloses the additional limitation of Claim Element 15[e].

281. Nikzad also discloses the additional limitation of Claim Element 15[e]. Figure 2-7 below shows the formation of a three-dimensional object when a feedstock filament is liquified and dispensed through the nozzle of the apparatus as the nozzle moves about.

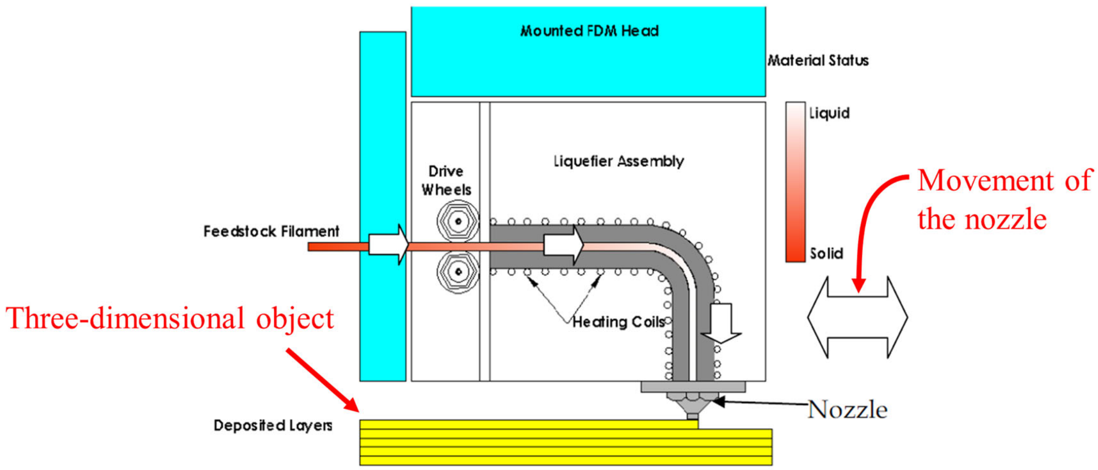


Figure 7-2: Fused Deposition Modelling process in FDM3000

(Ex. 1009, Figure 7-2; annotated.)

g. "curing the curable liquid material in the path of composite material." (Claim Element 15[f])

282. It is my opinion that Ma in combination with Nikzad discloses Claim Element 15[f]. For example, Claim Element 15[f] is identical to Claim Element 14[d], which Ma discloses in Ground 1. For at least the same reasons presented above in connection to Claim Element 14[d] in Ground 1, Ma in combination with Nikzad discloses Claim Element 15[f].

2. Motivation to Combine Ma and Nikzad

283. It is my opinion that a POSITA would have been motivated to combine Ma and Nikzad for the following reasons.

284. A POSITA who is aspired to improve Ma's product quality would be highly motivated to look beyond the teachings of Ma and seek references within

the same field of endeavor as part of the normal course of his/her own research. This means that a POSITA would be inclined to identify references which are not limited to the disclosure of fiber-reinforced building materials, but nevertheless cover important aspects of the rapid prototyping process in greater detail. It is my opinion that such reference is Nikzad.

285. More specifically, a POSITA would have realized, based on Ma's disclosure, that filler materials pre-mixed with the resin can **be highly beneficial for the mechanical properties** of the resulting structure; not to mention the associated **cost benefits**, such as **reducing the amount of resin used and reducing the resin's curing time**. (*See*, *e.g*., Ex. 1007, item 2(a) at p. 22 and p. 47.) However, Ma provides sparse details on this subject and these benefits would have prompted a POSITA to look elsewhere.

286. A POSITA would have recognized that both Ma and Nikzad are directed **to the same field of endeavor**—*i.e*., to rapid prototyping manufacturing methods for fabricating three-dimensional objects from **composite materials**. (*See*, *e.g*., Ex. 1007, p. iv and Ex. 1009, p. 25.) Nikzad's disclosure on fillers premixed with matrix materials to improve the mechanical properties of the resulting composite structure would have motivated a POSITA to consider variations and use these variations in the same field (*e.g*., in Ma) to improve the

mechanical properties of the structures formed by Ma's methods. These variations would also be driven by market forces, such as the need for "high strength-to-weight ratio" structures in aerospace and medical applications reported by Ma. (Ex. 1007 at p. 14.)

287. A POSITA would have recognized that applying Nikzad's teachings to Ma would yield predictable results because this would be based on the combination of prior art elements (*e.g.*, fiber fillers) according to known methods (*e.g.*, pre-mixing fiber fillers in a matrix material) or be the result of applying a known technique (*e.g.*, pre-mixing fiber fillers in a matrix material) to a known device (method or product) ready for improvement. A POSITA would know, based on Ma's disclosure, that filler materials are known in the art and have associated benefits. A POSITA would turn to Nikzad for additional considerations and suggestions with regard to **the type, shape, and size** of the filler material. Therefore, a POSITA would be highly motivated to combine Ma and Nikzad to capitalize on the benefits discussed above.

H. Ground 7: Lipsker Renders Obvious Claims 16-19

1. Independent Claim 16

288. It is my opinion that Lipsker discloses each and every limitation of Claim 16 for at least the same reasons discussed above in Ground 2.

2. Independent Claim 17

289. It is my opinion that Lipsker discloses each and every limitation of Claim 17 for at least the same reasons discussed above in Ground 2.

3. Independent Claim 18

290. It is my opinion that Lipsker discloses each and every limitation of Claim 18.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 18[pre])

291. To the extent the preamble is limiting, it is disclosed by Lipsker because the preamble of Claim Element 18 is identical to the preamble of Claim 16, which Lipsker discloses.

b. "directing a curable liquid material to a nozzle;" (Claim Element 18[a])

292. Lipsker discloses Claim Element 18[a] because Claim Element 18[a] is identical to Claim Element 16[a], which Lipsker discloses.

c. "directing a continuous strand material to the nozzle;" (Claim Element 18[b])

293. Lipsker discloses Claim Element 18[b] because Claim Element 18[b] is identical to Claim Element 16[b], which Lipsker discloses.

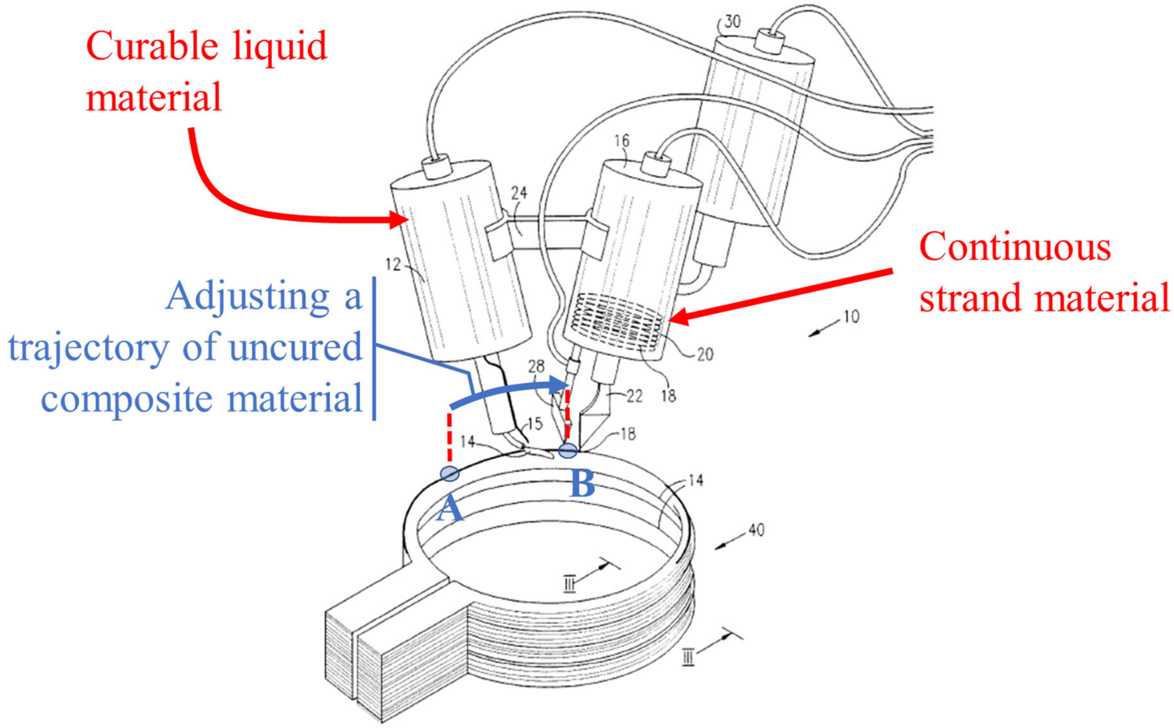
d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 18[c])

294. Lipsker discloses Claim Element 18[c] because Claim Element 18[c] is identical to Claim Element 16[c], which Lipsker discloses.

e. "adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle; and" (Claim Element 18[d])

295. It is my opinion that Lipsker discloses Claim Element 18[d]. For example, a POSITA would have understood that Figure 2 of Lipsker shows forming a three-dimensional object by **adjusting the trajectory** of the wire path coated with adhesive **from location A to a new location B** ("adjusting a trajectory of the path of uncured composite material to a new location") immediately after or while the path of uncured composite material is discharged from the nozzle ("after discharge from the nozzle").

FIG. 2



(Ex. 1006, Figure 2; annotated.) This is because the **uncured path** is still pliable, as opposed to being fixed into place when cured. And for this reason, the uncured path can be **relocated** to a new location by **adjusting the path's trajectory** to properly follow the object's geometry. Once the path is in the desired position, it can be cured.

296. With respect to the process depicted in Figure 2, Lipsker discloses:

> **Actuator 30 preferably dispenses layers of wire 18 in accordance with the geometry of object 34** [as depicted in Figure 1], and adhesive dispenser 12 applies adhesive 14 to wire 18 so as to bond [after curing] a previously dispensed portion of wire 18 to a presently

> dispensed portion of wire 18. **A successive layer of wire 18 may be dispensed one on top of a previous layer. Adhesive 14 then cures so that the layers of wire 18 form a prototype 40 of object 34.**

(*Id.*, 5:24-32.) A POSITA would have further understood that the process depicted in Figure 2 can be equally performed by the apparatus shown in Figure 5 where the wire ("the continuous strand") is discharged from nozzle 22 pre-coated with the adhesive 12 ("the curable liquid material").

297. Accordingly, Lipsker discloses Claim Element 18[d].

f. "curing the curable liquid material in the path of uncured composite material at the new location after adjusting." (Claim Element 18[e])

298. It is my opinion that Lipsker discloses Claim Element 18[e]. As discussed above in Claim Element 18[d], Lipsker discloses that once the wire layer pre-coated with uncured adhesive ("the path of uncured composite material") is laid down to the new location (*e.g.*, point B in Figure 2 above), adhesive 14 ("the curable liquid material") is cured to bond the freshly disposed layer to the underlying cured layers. Curing adhesive 14 ("the curable liquid material") occurs by exposing the adhesive to UV light via an optic fiber, as discussed in Claim 3 of Ground 3. Accordingly, a POSITA would have understood that Lipsker discloses Claim Element 18[e].

4. Independent Claim 19

299. It is my opinion that Lipsker discloses each and every limitation of Claim 19 for at least the reasons discussed above in Ground 2.

I. Ground 8: The Combination of Lipsker and Crump Renders Obvious Claim 13 and 20

1. Independent Claim 13

300. It is my opinion that Lipsker in combination with Crump discloses each and every limitation of Claim 13.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 13[pre])

301. To the extent the preamble is limiting, it is disclosed by Lipsker and Crump, alone and in combination.

302. For example, Lipsker discloses the preamble of Claim 13 because the preamble of Claim 13 is identical to that of Claim 16, which Lipsker discloses. Crump also discloses the preamble of Claim 13 for at least the reasons discussed above in Ground 3.

b. "directing a curable liquid material to a nozzle;" (Claim Element 13[a])

303. Claim Element 13[a] is identical to Claim Element 16[a], which Lipsker discloses in Ground 2. Therefore, Lipsker in combination with Crump discloses Claim Element 13[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 13[b])

304. Claim Element 13[b] is identical to Claim Element 16[b], which Lipsker discloses in Ground 2. Therefore, Lipsker in combination with Crump discloses Claim Element 13[b].

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 13[c])

305. Claim Element 13[c] is identical to Claim Element 16[c], which Lipsker discloses in Ground 2. Therefore, Lipsker in combination with Crump discloses Claim Element 13[c].

e. "bonding an end point of the path of composite material to an anchor; and" (Claim Element 13[d])

306. It is my opinion that Lipsker in combination with Crump discloses Claim Element 13[d].

307. Lipsker discloses that the adhesive ("the curable liquid material") in the adhesive-coated wire ("the path of composite material") forms bonding sites between previously and presently dispensed paths. Lipsker explains:

> Actuator 30 preferably dispenses layers of wire 18 in accordance with the geometry of object 34, and adhesive dispenser 12 applies adhesive 14 to wire 18 so as **to bond a previously dispensed portion of wire 18 to a presently dispensed portion of wire 18. A successive layer of Wire 18 may be dispensed one on top of a previous layer.** Adhesive 14 then cures so that the layers of Wire 18 form a prototype

40 of object 34.

(Ex. 1006, 5:25-29.) And "[a]dhesive 18 may be applied **to bond wire 18 to bed 26**, if desired, in order to **fix the first layer of wire 18 in place**." (*Id*., 5:50-52.) A POSITA would have understood that "**bonding**" is an outcome of the curing process, which causes the matrix material **to harden and adhere** to the previous layer or to the bed. Each bonding site to which the presently dispensed path is attached is the recited "anchor."

308. Crump, similar to Lipsker, discloses forming **bonding sites**, which **anchor** the building material to any desired surface, **by solidifying the building material**. For example, Crump discloses "dispensing a material at a controlled rate from a dispensing head unto a substrate or base member …, with the material being dispensed in multiple layers **which solidify and adhere** to each other to build up the article." (Ex. 1008, 3:10-16.) According to Crump, **these bonding sites are anchors** or **anchor point locations**. Crump explains: "For the object shown in FIG. 12 the strands **are anchored** at two points and also to each other where they intersect."

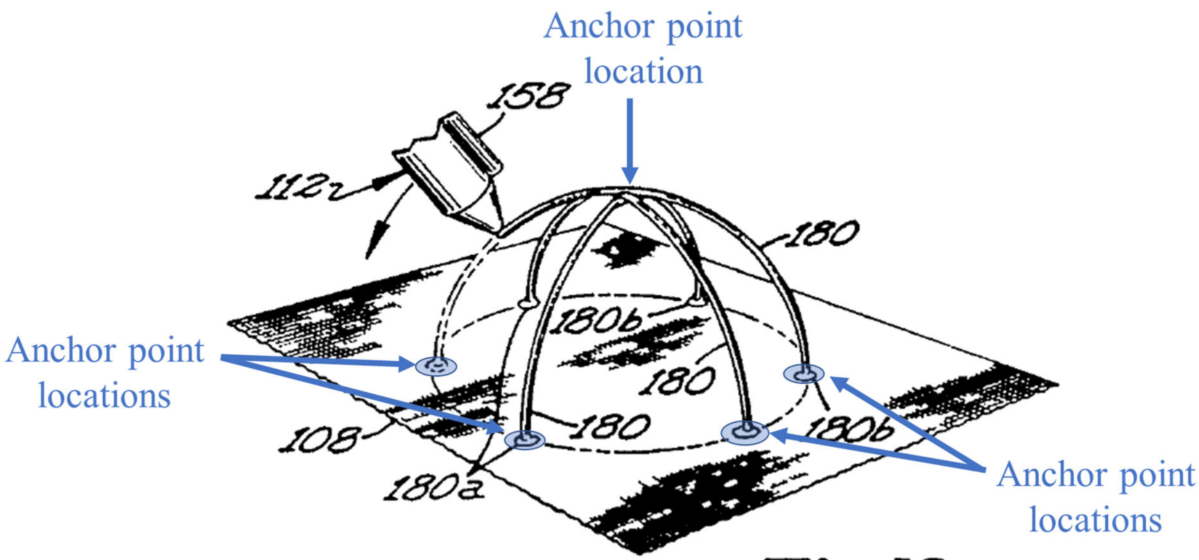


Fig 12

(*Id.*, Figure 12; annotated.)

309. A POSITA would have found that the bonding sites or anchor locations disclosed by Lipsker and Crump correspond to the recited "anchor."

310. Further, and as discussed in the analysis presented for Claim Element 13[d] in Ground 5, irrespective of the fact that Crump does not discuss fiber-based materials, a POSITA would have found that the concept of "bonding an end point of the path to [] an anchor" is neither new nor novel, as demonstrated by Crump. And because Lipsker discloses the same concept with Crump and **explicitly discloses** a "path of composite material," Lipsker in combination with Crump discloses Claim Element 13[d].

f. "moving the nozzle during discharging to cause the path of composite material to extend away from the anchor; and" (Claim Element 13[e])

311. It is my opinion that Lipsker in combination with Crump discloses Claim Element 13[e]. A POSITA would have understood that once the adhesive-coated wire ("the path of composite material") of Lipsker is bonded to a location, subsequent movement of the nozzle while discharging additional adhesive-coated wire **inevitably** causes the discharged wire portion "to extend away from the anchor" since the anchor is a stationary point.

312. Furthermore, and as discussed in Ground 5, a POSITA would have realized that Crump discloses the concept of "moving the nozzle during discharging to cause the path [] to extend away from the anchor." And because Lipsker discloses the same concept with Crump, and additionally, explicitly discloses a "path of composite material," Lipsker in combination with Crump discloses Claim Element 13[e].

g. "exposing the curable liquid material in the path of composite material to a cure energy while the nozzle is moving such that the path of composite material is hardened at a fixed location in three-dimensional space without support at locations between the anchor and the nozzle." (Claim Element 13[f])

313. It is my opinion that Lipsker in combination with Crump discloses Claim Element 13[f]. As discussed above in Ground 2, Lipsker discloses curing

the adhesive ("the curable liquid material") by exposing it to UV light—*i.e.*, UV energy. (*See*, *e.g.*, 3:42-46.) Accordingly, Lipsker discloses "exposing the curable liquid material in the path of composite material to a cure energy." A POSITA would have also understood that Lipsker's apparatus is capable of curing the adhesive while "the nozzle is moving." Therefore, Lipsker discloses "exposing the curable liquid material in the path of composite material to a cure energy while the nozzle is moving."

314. A POSITA who is looking to find ways to fabricate more complex and elaborate three-dimensional objects, such as free-standing three-dimensional structures, would be inclined to look beyond the teachings of Lipsker, as part of the normal course of his/her own research. For example, a POSITA would have been motivated to look into the work of others, such as the work from Crump, as discussed in Ground 5—the analysis of which is incorporated here.

315. A POSITA would have envisioned that Crump's teachings would be applicable to Lipsker if an adhesive ("a curable liquid material") is appropriately selected to **harden rapidly** when exposed to UV light ("a cure energy"). Indeed, Lipsker is consistent with this notion because Lipsker acknowledges that "[t]he adhesive is preferably **a quick curing adhesive.**" (*See* Ex. 1006, 2:29). Further, Lipsker discloses that "**no external supports are generally needed to support**

the deposited layers" (*id*., 1:57-59), which means that Lipsker is able to produce three-dimensional structures "without support at locations between the anchor and the nozzle." This is because Lipsker's wire can provide additional rigidity and support to the free-standing structure without the need to rely exclusively on the curing characteristics of the adhesive, as would be understood by a POSITA. Therefore, a POSITA, based on the teachings from Crump and disclosure from Lipsker, would have established that Lipsker is perfectly capable of forming free-standing structures by virtue of its fast-curing adhesive material and the use of a wire core.

316. Accordingly, Lipsker in combination with Crump discloses Claim Element 13[f].

2. Claim 20: "wherein discharging from the nozzle the first path of composite material and the second path of composite material includes simultaneously discharging the first and second paths of composite material."

317. Claim 20 depends from Claim 19, which Lipsker discloses. It is my opinion that Lipsker in combination with Crump discloses Claim 20 for at least the reasons discussed above in Ground 4.

3. Motivation to Combine Lipsker and Crump

318. A POSITA would have been motivated to combine Lipsker and Crump for at least the reasons discussed above in Ground 4, section V.E.2.

J. Ground 9: The Combination of Lipsker and Nikzad Renders Obvious Claim 15

1. Independent Claim 15

319. It is my opinion that Lipsker in combination with Nikzad discloses each and every limitation of Claim 15.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 15[pre])

320. To the extent the preamble is limiting, it is disclosed by Lipsker and Nikzad, alone and in combination. For example, the preamble of Claim 15 is identical to that of Claim 16, which Lipsker discloses in Ground 2. Nikzad also discloses the preamble of Claim 15, as discussed in Ground 6.

b. "directing a curable liquid material to a nozzle;" (Claim Element 15[a])

321. Claim Element 15[a] is identical to Claim Element 16[a], which Lipsker discloses in Ground 2. For at least the same reasons presented above in Claim Element 16[a], Lipsker in combination with Nikzad discloses Claim Element 15[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 15[b])

322. Claim Element 15[b] is identical to Claim Element 16[b], which Lipsker discloses in Ground 2. For at least the same reasons presented above in Claim Element 16[b], Lipsker in combination with Nikzad discloses Claim

Element 15[b].

d. "directing flakes of fiber to the nozzle;" (Claim Element 15[c])

323. In the background section, Lipsker discusses limitations of fused deposition modeling (FDM) processes. (*See*, *e.g*., Ex. 1006, 1:24-35.) In 2012 (*e.g*., around the priority date of '798 patent), a POSITA looking at Lipsker's disclosure, which was made available on November 28, 2000, would be inclined to look **at more contemporary** FDM references, like Nikzad's that was published on September 28, 2011, to get updated on the recent developments in the FDM arena as part of the normal course of his/her own research. After all, FDM is a rapid prototyping method like Lipsker's and therefore pertinent to a POSITA's research.

324. As discussed in Ground 6, Nikzad discloses the use of flakes of fiber as fillers in polymer building materials to increase the modulus and strength of the resulting composite three-dimensional structure. Therefore, a POSITA looking into capitalizing on the benefits disclosed by Nikzad, would have understood that fiber flakes, similar to the iron fiber flakes disclosed by Nikzad, can be pre-mixed with Lipsker's polymer adhesive (*see* Ex. 1006, at 3:35-38 and Claim 4) to improve the mechanical properties of Lipsker's adhesive; and by extension increase the stiffness of the resulting three-dimensional structure. And because Lipsker discloses "directing a curable liquid material to a nozzle," as discussed in

connection to Claim Element 16[b] in Ground 2, it follows that Lipsker in combination with Nikzad discloses "directing flakes of fiber [pre-mixed with the adhesive ("the curable liquid material")] to the nozzle" according to Claim Element 15[c].

325. Thus, Lipsker in combination with Nikzad discloses Claim Element 15[c].

e. "discharging from the nozzle a path of composite material containing the continuous strand material and the flakes of fiber at least partially coated with the curable liquid material;" (Claim Element 15[d])

326. For at least the reasons discussed above in Claim Element 15[c], Lipsker in combination with Nikzad discloses Claim Element 15[d].

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 15[e])

327. It is my opinion that Lipsker and Nikzad, alone and in combination, disclose the additional limitation of Claim Element 15[e].

328. For example, the limitation of Claim Element 15[e] is identical to that of Claim Element 16[e], which Lipsker discloses in Ground 2. Accordingly, Lipsker discloses the additional limitation of Claim Element 15[e]. Nikzad also discloses that additional limitation Claim Element 15[e] at least for the reasons discussed above in Ground 4.

g. "curing the curable liquid material in the path of composite material." (Claim Element 15[f])

329. Claim Element 15[f] is identical to Claim Element 17[d], which Lipsker discloses in Ground 2. For at least the reasons presented in Ground 2 for Claim Element 17[d], Lipsker in combination with Nikzad discloses Claim Element 15[f].

2. Motivation to Combine Lipsker and Nikzad

330. It is my opinion that a POSITA would have been motivated to combine Lipsker and Nikzad for the following reasons.

331. A POSITA who is aspired to improve Lipsker's product quality would be highly motivated to look beyond the teachings of Lipsker and seek references within **the same field of endeavor** as part of the normal course of his/her own research on rapid prototyping. This means that a POSITA would be inclined to identify references which may not be limited to the disclosure of fiber-reinforced building materials, but nevertheless cover other important aspects of the rapid prototyping process in greater detail. It is my opinion that Nikzad is such reference.

332. For example, a POSITA familiar with Lipsker's disclosure would have known that Lipsker discusses limitations of FDM-based processes that were available circa 2000. However, the same POSITA in 2012 (*e.g.*, around the

priority date of ’798 patent) would be prompted to seek more contemporary FDM references (such as Nikzad’s, published circa 2011) to get informed on the **recent** developments in the FDM field. And because FDM is a rapid prototyping process, like Lipsker’s, a POSITA would be motivated to consider such references for providing valuable aspects of the rapid prototyping process.

333. Nikzad’s disclosure on fillers pre-mixed in matrix materials to improve the mechanical properties of the resulting composite structure would not have gone unnoticed, and would have prompted a POSITA to consider variations of Nikzad’s teachings. A POSITA would have been motivated to use these variations in the same field (*e.g.*, in Lipsker) to improve the mechanical properties of the objects formed by Lipsker. These variations would also be triggered by design incentives or market forces, such as the need to fabricate three-dimensional objects without supporting structures as reported by Lipsker. (Ex. 1008, at 1:32-35).

334. A POSITA would have recognized that applying Nikzad’s teachings to Lipsker would yield predictable results because this would be based on the combination of prior art elements (*e.g.*, fiber fillers) according to known methods (*e.g.*, pre-mixing fiber fillers in a matrix material) and/or be the result of applying a known technique (*e.g.*, pre-mixing fiber fillers in a matrix material) to a known

device (method, or product) ready for improvement. A POSITA would have found that Nikzad provides considerations and suggestions regarding **the type, shape, and size** of the filler material. Therefore, a POSITA would be highly motivated to combine Lipsker with Nikzad to capitalize on the aforementioned gains.

K. Ground 10: The Combination of Lipsker and Ma Renders Obvious Claims 1-3, 5-12, and 14

1. Independent Claim 1

335. It is my opinion that Lipsker in combination with Ma discloses each and every limitation of Claim 1.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 1[pre])

336. To the extent the preamble is limiting, it is disclosed by Lipsker and Ma, alone and in combination. For example, the preamble of Claim 1 is identical to that of Claim 16, which Lipsker discloses in Ground 2. Ma also discloses the preamble of Claim 1, as discussed above in Ground 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 1[a])

337. Lipsker and Ma, alone and in combination, disclose Claim Element 1[a]. Claim Element 1[a] is identical to Claim Element 16[a], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 1[a] in Ground 1.

c. "directing a continuous strand material to the nozzle;" (Claim Element 1[b])

338. Lipsker and Ma, alone and in combination, disclose Claim Element 1[b]. Claim Element 1[b] is identical to Claim Element 16[b], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 1[b] in Ground 1.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 1[c])

339. Lipsker and Ma, alone and in combination disclose Claim Element 1[c]. Claim Element 1[c] is identical to Claim Element 16[c], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 1[c] in Ground 1.

e. "bonding an end point of the path of composite material to an anchor; and" (Claim Element 1[d])

340. It is my opinion that Lipsker and Ma, alone and in combination, disclose Claim Element 1[d]. For example, Claim Element 1[d] is identical to Claim Element 13[d], which Lipsker discloses in Ground 8. Similarly, Ma discloses Claim Element 1[d], as discussed in Ground 1.

f. "moving the nozzle away from the anchor during discharging to pull the path of composite material out of the nozzle." (Claim Element 1[e])

341. It is my opinion that Lipsker in combination with Ma discloses Claim Element 1[e]. As discussed in Claim Element 1[d], Lipsker discloses "bonding an end point of the path of composite material to an anchor." A POSITA would have understood based on his/her own knowledge that anchoring can be used to create

tension in the path and cause the path to be pulled out of the nozzle as the nozzle moves away from the anchor. This is analogous to anchoring an adhesive tape on a surface and pulling the tape dispenser away from the anchor point to automatically pull the tape from the dispenser. In other words, **anchoring implies a passive supplying process**; otherwise, there would be no need to form anchors—like in the case of active supplying process where the wire is **pushed** through the nozzle via a roller-based mechanism, **which is notably absent** from Lipsker's disclosure. Indeed, Lipsker discloses:

> wire dispenser 16 may comprise a bobbin for holding the wire 18 and wire 18 may simply be spooled off from the bobbin, such as through wheels and guides to prevent snagging, in a manner similar to that of a sewing machine.

(Ex. 1006, 3:62-66.) Accordingly, a POSITA would have understood that Lipsker discloses **a passive supplying process for its wire** resembling the operation of a sewing machine in which the thread is first stitched (*i.e.*, anchored) on a piece of cloth and subsequently spooled off from a bobbin (*i.e.*, pulled) as the cloth is pushed away underneath the weaving needle.

342. A POSITA eager to learn more about the passive supplying process would be inclined to look beyond Lipsker and find references, like Ma, that describe the passive supplying process in greater detail. As discussed in Ground 1,

Ma not only explicitly discloses "pull[ing] the path of composite material out of the nozzle", but also explains how the anchor formation relates to pulling.

343. Accordingly, Lipsker in combination with Ma discloses Claim Element 1[e].

2. Claim 2: "wherein bonding the end point of the path of composite material to the anchor includes:"

344. Claim 2 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker and Ma, alone and in combination, disclose the additional limitations of Claim 2.

a. "placing the end point of the path of composite material on the anchor; and" (Claim Element 2[a])

345. As discussed in Ground 1, a POSITA would have understood that "placing the end point of the path of composite material on the anchor" corresponds to placing the path of composite material to a selected point location ("the anchor") to which the path will be attached. Both Lipsker and Ma, alone and in combination, disclose this limitation—for Lipsker *see*, *e.g.*, Claim Element 13[d] in Ground 8 and for Ma *see*, *e.g.*, Claim Element 2[a] in Ground 1.

b. "aiming a curing device at the path of composite material on the anchor." (Claim Element 2[b])

346. As discussed for Claim Element 16[d] in Ground 2, Lipsker discloses "aiming a curing device at the path of discharged composite material to cure the

curable liquid material," which, as discussed for Claim Element 13[d] in Ground 8, occurs over each anchor point location ("on the anchor"). Accordingly, Lipsker discloses the additional limitation of Claim Element 2[b]. Ma also discloses the additional limitation of Claim Element 2[b], as discussed in Ground 1.

3. Claim 3: "wherein aiming the curing device includes aiming at least one UV light."

347. Claim 3 depends from Claim 2, the additional limitation of which Lipsker and Ma disclose, alone and in combination. It is my opinion that Lipsker in combination with Ma discloses Claim 3 for at least the reasons presented in Ground 2.

4. Claim 5: "wherein aiming the at least one UV light includes aiming the at least one UV light from only a trailing side of the nozzle."

348. Claim 5 depends from Claim 3, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma also discloses Claim 5 for at least the reasons presented above in Ground 2.

5. Claim 6: "wherein discharging from the nozzle the path of composite material includes discharging the path of composite material through a nozzle orifice having a diameter of about 2 mm."

349. Claim 6 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma also discloses or renders obvious Claim 6. Lipsker discloses that its apparatus is able to handle

wires with a diameter down to 0.001 mm for superior accuracy. (*See*, Ex. 1006, 4:22-24 and 4:47-48.) Further, Lipsker in referring to Figure 4B discloses that "[w]ire dispenser 17 has an inner diameter D that is **slightly larger than the diameter of the wire being dispensed**." (*Id*., 4:20-21.) However, Lipsker does not discuss the dimensions of its nozzle 22. Therefore, a POSITA concerned with wire and nozzle dimensions and eager to learn more would be strongly motivated to look elsewhere. Ma studies in detail the effect of the nozzle's diameter and provides several **commonly used nozzle diameters**, including a nozzle diameter of 2 mm. (*See*, *e.g*., the analysis presented for Claim 6 in Ground 1.)

350. Accordingly, a POSITA would have found that Lipsker in combination with Ma discloses or renders obvious Claim 6 for at least the reasons presented above in connection to Claim 6 in Ground 1.

6. Claim 7: "wherein the continuous strand material includes a plurality of strands arranged in at least one of a tow, a roving, and a weave."

351. Claim 7 depends from Claim 6, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker and Ma, alone and in combination, disclose the additional limitation of Claim 7.

352. For example, Lipsker discloses that "throughout the specification and the claims the term "wire" encompasses any **slender**, dispensable building

element, such as, but not limited to, wire, rod, bar, **string**, **rope**, **thread**, **yarn**, **cord**, **filament**, fiber, **twine**, **strand**, chain, cable, or **wire twist**." (Ex. 1006, 2:18-22.) A POSITA would have understood that the above description of the term wire ("the continuous strand material") encompasses "a plurality of strands arranged in at least one of a tow, a roving, and a weave" since string, rope, yarn, twine, and wire twists are **composed of multiple strands of material** similar to a tow, a roving, and a weave. Accordingly, Lipsker discloses the additional limitation of Claim 7.

353. Ma also discloses the additional limitation of Claim 7, as discussed above in Ground 1.

7. Claim 8: "wherein directing the curable liquid material to the nozzle includes directing a filler material at least partially coated in the curable liquid material to the nozzle."

354. Claim 8 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma also discloses Claim 8.

355. A POSITA aspired to **improve the quality** of the fabricated three-dimensional object and to **reduce the fabrication cost**, which are both highly desirable outcomes, would be highly motivated to look beyond the teachings of Lipsker as part of the normal course of his/her own research. For example, a

POSITA would be inclined to look into Ma which discloses that fillers can be pre-mixed with the curable liquid material to: (i) reduce the curing time of the curable liquid material, (ii) reduce the amount of curable liquid material used, and (iii) improve the mechanical properties of the resulting structure, as discussed above in Ground 1.

356. And because Ma discloses Claim 8, Lipsker in combination with Ma discloses Claim 8.

8. Claim 9: "wherein the filler material includes pieces of fibers."

357. Claim 9 depends on Claim 8, which Lipsker in combination with Ma discloses. Lipsker in combination with Ma also discloses Claim 9 for at least the reasons discussed above in Ground 1 in connection to Ma.

9. Claim 10: "wherein the continuous strand material is hollow."

358. Claim 10 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma renders Claim 10 obvious. This is because Lipsker, similar to Ma, discloses glass fibers (*see*, *e.g.*, Ex. 1006, at 4:38-42), which a POSITA would have known to be available in the form of a hollow fiber material, as disclosed by Pang (*see* my analysis for Claim 10 in Ground 1). Further, a POSITA would have been familiar with the benefits of

glass fibers in reducing the weight of the fabricated structure without compromising the strength of the final product. Therefore, based on the combined disclosures from Lipsker and Ma, and further in view of his/her knowledge, a POSITA would have found that Lipsker in combination with Ma renders Claim 10 obvious.

10. Claim 11

359. Claim 11 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker and Ma, alone and in combination, disclose the additional limitations of Claim 11.

a. "further including: curing a first portion of the path of composite material;" (Claim Element 11[a])

360. Lipsker discloses that each fresh (*i.e.*, uncured) layer of adhesive-coated wire ("the path of composite material") is dispensed and cured on top of a previously dispensed and cured layer until the desired object is formed:

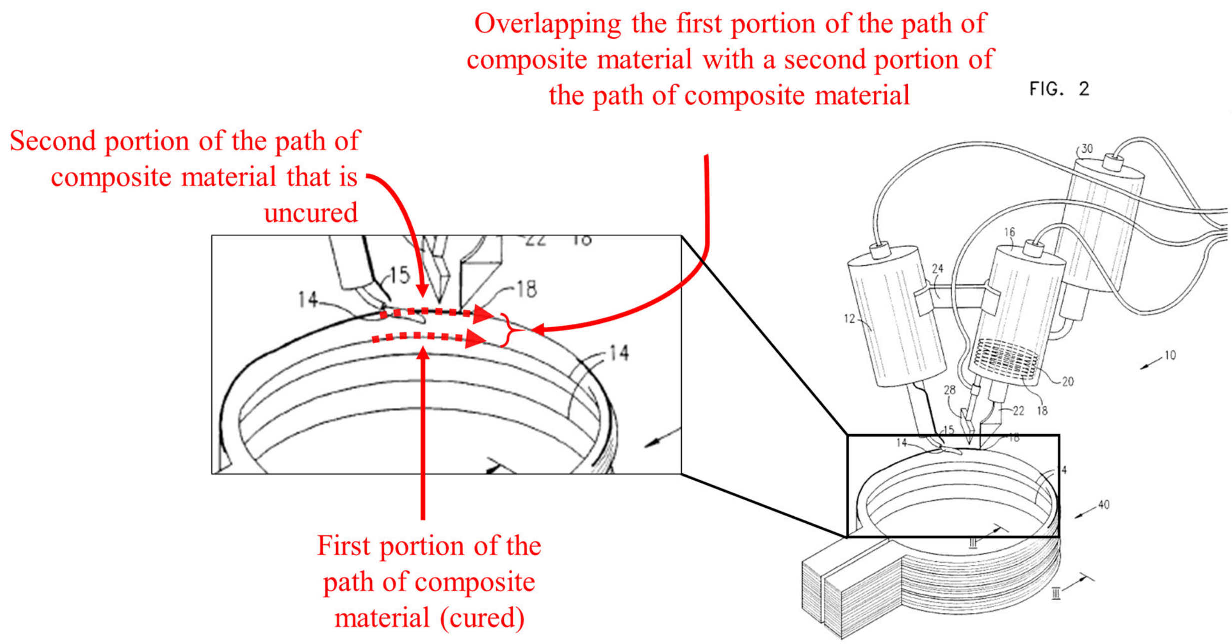
> Actuator 30 preferably dispenses layers of wire 18 in accordance with the geometry of object 34, and adhesive dispenser 12 applies adhesive 14 to wire 18 so as to bond [via curing] a previously dispensed [cured] portion of wire 18 to a presently dispensed [uncured] portion of wire 18. A successive [uncured] layer of wire 18 may be dispensed one on top of a previous [cured] layer. Adhesive 14 then cures so that the layers of wire 18 form a prototype 40 of object 34.

(Ex. 1008, 5:24-31.) Therefore, a POSITA would have understood that the previously dispensed and cured layer of wire corresponds to "curing a first portion of the path of composite material" recited in Claim Element 11[a].

361. As discussed in Ground 1, Ma also discloses the additional limitation of Claim Element 11[a].

b. "overlapping the first portion of the path of composite material with a second portion of the path of composite material that is uncured; and" (Claim Element 11[b])

362. As discussed above in Claim Element 11[a], Lipsker discloses that a fresh, uncured layer of wire ("a second portion of the path of composite material") is subsequently dispensed over a previously dispensed cured layer ("the first portion of the path of composite material"). Therefore, a POSITA would have understood from the above that Lipsker discloses "overlapping the first portion of the path of composite material with a second portion of the path of composite material that is uncured," as shown in Figure 2 below.



(Ex. 1006, Figure 2; annotated.)

363. As discussed in Ground 1, Ma (like Lipsker) also discloses the additional limitation of Claim Element 11[b].

c. "curing the second portion of the path of composite material while the first and second portions of the path of composite material are overlapped." (Claim Element 11[c]

364. As discussed above in Claim Element 11[a], Lipsker discloses "[a] successive layer of wire 18 ["second portion of the path of composite material"] may be dispensed one on top of a previous layer ["first portion of the path of composite material"]. **Adhesive 14 then cures** so that the layers of wire 18 form a prototype 40 of object 34." (Ex. 1006, 5:28-31.) And because curing the second portion of the path of composite material occurs "while the first and second

portions of the path of composite material are overlapped," as shown in Figure 2 above, Lipsker discloses the additional limitation of Claim Element 11[c].

365. Ma also discloses the additional limitation of Claim Element 11[c] for at least the reasons discussed above in Ground 1.

11. Claim 12: "wherein the overlapping includes wrapping the second portion of the path of composite material around the first portion of the path of composite material."

366. Claim 12 depends from Claim 1, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma also discloses Claim 12 for at least the reasons discussed above in Ground 2.

12. Independent Claim 14

367. It is my opinion that Lipsker in combination with Ma discloses each and every limitation of Claim 14.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 14[pre])

368. To the extent the preamble is limiting, it is disclosed by Lipsker and Ma, alone and in combination. For example, the preamble of Claim 14 is identical to that of Claim 16, which Lipsker discloses in Ground 2. Ma also discloses the preamble of Claim 14 in Ground 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 14[a])

369. Lipsker and Ma, alone and in combination, disclose Claim Element

14[a]. Claim Element 14[a] is identical to Claim Element 16[a], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 14[a] in Ground 1.

c. "directing a continuous strand material to the nozzle;" (Claim Element 14[b])

370. Lipsker and Ma, alone and in combination, disclose Claim Element 14[b]. Claim Element 14[b] is identical to Claim Element 16[b], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 14[b] in Ground 1.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 14[c])

371. Lipsker and Ma, alone and in combination, disclose Claim Element 14[c]. Claim Element 14[c] is identical to Claim Element 16[c], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 14[c] in Ground 1.

e. "curing the curable liquid material in the path of composite material; and" (Claim Element 14[d])

372. Lipsker and Ma, alone and in combination, disclose Claim Element 14[d]. Claim Element 14[d] is identical to Claim Element 17[d], which Lipsker discloses in Ground 2. Ma also discloses Claim Element 14[d] in Ground 1.

f. "moving the nozzle during discharging to create tension in the continuous strand material that remains after curing of the composite material." (Claim Element 14[e])

373. It is my opinion that Lipsker in combination with Ma discloses Claim

Element 14[e]. As discussed in Claim Element 1[e], a POSITA would have understood that Lipsker discloses **a passive supplying process for its wire** that resembles the operation of a sewing machine. Further, A POSITA who is eager to learn more about the passive supplying method would be inclined to look beyond Lipsker and find references, like Ma, that describe the passive supply method in greater detail. Therefore, and at least for the same reasons presented for Ma in connection to Claim Element 14[e] in Ground 1, Lipsker in combination with Ma discloses Claim Element 14[e].

13. Motivation to Combine Lipsker and Ma

374. For the motivation to combine Lipsker and Ma refer to Ground 2, section V.C.7.

L. Ground 11: The Combination of Lipsker, Ma, and Masters Renders Obvious Claim 4

1. Claim 4: "wherein aiming the at least one UV light includes aiming a plurality of lights from different angles around the nozzle."

375. Claim 4 depends from Claim 3, which Lipsker in combination with Ma discloses. It is my opinion that Lipsker in combination with Ma and Masters discloses Claim 4 for at least the same reasons presented above in Ground 3, the analysis of which is incorporated here.

2. Motivation to combine Lipsker, Ma, and Masters

376. A POSITA would be motivated to combine Lipsker, Ma, and Masters for at least the reasons presented above in Ground 3, section V.D.2.

M. Ground 12: Wohrl Renders Obvious Claims 1, 2, 11, 16, and 18

1. Independent Claim 1

377. It is my opinion that Wohrl discloses each and every limitation of Claim 1.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 1[pre])

378. To the extent the preamble is limiting, it is disclosed by Wohrl. For example, Wohrl is titled "Method for Manufacturing a Three-Dimensionally Twisted Rotor Blade Airfoil," (Ex. 1010, Title) and "relates to a method for the manufacture of a fibre reinforced component, particularly a three-dimensionally twisted rotor blade airfoil, by wrapping a core with a resin-impregnated fibre material." (*Id*., 1:1-4.)

379. And because a three-dimensionally twisted rotor blade airfoil **is a three-dimensional object**, Wohrl discloses the preamble of Claim 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 1[a])

380. Wohrl discloses that the resin matrix is a **liquid** because it **impregnates** or **wets** the fibre strand, and further, that the resin matrix is a "**curable** liquid material" because it is **precured** by a precuring facility. For

example, Wohrl discloses: “fibre strand 9 is **continuously impregnated** with **resin** material” (Ex. 1010, Abstract), and further that:

> fibre strands **wetted** with **a resin matrix** are pressed against the core for example, by means of a nip roller, and **the resin matrix precured** immediately thereafter, preferably **by a precuring facility** such as an infrared radiator coupled to the nip roller.

(*Id*., 2:21-26.) According to Wohrl, “the wrapped component is pressed to final size in a mould and [fully] cured in a furnace.” (*Id.*, 3:10-11.)

381. Figure 2 of Wohrl shows that “[t]he matrix material is supplied from a storage 16 to the matrix metering unit 14 through a flexible feed line 17” and from the matrix metering unit 14 to a nozzle through a feed duct 13. (*Id.*, 4:20-5:1.)

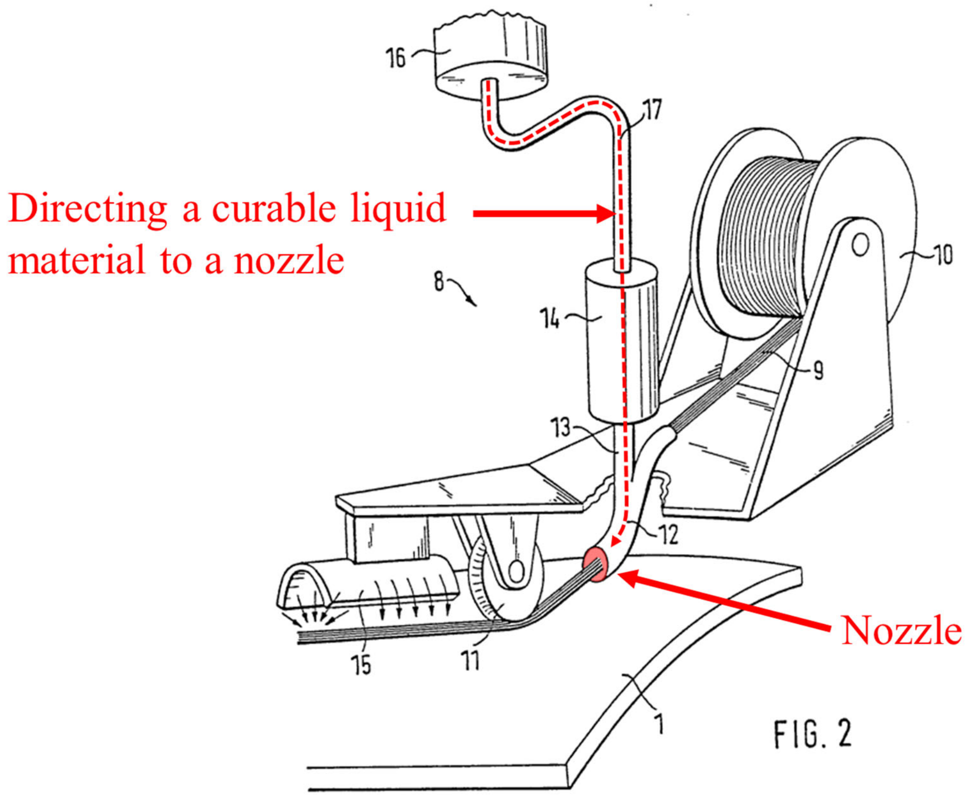


FIG. 2

(*Id.*, Figure 2; annotated.) Accordingly, Wohrl discloses Claim Element 1[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 1[b])

382. In referring to Figure 2, Wohrl discloses that fibre strand 9 ("a continuous strand material") is also directed to the nozzle via fibre feed duct 12. Accordingly, Wohrl discloses Claim Element 1[b].

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 1[c])

383. As discussed above in Claim Element 1[a], Wohrl discloses that fibre strand 9 ("the continuous strand material") is mixed with resin ("the curable liquid

material") inside fibre feed duct 12. (*See*, Ex. 1010, 4:23-27.) Subsequently, the impregnated or wetted fibre strand 9 exits fibre feed duct 12 through the nozzle. A POSITA would have understood that the impregnated or wetted fibre strand 9 is "a path of composite material containing the continuous strand material at least partially coated with the curable liquid material." Accordingly, Wohrl discloses Claim Element 1[c].

e. "bonding an end point of the path of composite material to an anchor; and" (Claim Element 1[d])

384. Wohrl discloses that precuring the path of impregnated fibre ("the path of composite material") causes it to **cement in a fixed point location** ("bonding an end point of the path of composite material to an anchor"). Wohrl explains: "[p]recuring the matrix material causes it to gel to **a point where the fibre is cemented in place** before the fibre matrix mixture still is fully cured" (*see* Ex. 1010, 3:7-9) and further "the fibre is **fixed to a point** where it can be laid on to radiused tracks. Thereafter, further fibre layers can be deposited in any desired orientation over the precured fibres" (*see id.*, 5:7-10). A POSITA would have understood from the above description that precuring **secures (*e.g.*, anchors) selected portions** of the fibre on a surface (or on a previous layer) so that the "fibre layers can be deposited in any desired orientation." This means that **precuring results in the formation of anchors** in selected portions of the fibre

(*e.g.*, partially cures the fibre). A POSITA would have further understood that subsequent curing in a furnace concludes the curing process **for the entire structure**. Accordingly, Wohrl discloses Claim Element [d].

f. "moving the nozzle away from the anchor during discharging to pull the path of composite material out of the nozzle." (Claim Element 1[e])

385. Wohrl discloses that "**[t]he fibre strand 9 unwound from the fibre drum 10 is pulled** by the nip roll 11 through the fibre feed duct 12 into which matrix material is fed in defined quantities from a matrix metering unit 14 through a feed duct 13." (Ex. 1010, 4:23-27.) A POSITA would have ascertained that Wohrl's description is consistent with **a passive supplying method** for fibre strand 9. Indeed, a POSITA would have known from his/her knowledge that the filament winding process disclosed by Wohrl is a passive material supplying method, as disclosed by others. *See*, for example, Ma at pp. 38 and 66. Indeed, Wohrl lacks of a mechanism or description suggesting, or otherwise disclosing, that fibre strand 9 is pushed through the nozzle.

386. And because, as discussed above in Claim Element 1[d], Wohrl discloses "bonding an end point of the path of composite material to an anchor," it follows that as the nozzle moves away from the anchor, the path of the composite material is pulled (*e.g.*, unwound) from fibre drum 10 so that additional material

can be laid down. Therefore, Wohrl discloses Claim Element 1[e].

2. Claim 2: "wherein bonding the end point of the path of composite material to the anchor includes:"

387. Claim 2 depends from Claim 1, which Wohrl discloses as discussed above. It is my opinion that Wohrl discloses each and every limitation of Claim 2.

a. "placing the end point of the path of composite material on the anchor; and" (Claim Element 2[a])

388. A POSITA would have understood that "placing the end point of the path of composite material on the anchor" corresponds to placing the path of composite material to a selected point location ("the anchor") on which the path will be attached. As discussed above in Claim Element 1[d], Worhl explicitly discloses cementing in place (anchoring) the impregnated fibre ("path of composite material") to a selected point location ("the anchor").

389. Accordingly, Wohrl discloses Claim Element 2[a].

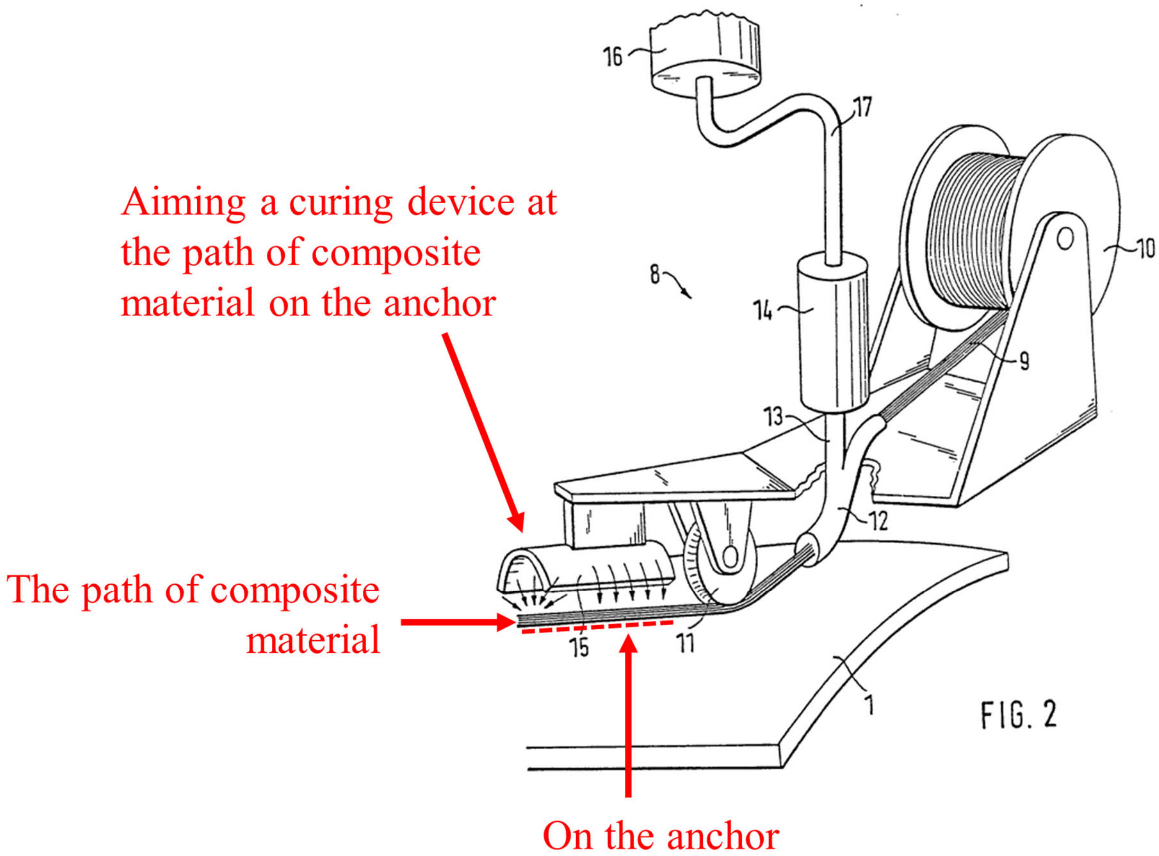
b. "aiming a curing device at the path of composite material on the anchor." (Claim Element 2[b])

390. As discussed above (*see*, *e.g.*, my analysis for Claim Element 1[d]), curing the laid impregnated fibre ("the path of composite material") causes the impregnated fiber to gel (*e.g.*, increase its viscosity/hardens) and stick into place. More specifically, the impregnated fibre is precured when exposed to precuring device 15 ("a curing device"), which causes the matrix material ("the curable

liquid material") "to **gel** to a point where **the fibre is cemented in place**." (Ex. 1010, 3:7-8; *see also id*., 5:3-8.)

391. Wohrl's precuring device 15 is "a curing device" because it at least partially cures (*e.g*., precures) the impregnated fibre. A POSITA would have understood that precuring device 15 could fully cure the material given sufficient time. Additionally, the '798 specification is consistent with this understanding because Wohrl's precuring device hardens the impregnated fibre ("the path of composite material").

392. Therefore, a POSITA would have understood that the matrix material ("the curable liquid material") in the impregnated fibre ("the path of composite material") hardens under precuring device 15 ("curing device") when the impregnated fibre is over an anchor point so that the impregnated fibre ("the path of composite material") is cemented "on the anchor." Figure 2 shows the aforementioned process, during which precuring device 15 ("a curing device") is aimed at the impregnated fibre ("the path of composite material") over "the anchor" location.



(*Id.*, Figure 2; annotated.) Therefore, Wohrl discloses Claim Element 2[b].

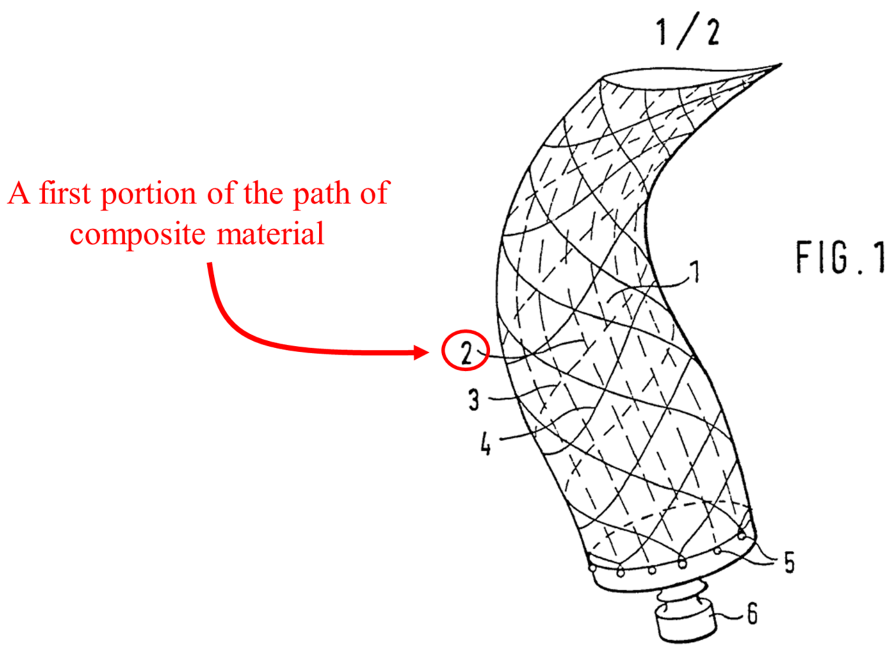
3. Claim 11

393. It is my opinion that Wohrl discloses each and every limitation of Claim 11.

a. "further including: curing a first portion of the path of composite material;" (Claim Element 11[a])

394. As discussed above in element 2[d], "precuring", as disclosed by Wohrl, encompasses the notion of "curing" recited in Elements 11[a]. Figure 1 of Wohrl shows an exemplary air foil 1 of a rotor blade. Air foil 1 is constructed

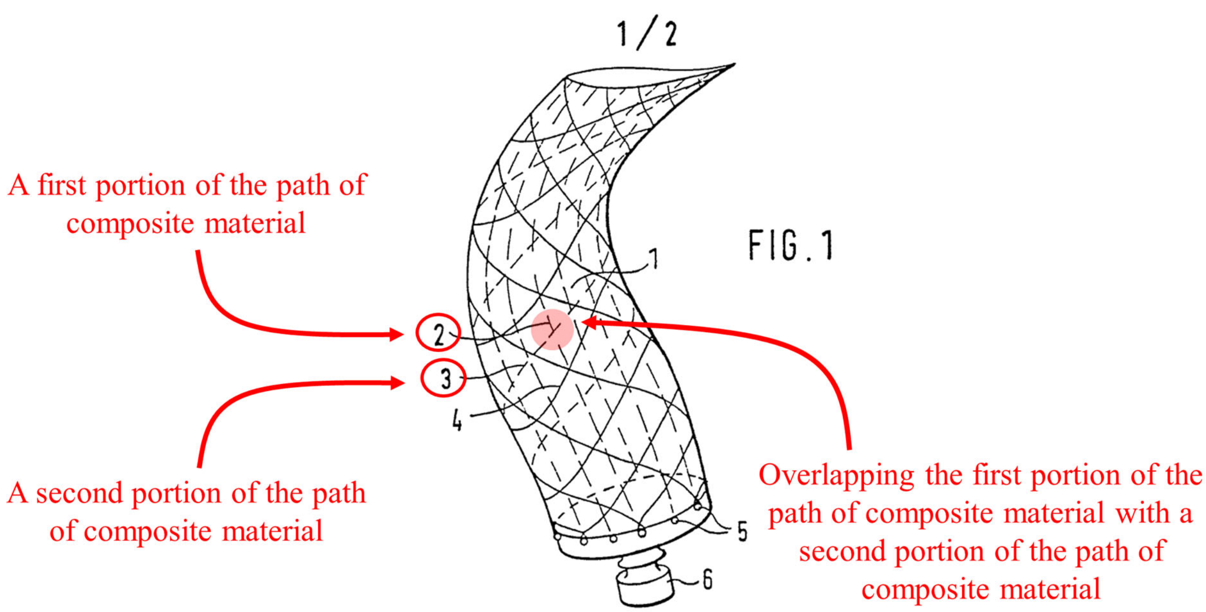
from **overlapping portions** of the impregnated fibre ("the path of composite material"). (*See*, *e.g.*, Ex. 1010 at 3:4-6 ("Depending on requirements several plies of fibre can be deposited **one over the other** in different or identical orientations.").) As would be understood by a POSITA, each portion of the path corresponds to a preferred direction, such as the main tensile direction 2 and diagonal directions 3 and 4. (*Id.*, 4:12-15.) A POSITA would have understood that the main tensile direction 2 may correspond to "a first portion of the path of composite material," which, as discussed above in Claim 2, is cured over predetermined anchor locations along tensile direction 2. Accordingly, Wohrl discloses Claim Element 11[a].



(*Id.*, Figure 1; annotated.)

b. "overlapping the first portion of the path of composite material with a second portion of the path of composite material that is uncured; and" (Claim Element 11[b])

395. Once the impregnated fibre is cured along tensile direction 2 ("first portion of the path of composite material"), a **fresh** (*i.e.*, **uncured**) path of impregnated fiber ("a second portion of the path of composite material") is dispensed, for example, in a direction that **overlaps** with the path of impregnated fiber along tensile direction 2 ("first portion of the path of composite material"). In the example of Figure 1 below, the "second portion of the path of composite material" may correspond to portions of the path of impregnated fiber along the diagonal direction 3.



(Ex. 1010, Figure 1; annotated.) Accordingly, Wohrl discloses Claim Element

11[b].

c. "curing the second portion of the path of composite material while the first and second portions of the path of composite material are overlapped." (Claim Element 11[c]

396. Because each portion of the path of the impregnated fibre ("the path of composite material") is dispensed, and subsequently cured according to the analysis presented in Claim 2, a POSITA would have understood that portions of the path of the impregnated fibre along the diagonal direction 3 ("the second portion of the path of composite material") are dispensed and cured while "the first and second portions of the path of composite material are overlapped," as shown in Figure 2 above.

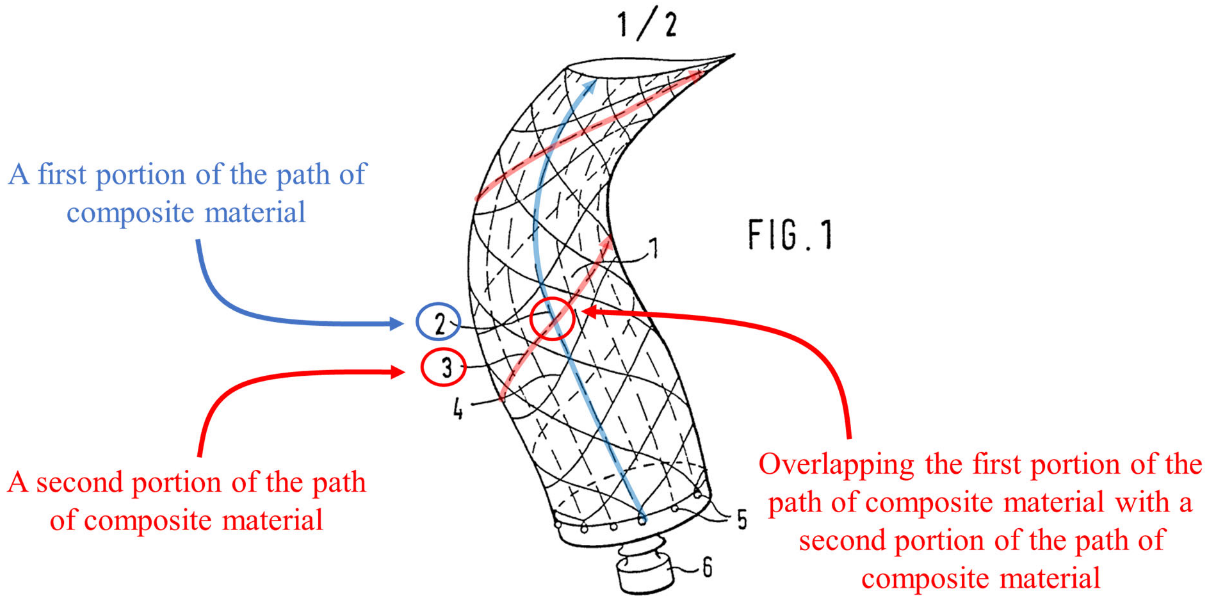
397. Accordingly, Wohrl discloses Claim Element 11[c].

4. Claim 12: "wherein the overlapping includes wrapping the second portion of the path of composite material around the first portion of the path of composite material."

398. Claim 12 depends from Claim 1, which Wohrl discloses. It is also my opinion that Wohrl discloses Claim 12.

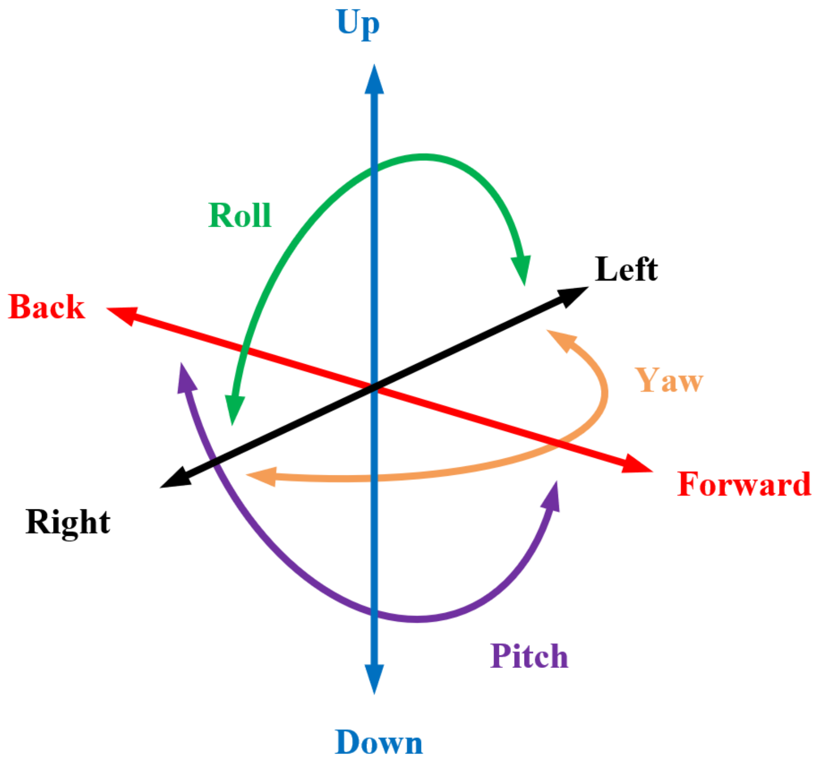
399. As discussed in Claim 11, Wohrl discloses with respect to Figure 1 that first and second paths of composite material overlap. In the analysis presented in Claim Element 11[b], which is incorporated here, a POSITA would have understood that a path along tensile direction 2 corresponds, for example, to a "first

portion of the path of composite material" and a path along diagonal direction 3 corresponds to a "second portion of the path of composite material." However, as shown in Figure 1 below, diagonal direction 3 (highlighted red) **wraps around** tensile direction 2 (highlighted blue).



(Ex. 1010, Figure 1; annotated.) It then follows that Wohrl discloses that "the overlapping includes wrapping the second portion of the path of composite material around the first portion of the path of composite material," as would be understood by a POSITA.

400. Besides the example provided above in Figure 1, Wohrl further discloses that the fibre laying device is attached to the "wrist" of a **six-axis** portal robot. (*Id*., 5:11:14.) This means that Wohrl's laying device is able to perform any of the following movements or any combination of the following movements:



(Movements representing six degrees of freedom.) Accordingly, a POSITA would have realized that such movement flexibility allows Wohrl's laying device to move so that "the overlapping includes **wrapping the second portion of the path of composite material around the first portion of the path of composite material**," as demonstrated by the example of Figure 1. Accordingly, Wohrl discloses Claim 12.

5. Independent Claim 16

401. It is my opinion that Wohrl discloses each and every limitation of Claim 16.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 16[pre])

402. To the extent the preamble is limiting, it is disclosed by Wohrl because the preamble of Claim 16 is identical to that of Claim 1, which Wohrl discloses.

b. "directing a curable liquid material to a nozzle;" (Claim Element 16[a])

403. Wohrl discloses Claim Element 16[a] because Claim Element 16[a] is identical to Claim Element 1[a], which Wohrl discloses.

c. "directing a continuous strand material to the nozzle;" (Claim Element 16[b])

404. Wohrl discloses Claim Element 16[b] because Claim Element 16[b] is identical to Claim Element 1[b], which Wohrl discloses.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 16[c])

405. Wohrl discloses Claim Element 16[c] because Claim Element 16[c] is identical to Claim Element 1[c], which Wohrl discloses.

e. "aiming a curing device at the path of discharged composite material to cure the curable liquid material;" (Claim Element 16[d])

406. Wohrl discloses Claim Element 16[d] as shown in Figure 2 below. *See* also my analysis for Claim Element 2[b] above.

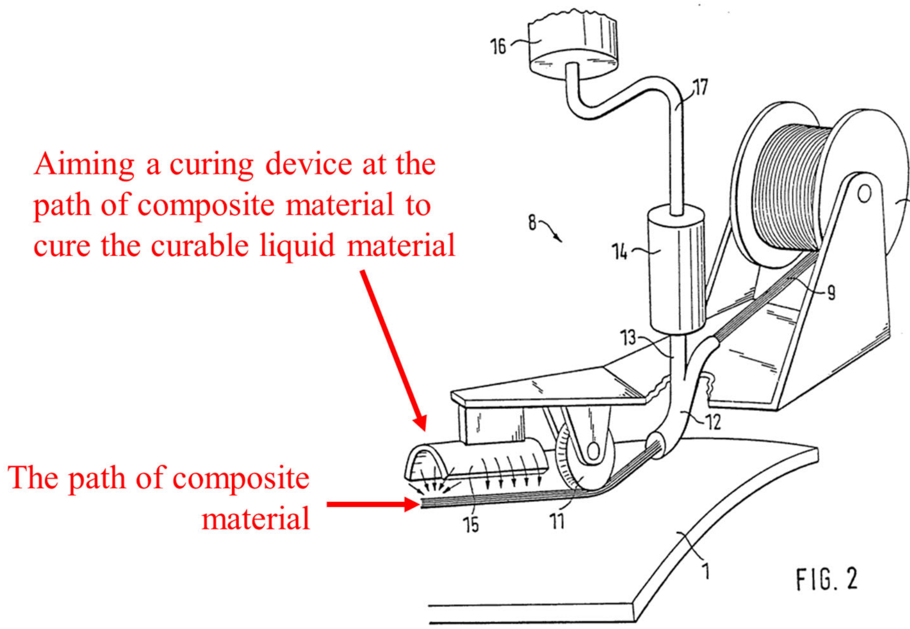


FIG. 2

(Ex. 1010, Figure 2; annotated.)

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 16[e])

407. As discussed above in Claim 1, Wohrl discloses a fibre laying device 8 that dispenses resin-impregnated fibre and subsequently cures the resin to cement the fibre in place to form a three-dimensionally twisted airfoil of a rotor blade ("the three-dimensional object"). And because the impregnated fibre is dispensed in various directions as a result of the nozzle's movement, as shown in Figure 1, it follows that Wohrl is "moving the nozzle during discharging to create the three-dimensional object." Accordingly, Wohrl discloses Claim Element 16[e].

g. "moving the curing device together with the nozzle." (Claim Element 16[f])

408. As shown in fibre laying device 8 of Figures 2 and 3, precuring device

15 ("the curing device") and duct 12 ("the nozzle") are **physically connected via** a common member. In other words, precuring device 15 ("the curing device") and duct 12 ("the nozzle") **are coupled together** via the common member.

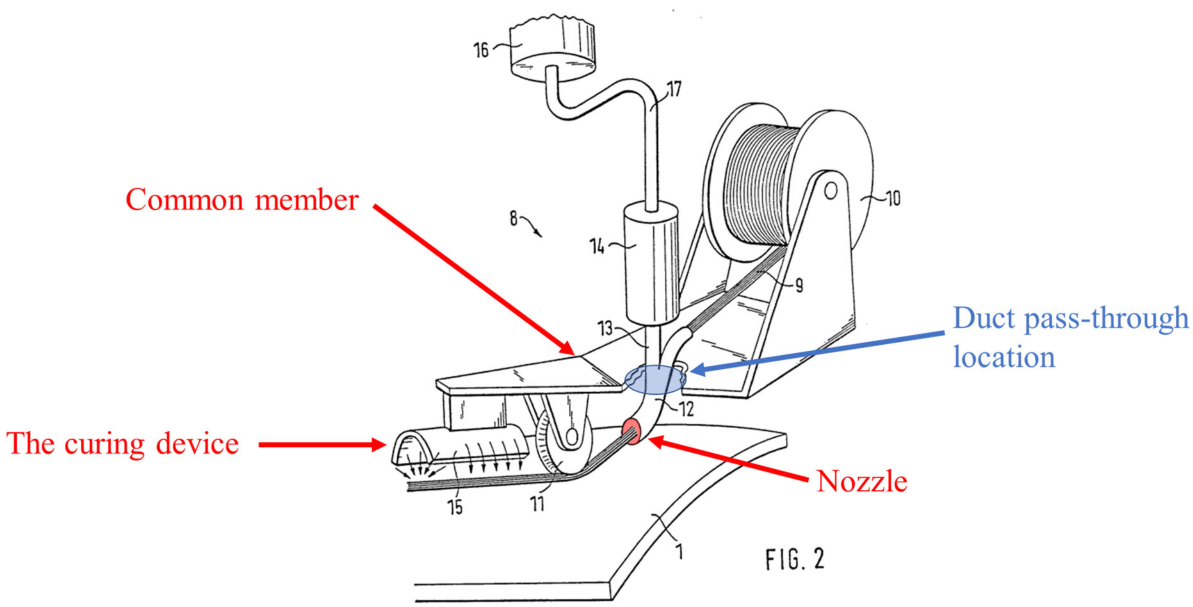


FIG. 2

(Ex. 1010, Figure 2; annotated.)

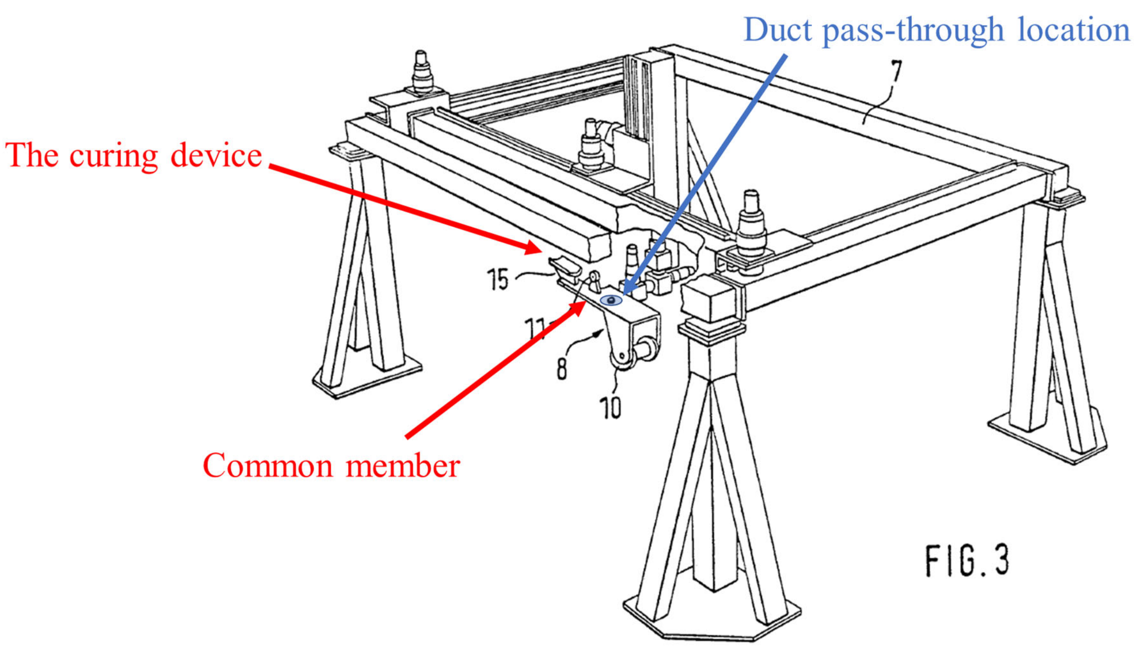


FIG. 3

(*Id.*, Figure 3; annotated.) Therefore, precuring device 15 ("the curing device") **moves together** with duct 12 ("the nozzle"). Accordingly, Wohrl discloses Claim Element 16[f].

6. Independent Claim 18

409. It is my opinion that Wohrl discloses each and every limitation of Claim 18.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 18[pre])

410. To the extent the preamble is limiting, it is disclosed by Wohrl because the preamble of Claim 18 is identical to that of Claim 1, which Wohrl discloses above.

b. "directing a curable liquid material to a nozzle;" (Claim Element 18[a])

411. Wohrl discloses Claim Element 18[a] because Claim Element 18[a] is identical to Claim Element 1[a], which Wohrl discloses above.

c. "directing a continuous strand material to the nozzle;" (Claim Element 18[b])

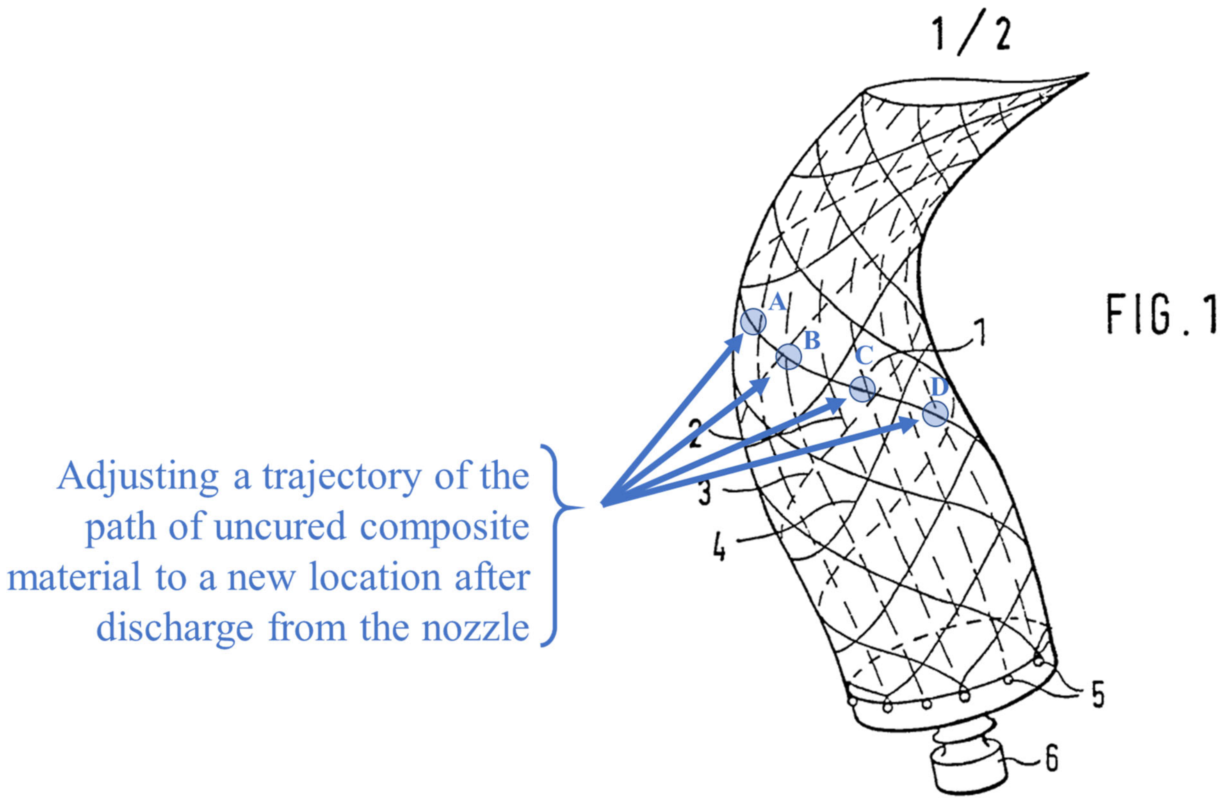
412. Wohrl discloses Claim Element 18[b] because Claim Element 18[b] is identical to Claim Element 1[b], which Wohrl discloses above.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 18[c])

413. Wohrl discloses Claim Element 18[c] because Claim Element 18[c] is identical to Claim Element 1[c], which Wohrl discloses above.

e. "adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle; and" (Claim Element 18[d])

414. As shown in Figure 1, Wohrl discloses "adjusting a trajectory of the path of uncured composite material to a new location after discharge from the nozzle." More specifically, a POSITA would have understood that the recited "new location" corresponds to an anchor point on which the resin-impregnated fibre path is eventually going to be anchored. In the example of Figure 1, each anchor point may coincide with the approximate location where the curvature of the path changes, as indicated by points A-D below.



(Ex. 1010, Figure 1; annotated.) Hence, the trajectory of the resin-impregnated fibre path ("the path of uncured composite material") can be adjusted from point A to point B (first "new location"), from point B to point C (the second "new location"), from point C to point D (the third "new location"), and so on.

415. Further, a POSITA would have understood that each fresh (uncured) section of the resin-impregnated fibre is initially discharged (*e.g.*, section AB) and precured over anchor location B ("a new location") before the next section of the resin-impregnated fibre (*e.g.*, section BC) is discharged from the nozzle and precured according to the airfoil's design. And because each fresh, uncured

section of the resin-impregnated fibre ("the path of uncured composite material") is pliable, the path's trajectory can be adjusted to a new location before the path is precured and anchored in place.

416. Accordingly, Wohrl discloses Claim Element 18[d].

f. "curing the curable liquid material in the path of uncured composite material at the new location after adjusting." (Claim Element 18[e])

417. Wohrl discloses Claim Element 18[e] at least for the reasons discussed above in Claim Element 18[d].

N. Ground 13: The Combination of Wohrl and Lipsker Renders Obvious Claims 3, 5, and 17

1. Claim 3: "wherein aiming the curing device includes aiming at least one UV light."

418. Claim 3 depends from Claim 1, which Wohrl discloses in Ground 12. It is my opinion that Wohrl in combination with Lipsker discloses Claim 3.

419. Wohrl discloses that precuring device 15 is an infrared (IR) radiator (*see*, *e.g.*, Ex. 1010, at Abstract, at 2:24-25, and at Claim 4) that cures the resin via **heat absorption**, as would be understood by a POSITA. This means that Wohrl discloses **a thermo-curable resin**. However, a POSITA who is aspired to **expedite** the curing process and reduce the fabrication time, or to simply explore alternatives to thermo-curing as part of the normal course of his/her own research would be motivated to look into readily available references beyond Wohrl. A

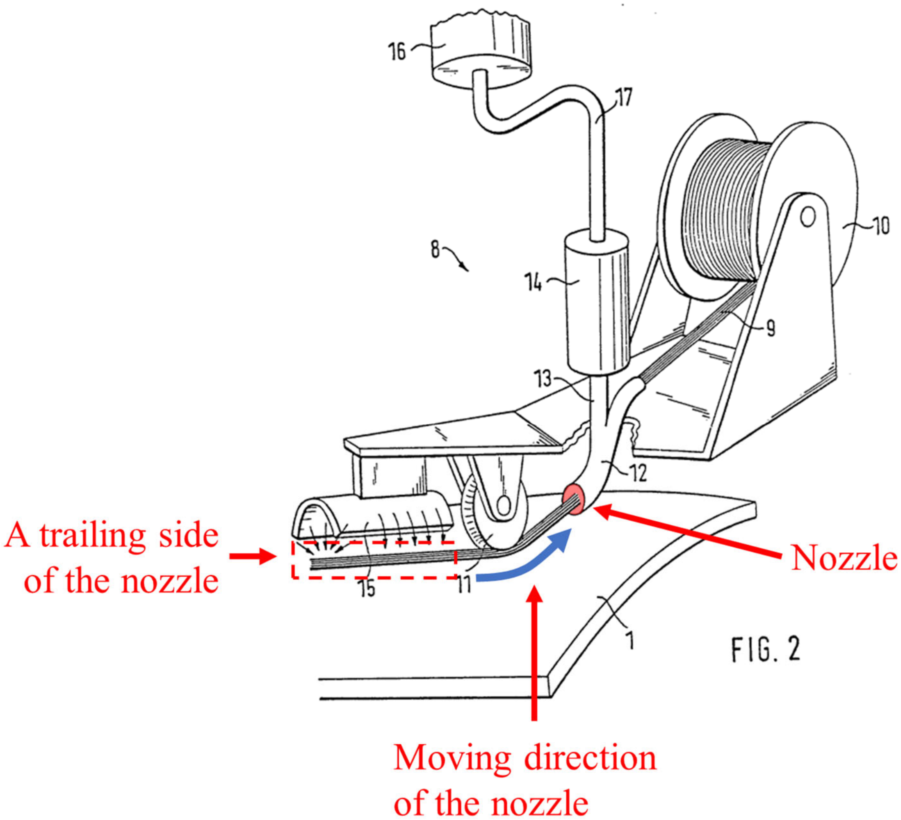
POSITA would have understood that Wohrl's filament winding process is closely related to Lipsker's rapid prototyping method, at the very least with respect to the curing principles disclosed therein. For example, Lipsker, similar to Wohrl, also discloses thermo-curable adhesives as a viable option for its method. (Ex. 1006, 3:33-35 and 3:40-41.) However, in its preferred embodiment, Lipsker discloses UV-curable adhesives that are cured when exposed to UV-light. (*See, e.g*., Claim 3 in Ground 2; Ex., 1006, 3:34-35, 3:41-46, and 6:38-40.) A POSITA would have anticipated that Wohrl's IR radiator and thermo-cured resin can be seamlessly replaced with a UV light source and a UV-cured resin, as demonstrated by Lipsker, to reduce the curing time and improve the efficiency of the fabrication process.

420. Accordingly, Wohrl in combination with Lipsker discloses Claim 3.

2. Claim 5: "wherein aiming the at least one UV light includes aiming the at least one UV light from only a trailing side of the nozzle."

421. Claim 5 depends from Claim 3, which Wohrl in combination with Lipsker discloses. It is my opinion that Wohrl in combination with Lipsker also discloses Claim 5.

422. According to Figure 2 below, Wohrl shows that precuring device 15 is aimed so that it trails (*e.g*., follows) the nozzle's movement from left to right.



(Ex. 1010, Figure 2; annotated.) In other words, precuring device 15 **is positioned so that it does not advance ahead of the nozzle**. A POSITA would have understood that positioning precuring device 15 on the trailing side of the nozzle ensures that the path is precured after it is dispensed from the nozzle. And because precuring device 15 and thermo-curable resin can be replaced with a UV radiator that emits UV light and with a UV-curable resin respectively, as discussed in Claim 3 above, Wohrl in combination with Lipsker discloses Claim 5.

3. Independent Claim 17

423. It is my opinion that Wohrl in combination with Lipsker discloses

each and every limitation of Claim 17.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 17[pre])

424. To the extent the preamble is limiting, it is disclosed by Wohrl and Lipsker, alone and in combination. The preamble of Claim 17 is identical to that of Claim 1, which Wohrl disclose, as discussed above in Ground 12. Lipsker also discloses the preamble of Claim 17, as discussed above in Ground 2.

b. "directing a curable liquid material to a nozzle;" (Claim Element 17[a])

425. Wohrl and Lipsker, alone and in combination, disclose Claim Element 17[a]. Claim Element 17[a] is identical to Claim Element 1[a], which Wohrl discloses, as discussed above in Ground 12. Lipsker also discloses Claim Element 17[a], as discussed above in Ground 2.

c. "directing a continuous strand material to the nozzle;" (Claim Element 17[b])

426. Wohrl and Lipsker, alone and in combination, disclose Claim Element 17[b]. Claim Element 17[b] is identical to Claim Element 1[b], which Wohrl discloses, as discussed above in Ground 12. Lipsker also discloses Claim Element 17[b], as discussed above in Ground 2.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 17[c])

427. Wohrl and Lipsker, alone and in combination, disclose Claim Element 17[c]. Claim Element 17[c] is identical to Claim Element 1[c], which Wohrl discloses, as discussed above in Ground 12. Lipsker also discloses Claim Element 17[c], as discussed above in Ground 2.

e. "curing the curable liquid material in the path of composite material;" (Claim Element 17[d])

428. Wohrl and Lipsker, alone and in combination, disclose Claim Element 17[d]. For example, Wohrl discloses curing the matrix material ("curing the curable liquid material") in the impregnated fiber ("in the path of composite material"), as discussed in Claim Elements 1[d] and 2[b] in Ground 12. Accordingly, Wohrl discloses Claim Element 17[d]. Lipsker also discloses Claim Element 17[d], as discussed above in Ground 2.

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 17[e])

429. Wohrl and Lipsker, alone and in combination, disclose Claim Element 17[e]. For example, Claim Element 17[e] is identical to Claim Element 16[e], which Wohrl discloses in Ground 12 and Lipsker discloses in Ground 2.

g. "selectively cutting the continuous strand material before the continuous strand material reaches the nozzle such that at least one portion of the path discharging from the nozzle contains only the curable liquid material." (Claim Element 17[f])

430. It is my opinion that Wohrl in combination with Lipsker discloses

Claim Element 17[f]. As discussed in Ground 2, Lipsker discloses a cutter/wire-dispenser configuration located upstream of the nozzle that enables Lipsker to dispense the adhesive ("the curable liquid material") without the wire ("the continuous strand material") when the wire is cut prior to entering the nozzle. A POSITA would have found that Lipsker's configuration enables Wohrl to fabricate geometric shapes that would be difficult to fabricate if fibers were being deposited. In addition, a POSITA would have appreciated that selective sections of an article may not require fibre. Therefore, **having the option to build these sections without the fibre to reduce the cost and the weight of the resulting structure would be highly desirable**. Therefore, combining Wohrl with Lipsker could lead to advantages in fabricating shapes that would be difficult or impossible with the technology from Wohrl alone. Hence, Wohrl in combination with Lipsker discloses Claim Element 17[f].

4. Motivation to Combine Wohrl and Lipsker

431. It is my opinion that a POSITA would have been motivated to combine Wohrl and Lipsker for the following reasons.

432. In examining Wohrl, a POSITA would have come to realize that the filament winding process disclosed by Wohrl is **the precursor** of the rapid prototyping processes that emerged a decade later. In fact, Wohrl's filament

winding process exhibits striking similarities with more recently developed rapid prototyping processes. For one, Wohrl's filament winding process is a fully automated and computerized method. Second, one can use it to successfully fabricate three-dimensional objects **from fiber reinforced composite material—** *i.e.*, **fibers impregnated with a curable material**. Lastly, it features independent mechanisms for feeding **a liquid adhesive material** and **a fibre** into a nozzle to **combine them into a composite material that is subsequently dispensed from the nozzle and cured** according to the design of a three-dimensional object.

433. Although a POSITA would have recognized that Wohrl discloses many of the fundamental concepts and baseline equipment used in subsequently developed rapid prototyping processes, it would have been in his/her best interest to explore more recent rapid prototyping processes. Such references would certainly include Lipsker, which shares Wohrl's fundamental teachings and principles. However, Lipsker, being more contemporary to Wohrl, benefits from advances in automation, equipment, and material selection. **Therefore, a POSITA eager to improve and modernize Wohrl's concepts, would be highly motivated to look into Lipsker to take advantage of Lipsker's teachings.**

434. And because the processes disclosed by Wohrl and Lipsker are closely related, a POSITA would have the expectation that the combination would yield

predictable results. Therefore, it is my opinion that it would have been obvious for a POSITA to combine the teachings of Wohrl and Lipsker as part of the normal course of his/her own research.

O. Ground 14: The Combination of Wohrl and Ma Renders Obvious Claims 6-10 and 14

1. Claim 6: "wherein discharging from the nozzle the path of composite material includes discharging the path of composite material through a nozzle orifice having a diameter of about 2 mm."

435. Claim 6 depends from Claim 1, which Wohrl discloses in Ground 12. It is my opinion that Wohrl in combination with Ma discloses Claim 6 for at least the reasons Ma discloses Claim 6 in Ground 1. For example, and as discussed above for Claim Element 1[e] in Ground 12, a POSITA would have known that Wohrl discloses a passive supplying method. A POSITA would have also appreciated the importance of the nozzle's orifice size in the process of the passive supplying method as studied by others, like Ma. And for this reason, **a POSITA would have been motivated to review other references that offer a more in depth analysis on this subject.** Accordingly, a POSITA would have been motivated to look into Ma for the aforementioned reasons. And because Ma discloses Claim 6 for at least the reasons discussed above in Ground 1, Wohrl in combination with Ma discloses Claim 6.

2. Claim 7: "wherein the continuous strand material includes a plurality of strands arranged in at least one of a tow, a roving, and a weave."

436. Claim 7 depends from Claim 6, which Wohrl in combination with Ma discloses. It is my opinion that Wohrl in combination with Ma also discloses Claim 7.

437. For example, Wohrl discloses **fiber strands** (plural) (*see* Ex. 1010, at 2:17-26) as "the continuous strand material" and Ma discloses impregnated fiber **tows**, as discussed in Ground 1. A POSITA would have come to the conclusion that Wohrl's fiber strands can be arranged, for example, in a tow, as disclosed by Ma. Accordingly, Wohrl in combination with Ma discloses Claim 7.

3. Claim 8: "wherein directing the curable liquid material to the nozzle includes directing a filler material at least partially coated in the curable liquid material to the nozzle."

438. Claim 8 depends from Claim 1, which Wohrl discloses. It is my opinion that Wohrl in combination with Ma discloses Claim 8 for at least the same reasons Ma discloses Claim 8 in Ground 1.

439. For example, as discussed in Ground 1, Ma discloses several benefits for using filler materials in the curable liquid material. A POSITA who is looking to improve the strength of Wohrl's reinforced fibers would have found that Wohrl can benefit from Ma's disclosure on filler materials in curable resins. For example,

introduction of a filler material in Wohrl's resin **can reduce shrinkage and improve the mechanical properties of the reinforced fiber** (*see,* Ex. 1007, at p. 22)—**both of which are very relevant to Wohrl's aspirations**. And because the filler material may be pre-mixed with the resin and carried by the resin to the nozzle, Wohrl in combination with Ma discloses Claim 8.

4. Claim 9: "wherein the filler material includes pieces of fibers."

440. Claim 9 depends from Claim 8, which Wohrl in combination with Ma discloses. Wohrl in combination with Ma also discloses Claim 9 for at least the same reasons Ma discloses Claim 9 in Ground 1.

5. Claim 10: "wherein the continuous strand material is hollow."

441. Claim 10 depends from Claim 1, which Wohrl in combination with Ma discloses. It is my opinion that Wohrl in combination with Ma renders obvious Claim 10 for at least the reasons discussed in Ground 1. For example, a POSITA would have known based on his/her own knowledge that glass fibers, and particularly hollow glass fibers as disclosed by Pang (*see* my analysis for Claim 10 in Ground 1), are a light-weight material that increases the mechanical strength of the resulting structure. This would have been a desirable outcome for Wohrl's airfoils, which are designed for aviation and aerospace applications and need to

exhibit "low density, high tensile strength and relative ease of shaping" (*see*, Ex. 1010 at 1:7-9). Therefore, a POSITA would have been motivated to consider the teachings of Ma and others (*see* Pang) to improve on Wohrl's methods.

6. Independent Claim 14

442. It is my opinion that Wohrl in combination with Ma discloses each and every limitation of Claim 14.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 14[pre])

443. To the extent the preamble is limiting, it is disclosed by Wohrl and Ma, alone and in combination. The preamble of Claim 14 is identical to that of Claim 1, which Wohrl discloses in Ground 12 and Ma discloses in Ground 1.

b. "directing a curable liquid material to a nozzle;" (Claim Element 14[a])

444. It is my opinion that Wohrl and Ma, alone and in combination, disclose Claim Element 14[a]. For example, Claim Element 14[a] is identical to Claim Element 1[a], which Wohrl discloses in Ground 12 and Ma discloses in Ground 1.

c. "directing a continuous strand material to the nozzle;" (Claim Element 14[b])

445. It is my opinion that Wohrl and Ma, alone and in combination, disclose Claim Element 14[b]. For example, Claim Element 14[b] is identical to

Claim Element 1[b], which Wohrl discloses in Ground 12 and Ma discloses in Ground 1.

d. "discharging from the nozzle a path of composite material containing the continuous strand material at least partially coated with the curable liquid material;" (Claim Element 14[c])

446. It is my opinion that Wohrl and Ma, alone and in combination, disclose Claim Element 14[c]. For example, Claim Element 14[c] is identical to Claim Element 1[c], which Wohrl discloses in Ground 12 and Ma discloses in Ground 1.

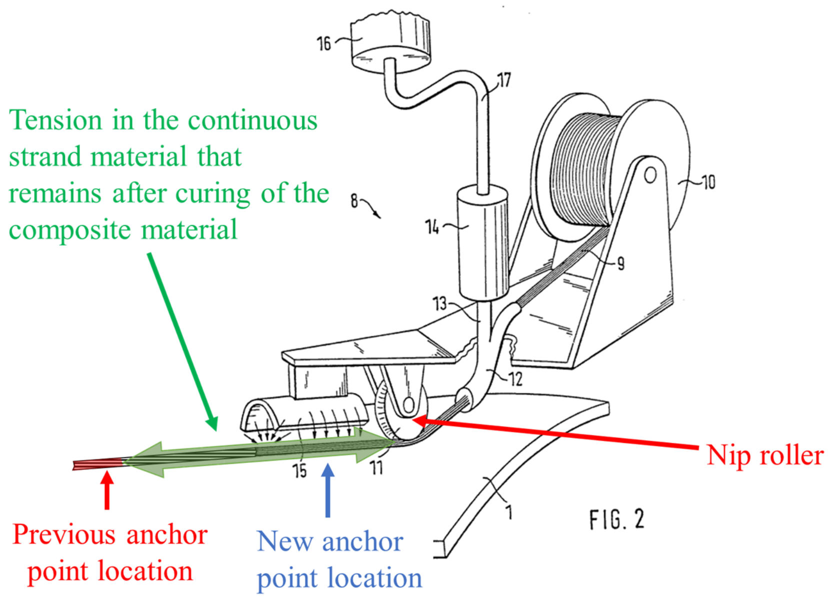
e. "curing the curable liquid material in the path of composite material; and" (Claim Element 14[d])

447. It is my opinion that Wohrl and Ma, alone and in combination, disclose Claim Element 14[d]. For example, Claim Element 14[d] is identical to Claim Element 17[d], which Wohrl discloses in Ground 13. Ma also discloses Claim Element 14[d], as discussed above in Ground 1.

f. "moving the nozzle during discharging to create tension in the continuous strand material that remains after curing of the composite material." (Claim Element 14[e])

448. It is my opinion that Wohrl in combination with Ma discloses Claim Element 14[e]. For example, as discussed in Claim Element 1[e] in Ground 12, a POSITA would have understood that Wohrl's description is consistent with **a**

passive supplying method. A POSITA who desires to learn more about the passive supplying method would be inclined to look beyond Wohrl and find references, like Ma, that describe the passive supplying method in greater detail. As discussed in Ground 1, Ma not only explicitly discloses "pull[ing] the path of composite material out of the nozzle", but also **explains how pulling translates to tension in the towpreg** ("the continuous strand material") that "remains after curing of the composite material" (*see* my analysis for Claim Element 14[e] in Ground 1). Based on Ma's disclosure, a POSITA would have anticipated that tension building in the reinforced fiber between nip roller 11 and a previous anchor point location "remains after curing." This is shown schematically in annotated Figure 2 below where the tension is represented with a green double arrow along the length of the impregnated fibre between nip roller 11 and a previous anchor point location.



(Ex. 1010, Figure 2; annotated.) Accordingly, a POSITA would have found that Wohrl in combination with Ma discloses Claim Element 14[e].

7. Motivation to Combine Wohrl and Ma

449. A POSITA would have been motivated to combine Wohrl and Ma for a number of reasons.

450. In examining Wohrl, a POSITA would have come to realize that the filament winding process disclosed by Wohrl is **the precursor** of the rapid prototyping processes that emerged a decade later. In fact, Wohrl's filament winding process exhibits striking similarities with more recently developed rapid prototyping processes. For one, Wohrl's filament winding process is a fully automated and computerized method. Second, one can use it to successfully fabricate three-dimensional objects **from fiber reinforced composite material —**

i.e., **fibers impregnated with a curable material**. Lastly, it features independent mechanisms for feeding **a liquid adhesive material** and **a fibre** into a nozzle to **combine them into a composite material that is subsequently dispensed from the nozzle and cured** according to the design of a three-dimensional object.

451. Although a POSITA would have recognized that Wohrl discloses many of the fundamental concepts and baseline equipment used in subsequently developed rapid prototyping processes, it would have been in his/her best interest to explore more recent studies on rapid prototyping processes. Such studies would certainly include Ma. This is because Ma carefully reviews its material selection and studies how equipment can impact the dispensing mechanism in rapid prototyping processes that use fiber reinforced materials. **Therefore, a POSITA eager to improve and modernize Wohrl's concepts, would be highly motivated to look into Ma to take advantage of Ma's teachings.**

452. And because the processes disclosed by Wohrl and Ma are closely related, a POSITA would have the expectation that the combination would yield predictable results. Therefore, it is my opinion that it would have been obvious for a POSITA to combine the teachings of Wohrl and Ma as part of the normal course of his/her own research.

P. Ground 15: The Combination of Wohrl and Nikzad Renders Obvious Claim 15

1. Independent Claim 15

453. It is my opinion that Wohrl in combination with Nikzad discloses each and every limitation of Claim 15.

a. "A method of manufacturing of a three-dimensional object, comprising:" (Claim Element 15[pre])

454. To the extent that the preamble of Claim 15 is limiting, it is disclosed by Wohrl and Nikzad, alone and in combination. For example, the preamble of Claim 15 is identical to that of Claim 1, which Wohrl discloses in Ground 12. Nikzad also discloses the preamble of Claim 15, as discussed in Ground 6.

b. "directing a curable liquid material to a nozzle;" (Claim Element 15[a])

455. Claim Element 15[a] is identical to Claim Element 1[a], which Wohrl discloses in Ground 12. For at least the same reasons presented above in connection to Claim Element 1[a], Wohrl in combination with Nikzad discloses Claim Element 15[a].

c. "directing a continuous strand material to the nozzle;" (Claim Element 15[b])

456. Claim Element 15[b] is identical to Claim Element 1[b], which Wohrl discloses in Ground 12. For at least the same reasons presented above in connection to Claim Element 1[b], Wohrl in combination with Nikzad discloses Claim Element 15[b].

d. "directing flakes of fiber to the nozzle;" (Claim Element 15[c])

457. As discussed in Ground 6, Nikzad discloses **adding flakes of fiber to a polymer** to increase the modulus and strength of the resulting composite material. A POSITA who is looking to improve the strength of Wohrl's reinforced fibers would have found that Wohrl can benefit from Nikzad's disclosure on filler materials. For example, a POSITA would have expected that introduction of a filler material in Wohrl's curable resin can improve the mechanical properties of the resulting reinforced fiber, which is very relevant to Wohrl's aspirations. More specifically, a POSITA would have understood that **fiber flakes**, similar to the iron fiber flakes disclosed by Nikzad, **can be pre-mixed with the resin disclosed by Wohrl** to improve the mechanical properties of the resulting three-dimensional airfoil structure, which is required to sustain excessive forces during operation (*see* Ex. 1010 at 3:27-4:3 and 4:15-19). And because Wohrl discloses "directing a curable liquid material to a nozzle," as discussed in Claim Element 1[a] of Ground 12, it follows that Wohrl in combination with Nikzad discloses "directing flakes of fiber [pre-mixed with the resin ("the curable liquid material")] to the nozzle" according to Claim Element 15[c].

458. Thus, Wohrl in combination with Nikzad discloses Claim Element 15[c].

e. "discharging from the nozzle a path of composite material containing the continuous strand material and the flakes of fiber at least partially coated with the curable liquid material;" (Claim Element 15[d])

459. For at least the reasons discussed above in Claim Element 15[c], Wohrl in combination with Nikzad discloses Claim Element 15[d].

f. "moving the nozzle during discharging to create the three-dimensional object; and" (Claim Element 15[e])

460. It is my opinion that Wohrl and Nikzad, alone and in combination, disclose the additional limitation of Claim Element 15[e].

461. For example, the limitation of Claim Element 15[e] is identical to that of Claim Element 16[e], which Wohrl discloses in Ground 12. Nikzad also discloses that additional limitation Claim Element 15[e] at least for the reasons discussed above in Ground 6.

g. "curing the curable liquid material in the path of composite material." (Claim Element 15[f])

462. Claim Element 15[f] is identical to Claim Element 17[d], which Wohrl discloses in Ground 13. For at least the reasons presented in Ground 13 for Claim Element 17[d], Wohrl in combination with Nikzad discloses Claim Element 15[f].

2. Motivation to Combine Wohrl and Nikzad

463. It is my opinion that a POSITA would have been motivated to

combine Wohrl and Nikzad for the following reasons.

464. In examining Wohrl, a POSITA would have come to realize that the filament winding process disclosed by Wohrl is **the precursor** of the rapid prototyping processes that emerged a decade later. In fact, Wohrl's filament winding process exhibits striking similarities with more recently developed rapid prototyping processes. For one, Wohrl's filament winding process is a fully automated and computerized method. Second, one can use it to successfully fabricate three-dimensional objects **from fiber reinforced composite material—** *i.e.*, **fibers impregnated with a curable material**. Lastly, it features independent mechanisms for feeding **a liquid adhesive material** and **a fibre** into a nozzle to **combine them into a composite material that is subsequently dispensed from the nozzle and cured** according to the design of a three-dimensional object.

465. Although a POSITA would have recognized that Wohrl discloses many of the fundamental concepts of subsequently developed rapid prototyping processes, it would have been in his/her best interest to explore more recent rapid prototyping processes, including Fused Deposition Modelling (FDM). This means, that a POSITA would be inclined to identify references which may not be limited to the disclosure of fiber-reinforced building materials, but nevertheless cover other important aspects of the rapid prototyping process in greater detail. It is my

opinion that Nikzad is such reference.

466. Wohrl discloses, and a POSITA would acknowledge, that improving the mechanical properties of the constituent materials is critical for fabricating parts intendent for aviation and aerospace applications. Consequently, **a POSITA eager to improve and modernize Wohrl's concepts, would be highly motivated to look into references that focus on these aspects.** For example, Nikzad discloses that fiber fillers can be successfully used in polymer matrices to increase the tensile modulus and tensile strength of the resulting composite material. (Ex. 1009, p. 64.) This disclosure from Nikzad would prompt a POSITA to consider variations of Nikzad's teachings and combine them with concepts disclosed by Wohrl to improve the mechanical properties of resulting structures. For example, a POSITA would have found that Wohrl can benefit from Nikzad's disclosure in that appropriate fiber fillers, as disclosed by Nikzad, may be incorporated into Wohrl's resin to further improve the mechanical properties of the resulting three-dimensional structure. This would have been a desirable outcome for a POSITA.

467. Therefore, a POSITA familiar with the known benefits of fiber fillers in polymer materials, as described by Nikzad, would have a good reason to pursue the known options within his/her technical grasp and apply Nikzad's teachings and suggestions to Wohrl with high expectation of success.

468. For at least the reasons set forth above, it is my opinion that a POSITA would be motivated to combine Wohrl and Nikzad.

VI. CONCLUSION

469. In my opinion, based on my review of the ’798 patent, the materials referenced herein, and my knowledge of what a person of ordinary skill in the art would have known at and before the ’798 patent’s priority date about the technology at issue, a POSITA would have understood all of the limitations of the challenged claims 1-20 to be present and described in Ma, Lipsker, Masters, Crump, Nikzad, and Wohrl. It is also my opinion that a POSITA would have understood all of the claim elements of the challenged Claims 1, 2, 6-11, 14, 18 to be present and unpatentable as obvious by Ma; Claims 3, 5, 12, 16, 17, and 19 to be present and unpatentable as obvious over Ma in view of Lipsker; Claim 4 to be present and unpatentable as obvious over Ma in view of Lipsker and Masters; Claim 20 to be present and unpatentable as obvious over Ma in view of Lipsker and Crump; Claim 13 to be present and unpatentable as obvious over Ma in view of Crump; Claim 15 to be present and unpatentable as obvious over Ma in view of Nikzad; Claims 16-19 to be present and unpatentable as obvious over Lipsker; Claims 13 and 20 to be present and unpatentable as obvious over Lipsker in view of Crump; Claim 15 to be present and unpatentable as obvious over Lipsker in

view of Nikzad; Claims 1-3, 5-12, and 14 to be present and unpatentable as obvious over Lipsker in view of Ma; Claim 4 to be present and unpatentable as obvious over Lipsker in view of Ma and Masters; Claims 1, 2, 11, 12, 16, and 18 to be present and unpatentable as obvious over Wohrl; Claims 3, 5, and 17 to be present and unpatentable as obvious over Wohrl in view of Lipsker; Claims 6-10 and 14 to be present and unpatentable as obvious over Wohrl in view of Ma; and Claim 15 to be present and unpatentable as obvious over Wohrl in view of Nikzad.

470. Accordingly, it is my opinion that challenged claims 1-20 should be found unpatentable.

471. I understand from counsel that the Patent Owner in the underlying district court litigation has not yet identified any evidence with respect to secondary considerations of non-obviousness.

472. To the extent the Patent Owner cites any evidence of sales or any praise or any industry recognition of products that the Patent Owner asserts to implement the claimed invention, I am not aware of any information demonstrating that any purported increased sales, commercial success, praise, or any other secondary factor (that the Patent Owner may assert) was a result of the particular features recited in the ’798 patent’s claims. Since the Patent Owner has not yet identified any evidence of secondary considerations, the Patent Owner cannot

demonstrate that the limitations of the claimed invention in particular, as opposed to other features of the products at issue, were the factors that caused any increased sales, praise, or any other asserted secondary considerations.

473. Thus, based on my review of the evidence to date, I can summarize my opinions regarding any alleged secondary considerations of non-obviousness relating to the ’798 patent, as follows:

474. No commercial success of the claimed invention. The Patent Owner has not cited any evidence of particular commercial success of products embodying the ’798 patent as opposed to products that do not embody the ’798 patent. The Patent Owner has not cited any evidence that any commercial success of any products is particularly a result of the claimed inventions recited in the ’798 patent’s claims and not due to any other facts.

475. No long-felt but unsolved need. The Patent Owner has not cited any evidence of any long-felt need that remained unsolved in the prior art before the ’798 patent. To the contrary, as discussed above, the prior art solved the problems that the ’798 patent purported to address.

476. No failure of others. The Patent Owner has not cited any evidence of anyone who tried, but failed, to solve the problems addressed by the ’798 patent. As shown by my analysis above, there existed prior art references that successfully

disclosed and rendered obvious the subject matter claimed by the ’798 patent.

477. No copying of the claimed invention. The Patent Owner has not cited any evidence that any other party ever copied from the ’798 patent and its claimed invention.

478. No unexpected results of the claimed invention. The Patent Owner has not cited any evidence of unexpected results achieved by the ’798 patent’s claimed invention. To the contrary, the prior art disclosed the predictable, expected results that show why the ’798 patent’s claims are obvious as discussed in my Declaration.

479. No praise for the claimed invention. The Patent Owner has not cited any evidence of praise for the claimed invention recited in the ’798 patent.

480. No surprise or skepticism at the claimed invention. The Patent Owner has not cited any evidence that observers were surprised by, or skeptical of, the claimed invention recited in the ’798 patent.

481. No departure from the wisdom of the prior art. The Patent Owner has not cited any evidence that the claimed inventions of the ’798 patent departed from the wisdom of the prior art. The ’798 patent claims subject matter that was already present in the prior art, including in the references discussed in my analysis above.

482. Moreover, with respect to the considerations discussed above, I also

refer to and incorporate my opinions stated throughout this Declaration, including my analysis showing that the ’798 patent is directed to techniques known in the prior art and does not provide any inventive technology.

483. To the extent the Patent Owner at a later date cites or provides any other evidence regarding secondary considerations, including any expert opinions, I reserve the right to supplement my analysis and opinions to comment on it.

484. Furthermore, I reserve the right to supplement my opinions in the future to respond to any arguments or positions that the Patent Owner may raise, taking account of new information as it becomes available to me.

485. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Respectfully submitted,

Dated: June 29, 2022

David Rosen, Ph.D.

David W. Rosen
Professor
The George W. Woodruff School of Mechanical Engineering

I. EARNED DEGREES

Degree	Year	University	Field
Ph.D.	1992	University of Massachusetts	Mechanical Engineering
M.S.	1987	University of Minnesota	Mechanical Engineering
B.ME.	1985	University of Minnesota	Mechanical Engineering

II. EMPLOYMENT HISTORY

Title	Organization	Years
Research Director for DManD Center	Engineering Product Development Pillar, Singapore University of Technology and Design	2018-present
Professor & Research Director for DManD Center	Engineering Product Development Pillar, Singapore University of Technology and Design	2016-2018
Visiting Professor	School of Mechanical and Aerospace Engineering Nanyang Technological University, Singapore	2015 - 2016
Associate Chair for Administration	George W. Woodruff School of Mechanical Engineering Georgia Institute of Technology, Atlanta, GA.	2009 - 2016
Associate Chair for Graduate Studies	George W. Woodruff School of Mechanical Engineering Georgia Institute of Technology, Atlanta, GA.	2007 – 2009
Visiting Professor	Dept. of Mechanical and Manufacturing Engr., Loughborough University, Loughborough, UK	2005 - 2011
Professor	George W. Woodruff School of Mechanical Engineering Georgia Institute of Technology, Atlanta, GA.	2004 – present
Associate Professor	George W. Woodruff School of Mechanical Engineering	1998-2004
Assistant Professor	George W. Woodruff School of Mechanical Engineering	1992-1998
Instructor	George W. Woodruff School of Mechanical Engineering	Summer 1992.
Research Assistant	Mechanical Design Automation Laboratory, Department of Mechanical Engineering, University of Massachusetts, Amherst, MA.	1989 – 1992
Visiting Research Scientist	Ford Scientific Research Laboratory, Ford Motor Co., Dearborn, MI.	1990
Software Engineer	Computervision and Prime Computer, Bedford, MA.	1987 – 1989
Research and Teaching Assistant	Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN.	1984 – 1987
Programmer	Control Data Corporation, St. Paul, MN.	1986
Programmer	Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN.	1984
Intern Engineer	General Resource Corporation, Hopkins, MN.	1981 – 1983

III. HONORS AND AWARDS

A. International or National Awards

1. Best Paper Award in the Artificial Intelligence and Expert Systems section at the ASME Computers in Engineering Conference for paper #8 in Conference Presentations with Proceedings, August 1992.
2. Distinguished Paper Award in ASME Design Theory and Methodology Conference for paper #26 in section IV.B (Refereed Conference Proceedings), August 1996.
3. Engineer of the Year in Education, Society of Professional Engineers, Metro Atlanta Section, 1997.
4. Highly Commended Award (awarded by the Literati Club of MCB Press) for paper IV.B.1.15, published in the Rapid Prototyping Journal, 1999.
5. Fellow, American Society of Mechanical Engineers, 2003.
6. 2nd Runner Up, Excellence Award, 3D Systems North American User Group Conference, Destin, FL, March 24-27, 2003.
7. 2nd Runner Up, Stereolithography Excellence Award, 3D Systems North American User Group Conference, Anaheim, CA, April 26-29, 2004.
8. 1st Runner Up, Stereolithography Excellence Award, 3D Systems North American User Group Conference, Tucson, AZ, April 3-8, 2005.
9. Outstanding Paper Award, Solid Freeform Fabrication Symposium, 2005 (for IV.B.2.78).
10. Best Paper Award, ASME CIE Conference, 2005 (for IV.B.2.85).
11. 1st Runner Up, Stereolithography Excellence Award, 3D Systems North American User Group Conference, Tucson, AZ, April 30 – May 4, 2006.
12. Best Presentation Award, Solid Freeform Fabrication Symposium, Austin, TX, Aug. 6-8, 2007 (for paper IV.D.66).
13. Best Paper Award, ASME Design for Manufacturing and Life Cycle Conference, 2008. Authors: C.B. Williams, F. Mistree, D.W. Rosen (for paper IV.B.2.102).
14. Outstanding Paper Award, Solid Freeform Fabrication Symposium, Austin, TX, Aug. 4-6, 2008 (for paper IV.D.69).
15. First Place, Selective Laser Sintering Excellence Award, 3D Systems User Group Conference, Daytona Beach, FL, March 15-19, 2009.
16. Best Paper Award, ASME Computers & Information in Engineering Conference, 2009. Authors: G.C. Graf, J. Chu, S. Engelbrecht, D.W. Rosen (for paper IV.B.2.104).
17. Outstanding Paper Award, Solid Freeform Fabrication Symposium, Austin, TX, Aug. 9-11, 2010 (for paper IV.D.81).
18. Best Paper Award, Virtual and Rapid Prototyping Conference, Leiria, Portugal, Sept 28 - Oct 1, 2011 (for paper IV.D.85).
19. Best Paper Award, Int’l Conference on MicroManufacturing, Chicago, March 12-14, 2012, (for paper IV.B.2.124).
20. ASME Computers and Information in Engineering Division Excellence in Research Award, 2012.
21. Solid Freeform Fabrication Symposium, International Freeform and Additive Manufacturing Excellence (FAME) Award, 2013.
22. Outstanding Presentation Award, Solid Freeform Fabrication Symposium, 2013 (for paper IV.B.2.137).

23. Best Paper Award, International Conference on Progress in Additive Manufacturing, Singapore, May 26-28, 2014 (for paper IV.B.2.141).
24. Best Paper Award, ASME Computers and Information in Engineering Conference, Systems Engineering, Information, and Knowledge Management Technical Committee, Aug. 22, 2016 (for paper IV.B.2.158).
25. Best Paper Award, ASME Computers and Information in Engineering Conference, Computer-Aided Product and Process Design Technical Committee, Aug. 27, 2018 (for paper IV.B.2.167).
26. Best Paper Award, Journal of Manufacturing Systems, for paper IV.A.2.71 for the paper with the most citations during 2015-2019.
27. ASTM International Additive Manufacturing Award of Excellence in Research, Nov. 2021.

B. Institute or School Awards

1. Best Masters Thesis Award for Matthew Bauer's Masters thesis, Georgia Tech chapter of Sigma Xi 1998.

IV. RESEARCH, SCHOLARSHIP, AND CREATIVE ACTIVITIES

A. Published Books, Book Chapters, and Edited Volumes

1. Books

1. Gibson, I, Rosen, D.W., Stucker, B., *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing*, Springer, 2010. ISBN: 978-1-4419-1119-3.
2. Gibson, I, Rosen, D.W., Stucker, B., *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing,* Second Edition, Springer, 2015. ISBN: 978-1-4939-2113-3.
3. Gibson, I, Rosen, D.W., Stucker, B., Khorasani, M., *Additive Manufacturing Technologies,* Third Edition, Springer, 2021. ISBN 978-3-030-56127-7

2. Refereed Book Chapters

1. **Bauer, M. D., Siddique, Z.**, and Rosen, D. W., "Virtual Prototyping In Simultaneous Product/Process Design For Disassembly." Book chapter in: Rapid Response Manufacturing: Contemporary Methodologies, Tools and Technologies, Ed. John Dong, Chapman & Hall, 1997.
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12. Hopkinson, N., Rosen, D.W., "Modeling for Polymer AM Processes," *ASM Handbook Volume 24A: Additive Manufacturing Processes*, D.L. Bourell, W. Frazier, H. Kuhn, and M. Seifi, editors, 2020.
13. Rosen, D.W., Kim, S., "Design and Manufacturing Implications of AM," *ASM Handbook Volume 24A: Additive Manufacturing Processes*, D.L. Bourell, W. Frazier, H. Kuhn, and M. Seifi, editors, 2020. doi: 10.31399/asm.hb.v24.a0006560

3. Edited Volumes

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2. Michopoulos, J., Paredis, C.C., Rosen, D.W., Vance, J., Editors, Advances in Computers and Information in Engineering Research, Volume 2, ASME Press, 2021. ISBN: 9780791862025

B. Refereed Publications and Submitted Articles

1. Published and Accepted Journal Articles

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80. **Williams, C.B.**, Allen, J.K., Rosen, D., Mistree, F., “Towards the Design of a Layer-Based Additive Manufacturing Process for the Realization of Metal Parts of Designed Mesostructure**,”** Proc. Solid Freeform Fabrication Symposium, Austin, TX, Aug. 1-3, 2005.
81. **Pierce, RS**, Rosen, DW, “Simulation of Mating Between Non-Analytic Surfaces Using a Mathematical Programming Formulation,” Proc. ASME Computers and Information in Engineering Conference, paper DETC2005-84342, Long Beach, CA, Sept 24-28, 2005.
82. **Pierce, RS**, Rosen, DW, “A Method for Integrating Form Errors Into Geometric Tolerance Analysis,” Proc. ASME Design Automation Conference, paper DETC2005-84343, Long Beach, CA, Sept 24-28, 2005.
83. Rosen, DW, **Nguyen, AN**, “Simulation Methods for Formable Crust Skins of Digital Clay Human-Computer Interface Devices,” Proc. ASME Computers and Information in Engineering Conference, paper DETC2005-84455, Long Beach, CA, Sept 24-28, 2005.
84. **Chen, Y, Wang, H**, Rosen, DW, Rossignac, J, “Filleting and Rounding using a Point-Based Method,” Proc. ASME Design Automation Conference, paper DETC2005-DAC85408, Long Beach, CA, Sept 24-28, 2005.
85. **Wang, H, Chen, Y**, Rosen, DW, “A Hybrid Geometric Modeling Method for Large Scale Conformal Cellular Structures, Proc. ASME Computers and Information in Engineering Conference, paper DETC2005-85366, Long Beach, CA, Sept 24-28, 2005. **Best Paper Award**.
86. **Wilson, J.**, Rosen, D.W., “Selection for Rapid Manufacturing under Epistemic Uncertainty,” Proc. ASME Design Automation Conference, paper DETC2005/DFMLC-85264, Long Beach, CA, Sept 24-28, 2005.

87. **Choi, H-J**, Allen, JK, Rosen, DW, McDowell, DL, Mistree, F, "An Inductive Design Exploration Method for the Integrated Design of Multi-scale Materials and Products," Proc. ASME Design Automation Conference, paper DETC2005-85335, Long Beach, CA, Sept 24-28, 2005.
88. **Williams, C.B.**, Mistree, F., Rosen, D.W., "Investigation of Additive Manufacturing Processes for the Manufacture of Parts with Designed Mesostructure," Proc. ASME Design for Manufacturing Conference, paper DETC2005/DFMLC-84832, Long Beach, CA, Sept 24-28, 2005.
89. **Tse, L.A.**, Rosen, D.W., "3D Membrane Electrode Assemblies (MEAs) for Direct Methanol Fuel Cells," ASME IMECE, paper IMECE2005-81843, Orlando, Nov. 5-11, 2005.
90. **Wang, H., Johnston, S.J.**, Rosen, D.W., "Design of a Graded Cellular Structure for an Acetabular Hip Replacement Component, Solid Freeform Fabrication Symposium, Austin, TX, pp. 111-123, Aug. 14-16, 2006.
91. **Mocko, G.**, Rosen, D.W., Mistree, F., "A Critical Analysis of Description Logics for Engineering Information Management," ASME Computers in Engineering Conference, paper #DETC2006-99473, Philadelphia, Sept. 10-13, 2006.
92. **Udoyen, N.**, Rosen, D.W., Mistree, F., "Description Logic Representation of Finite Element Analysis Models for Automated Retrieval," ASME Computers in Engineering Conference, paper #DETC2006-99451, Philadelphia, Sept. 10-13, 2006.
93. **Wang, H.**, Rosen, D.W., "An Automated Design Synthesis Method for Compliant Mechanisms with Application to Morphing Wings," ASME Mechanisms Conference, paper #DETC2006-99661, Philadelphia, Sept. 10-13, 2006.
94. **Williams, C.B.**, Rosen, D.W., "Cellular Materials Manufactured via 3D Printing of Metal Oxide Powders," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 6-8, 2007.
95. **Williams, C.B.**, Rosen, D.W., 'Manufacturing Cellular Materials via Three-Dimensional Printing of Metal Oxide Powders,' Virtual and Rapid Prototyping (VRAP) Conference, Leiria, Portugal, Sept. 2007.
96. **Mocko, G**, Rosen, D.W., Mistree, F., "Decision Retrieval and Storage Enabled Through Description Logic," Proc. ASME Computers and Information in Engineering Conference, paper #DETC2007-35644, Las Vegas, NV, Sept. 4-7, 2007.
97. **Yim, S.**, Rosen, D.W., "Case-Based Retrieval Approach of Supporting Process Planning in Layer-Based Additive Manufacturing," Proc. ASME Computers and Information in Engineering Conference, paper #DETC2007-35309, Las Vegas, NV, Sept. 4-7, 2007.
98. **Wilson, J.O.**, Rosen, D.W., "Systematic Reverse Engineering of Biological Systems," Proc. ASME Design Theory and Methodology Conference, paper #DETC2007-35395, Las Vegas, NV, Sept. 4-7, 2007.
99. **Yim, S., Wilson, J.O.**, Rosen, D.W., "Development of an Ontology for Bio-Inspired Design using Description Logics," PLM'08 Conference, Seoul, Korea, July 9-11, 2008.
100. Rosen, D.W, **Margolin, L., Vohra, S.**, "Printing High Viscosity Fluids via Ultrasonic Droplet Generation," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 4-6, 2008.
101. **Jariwala, W., Ding, F., Zhao, X.**, Rosen, D.W., "A Thick Film Fabrication Process on Transparent Substrate using Mask Projection Micro-Stereolithography," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 4-6, 2008.
102. **Williams, C.B.**, Mistree, F., Rosen, D.W., "A Functional Classification Framework for the Conceptual Design of Layered Manufacturing Technologies," ASME Design for Manufacturing and Life Cycle Conference, paper DETC2008-49353, Brooklyn, NY, Aug. 3-6, 2008. **Best paper award**.

103. **Williams, C.B.**, Mistree, F., Rosen, D.W., “The Systematic Design of a Layered Manufacturing Process for the Realization of Metallic Parts of Designed Mesostructure,” ASME Design Education Conference, paper DETC2008-49457, Brooklyn, NY, Aug. 3-6, 2008.

104. Rosen, D.W., “Thoughts on Hierarchical Modeling Methods for Complex Structures,” Int’l CAD Conference and Exhibition, Reno, June 8-12, 2009.

105. **Graf, G.C., Chu, J., Engelbrecht, S.**, Rosen, D.W., “Synthesis Methods for Lightweight Lattice Structures,“ ASME Computers & Information in Engineering Conference, paper #DETC2009-86993, San Diego, Aug 31 - Sept 2, 2009. **Best paper award**.

106. **Wilson, J., Chang, P., Yim, S.**, Rosen, D.W., “Developing a Bio-inspired Design Repository using Ontologies,” ASME Design Theory and Methodology Conference, paper #DETC2009-87272, San Diego, Aug 31 - Sept 2, 2009.

107. **Jariwala, A.S., Ding, F., Zhao, X.**, Rosen, D.W., “A Process Planning Method for Thin Film Mask Projection Micro-Stereolithography,” ASME Computers & Information in Engineering Conference, paper #DETC2009-87532, San Diego, Aug. 30- Sept 2, 2009.

108. Wang, Y., Rosen, D.W., “Multiscale heterogeneous Modeling with Surfacelets,” Int’l CAD Conference and Exhibition, Dubai, June 21-25, 2010.

109. Liu, X., Rosen, D.W., Yu, Z., “Ontology based Knowledge modeling and Reuse Approach in Product Redesign,” Proceedings of the 2010 IEEE International Conference on Information Reuse and Integration, Las Vegas, NV, Aug. 4-6, 2010.

110. **Jariwala, A., Ding, F.**, Rosen, D.W., “Process Planning for the Film Micro Stereolithography Process,” Solid Freeform Fabrication Symposium, Austin, TX, Aug 9-11, 2010.

111. Loney, D.A., **Zhou, W.**, Degertekin, F.L., Fedorov, A.G., Rosen, D.W., “Acoustic Analysis of Viscous Fluid Ejection using Ultrasonic Atomizer,” Solid Freeform Fabrication Symposium, Austin, TX, Aug 9-11, 2010.

112. **Wu, W.**, Chen, Y., Wang, W., Qin, X., Rosen, D.W., “Employing Rapid Prototyping Biomedical Model to Assist the Surgical Planning of Defect Mandibular Reconstruction,” 3rd Int’l Conf. on Biomedical Engineering and Informatics, Yantai, China, Oct. 16-18, 2010.

113. **Kang, J., Scholz, T.**, Ku, D.N., Rosen, D.W., “Pump Design for a Portable Renal Replacement System,” ASME IMECE, paper IMECE2010-38245, Nov. 12-18, 2010.

114. **Chang, P.S.**, Rosen, D.W., “The Size Matching and Scaling Method: A Synthesis Method for the Design of Mesoscale Cellular Structures,” International Conference on Manufacturing Automation, Hong Kong, Dec. 13-15, 2010.

115. Liu, X., Rosen, D.W., “Ontology based Knowledge Modeling and Reuse Approach of Supporting Process Planning in Layer-based Additive Manufacturing,” International Conference on Manufacturing Automation, Hong Kong, Dec. 13-15, 2010.

116. **Zhou, W., Wu, D.,** Ding, X., Rosen, D.W., “Customer Co-Design of Computer Mouse for Mass Customization without Causing Mass Confusion,” International Conference on Manufacturing Automation, Hong Kong, Dec. 13-15, 2010.

117. **Zhou, W.,** Loney, D., Degertekin, F.L., Fedorov, A.G., Rosen, D.W., “Shape Evolution of Droplet Impact Dynamics in Ink-Jet Manufacturing,” Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2011.

118. Rosen, D.W., **Jeong, N.**, Wang, Y., “A Hierarchical, Heterogeneous CAD Modeling Approach,” ASME Computers & Information in Engineering Conference, paper #DETC2011-47550, Washington, DC, Aug 29-31, 2011.

119. **Yim, S.**, Rosen, D.W., "A Framework for Self-Realizing Process Models for Additive Manufacturing," ASME Computers & Information in Engineering Conference, paper #DETC2011-47425, Washington, DC, Aug 29-31, 2011.

120. **Chang, P.S.**, Rosen, D.W., "An Improved Size, Matching and Scaling Method for the Design of Deterministic Mesoscale Truss Structures," ASME Computers & Information in Engineering Conference, paper #DETC2011-47729, Washington, DC, Aug 29-31, 2011.

121. **Kang, J., Jariwala, A.**, Rosen, D.W., "An Empirical Model for the Prediction of Hemodialysis System Performance," ASME IMECE, paper IMECE2011-62395, Denver, CO, Nov. 11-17, 2011.

122. **Wu, W.**, Zhao, J., Zhang, L., Wang, W., Rosen, D.W., "Reconstruction of lateral mandible defect based on finite element analysis and rapid prototyping,"2011 International Conference on Mechatronics and Applied Mechanics, Hong Kong, Dec. 27-28, 2011.

123. **Mathai, G.**, Melkote, S., Rosen, D., "Effect of Machining Parameters on Burr Size of Micromilled Foils," Int'l Conference on MicroManufacturing, Chicago, March 12-14, 2012. **Best Paper Award**.

124. Olsen, T.W., **Mathai, G.**, Loftness, P., Melkote, S., Rosen, D., Erdman, A., "A novel Surgical method and Support device for Translocating Autologous Tissue Grafts to the Sub-Area Centralis: In vivo Porcine Model," the Associate for Research in Vision and Ophthalmology (ARVO 2012), Fort Lauderdale, FL, May 6-10, 2012.

125. Schaefer, D., Thames, J.L., Wellman, R., **Wu, D., Yim, S.**, Rosen, D, "Distributed Collaborative Design and Manufacture in the Cloud—Motivation, Infrastructure, and Education." ASEE Annual Conference and Exposition, San Antonio, TX, June 10-13, 2012.

126. **Jariwala, A.**, Schwerzel, R.E., Rosen, D.W., "Two Dimensional Real-Time Interferometric Monitoring System for Exposure Controlled Projection Lithography, ASME Int'l Symposium on Flexible Automation, St. Louis, MO, June 18-20, 2012.

127. **Wu, D.,** Thames, J.L., Rosen, D.W., Schaefer, D., "Towards a Cloud-Based Design and Manufacturing Paradigm: Looking Backward, Looking Forward," ASME Computers & Information in Engineering Conference, paper #DETC2012-70780, Chicago, August 12-15, 2012.

128. **Zhou, W.,** Loney, D., Fedorov, A.G., Degertekin, F.L., Rosen, D.W., "Shape characterization for droplet impingement dynamics in Ink-jet deposition," ASME Computers & Information in Engineering Conference, paper #DETC2012-71026, Chicago, August 12-15, 2012.

129. **Yim, S.**, Rosen, D.W., "Build Time and Cost Models for Additive Manufacturing Process Selection," ASME Computers & Information in Engineering Conference, paper #DETC2012-70940, Chicago, August 12-15, 2012.

130. **Hume, C.**, Rosen, D.W., "Identification of Platform Variables in Product Family Design using Sensitivity Analysis," ASME Design Automation Conference, paper #DETC2012-71198, Chicago, August 12-15, 2012.

131. Rosen, D.W., Summers, J.D., "Mechanical Engineering Modeling Language (MEML): Necessary Research Directions," Int'l Conference on Innovative Design & Manufacturing, Taipei, Taiwan, Dec. 12-14, 2012.

132. **Mathai, G.**, Melkote, S., Rosen, D., "Material Removal during Abrasive Impregnated Brush Deburring of Micromilled Grooves in NiTi Foils," Int'l Conference on MicroManufacturing, Victoria, Canada, March 25-28, 2013.

133. **Wu, D., Greer, J.J.**, Rosen, D.W., Schaefer, D., "Cloud Based manufacturing: Drivers, Current Status, and Future Trends," ASME Manufacturing Science and Engineering Conf., paper #MSEC2013-1106, Madison, WI, June 10-14, 2013.

134. **Jeong, N.**, Rosen, D.W., Wang, Y., "A Comparison of Surfacelet-Based Methods for Recognizing Linear Geometric Features in Material Microstructure," ASME Computers and Information in Engineering Conference, paper #DETC2013-13370, Portland, OR, Aug. 4-7, 2013.

135. Huang, W., Wang, Y., Rosen, D.W., "Inverse Surfacelet Transform for Image Reconstruction with Prior Knowledge," ASME Computers and Information in Engineering Conference, paper #DETC2013-12674, Portland, OR, Aug. 4-7, 2013.

136. **Wu, D.**, Morlock, M., Pande, P., Rosen, D.W., Schaefer, D., "Incorporating Social Product Development in Distributed Collaborative Design Education," ASME Design Engineering Conference., paper #DETC2013-13093, Portland, OR, Aug. 4-7, 2013.

137. **Zhou, W.,** Loney, D., Fedorov, A.G., Degertekin, F.L., Rosen, D.W., "Lattice Boltzmann Simulations of Multiple Droplet Interaction Dynamics in Inkjet Deposition," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2013. **Outstanding Presentation Award**

138. **Jones, H.H., Kwatra, A.**, Jariwala, A., Rosen, D.W., "Real-Time Selective Monitoring of Exposure Controlled Projection Lithography," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2013.

139. Summers, J.D., Rosen, D.W., "Mechanical Engineering Modelling Language (MEML): Requirements for Conceptual Design," International Conference on Engineering Design, Seoul, South Korea, Aug. 19-22, 2013.

140. **Wu, D.**, Schaefer, D., Rosen, D.W., "Cloud-Based Design and Manufacturing: A Social Network Analysis," International Conference on Engineering Design, Seoul, South Korea, Aug. 19-22, 2013.

141. Rosen, D.W., "What are Principles of Design for Additive Manufacturing?" Int'l Conf on Progress in Additive Manufacturing, Singapore, May 26-28, 2014. **Best paper award.**

142. Jariwala, A., **Vaish, S.**, Rosen, D.W., "Enabling Institute-wide Multidisciplinary Engineering Capstone Design Experiences," ASEE Summer Conference, 2014.

143. **Wu, D.**, Rosen, D.W., Wang, L., & Schaefer, D., "Cloud-Based Manufacturing: Old Wine in New Bottles?" Proceedings of the 47th CIRP Conference on Manufacturing Systems, Windsor, Ontario, Canada, April 28-30, 2014.

144. **Jones, H.H.**, Jariwala, A.S., Rosen, D.W., "Towards Real Time Control of Exposure Controlled Projection Lithography," ASME International Symposium on Flexible Automation, Awaji-Island, Japan, July 14-16, 2014.

145. Alzahrani, M., Rosen, D.W., Choi, S.K., "Design of Truss-like Cellular Structures using Element Density Information from Homogenization Topology Optimization," ASME Computers and Information in Engineering Conference, paper DETC2014-34566, Buffalo, NY, Aug 17-20, 2014.

146. Huang, W., Rosen, D.W, Wang, Y., "A Multi-scale Materials Design Method with Seamless Zooming Capability based on Surfacelets," ASME Design Automation Conference, paper DETC2014-34435, Buffalo, NY, Aug 17-20, 2014.

147. Rosen, D.W., "Multi-Scale, Heterogeneous CAD Representation for Metal Alloy Microstructures," ASME Computers and Information in Engineering Conference, paper DETC2014-34563, Buffalo, NY, Aug 17-20, 2014.

148. **Park, S.I.**, Rosen, D.W., "Effective Mechanical Properties of Lattice Material Fabricated by Material Extrusion Additive Manufacturing," ASME Computers and Information in Engineering Conference, paper DETC2014-34683, Buffalo, NY, Aug 17-20, 2014.

149. **Zhao, X.**, Rosen, D.W., "Process Modeling and Advanced Control Methods for Exposure Controlled Projection Lithography," American Control Conference, Chicago, July 1-3, 2015.

150. **Lei, N.**, Moon, S.K., Rosen, D.W., "Redefining Product Family Design for Additive Manufacturing," International Conference on Engineering Design, Milan, Italy, July 27-30, 2015.

151. Rosen, D.W., "A Set-Based Design Method for Material-Geometry Structures by Design Space Mapping," ASME Design Automation Conference, paper DETC2015-46760, Boston, Aug. 2-5, 2015.

152. Gorguluarslan, R., **Park, S-I.**, Rosen, D.W., Choi, S-K., "Material Characterization via a Multi-Level Stochastic Upscaling Technique, ASME Design Automation Conference, paper DETC2015-46819, Boston, Aug. 2-5, 2015.

153. **Zhao, X.**, Rosen, D.W., "Parameter Estimation Based Real-Time Metrology for Exposure Controlled Projection Lithography," Solid Freeform Fabrication Symposium, Aug. 10-12, 2015.

154. **Park, S-I.**, Rosen, D.W., "Quantifying Mechanical Property Degradation of Cellular Material using As-Fabricated Voxel Modeling for the Material Extrusion Process," Solid Freeform Fabrication Symposium, Aug. 10-12, 2015.

155. **Zhao, C.** Jariwala, A.S., Rosen, D.W., "Real Time Monitoring of Exposure Controlled Projection Lithography with Time-Varying Scanning Points," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2016.

156. **Zhao, X.**, Wang, J. **Zhao, C.**, Jariwala, A.S., Rosen, D.W., "Experimental Investigation of Real-Time Metrology for Exposure Controlled Projection Lithography," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2016.

157. **Kelley, M.**, Rosen, D.W., "Reconfigurable User Interfaces for CAD Applications," ASME Computers and Information in Engineering Conference, paper IDETC2016-60202, Charlotte, NC, Aug. 21-24, 2016.

158. **Dinar, M.**, Rosen, D.W., "An Ontology for Design for Additive Manufacturing," ASME Computers and Information in Engineering Conference, paper IDETC2016-60196, Charlotte, NC, Aug. 21-24, 2016.

159. **Park, S-I.**, Rosen, D.W., "Homogenization of Mechanical Properties for Additively Manufactured Periodic Lattice Structure Considering Joints Stiffening Effects," ASME Computers and Information in Engineering Conference, paper IDETC2016-59730, Charlotte, NC, Aug. 21-24, 2016.

160. Cvitanic, T., Lee, B., Song, H.I., Fu, K., Rosen, D., "LDA v. LSA: A Comparison of Two Computational Text Analysis Tools for the Functional Categorization of Patents," Int'l Conference on Case Based Reasoning, Atlanta, GA, Oct 31 – Nov 2, 2016.

161. Patel, S.V., Mignone, P.J., Tan, M.K.M., Rosen, D. "Reverse Natures: Design Synthesis of Texture-based Metamaterials (TBMs), International Conference on Engineering Design, Vancouver, Canada, Aug. 21-25, 2017.

162. **Wang, J., Zhao, C.**, Jariwala, A., Rosen, D.W, "Process Modeling and In-situ Monitoring of Photopolymerization for Exposure Controlled Projection Lithography (ECPL)," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 7-9, 2017.

163. **Watanabe, N.**, Shofner, M.L., Rosen, D.W, "Tensile Mechanical Properties of Polypropylene Composites Fabricated by Material Extrusion," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 7-9, 2017.

164. **Zhao, X.**, Rosen, D.W., "Real-Time Process Measurement and Feedback Control for Exposure Controlled Projection Lithography," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 7-9, 2017.

165. Rosen, D.W., Na Ayutthaya, D.H., Koomsap, P., "Additive and digital manufacturing design tools: an application of product-service system design," Asia-Design Engineering Workshop, Seoul, South Korea, Dec. 11-12, 2017.

166. Kim, S., Ko, H., Witherell, P., Rosen, D.W., "A Design for additive manufacturing ontology to support manufacturability analysis," ASME Design Automation Conference, paper DETC2018-85848, Quebec City, Canada, Aug. 26-29, 2018.

167. **Hansen, J-T.**, Rosen, D.W., "A Product Family Design Method for Configuration and Spatial Layout Requirements," ASME Computers and Information in Engineering Conference, paper DETC2018-85680, Quebec City, Canada, Aug. 26-29, 2018.

168. Hassani, V., Khabazi, Z., Raspall, F., Banon, C., Rosen, D.W., "Form-Finding and Structural Shape Optimization of the Metal 3D-Printed Multi-Branch Node with Complex Geometry," CAD Conference, Singapore, June 24-26, 2019. DOI: 10.14733/cadconfP.2019.24-28

169. Tang, Y, Xiong, Y, Park, S-I, Boddeti, GN, Rosen, DW, "Generation of Lattice Structures With Convolution Surface," CAD Conference, Singapore, June 24-26, 2019. DOI: 10.14733/cadconfP.2019.69-74

170. Raju, N., Kim, S., Rosen, D.W., "A Characterization Method for Mechanical Properties of Metal Powder Bed Fusion Parts," 40th International MATADOR Conference, Hangzhou, China, July 8-10, 2019.

171. Zhang, Z., Hua, B-S., Rosen, D.W., Yeung, S-K., "Rotation Invariant Convolutions for 3D Point Clouds Deep Learning," Int'l Conference on 3D Vision, Quebec, Canada, Sept. 16-19, 2019.

172. Raju, N., Rosen, D.W., "Fatigue Properties of 3D Printed Maraging Steel," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 3-6, 2021.

173. Rosen, D.W., Choi, Y.M, "Extending Product Family Design Methods to Product-Service-System Family Design," International Conference on Engineering Design, Gothenburg, Sweden, Aug. 16-20, 2021.

3. Other Refereed Materials

no data

4. Submitted Journal Articles

1. Kim, S., Tang, Y., Rosen, D.W., "A Systematic Design Method for Reconceptualize Product Architecture by Leveraging Additive Manufacturing Design Benefits," *J. Engineering Design*, submitted 9/2021.
2. Raju, N., Rosen, D.W., "Influence of post-processing and build orientation effects on mechanical properties of 300 Grade Maraging Steel," *3D Printing and Additive Manufacturing*, submitted 8/2021.
3. Wang, Z., Rosen, D.W., "Manufacturing Process Classification Based on Heat Kernel Signature and Convolutional Neural Networks," *Journal of Intelligent Manufacturing*, submitted 12/21.

C. Other Publications and Creative Products

1. Non-refereed Conference Presentations with Proceedings

1. Bras, B. and Rosen, D., "Computer-Aided Design for De- & Remanufacturing," NSF Design and Manufacturing Grantees Conference, Albuquerque, pp. 19-20, Jan. 2-5, 1996.
2. Bras, B., Goel, A., Mistree, F. and Rosen, D., "Virtual Design, Service, and Demanufacture Studio," NSF Design and Manufacturing Grantees Conference, Albuquerque, pp. 21-22, Jan. 2-5, 1996.
3. Bras, B. and Rosen, D., "Computer-Aided Design for De- & Remanufacturing," NSF Design and Manufacturing Grantees Conference, Seattle, pp. 47-48, Jan. 7-10, 1997.

4. Bras, B., Goel, A., Mistree, F. and Rosen, D., "Virtual Design, Service, and Demanufacture Studio," NSF Design and Manufacturing Grantees Conference, Seattle, pp. 45-6, Jan. 7-10, 1997.
5. **McClurkin, J.** and Rosen, D. W., "A Build Style Selection Method for Stereolithography," Proceedings North American Stereolithography User Group Conference, Orlando, February 16-20, 1997.
6. Graver, T., Rosen, D.W., McGinnis, L., "Engaging Industry in Lab-Based Manufacturing Education," ASEE Annual Conference, June 1997.
7. Clark, D. D., Mistree, F., Rosen, D.W. and Allen, J.K., "Function-Behavior-Structure: A Model for Decision-Based Design," American Society of Engineering Education, Paper No: 162501, Milwaukee, WI, June 15-18, 1997.
8. **McClurkin, J.** and Rosen, D. W., "Build Style Decision Support for Stereolithography," Proceedings Solid Freeform Fabrication Symposium, Austin, TX, pp. 627-34, August 11-13, 1997.
9. Beisher, E., Goel, A., and Rosen, D. W., "Product and Plan Models for Adaptive Disassembly Planning," Symposium on Methodologies of Intelligent Systems (ISMIS'97), Charlotte, North Carolina, October 15-18, 1997.
10. Allen, J. K. and Rosen, D. W., "Design Methodology Issues in a Distributed Studio for Rapid Tooling and Molded Parts," CIRP International Design Seminar Proceedings: Multimedia Technologies for Collaborative Design and Manufacturing, Los Angeles, pp. 21-28, October, 8-10, 1997.
11. Graver, T. W. and Rosen, D. W, "Solving the Key Problems of Making Rapid Tools," Proc. of Autofact 97, Detroit, November 3-6, 1997.
12. Rosen, D. W., Allen, J. K., Colton, J. S., Kurfess, T. R., Mistree, F., Starr, T. L., Fujimoto, R. M., and Schwan, K., "A Rapid Tooling TestBed for Injection Molding," NSF Design and Manufacturing Grantees Conference, Monterrey, Mexico, Jan. 5-8, 1998.
13. Allen, J., **Escoe, K.**, Herrmann, A., **Jangha, S., Lynn, C.**, Maier-Speredelozzi, V., Rosen, D., **West, A.**, and Xiao, A., "Automation of Design for Manufacturing Events to Improve the Product Realization Process," 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, September 2-4, 1998.
14. **Lynn, C. M., West, A.**, and Rosen, D., "A Process Planning Method and Data Format for Achieving Tolerances in Stereolithography," Proceedings Solid Freeform Fabrication Symposium, Austin, TX, pp. August 10-12, 1998.
15. Rosen, D.W., "Progress Towards a Distributed Product Realization Studio: The Rapid Tooling TestBed," IFIP WG 5.2 Third Workshop of Knowledge Intensive CAD, Tokyo, Dec. 1-4, 1998.
16. Rosen, D. W., Allen, J. K., Colton, J. S., Kurfess, T. R., Mistree, F., Starr, T. L., Fujimoto, R. M., and Schwan, K., "A Rapid Tooling TestBed for Injection Molding," NSF Design and Manufacturing Grantees Conference, Long Beach, CA, Jan. 4-7, 1999.
17. Wiens, G.J. and Rosen, D.W., "At the Cutting Edge with Rapid Tooling," Panel Session at the National Manufacturing Week Show, Chicago, March 15-18, 1999.
18. **Lynn, C.M.** and Rosen, D.W., "SLA-250 Parts vs. Geometric Tolerances: Quantitative Results," 1999 North American Stereolithography User Group Conference, Orlando, May 17-20, 1999.
19. **West, A.**, and Rosen, D., "Process Planning Based on User Preferences," Proceedings Solid Freeform Fabrication Symposium, Austin, TX, pp. 67-76, August 9-11, 1999.
20. **Jangha, S.** and Rosen, D., "An Ejection Mechanism Design Method for Stereolithography Tools," Proceedings Solid Freeform Fabrication Symposium, Austin, TX, pp. 219-228, August 9-11, 1999.

21. Rosen, D. W., Allen, J. K., Colton, J. S., Kurfess, T. R., Mistree, F., Starr, T. L., Fujimoto, R. M., and Schwan, K., "A Rapid Tooling TestBed for Injection Molding," NSF Design and Manufacturing Grantees Conference, Vancouver, BC, Jan. 5-7, 2000.
22. Rosen, D.W. and **Siddique, Z.**, "The Product Family Reasoning System – Design Methods for Enabling Product Variety," NSF Design and Manufacturing Grantees Conference, Vancouver, BC, Jan. 5-7, 2000.
23. Rosen, D.W., "Rapid Manufacturing Enablers: Product Fabrication without Assembly," Advanced Rapid Prototyping & Manufacturing 2000 Symposium, Georgia Tech, February 7-8, 2000.
24. Xiao, A., Allen, J.K., Rosen, D., and Mistree, F., "A Method to Design Product Architecture is a Distributed Product Realization Environment," Proceedings of the IEEE 9th International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE-2000), National Institute of Standards and Technology (NIST), Gaithersburg, Maryland. June 14-16, 2000.
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2. Software

no data

3. Patents

a) Patents Awarded

1. "Digital Clay Apparatus and Method," Wayne Book, Mark Allen, Imme Ebert-Uphoff, Ari Glezer, David Rosen, Jarek Rossignac. Filed: June 2002. Granted: 2004. US # 6,836,736.
2. "Digital Clay Apparatus and Method," Wayne Book, Mark Allen, Imme Ebert-Uphoff, Ari Glezer, David Rosen, Jarek Rossignac. Filed: July 2004. Granted: 2006. US # 7,047,143.
3. "Method for Making Ophthalmic Devices," Raphael Andino, Scott Meece, David Rosen, Benay Sager. Application 11/787,614. Filed Jan. 2008. Granted: Dec 2010. US # 7,860,594.
4. "Tissue Support Structure," Timothy Olsen, David Rosen, Shreyes Melkote, George Mathai. Filed March 2013. Granted: Jan 2017. US # 9,539,082.
5. "Fabricating Parts from Photopolymer Resin," Amit Jariwala, David Rosen, Fei Ding, Filed July 2011, Granted: June 2016. US # 9,367,049.

b) Provisional Patents, Applications, and Invention Disclosures

<u>Provisional Patents and Applications</u>

1. "Method for Making Opthalmic Devices using Single Mold Stereolithography," David Rosen, Scott Johnston, Ameya Limaye, Robert Schwerzel, Allen Gilliard. Filed: March 2008. Based on GTID: 3826 and 4140.
2. "Lattice and Cellular Structures via Additive Manufacturing and Method of Making the Same," James Williams, Luis Folgar, Gary Schlumberger, David Rosen. Filed: March 30, 2009. Based on GTID: 4656.

3. “Valveless Pump,” David Rosen, David Ku, Jane Kang, Patent Application Publication US 2013/0071271A1, March 2013.

Invention Disclosures

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2. “Stereolithography and MEMS Integrated Processing,” Laam Angela Tse, Peter Hesketh, David Rosen. June 2001.
3. “Injection Mold Design Method and System for 2-Piece and Multi-Piece Molds,” Yong Chen and David Rosen, Nov. 2001. GT ID 2576.
4. “Digital Clay for Shape Input to and Display from a Computer,” Wayne Book, Mark Allen, Imme Ebert-Uphoff, Ari Glezer, David Rosen, Jarek Rossignac. May 2001. GTID: 2494.
5. “Stereolithography for Fuel Cell Fuel Delivery System,” Chi-Fu Wu, Peter Hesketh, and David Rosen, Oct. 2002.
6. “Injection Mold Design Method and System for Multi-Piece Molds with Planar Parting Planes,” Yong Chen and David Rosen, March 2003. GT ID 2856.
7. “Paper Machine Clothing Check Valves to Improve Dewatering,” David Rosen, June 2005. GTID 3513.
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9. “Mask Projection Stereolithography for Customized Lenses,” Ameya Limeya, David Rosen, June 2005. GTID 3532.
10. “Smooth Stereolithography Surfaces,” Benay Sager and David Rosen, November 2005. GTID: 3680.
11. “Single Mold Stereolithography for Contact Lens Manufacture,” Scott Johnston, David Rosen, Ameya Limaye, Robert Schwerzel, April 2006. GTID: 3826.
12. “Practical Method for Single Mold Stereolithography,” Robert Schwerzel, David Rosen, March 2007. GTID: 4140.
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14. “Lattice and Cellular Structures via Additive Manufacturing and Method of Making the Same,” James Williams, Luis Folgar, Gary Schlumberger, David Rosen. November 2008. GTID: 4656.
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18. “Pump Design for a Portable Renal Replacement System,” Jane Kang, David Ku, David Rosen, February 2010. GTID: 5161.
19. “System and Method to Fabricate Parts for Photopolymer Resin on Flat, Curved, and Inclined Surfaces,” Fei Ding, Amit Jariwala, David Rosen. May 2010. GTID: 5296.
20. “Fluid Interface Supported Printing for Three-Dimensional Object Fabrication,” Nicholas Mulka, Amit Jariwala, Robert Schwerzel, David Rosen. July 2021, GTID: 8774.

4. Other Creative Products

Editorials

1. Rosen, D.W., “Design for Additive Manufacturing: Past, Present, and Future Directions,” ASME J. Mechanical Design, Vol. 136, No. 9, 2014.
2. Rosen, D.W., Seepersad, C.C., Simpson, T.W., Williams, C.B., “Designing for Additive Manufacturing: A Paradigm Shift in Design, Fabrication, and Qualification,” ASME J. Mechanical Design, Vol. 137, No. 9, 2015.

Company Reports

1. **Siddique, Z.**, Rosen, D. W., and Wang, N., “Investigations of Platform Commonality using Configuration Design Methods,” Ford Scientific Research Laboratory Report # SR-97-168, 1997.

Project Reports

1. Bourell, D.L., Leu, M., Rosen, D.W. (2009) “Roadmap for Additive Manufacturing: Identifying the Future of Freeform Processing,” final report from NSF and ONR workshop, University of Texas at Austin, April.

D. Presentations

1. Keynote Addresses and Plenary Lectures

1. **Chu, C, Graf, G**, Rosen, D.W., “Design for Additive Manufacturing of Cellular Structures,” Computer-Aided Design & Applications Conference, Orlando, FL, June 23-27, 2008.
2. Rosen, D.W., “Design for Additive Manufacturing: CAD for Cellular Structures,” Virtual and Rapid Prototyping (VRAP) Conference, Leiria, Portugal, Oct. 6-10, 2009.
3. Rosen, D.W., “Design Concept and Methods to Leverage Additive Manufacturing,” International Conference on Manufacturing Automation, Hong Kong, Dec. 13-15, 2010.
4. Rosen, D.W., “Efficiency Advantages of Additive Manufacturing,” Int’l Symposium on Green Manufacturing and Applications, Jeju, Korea, Aug. 27-29, 2012.
5. Rosen, D.W., “Information Modeling for Innovative Design and Manufacturing: Is a Mechanical Engineering Markup Language Feasible?” Int’l Conference on Innovative Design & Manufacturing, Taipei, Taiwan, Dec. 12-14, 2012.
6. Rosen, D.W., “Multi-Scale Computer-Aided Design for Additive Manufacturing,” Int’l Conference on Innovative Design and Manufacturing, Montreal, Canada, Aug. 13-15, 2014.
7. Rosen, D.W., “High Viscosity Printing,” NIP30/Digital Fabrication Conference, Philadelphia, Sept 7-11, 2014.
8. Rosen, D.W., “Controlling Localized Photopolymerization: Advances in Stereolithography,” Int’l Conf Additive Manufacturing-Biomanufacturing, Beijing, China, Nov. 12-14, 2014.
9. Rosen, D.W., “Design for Additive Manufacturing: Leveraging the Unique Capabilities of AM,” Procter & Gamble Chemistry & Materials Joint Symposium, Cincinnati, OH, Oct. 15, 2015.
10. Rosen, D.W., “Design for Additive Manufacturing: Topology Optimization,” Progress in Additive Manufacturing Conference, Singapore, May 18, 2016.
11. Rosen, D.W., “Trends in Additive Manufacturing,” Korean Society of Manufacturing Technology Engineers, Jeju City, South Korea, Nov. 3, 2016.
12. Rosen, D.W., “Additive Manufacturing: Processes and Trends,” Asia-Korea Conference on Science & Technology, Singapore, Nov. 16-18, 2017.
13. Rosen, D.W., “Polymers in Additive Manufacturing: Survey and Opportunities,” TMS Conference, Phoenix, AZ, March 11-15, 2018.
14. Rosen, D.W., “Standards Developments in Additive Manufacturing,” Progress in Additive Manufacturing Conference, Singapore, May 16, 2018.
15. Rosen, D.W., “Advances in Design for Additive Manufacturing,” International Conference on Engineering Innovation, Bangkok, Thailand, July 5-6, 2018.

16. Rosen, D.W., “Design for Additive Manufacturing: Opportunities and Challenges,” CAD Conference, Singapore, June 24-26, 2019.
17. Rosen, D.W., “Design for Additive Manufacturing: Opportunities and Challenges,” ASME IMECE Design, Systems and Complexity Track, Salt Lake City, Nov. 13, 2019.
18. Rosen, D.W., “Active Transdisciplinary Engineering Education for Competence Development in an Intelligent Manufacturing Era,” International Conference on Active Learning in Engineering Education (PAEE/ALE 2020), Pathumthani, Thailand, August 26-28, 2020.
19. Rosen, D.W., “Smart Additive Manufacturing Process Chains,” Int’l Symposium on Precision Engineering and Sustainable Manufacturing (PRESM 2021), Jeju City, South Korea, July 21-23, 2021.
20. Rosen, D.W., “Design for the Additive Manufacturing Process Chain,” plenary lecture at Solid Freeform Fabrication Symposium, Austin, TX, Aug. 2-4, 2021.
21. Rosen, D.W., “Design of Human/Social-Cyber-Physical Systems: Implications for Future Intelligent Manufacturing Systems,” 2021 Annual Meeting of the International Coalition of Intelligent Manufacturing, Beijing, China, Dec. 7, 2021.

2. Invited Conference and Workshop Presentations

1. Rosen, D.W., “Trusses, Tools, and Tolerances: Examples of Integrating Design and Manufacture,” (invited talk) Spatial Summit, Boulder, CO, June 2-4, 2003.
2. Rosen, D.W., “Information and Knowledge Management in PLM –Some Research Opportunities,” ASME Computers and Information in Engineering Conf., Panel Session on “From Engineering Database Management to Product Lifecycle Management,” Salt Lake City, Sept 29-Oct 1, 2004.
3. Rosen, D.W., “Personalized Manufacturing,” ASME Design Automation Conference, Panel Session on “Strategic Engineering,” Salt Lake City, Sept 29 – Oct 1, 2004 (invited).
4. Rosen, D.W., “Design for Additive Manufacturing,” ASME Computers and Information in Engineering Conf., Panel Session on “Design for X,” Salt Lake City, Sept 29-Oct 1, 2004 (invited).
5. Rosen, D.W., “Additive Manufacturing of Cellular Structures,” ASME Computers and Information in Engineering Conf., Panel Session on “Object Modeling and CAD for Emerging Bio/Micro/Nano Systems,” Long Beach, CA, Sept 25-29, 2005 (invited).
6. Rosen, D.W., “Cellular Structures for High Stiffness, Compliance, and Other Multifunctional Applications,” ASME IMECE, Panel Session on Rapid Prototyping, Orlando, Nov. 6-11, 2005.
7. Rosen, D.W., “Design for Additive Manufacturing Methods with Application to Medical Implant Development,” invited talk at the Indo-US Workshop on Solid Freeform Fabrication for Tissue Engineering and Biomedical Applications, Bangalore, India, February 22-24, 2007.
8. **Yim, S., Wilson, J.O.**, Rosen, D.W., “An Ontology for Bio-Inspired Engineering Design,” Ontology Workshop, KAIST, Daejon, Korea, July 8, 2008 (invited).
9. Rosen, D.W., “SSS Approach and Creativity Metrics for Bio-Inspired Design,” Bio-Inspired Workshop: Charting a Course for Computer-Aided Bio-inspired Design Research, Palo Alto, CA, March 20, 2011.
10. Rosen, D.W., “Computer-Aided Design for Additive Manufacturing: Can We Exploit Shape and Material Complexity Capabilities?” Laser Based Production Processes Conference, Heriot-Watt University, June 26, 2012.
11. Rosen, D.W., “Rapid Manufacturing 101 and Roadmap,” NSF Summer Institute on Nanomechanics and Nanomaterials and Micro/Nanomanufacturing, Northwestern University, May 29-31, 2013.
12. Rosen, D.W., “Design for Additive Manufacturing,” NSF Summer Institute on Nanomechanics and Nanomaterials and Micro/Nanomanufacturing, Northwestern University, May 29-31, 2013.

13. Rosen, D.W., "What Should CAD be for Exploring Unexplored Design Spaces?" DARPA/ISAT Workshop on Rethinking CAD, Arlington, VA, Oct. 24, 2013.
14. Rosen, D.W., "Additive Manufacturing Education at Georgia Tech," NSF Workshop on the Educational Needs and Opportunities in Additive Manufacturing, Arlington, VA, April 10-11, 2014.
15. Rosen, D.W., "Design for Additive Manufacturing Technologies for Lightweight Structures," Raytheon Additive Manufacturing Workshop, Indianapolis, IN, June 4, 2014.
16. Rosen, D.W. and Collins, S., "ASTM International F42 Committee on Additive Manufacturing," Raytheon Additive Manufacturing Workshop, Indianapolis, IN, June 4, 2014.
17. Rosen, D.W., "Overview of Processes for Additive Manufacturing," NSF Workshop on the Environmental Implications of Additive Manufacturing, Arlington, VA, October 14-15, 2014.
18. Rosen, D.W., "Design for Additive Manufacturing," panelist at AIAA Science and Technology Forum and Exposition, session: Advanced Manufacturing and its Impact on the Design Process of the Future, Kissimmee, FL, Jan. 5-9, 2015.
19. Rosen, D.W., "Impacts of Additive Manufacturing on DFM/DFA and DFLC," Panelist at ASME Design Automation Conference, Boston, Aug. 3-5, 2015.
20. Rosen, D.W., "AM Founders and Futurists," Panelist at ASME AM3D, Boston, Aug. 3-5, 2015.
21. Rosen, D.W., "Design for Additive Manufacturing," workshop at the School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, May 23, 2016.
22. Rosen, D.W., "Key Challenges Faced by Industry in Consideration of Public Comments," Workshop on Key Aspects of Good Regulatory Practice, Jakarta, Indonesia, March 16, 2017.
23. Rosen, D.W., "Standardization Efforts for Additive Manufacturing in ASTM International," 2nd Shanghai Additive Manufacturing Association International Forum, Shanghai, China, Oct. 20-22, 2017.
24. Rosen, D.W., "Trends and Opportunities in Additive Manufacturing," Panel discussion, Stratasys 3D Printing Forum, Shanghai, China, Oct. 24, 2017.
25. Rosen, D.W., Dunn, M.L., Lim, K.H., "Voxel-Based Digital Design and Manufacturing," Stratasys 3D Printing Forum, Shanghai, China, Oct. 24, 2017.
26. Rosen, D.W., "Smart Manufacturing," Panel discussion, Smart Nation in Singapore workshop, Singapore, Oct. 27, 2017.
27. Rosen, D.W., "Advanced Optimization Strategies for Additive Manufacturing," A*Star Design Workshop, Singapore, Nov. 7-9, 2017.
28. Rosen, D.W., "Impacts of 3D Printing on Industry 4.0 – and Vice Versa," Asia-Korea Conference on Science & Technology, Singapore, Nov. 16-18, 2017.
29. Rosen, D.W., "Digital Design and Manufacturing," Keppel Offshore Marine Technology & Engineering Program, Nov. 13, 2017.
30. Rosen, D.W., "4D Printing," Disruptive Innovation Summit, Singapore, Feb. 5-6, 2018.
31. Rosen, D.W., "Digital Manufacturing and Design for the Aerospace Industry," Singapore Aviation Safety Seminar, Singapore, March 26-28, 2018.
32. Rosen, D.W., "How Additive Manufacturing/3D Printing Will Upend Traditional Manufacturing," Smart Manufacturing, 3D Printing and Industry 4.0 Forum, Singapore, May 8-9, 2018.
33. Boddeti, G.N., Weeger, O., Park, S.I., Xian, Y., Dunn, M.L., Rosen, D.W., "Additive Manufacturing Opportunities: Multiscale Topology Optimization and Related Topics," International Union of Theoretical and Applied Mechanics Symposium, When Topology Optimization Meets Additive Manufacturing – Theory and Methods, Dalian, China, Oct 8-12, 2018.

34. Rosen, D.W., “Design for Additive Manufacturing,” ASTM Additive Manufacturing Center of Excellence Training Workshop, Auburn, AL, March 25, 2019.
35. Rosen, D.W., “Connecting Information Technology and Operational Technology for Digital Manufacturing,” 4th Annual Manufacturing Excellence, Singapore, July 30, 2019.
36. Rosen, D.W., “Design for Additive Manufacturing,” Department of Mechanical Engineering, King Mongkut University of Technology North Bangkok, Bangkok, Thailand, August 3, 2019.
37. Rosen, D.W., “Additive Manufacturing Education at Georgia Tech,” Materials Science & Technology, Portland, OR, Sept. 29 – Oct 3, 2019.
38. Rosen, D.W., “Multiscale design representations and a material template,” Center for Additive Manufacturing Systems annual meeting, Jeju City, South Korea, Dec. 19, 2019.
39. Rosen, D.W., “Design for Additive Manufacturing,” ASTM Additive Manufacturing Center of Excellence Training Workshop, El Paso, TX, Feb. 10, 2020.
40. Rosen, D.W., “Design for the Additive Manufacturing Process Chain,” Baker Hughes Additive Manufacturing Symposium, May 29, 2020.
41. Rosen, D.W., “How AI and Product-Process Co-Design will change Computer-Aided Design,” Defence Science Organization workshop, Singapore, August 7, 2020.
42. Rosen, D.W., “Product-Process Co-Design Optimization,” Digital Manufacturing and Design Centre Symposium, Singapore, Sept 1-3, 2020.
43. Rosen, D.W., “Multi-scale Topology Optimization for Additive Manufacturing,” Int’l Symposium on Precision Engineering and Sustainable Manufacturing, Seoul, South Korea, Nov 16-18, 2020.
44. Rosen, D.W., “Smart Additive Manufacturing Process Chains for Part Production and Design,” ASME Manufacturing Science and Engineering Conference (MSEC), Smart Additive Manufacturing symposium, June 21-25, 2021.
45. Rosen, D.W., “DEmocratizing Manufacturing Accessibility for Designers (DEMAND): “uber” for manufacturing,” workshop at Northwestern University, Aug. 3-5, 2021.

3. Conference and Workshop Presentations

1. Rosen, D. W., “Functions Transforming Engineering Designs into Manufactured Products,” Eighth Summer Conference on General Topology and Applications, Queens College, Flushing, NY, June 18-20, 1992.
2. Peters, T J, Rosen, D. W., and Shapiro, V., “Topological Spaces for Modeling Feature Conversions from Design to Manufacturing,” Third SIAM Conference on Geometric Design, Tempe, AZ, Nov. 1993.
3. Rosen, D. W. and Duffey, M., “Can DFM Methods Help Address Strategic Design Decisions?” ORSA-TIMS Conference, Detroit, October 24-26, 1994.
4. Rosen, D. W., “Strategic Design: Enabling Customized, High Value Engineered Products in Distributed Enterprises,” American Economics Association Annual Conference, Atlanta, Jan 4-6, 2002.
5. Rosen, D.W., “Rapid Prototyping for Mass Customization,” CASA-RPA Technology Forum on Mass Customization enabled by Rapid Technologies, Georgia Tech, August 13, 2002.
6. Rosen, D.W., “Truss Structure Design and Manufacturing for Ultra-Lightweight Stiff and Compliant Structures,” SME SUMMIT Conference, Los Angeles, March 28-30, 2006.
7. Rosen, D.W., Johnston, S., Reed, M., Wang, H., “Computational Design of 3-D Mesoscopic Lattice Structures for Stiffness and Compliance,” World Congress on Computational Mechanics, Los Angeles, July 16-21, 2006.

8. **Sager, B.**, Rosen, D.W., "SL Surface Finish Characterization via Development and Validation of Analytical Cure Model," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 14-16, 2006.
9. **Meacham, J.M., O'Rourke, A., Yang, Y.**, Fedorov, A.G., Degertekin, F.L., Rosen, D.W., "Printing High Viscosity Fluids using Ultrasonic Droplet Generation," Virtual and Rapid Prototyping (VRAP) Conference, Leiria, Portugal, Oct. 6-10, 2009.
10. Rosen, D.W., **Sohail, A.**, "Multifunctional Devices enabled by Additive Manufacturing," Solid Freeform Fabrication Symposium, Austin, TX., Aug. 12-14, 2013.
11. Cooke, A.L., Folgar, C.E., Folgar, L.N., Williams, J., Rosen, D.W., **Park, S-I.**, "An Investigation of the Material Properties of Laser Sintered Parts Incorporating Conformal Lattice Structure (CLS) Technology," Solid Freeform Fabrication Symposium, Austin, TX., Aug. 12-14, 2013.
12. Rosen, D.W., "The FAME Award: Looking Backward and Forward 15 Years," Solid Freeform Fabrication Symposium, Austin, TX., Aug. 12-14, 2013.
13. Rosen, D.W., "A High School Education Program in Systems Engineering and Additive Manufacturing," Workshop on Design in Engineering Education, National University of Singapore, Sept. 23, 2013.
14. Rosen, D.W., "Research on Sensors and Closed-Loop Control for Additive Manufacturing," Additive/Aerospace Pre-Summit Workshop: Standards for Advanced Additive Manufacturing Platforms, Los Angeles, Oct. 16-18, 2013.
15. **Jones, H.H.**, Jariwala, A.S., Rosen, D.W., "Fabrication Results from Real-Time Control of the Exposure Controlled Projection Lithography Process," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 406, 2014.
16. Rosen, D.W., "Issues and Challenges: Design – Then," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 4-6, 2014.
17. Rosen, D.W., "Design, CAD, and Process Modeling for Additive Metal Platforms," Additive/Aerospace Workshop: Additive Manufacturing for Aerospace 101, Los Angeles, Nov. 4-6, 2014.
18. Rosen, D.W., "AlpZhi, Inc. Start-Up Pitch," Additive Disruption Summit, Santa Clara, CA, April 1-2, 2015.
19. **Jeong, N.**, Rosen, D.W., "Recognizing 2D non-linear geometric features in material microstructure using 2D Cylinderlet based method," Solid Freeform Fabrication Symposium, Aug. 10-12, 2015.
20. Allison, J., Sharpe, C., Rosen, D.W., Seepersad, C.C., "Direct Metal Laser Sintering of Lattice Structures," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2016.
21. **Hume, C.**, Rosen, D.W., "Material Jetting Feature Resolution and Scale-up for Variable Resistance Filter Fabrics," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2016.
22. **Park, S.I.**, Watanabe, N., Shofner, M., Treat, N., Rosen, D.W., "Estimating Strength of Material Extrusion Lattice Structures based on Interlayer Bonding Strength from Process Simulation with Thermal Analysis," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 8-10, 2016.
23. **Zhao, X.**, Rosen, D.W., "Real-Time Metrology for Photopolymer Additive Manufacturing with Exposure Controlled Projection Lithography," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 7-9, 2017.
24. Rosen, D.W., "Research in the Digital Manufacturing and Design Centre at SUTD," 2nd Shanghai Additive Manufacturing Association International Forum, Shanghai, China, Oct. 20-22, 2017.
25. Hume, C, Rosen, DW, "Numerical Modeling and Evaluation of Material Jetting-Based Additive Manufacturing," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2019.

26. Raju, N, Rosen, DW, "Study of Printing Direction, Post-Processing Effects on Mechanical and Material Properties of EOS MS1 Maraging Steel," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2019.
27. Park, S-I., Xiong, Y., Tang, Y., Rosen, D.W., "Development of Implicit CAD System for Multi-material Additive Manufacturing," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2019.
28. Emami, M.M., Rosen, D.W., "Explanatory Multiphysics Modelling of Generated Heat in Vat Photopolymerization"," Solid Freeform Fabrication Symposium, Austin, TX, Aug. 12-14, 2019.
29. Emami, M.M., Rosen, D.W., "Explanatory Multiphysics Modelling of Generated Heat in Vat-Polymerization," International Conference on Simulation for Additive Manufacturing, Pavia, Italy, Sept. 11-13, 2019.
30. Jamshidian, M., Boddeti, N., Rosen, D.W., Weeger, O., "Large deformation response of 3D printed soft lattice structures using micromechanical finite element analysis," International Conference on Simulation for Additive Manufacturing, Pavia, Italy, Sept. 11-13, 2019.
31. Park, S-I., Tang, Y., Xiong, Y, Rosen, D.W., "Design for 4D Printing by Enabling Eigenstrains," 56^{th} Meeting of the Society of Engineering Science, St. Louis, MO, Oct. 13-15, 2019.
32. Emami, M., Rosen, D.W., "Process Planning for a Grayscale Frontal Photopolymerization Process," Int'l Symposium on Precision Engineering and Sustainable Manufacturing (PRESM 2021), Jeju City, South Korea, July 21-23, 2021.

4. Invited Seminar Presentations

1. "Evaluation of the Noodles Solid Modeler and its Use in a Feature-Based Design System," Ford Scientific Research Lab, CAE Department, December 12, 1990.
2. "A Feature-Based Representation to Support Design-for-Manufacturing," ASME Boston Chapter, Computers in Mechanical Engineering Section, April 4, 1991.
3. "Conversions of Feature-Based Mechanical Design Representations for Manufacturability and Performance Analyses," presented at GWW School of Mechanical Engineering, Georgia Tech, January 29, 1992.
4. "The Role of Features in the Product Realization Process," presented at the Engineering Design Research Center, Carnegie Mellon University, October 22, 1992.
5. "Formal Properties of the Design/Manufacturing Interface," (with Dr. Tom Peters, University of Connecticut) at Dept. of Mechanical Engineering, University of South Carolina, Columbia, June 14, 1993.
6. "Software Architecture for Design and Analysis of Aircraft Evacuation Systems," presented at BFGoodrich R&D Center, Brecksville, OH, September 27, 1993.
7. "Topological Spaces for the Design/Manufacturing Interface," (with Dr. Tom Peters), Dept. of Informatics and Operations Research, University of Montreal, October 14, 1993.
8. "Environmentally Conscious Design," presented (with Dr. Bert Bras) to Chrysler managers and engineers at Georgia Tech, December 9, 1993.
9. "Georgia Tech Capabilities in CAE, Design and Manufacturing," presented (with Dr. Jonathan Colton) to Ford Powertrain Operations, Dearborn, MI, August 9, 1994.
10. "Mechanical Engineering Perspectives on Computing and Software Engineering Education," presented at the Software Engineering Workshop, University of Connecticut, Storrs, CT, August 18-19, 1994.
11. "The Systems Realization Laboratory at Georgia Tech," presented to CAE Group at Ford Scientific Research Laboratory, Dearborn, MI, October 26, 1994.

12. "Virtual Prototyping in the Virtual Design Studio," presented at Fraunhofer-IGD (Institute for Computer Graphics), Darmstadt, Germany, June 23, 1995.
13. "Rapid Physical and Virtual Prototyping in Product Development," presented as part of a 3-day course on IPPD to Army program managers, sponsored by the National Center for Advanced Technologies, Crystal City, VA, July 13, 1995.
14. "Virtual Prototyping for Product Demanufacturing and Disassembly," presented to the Recycling Group at Chrysler, Auburn Hills, MI, July 17, 1995.
15. "Extending the Domain of Problem Solving in CAD Systems - The Goal-Directed Geometry Formulation and Solution Method," presented at the Institute for Applied Mathematics, Consiglio Nazionale delle Ricerche, Genoa, Italy, June 13, 1996.
16. "Reducing Cycle Time through Virtual & Rapid Prototyping Methods," presented as part of a 3-day course on IPPD to Navy program managers, sponsored by the National Center for Advanced Technologies, Crystal City, VA, October 15-17, November 19-21, 1996.
17. "Parts, Prototypes, Plans, and Tools," presented at the STEP-Based Workshop on Solid Interchange Formats at NIST, Gaithersburg, MD, November 25, 1996.
18. "Open Engineering Systems: From Life Cycle Design to Designing Product Families," presented at the Ford Scientific Research Laboratory, Dearborn, MI, April 22, 1997.
19. "Investigations of Platform Commonality using Configuration Design Methods," presented at the Ford Scientific Research Laboratory, Dearborn, MI, January 9, 1998.
20. "The Value of Prototypes in Engineering Design," Special Design Seminar, University of Minnesota, November 3, 1998.
21. "The Georgia Tech Research Program in Rapid Prototyping and Manufacturing: Toward a Rapid Tooling Testbed," Mechanical Engineering Department Seminar, University of Minnesota, November 4, 1998.
22. "Product Realization in a Distributed Engineering Environment," NIST Manufacturing Systems Integration Division, with Farrokh Mistree, July 27, 1999.
23. "The Rapid Prototyping & Manufacturing Institute," Gulfstream Advanced Design Group, March 8, 2001.
24. "Utility Theory Based Methods for Rapid Prototyping Selection," Software Solutions for Rapid Prototyping Workshop, Hong Kong, July 5, 2001.
25. "Design Methods for Injection Molds and Applications to Rapid Tooling," Department of Mechanical Engineering, University of Connecticut, November 21, 2001.
26. "The Rapid Prototyping & Manufacturing Institute," Beckman-Coulter, Miami, FL, Sept. 26, 2002.
27. "The Rapid Tooling Testbed: A Distributed Design-For-Manufacturing System," Dept. of Mechanical Engineering, University of Michigan, Sept. 18, 2003.
28. "Additive Manufacturing Technologies for Dental Restorations and Orthodontics," School of Dentistry, Medical College of Georgia, Augusta, GA, February 4, 2004.
29. "Process Planning for Additive Manufacturing: Issues, Methods, and Challenges," Dept. of Mechanical Engineering, Michigan Technological University, Houghton, MI, April 1, 2004.
30. "Process Planning and Design-for-Additive Manufacturing: Issues, Methods, and Challenges," Dept. of Industrial Engineering, University at Buffalo, Buffalo, NY, Nov. 5, 2004.
31. "Additive Manufacturing Research in the RPMI," Dept. of Mechanical and Manufacturing Engineering, Loughborough University, UK, July 19, 2005.
32. "Rapid Prototyping and Manufacturing," Puerto Rico Manufacturers Association, Manufacturing Summit, San Juan, PR, Nov. 3-4, 2005.

33. "Cellular Structures: A New Material Mesostructure for Multifunctional Applications," Invited seminar at the Department of Mechanical, Materials, and Aerospace Engineering, Illinois Institute of Technology, April 12, 2006.
34. "Cellular Structures: A New Material Mesostructure for Multifunctional Applications," Invited seminar at the Department of Mechanical Engineering and Mechanics, Drexel University, Sept. 11, 2006.
35. "Cellular Structures and Adaptive Skins: Conceptual Materials for Multifunctional Applications," invited seminar at NASA Langley, Hampton, VA, Dec. 1, 2006.
36. "Computer-Aided Design Methods for Additive Manufacturing," School of Mechanical and Manufacturing Engineering, Loughborough University, June 3, 2008.
37. "Graduate Studies at the George W. Woodruff School of Mechanical Engineering," Dept. of Mechanical and Automation Engineering, Chinese University of Hong Kong, Hong Kong, Oct. 13, 2008.
38. "Graduate Studies at the George W. Woodruff School of Mechanical Engineering," Dept. of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China, Oct. 14, 2008.
39. "Graduate Studies at the George W. Woodruff School of Mechanical Engineering," Dept. of Mechanics & Aerospace Engineering, Peking University, Beijing, China, Oct. 15, 2008.
40. "Design for Additive Manufacturing," Dept. of Precision Instruments & Mechanology, Tsinghua University, Beijing, China, Oct. 16, 2008.
41. "Design for Additive Manufacturing," Dept. of Mechanical Engineering, Xi'an Jiao Tong University, Xi'an, China, Oct. 17, 2008.
42. "Graduate Studies at the George W. Woodruff School of Mechanical Engineering," Dept. of Mechanical Engineering, Xi'an Jiao Tong University, Xi'an, China, Oct. 17, 2008.
43. "Design for Additive Manufacturing," Dept. of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea, Oct. 21, 2008.
44. "Graduate Studies at the George W. Woodruff School of Mechanical Engineering," Dept. of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea, Oct. 21, 2008.
45. "Design for Additive Manufacturing: Searching in Unexplored Regions of the Design Space," Dept. of Mechanical Engineering, Seoul National University, Seoul, Korea, Oct. 22, 2008.
46. "Design for Additive Manufacturing: Exploiting the Unique Capabilities of Additive Manufacturing Processes," Dept. of Mechanical Engineering, Iowa State University, Ames, IA, Oct. 20, 2009.
47. "Computer-Aided Design for Additive Manufacturing," Dept. of Mechanical Engineering, Clemson University, Oct. 30, 2009.
48. "Roadmap for Additive Manufacturing: Identifying the Future of Freeform Processing," Edison Welding Institute, Additive Manufacturing Consortium meeting, Columbus, OH, Feb. 11-12, 2010.
49. "Design for Additive Manufacturing: Opportunities with Cellular Structures," Hong Kong University of Science and Technology, Dept. of Industrial Engineering, Dec. 15, 2010.
50. "Controlling Local Photopolymerization: Research in Stereolithography Manufacturing Processes," Texas Tech University, Dept. of Mechanical Engineering, Oct. 17, 2011.
51. "Controlling Localized Photopolymerization: Research in Stereolithography Manufacturing Processes," University of Southern California, Dept. of Industrial & Systems Engineering, Oct. 23, 2012.
52. "Computer-Aided Design for Additive Manufacture," University of Connecticut, Dept. of Mechanical Engineering, Nov. 30, 2012.
53. "Additive Manufacturing: 3D Printing Processes, Applications, and Design Considerations," Int'l Conf. on Engineering Design, Workshop on Additive Manufacturing, Seoul, Korea, Aug 19-22, 2013.

54. “Computer-Aided Design for Additive Manufacture,” Nanyang Technical University, School of Mechanical and Aerospace Engineering, Singapore, Sept. 25, 2013.
55. “Computer-Aided Design for Additive Manufacture,” Singapore University of Technology and Design, Singapore, Sept. 25, 2013.
56. “High Viscosity Ink-Jet Printing and Stereolithography 3D Printing Research,” School of Mechanical Science and Engineering, Jilin University, Changchun, China, July 17, 2014.
57. “High Viscosity Ink-Jet Printing and Stereolithography 3D Printing Research,” School of Mechanical Engineering and Automation, Northeastern University, Shenyang, China, July 18, 2014.
58. “Design and CAD for Additive Manufacturing,” GKN Aerospace, St. Louis, MO, Feb 27, 2015.
59. “Navigating Process-Structure-Property Relationships for Simultaneous Product-Material-Process Design,” Singapore University of Technology & Design, Engineering Product Development Pillar, March 18, 2015.
60. “Heterogeneous (Geometry+Materials) Modeling for Design for Additive Manufacturing,” Nanyang Technological University, Dept. of Mechanical and Aerospace Engr., Singapore, March 24, 2015.
61. “Heterogeneous (Geometry+Materials) Modeling for Design for Additive Manufacturing,” Institute for High Performance Computing, A*Star, Singapore, March 26, 2015.
62. “Towards Simultaneous Product-Material-Process Design for Additive Manufacturing,” Dept. of Mechanical Engineering, University of Illinois, Chicago, April 7, 2015.
63. “Process Modeling and Design for Additive Manufacturing,” Applied Materials, Inc., May 12, 2015.
64. “AlpZhi Technology and Commercialization,” Applied Materials Ventures, May 12, 2015.
65. “Computer-Aided Design and Optimization for Additive Manufacturing,” Siemens Energy, webinar, May 20, 2015.
66. “Modeling, Sensing, and Controlling High Precision Stereolithography,” Nanyang Technological University, Dept. of Mechanical and Aerospace Engr., Singapore, July 9, 2015.
67. “Design for Additive Manufacturing: Emerging Tools and Guidelines,” ASME AM3D, Boston, Aug. 10-12, 2015.
68. “ASTM International F42 Committee on Additive Manufacturing,” ASME Y14.46 Committee meeting, Boston, Aug. 12, 2015.
69. “Models of Distributed Properties: Towards Multi-Scale 4D Representations,” DARPA Design for Advanced Manufacturing workshop, Arlington, VA, Sept. 30, 2015.
70. “Towards Simultaneous Product-Material-Process Design for Additive Manufacturing,” Dept. of Mechanical Engineering, Politechnico di Milano, Milan, Italy, Oct. 2, 2015.
71. “Design for Additive Manufacturing,” Dept. of Mechanical Engineering, North Dakota State University, Fargo, ND, Oct. 16, 2015.
72. “Towards Simultaneous Product-Material-Process Design for Additive Manufacturing,” Dept. of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, March 21, 2016.
73. “Design for Additive Manufacturing: Lattice Structures & Topology Optimization, Sandia Topology Optimization Workshop, Houston, TX, March 30, 2016.
74. “A Design Guidance System for Additive Manufacturing,” Siemens Energy, Orlando, FL, April 21, 2016.
75. “Towards Simultaneous Product-Material-Process Design for Additive Manufacturing,” Siemens Corporate Technology, Princeton, NJ, May 3, 2016.
76. “Additive Manufacturing: Processes and Trends,” Dept. of Mechanical Engineering, Sungkyunkwan University, Suwon, South Korea, Nov. 1, 2016.
77. “Entrepreneurship Initiatives at Georgia Tech and SUTD,” College of Engineering, Sungkyunkwan University, Suwon, South Korea, Nov. 2, 2016.

78. "Digital Manufacturing and Design Research at the Singapore University of Technology & Design," Department of Industrial Systems Engineering, Asian Institute of Technology, Bangkok, Thailand, March 20, 2017.
79. "Digital Manufacturing and Design Research at the Singapore University of Technology & Design," Department of Mechanical Engineering, King Mongkut University of Technology North Bangkok, Bangkok, Thailand, March 21, 2017.
80. "Process Measurement and Control of Mask Projection Stereolithography Processes," School of Mechanical Science and Engineering, Huazhong University of Science and Technology, June 21, 2017.
81. "Additive Manufacturing Research at Georgia Tech and Singapore University of Technology & Design," Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, June 21, 2017.
82. "Process Measurement and Control for a Mask-Projection Stereolithography Process," Department of Mechanical Engineering, Aalto University, Espoo, Finland, Oct. 13, 2017.
83. "Computer-Aided Design for Additive Manufacturing: Design with Geometry+Materials+Properties," School of Mechanical Science and Engineering, Huazhong University of Science and Technology, June 12, 2018.
84. "Industrial Digital Design and Additive Manufacturing Workflows," Shining 3D, Hangzhou, China, June 19, 2018.
85. "Additive Manufacturing Technologies and Applications," College of Engineering, King Mongkut University of Technology North Bangkok, Bangkok, Thailand, August 2, 2019.
86. "Design for Additive Manufacturing: Opportunities and Challenges," Dept. of Mechanical Engineering, Ecole Normale Superieure Paris-Saclay, Sept. 18, 2019.
87. "Multimaterial Digital Design Research," LEGO Systems A/S, Billund, Denmark, Sept 15, 2019.
88. "Beyond Design for Manufacturing: Towards Simultaneous Product-Material-Process Design," Dept. of Mechanical Engineering, Stevens Institute of Technology, Nov. 15, 2019.
89. "Design for Additive Manufacturing," ASTM Center of Excellence Webinar, June 9, 2020.
90. "Design for Additive Manufacturing," ASTM Center of Excellence Webinar, March 24, 2021.
91. "Design for Additive Manufacturing," America Makes and ANSI Standards Workshop, March 31, 2021.
92. "Multi-scale Design of Fiber-Reinforced Composite Structures for Additive Manufacturing," Sabanci University, Integrated Manufacturing Research and Application Center, (virtual) April 7, 2021.
93. "Design for Additive Manufacturing," ASTM Center of Excellence Webinar, August 11, 2021.
94. "Perspectives on Design for Additive Manufacturing," School of Aerospace and Mechanical Engineering, University of Oklahoma, Oct. 21, 2021.
95. Digital Design and Manufacturing as a Cyber-Physical-Human System," A*STAR Institute for High Performance Computing, Singapore, January 10, 2022.

E. Grants and Contracts

1. As Principal Investigator

1. Virtual Design, Service, and Demanufacture Studio
   National Science Foundation
   PI. Collaborators: Farrokh Mistree, Bert Bras, Nelson Baker (CEE), and Ashok Goel (COC).

Total Dollar Amount: $417,000. Period of Contract: 10/94 – 9/97.
Candidate's Share: ~33% ($139K)

2. Ship Design for Producibility
   PI
   US Navy, subcontract under Advanced Marine Enterprises, Inc.
   Total Dollar Amount. $55,892. Period of Contract: 1/95 – 12/95.
3. A Rapid Tooling Testbed for Injection Molding
   National Science Foundation.
   PI: David Rosen, Co-PIs: Janet Allen, Jonathan Colton, Thomas Kurfess, Farrokh Mistree, Thomas Starr (MSE), Richard Fujimoto (COC), Karsten Schwan (COC).
   Total Dollar Amount: $1,350,000. Period of Contract: 9/97 – 8/00.
   Candidate's Share: ~33% ($450)
4. The Product Family Reasoning System – Design Methods for Enabling Product Variety
   National Science Foundation
   PI. Total Dollar Amount: $168,218. Period of Contract: 1/1999 - 12/2001.
5. Characterization of PVA for use in Stereolithography Machines
   CibaVision Corp.
   PI. Total Dollar Amount: $137,400. Period of Contract: 3/2002 - 4/2004.
6. Paper Machine Clothing Research
   Albany, International.
   PI. Co-PIs: Jonathan Colton, Cliff Henderson, John Muzzy
   Total Dollar Amount: $63,000. Period of Contract: 1/04 - 12/04
   Candidate's Share: ~25% ($16k)
7. Development and Commercialization of MicroStereolithography (MSLA) Technology
   National Collegiate Inventors and Innovators Alliance.
   PI. Co-PI: Marie Thursby
   Total Dollar Amount: $17,000. Period of Contract: 7/04 - 6/05
   Candidate's Share: 100%
8. Stereolithography for Corrective Lens Manufacturing
   Georgia Research Alliance
   PI. Total Dollar Amount: $47,600. Period of Contract: 7/04 - 6/05
9. Characterization of PVA for use in Stereolithography Machines
   CibaVision Corp.
   PI. Total Dollar Amount: $55,100. Period of Contract: 1/05 - 12/05
10. Paper Machine Clothing Research
    Albany, International.
    PI. Co-PIs: Jonathan Colton, Cliff Henderson, John Muzzy
    Total Dollar Amount: $81,000. Period of Contract: 1/05 - 12/05
    Candidate's Share: ~50% ($40.5k)
11. Synthesis Methods for Structural and Compliant Mesostructured Parts
    National Science Foundation.
    PI. Total Dollar Amount: $190,000. Period of Contract: 8/05 - 7/08.
12. Stereolithography for Corrective Lens Manufacturing
    Georgia Research Alliance
    PI. Total Dollar Amount: $50,000, Period of Contract: 9/05 - 8/06
13. Paper Machine Clothing Research
    Albany, International.

PI. Co-PI: Cliff Henderson
Total Dollar Amount $81,000. Period of Contract: 1/06 - 12/06
Candidate's Share: 50% ($40.5k)

14. CustomVision
    Georgia Tech VentureLab program.
    PI. Total Dollar Amount: $50,000. Period of Contract: 9/06 - 6/07
15. Cytometer Housing Manufacture Research
    RMD, Inc. subcontract from NASA SBIR.
    PI: Total Dollar Amount: $10,000. Period of Contract: 12/05 - 5/06
16. Development of an Implantable Artificial Kidney
    Mason Trust Foundation.
    PI. Co-PI: David Ku
    Total Dollar Amount: $480,000. Period of Contract: 8/06 - 1/10
17. Cytometer Housing Manufacture Research
    RMD, Inc. subcontract from NASA SBIR.
    PI. Total Dollar Amount: $75,000. Period of Contract: 1/07 - 12/08
18. Manufacturing Research for Paper Machine Clothing
    Albany, International.
    PI. Co-PI: Cliff Henderson
    Total Dollar Amount: $85,000. Period of Contract: 1/07 - 12/07
19. Characterization of PVA for use in Stereolithography Machines
    CibaVision Corp.
    PI. Co-PIs: V. Breedveld, M. Gallivan, C. Henderson
    Total Dollar Amount: $621,000. Period of Contract: 3/07 - 2/10
    Candidate's Share: ~50% ($310k)
20. Stereolithography for Corrective Lens Manufacturing
    Georgia Research Alliance
    PI. Co-PIs: V. Breedveld, M. Gallivan, C. Henderson
    Total Dollar Amount: $94,000. Period of Contract: 7/07 - 6/08
    Candidate's Share: ~33% ($31k)
21. Drop-on-Demand Deposition of Complex Fluids for 3-D Manufacturing
    National Science Foundation.
    PI, co-PIs: F. L. Degertekin, A. Fedorov.
    Total Dollar Amount: $371,000. Period of Contract: 7/09 - 6/12
    Candidate's Share: ~40% ($140k)
22. A Multiscale Heterogeneous Foundation for Computer-Aided Design,
    National Science Foundation
    PI. co-PI: Yan Wang
    Total Dollar Amount: $359,000. Period of Contract: 9/10 - 8/13
    Candidate's Share: 50% ($180k)
23. Film Microstereolithography Process.
    Georgia Research Alliance, VentureLab program.
    PI. Total Dollar Amount: $50,000. Period of Contract: 7/10 - 6/11.
24. Infusion Finger Pumps for Biomedical Applications.
    Georgia Research Alliance, VentureLab program.
    PI. co-PI: David Ku.

Total Dollar Amount: $25,000. Period of Contract: 9/10 - 6/11.
Candidate's Share: ~75% ($19k)

25. Film MicroStereolithography for Microlens Fabrication
NSF SBIR, subcontract from AlpZhi, Inc.
PI. Total Dollar Amount: $38,000. Period of Contract: 1/11 - 6/11.
26. Interdisciplinary Undergraduate Design Minor.
GT FIRE Program.
PI. co-PIs: Sabir Khan, Ali Mazalek.
Total Dollar Amount: $38,000. Period of Contract: 5/11 - 4/13.
Candidate's Share: 50% ($19k)
27. Workshop on Mechanical Engineering Design Knowledge Modeling
National Science Foundation.
PI. co-PI: J. Summers (Clemson U).
Total Dollar Amount: $47,314. Period of Contract: 8/11 - 7/13
Candidate's Share: ~70% ($33k)
28. Film Microstereolithography Process
Georgia Research Alliance, VentureLab program, Phase IIa.
PI. Total Dollar Amount: $50,000. Period of Contract: 7/11 - 6/12.
29. Sensing and Control of Photopolymerization-Based Additive Manufacturing Processes.
National Science Foundation
PI. Total Dollar Amount: $269,000. Period of Contract: 8/12-7/15.
30. AlpZhi, Inc., Film Microstereolithography Process.
Georgia Research Alliance, VentureLab program, Phase IIB.
PI. Total Dollar Amount: $50,000. Period of Contract: 7/12 - 6/13.
31. Exposure Controlled Projection Lithography for Fabrication of Physical Shaped GRIN Optics,.
NSF SBIR, subcontract from AlpZhi, Inc.
PI. Total Dollar Amount: $36,442. Period of Contract: 7/13-12/13.
32. Optimal Design of New Door Operator
ThyssenKrupp Elevators.
PI. co-PI: Seung-Kyum Choi.
Total Dollar Amount: $29,000. Period of Contract: 6/2014 – 9/2014.
Candidate's Share: 50% ($14,500).
33. Reinforced Polymers for Material Extrusion Additive Manufacturing
Imerys Corp.
PI. co-PI: Meisha Shofner.
Total Dollar Amount: $200,000. Period of Contract: 6/2014 – 9/2016.
PI Share: 55% ($110,000)
34. Materials and Processes for High Aspect Ratio Features on Dryer Fabrics
Kimberly-Clark Corp.
PI. co-PI: Meisha Shofner.
Total Dollar Amount: $425,000, 1/2015 – 12/2018.
Candidate's Share: 20% ($85,000).
35. AlpZhi, Inc., Film Microstereolithography Process.
Georgia Research Alliance, VentureLab program, Phase IIC.
PI. Total Dollar Amount: $50,000. Period of Contract: 11/14 - 6/15.
36. A Design Guidance System for Additive Manufacturing.
America Makes.
PI. co-PI: C. Seepersad (U Texas), S.Musuvathy (Siemens), J. Berlin (Stratasys)

Total Dollar Amount: $999,959, Cost Share: $1.08M. Period of Contract: 10/15 – 9/17.
Candidate's Share: ~25% ($276,000).

37. Product Family Configuration System
Wincor-Nixdorf, Inc.
PI. Total Dollar Amount: $30,768. Period of Contract: 9/15 – 11/15.

At SUTD:

38. Computer-Aided Design for Additive Manufacturing: Simultaneous Product-Material-Process Design
Digital Manufacturing and Design research center, Singapore University of Technology & Design.
PI. Co-PIs: Q. Ge, N. Raghavan.
Total Dollar Amount: US$1,080,000. Period of Performance: 4/17-9/20
Candidate's Share: ~50% ($500k)
39. Standards for Design Rules for Additive Manufacturing
National Additive Manufacturing Innovation Cluster (Singapore).
PI. Co-PI: KH Lim (SUTD).
Total Dollar Amount: US$144,000. Period of Contract: 5/17-4/19
Candidate's Share: 80% ($115k)
40. Integration of Fiber Reinforced Composites and Additive Manufacturing — CPV Pressure Reducer
National Additive Manufacturing Innovation Cluster (Singapore)
PI. Total Dollar Amount: US$64,300. Period of Contract: 7/17 – 6/18.
41. Micro-optics Component Fabrication using Mask Projection Stereolithography
National Additive Manufacturing Innovation Cluster (Singapore).
PI. Total Dollar Amount: US$166,000. Period of Contract: 8/17-7/19.
42. Standards and Framework Equivalency Methodology Development for Additive Manufacturing of Engineering Components
National Additive Manufacturing Innovation Cluster (Singapore).
PI. Total Dollar Amount: US$108,670. Period of Contract: 4/18-3/19.
43. AI in Metrology for Additive Manufacturing
Digital Manufacturing and Design research center, Singapore University of Technology & Design.
PI. Total Dollar Amount: US$265,000. Period of Performance: 4/18-9/20
44. Additive Manufacturing Standards for the Singapore Armed Forces
National Additive Manufacturing Innovation Cluster (Singapore).
PI. Total Dollar Amount: US$180,450. Period of Contract: 12/18-12/20.
45. Standard Development for Additive Manufacturing Material: Maraging Steel
National Additive Manufacturing Innovation Cluster (Singapore).
PI. Total Dollar Amount: S$101,400, US$75,000. Period of Contract: 8/2020-3/2021.

2. Co-Principal Investigator

1. Development of an Integrated and Collaborative Design-Learning Simulator
Joint proposal with Janet Allen and Farrokh Mistree (ME) and Mark Guzdial (CoC).
GT EduTech Program
Amount Requested: $26,300, 1 Year, March 1994. Result: Awarded (6/94 – 5/95)
2. Design for Demanufacturing
GT Manufacturing Research Center. Joint with Bert Bras and Kok-Meng Lee.
Amount Requested: $86,783, 1 year. Result: Awarded. $15,000 (9/94 – 9/95).
3. Computer-Aided Design for Demanufacturing and Remanufacturing
National Science Foundation Joint with Bert Bras.
Amount Requested: $257,480, 3 yrs. Result: Awarded: $217,000 (9/94 – 8/97).

4. Design for Automated Demanufacturing of Electronic Products
GT Manufacturing Research Center. Joint with Bert Bras and Kok-Meng Lee.
Amount Requested: $40,000, 1 year. Result: Awarded. $32,000. (9/95 – 8/96).
5. Distributed Design and Manufacturing: A Practical Usage Scenario
NIST. PI: Farrokh Mistree. Co-PI's: Janet Allen and David Rosen
Amount Requested: $50,000. 1 year. Result: Awarded (10/99), $25,000, 1 year.
6. Laser-Jet CVD Rapid Prototyping of Electronic Devices and Laminated Materials
National Science Foundation.
PI: Jack Lackey, Co-PI's: Iwona Jasiuk and David Rosen.
Total Dollar Amount: $320,000. Period of Contract: 4/00 - 3/03
Candidate's Share: ~33% ($100k)
7. ITR/PE+SY Digital Clay for Shape Input and Display
National Science Foundation.
PI: Wayne Book. Co-PIs: M. Allen, I. Ebert-Uphoff, A. Glezer, D. Rosen, J. Rossignac
Total Dollar Amount: $2,000,000. Period of Contract: 9/01 - 8/06
Candidate's Share: ~12% ($250k)
8. Development of a Microfabricated Miniature Fuel Cell
T/J Technology (NIST ATP contract).
PI: Peter Hesketh. Co-PI: Paul Kohl, D. Rosen
Total Dollar Amount: $350,000. Period of Contract: 6/03 - 7/04
Candidate's Share: ~20% ($65k)
9. Roadmap for Additive Manufacturing Workshop
NSF and ONR
PI: David Bourell (Univ. Texas). Co-PIs: D. Rosen, M. Leu (Missouri Univ S&T).
Total Dollar Amount: $75,000. Period of Contract: 1/09 - 12/09.
Candidate's Share: 10% ($7.5k)
10. Design and Manufacturing of a Surgical Support Structure
VentureLab.
PI: Tim Olsen (Emory U). co-PIs: S. Melkote, D. Rosen
Total Dollar Amount: $50,000. Period of Contract: 1/09 – 12/09.
Candidate's Share: 17% ($8.5k)
11. Tissue Support for Suprachoroidal Surgery
Emtech Bio program.
PI: Tim Olsen (Emory U). co-PIs: S. Melkote, D. Rosen
Total Dollar Amount: $100,000. Period of Contract: 9/09 - 8/10
Candidate's Share: 20% ($20k)
12. CCLI: Biologically !nspired Design: A novel interdisciplinary biology-engineering curriculum,
National Science Foundation
PI: Jeannette Yen, co-PIs: A. Goel, D. Rosen, C. Tovey, M. Weissburg.
Total Dollar Amount: $600,000. Period of Contract: 9/10 - 8/12
Candidate's Share: ~7% ($40k)
13. Ultralight-but-Robust Automotive Vehicle with Strong, Lightweight, Next-generation Material.
Korea Institute for Advancement of Technology.
PI: Seung-Kyum Choi. co-PI: Richard Neu, David Rosen
Total Dollar Amount: $35,000. Period of Contract: 1/2011 - 6/2011
Candidate's Share: 20% ($7k)
14. MENTOR: Manufacturing Experimentation and Outreach
DARPA, MENTOR program.

PI: Dan Schrage (AE). co-PI: David Rosen.
Total Dollar Amount: $1,000,000. Period of Contract: 9/11 - 8/12
Candidate's Share: 12% ($120k)

15. Development of iFAB Manufacturing Process and Machine Capability Library
DARPA, iFAB program.
PI: Shreyes Melkote). co-PI: David Rosen and 6 others.
Total Dollar Amount: $1,468,644. Period of Contract: 6/11 - 5/12
Candidate's Share: ~8% ($100k)

16. Reliability-based Design and Manufacturing of Cellular Structures
National Science Foundation
PI: S-K. Choi. co-PI: D Rosen.
Total Dollar Amount: $375,000. Period of Contract: 8/2012 - 7/2015.
Candidate's Share: ~40% ($170,000).

17. Analytical Certification for Additive Manufacturing Parts and Processes under Uncertainty
National Science Foundation
PI: S-K. Choi. co-PI: D Rosen.
Total Dollar Amount: $100,000. Period of Contract: 8/2015-7/2018.
Candidate's Share: ~10% ($10,000).

18. Enhancing the Model-Based Definition with Manufacturing Information through Linked Data for Design Exploration
DMDII
PI: Veronica Brandstetter (Siemens CT). co-PIs: DW Rosen, others at Siemens, Koneksys, MetaMorph, Raytheon
Total Dollar Amount: $1,000,000. Period of Contract: 18 months. Selected for award Feb 2017. Suspended due to a company's withdrawal from the project. Assigned to S. Melkote since I was on leave-of-absence. Project was reactivated in Oct 2018.
Candidate's Share: $134,477

19. A Data-Driven Approach to Future Cyber Manufacturing as a Service
National Science Foundation
PI: S Melkote. Co-PI: D Rosen
Total Dollar Amount: $300K. Period: 24 months. Awarded March 2021
Candidate's share: $140,000

At SUTD

20. 3D Printing Architecture: Digital Design and Manufacturing of Bespoke Space Frames using Additive Manufacturing,
SUTD/Zhejiang University Research Collaboration Grant
PI. F. Raspall, co-PI C Banon, DW Rosen.
Total Dollar Amount: US$552,000. Period of Contract: 8/2017 – 7/2020.
Candidate's Share: ~38% ($211,000)

21. Industrial Digital Design and Manufacturing Workflows
Advanced Manufacturing Enterprise Program, Singapore.
Co-PI. PI: A Silva. Co-PIs: YW Zhang, S. Narayanaswamy, GS Soh, DW Rosen.
Total Dollar Amount: US$11,000,000. Period of Contract: 3/2020 – 2/2023.
Candidate's Share: ~11% ($1.2M)

22. An Integrated Sense-Analysis-Print Process for On-demand Printing of Insoles
National Additive Manufacturing Innovation Cluster (Singapore).

PI. Total Dollar Amount: S$230,400, US$170,000. Period of Contract: 8/2019-6/2021
Candidate's Share: 75% (S$172,800, US$127,000)

Pending

1.

3. As Senior Personnel or Contributor

no data

4. Pending Proposals

F. Other Scholarly and Creative Accomplishments

Start-Up Companies

1. AlpZh, Inc. Incorporated Nov. 2009. Founders: A.S. Jariwala, F. Ding, D.W. Rosen. Commercializing the mask-projection stereolithography technology developed during a Ciba Vision research contract. Awarded two NSF SBIR grants and four GT VentureLab grants.
2. Additive Manufacturing Technologies, Inc. Founded March 2010. Founders: J. Williams, D.W. Rosen. Commercializing the TrussCreator software for lightweight structure design that was developed during an NSF grant and Air Force contract.

G. Societal and Policy Impacts

no data

H. Other Professional Activities

Engineering Consulting

1. Lawrence Livermore National Laboratory. Assessment of Competitive Product and Process Design Strategies. 6/26/94 - 7/13/94.
2. Albany International. Evaluation of Droplet Generation Manufacturing Methods. Nov. 2007.
3. Boeing. Methods for Eliminating STL Files. Nov.-Dec. 2007.
4. Albany International. Evaluation of droplet generation manufacturing methods; expert witness on patent litigation. June - Sept 2009.
5. EOS, GmbH. Expert witness in tariff litigation regarding classification of their laser sintering and melting machines. May 2010 - April 2011.
6. Align Technology, member Scientific Advisory Board, 2013. Board meeting Jan 10-11, 2013.
7. ExOne Corp., Software Environment for Additive Manufacturing. Aug-Dec, 2013.
8. Waldemar Link GmbH, Nov. 2019.
9. Xometry. Evaluate 3D Hubs online quoting system. Aug-Sept 2020.

V. TEACHING

A. Courses Taught

Semester, Year	Course Number	Course Title	No. Students
Fall 2021	ME 6124-A	Finite Element Method	35
Fall 2021	ME 6124-Q	Finite Element Method	12

Spring 2021	ME 6104-A	Fundamentals of CAD	21
Spring 2021	ME 6104-Q	Fundamentals of CAD	9
Spring 2021	ME 6124-A	Finite Element Method	21
Spring 2021	ME 6124-Q	Finite Element Method	9
Fall 2020	ME 6124-A	Finite Element Method	21
Fall 2020	ME 6124-Q	Finite Element Method	9
Summer 2020	ME 6124-A	Finite Element Method	10
Summer 2020	ME 6124-Q	Finite Element Method	7
Spring 2020	ME 7227-A	Rapid Prototyping in Engineering	22
Spring 2020	ME 7227-Q	Rapid Prototyping in Engineering	20
Spring 2020	ME 2016	Computing Techniques	40
Fall 2019	ME 3801	Intro to Additive Manufacturing	10
Fall 2019	ME 6124-A	Finite Element Method	41
Fall 2019	ME 6124-Q	Finite Element Method	14
Spring 2019	ME 2016	Computing Techniques	36
Fall 2018	ME 6124-A	Finite Element Method	33
Fall 2018	ME 6124-Q	Finite Element Method	18
Spring, 2016	ME 6104-A	Fundamentals of CAD	44
Spring, 2016	ME 6104-Q	Fundamentals of CAD	23
Fall 2015	ME 4803	Design Across Disciplines	11
Spring, 2015	ME 6104-A	Fundamentals of CAD	44
Spring, 2015	ME 6104-Q	Fundamentals of CAD	26
Fall, 2014	ME 7227-A	Rapid Prototyping in Engineering	20
Fall, 2014	ME 7227-Q	Rapid Prototyping in Engineering	18
Spring, 2014	ME 6104-A	Fundamentals of CAD	31
Spring, 2014	ME 6104-Q	Fundamentals of CAD	15
Fall, 2013	ME 4803	Design Across Disciplines	8
Spring, 2013	ME 6104-A	Fundamentals of CAD	28
Spring, 2013	ME 6104-Q	Fundamentals of CAD	13
Spring, 2013	ME 4803	Design Across Disciplines	6
Spring, 2012	ME 6104	Fundamentals of CAD	25
Spring, 2012	ME 6104-Q	Fundamentals of CAD	4
Spring, 2011	ME 6104	Fundamentals of CAD	30
Fall, 2010	ME 7227	Rapid Prototyping in Engineering	21
Spring, 2010	ME 6104	Fundamentals of CAD	50
Spring, 2009	ME 6104	Fundamentals of CAD	30
Spring, 2008	ME 6104	Fundamentals of CAD	32
Spring, 2007	ME 6104	Fundamentals of CAD	30

B. Individual Student Guidance

1. Ph.D. Students

a) Graduated

1. Scott Pierce Began advising during Summer 1994. Passed Ph.D. Qualifiers: Fall 1993. Graduation date: Summer 2003. Current Position: Assistant Professor, Western Carolina University.
   Dissertation Title: A Method for Integrating Form Errors into Tolerance Analysis.
   Journal Publications: IV.B.41, IV.B.44. Conference Publications: IV.B.24, IV.B.31, IV.B.38, IV.B.81, IV.B.82.
2. Zahed Siddique Began advising as Ph.D. student Summer 1996. Passed Ph.D. Qualifiers: Spring 1997. Graduation date: May 2000.
   Dissertation Title: Common Platform Development: Designing for Product Variety.
   Position: Associate Professor, University of Oklahoma.
   Journal Publications: IV.B.13, IV.B.17, IV.B.22. Book Chapters: IV.A.1, IV.A.5.
   Conference Publications: IV.B.23, IV.B.25, IV.B.35, IV.B.39, IV.B.42, IV.B.43, IV.C.25, IV.C.33.
   Other Publications: IV.C.4.1.
3. Yong Chen Began advising as Ph.D. student Spring 1998. Passed Ph.D. Qualifiers: Spring 1999. Graduated: Fall 2001. Position: Associate Professor, University of Southern California.
   Dissertation Title: Computer-Aided Design for Rapid Tooling: Methods for Mold Design and Design-for-Manufacture
   Journal Publications: IV.B.28, IV.B.30, IV.B.31, IV.B.33, IV.B.47. Conference Publications: IV.B.45, IV.B.49, IV.B.53, IV.B.54, IV.B.57, IV.B.62, IV.B.65, IV.B.84, IV.B.85
4. Hongqing Wang Began Ph.D. studies Fall 2001. Passed Ph.D. Qualifiers: Spring 2001. Graduation: December 2005. Position: Analyst at Wells Fargo
   Dissertation Title: A Unit Cell Approach for Lightweight Structure and Compliant Mechanism
   Conference Presentations: IV.B.58, IV.B.63, IV.B.68, IV.B.84, IV.B.85, IV.B.90, IV.B.93, IV.C.42, IV.C.60, IV.C.61, IV.C.62, IV.C.63, IV.D.13 (w/o proceedings).
5. Laam Angela Tse Began advising Fall 2002. Passed Ph.D. Qualifiers: Spring 2004. Presented Proposal: 10/2004. Graduation: Summer 2006. Position: Manufacturing Engineer at Baker-Hughes.
   Dissertation Title: Membrane Electrode Assembly (MEA) Design for Power Density Enhancement of Direct Methanol Fuel Cells (DMFCs)
   Journal Publications : IV.B.29, IV.B.35. Conference Presentations: IV.B.89, IV.C.27, IV.C.28, IV.C.30, IV.C.34, IV.C.35, IV.C.36, IV.C.37, IV.C.54, IV.C.57.
6. Benay Sager Began Ph.D. studies Summer 2003. Passed Ph.D. Qualifiers: Spring 2004. Presented Proposal: 10/2004. Graduation: Spring 2006. Position: Consultant, McKinsey.
   Dissertation Title: SLA Characterization for Surface Finish Improvement: Inverse Design Methods for Process Planning
   Book Chapter: IV.A.10. Journal Publications: IV.B.50. Conference Presentations: IV.B.74, IV.B.79, IV.C.38, IV.C.44, IV.C.55, IV.C.58, IV.C.59, IV.D.14 (w/o proceedings).
7. Christopher Williams Began Ph.D. studies Spring 2004. Co-Advisor: Dr. F. Mistree. Graduation: Spring 2008. Position: Associate Professor at Virginia Tech
   Dissertation Title: Design and Development of a Layer-Based Additive Manufacturing Process for the Realization of Metal Parts of Designed Mesostructure
   Book Chapter: IV.A.7. Journal Papers: IV.B.47, IV.B.57, IV.B.60. Conference Presentations: IV.B.64, IV.B.76, IV.B.80, IV.B.88, IV.B.94, IV.B.95, IV.C.63.
8. Nsikan Udoyen Began advising Summer 2004. Presented Proposal: 11/2004. Co-Advisor: Dr. F. Mistree. Graduation date: Fall 2006. Position: Manufacturing engineer, Intel.

Dissertation Title: Information Modeling for Intent-Based Retrieval of Parametric Finite Element Analysis Models
Journal Publications: IV.B.49, IV.B.52. Conference Presentations: IV.B.92

9. Sungshik Yim Began advising Summer 2004. Defended dissertation: Nov. 2006. Graduation: 5/2007.
Dissertation Title: A retrieval method (DFM framework) for automated retrieval of design for additive manufacturing problems. Position: Unknown.
Journal Publications: IV.B.48. Conference Presentations: IV.B.97, IV.B.105, IV.C.64, IV.D.16 (w/o proceedings)

10. Greg Mocko Began advising Fall 2004. Presented Proposal: 12/2004. Co-Advisor: Dr. F. Mistree. Graduation: Spring 2006. Position: Associate Professor at Clemson University
Dissertation Title: A Knowledge Framework for Integrating Multiple Perspectives in Decision-Centric Design
Conference Presentations: IV.B.91, IV.B.96

11. Ameya Limaye Began Ph.D. studies Fall 2004. Passed Ph.D. Qualifiers: Fall 2005. Graduation: Fall 2007. Position: Manufacturing engineer at Intel.
Dissertation Title: Process planning method for Mask Projection Stereolithography
Journal Publications: IV.B.39, IV.B.40. Conference Presentations: IV.B.73, IV.B.78, IV.D.54, IV.D.56, IV.D.67.

12. Jamal Wilson Began Ph.D. studies Fall 2005. Passed Ph.D. Qualifiers: Spring 2005. Graduation: Fall 2008. Position: R&D engineer, Coca-Cola
Dissertation Title: A Systematic Approach to Bio-Inspired Conceptual Design
Book Chapter: IV.A.8. Journal Publications: IV.B.54, IV.B.55. Conference Presentations: IV.B.86, IV.B.98, IV.B.105, IV.D.16 (w/o proceedings).

13. Amit Jariwala Began advising Fall 2007. Graduation: May 2013.
Position: Director of Design & Innovation, ME School, Georgia Tech
Dissertation Title: Modeling and Process Planning for Exposure Controlled Projection Lithography
Journal Publications: IV.B.59, IV.B.66. Conference Presentations: IV.B.101, IV.B.107, IV.B.110, IV.B.122, IV.B.126, IV.B.138, IV.C.81, IV.C.84, IV.C.88, IV.C.95.

14. Jane Kang Began advising Fall 2008. Co-advisor: C. Aidun. Passed Ph.D. Qualifiers: Fall 2010. Graduation: Summer 2015. Position: Wireline engineer, Schlumberger.
Dissertation Title: Migration of Blood Cells in Non-Uniform Suspension for a Dialyzer Design
Journal Publications: IV.B.61, IV.B.1 (submitted). Conference Presentations: IV.B.113, IV.B.122, IV.C.72.

15. George Mathai Began co-advising with Dr. Shreyes Melkote Fall 2008. Passed Ph.D. Qualifiers: Spring 2009. Graduation: Fall 2012. Position: Manufacturing engineer, Caterpillar.
Abrasive Assisted Brush Deburring of Micromilled Features with Application to a Novel Surgical Device
Journal Publications: IV.B.68, IV.B.69, IV.B.73. Conference presentations: IV.B.123, IV.B.124. IV.B.132.

16. Namin Jeong Began advising Fall 2009. Passed Ph.D. Qualifiers: Spring 2011. Graduation: Fall 2015. Position: none.
Dissertation Title: A Surfacelet-Based Method for Constructing Geometric Models of Microstructure
Journal Publications: IV.B.67, IV.B.82. Conference presentations: IV.B.119, IV.B.134, IV.C.80, IV.C.85, IV.C.91, IV.C.94, IV.C.100.

17. Wenchao Zhou Began advising Fall 2009. Passed Ph.D. Qualifiers: Fall 2010. Graduation: Spring 2014. Position: Associate Professor at University of Arkansas.

Dissertation Title: Interface Dynamics in Inkjet Deposition
Journal Publications: IV.B.63, IV.B.70; IV.B.77, IV.B.78. Conference presentations: IV.B.111, IV.B.116, IV.B.118, IV.B.137, IV.C.79, IV.C.85, IV.C.96.

18. Dazhong Wu Began co-advising with Dr. Dirk Schaefer Fall 2011. Passed Ph.D. Qualifiers: Spring 2011. Graduation: Fall 2014. Position: Assistant Professor at University of Central Florida
Dissertation Title: Cloud-Based Design and Manufacturing: A Network Perspective
Journal Publications: IV.B.65, IV.B.71, IV.B.74, IV.B.81, IV.B.87, IV.B.89. Conference presentations: IV.B.125, IV.B.127, IV.B.133, IV.B.136, IV.B.140, IV.B.143.
19. Sang-In Park Began advising Summer 2011. Passed Ph.D. Qualifiers: Spring 2013. Graduation: Fall 2016. Position: Assistant Professor, Incheon National University, South Korea
Dissertation Title: Estimating Mechanical Properties of Cellular Solid Materials from Additive Manufacturing Processes
Journal Publications: IV.B.1.72, IV.B.1.80, IV.B.85, IV.B.1.88, IV.B.1.91. Conference presentations: IV.B.148, IV.B.152, IV.B.154, IV.C.87, IV.C.90, IV.C.93, IV.D.23 (w/o proceedings).
20. Xiayun Zhao Began advising Spring 2014. Graduation: Spring 2017.
Position: Assistant Professor, University of Pittsburgh
Dissertation Title: Process Measurement and Control for Exposure Controlled Projection Lithography
Journal Publications: IV.B.84, IV.B.93, IV.B.94, IV.B.97, IV.B.102. Conference presentations: IV.B.149, IV.B.153, IV.B.156, IV.C.97, IV.C.99.

b) In Process

1. Chad Hume Began advising Fall 2010. Passed Ph.D. Qualifiers: Fall 2012.
Conference Presentations: IV.D.3.23
2. Jonathan Holmes Began advising Spring 2013. Passed Ph.D. Qualifiers: Spring 2016. Presented Ph.D. proposal in August 2018.
Dissertation Title: Development of Novel Mixing Techniques for Material Extrusion Processes to Produce Functionally Graded Materials
3. Yeming Xian Began advising Fall 2015 (co-adviser G. Paulino, 2020). Passed Ph.D. Qualifiers: Spring 2017. Presented Ph.D. proposal in December 2020.
Dissertation Title: Extensions of Topology Optimization for Additive Manufacturing
Journal Publications: IV.B.112. Conference presentations: IV.C.104, IV.C.112.
4. Zhichao Wang Began advising Spring 2021.
5. Taylor Allen Began advising Fall 2021.
6. Abdulmajeed Altassan Began advising Fall 2021.
7. Janet Wong Began advising Fall 2021.

2. M.S. Thesis Students

a) Graduated

1. Steven Hassenzahl Began advising during Summer 1992, graduated June 1994.
Thesis title: Extensions of CAD Representations to Support Configuration Design of Assemblies.
Position: NCR, Product Design Engineer.
Journal Publications: IV.B.9.
2. Stewart Coulter Began advising 9/92. Co-advisee with Bert Bras. Graduated 12/94.
Thesis title: Representation of Geometric Constraints in Parametric Synthesis.
Position: Research Engineer, Accenture.
Journal Publications: IV.B.11. Conference presentations: IV.B.16, IV.B.21.

3. Patrick Newcomb Began advising Fall 1993. Graduated 5/01. Co-advisee with Bert Bras.
   Thesis Title: Implications of Modularity on Product Design for the Life Cycle.
   Position: Research Scientist, Georgia Tech
   Journal Publications: IV.B.9, IV.B.16. Conference presentations: IV.B.26.
4. Matthew Bauer Began advising during Fall 1994. Presented Thesis: 6/97. Graduation: 12/97.
   Thesis Title: Integration of Product & Disassembly Process Design in Parametric Synthesis.
   Position: Software Engineer, Alventive.
5. Zahed Siddique Began advising during Fall 1994. Graduated June 1996.
   Thesis Title: Conversion of CAD Model Data for Virtual Prototypes for Disassembly.
6. Joel McClurkin Began advising Fall 1995. Graduated June 1997.
   Thesis Title: A Computer-Aided Build Style Decision Support Method for Stereolithography.
   Position: Design Engineer at Schlumberger.
   Journal Publications: IV.B.15. Conference presentations: IV.C.5, IV.C.7.
7. Brian Harper Began advising Winter 1996. Graduated: June 1998.
   Thesis Title: A CAD Environment for De- & Remanufacturing Assessments.
   Position: Senior Engineer at MERC.
   Journal Publications: IV.B.21. Conference presentations: IV.B.36, IV.B.42.
8. Charity Lynn Began advising Spring 1997. Graduated: September 1998.
   Thesis Title: Accuracy Models for SLA Build Style Decision Support.
   Position: Manufacturing Engineer at Kimberley-Clark.
   Journal Publications: IV.B.20. Conference presentations: IV.C.13, IV.C.14, IV.C.18.
9. Sundiata Jangha Began advising Spring 1997. Graduated: May 2002.
   Thesis Title: An Ejection Mechanism Design Method for Rapid Injection Molding Tools.
   Position: Ph.D. student at Georgia Tech.
10. Chris Franck Began advising Fall 1997. Graduated: 12/99.
    Thesis Title: Assessing the Value of Rapid Prototyping and Tooling in Product Design Processes
    Position: Design Engineer at Motorola.
    Conference presentations: IV.B.50.
11. Aaron West Began advising Fall 1997. Graduated: 6/99.
    Thesis Title: A Decision Support System for Fabrication Process Planning of Stereolithography.
    Position: Design Engineer at Northrup-Grumman.
    Journal Publications: IV.B.23. Conference presentations: IV.B.44, IV.C.13, IV.C.14, IV.C.19.
12. Alok Kataria Began advising Fall 1998. Graduated: 8/2000.
    Thesis Title: Standardization and Process Planning for Building Around Inserts in SLA.
    Position: Services Consultant at Velant, Inc. (ATDC start-up).
    Journal Publications: IV.B.27. Conference presentations: IV.B.46, IV.B.51
13. Shiva Prasad Sambu Began advising Fall 1999. Graduated: 12/2001
    Thesis Title: A Design for Manufacture Method for Rapid Prototyping and Rapid Tooling
    Position: Manufacturing Engineer, Align Technology.
    Journal Publications: IV.B.23, IV.B.31, IV.B.34. Conference presentations: IV.B.56, IV.B.62.
14. Hongqing Wang Began advising Fall 1999. Graduation: 12/2001
    Thesis Title: Computer-Aided Design Methods for the Additive Fabrication of Truss Structures.
15. Brian Corbett Began advising Fall 2000. Graduation: 5/2003
    Thesis Title: Configuration Design Methods and Mathematics for Product Families.
    Position: Manufacturing Engineer, Bell Helicopter.
    Journal Publications: IV.B.32. Conference presentations: IV.C.70.

16. Benay Sager   Began advising Fall 2000. Graduation: 5/2003
    Thesis Title: A Method for Understanding and Predicting SLA Resolution.
17. Christopher Williams Began advising Fall 2000 with Farrokh Mistree. Graduation: 12/2003.
    Thesis Title: A Constructal Theory Approach to Product and Process Family Design.
18. Austina Nguyen   Began advising Fall 2001. Graduation: 8/2004
    Thesis Title: Design and Manufacture of Skins for Digital Clay Human-Computer Interface Devices.
    Position: Engineer at Lexmark
    Conference presentations: IV.B.68, IV.B.83, IV.C.42, IV.C.43.
19. Jae-Hyoung Park   Began advising Fall 2001. Graduation: 5/2003
    Thesis Title: Process Planning for Laser Chemical Vapor Deposition.
    Position: Design Engineer, Samsung.
    Conference presentations: IV.B.67, IV.B.71, IV.C.39.
20. Ameya Limaye   Began advising Fall 2002. Graduation: 12/04
    Thesis Title: Design and Analysis of a Mask Projection Micro-Stereolithography System.
21. Jamal Wilson   Began advising Fall 2003. Graduation: 5/2006.
    Thesis Title: Selection for Rapid Manufacturing under Epistemic Uncertainty.
22. Lauren Margolin   Began advising Fall 2004.   Graduation: 12/2006
    Thesis Title: Ultrasonic Droplet Generation Jetting Technology for Additive Manufacturing: An Initial Investigation
    Position: Design engineer, Lutron.
    Conference presentations: IV.D.58, IV.C.59.
23. Ted Anderson   Began advising Spring 2006. Graduation: Spring 2007.
    Thesis Title: Simulation and Fabrication of a Formable Surface for the Digital Clay Haptic Device
    Position: Engineer, Marshall Space Flight Center.
24. Greg Graf   Began advising Spring 2007. Graduation: Spring 2009
    Thesis Title: Development of Specialized Base Primitives for Meso-Scale Conforming Truss Structures
    Journal papers: IV.B.51, IV.B.53. Keynote: IV.D.1. Conference presentations: IV.B.104, IV.C.68.
    Position: Engineer, Link Systems.
25. Jeff Olson   Began advising Summer 2007. Graduation: Spring 2009
    Thesis Title: Design and Modeling of a Portable Hemodialysis System.
    Position: Product Development Engineer, Kids II.
    Conference presentations: IV.C.72.
26. Sarah Engelbrecht   Began advising Fall 2007. Graduation: Spring 2009.
    Thesis Title: Design of Meso-Scale Cellular Structure for Rapid Manufacturing
    Position: Design Engineer, Northrup-Grumman.
    Journal papers: IV.B.53. Conference presentations: IV.B.104, IV.C.69, IV.C.70, IV.C.74.
27. Chen Chu   Began advising Fall 2007. Graduation: Summer 2009.
    Thesis Title: Design Synthesis for Morphing 3D Meso-scale Structure
    Position: Design Engineer, Michelin.
    Journal papers: IV.B.51, IV.B.53. Keynote: IV.D.1. Conference presentations: IV.B.104, IV.C.68.
28. Xiayun Zhao   Began advising Spring 2008. Graduation: Spring 2009.
    Thesis Title: Process Planning for Thick-Film Mask Projection Micro Stereolithography
    Position: Ph.D. student at GT.
    Conference presentations: IV.B.101, IV.B.107.

29. Patrick Chang Began advising Fall 2008. Graduated: Fall 2011.
Thesis Title: An Improved Size, Matching, and Scaling Method for the Design of Deterministic Mesoscale Truss Structures
Position: Design engineer, Nikon Research.
Journal Papers: IV.B.62. Conference presentations: IV.B.106, IV.B.114, IV.B.121.

30. Jane Kang Began advising Fall 2008. Graduated: Spring 2010.
Thesis Title: Pump Design for a Portable Renal Replacement System
Position: Ph.D. student at GT
Conference presentations: IV.C.72.

31. Jason Nguyen Began advising Fall 2010. Graduated: Summer 2012.
Thesis Title: A Heuristic Optimization Method for the Design of Meso-Scale Truss Structure for Complex-Shaped Parts
Position: Design engineer, BP
Journal Publications: IV.B.72. Conference presentations: IV.C.87, IV.C.90, IV.C.93.

32. Chad Hume Began advising Fall 2010. Graduated: Fall 2013.
Thesis Title: Platform Variability Identification using Sensitivity Analysis for Product Platform Design
Position: Ph.D. student, GT
Conference Presentations: IV.B.130.

33. Narumi Watanabe Began advising Fall 2014. Graduated: Fall 2016.
Thesis Title: Computational and Experimental Investigation of Reinforced Polymers for Material Extrusion Additive Manufacturing
Position: design engineer, Boeing
Conference presentations: IV.C.1.102, IV.D.3.23

34. Ying Zhang Began advising Fall 2014; co-advised with Amit Jariwala. Graduated: Fall 2016.
Thesis Title: Empirical Process Planning for Exposure Controlled Projection Lithography
Position: graduate student at Univ. Toronto
Conference presentations: IV.C.1.101, IV.D.3.23

35. Changxuan Zhao Began advising Spring 2015; co-advised with Amit Jariwala. Graduated: Summer 2017.
Thesis Title: Real-Time Monitoring of Exposure Controlled Projection Lithography (ECPL) Process
Position: PhD student at Georgia Tech.
Conference presentations: IV.B.2.155, IV.B.2.156

36. John-Travis Hansen Began advising Fall 2015. Graduated: Fall 2017.
Thesis Title: Empirical Process Planning for Exposure Controlled Projection Lithography
Position: mechanical designer,
Journal Publications: IV.B.1.103. Conference presentations: IV.B.2.167

b) In Process

1. Nicholas Mulka Began advising Fall 2020; co-advised with Amit Jariwala.
Thesis Title: Fluid Interface Supported Printing for Three-Dimensional Object Fabrication
Position: tbd
Conference presentations: IV.C.1.125

<u>M.S. Special Problems students.</u>

1. Dan Ganser 1993 Recognition of Machinable Volumes from a Part CSG Tree for Automated NC Programming.

2. Dainelle Swann 1993 Tool Design Considerations from Feature-based Component Design for Vacuum Forming.
3. M. C. Ramesh 1996 Surface Fitting to Point Cloud Data
4. Kevin Kamphuis 1996 Robust Rapid Tooling for Injection Molding
5. Imran Yusuf 1996 Rapid Tooling: ACES Injection Molding
6. Brian VanHeil 1997 Alternative Ejection Methods for Rapid Tooling
7. E. Kenneth Escoe 1999 A Working Database for the Rapid Tooling Testbed
8. Paul Lowe 2001 Toward Restorative Dentistry through Mechanical CAD and Rapid Prototyping
9. John Edie 2003 Work Environment Plan to Support Design of Machinery for Closure Molding
10. Loren Ybbarando 2003 A Learning Environment for Computer-Aided Design
11. Kevin Au 2005 Applying Rapid Manufacturing Technologies to Fabricate Space Based Solar Array Substrates
12. Abeera Sohail 2013 Vibration Characteristics of AM-Fabricated Lattice Structures
13. Hamed Ammar, 2019 Determining Manufacturability using Machine Learning/AI

3. Undergraduate Special Problems Students

1. Thomas Yu 1993, 1994 Product Design for Disassembly, Service, and Recycling.
2. Jeff Henderson 1995, 96 Packaging Methodology through Computer-Aided Design.
3. David Cowden 1995 A Design Studio Metaphor for CAD Tools.
4. Russell Holmes 2002-03 Process Planning in LCVD
5. Jeff Lloyd 2006 Truss Structure Modeling
6. Marques Reed 2006 Truss Structure Analysis
7. Amanda O'Rourke 2006-7 Fine Feature Manufacturing with Stereolithography
8. Parichit Kumar 2008 Rapid Prototyping Selection Software
9. Prisca Cleveland (ECE) 2010-11 Microstereolithography
10. Andrew Perez (ECE) 2010-11 Microstereolithography
11. Rachel Van Stelle 2011 Microstereolithography
12. Harold Nikoue (AE) 2011 Microstereolithography
13. Troy Messina (ECE) 2011 Microstereolithography
14. Michael Werve (ECE) 2011 Microstereolithography
15. Renea Neal (PTFE/MSE) 2011-12 Microstereolithography
16. Amanda Loftin (PTFE/MSE) 2012 Microstereolithography
17. DongHoon Yeum (MSE) 2012 Microstereolithography
18. Yunfeng Chen (ECE) 2012 Microstereolithography
19. Aditi Chandak (ME) 2012 Microstereolithography
20. Joel Mathew (ME) 2012 Microstereolithography
21. Benjamin Sullivan 2012 Microstereolithography
22. William Borzon 2012, 2013 Microstereolithography

23. Abhishek Kwatra 2013, 2014 Cleaning system for microstereolithography parts (PURA award winner, Air Products fellowship)
24. Ying Zhang 2014 Microstereolithography
25. Christopher May 2015 Product Family Design Literature Survey
26. Jenny Wang 2016-17 Microstereolithography
27. Irene Cho 2020 Manufacturing Process Identification using Machine Learning
28. Ricardo Meisozo 2020 Manufacturing Process Identification using Machine Learning
29. Alizay Shah 2020 Manufacturing Process Identification using Machine Learning
30. Benjamin Lublin 2020 Wheelchair design
31. Luke Pasquarelli 2020 Wheelchair design
32. Taylor Reed Blanchard 2020 Wheelchair design
33. William Wild 2020 Wheelchair design
34. Carlos Sosa 2020 Manufacturing Process Identification using ML

4. Service on Thesis or Dissertation Committees

a) Internal

Grad. Year	Degree	Student	School or College
1998	Ph.D.	Stewart Coulter, Timothy Simpson	GWW School
	Masters	Andre Claudet, Uma Sankar, Roberto Ortega, Greg Mumpower, Gabrial Hernandez	GWW School
	Masters	Kent Dawson	ChE
1999	Ph.D.	Elizabeth Judson	MSE
	Masters	Amy Herrmann, Scott McDermott	GWW School
	Masters	James Hemrick	MSE
2000	Ph.D.	Thomas Tucker	GWW School
	Masters	Chad Moore, Bradley Geving, Brian Fuhrman, Ruben Lanz	GWW School
2001	Ph.D.	Andre Claudet, Dan Jean, Chad Duty, Gabriel Hernandez	GWW School
	Ph.D.	Kenneth Dawson	Chem. Engr.
	Ph.D.	Joon Park	Management
	Masters	Haejin Choi, Carolyn Conner-Seepersad, Brian Davis, Jacob Diez, Rahul Kulkarni, Xavier Ottemer, Angela Tse	GWW School
2002	Ph.D.	Carolyn Conner-Seepersad	GWW School
	Masters	Matthew Chamberlain, Marco Fernandez, Yanyan Tang, Tosin, Tomori	GWW School
2003	Ph.D.	Angran Xiao	GWW School
	Masters	Paul Bosscher, Michael Carone, Samuel Dessolin, Casey McIntosh, Megan Shilling	GWW School
2004	Ph.D.	Myong Kee Jeong	ISyE
	Ph.D.	Yao Lin, James Nichols	GWW School
2005	Ph.D.	Yanyan Tang	ChBE
	Ph.D.	Hae-Jin Choi, Marco Fernandez, Jitesh Panchal, Haihung Zhu	GWW School
	Masters	Tim Ernst, Rakesh Kulkarni	GWW School
2006	Masters	Bert Bradley, Davis Garth	GWW School
2007	Ph.D.	Benita Comeau	ChBE

	Ph.D.	Matt Chamberlain	GWW School
	Masters	Gautam Jadhav	GWW School
2008	Masters	Kenway Chen, Jiten Patel	GWW School
2010	Ph.D.	Stephanie Thompson, Siddarth Athreya	GWW School
	Ph.D.	Matthew Simons	Aero Engr.
2011	Masters	Sean Tessier	GWW School
2012	Ph.D.	Nate Sirirojvisuth	AE
	Masters	Edin Crnic	GWW School
2013	Ph.D.	Anirudh Rudraraju	GWW School
2014	Ph.D.	Wei Huang	GWW School
	Masters	Mahmoud Alzahrani, Recep Gorguluarslan	GWW School
2016	Ph.D.	Recep Gorguluarslan, Masoumeh Aminzadeh	GWW School
2018	Ph.D.	Jiangtao Wu	GWW School
	Ph.D.	Emily Fitzharris	MSE
2019	Masters	Richard Nwaeri	GWW School
2020	Ph.D.	Hyeonik Song	GWW School
	Ph.D.	Ricardo Bonilla-Alicea	GWW School
	Ph.D.	Oliver Giraldo Londono	CEE
2021	Ph.D.	Hyeonik Song	GWW School
2021	Ph.D.	Alexander Murphy	GWW School
2021	Ph.D.	Bumsoo Lee	GWW School
2021	Ph.D.	Tuo Zhao	CEE
2021	Masters	Emily Alcazar	CEE

b) External

Grad. Year	Degree	Student	School or College
2000	Masters	Michael Pearson	University of Louisville, Chemical Engineering
2003	Ph.D.	Yang Yong	Nat'l Univ. of Singapore
	Ph.D.	Naguib Saleh	Loughborough Univ, UK
2011	Ph.D.	David Brackett	Loughborough Univ., UK
2012	Ph.D.	Martin Baumers	Loughborough Univ., UK
2015	Ph.D.	Ningrong Lei	MAE, Nanyang Tech. U (Singapore)
2016	Ph.D.	Athena Jalalian	Nat'l Univ. Singapore
	Ph.D.	Samyeon Kim	Nanyang Tech U
2017	Ph.D.	Pekka Lehtinen	Aalto Univ, Finland
	M.S.	Shahrain Bin Mahmood	Newcastle Univ, Singapore
2018	Ph.D.	Hyunwoong Ko	MAE, Nanyang Tech. U (Singapore)
2019	Ph.D.	Enea Sacco	MAE, Nanyang Tech. U. (Singapore)
2020	Ph.D.	Davide Redaelli	Polytecnico di Milano (Italy)
2021	Ph.D.	Aprilia	MEA, Nanyang Tech. U. (Singapore)
2021	Ph.D.	James Alum	Loughborough Univ, UK

5. Mentorship of Postdoctoral Fellows and Visiting Scholars

<u>Post-Doctoral Students supervised.</u>

1. Scott Johnston Advised: Sept. 2005 to Sept 2006.
   Conference Presentations: IV.B.90, IV.D.60, IV.D.61, IV.D.62, IV.D.13 (w/o proceedings).
2. Sanjay Vohra Advised: May 2007 - May 2008.
   Conference Presentations: IV.B.100.
3. Yong Yang Advised: June 2007 – June 2009.
   Journal Publications: IV.B.56. Conference Publications: IV.D.72, IV.D.76, IV.D.17 (w/o proceedings).
4. Fei Ding Advised: August 2007 – Aug. 2010.
   Journal Publications: IV.B.60. Conference Presentations: IV.B.101., IV.B.107., IV.B.110, IV.D.81.
5. J. Mark Meacham Advised: September – December 2008
   Journal Publications: IV.B.57. Conference Publications: IV.D.76, IV.D.17 (w/o proceedings).
6. Mahmoud Dinar Advised: December 2015 – May 2016
7. Sang-In Park Advised: November 2016 - May 2017

At SUTD

8. Mahdi Emami Advised: Jan 2017 – Dec. 2019
9. Samyeon Kim Advised: May 2017 – Aug. 2020
10. Vahid Hassani Advised: June 2017 – February 2019
11. Sang-In Park Advised: July 2017 – February 2019
12. Yi Xiong Advised: October 2017 – April 2020
13. Yunlong Tang Advised: October 2018 – Feb. 2020
14. Narasimha Boddeti Advised: January 2018 – December 2019
15. Zhiyuan Zhang Advised: May 2018 – Sept. 2020
16. Fangfang Wang Advised: June 2019 – Feb. 2020
17. Chao Yuan Advised: June 2019 – Sept. 2020
18. Jingchao Jiang Advised: Sept. 2019 – July 2020
19. Guoying Dong Advised: Nov. 2019 – present
20. Mostafa Jamshidian Advised: January 2020 – July 2020
21. Yangfan Li Advised: 2021

<u>Visiting Scholars supervised.</u>

1. Wenzheng Wu, Ph.D. student at Northwestern University, China. Advised Sept 2009 - Oct. 2010. Journal Papers: IV.B.64. Conference Presentations: IV.B.112, IV.B.123, IV.D.78.
2. Xijuan Liu, Associate Professor, Shanghai Dianji University. Visited Jan 2010 - Jan 2011. Conference Presentations: IV.B.109, IV.B.115.
3. Ningrong Lei, Ph.D. student at Nanyang Technological University, Singapore. Advised Sept. – Dec. 2014.
4. Marco Rossoni, Ph.D. student at Polytecnico di Milano, Milan, Italy. Advised Jan. - June 2019.
5. Mingeon Kim, Ph.D. student at Chung-Ang University, Korea. Advised Oct. 2021-March 2022.
6. Hyewon Shim, Ph.D. student at Sungkyungkwan University, Korea. Advised Oct. 2021-March 2022.

C. Other Teaching Activities

1. Course Development

1. Developed ME 6176, Computer-Aided Design Systems, as a course on the role of prototyping in engineering design, enabled by the usage of CAD and information technology. Course modules were developed on design process modeling, rapid prototyping technologies and their selection, virtual prototyping, and data handling for rapid prototyping. In 1996, a quarter-long design project was organized in conjunction with Siemens Residential Products Division. In 1998, a 3 week course module on rapid prototyping process planning was added.
2. Created, developed, and taught ME 7227 – Rapid Prototyping in Engineering in 2000. About half of the course material was a result of RPMI research. 15 students took the course from several research areas within the GWW School. In 2004, the course was revised and redeveloped to enable internet-based delivery through the GT Distance Learning program. Offered again in 2006. Course material formed the foundation for a new textbook on additive manufacturing (see IV.A.1).
3. Created a new interdisciplinary design course, ME4803, along with Sabir Khan (Arch, ID) and Alexandra Mazalek (LCC). Taught the course in Spring 2012, Spring 2013, Fall 2013, and Fall 2015. In the 2013 offerings, course modules were developed on CAD, 3D printing, and design processes. Projects were exhibited in the TechArts Festival (Spring), the GT Mini-Maker Faire (Fall), and Capstone Expo (Spring and Fall).

2. Course Improvement

1. Developed a three week module on solid modeling for ME 6175, Fundamentals of Computer-Aided Design in 1993 and 1994. Also developed a two week module on rapid prototyping, emphasizing the issues involved in automating the CAD-to-RP transfer in 1996.
2. Developed and delivered a companion lab course for ME 3110 (with Janet Allen and Farrokh Mistree) to test the efficacy of computer-based collaboration in a design course. Ran the lab as an optional Special Problems course (ME 4901). This activity was part of the funded EduTech project (VI.A.1). 1994-5.
3. Developed course materials and video-taped lectures to enable offering ME 6104 – Fundamentals of Computer-Aided Design, as an "internet course," during Fall 2001. To date, ME 6104 has been offered via the internet every year starting in Spring 2002.

3. Professional Development/Continuing Education

1. Developed a 2-day Technical Presentation (through GT's Continuing Education) entitled "Design for Recycling" with Dr. Bert Bras and delivered at General Motors, July 31-Aug. 1, 1995.

VI. SERVICE

A. Professional Contributions

1. Editorial Board Memberships

1. Co-editor for a special issue (Vol. 5, No. 3/4, 1993) of the journal Research in Engineering Design. Special Issue is entitled: "Advances in Representations and Reasoning for Mechanical CAD."
2. Associate Editor, *ASME J. of Computing and Information Science in Engineering*, 2000 – 2006.
3. Co-editor for special issue (Vol. 4, No. 1, March 2004) of the *ASME J. of Computing and Information Science in Engineering* entitled "Computer-Aided Conceptual Design." Co-editor is Imre Horvath.
4. Member, Editorial Board, *Biofabrication Journal*, 2008 - 2011.
5. Member, Editorial Board, *Rapid Prototyping Journal*, 2008 – present.

6. Member, Editorial Board, *Int'l J. of Precision Engineering and Manufacturing*, 2011 - 2018.
7. Member, Editorial Board, ASME Advances in Computers and Information in Engineering Research book series, 2012 – present.
8. Member, Editorial Board, *Additive Manufacturing*, 2014 – present.
9. Member, Editorial Board, *Additive Manufacturing and 3D Printing*, 2014.
10. Co-editor, special issue of *ASME Journal of Mechanical Design* on Design for Additive Manufacturing. Co-editors: C. Seepersad, T. Simpson, C. Williams. 2015

2. Society Offices, Activities, and Membership

1. Fellow, American Society of Mechanical Engineers, 2003. Member, 1985 – present.
2. Member, American Society of Engineering Educators, 1993 – 2005; 2009-present.
3. Member, Society of Manufacturing Engineers, 1996 – 2013.
4. Member, Executive Committee of the Computers in Engineering Division of ASME, 1996-2002.
5. Lead, Lattice Structures Task Group, ASTM F-42 Standards for Additive Manufacturing, 2010-2012.
6. Chair, Design Subcommittee, ASTM F-42 Standards for Additive Manufacturing, 2012-present.

3. Organization and Chairmanship of Technical Sessions, Workshops, and Conferences

1. Co-Chair, 4th ACM Siggraph Symp. On Solid Modeling and Applications. Atlanta, May 14-16, 1997.
2. Chair and Organizer for AI/Features Technical Area of the ASME Computers in Engineering Conference, 1997. Reviews were organized for 14 papers, sessions organized, and best paper selected.
3. Technical Program Chair for ASME Computers in Engineering Conference, Atlanta, 1998.
4. Organizer of special sessions on rapid prototyping in the ASME CIE, Design For Manufacturing, and Design Automation Conferences, 2000.
5. Host and Organizer, Advanced Rapid Prototyping & Manufacturing 2000 Symposium and Expo. Georgia Tech. Feb. 7-8, 2000.
6. Session organizer for "Representations, Optimization, and Simulation in Product Development" for the second Gordon Conference on Theoretical Foundations for Product Design and Manufacturing, June 11-16, 2000, Plymouth, NH.
7. Chair for the Computer-Aided Product Development Technical Committee of the ASME CIE Division. Organized reviews of 20 papers. 2001.
8. Host and Organizer, Society of Manufacturing Engineers Technology Forum on Mass Customization Enabled by Rapid Technologies. Georgia Tech. August 13, 2002.
9. Conference Chair, ASME Computers and Information in Engineering Conference, 2002.
10. Host and Organizer, Advanced Rapid Prototyping & Manufacturing 2002 Symposium and Expo. Georgia Tech. Oct. 9-10, 2002.
11. Chair, ASME Computers and Information in Engineering Division, 2001-2.
12. Chair, ASME CIE Computer-Aided Product Development Technical Comm., 2004.
13. Co-chair, Panel on Object Modeling, ASME CIE Conference, 2005.
14. Co-Chair, DARPA/ISAT Workshop on Rethinking CAD, Arlington, VA, Oct. 24-25, 2013.
15. Co-Chair, Digital Manufacturing and Design Centre Symposium, Singapore, Sept 1-3, 2020.

4. Technical Journal or Conference Referee Activities

11. Reviewer, 2011, Solid Freeform Fabrication Symposium; total of 5 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, ASME J of Manufacturing Science and Engineering, Rapid Prototyping Journal, Computer-Aided Design, Bioinspiration & Biomimetics, Structural and Multidisciplinary Optimization, Int'l J. of Computer-Integrated Manufacturing, J. Manufacturing Processes, IMECE J. of Mechanical Engineering Science*.
12. Reviewer, 2012, ASME DETC/CIE Conferences, Solid Freeform Fabrication Symposium; total of 8 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, ASME J of Manufacturing Science and Engineering, Rapid Prototyping Journal, Computer-Aided Design, Virtual and Physical Prototyping*.
13. Reviewer, 2013, ASME DETC/CIE, MSEC, NAMRC Conferences, Solid Freeform Fabrication Symposium; total of 9 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, ASME J of Manufacturing Science and Engineering, ASME J. Micro and Nano-Manufacturing, Rapid Prototyping Journal, Computer-Aided Design, Robotics and Computer Integrated Manufacturing, Int'l J. Precision Engineering and Manufacturing, J. Advanced Manufacturing Technologies*.
14. Reviewer, 2014, ASME DETC/CIE, MSEC, NAMRC Conferences, Solid Freeform Fabrication Symposium; total of 12 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, ASME J of Manufacturing Science and Engineering, ASME J. Mechanisms and Robotics, Rapid Prototyping Journal, Computer-Aided Design, J. Materials Research, J. Advanced Manufacturing Technology, Manufacturing Letters, Structural and Multidisciplinary Optimization, Int'l J. Precision Engineering and Manufacturing, ACS Macro Letters*.
15. Reviewer, 2015, ASME DETC/CIE, MSEC, NAMRC Conferences, Solid Freeform Fabrication Symposium; total of 12 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, ASME J of Manufacturing Science and Engineering, ASME J. Mechanisms and Robotics, Rapid Prototyping Journal, Computer-Aided Design, J. Materials Research, J. Advanced Manufacturing Technology, Manufacturing Letters, Structural and Multidisciplinary Optimization, Surface Topography:Metrology & Properties , Nature Scientific Reports*.
16. Reviewer, 2016, ASME DETC/CIE, MSEC, NAMRC Conferences, Solid Freeform Fabrication Symposium; total of 12 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, AIEDAM, Additive Manufacturing, Applied Mathematical Modeling, Applied Materials & Interfaces, Materials & Design, IEEE Trans. Automation Science and Engineering*.
17. Reviewer, 2017, ASME DETC/CIE, MSEC, NAMRC Conferences, Solid Freeform Fabrication Symposium; total of 12 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, Journal of Micromechanics and Microengineering, IEEE Transactions on Automation Science and Engineering, Measurement Science & Technology, Additive Manufacturing, Materials & Design, Rapid Prototyping Journal, AIEDAM, Int'l J. Precision Engineering and Manufacturing, Computer-Aided Design, Int'l J. Mechanical Sciences*
18. Reviewer, 2018, ASME DETC/CIE, Solid Freeform Fabrication Symposium; total of 6 papers. Reviewer for *ASME J. of Mechanical Design, ASME J. of Computing and Information Science in Engineering, Additive Manufacturing, Materials & Design, Rapid Prototyping Journal, ACS Applied Materials & Interfaces, AIEDAM, Int'l J. Precision Engineering and Manufacturing, Computer-Aided Design, Int'l J. Mechanical Sciences, Scientific Reports, Int'l J Numerical Methods in Engineering, Virtual and Physical Prototyping, Journal of Engineering Design, Mechanics of*

Materials, J Computational Design and Engineering, Optics & Laser Technology, IEEE Transactions on Automation Science and Engr.

19. Reviewer, 2019, ASME DETC/CIE, Solid Freeform Fabrication Symposium; total of 4 papers. Reviewer for *ASME J. of Mechanical Design, Additive Manufacturing, Rapid Prototyping Journal, J. of Materials Processing Technology, Computers in Industry, Int'l J Numerical Methods in Engineering, Virtual and Physical Prototyping, Int'l. J. Advanced Manufacturing Technologies, Optics & Laser Technology, Research in Engineering Design, Computer Methods in Applied Mechanics and Engineering, Advanced Engineering Informatics, Structural and Multidisciplinary Optimization.*
20. Reviewer, 2020 for (30 total): *ASME J. of Mechanical Design, Additive Manufacturing, Rapid Prototyping Journal, Computers in Industry, Int'l J Numerical Methods in Engineering, Acta Biomaterialia, Virtual and Physical Prototyping, Int'l. J. Advanced Manufacturing Technologies, CIRP J. Manufacturing Science and Technology, Precision Engineering, Applied Materials Today, J. of Intelligent Manufacturing, J. Materials Engineering and Performance, ACS Applied Polymer Materials, Frontiers in Physics*
21. *Reviewer, 2021 for (28 Total): ASME J. of Mechanical Design, Additive Manufacturing, Structural and Multidisciplinary Optimization, Manufacturing Letters, Computers in Industry, Rapid Prototyping Journal, Materials and Design, Virtual and Physical Prototyping, ASTM Selected Technical Papers, Journal of Intelligent Manufacturing, Frontiers in Physics, The Visual Computer, International Journal on Interactive Design and Manufacturing, Scientific Reports,*

5. Proposal Panels and Reviews

1. Panel reviewer of eight proposals at NSF (Arlington, VA) in April 1997.
2. Reviewer in 1998: 3 mailed proposals, Panel in June
3. Reviewer in 1999: Panel in June
4. Reviewer in 2000: Panel in December
5. Reviewer in 2002: Panel in May, Panel in November
6. Reviewer in 2004: Panel in December
7. Reviewer in 2007: Panel in May
8. Reviewer in 2009: Panel in November
9. Reviewer in 2011: Panel in May
10. Reviewer in 2013: Panel in May
11. Reviewer in 2014: Panel in May, Panel in September
12. Reviewer in 2015: Panel in October

6. Other Involvement

1. Member, Program Committee, Euro RP 2001 – European Conference on Rapid Prototyping & Manufacturing, Paris, France, June 7-8, 2001.
2. Member, Program Committee, EcoDesign 2003, 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing, Dec. 8-11, 2003, Tokyo, Japan.
3. Member, Program Committee, International Symposium on Tools and Methods of Competitive Engineering (TMCE), 1998 – 2006.
4. Member, Program Committee, Euro RP 2004 – European Forum on Rapid Prototyping, Paris, Sept. 14-15, 2004.
5. Member, Advisory Board, CAD'05, Bangkok, Thailand, June 20-24, 2005.
6. Member, Advisory Board, CAD'06, Phuket, Thailand, June 19-23, 2006.

7. Member, Advisory Committee, SFF Symposium, Austin, TX, Aug. 2006-present.
8. Member, Advisory Board, CAD'07, Honolulu, Hawaii, June 25-29, 2007.
9. Member, Program Committee, Int'l Conf. on Manufacturing and Automation, Singapore, May 28-30, 2007.
10. Member, Scientific Committee, Virtual and Rapid Prototyping Conferences, Leiria, Portugal, 2007 - 2013. Manchester, UK, 2015.
11. Member, International Program Committee, International Conference on Manufacturing and Automation, Hong Kong, Dec. 13-15, 2010.
12. Member, Advisory Committee, Int. Symposium on Green Manufacturing and Applications, Jeju, Korea, Aug 27-29, 2012.
13. Member, International Programme Committee, 5th International Conference on Research into Design (ICoRD'15), Bangalore, India, 2013-2015.
14. Member, ICED13 Scientific Committee, Int'l Conference on Engineering Design, Seoul, Korea, Aug 19-22, 2013.
15. Member, ICED15 Scientific Committee, Int'l Conference on Engineering Design, Milan, Italy, July 27-30, 2015.
16. Member, ICED17 Scientific Committee, Int'l Conference on Engineering Design, Vancouver, Canada, Aug 21-25, 2017.
17. Member, ASME Additive Manufacturing & 3D Printing (AM3D) Conference organizing committee, Boston, Aug 2-5, 2015.
18. Member, ASME Additive Manufacturing & 3D Printing (AM3D) Conference organizing committee, Charlotte, Aug 21-24, 2016.
19. Member, ICIDM17, Steering Committee, Int'l Conference on Innovative Design and Manufacturing, Milan, Italy, July 17-19, 2017.
20. Member, ICEI2018, Advisory Board, Int'l Conference on Engineering Innovation, Bangkok, Thailand, July 5-6, 2018.
21. Member, Scientific Committee, CIRP Design Conference, Nantes, France, May 23-25, 2018.
22. Member, Scientific Committee, Progress in Additive Manufacturing (Pro-AM) Conference, Singapore, May 14-17, 2018.
23. Member, Modular and Offsite Construction Conference scientific committee, Banff, Alberta, Canada, May 21-24, 2019.
24. Member, Scientific Committee, Progress in Digital and Physical Manufacturing (ProDPM'19), Leiria, Portugal, Oct 2-4, 2019.
25. Member, Scientific Committee, International Conference on Research Advances in Additive Manufacturing, Nanjing, China, March, 2019, 2020.
26. Member, Scientific Advisory Board, International Conference on Computational Design and Engineering, Kuala Lumpur, Malaysia, June 28-30, 2020.
27. Member, Scientific Committee, Second International Conference on Progress in Digital and Physical Manufacturing, Leiria, Portugal, Oct 13-15, 2021.
28. Member, International Scientific Committee, Design for Additive Manufacturing Conference, Singapore, May 19-20, 2022.
29. Member, International Conference on Additive Manufacturing for a Better World, Singapore, August 23-25, 2022.

Book Reviews

1. Reviewed proposal for *Geometric Modeling for Engineers*, D. Ryan, CRC Press, January 2003.
2. Reviewed textbook: *Rapid Prototyping: Principles and Applications*, R. Noorani, Oxford University Press, January 2003.

Other Service

1. Member, WTEC Panel on Assessment of European Research and Development in Additive/Subtractive Manufacturing, Site visits to European research centers, Oct. 19-25, 2003.

B. Public and Community Service

1. Judge, Science Olympiad - Middle School Regional Tournament, Mouse-trap cars, February 27, 1993.
2. Judge, ASME Regional Student Conference, Old Guard Competition Finals, April 3, 1993.
3. Judge, Science Olympiad - High School Regional Tournament, Scrambler cars, January 28, 1994.
4. Judge, Science Olympiad - High School State Tournament, Scrambler cars, March 25, 1995.
5. Judge, Science Olympiad - High School National Tournament, Scrambler cars, May 18, 1996.
6. Judge, Science Olympiad - High School State Tournament, Scrambler cars, April 5, 1997.
7. Judge, Table Clinic Research, School of Dentistry, Medical College of Georgia, Feb. 4, 2004.

C. Institute Contributions

1. Institute Committee Service

no data

2. College Committee Service

no data

3. School Committee Service

9. Member, Faculty Recruiting Committee, GWW School of Mechanical Engineering, 2000-05.
10. Member, Faculty Advisory Committee, GWW School of Mechanical Engineering, 2001 – 2003.
11. Chair, Faculty Recruiting Committee, GWW School of Mechanical Engineering, 2003-4.
12. Member, Graduate Committee, GWW School of Mechanical Engineering, 2004-5.
13. Member, Periodic Peer Review Committee, GWW School of Mechanical Engineering, 2004-5.
14. Member, Ad Hoc Graduate Math Committee, GWW School of Mechanical Engineering, 2004-5.
15. Member, Ad Hoc Research Retreat Committee, GWW School of Mechanical Engineering, 2004-5.
16. Chair, Graduate Committee, GWW School of Mechanical Engineering, 2005-6.
17. Chair, GWW Savannah Recruiting Committee, GWW School of Mechanical Engineering, 2005-7.
18. Member, GWW Savannah Advisory Committee, GWW School of Mechanical Engineering, 2005-6.
19. Member, GT Academic Senate, 2005-7.
20. Member, GT Institute Graduate Curriculum Committee, 2008-11.
21. Member, GT Oliver Professor of Practice Search Committee, 2009-10.
22. Member, GWW Ad Hoc Committee on Teaching Loads, 2010.
23. Chair, GWW Ad Hoc Search Committee for Director - Financial Services & Administration, 2011.
24. Chair, GWW Ad Hoc Search Committee for Director of Design & Innovation, 2012.
25. Chair, GWW Ad Hoc Search Committee for Machine Shop Supervisor, 2012.

26. Member, GWW Reappointment, Promotion, Tenure Committee, 2012-15.
27. Chair, GWW Ad Hoc Committee on Design Position Responsibilities, 2013.
28. Chair, GWW Ad Hoc committee on Design and Fabrication Studio, 2014-15.
29. Chair, GWW Ad Hoc Search Committee for ME1770 Academic Professional, 2015.
30. Member, GWW Undergraduate Committee, 2018-19.
31. Chair, GWW Periodic Peer Review committee, 2019.
32. Member, GWW Graduate Committee, 2019-2022.
33. Co-Chair, GWW ad hoc committee on PhD Qualifying Exams, 2019-2020.
34. Chair, GWW Reappointment, Promotion, Tenure Committee, 2020.
35. Member, GWW Reappointment, Promotion, Tenure Committee, 2021.
36. Member, GWW ad hoc committee on PhD Qualifying Exam Implementation, 2020-21.

4. Program Development: Research

Director, Rapid Prototyping and Manufacturing Institute, 1995 – present. Responsibilities include soliciting faculty involvement, formulating educational and research programs, directing the research program, supervising student projects, and coordinating operations of the laboratory with other stakeholders. Nine other faculty from 3 Schools (ME, ChE, Mgmt) have conducted research funded by the RPMI. Many others utilize the RPMI equipment and facilities in support of their research.

Between 5 and 14 companies have been members of the RPMI, contributing between $130K and $280K in funds and in-kind donations. Dr. Rosen directs the allocation of these funds.

ADDITIONAL INFORMATION

Significant Industry Gifts to Dr. Rosen in Support of Research

1. AT&T, $4000, November, 1995.
2. Ford Motor Company, $9000, July 1997.
3. Ford Motor Company, $10,000, February 1998.
4. Ford Motor Company, $15,000, June 1998.
5. Ford Motor Company, $10,000, January 2000.
6. Albany International, $17,000, November 2007.
7. Albany International, $20,000, June 2008.
8. Albany International, $20,000, April 2009.