

UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD

ROBERT BOSCH LLC, and
MERCEDES-BENZ USA LLC,
Petitioners,

v.

WESTPORT FUEL SYSTEMS CANADA INC.,
Patent Owner.

U.S. Patent No. 6,575,138
Case No. IPR2023-00293

DECLARATION OF DR. J. MATT QUINLAN

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I, Dr. J. Matt Quinlan, declare as follows:

I. INTRODUCTION

1. I have been retained by Robert Bosch Corp. (“Robert Bosch”) as an independent expert consultant in this proceeding before the United States Patent and Trademark Office (“PTO”). I am not an employee of Robert Bosch or any affiliate or subsidiary of Bosch or any of the other petitioners or real parties-in-interest in this petition.

2. I have been asked to consider whether certain references teach or suggest the features recited in certain claims of U.S. Patent No. 6,575,138 B2 to Welch et al., which I refer to herein as the ’138 patent.

3. My opinions and the bases for my opinions are set forth below.

4. I am being compensated at my ordinary and customary rate of \$400 per hour for my work, plus reimbursement for any reasonable expenses. My compensation is based solely on the amount of time that I devote to activity related to this case and is in no way contingent on the nature of my findings, the presentation of my findings in testimony, or the outcome of this or any other proceeding. I have no other financial interest in this proceeding.

II. EDUCATION BACKGROUND, PROFESSIONAL EXPERIENCE, AND OTHER QUALIFICATIONS

5. My curriculum vitae (“CV”) is attached hereto as Attachment A and provides an accurate identification of my background and experience.

6. I am currently an assistant professor in the Mechanical and Aerospace Engineering department at the University of Colorado, Colorado Springs (“UCCS”).

I am also the Director of UCCS’s Combustion and Acoustics Lab.

7. I received a B.S. in mechanical engineering from Colorado State University in 2001.

8. From 2001 to 2006, I worked as a fuel systems engineer at Sturman Industries. My responsibilities included the development, testing, design, analysis, and customer interface/installation of diesel fuel injectors.

9. Starting in 2006, I returned to Colorado State University to continue my studies. I received a M.S. in mechanical engineering in 2009.

10. Starting in 2009, I attended the Georgia Institute of Technology. While there, I served as a Graduate Research Assistant and Research Engineer, focusing on combustion instability in liquid propellant rocket engines and the remote measurement of rocket engine chamber pressure dynamics.

11. I received a Ph.D. in aerospace engineering from the Georgia Institute of Technology in 2015.

12. From 2005 to the present, I also worked as a consultant engineer for my own consulting firm, known as Quinlan Engineering and Design, LLC. I engage in engineering design, development, and analysis in fuel systems.

13. I joined the faculty at UCSS in 2018 as a visiting assistant professor and permanently in 2019 as an assistant professor.

14. I am the named inventor on a number of patents relating to automotive technology, including fuel injectors. These patents include, for example, U.S. Patent No. 7,681,592 (entitled “Three-way poppet valves with floating seat”), U.S. Patent No. 8,282,020 (entitled “Three-way valves and fuel injectors using the same”), and U.S. Patent No. 8,366,018 (entitled “Oil Intensified common rail injectors”).

15. I have also co-authored papers relating to fuel injectors, including “Evaluation of a 3-Way Direct Needle Control Unit Injector on Hydraulic Test Bench and V8 Engine,” SAE Technical Paper 2004-01-0024 (2004).

16. A complete list of my patents and publications is included as part of my attached CV.

III. ASSIGNMENT AND MATERIALS CONSIDERED

17. I have been asked to provide analysis and explain the subject matter of the '138 patent, including the state of the art when the '138 patent application was filed. I have also been asked to consider, analyze, and explain certain prior art to the '138 patent, including how that art relates to the challenged claims of the '138 patent and to provide my opinions regarding whether that art invalidates the claimed subject matter.

18. The opinions expressed in this declaration are not exhaustive of opinions I may offer in the future regarding the unpatentability of the claims of the '138 patent. Therefore, the fact that I do not address a particular point should not be understood to indicate an agreement on my part that any claim complies with the requirements of any applicable patent or other rule.

19. I reserve the right to amend and supplement this declaration in light of additional evidence, arguments, or testimony presented during this IPR or related proceedings on the '138 patent.

20. In forming the opinions set forth in this declaration, I have considered and relied upon my education, knowledge of the relevant field, knowledge of scientific and engineering principles, and my experience. I have also reviewed and considered the '138 patent (Exhibit 1001), its prosecution history (Exhibit 1002), and the following additional materials:

Exhibit	Description
1004	U.S. Patent No. 5,479,902 to Wirbeleit et al. (“Wirbeleit”)
1005	DE 197 08 304 A1 to Klügl (“Klügl”)
1006	Certified translation of Klügl and associated translator’s declaration
1007	U.S. Patent No. 5,735,240 B1 to Ito et al. (“Ito”)
1008	U.S. Patent No. 6,295,969 B1 to Kato et al. (“Kato”)
1009	U.S. Patent No. 5,697,554 B1 to Auwaerter et al. (“Auwaerter”)
1010	U.S. Patent No. 4,725,002 to Trachte (“Trachte”)

1011	U.S. Patent No. 5,630,550 to Kurishige et al. (“Kurishige”)
1012	U.S. Patent No. 4,684,067 to Cotter et al. (“Cotter”)
1013	EP 0 107 894 A2 to Beck et al. (“Beck”)
1014	U.S. Patent No. 4,284,263 to Newcomb (“Newcomb”)
1015	GB 2 318 390 A to Roessler et al. (“Roessler”)
1022	<u>Plaintiff Westport Fuel Systems Canada Inc.’s Disclosure of Asserted Claims and Infringement Contentions</u> from <i>Westport Fuel Systems Canada Inc. v. Ford Motor Company</i> , Case No. 2:21-cv-00453 (E.D. Tex.)
1023	U.S. Patent No. 6,148,842 to Kappel et al. (“Kappel”)
1024	U.S. Patent No. 5,779,149 to Hayes, Jr. (“Hayes”)

IV. UNDERSTANDING OF THE LAW

21. I am not an attorney but have been instructed in and applied the law as described in this section.

22. I understand that the first step in comparing an asserted claim to the prior art is for the claim to be properly construed. I address how a person of ordinary skill in the art (“POSITA”) would have understood the claims in Section VIII below.

23. I have been further instructed and understand that a patent claim is unpatentable and invalid as obvious if the subject matter of the claim as a whole would have been obvious to a POSITA of the claimed subject matter as of the time of the invention at issue. I understand that when assessing the obviousness of claimed subject matter, the following factors are evaluated: (1) the scope and content

of the prior art; (2) the difference or differences between each claim of the patent and the prior art; and (3) the level of ordinary skill in the art at the time the patent was filed.

24. I understand that claimed subject matter may be obvious in view of more than one item of prior art. I understand, however, that it is not enough to show simply that all the limitations of the claimed subject matter are spread throughout the prior art. Instead, for claimed subject matter to be obvious over multiple references, there must be some reason or motivation for a POSITA to combine the prior art references to arrive at the claimed subject matter.

25. I have been informed that, in seeking to determine whether an invention that is a combination of known elements would have been obvious to a POSITA at the time of the invention, one must consider the references in their entirety to ascertain whether the disclosures in those references render the combination obvious to such a person.

26. I have been informed and understand that, while not required, the prior art references themselves may provide a teaching, suggestion, motivation, or reason to combine, but other times the motivation linking two or more prior art references may be supplied by common sense or the background knowledge of a POSITA at the time of the invention.

27. I understand that a particular combination may be proven obvious by showing that it was obvious to try the combination. I have been informed that, if a technique has been used to improve one device, and a POSITA would recognize that it would improve similar devices in the same way, using the technique is obvious unless its actual application is beyond his or her skill.

28. I further understand that an obviousness analysis recognizes that market demand, rather than scientific literature, often drives innovation, and that a motivation to combine references also may be supplied by the direction of the marketplace. For example, when there is a design need or market pressure to solve a problem and there are a finite number of identified, predictable solutions, a POSITA has good reason to pursue the known options within his or her technical grasp because the result is likely the product not of innovation but of ordinary skill and common sense.

29. I have been informed that the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. Thus, where all of the elements of a claim are used in substantially the same manner, in devices in the same field of endeavor, the claim is likely obvious.

30. Additionally, I understand that a patent is likely to be invalid for obviousness if a POSITA can implement a predictable variation or if there existed

at the time of the invention a known problem for which there was an obvious solution encompassed by the patent's claims. Therefore, when a work is available in one field of endeavor, design incentives and other market forces can prompt variations of it, either in the same field or a different one.

31. I further understand that combining embodiments related to each other in a single prior art reference would not ordinarily require a leap of inventiveness.

32. I also understand that a POSITA must have had a reasonable expectation of success when combining references for claimed subject matter to be obvious.

33. I have been informed and I understand that factors referred to as “objective indicia of non-obviousness” or “secondary considerations” are also to be considered when assessing obviousness when such evidence is available. I understand that these factors can include: (1) commercial success; (2) long-felt but unresolved needs; (3) copying of the invention by others in the field; (4) initial expressions of disbelief by experts in the field; (5) failure of others to solve the problem the claimed subject matter solved; and (6) unexpected results.

34. I also understand that evidence of objective indicia of non-obviousness must be commensurate in scope with the claimed subject matter. I further understand that there must be a relationship, sometimes referred to as a “nexus,” between any such secondary indicia and the claimed invention.

35. Finally, I have been informed that one cannot use hindsight to determine that an invention was obvious.

36. I provide my opinions in this declaration based on the guidelines set forth above.

V. LEVEL OF SKILL IN THE ART

37. I have been informed and understand that the level of ordinary skill in the relevant art at the time of the invention is relevant to inquiries such as the meaning of claim terms, the meaning of disclosures found in the prior art, and the reasons a POSITA may have for combining references.

38. I have been informed and understand that factors that may be considered in determining the level of ordinary skill include: (1) the education of the inventor; (2) the type of problems encountered in the art; (3) prior art solutions to those problems; (4) rapidity with which innovations are made; (5) sophistication of the technology; and (6) education level of active workers in the relevant field. I have been further informed and understand that a POSITA is also a person of ordinary creativity.

39. A POSITA in the technology field of the '138 patent would, in my opinion, have had a degree in mechanical engineering or a similar discipline, along with 2 years of professional experience working with the design and development

of fuel injection systems for internal combustion engines or an equivalent level of skill, knowledge, and experience.

40. In my opinion, this POSITA would have been aware of and generally knowledgeable about how fuel injectors and the valves used within are structured and operate, and how they are used to deliver fuel to an engine's combustion chambers.

41. In my opinion, a POSITA would have had the same basic level of skill and background knowledge regardless of whether the '138 patent is entitled to an October 1999, March 2000, or May 2001 filing date.

42. In view of my educational background (e.g., a M.S. in mechanical engineering and Ph.D. in aerospace engineering) and work experience in the fuel injector field, I am a person of more than the ordinary level of skill in the art of the '138 patent. In forming my opinion, I have drawn on my academic background and professional experiences. My opinions herein, however, were formed taking into account the perspective of an ordinarily skilled artisan.

VI. THE '138 PATENT'S EFFECTIVE FILING DATE

43. I understand that the application leading to the '138 patent was filed on May 23, 2001.

44. Based on my review of the '138 patent, I note that it both identifies itself as a continuation-in-part of a March 9, 2000 application, and makes reference to an October 15, 1999 provisional application.

45. For purposes of this declaration, I have been instructed to use October 15, 1999 as the effective filing date of the '138 patent. My opinions in this declaration were formed from the perspective of a POSITA as of October 15, 1999, including both the knowledge of a POSITA at that time as well as how a POSITA would have understood the prior art. Nevertheless, the opinions I express in this declaration would be the same regardless of whether the '138 patent has an October 15, 1999, a March 9, 2000, or a May 23, 2001 effective filing date.

VII. THE '138 PATENT

A. Overview

46. The '138 patent relates to fuel “injectors for internal combustion engines” that are “directly controllable” by a piezoelectric or magnetostrictive actuator. (Ex. 1001, 1:16-20.)

47. According to the patent, the injector also includes a “passive hydraulic link.” (*Id.*, 1:21.)

48. The patent begins by discussing prior art fuel injectors.

49. Here, the patent explains that as of its filing, it was known to be beneficial to engage in “[d]irect injection.” Direct injection entails injection directly into the combustion chamber of an internal combustion engine. (*Id.*, 1:23-40.)

50. The patent explains that this type of injection—in contrast to indirect injection into the manifold and outside of the combustion chamber—is “desirable” because it improves engine performance and reduces emissions. (*Id.*)

51. The patent also explains that prior direct fuel injection systems that were “hydraulically actuated” or “use piezoelectric actuator[s]” were known and available. (*E.g., id.*, 2:13-17, 2:52-55.)

52. The patent goes on, however, to identify certain purported problems with these known systems.

53. For instance, hydraulically actuated systems require “additional hydraulic hardware,” which adds “increased bulkiness” and subjects the system to a “delayed response” and reduced “controllability of movement of the injection valve.” (*Id.*, 2:23-46.)

54. Further, known piezoelectric actuators were purportedly only used to “operate a control valve, which in turn controls the flow of a hydraulic fluid to operate an injection valve” resulting in delayed injector operation and increased complication. (*Id.*, 2:52-64.)

55. After discussing these known fuel injectors, the '138 patent proposes a “directly actuated” injector that does not include “an intermediate active hydraulic operator generating any actuating forces.” (*Id.*, 2:64-67.)

56. The '138 patent explains that its injector does include a “passive hydraulic link.” (*Id.*, 4:10-12, 34-38; 7:23-37.)

57. The patent explains however, that in contrast to “[c]onventional active hydraulic operators,” the “passive hydraulic link” employed by its injector “merely transmits the actuating forces” or serves as a “load path” “but is not employed to generate an actuating force for actuating the valve.” (*Id.*)

58. The patent also notes that the “passive hydraulic link” provides a “further advantage” in that it “may be employed to correct for differential thermal expansion, wear and dimensional variability within permitted manufacturing and assembly tolerances.” (*Id.*, 7:57-60.)

59. The link does this by “auto-adjusting itself in response to these effects by allowing movement of hydraulic fluid between opposite sides of [a] hydraulic piston” to “re-zero[] itself to ensure that a desired valve member lift is maintained.” (*Id.*, 7:60-65.)

60. The below annotated versions of Figures 1 and 2 of the '138 patent provide an example of an “outwardly opening directly actuated fuel injection valve.” (*Id.*, 8:61-63.)

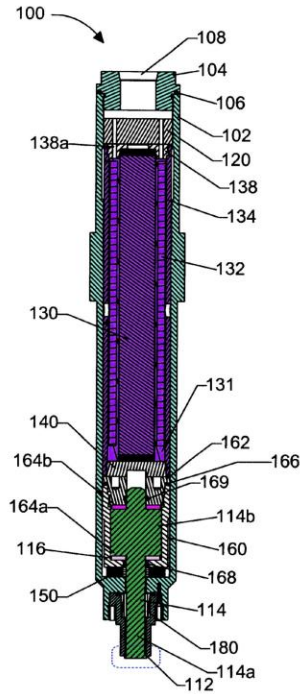


FIG. 1

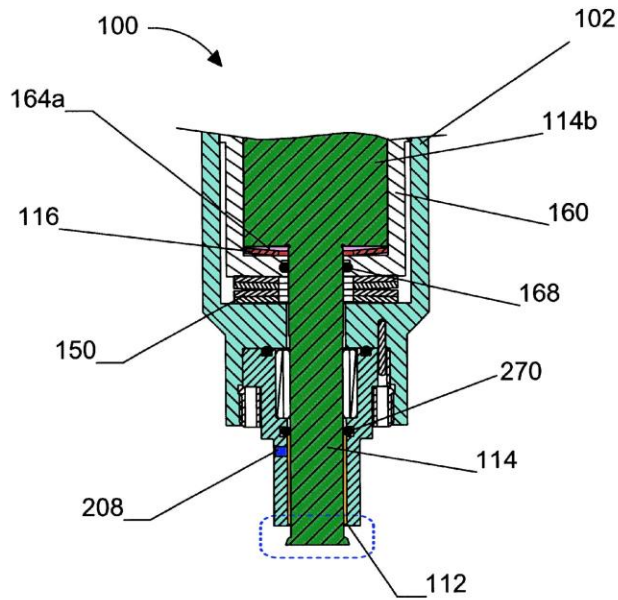


FIG. 2

(*Id.*, Figs. 1-2 (annotated).)

61. The elements of this injector have been annotated as follows:

62. **Teal:** A “valve housing 102” and “[v]alve cap 104” that “provide a fluidly sealed valve body.” (*Id.*, 9:4-6.)

63. **Blue:** A “fuel inlet 208,” as shown in Figure 2. (*Id.*, 13:34.)

64. **Orange:** The injector interior that receives fuel from the inlet. (*Id.*, 9:4-9.)

65. **Green:** A “valve member 114” located within the injector. (*Id.*, 9:23-27.)

66. **Dashed blue outline:** A “valve seat 112” that is contacted by one end of the valve member 114 to close the injector. (*Id.*, 9:23-27, 59-64.)

67. **Red:** A “valve spring 116” in the form of a “disc or washer spring” (or a “coil spring”) that “biases” the member 114 “in the closed position.” (*Id.*, 10:13-19.)

68. **Purple:** A “magnetostrictive actuator” including a member 130, bobbin 131, coil 132, and flux tube 134 located within the housing. (*Id.*, 10:41-46.)

69. **Pink:** “[H]ydraulic fluid 164b” of “a hydraulic link assembly.” (*Id.*, 11:65-67; 14:16-22.)

70. The patent also explains how the injector operates. More particularly, to open the injector, current is applied to the actuator causing it to “grow[] in length.” (*Id.*, 10:51-60.)

71. This causes the actuator to push an intermediate “sliding pole 140” towards the “valve member 114 to provid[e] a force for opening injection valve 100.” (*Id.*, 10:59-62.)

72. “The opening force generated by the actuator assembly is transmitted to valve member 114 through” “hydraulic fluid 164b” of the “a hydraulic link assembly.” (*Id.*, 11:65-67; 14:16-22.) During actuation, fluid “does not have time to flow” out of the space that contains it and fluid 164b thus “acts as a solid.” (*Id.*, 14:26-40.)

73. The patent also explains that the injector allows for “[a]uto-adjustments” via “the migration of hydraulic fluid from chamber 164b on one side

amplified distance. Needle 4, which is connected to the piston 6, then lifts and valve 1 opens. (*Id.*, 5:45-67.)

78. The applicant responded to the Examiner's rejection in February 2003 by noting that Kurishige is a "conventional 'dynamic' hydraulic system, which relies upon the flow of hydraulic fluid" from chamber 10 to the inner cylinder "to actuate a needle valve." (Ex. 1002, pp. 134, 136-37.)

79. The applicant then argued that Kurishige is "structurally and functionally distinguished from the applicants' 'passive' hydraulic link. In a 'dynamic' hydraulic system, the hydraulic fluid does not 'act substantially as a solid with the thickness being substantially constant while the actuator assembly is actuated', as recited in claim 1 ... because the hydraulic fluid must flow from one chamber to another to cause needle movement." (*Id.*)

80. The claims were allowed immediately after this response. (*See id.*, pp. 166-168.).

C. The '138 Patent's Claims

81. For reference, claims 1-3, 6, 13-14, 17-21, 26-28, and 41 of the '138 patent are reproduced below:

1. An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:

(a) a valve housing comprising:

- a fuel inlet port;
- an interior chamber fluidly connected to said fuel inlet port; and
- a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;
- (b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;
- (c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;
- (d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position;
- and

(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.

2. The injection valve of claim **1** wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by differential thermal expansion.

3. The injection valve of claim **2** wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by wear to components of said injection valve.

6. The injection valve of claim **1** wherein said actuator assembly comprises a dimensionally responsive member.

13. The injection valve of claim **6** wherein said dimensionally responsive member is formed from a piezoelectric material.

14. The injection valve of claim **6** further comprising a compression spring member for applying a compressive force to said dimensionally responsive member.

17. The injection valve of claim **6** wherein said actuator assembly is controllable to maintain said desired lift between 10 and 100 percent of maximum lift.

18. The injection valve of claim **17** wherein said lift is controllable by varying at least one of the electric current, the electric voltage and the magnetic field imposed upon said dimensionally responsive member.

19. The injection valve of claim **6** wherein said valve member is controllable such that said valve member moves between said open and closed positions in less than about 200 microseconds.

20. The injection valve of claim **6** further comprising a biasing mechanism for applying a compressive force to said dimensionally responsive member.

21. The injection valve of claim **1** wherein said biasing mechanism comprises a spring.

26. The injection valve of claim **1** wherein said fuel is injected into said combustion chamber at a pressure greater than about 2000 psi (about 13.8 Mpa).

27. The injection valve of claim **1** wherein said valve housing comprises a plurality of parts which are joined with each other to provide a fluidly sealed body.

28. The injection valve of claim **1** wherein said valve housing, said valve member and said actuator assembly are selected from materials having thermal expansion coefficients sufficiently compatible such that changes in the dimensional relationship between said components caused by changes in temperature are reduced.

41. A method of operating a fuel injection valve for an internal combustion engine, said injection valve having a longitudinal axis, said method comprising:

- (a) actuating a dimensionally responsive member comprising at least one of a magnetostrictive material and a piezoelectric material, said dimensionally responsive member expanding in length in the direction of said longitudinal axis upon actuation of said actuator;
- (b) transferring movement caused by said actuated dimensionally responsive member through a passive hydraulic link to cause a corresponding movement of a valve member to open said valve by

lifting said valve member away from a valve seat and compressing a biasing mechanism that biases said valve in a closed position, said passive hydraulic link comprising a hydraulic cylinder which houses a piston and is filled with a hydraulic fluid, wherein said hydraulic fluid forms a layer between said piston and a cylinder head and because of the short duration that said valve is open, said hydraulic fluid does not have time to flow from one side of said piston to the other side and while said injection valve is open, said layer of hydraulic fluid acts as an incompressible solid so that movement caused by the actuation of said dimensionally responsive member is transmitted through said fluid layer;

- (c) deactuating said dimensionally responsive member to contract the length of said dimensionally responsive member to unload said biasing mechanism and cause a corresponding movement of said valve member to close said valve;
- (d) providing sufficient time between consecutive valve openings to allow at least some of said hydraulic fluid within said passive hydraulic link to flow from one side of said piston to the other side of said piston.

VIII. CLAIM CONSTRUCTION

82. I am not a legal expert or an attorney and offer no opinions on the law. I understand that claim construction is a matter of law. I have been informed by counsel of the legal standards that apply to claim construction in an *inter partes* review, and I have applied them in forming my opinions. I understand that during an *inter partes* review, however, the same claim construction standard used in federal district court is applied when addressing the meaning of claim terms.

83. I have been informed that the words of a claim are generally given the ordinary and customary meaning that the term or phrase would have to a POSITA at the time of the invention in view of the surrounding claim language, the specification and the file history (collectively, the “intrinsic evidence” or “intrinsic record”).

84. I also understand that courts may consider extrinsic evidence, such as expert and inventor testimony, dictionaries, and learned treatises (collectively, the “extrinsic evidence” or the “extrinsic record”), but that such extrinsic evidence should be given less weight than the intrinsic evidence.

85. In my opinion, the terms of the ’138 patent’s claims do not require further construction and can be afforded their plain and ordinary meaning.

86. I understand that Patent Owner has alleged that the claims cover a nozzle/needle injection valve that is controlled indirectly through a pilot valve. This type of pilot valve may also be called a first-stage or indirect-acting valve. A pilot

actuated nozzle injector valve is one where the pilot valve armature acted upon by the actuator does not itself open a fluid pathway into the combustion chamber but instead only opens the pilot valve that in turn triggers other components to open the injection pathway. (See, e.g., Ex. 1022, p. 24 (pointing to an alleged “valve seat” and “valve member” that form an intermediate valve that does not open to the combustion chamber).) Care must be taken in understanding the context when the term valve is used in this case.

87. I disagree that the claims can be properly interpreted to extend to an indirectly actuated valve.

88. First, it is contrary to the claim language itself.

89. Claim 1 requires a “valve member” that “cooperat[es] with” a “valve seat” “to seal” an “interior chamber from [the] combustion chamber.” (Ex. 1001, claim 1.)

90. In my opinion, this shows that it is the valve member itself, and not some other structure, that operates to open and close/seal a fluid path from the injector’s “interior chamber” to the “combustion chamber.”

91. Claim 1 also provides that the “valve member” has “one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber.”

92. This means that one end of the “valve member” must exist at a point inside of the housing and the other end must exist on the combustion chamber side of the nozzle valve seat. Furthermore, the valve member opens the nozzle—connecting the interior of the injector interior chamber to the combustion chamber—by moving away from the nozzle valve seat, towards the combustion chamber. It is not an intermediate valve located entirely inside and within the housing.

93. In my opinion, the specification confirms that the ’138 patent’s claims require a directly actuated injector.

94. In particular, the specification repeatedly and consistently characterizes the invention is a “directly actuated injector.” (*Id.*, 8:32-33; *see also* Abstract, 1:16-21; 2:66-67; 16:37-39.)

95. Moreover, the patent contrasts its directly actuated valve with prior art valves that are indirectly actuated. (*See, e.g., id.*, 2:52-3:7.)

96. The ’138 patent is even entitled “Directly Actuated Injection Valve.” (*Id.*, Cover.)

IX. UNPATENTABILITY ANALYSIS

97. For the reasons I explain in greater detail below, it is my opinion that as of the effective filing date of the ’138 patent, a POSITA would have considered claims 1-3, 6, 13-14, 17-21, 26-28, and 41 of the ’138 patent to be unpatentable as obvious over the prior art discussed in this declaration.

A. Overview of the Prior Art

98. The following paragraphs provide an overview of the main prior art references I discuss throughout this declaration.

1. Wirbeleit

99. Wirbeleit indicates on its face that it issued January 2, 1996. (Ex. 1004, Cover.) In view of this date of issuance, which predates the '138 patent's filing by more than a year, I understand that Wirbeleit is prior art to the '138 patent under at least 35 U.S.C. § 102(b).

100. Wirbeleit is not cited on the face of the '138 patent. It also was not discussed or mentioned during the '138 patent's prosecution history.

101. Wirbeleit relates to a “fuel injection system for a Diesel engine.” (*Id.*, 1:45-46.)

102. Wirbeleit's injector has a “control needle” with fuel injection orifices that can be “exposed to a degree controllable ... depending on engine operating parameters.” (*Id.*, 1:52-57.) This allows for different, controllable amounts of fuel injection. (*See id.*)

103. Wirbeleit's injector is shown in the below annotated figure:

108. **Red:** A “spring 7” that forces the tip of a “control needle 5” (green) onto a “valve seat 8” to close the injector. (*Id.*)

109. **Purple:** A “piezo” or “magnetostrictive actuator 21.” (*Id.*, 2:60-65.)

110. **Pink:** A “hydraulic transmission element 22” through which the force exerted by the actuator is passed to the control piston/needle for purposes of opening the injector. (*Id.*)

111. Again, Wirbeleit explains that the desired needle lift off the valve seat and the corresponding amount by which the needle’s orifices are exposed “is maintained by voltage control of the actuator 21.” (*Id.*, 3:1-7.)

2. Klügl

112. Klügl indicates on its face that it published September 10, 1998. (*See* Ex. 1006, Cover.) In view of this date of publication, which predates the ’138 patent’s filing by more than a year, I understand that Klügl is prior art to the ’138 patent under at least 35 U.S.C. § 102(b).

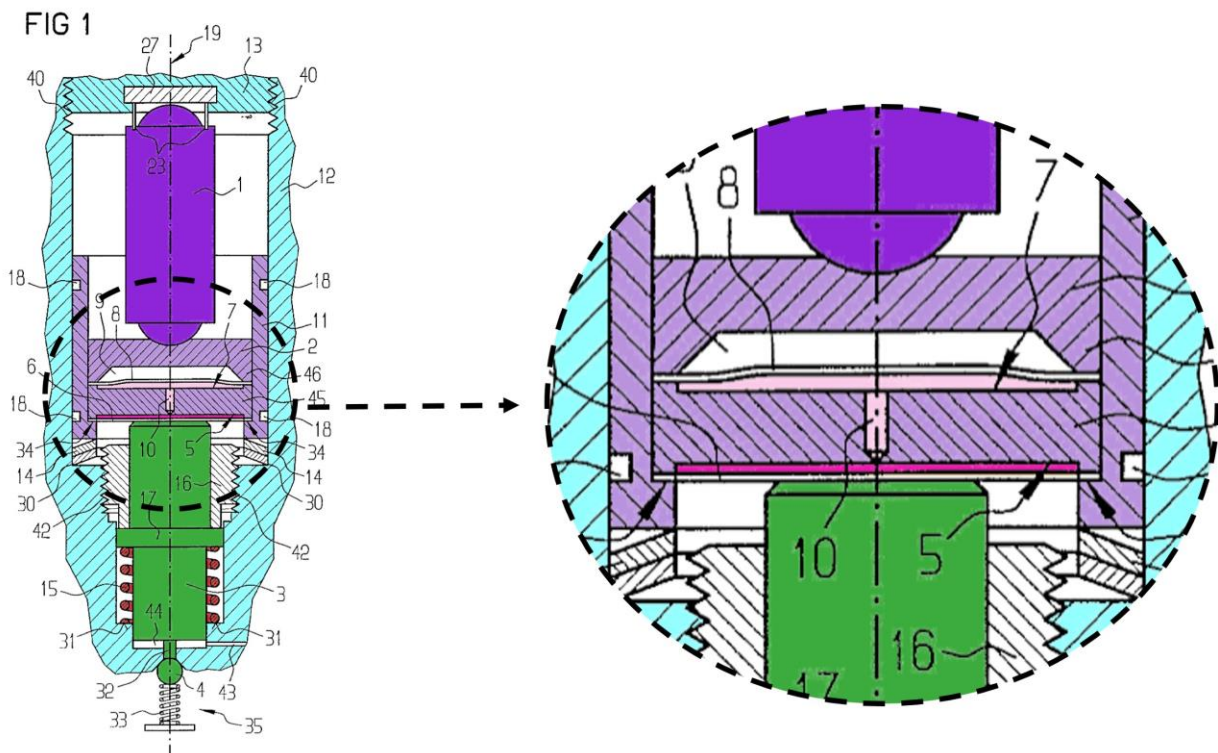
113. Klügl is not cited on the face of the ’138 patent. It also was not discussed or mentioned during the ’138 patent’s prosecution history.

114. Klügl published in German. Throughout this declaration I will refer to and cite to a certified translation (Ex. 1006) of Klügl.

115. Klügl related to a “power transmission device” to “transmit the movement of a piezoelectric actuator” for valve opening and closing in a fuel injector. (*Id.*, 1:7-12.)

116. Klügl explains that a chamber of hydraulic fluid within this device not only transfers this opening force, but also allows the injector to adjust for the effects of “thermal expansion differences and gradual wear.” (*Id.*, 3:63-4:31.)

117. Klügl’s injector is shown in the below annotated figure. The central portion of the figure has been excerpted and expanded to the right to better show the chamber of hydraulic fluid:



(*Id.*, Fig. 1.)

118. The various injector components shown in this figure are discussed in more detail below:

119. **Teal:** The injector includes an outer “housing 12” and “upper stop 13” that surround its components. (*Id.*, 1:47-51.)

120. **Green:** A “drive piston 3”—along with connected “drive needle 32,” “ball 4,” and “shoulder ring 17”—are located within the injector. (*Id.*, 2:35-39, 50-57.)

121. **Red:** A “spring 15” forces the “drive piston 3” (green) upwards, allowing “spring 33” to force the “drive needle 32” and “ball 4” (both also green) upwards to close the injector. (*Id.*, 2:35-39, 50-57.)

122. **Dark purple:** A “piezoelectric actuator 1” to which a signal can be applied causing it to expand for purposes of opening the injector. (*Id.*, 1:47-51.)

123. **Light purple:** A “transmission module 2” that is pressed downward towards the piston 3 by the expanding actuator. (*Id.*, 3:23-33.)

124. **Dark pink:** Force is transmitted from the actuator to the piston through incompressible hydraulic fluid “located in [a] pressure chamber 5.” (*Id.*, 3:26-29.) Klügl explains that during actuation, only “an insignificant amount” of hydraulic fluid flows out of chamber 5. (*Id.*, 4:11-22.) But, during idle periods, hydraulic fluid can move from chamber 5 through “throttle 10” (an orifice) to chamber 7 (**light pink**) to “automatic[ally] adjust[]” for “thermal expansion differences and gradual

wear” and keep the “drive piston 3” in contact with “transmission module 2.” (*Id.*, 3:50-4:33.) The hydraulic fluid is completely captured and contained within the transmission module. (*See id.*; Fig. 1.) There is no external fluid source. (*See id.*)

125. When the injector is actuated, the piston’s ball 4 is moved off its seat causing the pressure in a “pressure chamber” to drop, an “injection needle” to open, and fuel to be injected. (*Id.*, 3:30-38.)

3. Newcomb

126. Newcomb indicates on its face that it issued August 18, 1981. (*See Ex. 1014, Cover.*) In view of this date of issuance, which predates the ’138 patent’s filing by more than a year, I understand that Newcomb is prior art to the ’138 patent under at least 35 U.S.C. § 102(b).

127. Newcomb is not cited on the face of the ’138 patent. It also was not discussed or mentioned during the ’138 patent’s prosecution history.

128. Newcomb relates to a “control valve such as a ... fuel injection valve for controlling flow of a medium.” (*Id.*, 1:5-7.)

129. Newcomb explains that the materials used to make such a valve should be chosen such that the materials’ coefficients of thermal expansion are selected so as to “enable[] the effects of thermal expansion to be reduced....” (*Id.*, 1:45-49.)

4. Hayes

130. Hayes indicates on its face that it issued July 14, 1998. (*See* Ex. 1024, Cover.) In view of this date of issuance, which predates the '138 patent's filing by more than a year, I understand that Hayes is prior art to the '138 patent under at least 35 U.S.C. § 102(b).

131. While Hayes is listed on the face of the '138 patent, it was not discussed or mentioned by the examiner during the '138 patent's prosecution history.

132. Hayes relates to an indirectly actuated fuel injector. (*Id.*, 1:7-9.) This is an injector where the nozzle needle valve is indirectly controlled by a pilot valve.

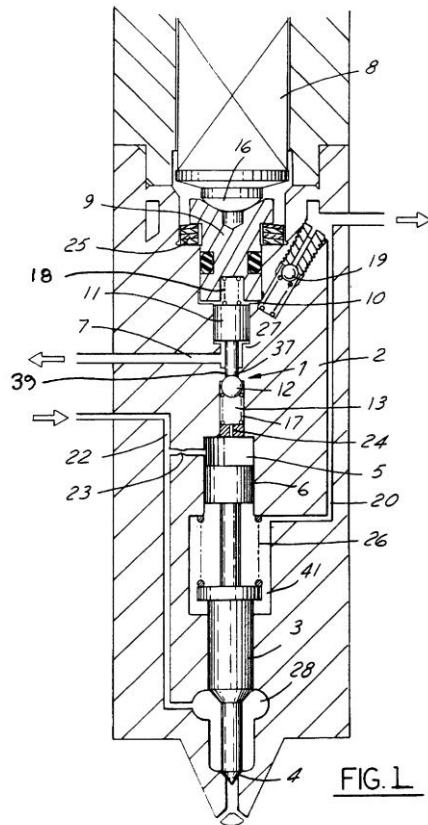
133. Hayes explains that such an injector includes an intermediate “control valve 1” sealed by a ball-shaped “component 12.” (*Id.*, 2:7-15, 30-33.)

134. Activating the actuator of the injector opens this control valve. (*Id.*, 3:24-45.)

135. Hayes also explains how this in turn opens a valve into the combustion chamber.

136. In particular, opening the intermediate control valve lowers the pressure in a “chamber 5,” which causes a separate “valve needle 3” to lift and open a passage into combustion chamber. (*Id.*, 3:53-63.) Fuel supplied by a “feeding line 22 which feeds the fuel at high pressure,” is then injected through the passage opened by the needle. (*Id.*, 2:45-48, 3:53-63.)

137. Figure 1 of Hayes shows these various components:



(*Id.*, Fig. 1.)

B. Ground 1: Claims 1-3, 6, 13-14, 17-21, 26-27, and 41 Are Obvious Over Wirbeleit and Klügl

138. In my opinion, a POSITA would have considered Wirbeleit and Klügl to be within the scope of the prior art and highly relevant to the patentability of the '138 patent's claims.

139. In my opinion, moreover, when viewed and considered in light of the knowledge possessed by a POSITA, Wirbeleit and Klügl together disclose all the

limitations of and render claims 1-3, 6, 13-14, 17-21, 26-27, and 41 of the '138 patent obvious.

140. In addition, not only would a POSITA have been motivated to combine and collectively consider the teachings of these references to arrive at the subject matter claimed by the '138 patent, but they would have had a reasonable expectation of success when doing so.

1. Claim-By-Claim Analysis

a. Claim 1

[1-p] “An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:”

141. In my opinion, to the extent the preamble is limiting, Wirbeleit teaches the claimed *“injection valve.”*

142. Wirbeleit explains that it relates to a “fuel injection system for a Diesel engine....” (Ex. 1004, 1:7-8.)

143. Wirbeleit’s fuel injection system includes “valve-controlled injectors [for] the injection of fuel under the control of an electronic control unit.” (*Id.*, 1:8-12.)

144. Wirbeleit also explains that its injector valve is meant for use with “direct-injection Diesel engines.” (*Id.*, 1:30-37.)

145. As of the filing of the '138 patent, a POSITA would have understood that a “direct-injection” engine is one in which fuel is injected directly into an engine’s combustion chamber, and not indirectly into the engine manifold.

146. Showing this, numerous prior art references explain that this is what “direct” injection entails.

147. For instance, a “direct cylinder injection system” was known to be one in which “the fuel injector is mounted in the cylinder block and sprays ... into the cylinder bore” (See Ex. 1007, 2:7-10.)

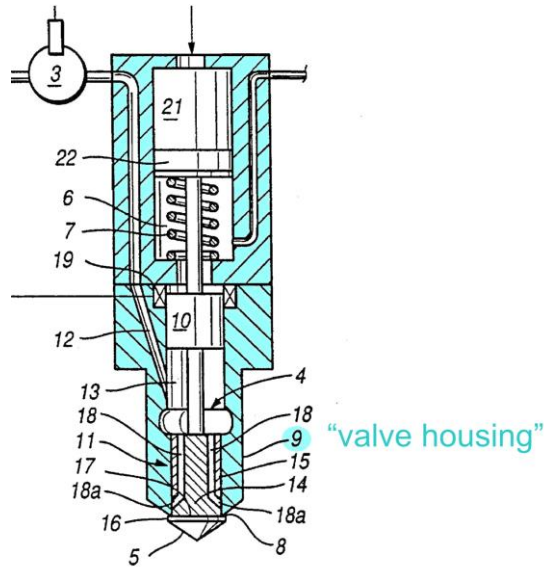
148. Similarly, in contrast to an “indirect injection” system that injects fuel into the manifold, a “direct injection system[]” “inject[s] fuel directly into the combustion chamber.” (Ex. 1008, 1:16-24.)

[1(a)] “(a) a valve housing comprising:”

149. In my opinion, Wirbeleit includes the claimed “*valve housing.*”

150. Wirbeleit explains that its “injector” includes an “injector body 9” that surrounds and contains the other injector components. (Ex. 1004, 2:31-35.)

151. Body 9 of Wirbeleit’s injector has been highlighted in teal in the figure below. Note that this figure (which is Wirbeleit’s only figure) has been cropped throughout this declaration to better focus on the depicted injector:



(*Id.*, Fig. (annotated).)

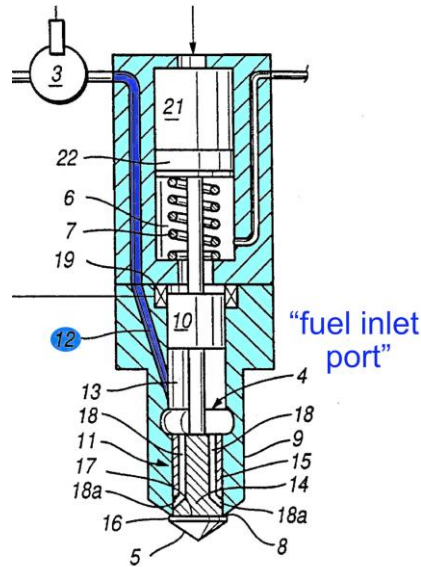
[1(a)-1] “a fuel inlet port;”

152. In my opinion, Wirbeleit includes the claimed ***“fuel inlet port.”***

153. Wirbeleit’s “fuel inject[or]” includes “a fuel injection conduit structure with a common supply conduit 3 for all injectors.” (Ex. 1004, 2:27-30.)

154. A “fuel admission passage 12” in “communication with the common supply conduit 3” allows fuel to enter the injector. (*Id.*, 2:35-40.)

155. Wirbeleit’s fuel admission passage 12 is highlighted below in blue:



(*Id.*, Fig. (annotated).)

[1(a)-2] “an interior chamber fluidly connected to said fuel inlet port; and”

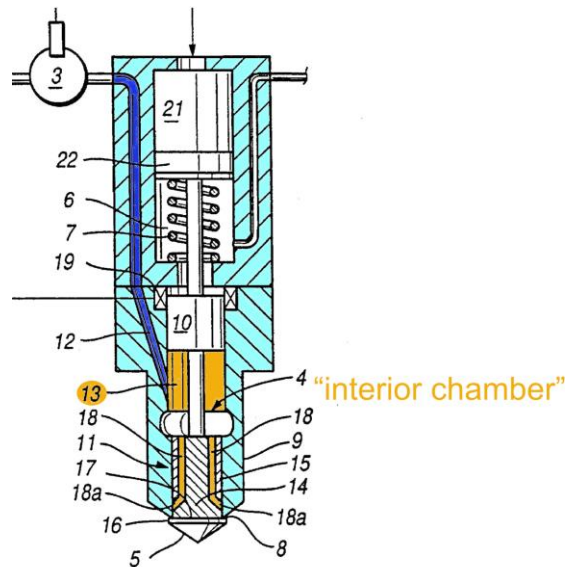
156. In my opinion, Wirbeleit includes the claimed “*interior chamber.*”

157. Wirbeleit explains that its injector includes a “slot orifice 4” within its injector body that contains “an injector orifice control needle 5.” (Ex. 1004, 2:31-32.)

158. Wirbeleit also explains its needle “delimit[s] a pressure chamber 13 which is in communication with the common supply conduit 3 by way of [the] fuel admission passage 12.” (*Id.*, 2:35-40.) This pressure chamber 13 is connected to grooves 18 and orifices 18a within the needle through which fuel can flow to exit the injector. (*See id.*)

159. In my opinion, these spaces within Wirbeleit’s injector—including the chamber 13, grooves 18, and orifices 18a—are the claimed “interior chamber.” Further, fuel flows from the admission passage 12 to these spaces as required.

160. The spaces are highlighted below in orange:



(*Id.*, Fig. (annotated).)

1(a)-3] “a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;”

[1-b] “(b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;”

161. In my opinion, Wirbeleit also includes the claimed “*valve seat*” and “*valve member.*”

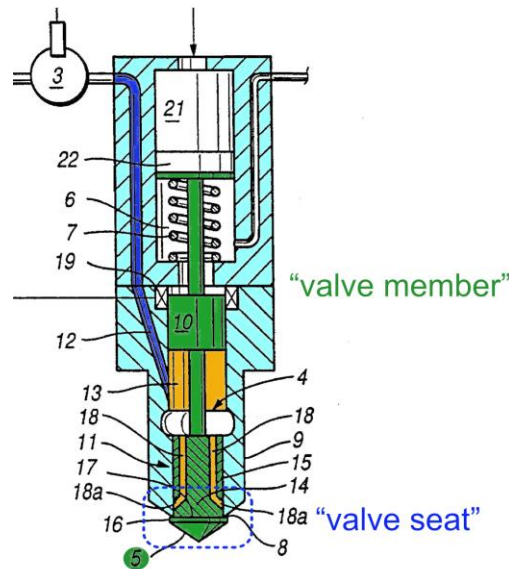
162. Wirbeleit’s injector includes “an injector orifice control needle 5” within its “injector body 9.” (Ex. 1004, 2:31-32; *see also* Abstract, 1:48-49.)

163. Wirbeleit’s needle 5 includes a “piston-like needle tip 11” with a “collar 16 which is disposed outside the injector body 9....” (*Id.*, 2:35-37, 40-45.) The “rear side 17” of the “collar 16” “forms the valve seating surface.” (*Id.*, 2:43-45.)

To close the injector, the rear side 17 of collar 16 is “forced onto the valve seat 8 on the injector body 9.” (*Id.*, 2:31-35; *see also* Abstract, 1:48-52.)

164. Because it includes an end (tip 11 with collar 16 and rear side 17) that incorporates with a valve seating surface to seal the injector, Wirbeleit includes the claimed “**valve member**” that “*cooperat[es] ... to seal*” with a “**valve seat**.”

165. Wirbeleit’s valve member is highlighted green below. The valve seat is circled:



(*Id.*, Fig. (annotated).)

166. Wirbeleit’s needle is also, in my opinion, “*extendable from said valve seat toward said combustion chamber,*” and can both “*fluidly seal[] against said valve seat*” to close Wirbeleit’s injector, and “*lift[] away from said valve seat*” to open the injector as claimed.

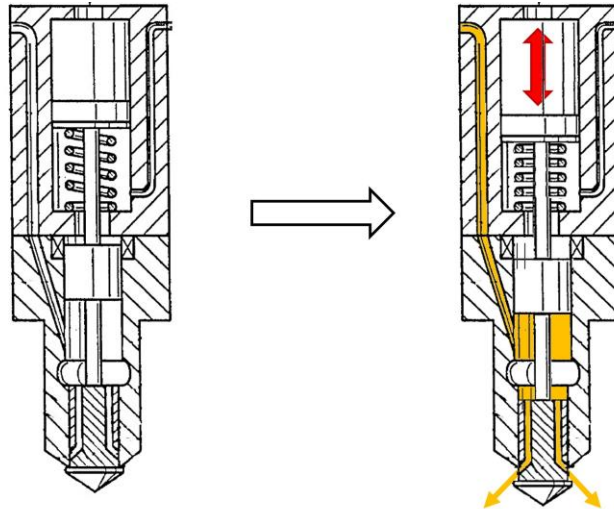
167. In this regard, Wirbeleit explains that its “control needle 5” is both “movable outwardly for opening the orifice” to facilitate fuel injection, and can be “forced onto the valve seat 8 on the injector body 9” to close the valve and stop injection. (Ex. 1004, 2:31-35.)

168. Similarly, according to Wirbeleit, its needle moves between a position where the needle’s “slot-shaped orifices” are “fully covered when the control needle is seated” to another position where the orifices are “exposed” (*Id.*, Abstract; 1:52-58 (likewise explaining that the needle’s “slot-shaped orifices ... are fully covered when the control needle is seated but which are exposed” by moving the needle); 3:5-11 (again explaining that the needle moves from one position where “[a]n appropriate injector slot orifice cross-section 18a ... is maintained” and a “rest position in which the needle tip 11 is seated on valve seat 8”).)

169. Movement of Wirbeleit’s needle between closed and open positions is shown in the below demonstrative prepared using Wirbeleit’s figure.

170. Closed position: In the figure on the left, Wirbeleit’s needle is forced against the valve seat at the end of the injector body closing the injector. This is the closed position.

171. Open position: In the figure on the right, Wirbeleit’s needle has moved out of the injector body and off the valve seat exposing the slot orifices and allowing fuel (shown in yellow) to be injected. This is the open position:



(See Ex. 1004; Fig.)

172. Further, as noted above, the “lift position” of Wirbeleit’s needle can both be controlled by an “electronic control unit” and measured using a “needle lift sensor.” (*Id.*, 2:4-10.)

[1(c)] “(c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;”

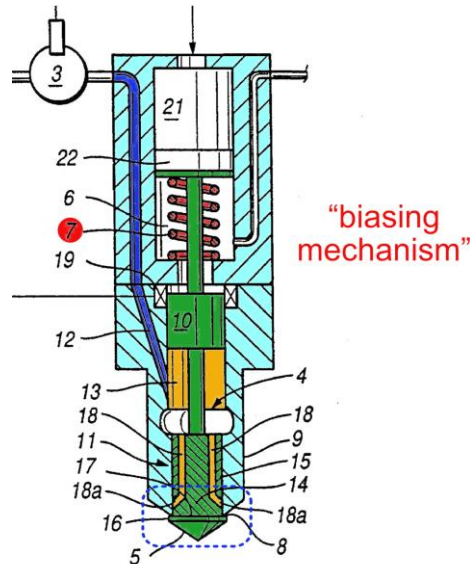
173. In my opinion, Wirbeleit includes the claimed “*biasing mechanism.*”

174. Wirbeleit explains that its injector includes a “return spring 7 disposed in [a] spring chamber 6.” (Ex. 1004, 2:35-36.)

175. According to Wirbeleit, this spring “force[s]” the “injector orifice control needle 5 ... onto the valve seat 8 on the injector body 9” to close the valve. (*Id.*, 2:31-36.) Similarly, Wirbeleit explains that its “injectors” have “fuel injection control needle engaged by springs so as to be normally seated on a valve seat.” (*Id.*, Abstract.) Likewise, “the orifice control needle is returned by the return spring 7 to

a rest position in which the needle tip 11 is seated on the valve seat 8.” (*Id.*, 3:7-11; see also 1:48-50.)

176. Wirbeleit’s spring 7 is shown in red below:



(*Id.*, Fig. (annotated).)

[1(d)] “(d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position; and”

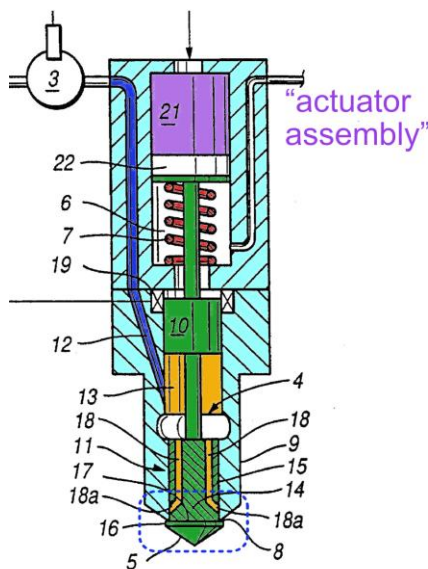
177. In my opinion, Wirbeleit’s injector includes the claimed ***“actuator assembly.”***

178. More particularly, Wirbeleit’s injector includes a “magnetostrictive actuator 21”—or alternatively a “piezo actuator”—that is located “[a]t the rear end of the orifice control needle 5 opposite its tip 11....” (Ex. 1004, 2:60-64.)

179. Additionally, the “[o]pening of the slot-injection orifices can be controlled by energizing [the] piezo actuator which acts on the injector needle ...

against a compression spring with a voltage-dependent force.” (*Id.*, 2:1-4; *see also* Abstract; 1:50-52.)

180. Wirbeleit’s actuator is highlighted in purple below:



(*Id.*, Fig. (annotated).)

[1(e)] “(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly”

181. In my opinion, the combination of Wirbeleit and Klügl teach everything this particular claim limitation requires.

182. As an initial matter, a POSITA would consider Wirbeleit’s injector to already employ a “hydraulic link assembly” “through which ... opening and closing forces are transmitted.”

183. Wirbeleit explains that its “magnetostrictive actuator 21 ... operates the orifice control needle 5 by way of a hydraulic transmission element 22....” (Ex. 1004, 2:60-64.).

184. Likewise, according to Wirbeleit either a “magnetostrictive actuator” or “a piezo actuator” can “act[] on the injector needle by way of a hydraulic transmission element against a compression spring....” (*Id.*, 2:1-3, 2:61.)

185. This hydraulic transmission element is the claimed hydraulic link.

186. According to Wirbeleit, during valve opening, force is exerted by the actuator and imparted through the hydraulic transmission element to the needle. In contrast, during valve closing, force is exerted from the spring, to the needle, and back through the hydraulic transmission element until a rest position is reached. (*See id.*; *see also* 3:5-11.)

187. Moreover, a POSITA would, in my opinion, understand this hydraulic link to be “*passive*” as required. There are two primary reasons for this.

188. First, Wirbeleit characterizes its “hydraulic transmission element” as a simple force pathway through which force from the actuator passes to the needle. (*Id.*, 2:1-3.) The hydraulic transmission element does not generate or amplify the force.

190. Wirbeleit's hydraulic transmission element highlighted below in pink:

191. Next, in my opinion, a POSITA would have considered the remainder of what this limitation requires obvious in view of the teachings of Klügl.

193. Like Wirbeleit's injector, Klügl's injector has an outer "housing 12" surrounding its various components. (*Id.*, 1:47-51.)

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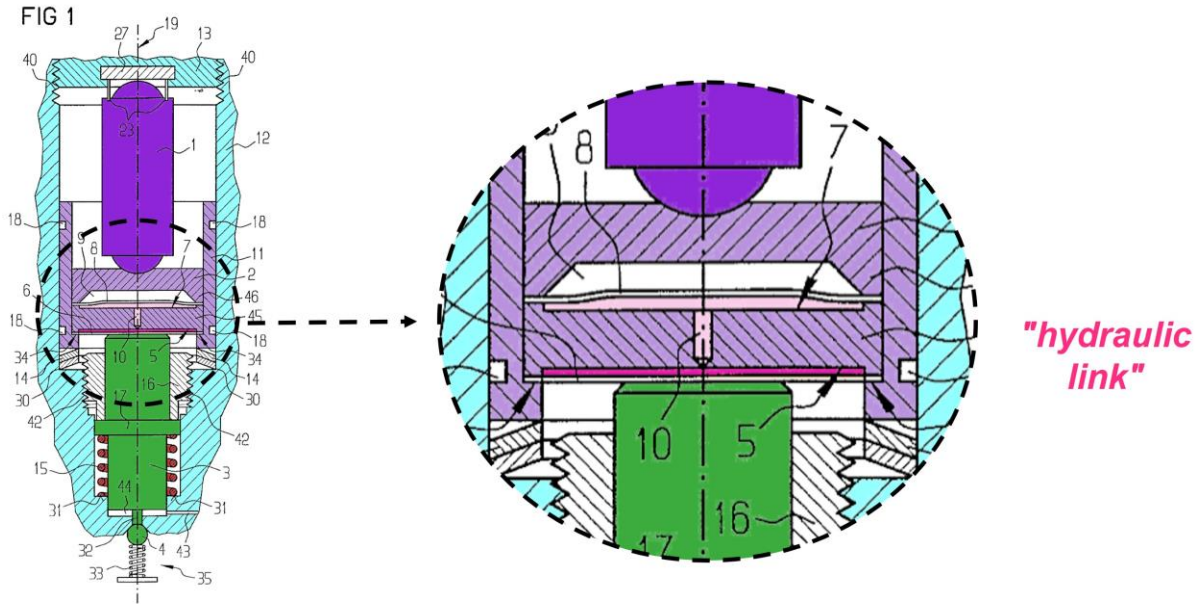
195. A “transmission module 2” is located between the actuator 1 and the “drive piston 3.” (*Id.*, 1:48-51; 2:23-41; Fig. 1.)

196. The drive piston 3 is attached to control needle 32 and in contact with ball 4, which Klügl also calls a “closing element 4.” The ball/closing element 4 forms a “servo valve” that “is used to control an injection needle.” (*Id.*, 2:50-57.)

197. A “spring 15” exerts an upward force on the drive piston 3 via the attached check ring 17 to close the valve. (*Id.*, 2:35-44.)

198. The transmission module 2 includes a “pressure chamber 5” filled with “transmission medium” such as “a hydraulic fluid, which has low compressibility.” (*Id.*, 1:60-2:4.) The transmission module also includes a “throttl[e]” (orifice) or “connecting bore 10” that connects the “pressure chamber 5 to a compensating chamber 7.” (*Id.*) The compensating chamber 7 is filled with the same transmission medium as the pressure chamber 5. (*Id.*) The transmission medium/hydraulic fluid is completely captured and contained within the transmission module. (*See id.*; Fig. 1.) As such, there is no external fluid source. (*See id.*)

199. These components are shown in the below annotated version of Fig. 1. The region of Fig. 1 showing chamber 5 has also been excerpted and expanded in size to the right for emphasis purposes:



(Id., Fig. 1 (annotated).)

200. The same coloring scheme used when comparing Wirbeleit to claim 1 has been employed. More particularly:

201. **Teal**: Housing 12 (Klügl's "valve housing").

202. **Dark and light purple**: The piezoelectric actuator 1 and transmission module 2 (Klügl's "actuator assembly").

203. **Green**: The drive piston, needle, and ball (Klügl's "valve member").

204. **Red**: The valve-closing spring (Klügl's "biasing mechanism").

205. **Dark pink**: The pressure chamber 5 (Klügl's "hydraulic link")

206. **Light pink**: Throttle 10 and compensation chamber 7.

207. During valve opening, when the "piezoelectric actuator 1 is ... controlled" (energized) by application of an appropriate signal, the actuator expands

causing “pressure” to be “exerted on the drive piston 3 via ... the transmission medium located in the pressure chamber 5...” (*Id.*, 3:23-29.)

208. In the embodiment shown in Klügl’s Figure 1, the movement of the actuator results in the same amount of movement of the piston without amplification. In other words, there is no change in the “stroke translation.” (*Id.*, Fig. 1; 1:41-42, 3:23-29.) As the fluid in chamber 5 is held in place by a membrane 6 and moves through a cylindrical space of constant width and unchanging shape, the thickness of the fluid in chamber 5 will remain constant throughout actuation. (*See id.*)

209. Showing this, Klügl itself explains that in opposition to its Figure 3, the injector of Figure 1 does not “achieve[] a stroke ratio between deflection of the piezoelectric actuator 1 and the deflection of the drive piston 3.” (*Id.*, 7:12-13.)

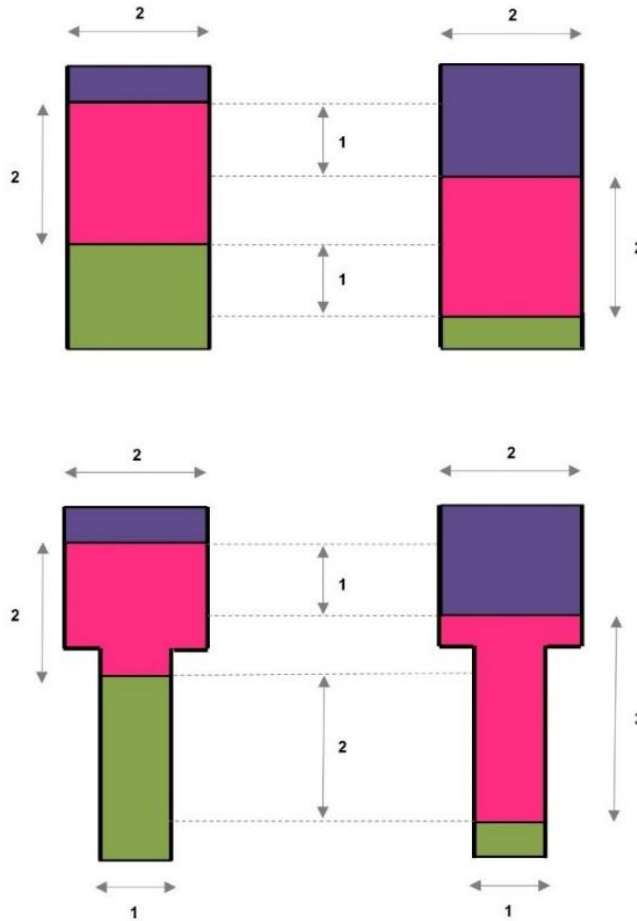
210. Klügl contrasts this with the embodiment shown in Figure 3, which does provide a change in “stroke translation” by applying a “stroke ratio” such that the movement of the piston exceeds that of the actuator. (*Id.*, 1:41-46; 7:12-13.) This occurs because the dimensions of chamber 5 change during actuation in that particular figure’s embodiment. (*See id.*, Fig. 3.)

211. Klügl also explains that in the embodiment shown in Fig. 1, the chamber 5 is filled with hydraulic fluid of “low compressibility.” (*Id.*, 2:1-2.) Additionally, while the transmission module includes a “throttle 10” that connects chamber 5 to chamber 7, this throttle is “dimensioned in relation to the transmission

medium such that during normal activation” “only an insignificant amount of transmission medium flows into the compensation chamber.” (*Id.*, 4:11-22.)

212. It follows that the hydraulic fluid in chamber 5 will not flow, will maintain substantially the same thickness, and will act substantially as a solid during actuation. The fluid is unable to leave chamber 5 during actuation (it cannot flow through throttle 10 and is held in place by a membrane 6). It is incompressible (so it will not change volume upon application of pressure). As a result, during the actuation, the distance between the actuator and piston remains constant (so as to ensure that there is a unity stroke ratio).

213. As a further clarification, I have prepared the below demonstrative. The figures on the top represent Klügl’s injector from Figure 1. The figures on the bottom represent Klügl’s injector from Figure 3. The actuator is shown in purple. The intermediate hydraulic fluid is shown in pink. The control piston (which pushes on the needle) is shown in green.



214. As shown in the top figures, when the actuator is expanded, the control piston moves by a distance equal to the amount of actuator expansion. Because the hydraulic fluid is incompressible and located in a cylindrical space, its thickness stays the same. Again, this is representative of Klügl's Figure 1 and is what the '138 patent's claims require.

215. But, when the actuator in the bottom set of figures expands, the hydraulic fluid is pushed from a cylinder of larger diameter into a cylinder of smaller diameter. While the volume of the fluid stays constant (as it is incompressible), its thickness changes (as it is now contained in a differently shaped space). This causes

the needle to be moved by a distance greater than the expansion of the actuator. Again, this is representative of Klügl's Figure 3 and is what Klügl means when it refers to a "stroke ratio" or "stroke translation." In the bottom figure here the actuator to control piston stroke ratio is 1:2.

216. In addition to teaching a passive hydraulic link that acts as a solid with constant thickness during actuation (i.e., the fluid in chamber 5 of Figure 1), Klügl also explains that "if there are long-lasting pressure differences between the pressure chamber 5 and the compensation chamber 7 ... the transmission medium is exchanged between the compensation chamber 7 and the pressure chamber 5 via the throttle 10." (*Id.*, 4:25-31.)

217. According to Klügl, this allows its injector to account for "thermal expansion differences and gradual wear" and ensures that the "drive piston 3" remains in contact with the transmission module. (*Id.*, 3:50-4:31.)

218. Again, Wirbeleit already employs a hydraulic transmission element 22 to transfer the movement of its actuator 21 to its needle 5 through piston 10. As I have explained, this element is passive in that it simply transfers force instead of generating it.

219. Wirbeleit explains that this element 22 "is not shown in detail." (Ex. 1004, 2:64.) As discussed above, however, Klügl discusses how such a hydraulic element should be structured and operate.

220. In Klügl, as in Wirbeleit, force from an actuator passes through the hydraulic fluid in chamber 5 to the piston 3 for purposes of opening a valve during actuation. As I have explained, in Figure 1, the fluid in the chamber 5 simply transmits the actuator force. It does not generate force or engage in amplification.

221. Further, Klügl explains that fluid does not flow into or out of chamber 5 during actuation. Thus, in my opinion this chamber and the fluid it contains, just like Wirbeleit's hydraulic transmission element 22, is the claimed *“passive hydraulic link”* that acts as a *“solid.”*

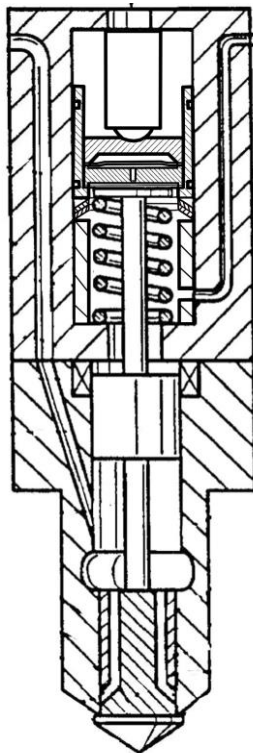
222. As I have noted, Klügl states that the fluid in chamber 5 has a low compressibility. And, as I have also explained, in the embodiment of Figure 1, no stroke amplification or change in translation distance occurs and chamber 5 does not change dimension during actuation. As a result, its *“thickness”* is *“substantially constant”*

223. Finally, Klügl explains that fluid can flow between chambers 5 and 7 through the throttle 10 during times of rest to account for thermal expansion or wear so as to ensure that the various components (such as the piston 3 and transmission module 2) remain in contact. Thus, in my opinion, its *“thickness ... is adjustable while said actuator is not activated in response to changes in the dimensional relationship between components.”*

224. Further, Wirbeleit's system is meant to facilitate control of the amount of "needle lift." (Ex. 1004, 2:1-12)

225. Because Klügl's transmission module 2 is designed to keep the injector's components in contact, a POSITA would have understood that when applied to Wirbeleit, Klügl's transmission module 2 would maintain the intended needle lift or position range despite wear and thermal expansion. Thus, my opinion, the references teach the maintenance of the claimed ***"desired valve lift upon activation."***

226. An example application of Klügl to Wirbeleit—with Wirbeleit's hydraulic transmission element 22 replaced with Klügl's transmission module—is shown in the demonstrative below:



b. Claim 2

227. Claim 2 depends on claim 1 and further requires:

“wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by differential thermal expansion.”

228. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

229. In my opinion, Klügl teaches the claimed *“auto-adjustable”* *“hydraulic link.”*

230. In particular, Klügl explains that when its actuator is “in the rest position,” “if there are long-lasting pressure differences between the pressure chamber 5 and the compensation chamber 7, ... transmission medium is exchanged between the compensation chamber 7 and the pressure chamber 5 via the throttle 10.” (Ex. 1006, 3:50-4:31.)

231. According to Klügl, this “automatic adjustment” accounts for the effects of “thermal expansion differences and gradual wear” of its components and ensures that the “drive piston 3” remains in contact with the “transmission module 2” even if temperature changes or wear cause size changes. (*Id.*, 3:52-62; 4:25-31.)

c. Claim 3

232. Claim 3 depends on claim 2 and further requires:

“wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by wear to components of said injection valve.”

233. As explained above, Wirbeleit and Klügl teach everything claim 2 requires.

234. In my opinion, Klügl teaches the additional limitation of claim 3 for the same reasons discussed in connection with claim 2: its transmission module 2 allows for fluid flow between chambers 5 and 7 during injector idle periods to account for not only thermal expansion, but also component wear.

d. Claim 6

235. Claim 6 depends on claim 1 and further requires:

“wherein said actuator assembly comprises a dimensionally responsive member.”

236. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

237. In my opinion, Wirbeleit teaches the additional limitation of claim 6.

238. In particular, Wirbeleit’s injector includes either a “magnetostrictive actuator 21” or “piezo actuator” that expands in length (i.e., is dimensionally responsive) to open or close the injector. (Ex. 1004, 2:60-64; *see also* 2:1-4, 13-17.)

e. Claim 13

239. Claim 13 depends on claim 6 and further requires:

“wherein said dimensionally responsive member is formed from a piezoelectric material.”

240. As explained above, Wirbeleit and Klügl teach everything claim 6 requires.

241. In my opinion, Wirbeleit teaches the additional limitation of claim 13: Wirbeleit includes a piezoelectric actuator 21. (Ex. 1004, 2:60-65; *see also* 2:1-4, 13-17.)

f. Claim 14

242. Claim 14 depends on claim 6 and further requires:

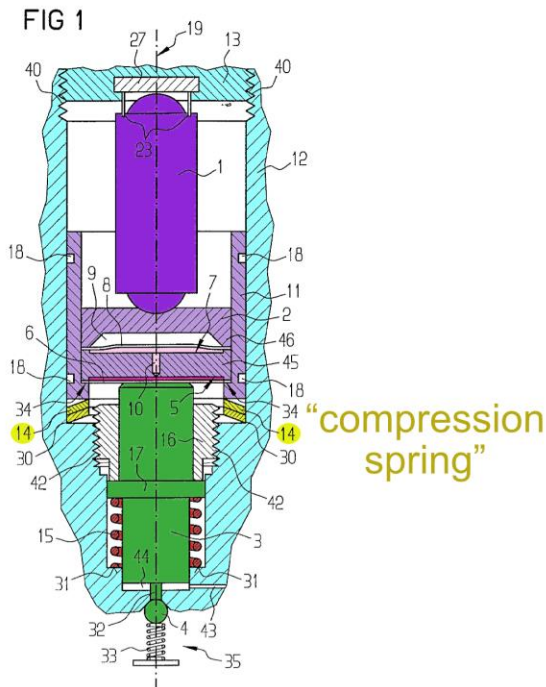
“a compression spring member for applying a compressive force to said dimensionally responsive member.”

243. As explained above, Wirbeleit and Klügl teach everything claim 6 requires.

244. In my opinion, the **“*compressing spring member*”** required by claim 14 is taught by Klügl.

245. In particular, Klügl’s injector includes a “disk spring 14” that allows the piezoelectric actuator 1 to be “pre-stress[ed] against” the valve housing 12 via the “transmission module 2.” (Ex. 1006, 2:11-21; 3:16-19.)

246. This disk spring 14 is highlighted in yellow below:



(*Id.*, Fig. 1 (annotated).)

247. In my opinion, a POSITA would have considered it obvious to use this disk spring 14 along with Klügl’s transmission module 2 as it will maintain contact between the transmission module 2 and the actuator 1, and improve the injector’s performance by pre-stressing the actuator.

g. Claim 17

248. Claim 17 depends on claim 6 and further requires:

“wherein when said actuator assembly is controllable to maintain said desired lift between 10 and 100 percent of maximum lift.”

249. As explained above, Wirbeleit and Klügl teach everything claim 6 requires.

250. In my opinion, Wirbeleit teaches the additional limitation of claim 17.

251. Wirbeleit explains that the “[o]pening of the slot-injection orifices can be controlled by energizing a piezo actuator which acts on the injector needle by way of a hydraulic transmission element...” (Ex. 1004, 2:1-3.)

252. The “desired injector orifice cross-section can be obtained by way of voltage control of the piezo actuator” which enables a variable and controllable “momentary lift position of the orifice needle.” (*Id.*, 2:4-12.) Similarly, Wirbeleit explains that “[a]n appropriate slot orifice cross-section” can be “maintained by way of voltage control of the actuator.” (*Id.*, 3:5-6.)

253. This means that in Wirbeleit, different, controllable amounts of needle lift are employed so as to allow “the injection orifice cross-section of the injector” to be “variable and ... controlled depending on the requirements” for “engine performance...” (*Id.*, 1:59-63; *see also* 3:13-14.)

254. Wirbeleit does not specifically reference adjustment of its valve needle lift by an amount “***between 10 and 100 percent of maximum lift.***”

255. Regardless, as I explain above, Wirbeleit does teach a valve needle that allows for a controllable amount of lift that is achieved by supplying the actuator with a specific voltage.

256. In my opinion, a POSITA would consider it highly obvious to control the lift of Wirbeleit’s needle across this claimed range. Wirbeleit already allows for 100% lift (the position providing fully open orifices). And, it also allows for variable

lift less than 100%, which a POSITA would have recognized obviously includes 10% lift (the position providing mostly closed injection orifices). Allowing for a particular range of needle lift control—such as 10% to 100%—would have been considered nothing more than a routine design choice that could be achieved by simply supplying the actuator with the correct signal needed to achieve a desired lift.

257. In my opinion, the fact that the '138 patent identifies no importance or significance to the use of a range of “10 to 100 percent of maximum lift” confirms that this range would have been considered obvious by a POSITA and amounts to be a routine, obvious design choice.

258. Rather than identifying anything important about the claimed range, the '138 patent notes that its actuator is meant to “provide for” a degree of “partial lifting.” (Ex. 1001, 8:19-21.)

259. This is exactly what Wirbeleit’s injector does: it allows for either full or partial needle lift, as desired.

h. Claim 18

260. Claim 18 depends on claim 17 and further requires:

“wherein said lift is controllable by varying at least one of the electric current, the electric voltage and the magnetic field imposed upon said dimensionally responsive member.”

261. As explained above, Wirbeleit and Klügl teach everything claim 17 requires.

262. The additional limitation of claim 18 is taught by Wirbeleit.

263. In particular, Wirbeleit explains that its needle “lift position” and the corresponding “[o]pening of the slot-injection orifices can be controlled by energizing a piezo actuator which acts on the injector needle ... with a voltage-dependent force.” (Ex. 1004, 2:1-4; *see also* 2:10-12; 3:1-7.)

i. Claim 19

264. Claim 19 depends on claim 6 and further requires:

“wherein said valve member is controllable such that said valve member moves between said open and closed positions in less than about 200 microseconds.”

265. As explained above, Wirbeleit and Klügl teach everything claim 6 requires.

266. In my opinion, the additional limitation of claim 19 is taught by Wirbeleit and Klügl.

267. Wirbeleit explains that its valve “injection time is adjustable depending on engine operating parameters.” (Ex. 1004, 3:15-16.)

268. Klügl provides an example of standard injection times known at the time the ’138 patent was filed.

269. In particular, according to Klügl the “actuation times” of an injection valve should be “in the range of milliseconds, preferably between 0 ms and 10 ms. Rapid actuation times are 0.1 to 1 ms” (or 100 to 1000 microseconds). (Ex. 1006, 4:22-24.)

j. Claim 20

270. Claim 20 depends on claim 6 and further requires:

“a biasing mechanism for applying a compressive force to said dimensionally responsive member.”

271. As explained above, Wirbeleit and Klügl teach everything claim 6 requires.

272. In my opinion, the additional limitation of claim 20 is taught by Klügl for the same reasons discussed for claim 14: Klügl includes a disk spring 14 that applies a pre-loading force to its piezoelectric actuator 1. (*See supra* Section IX.B.1.f.)

k. Claim 21

273. Claim 21 depends on claim 1 and further requires:

“wherein said biasing mechanism comprises a spring.”

274. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

275. In my opinion, the additional limitation of claim 21 is taught by Wirbeleit for the same reasons discussed for claim 1: Wirbeleit’s injector includes a return spring 7 that applies force to close the injector. (*See supra* Section IX.B.1.a.[1(c)].)

l. Claim 26

276. Claim 26 depends on claim 1 and further requires:

“wherein said fuel is injected into said combustion chamber at a pressure greater than about 2000 psi (about 13.8 Mpa).”

277. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

278. In my opinion, a POSITA would have considered the additional limitation of claim 26 obvious in view of Wirbeleit.

279. Wirbeleit states that its injection valve is meant for use with a “high pressure” fuel injection system. (Ex. 1004, 2:27-30.)

280. As of the ’138 patent’s filing, it was well known that “high pressure” fuel injection systems were able to inject fuel at pressures well in excess of 2000 psi.

281. For instance, it was known that injection pressure should vary with engine speed, from a “relatively low pressure ... of approximately 2000 psi” at lower/idle speed and load, to pressures as high as 15,000 psi at higher engine speeds/loads. (*E.g.*, Ex. 1012, 5:48-52, 7:1-14; *see also* Ex. 1013, 11:25-31 (referencing injection pressures up to 1550.9 bar, or approximately 22,000 psi).)

m. Claim 27

282. Claim 27 depends on claim 1 and further requires:

“wherein said valve housing comprises a plurality of parts which are joined with each other to provide a fluidly sealed body.”

283. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

284. In my opinion, both Wirbeleit and Klügl teach sealed valve housings with a *“plurality” of “joined” “parts.”*

285. As shown in Wirbeleit’s figure, Wirbeleit’s “injector body 9” includes an upper and lower piece that together form an interior, sealed “slot orifice 4” and “fuel admission passage.” (See Ex. 1004, 2:31-39; Fig.)

286. Klügl’s injector also has a multi-part structure. In particular, the injector includes an “upper stop 13 [that] is connected to the housing 12 via a screw thread 40.” (Ex. 1006, 1:57-60; Fig. 1.)

287. This was a very common fuel injector design when the ‘138 patent was filed. Fuel injectors routinely included housings formed from multiple parts. This renders the injectors less costly to manufacture and easier to assemble (forming the housing from one piece, in contrast, would make it very difficult to make and install the various required injector components within that housing).

n. Claim 41

288. Claim 41 is another independent claim. For reference, I have reproduced the entirety of this claim above. (See Section VII.C.)

289. Claim 41 is directed to a *“method of operating a fuel injection valve”* like that required by claim 1.

290. Due to the similarity between what claim 41 and claim 1 require, in my opinion, the combination of Wirbeleit and Klügl teach everything required by this method for the same reasons I have already explained for claim 1.

291. Though I have included some additional discussion regarding claim 41 below, a fuller explanation can be found above in the discussion of claim 1.

292. In my opinion, injector taught by the Wirbeleit and Klügl references ***“(a) actuate[es] a dimensionally responsive member”*** and ***“(c) deactuat[es] said dimensionally responsive member”*** to open and close an injector.

293. In this regard, Wirbeleit includes a piezoelectric actuator 21 that expands in length along the injector’s longitudinal axis when voltage is applied, and contracts in length when voltage is removed. (*See supra* Section IX.B.1.a.[1(d)].)

294. Further, Wirbeleit’s spring 7 facilitates valve closing during de-actuation. (*See supra* Section IX.B.1.a.[1(c)].)

295. Wirbeleit and Klügl’s injector also ***“(b) transfer[s] movement caused by said actuated dimensionally responsive member through a passive hydraulic link”*** to move a ***“valve member”*** and cause it to lift from a ***“valve seat.”***

296. Here, Wirbeleit teaches that the force exerted by its actuator is passed through a hydraulic transmission element 22 to a valve needle 3 causing it to unseat. (*See supra* Section IX.B.1.a.[1(e)].)

297. Further, as I have explained, when Klügl's teachings are applied, a POSITA would understand that this element would act as a solid and maintain its thickness during actuation. (*See id.*)

298. Klügl also, in my opinion, includes the claimed ***“hydraulic cylinder which houses a piston”*** (which the claim provides are part of the “passive hydraulic link”).

299. In particular, Klügl transmission module 2, which includes hydraulic fluid filled chamber 5 through which the actuating forces are passed, is designed to move up and down. (*See* Ex. 1006, 2:7-16; Fig. 1.) Thus, it corresponds to the claimed “piston.”

300. Further, this module is surrounded by a cylindrical “guide sleeve 11” located within the hollow interior of the injector's housing 12. The portion of the housing through which this sleeve moves is the claimed “hydraulic cylinder” that “houses” the “piston.”

301. Finally, in my opinion, the references teach ***“(d) providing sufficient time between consecutive valve openings to allow at least some of said hydraulic fluid within said passive hydraulic link to flow from one side of said piston to the other side of said piston.”***

302. In particular, Klügl teaches that its transmission module 2 includes a bore 10 (throttle/orifice), which allows the fluid from chamber 5 on one side of the

module to flow to chamber 7 on the other side of the module during injector idle periods. (*See supra* Section IX.B.1.a.[1(e)].)

2. Motivation to Combine

303. A POSITA would have considered it obvious and would have been motivated to combine the teachings of Wirbeleit and Klügl.

304. As I have explained, Wirbeleit employs a “hydraulic transmission element 22” that is, according to Wirbeleit, “not shown in detail.” (Ex. 1004, 2:60-64.)

305. Given that Wirbeleit requires the use but does not depict the specifics of its hydraulic transmission element, a POSITA would have been required to consult their own background knowledge and other available designs known in the art at the time the ’138 patent was filed when implementing Wirbeleit.

306. In my opinion, a POSITA would have considered Klügl to be an example of one such design for use with Wirbeleit.

307. In my opinion, a POSITA would have considered Klügl’s “transmission module 2” to be particularly suitable for use with Wirbeleit. As discussed in the following paragraphs, there are several reasons for this.

308. As an initial matter, Wirbeleit and Klügl are structurally and functionally similar.

309. Klügl’s “transmission module 2” is like Wirbeleit’s “hydraulic transmission element 22” in that it is hydraulic-based and can passively transfer force from an actuator to a fuel injector control piston or needle for purposes of opening a valve. (*E.g.*, Ex. 1006, 1:60-2:10, 3:23-29.)

310. Further, both Wirbeleit and Klügl employ a piezoelectric (or alternatively magnetostrictive) actuator that applies force to a control piston through a hydraulic element so as to open a valve.

311. Both Wirbeleit and Klügl also employ a spring that applies force to the needle for purposes of closing the valve.

312. In my opinion, these structural and functional similarities would have provided a POSITA with a strong motivation to use Klügl’s transmission module 2 when implementing Wirbeleit’s hydraulic transmission element 22.

313. A POSITA would also, in my opinion, have been motivated to use Klügl’s “transmission module 2” with Wirbeleit because doing so would be understood to provide other important benefits that would improve Wirbeleit’s operation.

314. Primary among these is the ability to account for the effects of differential thermal expansion and wear.

315. As I have explained, Klügl’s “transmission module 2” uses an incompressible hydraulic fluid that does not flow out of a chamber 5 during actuation but can move between a chamber 5 and chamber 7 during periods of rest.

316. This, according to Klügl, not only allows for transmission of force without application of a non-unity stroke ratio (i.e., the needle still moves by the same distance the actuator expands) but also allows for “automatic adjustment” of the injector to account for the effects of “wear,” “aging,” and “thermal expansion.” (Ex. 1006, 3:50-4:31.)

317. In my opinion, when the ’138 patent was filed, a POSITA would have recognized that one “known” “aim” when designing an injection valve should be to “compensat[e]” for the “effects of temperature changes, wear and manufacturing tolerances” on the valve’s “actuating displacement.” (*E.g.*, Ex. 1009, 1:9-16.)

318. This same design goal is expressed repeatedly in the prior art. (*See, e.g.*, Ex. 1010, 1:41-52 (explaining that an injector “valve needle and its valving element” must “always perform the same opening stroke” regardless of “temperature fluctuations,” “wear,” or “manufacturing tolerances”).).

319. In my opinion, a POSITA would have known that Wirbeleit is no different and is subject to the same issues as other known fuel injectors. Thus, the same design considerations discussed above apply equally to Wirbeleit.

320. In particular, a POSITA would have understood that temperature changes, wear, or manufacturing issues could cause Wirbeleit's injector components—like the components of any injector—to also become misaligned, inefficient, or even non-functional.

321. Indeed, because Wirbeleit's injector is intended to allow for precise control over the amount of travel of its needle, a POSITA would have considered it particularly important that its injector components remain in proper alignment. Otherwise, application of control signals to Wirbeleit's actuator could result in the incorrect amount of needle movement. Similarly, Wirbeleit's needle lift sensor 19 is designed to sense the position of the control piston 10. If this control piston does not move by the same distance as the actuator, Wirbeleit's control system would not allow for the same, straightforward operation it currently does.

322. In my opinion, a POSITA would have understood that use of Klügl's "transmission module 2" would address this problem.

323. In particular, using Klügl's transmission module 2 (in particular that shown in Figure 1), force would still be transmitted between Wirbeleit's actuator and its needle.

324. But, during periods of rest when the injector is idle, hydraulic fluid could flow between chambers 5 and 7 to account for any dimensional changes resulting from thermal expansion and wear.

325. A POSITA would have recognized that this would substantially improve Wirbeleit by rendering it more able to account for and automatically adapt to the types of conditions routinely encountered by a fuel injector. It would also ensure that Wirbeleit's injector continues to deliver the range of needle movement intended when different signals are applied to its actuator.

326. A POSITA would have recognized that there are further benefits that would have derived from application of Klügl's transmission module 2 to Wirbeleit. These would, in my opinion, have also motivated combination.

327. For instance, Klügl explains that its device, which of course includes its transmission module 2, is "particularly compact and easy-to-assemble." (Ex. 1006, 1:20-22.) Similarly, the device is structured such that its components can be "pre-assembled." (*Id.*, 1:26-38.)

328. In my opinion, a POSITA would have recognized that this would further improve Wirbeleit's injector.

329. Using use Klügl's "transmission module 2," Wirbeleit's injector would be more compact, leading to an overall smaller injector allowing it to be more readily integrated into an engine.

330. For instance, it would no longer be necessary to reserve a large space between the actuator and control piston to house a substantial amount of hydraulic fluid as depicted in Wirbeleit's figure. Nor would it be necessary include separate

seals, gaskets, or the other types of structure to keep this element's hydraulic fluid in place and prevent it from escaping or leaking out of its designated space. Instead, only a small amount of hydraulic fluid would need to be housed in transmission module 2, which is itself already structured to keep fluid in place.

331. Relatedly, a smaller sized element 22 would also be understood by a POSITA to be beneficial in that it would allow for further design flexibility elsewhere in the injector. For example, differently sized or shaped interior chambers, fuel supply pathways, or nozzles that may not have been available previously due, for instance, to the length of the injector caused by the amount of hydraulic fluid used by Wirbeleit, would now be able to be more readily accommodated.

332. In the same fashion, a POSITA would have recognized that the injector's performance would be improved by keeping the volume of fluid in element 22 small so as to ensure that the fluid has low compressibility and effectively eliminate the possibility of delays of motion transmission from the actuator to control piston.

333. Further, a POSITA would have recognized that use of Klügl's separate, preassembled, "particularly simple [to] manufacture" transmission module 2 in place of Wirbeleit's built-in "hydraulic transmission element 22" would have simplified the overall process of manufacturing Wirbeleit's injector. (*Id.*, 1:26-34.)

334. Manufacturing Wirbeleit's injector would require a step during injector assembly in which a substantial amount of hydraulic fluid must be supplied to the interior of its injector as no provision has been made to fill 22 through operation, such as through fuel or hydraulic ports or leak paths. This necessitates the presence of equipment capable of supplying this liquid without contaminating it in some way that will impede its operation. This step would be eliminated using Klügl's transmission module 2: the transmission module 2 (including the hydraulic fluid it contains) can be assembled separate from the injector. The transmission module 2 then simply needs to be inserted into the injector housing during injector assembly.

335. A POSITA would also have understood that Klügl's "transmission module 2" allows for the use of other injector components that would further improve Wirbeleit's operation.

336. For example, Klügl's injector includes an "upper stop 13" and a "lower stop 16" that are both attached via "screw" connections and can be used to set the compression of the piezoelectric actuator, disk spring 14, and spring 15. (Ex. 1006, 1:57-60; 2:35-39.)

337. Klügl explains that this allows "the piezoelectric actuator 1," transmission module 2," and "drive piston 3" to be "pre-adjusted" "[d]uring ... production of the injection valve." (*Id.*, 3:1-10.)

338. In my opinion, this would have further motivated application of Klügl to Wirbeleit. Using similar adjustment mechanisms (which are again allowed by Klügl’s injector design, including its use of transmission module 2) would allow Wirbeleit’s injector be adjusted at the time of manufacture to account for slight variations of component size, or to refine the load on the injector’s components. A POSITA would have understood that this would have had the potential to improve (or at the very least refine) the operation of the injector.

339. In my opinion, a POSITA would also have been motivated to retain Wirbeleit’s directly actuated and controllable valve design when applying the teachings of Klügl.

340. As I have summarized above, Wirbeleit identifies its injector’s ability to control the orifice openings an important feature as it allows for the injection amount to be controlled “depending on engine operating parameters.” (Ex. 1004, 1:52-58, 2:1-12.)

341. In my opinion, a POSITA would have similarly recognized this to be a highly beneficial feature.

342. For instance, it was known that controlling injection in this manner allows the “opening stroke of the valve member and the injection time” to be adjusted based on the engine’s current operating conditions to “optimize[]” fuel “consumption” and minimize “emission.” (*E.g.*, Ex. 1015 at 3; *see also id.* at 1

(explaining that adjusting needle valve lift allows for “low fuel consumption and emissions ... over [a] wide range[]” of engine operating conditions).)

343. Engaging in the type of control taught by Wirbeleit also allows injector performance to be tailored to ensure “smooth running of the internal combustion engine.” (*Id.* at 3.)

344. Further, the control provided by Wirbeleit allows for valve adjustment “dynamically” during operation allowing for even further refinement of engine performance. (*Id.*)

345. In my opinion, these benefits would have not only provided a POSITA with a strong motivation to use Wirbeleit in the first place, but would also have led a POSITA to maintain the ability to control valve lift even if making other changes, including the application of Klügl’s transmission module as discussed above, to Wirbeleit’s injector. In order to accomplish this, a POSITA would have maintained Wirbeleit’s direct acting configuration when including Klügl’s transmission module.

346. Next, in my opinion, a POSITA would have considered the use of Klügl’s “transmission module 2” with Wirbeleit to be nothing more than a routine design choice.

347. As I have explained, Wirbeleit teaches a fuel injector with controllable valve lift that allows the injection amount to be tailored to engine operation. Further, it already includes a passive hydraulic force transmission element.

348. Klügl teaches a hydraulic transmission element like that employed by Wirbeleit. Further, it explains that this element is designed to automatically adjust to account for the effects of thermal expansion and wear.

349. A POSITA would have understood that combining these two references' teachings results in an injector that continues to exhibit these very same benefits: the combined injector would still allow for controllable lift as taught by Wirbeleit, would still transmit force through a hydraulic element as taught by both references, and would now be able to account for thermal expansion and wear as taught by Klügl.

350. In my opinion, a POSITA would also have had a reasonable expectation of success when combining Wirbeleit and Klügl.

351. As I explain above, a POSITA would have recognized that both Wirbeleit and Klügl are directed to injector valves. Indeed, both references teach injector valves that are structurally and functionally similar: both transmit the force of an actuator through a hydraulic element to a control piston for purposes of opening a valve. And, both employ a spring to exert a valve closing force.

352. In my opinion, this similarity would have led a POSITA to conclude that Klügl's "transmission module 2" and the other injector components associated with this module could be readily incorporated into Wirbeleit.

353. I note that Klügl does provide an example where a piezoelectric actuator is employed to open a “servo” or pilot valve (which in turn opens the injector’s nozzle valve).

354. In my opinion, a POSITA would not have considered Klügl to be only applicable to this type of injector.

355. Instead, a POSITA would have understood that Klügl’s “transmission module 2” could also be readily and successfully used in other types of injectors.

356. This, in my opinion, includes injectors like Wirbeleit’s, where the actuator directly controls a needle valve that opens the flow path into an engine’s combustion chamber.

357. Showing this, Klügl itself explains that use of its transmission module in connection with a servo valve is intended to be just an “example.” (Ex. 1006, 1:7-12.)

358. It then goes on to explain that its teachings—including its use of transmission module 2 to account for thermal expansion and wear—can be more broadly applied to the transmission of “movement of a piezoelectric actuator in an injection valve to” any “control element.” (*Id.*)

C. Ground 2: Claim 28 is Obvious Over Wirbeleit, Klügl, and Newcomb

359. In my opinion, a POSITA would have considered Wirbeleit, Klügl, and Newcomb to be within the scope of the prior art and highly relevant to the patentability of the '138 patent's claims.

360. In my opinion, when viewed and considered in light of the knowledge possessed by a POSITA, Wirbeleit, Klügl, and Newcomb together disclose all the limitations of and render claim 28 of the '138 patent obvious.

361. Claim 28 depends on claim 1 and further requires:

“wherein said valve housing, said valve member and said actuator assembly are selected from materials having thermal expansion coefficients sufficiently compatible such that changes in the dimensional relationship between said components caused by changes in temperature are reduced.”

362. As explained above, Wirbeleit and Klügl teach everything claim 1 requires.

363. In my opinion, a POSITA would have considered the additional limitation of claim 28 to be obvious in view of the teachings of Newcomb (Ex. 1014).

364. Newcomb, like Wirbeleit and Klügl, relates to a “control valve such as a ... fuel injection valve...” (*Id.*, 1:5-7.)

365. Newcomb explains that when such a valve employs a “piezoelectric element” as an actuator, “the potential stroke of the valve is usually small, for example, of the order to 10 or 20 micrometers.” (*Id.*, 1:31-34.)

366. Newcomb then explains that “[i]t is therefore essential to minimize the effects of thermal expansion on the valve parts so that flow through the valve will vary only slightly with changes of ambient temperature.” (*Id.*, 1:34-38.)

367. “One solution to [this] problem is to choose a material” (like “a nickel-iron alloy”) “for the valve housing” that “has a similar thermal expansion coefficient to that of the piezoelectric element.” (*Id.*, 1:38-41.)

368. Newcomb explains that as an alternative, different materials can be used so long as those materials have “coefficient[s] of thermal expansion” and dimensions that result in “equal” “linear expansion.” (*Id.*, 1:50-59.)

369. Newcomb provides an example of this where a “valve body 21” and valve opening “lower end piece 2a” are made from “steel having a thermal expansion coefficient of $12 \mu\text{m K}^{-1}$,” while the piezoelectric “actuating member 2” is formed from a ceramic that “has a thermal expansion coefficient of $4 \mu\text{m K}^{-1}$.” Above the piezoelectric actuator is located a “spacer 22b” “made from aluminum having a thermal expansion coefficient of $23 \mu\text{m K}^{-1}$.” (*Id.*, 3:39-47.)

370. Newcomb explains that the “length” of the spacer may be chosen in such a way that the piezo actuator and spacer together “maintain[e]” “a substantially fixed position with respect to the” “valve housing 21 even though changes in the temperature of the valve may take place.” (*Id.*, 3:52-68.)

371. In my opinion, applying this to the injector of Wirbeleit and Klügl results in what the claim requires: the injector's housing, valve member, and actuator would have been made from materials with sufficiently similar thermal expansion coefficients or compatibly selected materials in such a way as to reduce the overall influence of thermal expansion. As a result, using either approach, any change in relative dimension would be minimized.

372. A POSITA would have been motivated to combine these references' teachings.

373. For instance, Klügl itself already recognizes that injector valves should be designed to account for the effects of thermal expansion. (Ex. 1006, 3:52-55, 4:25-31, 6:29-33.)

374. Newcomb confirms this, explaining that it is "essential" that a fuel injector be designed to "minimize the effect[s] of thermal expansion." (Ex. 1014, 1:34-38.)

375. Use of Newcomb's first thermal coefficient selection teachings would serve to further this known design goal: use of materials with matching thermal expansion coefficients would minimize (or at least reduce) the effects of thermal expansion.

376. I also understand that Patent Owner itself has stated that "[i]n order to minimize dimensional variations from changes in temperature expected in internal

combustion engine applications, a reasonable engineer would select materials with similar thermal expansion coefficients for use in an injection valve.” (*E.g.*, Ex. 1022, p. 20).) A POSITA as of the ’138 patent’s filing would have engaged in this same material selection process.

377. Moreover, Newcomb explains that its valve design approach “enable[s] the effects of thermal expansion to be reduced without the use of comparatively costly ... materials.” (Ex. 1014, 1:45-49.)

378. In my opinion, this potential for cost reduction through the use of less expensive materials would have served to further motivate a POSITA to apply Newcomb’s teachings.

379. A POSITA would also have had a reasonable expectation of success.

380. Showing this, Newcomb itself explains that its material usage teachings are specifically intended for use with a “control valve such as a ... fuel injection valve.” (Ex. 1014, 1:5-7.) As I have explained, both Wirbeleit and Klügl teach fuel injection valves.

D. Ground 3: Claims 1-3, 6, 13-14, 17-21, 26-27, and 41 Are Obvious Over Klügl and Hayes

381. In my opinion, a POSITA would have considered Klügl and Hayes to be within the scope of the prior art and highly relevant to the patentability of the ’138 patent’s claims.

382. In my opinion, moreover, when viewed and considered in light of the knowledge possessed by a POSITA as shown by Hayes, Klügl itself discloses all the limitations of and render claims 1-3, 6, 13-14, 17-21, 26-27, and 41 of the '138 patent obvious when Patent Owner's understanding of the claims is applied.

1. Claim-by-Claim Analysis

a. Claim 1

[1-p] “An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:”

383. To the extent the preamble is limiting, it is taught by Klügl.

384. In particular, Klügl. teaches an “automotive” “injection valve.” (Ex. 1006, 1:7-12.)

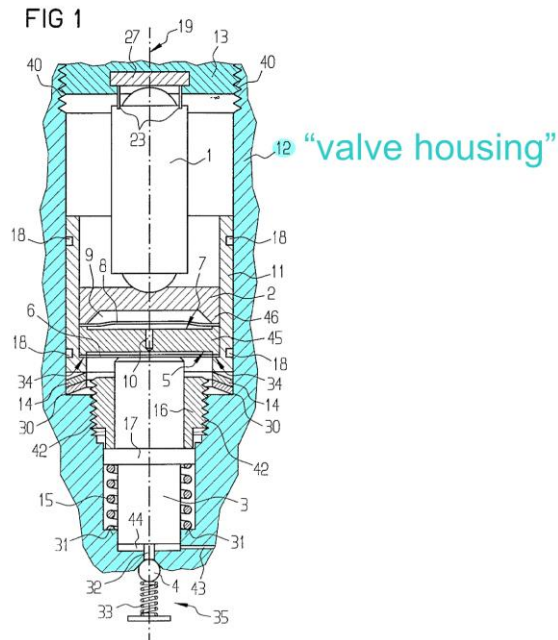
385. Further, Klügl explains that this valve controls injection into an “internal combustion engine.” (*Id.*, 2:54-57.) In my opinion, a POSITA would understand this to be a direct injection valve for injecting fuel into the combustion chamber.

[1(a)] “(a) a valve housing comprising:”

386. In my opinion, Klügl's injector includes the claimed “*valve housing.*”

387. In particular, Klügl's injector includes an “upper stop 13” and an outer “housing 12” that surrounds the valve components. (*Id.*, 1:47-51.)

388. This housing is shown below in teal:



(*Id.*, Fig. 1 (annotated).)

[1(a)-1] “a fuel inlet port;”

389. In my opinion, Klügl obviously includes the claimed “*fuel inlet port.*”

390. Klügl explains that a “servo valve” formed by “ball 4” (also referred to as a “closing member 4”) “control[s] an injection needle, which controls the injection of an internal combustion engine.” (Ex. 1006, 2:54-57.)

391. This “ball” is lifted from or lowered onto the “valve seat 35” by the “control needle 32” to “begin[.]” or “end[.]” “injection.” (*Id.*, 3:23-38, 39-49.)

392. The opening of the ball servo valve allows the opening of an injector nozzle needle—not shown in Klügl’s figure—as a “pressure chamber” that normally applies “high pressure to the injection needle” to be vented through the “relief line 43” to start fuel injection. (*Id.*, 3:33-38.)

393. Conversely, closing the servo valve allows “high pressure” to be “again applied” to the nozzle needle to close it and stop injection. (*Id.*, 3:39-49.)

394. In sum, in Klügl, the “injection needle” is moved to open/close a pathway to the combustion chamber.

395. While Klügl’s figures do not show the structure around its “injection needle,” in my opinion a POSITA would have understood that there would be a passage, conduit, line or other similar structure to supply fuel to the space adjacent to the “injection needle” such that fuel can be injected when the needle opens.

396. The purpose of the injection needle is to allow high pressure fuel to be sprayed into the combustion chamber when open, and stop the fuel spray when closed. To perform this function, high pressure fuel must be supplied to and stored behind the injection needle.

397. Other prior art shows how a POSITA would understand Klügl to be structured and operated. In my opinion, Hayes (Ex. 1024) provides an example.

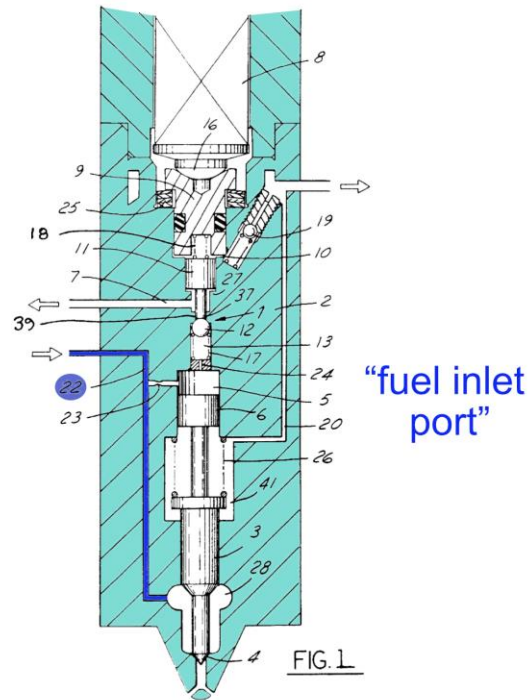
398. Hayes relates to an indirectly actuated fuel injector. (*Id.*, 1:7-14.) In other words, an injector where the nozzle needle valve is indirectly controlled by a pilot valve.

399. Hayes’s injector includes an intermediate “control valve 1” sealed by a ball-shaped “component 12.” (*Id.*, 2:7-15, 30-36.) This is analogous to the servo valve sealed by ball 4 in Klügl.

400. Actuating Hayes's injector opens the control valve. (*Id.*, 3:24-45.) This in turn lowers the pressure in a "chamber 5," which causes a separate "valve needle 3" to lift and open a passage into combustion chamber. (*Id.*, 3:53-63.) Fuel supplied by a "feeding line 22, which feeds the fuel at high pressure" is then injected through the passage opened by the needle. (*Id.*, 2:45-48, 3:53-63.)

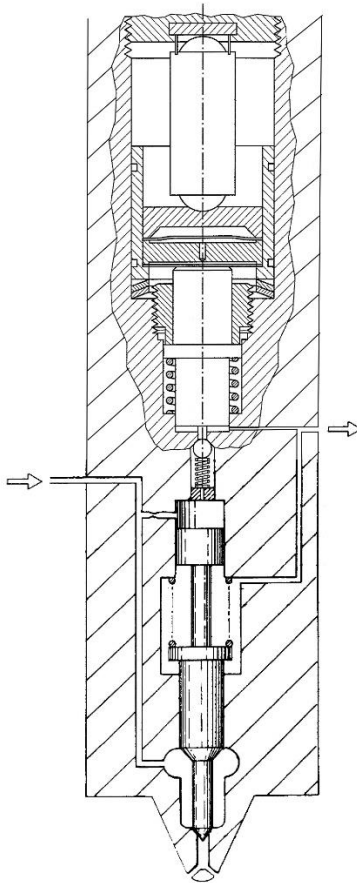
401. This operation is also analogous to that in Klügl. Activating Klügl's injector opens the servo valve formed by ball 4, lowers the pressure in a "pressure chamber," and causes an "injection needle" to unseat so fuel can be injected.

402. Given the structural and functional similarity between Klügl and Hayes, in my opinion a POSITA would have understood that Klügl would include a "feeding line" like that in Hayes to supply high pressure fuel to the area behind its injection needle. This line is the claimed "***fuel inlet port***" and is shown in blue below:



(Fig. 1 (annotated).)

403. As a further clarification, the below demonstrative summarizes how, in my opinion, a POSITA would understand the portion of the injector below Klügl's servo valve and in the area of its injection needle to be structured. To create this demonstrative, I have applied the relevant portions of the injector shown in Fig. 1 of Hayes to Fig. 1 of Klügl. As explained, a lower injection needle—controlled by the intermediate servo valve—opens/closes a passage into the combustion chamber to allow fuel supplied by the inlet to be injected:



(See Ex. 1006, Fig. 1; Ex. 1024, Fig. 1.)

[1(a)-2] “an interior chamber fluidly connected to said fuel inlet port; and”

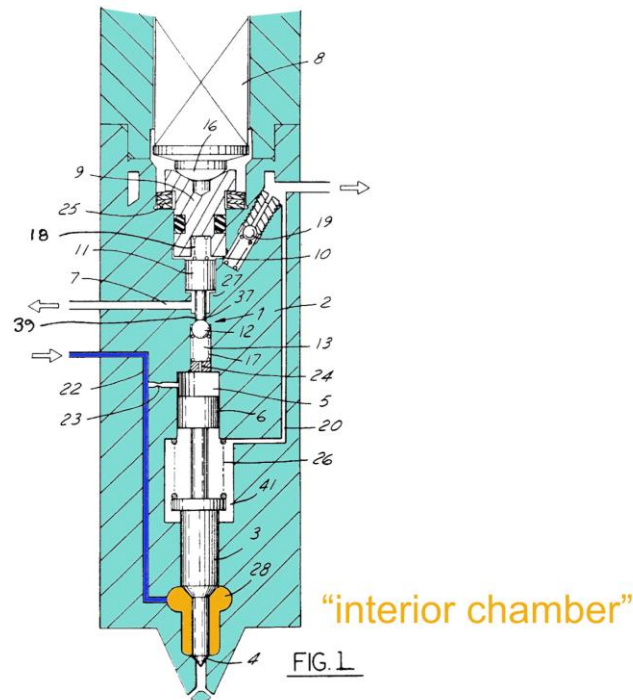
404. In my opinion, Klügl would obviously include the claimed “*interior chamber.*”

405. Again, as I have just explained, Klügl includes an “injection needle” that opens to the combustion chamber. (Ex. 1006, 3:33-38.)

406. As I have also explained, Hayes provides an example of how a POSITA would have understood the portion of Klügl’s injector around this needle to be structured.

407. In Hayes, fuel feed line 22 terminates in an “injection valve pressure chamber 28” located within the injector interior. (Ex. 1024, 2:45-47.)

408. This chamber 28 is shown in orange below. It corresponds to the claimed “*interior chamber*”:



(*Id.*, Fig. 1 (annotated).)

409. In my opinion, a POSITA would have understood that Klügl would include a similar interior space adjacent to its injection needle: this would ensure that an adequate distribution of fuel is present behind the needle to provide uniform injection into the combustion chamber when the needle opens.

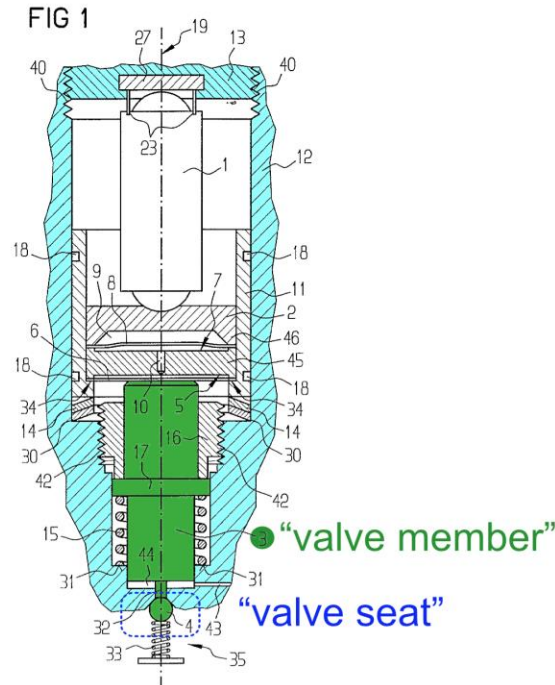
[1(a)-3] “a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;”

[1-b] “(b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;”

410. In my opinion, Klügl includes the claimed “*valve seat*” and “*valve member*” when Patent Owner’s understanding of the claim (with reference to an indirectly controlled injection valve) is applied. (See Section VIII above).

411. In particular, Klügl’s injector includes a “drive piston 3” that “merges into a control needle 32” at its lower end. (Ex. 1006, 2:50-53.) The “control needle 32 ... extends ... to a valve seat 35...” (*Id.*) There is a “ball 4,” which Klügl also calls a “closing element 4,” attached to this control needle that acts as a “closing element” when “pressed against the valve seat.” (*Id.*, 2:54-57.)

412. In my opinion, the piston 3, control needle 32, and ball 4 together form Klügl’s “*valve member.*” Klügl’s valve seat 35 is the claimed “*valve seat.*” The components making up the valve member area all highlighted in green below. The valve seat is circled:



(*Id.*, Fig. 1 (annotated).)

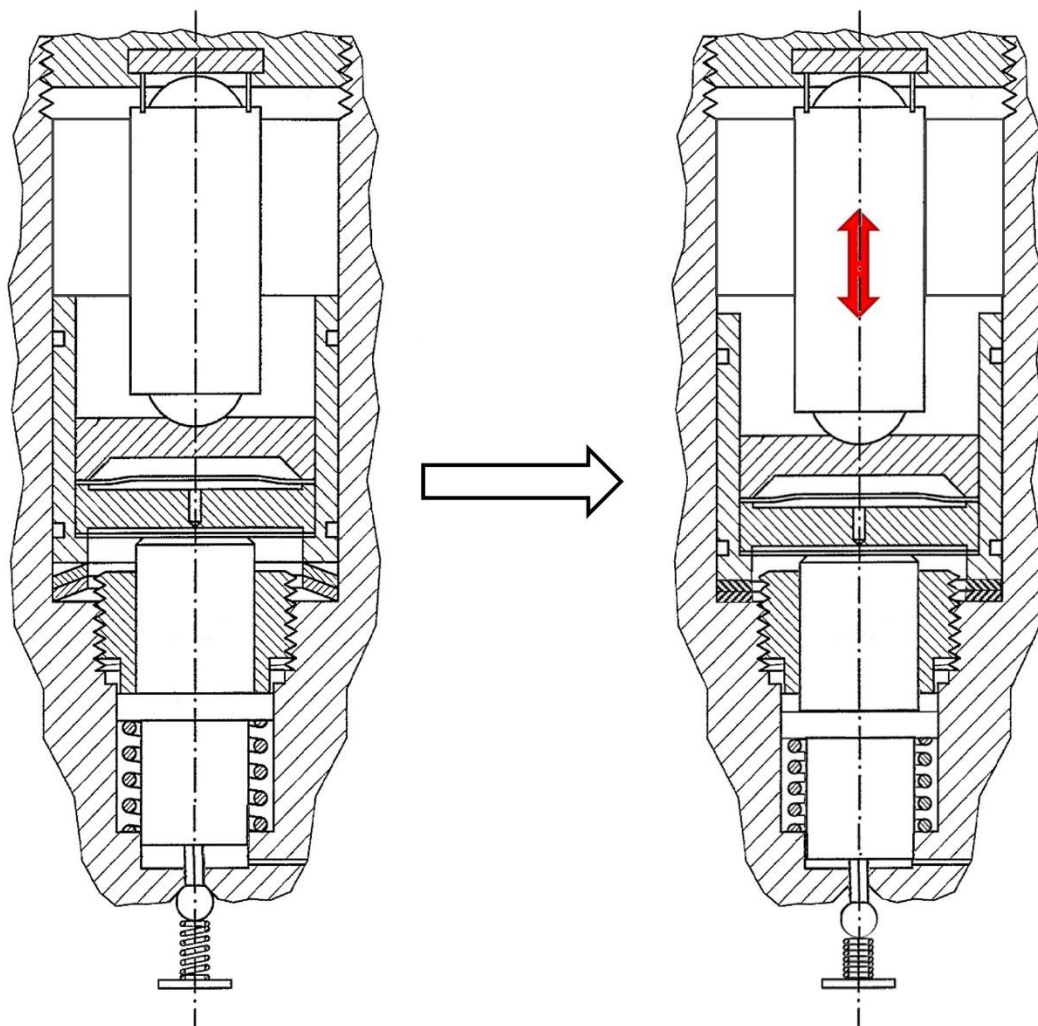
413. In my opinion, Klügl’s valve member is “*extendable from said valve seat toward said combustion chamber*” such that it “*lift[s] away from said valve seat*” to open the injector. It also “*cooperat[es] with*” the valve seat “*to seal said interior chamber from said combustion chamber*” to close the injector as this claim limitation requires.

414. To open the injector, Klügl’s actuator expands causing “[t]he drive piston 3” to be pressed downward or displaced towards the combustion chamber. This in turn causes the “closing element 4” that is attached to the piston to be “lifted off the valve seat 35 by the control needle 32.” (*Id.*, 3:23-33.)

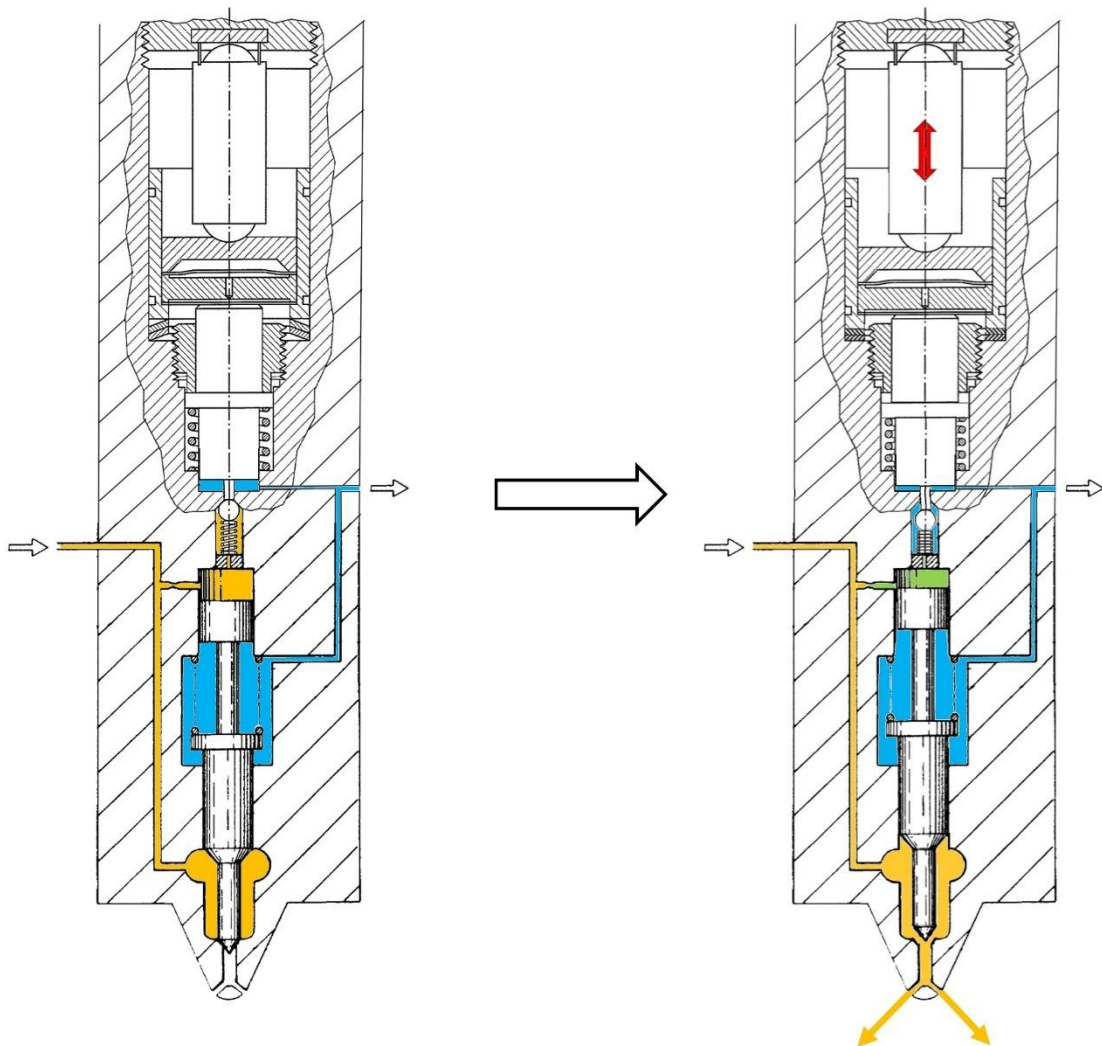
415. This lifting of element 4 off its seat causes “the pressure in the pressure chamber [to] drop[]” and “the injection needle” to “lift” so that injection to the combustion chamber can begin. (*Id.*, 3:33-38.) This is the open or lifted position (at least under Patent Owner’s understanding of this claim term): the valve member has moved so as to cause the fluid connection from the fuel supply to the combustion chamber via the injection needle.

416. To close the valve, the actuator is deenergized causing it to shrink. This in turn causes the spring to exert pressure on the piston so that “closing element 4” is “pushed ... back onto the assigned valve seat 35[.]” The pressure in the “pressure chamber” returns to a high level lowering the “valve needle” and ending injection. (*Id.*, 3:39-49.) This is the closed or sealed position (at least under Patent Owner’s understanding of this claim term): the valve member has again moved so as to cause the injection needle to seal the passage from the fuel supply to the combustion chamber.

417. These positions are shown in the below demonstrative prepared using Figure 1 of Klügl. The closed/sealed position is shown to the left, while the open position is shown to the right. The piston size has been slightly modified in the figures to allow for an exaggerated depiction of movement while ensuring that the relief line is maintained, *i.e.*, the piston wouldn’t block the relief line in operation.



418. In the combined injector of Hayes and Klügl, the figures below show the impact the opening/closing of Klügl's servo valve has on its injection needle (and how this results in fuel injection). Yellow represents areas of high pressure where high-pressure fuel is present. Blue represents areas of low pressure connected to the relief line. Green represents areas of intermediate pressure:



419. As noted above, movement of Klügl's piston 3, control needle 32, and ball/closing element 4 does not directly open a passage to the combustion chamber—only Klügl's injection needle does this.

420. Regardless, movement of Klügl's piston 3, control needle 32, and ball/closing element 4 indirectly opens this passage by lowering the pressure in Klügl's pressure chamber causing Klügl's injection needle to unseat so that fuel can be injected into the combustion chamber.

421. Again, as I have explained, in my opinion this type of indirect actuation is not what claim 1 requires. (*See supra* Section VIII.)

422. But, as I have also explained, I understand that Patent Owner has taken the opposite position.

423. Applying Patent Owner’s understanding of claim 1 to embrace indirectly actuated injectors, Klügl teaches what the claim requires.

424. In particular, it includes a “valve member” (its piston 3, control needle 32, and ball/closing element 4) that operates (indirectly) to either “fluidly seal[]” with a “valve seat” (valve seat 35) to stop injection, or “lift[]” (towards the combustion chamber) from that seat to start injection.

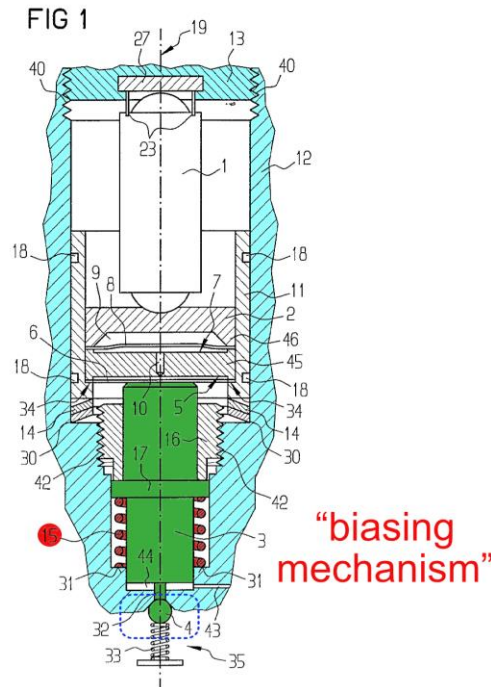
[1(c)] “(c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;”

425. In my opinion, Klügl includes the claimed **“biasing mechanism.”**

426. In particular, Klügl’s injector includes a “spring 15” that “bias[es]” the “drive piston 3 ... against a lower stop 16” located within the injector housing. (Ex. 1006, 2:35-36.)

427. The force exerted by this spring through the piston, along with cooperating force exerted on the ball 4 by a “valve spring 33”, causes “closing element 4” to be “seated on the valve seat 35” when the injector is in its “rest” state. (*Id.*, 3:11-13, 19-22, 39-45.)

428. Spring 15 is highlighted in red below:



(*Id.*, Fig. 1 (annotated).)

[1(d)] “(d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position; and”

429. In my opinion, Klügl’s injector includes the claimed “*actuator assembly.*”

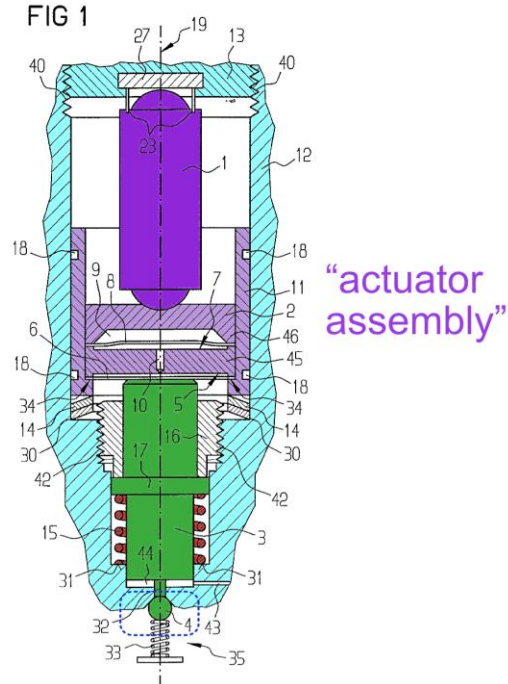
430. Klügl explains that a “piezoelectric actuator 1 is placed in” its “housing 12” “between an upper stop 13 and a transmission module 2....” (Ex. 1006, 1:47-51.)

431. The “length” of this actuator can be “adjusted” via application of a voltage over “control lines 23.” (*Id.*, 1:51-56.)

432. To open the injector, “the piezoelectric actuator 1 is ... controlled” “press[ing] the entire transmission module 2 ... in the direction of the drive piston 3” so as to “move[.]” the piston “against the spring force of the tension spring 15....” (*Id.*, 3:23-33.)

433. To close the injector, “activation of the piezo actuator 1 ends” causing “the piezoelectric actuator 1” to be “shortened” and “transmission module 2” to be “pushed” back “in the direction of the piezoelectric actuator 1.” (*Id.*, 3:39-45.)

434. The actuator 1 and transmission module 2 together constitute Klügl’s “actuator assembly.” The actuator 1 is shown in dark purple below, while the transmission module 2 is shown in light purple:



(Fig. 1 (annotated).)

[1(e)] “(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.”

435. In my opinion, Klügl teaches the claimed “*hydraulic link*.”

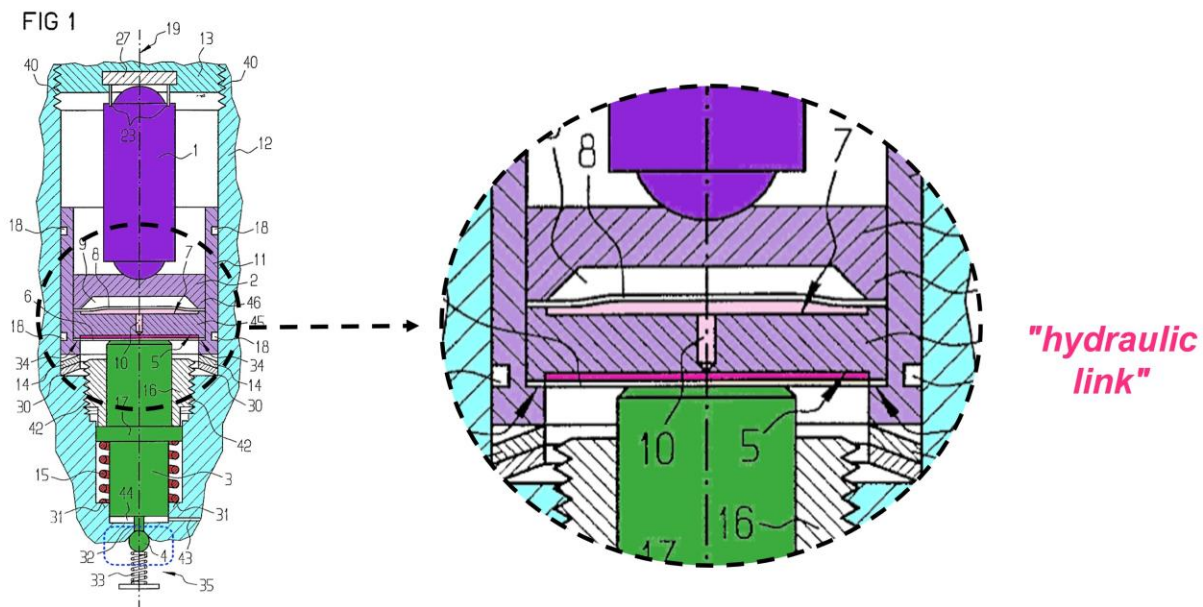
436. I have already explained above in Section IX.B.1.a.[1(e)] (when discussing Wirbeleit and claim 1), Klügl’s injector includes a chamber 5 filled with incompressible hydraulic fluid. When Klügl’s actuator expands, force from the actuator is transmitted to piston 3 through the fluid in this chamber to open the injector. Then, when the actuator is deactivated to close the injector, the closing force of the spring 15 is transmitted back through this same chamber 5 until a rest point is reached.

437. As I have also explained, the fluid in this chamber passively transmits force from the actuator 1 to the piston 3. The piston 3 moves by the same distance that the actuator 1 expands. Further, because the fluid is incompressible and cannot flow out of chamber 5 during actuation, the fluid acts as solid with constant thickness.

438. Further, due to the presence of bore or throttle 10 that connects to a chamber 7, during periods of rest and valve inactivity, fluid can move from the

chamber 5 through bore 10 to chamber 7 to automatically adjust and compensate for effects of thermal expansion and wear.

439. As a result, this fluid-filled chamber 5 corresponds to claimed ***“hydraulic link.”*** This link is highlighted dark pink below. The bore 10 and chamber 7 that allow for auto-adjustment during idle or rest periods are shown in light pink. As done earlier in this declaration, the central portion of the figure has been expanded to the right to better focus on the chamber 5:



(Fig. 1 (annotated).)

b. Claim 2

440. Claim 2 depends on claim 1 and further requires:

“wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by differential thermal expansion.”

441. As explained above, Klügl and Hayes teach everything claim 1 requires.

442. In my opinion, Klügl teaches the additional limitation of this claim for the same reasons discussed above: fluid can move from Klügl's chamber 5 to chamber 7 when the injector is at rest to account for the effects of thermal expansion. (See *supra* Section IX.B.1.b.)

c. Claim 3

443. Claim 3 depends on claim 2 and further requires:

“wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not actuated in response to changes in said dimensional relationship caused by wear to components of said injection valve.”

444. As explained above, Klügl and Hayes teach everything claim 2 requires.

445. In my opinion, Klügl teaches same reasons discussed above: fluid can move from Klügl's chamber 5 to chamber 7 when the injector is at rest to account for the effects of wear. (See *supra* Section IX.B.1.c.)

d. Claim 6

446. Claim 6 depends on claim 1 and further requires:

“wherein said actuator assembly comprises a dimensionally responsive member.”

447. As explained above, Klügl and Hayes teach everything claim 1 requires.

448. In my opinion, the additional limitation of this claim is taught by Klügl. Klügl employs a “piezoelectric actuator 1” that “preferably consists of a stack of piezoelectric elements” that extend in length in response to an applied voltage to open Klügl’s injector. (Ex. 1006, 1:52-56.)

e. Claim 13

449. Claim 13 depends on claim 6 and further requires:

“wherein said dimensionally responsive member is formed from a piezoelectric material.”

450. As explained above, Klügl and Hayes teach everything claim 6 requires.

451. In my opinion, the additional limitation of this claim is taught by Klügl. Klügl employs a “piezoelectric actuator 1” that “preferably consists of a stack of piezoelectric elements.” (Ex. 1006, 1:52-56.)

f. Claim 14

452. Claim 14 depends on claim 6 and further requires:

“a compression spring member for applying a compressive force to said dimensionally responsive member.”

453. As explained above, Klügl and Hayes teach everything claim 6 requires.

454. In my opinion, the additional limitation of this claim is taught by Klügl for the reasons discussed above: Klügl’s injector includes a “disk spring 14” to “pre-

stress[]” its piezoelectric actuator 1. (Ex. 1006, 2:11-21; 3:16-19; *see also supra* Section IX.B.1.f.)

g. Claim 17

455. Claim 17 depends on claim 6 and further requires:

“wherein when said actuator assembly is controllable to control said desired lift to between 10 and 100 percent of maximum lift.”

456. As explained above, Klügl and Hayes teach everything claim 6 requires.

457. In my opinion, the additional limitation of this claim is rendered obvious by Klügl.

458. Klügl explains that “the length” of its “piezoelectric actuator 1 can be adjusted” via a signal sent over “control lines 23” by a “control means 27.” (Ex. 1006, 1:51-56.)

459. In my opinion, even in an indirectly actuated injector, it is advantageous to be able to open the valve proportionally as Klügl teaches from small to full valve lifts. For instance, in the combined embodiment of Klügl and Hayes presented above, the proportional control of Klügl’s servo valve could additionally act as Hayes’s control volume vent orifice 24 and would allow for control of the injection needle valve’s opening and closing rates to improve noise and emissions.

460. Klügl teaches the general conditions of this claim. It is an injector with variable, controllable lift. Given this, in my opinion a POSITA would consider the claim to be obvious for the same reasons I note above. (*See supra* Section IX.B.1.g.)

h. Claim 18

461. Claim 18 depends on claim 17 and further requires:

“wherein said lift is controllable by varying at least one of the electric current, the electric voltage and the magnetic field imposed upon said dimensionally responsive member.”

462. As explained above, Klügl and Hayes teach everything claim 17 requires.

463. In my opinion, these references also teach the additional limitation of claim 18 for the reasons discussed in connection with claim 17: the lift of Klügl’s injector servo valve can be adjusted by controlling the voltage supplied to a piezoelectric actuator. This will in turn impact the hydraulic balance of the needle. (*See supra* Section IX.D.1.g.)

i. Claim 19

464. Claim 19 depends on claim 6 and further requires:

“wherein said valve member is controllable such that said valve member moves between said open and closed positions in less than about 200 microseconds.”

465. As explained above, Klügl and Hayes teach everything claim 6 requires.

466. In my opinion, the additional limitation of this claim is rendered taught by Klügl for the same reasons discussed above: Klügl’s valve can transition from an open to closed state in as little as 100 microseconds. (*See supra* Section IX.B.1.i.)

j. Claim 20

467. Claim 20 depends on claim 6 and further requires:

“a biasing mechanism for applying a compressive force to said dimensionally responsive member.”

468. As explained above, Klügl and Hayes teach everything claim 6 requires.

469. In my opinion, the further limitation of this claim this is taught by Klügl for the same reasons explained for claim 14: Klügl includes a disk spring 14 that applies a pre-loading force to its piezoelectric actuator 1. (*See supra* Section IX.D.1.f.)

k. Claim 21

470. Claim 21 depends on claim 1 and further requires:

“wherein said biasing mechanism comprises a spring.”

471. As explained above, Klügl and Hayes teach everything claim 6 requires.

472. In my opinion, the additional limitation of this claim is taught by Klügl. In particular, as I explained when discussing claim 1, Klügl’s injector includes a

spring 15 that applies force that causes the ball 4 to be pressed against its seat to seal and close the injector. (*See supra* Section IX.D.1.a.[1(c)].)

l. Claim 26

473. Claim 26 depends on claim 1 and further requires:

“wherein said fuel is injected into said combustion chamber at a pressure greater than about 2000 psi (about 13.8 Mpa).”

474. As explained above, Klügl and Hayes teach everything claim 1 requires.

475. Klügl’s injector employs a “high pressure” chamber to facilitate injection from its injector into an engine’s combustion chamber. (*E.g.*, 1006, 3:33-38.)

476. As I have explained above, a POSITA would have recognized that in such a high-pressure system, injection pressure would greatly exceed 2000 psi (particularly in a diesel engine). (*See supra* Section IX.B.1.l.)

m. Claim 27

477. Claim 27 depends on claim 1 and further requires:

“wherein said valve housing comprises a plurality of parts which are joined with each other to provide a fluidly sealed body.”

478. As explained above, Klügl and Hayes teach everything claim 1 requires.

479. In my opinion, the additional limitation of this claim is taught by Klügl. In particular, Klügl’s injector housing includes at least a “housing 12” and an “upper stop 13” that together form its sealed interior. (Ex. 1006, 1:49-51; Fig. 1.)

n. Claim 41

480. Claim 41 is another independent claim. For reference, I have reproduced the entirety of this claim above. (See Section VII.C.)

481. Claim 41 is directed to a *“method of operating a fuel injection valve”* like that required by claim 1.

482. Due to the similarity between what claim 41 and claim 1 require, in my opinion, the combination of Klügl and Hayes teach everything required by this method for the same reasons I have already explained for claim 1 (at least when Patent Owner’s understanding of the claim is applied).

483. Though I have included some additional discussion regarding claim 41 below, a fuller explanation can be found above in the discussion of claim 1.

484. In my opinion, the injector taught by the Klügl and Hayes references *“(a) actuate[es] a dimensionally responsive member”* and *“(c) deactuat[es] said dimensionally responsive member”* to open and close an injector.

485. In this regard, Klügl includes a piezoelectric actuator 1 that expands in length along the injector’s longitudinal axis when voltage is applied, and contracts in length when voltage is removed. (See *supra* Section IX.D.1.a.[(d)].)

486. Further, Klügl's spring 15 facilitates valve closing during de-actuation. (See *supra* Section IX.D.1.a.[1(c)].)

487. Klügl and Hayes's injector also ***“(b) transfer[s] movement caused by said actuated dimensionally responsive member through a passive hydraulic link”*** to move a ***“valve member”*** and cause it to lift from a ***“valve seat.”***

488. Here, Klügl teaches that the force exerted by its actuator is passed through incompressible hydraulic fluid in chamber 5 that is part of transmission module 2 to a piston 3 / needle 32 / ball 4 causing it to unseat. (See *supra* Section IX.D.1.a.[1(e)].)

489. The fluid in this chamber acts as a solid and maintain its thickness during actuation. (See *id.*)

490. Klügl also, in my opinion, includes the claimed ***“hydraulic cylinder which houses a piston”*** (which the claim provides are part of the “passive hydraulic link”).

491. In particular, Klügl transmission module 2, which includes hydraulic fluid filled chamber 5 through which the actuating forces are passed, is designed to move up and down. (See Ex. 1006, 2:12-21; Fig. 1.) Thus, it corresponds to the claimed “piston.”

492. Further, this module is surrounded by a cylindrical “guide sleeve 11” located within the hollow interior of the injector's housing 12. The portion of the

housing through which this sleeve moves is the claimed “hydraulic cylinder” that “houses” the “piston.” (See *id.*)

493. Finally, in my opinion, the references teach “*(d) providing sufficient time between consecutive valve openings to allow at least some of said hydraulic fluid within said passive hydraulic link to flow from one side of said piston to the other side of said piston.*”

494. In particular, Klügl teaches that its transmission module 2 includes a bore 10 (throttle/orifice) which allows the fluid from chamber 5 on one side of the module to flow to chamber 7 on the other side of the module during injector idle periods. (See *supra* Section IX.D.1.a.[1(e)].)

2. Motivation to Combine

495. This ground points to Hayes as an example of what a POSITA would understand Klügl to already teach. In other words, Hayes simply provides elaboration. Klügl is not being modified or changed in view of Hayes’s teachings.

496. Regardless, in my opinion, a POSITA would have been motivated to look to Hayes—and would have had a reasonable expectation of success when doing so—not only because of the structural and functional similarity of Hayes and Klügl, but also because Hayes teaches that its injector is designed to be “simple,” and “compensate[s] for tolerances and shifts due to temperature and wear.” (Ex. 1024, 1:32-35.) Klügl’s injector is designed with similar goals in mind.

E. Ground 4: Claim 28 is Obvious Over Klügl, Hayes, and Newcomb

497. In my opinion, a POSITA would have considered Klügl, Hayes, and Newcomb to be within the scope of the prior art and highly relevant to the patentability of the '138 patent's claims.

498. In my opinion, when viewed and considered in light of the knowledge possessed by a POSITA, Klügl, Hayes, and Newcomb together disclose all the limitations of and render claim 28 of the '138 patent obvious.

499. Claim 28 depends on claim 1 and further requires:

“wherein said valve housing, said valve member and said actuator assembly are selected from materials having thermal expansion coefficients sufficiently compatible such that changes in the dimensional relationship between said components caused by changes in temperature are reduced.”

500. As explained above, Klügl and Hayes teach everything claim 1 requires.

501. In my opinion, a POSITA would have considered the additional limitation of claim 28 to be obvious in view of the teachings of Newcomb (Ex. 1014) for the same reasons I have already discussed.

502. In particular, Klügl already recognizes that an injector should be designed to account for the effects of wear or thermal expansion. And, Newcomb teaches that these effects can be further minimized by employing materials with compatible thermal expansion coefficients as this particular claim requires. (*See supra* Section IX.C.)

F. Secondary Considerations of Non-Obviousness

503. Based on my review of the '138 patent's prosecution history, I note that no secondary considerations of non-obviousness were identified in connection with the patent's claims.

504. I am not separately aware of any evidence of commercial success, skepticism, failure of others, industry praise, unexpected results, or the like. Instead, as discussed above, it is my opinion that the subject matter embraced by the '138 patent's claims was known in the art and would have been expected to function as a working fuel injector.

I 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 willfully 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.

Date: 12/9/2022
Location: Monument, Colorado
Signature: 
Dr. J. Matt Quinlan

ATTACHMENT A

John “Matt” Quinlan

(719) 351-9770

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combustion.uccs.edu

EXPERIENCE

Assistant Professor

August 2019 to Present

University of Colorado—Colorado Springs, Colorado Springs, CO

- Designed, constructed, and tested an outwardly-opening pintle fuel injector to study hydrodynamics and atomization
- Designed, constructed, and tested a rocket baffle nonlinear acoustic damping facility, now developing software to calculate the theoretical damping magnitude
- Simulated 3-D detonation wave fronts with detailed (skeletal) chemical models to develop next generation rotating detonation engines
- Developing diffuse interface methods for reacting, two-phase flow simulations
- First co-PI on funded five-year NSF MRI project to purchase and oversee UCCS's first supercomputer (over 125 TFLOPS) in 2020—installed and rolling out to users currently
- Appointed as a fellow in 2022 and 2020 for the Air Force Research Lab Summer Faculty Fellowship—funding for faculty and graduate student for research at the United States Air Force Academy in combustion diagnostics and detonation simulations
- Was awarded a UCCS CRCW Seed Grant for work in hydrodynamic instabilities
- Taught eleven undergraduate and graduate courses

Consultant/Owner

2005 to Present

Quinlan Engineering and Design, LLC, Woodland Park, CO

- Diesel fuel system design, development, and analysis
- Mechanical component design, structural analysis, and failure analysis
- Combustion instability analysis and mitigation
- Hydraulic hybrid vehicle powertrain design and analysis

Visiting Assistant Professor

August 2018 to August 2019

University of Colorado—Colorado Springs, Colorado Springs, CO

- Taught eight courses over the year

Adjunct Instructor

August 2016 to August 2018

University of Colorado—Colorado Springs, Colorado Springs, CO

Research Engineer

April 2014 to August 2015

Georgia Institute of Technology, Atlanta, GA

- Co-Principal Investigator on NASA supported (about \$150,000/year) acoustic sensing in liquid rocket engine project
- Designed, built, and tested swirling, co-axial rocket injector with adjustable swirl.
- Developed pseudo-linear techniques to analyze high-amplitude acoustic sensor ports

Diesel Fuel System Engineer

2001 to 2006

Sturman Industries, Fuel System group, Woodland Park, CO

- Developed advanced prototype hydraulically intensified diesel fuel injectors, 3000 bar capable
- Developed advanced prototype common-rail diesel fuel injectors
- Primary structural analyst for Fuel System group
- Designed of mechanical components and assemblies for fuel systems
- Created print packages with geometric dimensioning and tolerancing (GD&T)
- Performed installations twice for German universities with a major automobile manufacturer
- Performed dynamometer and emissions mapping

EDUCATION

Doctor of Philosophy, Aerospace Engineering

Georgia Institute of Technology, Atlanta, GA

December 2015

Thesis: Investigation of Driving Mechanisms of Combustion Instabilities
in Liquid Rocket Engines via the Dynamic Mode Decomposition

Advisor: Ben T. Zinn

Concentration: Thermoacoustic instability

Minor: Mathematics

Focus areas: Combustion, acoustics, viscous flow, turbulence, and high-temperature gas dynamics

Research:

- Developed data analysis techniques to experimentally find stability determining Floquet multipliers for systems with periodic governing equations
- Responsible for laboratory-scale facility concept, design, analysis, and development capable of exhibiting full-scale-like combustion instabilities
- Used sub-scale facility to study mechanisms that drive combustion instability, including the acquisition and analysis of data from high-speed diagnostics
- Performed synchronized 10 kHz OH-planar laser induced fluorescence, particle image velocimetry, CH*-chemiluminescence, and acoustic pressure measurements to probe complex reacting/swirling flow
- Developed technique to analyze data based on dynamic mode decomposition, which preserves spatial/temporal relationship between synchronized diagnostics, extracting coupled dynamical modes
- Used the sub-scale facility, two-microphone wave decomposition, and real-time active acoustic impedance control to simulate a full-scale combustion instability at a frequency that is not a natural acoustic frequency of the system
- Wrote a finite element method based code to find the acoustic modes for geometrically complex combustion chambers

Masters of Science, Mechanical Engineering

Colorado State University, Fort Collins, CO

May 2009

Thesis: Combustion Stability in Baffled Rocket Engines

Advisor: Charles E. Mitchell

Co-Advisor: Allan T. Kirkpatrick

Concentration: Thermoacoustic instability

Other focus areas: Structural mechanics

Research:

- Developed and delivered new liquid rocket engine combustion stability code
- Code uses a Fourier matching technique allowing stability predictions for more complex combustion chambers
- Demonstrated ability to locate the stability boundary based on a number of parameters including acoustic mode, frequency, combustion gain, and combustion phase
- Code currently being used by commercial rocket engine manufacturer

Bachelor of Science, Mechanical Engineering

Colorado State University, Fort Collins, CO

May 2001

- Co-Captain FSAE Formula car team, 2000–2001

PUBLICATIONS & PATENTS

Refereed Journals

- Schmidt, E. M., **Quinlan, J. M.**, and Runnels, B. “Self-similar Diffuse Boundary Method for Phase Boundary Driven Flow,” *Physics of Fluids*, Vol. 34, No. 11, 2022.
- Kanagraajan, B., **Quinlan, J. M.**, Bojko, B., and Runnels, B. “A Diffuse Interface Method for Solid-Phase Modeling of Regression Behavior in Solid Composite Propellants,” *Combustion and Flame* Vol. 242, 2022.
- Alsulami, R., Lucas, S., Hageman, M., Knadler, M., **Quinlan, J. M.**, and Windom, B., “Coupling Effects of Physical and Chemical Properties on Jet Fuel Spray Flame Blowout,” *Proceedings of the Combustion Institute* Vol. 38, No. 2, 2021
- **Quinlan, J. M.**, and Zinn, B. T. “Development and Dynamical Analysis of Laboratory Facility Exhibiting Full-Scale Combustion Instability Characteristics,” *AIAA Journal*, Vol 55, No. 12, 2017.
- Emerson, B., Jagtap, S., **Quinlan, J. M.**, Renfro, M. W., Cetegen, B. M., Lieuwen, T. “Stability Analysis of Reacting Wakes: Flow and Density Asymmetry Effects,” *Physics of Fluids*, Vol. 28, No. 4, 2016.
- **Quinlan, J. M.**, Kirkpatrick, A., Milano, D., Mitchell, C. E., and Hinerman, T. D. “Analytical and Numerical Development of a Baffled Liquid Rocket Combustion Stability Code,” *Journal of Propulsion and Power*, Vol. 28, No. 1, 2012.

U.S. Patents

- 8,622,859 – Systems and methods for hybridization of a motor vehicle using hydraulic components – 2014
patentimages.storage.googleapis.com/98/12/19/b5196276017a4a/US8622859.pdf
- 8,366,018 – Oil intensified common rail injectors – 2013
patentimages.storage.googleapis.com/bc/bf/15/7f6af484c4c669/US8366018.pdf
- 8,282,020 – Three-way valves and fuel injectors using the same – 2012
patentimages.storage.googleapis.com/18/27/4d/b43fe73b70ab64/US8282020.pdf
- 7,681,592 – Three-way poppet valves with floating seat – 2010
patentimages.storage.googleapis.com/20/70/33/24dfd50ac9b5e0/US7681592B2.pdf

Journal Manuscripts in Preparation or Review

For current preprints visit www.researchgate.net/profile/Matt-Quinlan

- **Quinlan, J. M.** “Parametric Combustion Instabilities,” *AIAA Journal*.
- **Quinlan, J. M.** “Data Based Analysis of Periodic Phenomena: Floquet Theory Extended Dynamic Mode Decomposition,” *Journal of Fluid Mechanics*.

Conference Papers

- Day, J., **Quinlan, J. M.** “Modeling Nonlinear Acoustic Damping Due to Flow Separation,” *183rd Meeting of the Acoustical Society of America*. Vol. 1pEA8, Nashville, Tennessee, 2022.
- Schmidt, E. M., **Quinlan, J. M.**, Runnels, B. “A Self-Similar Diffuse Interface Method for a Rotating Ablating Cylinder,” *75th Meeting of the American Physical Society—Division of Fluid Dynamics*. Vol. Z16.07, Indianapolis, Indiana, 2022.
- **Quinlan, J. M.** “Parametric Combustion Instabilities,” *AIAA Science and Technologies Forum and Exposition*. Vol. AIAA-2022-1857, San Diego, California, 2022.
- Schmidt, E. M., **Quinlan, J. M.**, and Runnels, B. “Diffuse Interface Method for Coupling of Solid and Gaseous Phases in a 1D Verification Problem for Combustion of AP/HTPB,” *AIAA Science and Technologies Forum and Exposition*. Vol. AIAA-2022-2196, San Diego, California, 2022.
- Day, J. A., Erazo Papagayo, S., and **Quinlan, J. M.** “Baffle Blade Acoustic Damping,” *AIAA Propulsion and Energy Forum*. Vol. AIAA-2021-3573, Denver, Colorado, 2021.
- Erazo Papagayo, S., Day, J. A., Gamertsfelder, J. , Khare, P., and **Quinlan, J. M.** “Pintle Injector Spray Atomization: Liquid Sheet Breakup Quantification,” *AIAA Propulsion and*

- Energy Forum*. Vol. AIAA-2021-3630, Denver, Colorado, 2021.
- Rehl, A., **Quinlan, J. M.**, Scarborough, D., and Zinn, B. T. “Nonlinear Acoustic Response of Stand-Off Tubes Used in Acoustic Pressure Measurements—Part I: Experimental Study,” *170th Meeting of the Acoustical Society of America*. Vol. 2PEA4, Jacksonville, Florida, 2015.
 - **Quinlan, J. M.**, Scarborough, D., Rehl, A., and Zinn, B. T. “Nonlinear Acoustic Response of Stand-Off Tubes Used in Acoustic Pressure Measurements—Part II: Analysis,” *170th Meeting of the Acoustical Society of America*. Vol. 2PEA5, Jacksonville, Florida, 2015.
 - Damião, A., **Quinlan, J. M.**, Kim, Y. J., and Zinn, B. T. “Determination of Combustion Stability Margin Using the Filter Diagonalization Method,” *51st AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2015-4019, Orlando, Florida, 2015.
 - **Quinlan, J. M.**, and Zinn, B. T. “Transverse Combustion Instabilities: Modern Experimental Techniques and Analysis,” *50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2014-3682, Cleveland, Ohio, 2014.
 - **Quinlan, J. M.**, and Zinn, B. T. “Simulating Full-Scale Transverse Combustion Instabilities in a Lab-scale Facility,” *49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2013-4019, San Jose, California, 2013.
 - Bibik, A. V., Lubarsky, E., **Quinlan, J. M.**, Shcherbik, D., and Zinn, B. T. “Control of Tangential Combustion Instability by Asymmetric Baffle,” *Critical Phenomena under Extreme Impact (CPUEI-2012)*, Kharkov, Ukraine, 2012.
 - **Quinlan, J. M.**, Bibik, O., and Zinn, B. T. “Experimental and Numerical Combustion Instability Modes in Asymmetric Baffled Chambers,” *46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2010-6802, Nashville, Tennessee, 2010.
 - **Quinlan, J. M.**, Kirkpatrick, A., Milano, D., Mitchell, C. E., and Hinerman, T. D. “Analytical and Numerical Development of a Baffled Liquid Rocket Combustion Stability Code,” *45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2009-4865, Denver, Colorado, 2009.
 - Milano, D., **Quinlan, J. M.**, Kirkpatrick, A., Mitchell, C. E., and Hinerman, T. D. “Computation of Acoustic Oscillations and Combustion Stability in a Rocket Engine with Combined Hub/Blade Baffles,” *45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*. Vol. AIAA-2009-4866 Denver, Colorado, 2009.
 - Wolverton, M. A., Giordano, D., **Quinlan, J. M.**, and Zukowski, R. “Evaluation of a 3-Way Direct Needle Control Unit Injector on Hydraulic Test Bench and V8 Engine,” *2004 SAE World Congress*. Vol. SAE-2004-01-0024, Detroit, Michigan, 2004.

Talks

- **Quinlan, J. M.** “Swirling Flames and Floquet Multipliers: Parametric Combustion Instabilities,” *Invited talk—Department of Mechanical Engineering, Colorado State University*, Fort Collins, Colorado, January 2022.
- **Quinlan, J. M.** “Combustion Instabilities and Nonlinear Acoustic Damping,” *Invited talk—MAE Research Seminar, University of Colorado—Colorado Springs*, Colorado Spring, Colorado, October 2021.
- **Quinlan, J. M.** “Combustion Instabilities and Nonlinear Acoustic Damping,” *Invited talk—MAE Research Seminar, University of Colorado—Colorado Springs*, Colorado Spring, Colorado, October 2020.
- **Quinlan, J. M.** “Global Variational Methods: Numerical Approximations for Ordinary Differential Equations,” *Invited talk—Computational Science & Engineering Seminar, University of Colorado—Colorado Springs*, Colorado Spring, Colorado, July 2019.
- **Quinlan, J. M.** “Swirling Flames and Floquet Multipliers: Parametric Combustion Instabilities,” *Invited talk—Department of Mechanical and Aerospace Engineering, University of Colorado—Colorado Springs*, Colorado Spring, Colorado, March 2019.
- **Quinlan, J. M.**, Kim, Y. J., Damião, A., Yang, V., Zinn, B. T. “Theoretical, Numerical, and Experimental Investigations of the Fundamental Processes that Drive Combustion Instabilities in Liquid Rocket Engines,” *Air Force Office of Scientific Research (AFOSR) 2015 Space Propulsion and Power Contractors Meeting*, Arlington, Virginia, 2015.

- **Quinlan, J. M.**, Kim, Y. J., Damião, A., Yang, V., Zinn, B. T., Law, C. K. “Theoretical, Numerical, and Experimental Investigations of the Fundamental Processes that Drive Combustion Instabilities in Liquid Rocket Engines,” *Triservice Basic Science Energetic Materials Program Review*, Arlington, Virginia, 2014.
- **Quinlan, J. M.**, Kim, Y. J., Damião, A., Yang, V., Zinn, B. T., Law, C. K. “Theoretical, Numerical, and Experimental Investigations of the Fundamental Processes that Drive Combustion Instabilities in Liquid Rocket Engines,” *Air Force Office of Scientific Research (AFOSR) 2013 Space Propulsion and Power Contractors Meeting*, Arlington, Virginia, 2013.
- **Quinlan, J. M.**, Kim, Y. J., Baroncelli, M., Dumitrache, C., Zinn, B. T. “Development Of Actively Controlled LRE Simulator (ACLRES) Rig,” *Air Force Office of Scientific Research (AFOSR) 2012 Space Propulsion and Power Contractors Meeting*, Arlington, Virginia, 2012.

HONORS

Award: Abe Zarem Graduate Award For Distinguished Achievement—Astronautics 2022
AIAA

Advisee, Joseph Day won this national award for paper presented at a AIAA Student Conference. Joseph was awarded a funded trip to the 2023 AIAA SciTech Forum and Exposition to accept the award and a trip to present his work at the 2022 International Astronautical Congress in Paris. www.aiaa.org/get-involved/honors-awards/awards/award/award-abe-zarem-graduate-award-for-distinguished-achievement-astronautics

Fellowship: Air Force Research Lab Summer Faculty Fellowship 2022
AFOSR

Appointed as a fellow at the USAFA to perform research simulating detonations for application to rotating detonation engines; grant received with student Santiago Erazo for summer research

Fellowship: UCCS Undergraduate Research Academy 2022
University of Colorado—Colorado Springs

Research grant received with undergraduate student Duncan Schlueter for summer research

Fellowship: UCCS Undergraduate Research Academy 2021
University of Colorado—Colorado Springs

Research grant received with undergraduate student Sarah Chancellor for summer research

Fellowship: Air Force Research Lab Summer Faculty Fellowship 2020
AFOSR

Appointed as a fellow at the USAFA to perform research on combustion diagnostics for monopropellant, pintle injectors for various liquids; grant received with student Joseph Day for summer research

Fellowship: UCCS Undergraduate Research Academy 2019
University of Colorado—Colorado Springs

Research grant received with undergraduate student Joseph Day for summer research

Fellowship: UCCS EAS Undergraduate Research Scholars Program 2019
University of Colorado—Colorado Springs

Research grant received with undergraduate student Joseph Day

Scholarship: Combustion Energy Frontier Research Center—Summer School 2012
Princeton University, Princeton, NJ

Combustion Theory and Internal Combustion Engines

Scholarship: Combustion Energy Frontier Research Center—Summer School 2011
Princeton University, Princeton, NJ

Combustion Theory and Combustion Chemistry

TEACHING

Principles of Combustion (full responsibility for course—Grad) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2022
Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2022
Compressible Flow (full responsibility for course—Grad) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2022
Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2022
Rocket Propulsion (full responsibility for course—Grad) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2021
Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2021
Incompressible Flow (full responsibility for course—Grad) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2021
Engineering Thermodynamics II (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2021
Engineering Thermodynamics II (full responsibility for course—two sections) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2020
Principles of Combustion (full responsibility for course—Grad) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2020
Engineering Thermodynamics II (full responsibility for course—two sections) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2019
Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Summer 2019
Machine Design I (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2018
Materials Engineering (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2018
Engineering Measurement Lab (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2018
Machine Design I (full responsibility for course—two sections) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2018
Engineering Mechanics I (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2018
Engineering Measurement Lab (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2018
Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Summer 2018
Liquid Rocket Engines: Fundamentals and Green Propellants <i>AIAA Joint Propulsion Conference Short Course, Cincinnati, OH</i>	Summer 2018

Control of Aero. and Mech. Systems (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2018
Engineering Thermodynamics II (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Spring 2017
Engineering Mechanics II (full responsibility for course) <i>University of Colorado—Colorado Springs, Colorado Springs, CO</i>	Fall 2016
Introduction to Thermal Sciences (full responsibility for course) <i>Colorado State University, Fort Collins, CO</i>	Summer 2008
<i>Teaching Assistant – Mechanics and Thermodynamics of Flow Processes</i> <i>Colorado State University, Fort Collins, CO</i>	Fall 2008
<i>Mentoring – Undergraduate and Graduate Students</i> <i>Georgia Institute of Technology, Atlanta, GA</i>	2010 to 2015
● Mentored one PhD student—primary supervisor of his research ● Mentored two Masters students, both went on to pursue doctoral degrees ● Supervised undergraduate research with multiple students for multiple semesters	

DISSERTATION AND THESIS COMMITTEES

<i>Committee member</i> Sean Coughenour—Masters of Science in Mechanical Engineering “Design and Validation of a Microbubble Levitation Chamber Using an Acoustic Vortex Beam” University of Colorado—Colorado Springs, Colorado Springs, CO	2022
<i>Committee member</i> Andrew Gibson—Masters of Science in Mechanical Engineering “Application of Koopman Linear Quadratic Regulator to the Control of a Spherical Microbubble” University of Colorado—Colorado Springs, Colorado Springs, CO	2022
<i>Committee member</i> Danny Paredes—Masters of Science in Mechanical Engineering “Inviscid Flow Past Canonical Bodies” University of Colorado—Colorado Springs, Colorado Springs, CO	2021
<i>Committee member</i> Lluís Umbert Amat—Masters of Science in Mechanical Engineering “Tethered Aerobraking Design for Repeatable Maneuvers” University of Colorado—Colorado Springs, Colorado Springs, CO	2020

SERVICE

Committees

- Technical Discipline Co-Chair—AIAA SciTech Liquid Propulsion Technical Committee 2023
- Member—UCCS CRCW Seed Grant Review Committee 2022
- Technical Discipline Chair—AIAA SciTech Liquid Propulsion Technical Committee 2022
- Member—AIAA Liquid Propulsion Technical Committee 2015–2022
 - Education Subcommittee
 - Helped develop and teach content for rocket propulsion short course
 - Chaired technical sessions
- Member—UCCS Aerospace BS/MS Degree Committee 2021–2022
- Member—UCCS INCLINE (supercomputer) Management Committee 2020–2022
- Member—UCCS MAE Graduate Committee 2019–2022
- Member—UCCS MAE Instructor Hiring Committee 2019–2020
- Volunteer reviewer—interviewed candidates for the 2020 Georgia Tech President’s Scholars Program (four-year, full-ride scholarship for the top incoming student) and our recommended student was selected for the award 2020
- Member—UCCS MAE Curriculum Committee 2018–2019
- Member—ASA Engineering Acoustics Technical Committee 2016–2018
- Member—Aerospace Engineering Combustion Laboratory/Carbon-Neutral Energy Solutions Laboratory Safety Committee 2012–2015
 - Helped develop and implement formal Safety Review Process plan to ensure safe operation of laboratory facilities and experiments
- Member—Combustion Laboratory Long Term Planning Committee 2014
 - Helping formulate a 10-year plan for the direction of the laboratory
- Advisor—Aerospace Engineering Manufacturing and Prototyping Faculty Task Force 2014
 - Recommended equipment and personnel that should be available to students to properly learn about manufacturing processes and communication
- Member—Aerospace Engineering Combustion Laboratory Calibration Committee 2013
 - Committee proposed equipment and processes to properly calibrate the most commonly used measurements in the laboratory
- Member—Particle Image Velocimetry Error Analysis Group 2011–2012
 - Group organized to study and attempt to quantify the level and sources of experimental error

Peer Review

- Reviewer—Combustion and Flame 2022
- Reviewer—AIAA SciTech Forum 2022
- Reviewer—AIAA Propulsion & Energy Conference 2016–2021
- Reviewer—Journal of Propulsion and Power 2015, 2021
- Reviewer—AIAA Journal 2019
- Reviewer—Journal of the Acoustical Society of America 2018
- Reviewer—ASME Turbo Expo: Turbine Technical Conference 2015, 2017, 2018, 2019
- Reviewer—ACS PRF grants 2020

Organizations

- Order of the Engineer
- American Institute of Aeronautics and Astronautics

SKILLS

Certifications: Passed Fundamentals of Engineering Examination – 2000

Qualified to take Professional Engineering licensing exam

Programming Languages & Software: Fortran, Python, Julia, Git, CMake, LaTeX, Maple, Matlab, Tecplot, Chemkin, Cosmos (structural FEA), Abaqus (structural FEA), Mathcad, Ricardo Wave (engine simulation), Fluent (CFD), SolidWorks, Ubuntu, and Microsoft Office

Fabrication: CNC machining, EDM machining, milling, turning, forging, grinding, diamond tooling, engine building, MIG, TIG, and arc welding, injection molding, vacuum/pressure casting, metal matrix composites, material selections, heat treating, and carbon fiber composites

EXTRACURRICULAR ACTIVITIES

Outdoor Enthusiast

- Climbed Mount Rainer, July 2005
- Completed Imogene Pass Run three times (17.1 miles and over 5,000 feet elevation gain)

Avid Photographer

- 24 years experience developing film and photographs in personal darkroom
- Gallery Visitors' Choice Award during 2007 "Alternative Processes" show at nationally known Center for Fine Art Photography