

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

NISSAN MOTOR CO., LTD.,

Petitioner,

v.

LONGHORN AUTOMOTIVE GROUP LLC,

Patent Owner,

Patent No. 7,513,238B2 to Pfaff *et al.*

Issue Date: April 7, 2009

Title: DIRECTLY INJECTING INTERNAL COMBUSTION ENGINE

Inter Partes Review No.: IPR2025-01089

Declaration of Dr. Glenn R. Bower Ph.D., PE

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- ii. “wherein the piston has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction, and” 108
- iii. “[a] a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius [b] so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and”
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1. I, Glenn R. Bower Ph.D., PE, of Arena, Wisconsin, declare that:

I. INTRODUCTION

2. I have been retained as a technical expert by counsel on behalf of Nissan Motor Co., Ltd. (“Petitioner”). I understand that Petitioner is requesting that the Patent Trial and Appeal Board institute an *Inter Partes* review (“IPR”) proceeding of U.S. Patent No. 7,513,238B2 (“the ’238 Patent,” EX. 1001).

3. I have been asked by Petitioner’s counsel (“Counsel”) to provide my independent analysis and consideration of whether certain references teach or suggest the features recited in claims 1–14 (the “challenged claims”) of the ’238 Patent. My opinions and the bases for my opinions are set forth below. My opinions are based on my education and experience.

4. In writing this Declaration, I have considered the following: my own knowledge and experience, including my teaching and work experience in the fields of engine system design, piston recesses, fuel system design, and metallurgical engineering; and my experience of working with others involved in those fields.

5. I am not, and never have been, an employee of Petitioner. I have no financial interest in either party or in the outcome of this proceeding. I am being compensated for my work as an expert on an hourly basis, for all tasks involved. My compensation is not dependent on the outcome of these proceedings or on the content

of my opinions. I will not receive any added compensation based on the outcome of any IPR or other proceeding involving the '238 Patent.

II. QUALIFICATIONS

6. My qualifications for forming the opinions in this report are summarized here and explained in more detail in my curriculum vitae ("CV"), which is provided as Appendix A appended hereto.

7. As detailed in my CV, I have extensive experience in the design, development, and manufacture of engine systems, with a career spanning over 30 years in this field. I have specific expertise in the design and development of piston recesses and have a sound understanding of the relevant mechanical principles and constraints associated with the implementation of pistons including piston recesses into an engine system.

8. I earned my Bachelors of Science degree in Mechanical Engineering from the University of Wisconsin-Platteville in 1987. I earned by Masters of Science degree and Ph.D. in Mechanical Engineering from the University of Wisconsin-Madison in 1989 and 1992, respectively. My graduate advisor was Professor David E. Foster, who specialized in engines, combustion, and chemical kinetics.

9. My Ph.D. thesis involved looking at the effects of multiple injections into an engine-fed optical combustion chamber. I studied and reported on the effects of fuel spray penetration, combustion chamber swirl effects on spray plume

development and the discovery that multiple injections allowed for the simultaneous reduction of NO_x and soot emissions. Further studies conducted at the Engine Research Center solidified this discovery which is the basis for today's clean, fuel efficient compression ignition (i.e. diesel) engines.

10. I am a Board Certified Registered Professional Engineer in the State of Wisconsin: license # 29717.

11. I received the UWC-Richland Outstanding Alumni Award in 2001 and the SAE Faculty Advisor Award in 2001, 2008, and 2014. I also received the NSF Outstanding Faculty Advisor Award in 2000 and 2006. Last year, I received the SAE Autodrive Challenge II Advisor of the Year Award.

12. I am currently a Teaching Associate Professor at the University of Wisconsin-Madison. From 1995–2024, I was a Senior Scientist at the University of Wisconsin-Madison Engine Research Center and/or Faculty Associate in the University of Wisconsin-Madison Mechanical Engineering Department.

13. I teach various courses including engineering economics, freshman design, thermodynamics, fluid mechanics, internal combustion engines, and senior design. I have overseen the college's automotive shop and conduct research at the Engine Research Center since 1995 and 1992, respectively. I have been on the faculty at the University of Wisconsin-Madison since 1997.

14. I am a Faculty Advisory for the Wisconsin Autonomous Team, the Baja SAE Team, the Formula SAE Teams, and the Clean Snowmobile Team at the University of Wisconsin-Madison. During my tenure, 6 different teams have won 21 different international engineering competitions with 55 top 5 finishes. Through my roles on these Teams, I interact with approximately 50 students each semester that are enrolled in independent study. Each student selects his/her design project, some of which concentrate on calibrating an engine. To prepare each team for its international competition, I guide the students in designing, building, and testing all aspects of the vehicles. I teach students at all levels not only the technical aspects of building a vehicle, but the intricacies of each of the engine's components and how it affects the overall engine/vehicle performance. Several of the Teams program and calibrate their respective engine/vehicle controllers.

15. I am the University of Wisconsin-Madison SAE Student Section Faculty advisor. I have served as the SAE Milwaukee Section Nominating Committee Representative and routinely organize and chair technical sections for the SAE Small Engine Technology Conference. During my tenure, I have peer reviewed numerous technical papers.

16. I have been an active member of the SAE since 1988.

17. I also oversee the Phil Myers Automotive Center located in the Engineering Centers Building at the University of Wisconsin-Madison. This 5000

sq. ft. facility is the home to the Baja SAE Team, Formula SAE Team, the Clean Snowmobile Team, and the Wisconsin Autonomous Team.

18. In addition to designing new technologies, I have, throughout my career, mentored, trained, and supervised young engineers and can easily appreciate how a less experienced engineer or designer would perceive the prior art and approach the technical problems disclosed in the prior art.

19. I have previously served as an expert in ten IPR cases involving engine components. I also served as an expert in three patent infringement cases involving engine components and two International Trade Commission Investigations involving engine components.

20. I have been actively consulting since receiving my Ph.D. in 1992. I have developed and certified engine combustion analysis systems, been retained as a professional witness in personal injury cases and State of Wisconsin vehicular accident with injury cases, patent litigation, international arbitration, and hybrid vehicle development.

21. I have extensive practical experience in automotive powertrains, including hybrids and electrics, alternative fuels, engine emissions, fuel systems, engine aftertreatment systems, vehicle testing, high speed photography and in-cylinder engine combustion in addition to engine and hybrid controls. I am an experienced machinist and welder.

22. I also have experience with the U.S. Patent system. I am a named inventor of U.S. Patent No. 6,231,135 B1 for a Hybrid Brake System.

23. Based on my experience and education, I believe that I am qualified to opine as to the knowledge and level of skill of one of ordinary skill in the art at the time of the alleged invention of the '238 Patent ("POSITA"; refer to Section VIII.C, below) and what such a person would have understood at that time, and the state of the art during that time. Based on my experiences, I understand and know of the capabilities of persons of ordinary skill in this field during the mid-1990s to the late 2000s and specifically during the time before the time of the alleged invention of the '238 Patent. Indeed, I worked closely with many such persons in the field during that time frame.

III. MATERIALS AND OTHER INFORMATION CONSIDERED

24. All of the opinions contained in this declaration are based on the documents I have reviewed and my professional judgment, as well as my education, experience, and professional knowledge. I am not an attorney and I am not offering any legal opinions in this declaration.

25. In forming the opinions expressed in this declaration, I relied upon my education, knowledge, and experience in the relevant field of the art, and have considered the viewpoint of a POSITA as of October 29, 2003, which I understand to be the earliest effective filing date of the claims for purposes of this analysis. I

have considered the materials referenced herein, including the '238 Patent (EX. 1001), the prosecution history (EX. 1010) of the '238 Patent, and the following materials:

- Certified translation of Japanese Utility Model Application Publication No. S58-102720 to Ishida (“Ishida,” EX. 1005);
- Certified translation of Japanese Patent Application Publication No. 2697100 to Takatomo *et al.* (“Takatomo,” EX. 1006);
- U.S. Patent Application Publication No. 2002/0117146 to Gatellier *et al.* (“Gatellier,” EX. 1007);
- U.S. Patent No. 6,314,933 to Iijima *et al.* (“Iijima,” EX. 1008);
- Certified translation of Japanese Patent Application Publication No. S54-74012 to Oota (“Oota,” EX. 1009);
- U.S. Patent No. 6,161,518 to Nakakita *et al.* (“Nakakita,” EX. 1011);
- U.S. Patent Application Publication No. 2003/0217732 to Kataoka *et al.* (“Kataoka,” EX. 1012);
- U.S. Patent Application Publication No. 2004/0123832 to Quigley *et al.* (“Quigley,” EX. 1013);

- “Visualization and Analysis of the Impingement Processes of a Narrow-Cone DI Gasoline Spray,” *SAE Technical Paper Series*, 2001-01-2023, Published May 7, 2001, by Park *et al.* (“Park,” EX. 1014);
- “Internal Combustion Engine Fundamentals,” John B. Heywood, 1988 (“Heywood,” EX. 1015);
- European Patent Application Publication No. 0697511 to Sekiguchi *et al.* (“Sekiguchi,” EX. 1016);
- Excerpts from “Diesel-engine management”; 2nd Ed., Bosch, 1999 (“Bosch,” EX. 1017); and
- Other materials which I understand are attached to the Petition.

26. I have considered these materials through the lens of a POSITA, which is discussed further in Section VIII.C below) related to the '238 Patent as of the effective filing date, and I have done so during my review of these materials.

IV. SUMMARY OF MY OPINIONS

27. This Declaration explains the conclusions that I have formed based on my knowledge and experience and my review of the references (prior art) listed above. To summarize, I have concluded that:

- Claims 1-3, 5, and 6 are anticipated by, or minimally obvious over, Ishida;
- Claims 7 and 8 are obvious over Ishida and Oota;

- Claims 9-13 are obvious over Ishida and Gatellier;
- Claim 4 is obvious over Ishida and Iijima;
- Claim 14 is obvious over Ishida, Gatellier, and Iijima;
- Claims 1-3, 5, and 6 are obvious over Ishida, as evidenced by Takatomo;
- Claims 7 and 8 are obvious over Ishida and Oota, as evidenced by Takatomo;
- Claims 9-13 obvious over Ishida and Gatellier, as evidenced by Takatomo;
- Claim 4 is obvious over Ishida and Iijima, as evidenced by Takatomo;
- Claim 14 is obvious over Ishida, Gatellier, and Iijima, as evidenced by Takatomo;
- Claims 1-6 are obvious over Takatomo; and
- Claims 9-12 and 14 are obvious over Takatomo and Gatellier.

V. LEGAL PRINCIPLES

28. In forming my analysis and conclusions expressed in this declaration, I have applied the legal principles described in the following paragraphs, which were provided to me by Counsel.

A. Claim Construction

29. I understand that a claim must be construed under the *Phillips* standard.

Under that standard, words of a claim are given their plain and ordinary meaning as understood by person of ordinary skill in the art (also “POSITA”) at the time of invention, in light of the specification and prosecution history, unless those sources show an intent to depart from such meaning, as well as pertinent evidence extrinsic to the patent. For purposes of this declaration, I applied the plain and ordinary meaning of each term as would have been understood by a person of ordinary skill in art at the time of the alleged invention unless explicitly stated otherwise.

B. Anticipation

30. I understand that a patent claim is invalid if it is anticipated by a single item of prior art. I understand that an anticipation analysis involves two steps. First, the patent claims are construed to ascertain their scope. Second, each construed asserted claim is compared to the prior art reference on an element-by-element basis. If the prior art reference discloses or contains each and every element of the claimed invention, either expressly or inherently, then it anticipates the claim.

31. I understand that anticipation by inherent disclosure is appropriate only when a prior art reference necessarily includes or discloses the unstated claim element. I also understand that the discovery of a new or previously unreported or unappreciated property of a prior art composition, or of a scientific explanation for how a prior art composition operates, does not make the prior art composition patentably new to the entity or person that discovered the new property or mode

of operation. I further understand that there is no requirement that a POSITA would have recognized the inherent disclosure at the time of the invention.

32. For anticipation by a prior art publication or document, I understand that the reference's description must enable a POSITA to practice the claimed invention without undue experimentation. I further understand that the following factors may be considered to determine whether any experimentation would have been undue:

- a) The quantity of experimentation necessary;
- b) The amount of direction or guidance presented;
- c) The presence or absence of working examples;
- d) The nature of the claimed invention;
- e) The state of the prior art;
- f) The relative skill of those in the art;
- g) The predictability or unpredictability of the art; and
- h) The breadth of the claims.

C. Obviousness

33. I understand that a patent claim can be considered to have been obvious to a person of ordinary skill in the art at the time the application was filed. This means that, even if all of the elements of a claim are not found in a single prior art reference, the claim is not patentable if the differences between the subject matter in

the prior art and the subject matter in the claim would have been obvious to a person of ordinary skill in the art at the time the application was filed.

34. I further understand that a determination of whether a claim would have been obvious must consider several factors, including, among others:

- a) the level of ordinary skill in the art at the time the application was filed;
- b) the scope and content of the prior art; and
- c) what differences, if any, existed between the claimed invention and the prior art.

35. I understand that the teachings of two or more references may be combined in the same way as disclosed in the claims, if such a combination would have been obvious to a person of ordinary skill in the art. In determining whether a combination based on either a single reference or multiple references would have been obvious, it is appropriate to consider at least the following factors:

- a) whether the teachings of the prior art references disclose known concepts combined in familiar ways, which, when combined, would yield predictable results;
- b) whether a person of ordinary skill in the art could implement a predictable variation, and would see the benefit of doing so;
- c) whether the claimed elements represent one of a limited number of known design choices, and would have a reasonable expectation of success by a

person of ordinary skill in the art;

d) whether a person of ordinary skill in the art would have recognized a reason to combine known elements in the manner described in the claim;

e) whether there is some teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent; and

f) whether the innovation applies a known technique that had been used to improve a similar device or method in a similar way.

36. I understand that a person of ordinary skill in the art has ordinary creativity, and is not an automaton.

37. I understand that in considering obviousness, it is important not to determine obviousness using the benefit of hindsight derived from the patent being considered, and I have not done that in regards to my opinions expressed herein.

38. I understand that certain factors—often called “secondary considerations”—may support or rebut an assertion of obviousness of a claim. I understand that such secondary considerations include, among other things, commercial success of the alleged invention, skepticism of those having ordinary skill in the art at the time of the alleged invention, unexpected results of the alleged invention, any long-felt but unsolved need in the art that was satisfied by the alleged invention, the failure of others to make the alleged invention, praise of the alleged invention by those having ordinary skill in the art, and copying of the alleged

invention by others in the field. I further understand that there must be a nexus—a connection—between any such secondary considerations and the alleged invention. I also understand that contemporaneous and independent invention by others is a secondary consideration tending to show obviousness.

VI. OVERVIEW OF COMPRESSION IGNITION (I.E., DIESEL) INTERNAL COMBUSTION ENGINES

39. Almost all internal combustion engines use reciprocating engine geometry where pistons move up and down inside cylinders and, through each piston and a connecting rod, transfer power to a crankshaft and then to whatever the engine is driving. The pistons therefore move from a bottom of a cylinder to a top of the cylinder and then back down again. The bottom position of the piston is called “bottom dead center” (“BDC”) or “bottom center” (“BC”). The top position of the piston is called “top dead center” (“TDC”) or “top center” (“TC”). Each completed upward or downward motion of the piston is called a “stroke.”

40. The most common type of internal combustion engine uses a four-stroke cycle (see Figure 1-2 from Heywood below). These four strokes – a series of downward and upward motions of the piston – are called the intake stroke, the compression stroke, the expansion stroke, and the exhaust stroke. Normally, combustion occurs just before the end of the compression stroke through the start of the expansion stroke. Each piston oscillates between these strokes. *See EX.*

1015, 41, 43.

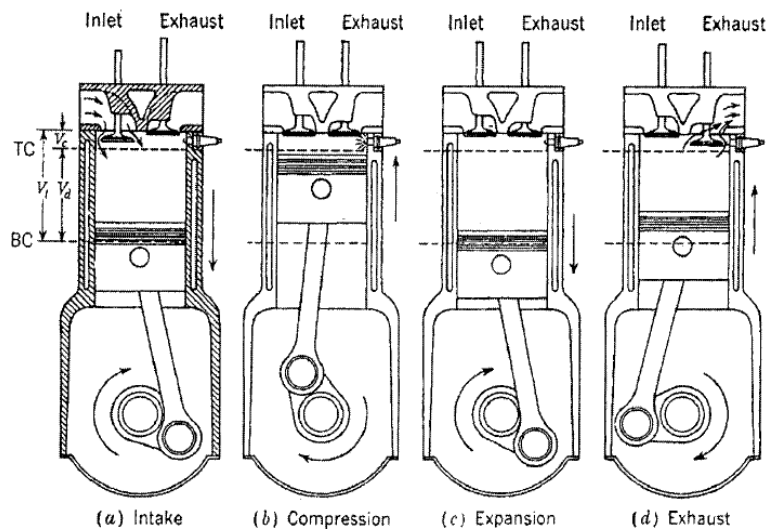


FIGURE 1-2
The four-stroke operating cycle.¹⁰

Id., 42.

41. Internal combustion engines are used to produce power by burning hydrocarbon fuels mixed with air. A cylinder head extends above each of the cylinders, and therefore each of the pistons. *Id.*, 46. The cylinders are disposed in a cylinder block. *Id.*, 44. The cylinder head is typically removably fastened to the cylinder block.

42. Compression-ignition (Diesel) internal combustion engines generate power at the crankshaft via reciprocating pistons that compress and ignite atomized/vaporized diesel fuel with air in the cylinders. Diesel engines activate intake valves and exhaust valves to pull intake air into the engine and expel exhaust gases out of the engine. Once the intake air is trapped in an engine's cylinder, the

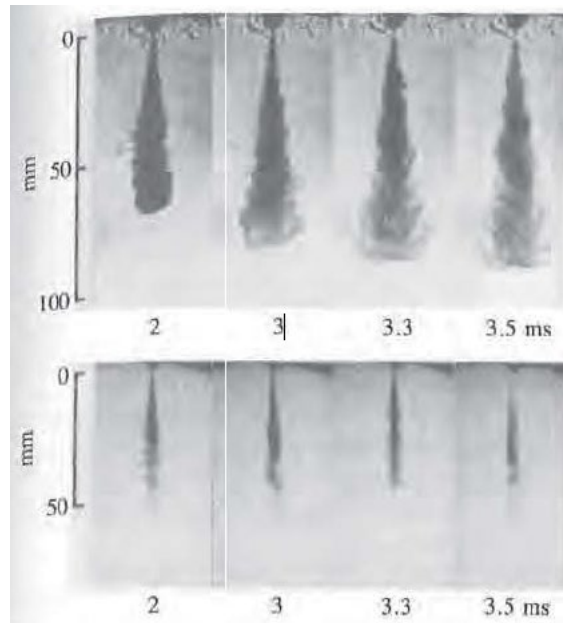
intake air is compressed by pushing the piston upward in the cylinder. This compression causes the temperature and the pressure of the trapped air to increase drastically. As the piston approaches its top-most position, the engine injects fuel (i.e., diesel fuel) into this hot air. This fuel may be injected at pressures over 20,000 pounds-per-square inch (psi), for example. This ultra-high injection pressure creates very small droplets that are subsequently vaporized by the hot air in the cylinder. Once vaporized, the fuel mixes with this trapped air. Ultimately, this vaporized fuel reaches its self-ignition temperature and the fuel ignites. Once the fuel ignites, it creates a local 'hot spot' that subsequently ignites any additional fuel and air mixtures entering this volume.

43. As the combustion process progresses, high-pressure, high-temperature exhaust gases are produced in the combustion chamber and the piston is "pushed" back down toward the bottom dead center position. Work is transferred from the high-pressure, high temperature exhaust gases by the downward movement of the piston to the crankshaft. The exhaust gases resulting from the combustion of the fuel and air mixture, along with any unburnt portion of the fuel and air mixture, are expelled through the cylinder exhaust port to an exhaust system for discharge to the atmosphere.

44. Most Diesel engines utilize a common rail fuel injection system which allows for pre-injections, multiple main injections, and post-injections. The

pre-injections and main injections are ratioed and positioned by the engine manufacturer to produce acceptable levels of in-cylinder soot and oxides of nitrogen (NO_x) while also reducing the audible noise that the engine emits.

45. The time at which an injection starts is often referred to as the engine's 'injection timing', which is commonly expressed as a number of degrees before (+) the piston arrives at top dead center or after (-) the piston arrives at top dead center. Positive injection timings often indicate early injection (injection before top dead center). Negative injection timings often indicate late injection (injection after top dead center). Late injection often includes injections slightly before top dead center (positive injection timings) or injections at top dead center. Injection may, for example, start before top dead center or at top dead center and end sometime after top dead center. When an injection starts, the high-pressure fuel inside the injector must start to accelerate the fuel out of the injection nozzle. The development of the spray plume is not instantaneous and this delay must be considered when optimizing an engine. As the fuel exits the nozzle, the liquid stream will break-up into droplets and form a spray plume – the length of the spray plume will increase until it reaches a steady size/length. Heywood shows pictures of the later portion of a spray plume development in a rapid-compression machine in Figure 10-20, reproduced below.



EX. 1015, 557.

46. It was conventional in the 1995–2010 timeframe for an engine to utilize multiple injections in a cycle of the piston. For example, engines commonly utilized one injection with an early injection timing and another injection with a late injection timing.

47. Compression ignition (Diesel) engines often use turbochargers to extract energy from the exhaust gases which is then used to compress the inlet air. This process can double or triple the density of the inlet air which can result in 2 to 3 times the power out of the same Diesel engine. As a rough approximation, the amount of engine power is proportional to the amount of air ingested into the cylinder.

48. Once discharged from the turbocharger, the exhaust gases flow

through a series of aftertreatment catalyst members which, when at the correct operating temperature, reduce harmful pollutants before the exhaust gases are discharged to the atmosphere.

VII. OVERVIEW OF COMPRESSION IGNITION INTERNAL COMBUSTION ENGINE EMISSION REDUCTION TECHNIQUES

49. The two predominant pollutants from a compression ignition (Diesel) engine that often must be addressed for emissions compliance are soot and oxides of nitrogen (NO_x).

50. Oxides of nitrogen are formed rapidly in high temperature combustion products. Nitrogen and oxygen molecules (2 oxygen atoms share electrons to form 1 oxygen molecule; 2 nitrogen atoms share electrons to form 1 nitrogen molecule) are broken apart and then combine to form oxides of nitrogen.

51. Soot is a by-product of incomplete combustion. Fuel is comprised of hydrogen and carbon atoms. The hydrogen atoms are very small and reactive compared to the carbon atoms. The hydrogen atoms are on the ‘outside’ of the fuel molecule and normally react (combust) first to form water molecules. If enough oxygen and sufficient gas/combustion temperatures exist, the carbon will then react to form carbon dioxide molecules. If there is insufficient oxygen and the gas temperatures reach a lower limit (the cylinder gas temperatures are lowered by the isentropic expansion of the cylinder gases as the piston moves downward), the

carbon will be trapped as a carbon atom. Multiple carbon atoms collide and ‘stick’ together to form soot particles. Soot particles are very porous and also routinely trap small amounts of unburnt fuel.

52. Diesel engines exhibit a phenomenon called the soot/NO_x trade-off. As the rate and the extent of combustion in a Diesel engine is predominately determined by the engine’s mixing capabilities (i.e. fuel spray that vaporizes and mixes with the air in the cylinder), fuel injected earlier in the combustion cycle tends to produce less soot and more oxides of nitrogen (NO_x).

53. Combustion of fuel when the piston is closest to its top-most position where it provides the smallest cylinder volume creates the highest combustion temperatures. Higher combustion temperatures correspond to higher NO_x formation but lower soot formation.

54. Lower combustion temperatures will create less NO_x but typically more soot. Combustion of the fuel as the piston is moving downward lowers combustion temperatures at the expense of fuel economy.

55. Another technique is to recirculate a percentage of the combustion products back into the intake system. This technique is known as “Exhaust Gas Recirculation” (EGR) and the gas provided back into the intake system is known as EGR gas. The EGR gas has sufficient time to mix uniformly with the fresh intake air. The EGR gas does not contain oxygen. When combustion occurs, the EGR gas

absorbs a portion of the combustion energy and thereby lowers the combustion temperature and hence the in-cylinder NO_x levels.

56. Since EGR positions the oxygen atoms/molecules further apart while lowering the combustion temperature, larger amounts of soot are generally created as the amount of the EGR gas is increased.

57. EGR gas is routinely cooled prior to being introduced into the intake system. For example, an exhaust gas heat exchanger (i.e., EGR cooler) can use engine coolant to cool the EGR gas. The cooled EGR gas lowers the overall intake temperature which provides lower combustion temperatures and ultimately results in further reduction of NO_x.

58. A soot filter collects soot particles that are in the exhaust gas as the exhaust gas flows through the soot filter.

59. A soot filter eventually becomes 'full' and needs to be regenerated by temporarily increasing the temperature of the exhaust gas in order to combust the soot off of the soot filter.

60. One manner in which this temperature increase is effectuated is to add unburnt fuel to the exhaust gas and then combusting the exhaust (i.e., using an igniter) downstream of the engine and upstream of the soot filter.

VIII. OVERVIEW OF THE '238 PATENT

61. The '238 Patent includes 14 claims, of which claim 1 is independent. EX. 1001, 4:41–6:19. The claims recite as follows (bold brackets and Roman numerals added for consistency with references in Section X):

1. [i] A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space, [ii] wherein the piston has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction, and [iii] [a] a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius [b] so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and [iv] [a] the surface is substantially planar and has an ascending gradient in the recess edge direction [b] such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being

distributed both in the elevation direction and in the recess edge direction.

2. The directly injecting internal combustion engine as claimed in claim 1, wherein a surface connected to the recess edge adjoins the surface of the piston recess.

3. The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.

4. The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.

5. The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the

recess edge forms an acute angle with an upper surface of the piston.

6. The directly injecting internal combustion engine as claimed in claim 5, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.

7. The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an obtuse angle with an upper surface of the piston.

8. The directly injecting internal combustion engine as claimed in claim 7, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.

9. The directly injecting internal combustion engine as claimed in claim 1, wherein an injection angle of the injection nozzle is between 50° and 120°.

10. The directly injecting internal combustion engine as claimed in claim 9, wherein a surface connected to the recess edge adjoins the surface of the piston recess.

11. The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.

12. The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.

13. The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the

recess edge forms an obtuse angle with an upper surface
of the piston.

14. The directly injecting internal combustion engine as
claimed in claim 10, wherein the surface connected to the
recess edge merges in a radius into an upper surface of the
piston.

A. Specification

62. The '238 Patent states that “present invention relates to a directly
injecting internal combustion engine with at least one cylinder which has a
combustion space and in which a piston executes an oscillating movement.” EX.
1001, 1:12–15. One such engine is a diesel internal combustion engine, as
recognized by the '238 Patent. Specifically, the '238 Patent provides that “[w]hen
early homogenization is to be achieved within the combustion space of an operating
internal combustion engine, in particular a diesel internal combustion engine, then
injection time points of approximately 130 to 30° before the top dead center of the
piston must be selected, since, at this time point, the combustion space pressure is
still relatively low, so that the injected fuel can penetrate very deeply into the
combustion space.” *Id.*, 1:25–32.

63. The '238 Patent provides that “[i]n order to prevent the injection jet from impinging onto the cylinder wall or the liner, as steep an injection angle as possible at the injection nozzle should be selected, in order to ensure as long a free jet length as possible” and “[t]his also requires the shape of the piston recess to be adapted to this injection....” *Id.*, 1:32–38. The '238 Patent explains that “it is not possible to operate the internal combustion engine with a homogeneous combustion process over its entire characteristic map, the piston recess must be designed both for homogeneous and for conventional mixture formation” and states that “[t]his is not easily possible in known solutions.” *Id.*, 1:39–43. The '238 Patent provides that “[a]n object of the present invention, therefore, is to provide a directly injecting internal combustion engine, in which the shape of the piston recess is configured such that the internal combustion engine can be operated by both a homogeneous and a conventional combustion process.” *Id.*, 1:44–48. Thus, the '238 Patent describes use of a specific piston geometry that facilitates fuel distribution for early injection timings and late injection timings.

64. The '238 Patent states that the “solution according to the invention ensures that the injection jet always impinges on the piston recess such that the injected fuel can be intermixed optimally with the air located in the combustion space, specifically independently of the time point of injection” and “[p]articularly the fact that an injection jet injected at the latest possible time point always impinges

onto the surface adjoining the elevation ensures that the momentum of the impinging injection jet is not nullified, i.e., with the result from nullification that it could no longer be used optimally for mixture formation, which, in turn, would entail an increased formation of black smoke.” *Id.*, 1:62–2:5.

65. The '238 Patent discloses “FIG. 1 shows an internal combustion engine 1 which has a crankcase 2 and a cylinder head 3” and that “[w]ithin the crankcase 2 of the internal combustion engine 1 is located at least one cylinder 4 which has a combustion space 5 and in which a piston 6 executes an oscillating movement in a way known per se.” *Id.*, 2:42–46.

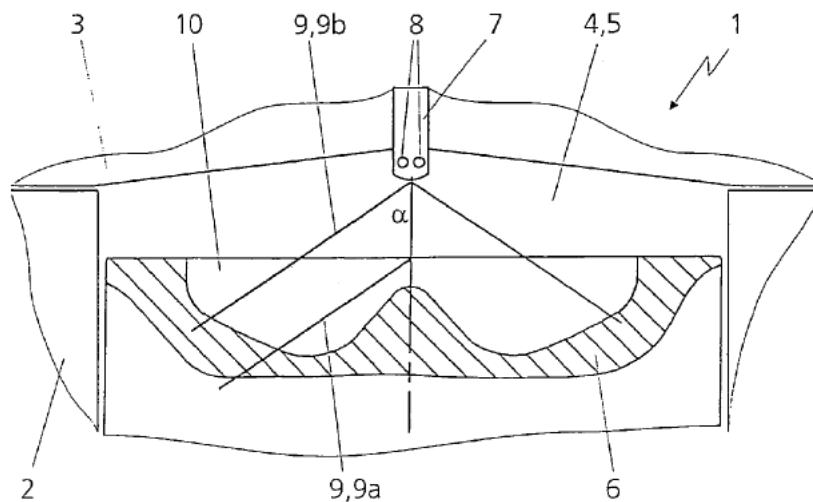


Fig. 1

Id., Fig. 1.

66. The '238 Patent provides that “FIG. 1 depicts two different injection jets, to be precise an injection jet 9a, which is obtained when the piston 6 is at a top dead center, and an injection jet 9b, which is obtained in the case of fuel injection at

the latest possible injection time point” and that “[t]he injection jets 9a and 9b are in each case illustrated merely as axes of an injection cone being distributed within the combustion space 5.” *Id.*, 2:54–60.

67. The '238 Patent states that “[t]he piston 6 has a piston recess 10 in its side facing the cylinder head 3.” *Id.*, 2:61–62. The '238 Patent provides that “[a]s can be seen in FIG. 2, the piston recess 10 has in its central region an elevation 11 extending in the direction of the cylinder head 3.” *Id.*, 3:1–3.

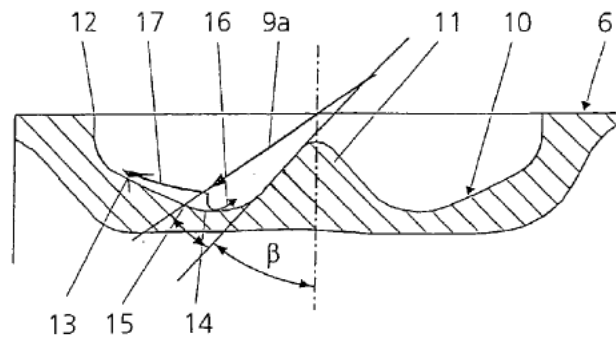


Fig. 2

Id., Fig. 2.

68. The '238 Patent states that “the elevation 11 has adjoining it in the direction of a recess edge 12, that is to say the end of the piston recess 10, a surface 13 which is connected to the elevation 11 via a radius 14 so that the injection jet 9a injected at the earliest possible time point impinges onto the surface 13 at an impingement point 15 and is distributed both in the direction of the elevation 11 and in the direction of the recess edge 12.” *Id.*, 3:8–15. The '238 Patent explains that “[t]his distribution of the injection jet 9a is important in order to intermix the fuel as

effectively as possible with the air located in the combustion space 5.” *Id.*, 3:15–18. The ’238 Patent provides that “[t]he fuel deflected in the direction of the elevation 11 is designated by the arrow 16, whereas the fuel deflected in the direction of the recess edge 12 is designated by the arrow 17.” *Id.*, 3:24–27. The ’238 Patent explains that “[i]t can be seen here, by the length of the arrows, that the fuel quantity deflected or distributed in the direction of the recess edge 12 is greater than the fuel quantity deflected in the direction of the elevation 11” and “[t]he radius 14 should be selected, in this respect, such that an accumulation of the fuel flowing back is avoided.” *Id.*, 3:27–32.

69. The ’238 Patent states that “FIG. 4 shows that the surface 13 adjoining the elevation 11 in the direction of the recess edge 12 is of essentially planar design and has an ascending gradient in the direction of the recess edge 12” and “[i]n other words, the surface 13 forms a plane which is at a constant angle γ to the injection jet 9 over the entire maximum injection duration.” *Id.*, 3:33–38.

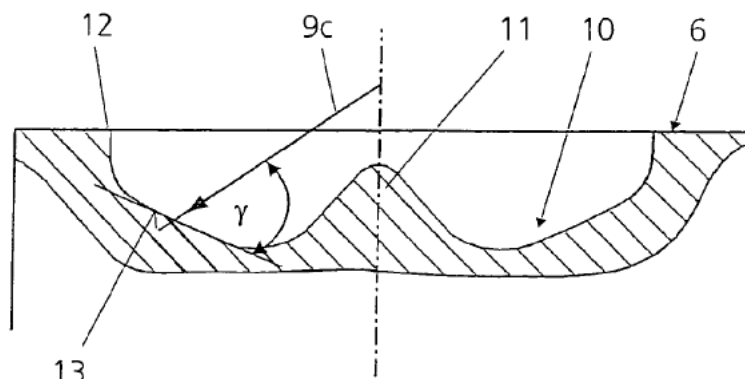
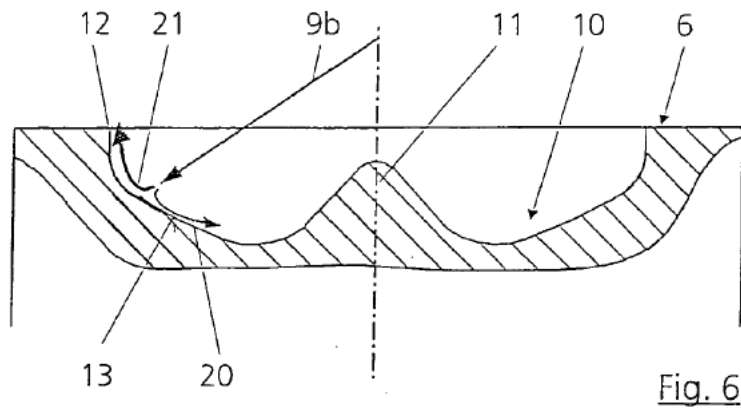


Fig. 4

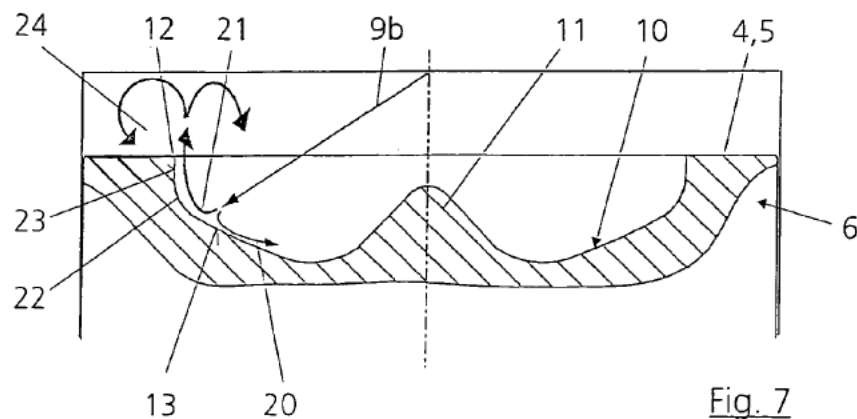
Id., Fig. 4.

70. The '238 Patent states that "FIG. 6 illustrates the injection jet 9b injected at the latest possible time point" and that "[i]n this case, the surface 13 has an extent in the direction of the recess edge 12 such that the injection jet 9b injected at the latest possible time point impinges onto the surface 13." *Id.*, 3:62–66.



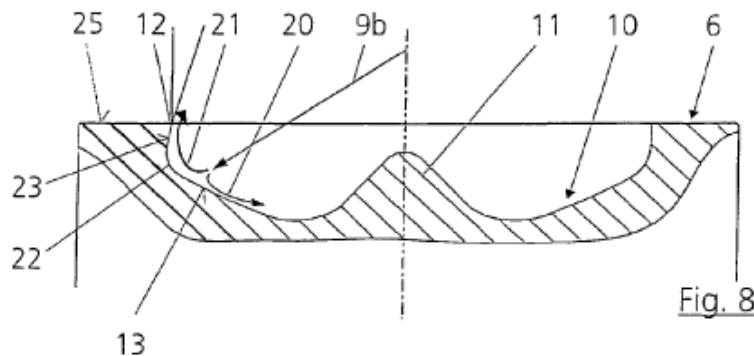
Id., Fig. 6.

71. The '238 Patent states that "[i]t is apparent from FIG. 7 that the surface 13 has adjoining it a surface 23 connected to the recess edge 12 via a radius 22." *Id.*, 4:8–9. This surface 23 is merely a geometric refinement of the piston recess.



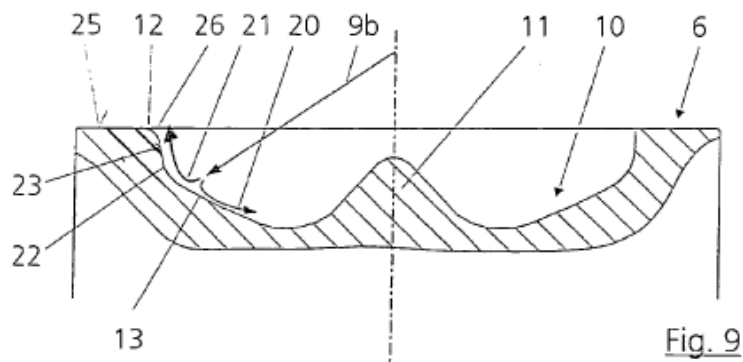
Id., Fig. 7.

72. The '238 Patent states that “[i]n the embodiment according to FIG. 8, the surface 23 connected to the recess edge 12 forms an acute angle with the upper surface 25 of the piston 6” and that “[t]he supply of fuel to a glow plug or spark plug, not illustrated, can thereby be improved.” *Id.*, 4:22–25. Similar to above, the acute angle formed by the surface 23 is merely a geometric refinement of the piston recess.



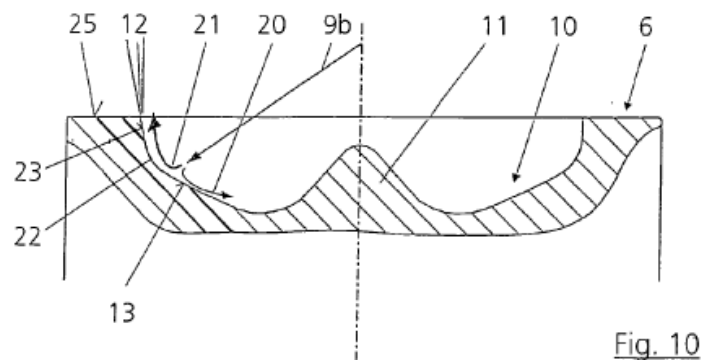
Id., Fig. 8.

73. The '238 Patent provides that “[i]n the embodiment according to FIG. 9, the surface 23 merges at a radius 26 into the upper surface 25 of the piston 6.” *Id.*, 4:26–27. Similar to above, the radius 26 is merely a geometric refinement of the piston recess.



Id., Fig. 9.

74. The '238 Patent states that "FIG. 10 illustrates an embodiment in which the surface 23 connected to the recess edge 12 forms an obtuse angle with the upper surface 25 of the piston 6." *Id.*, 4:27–30. Similar to above, the obtuse angle formed by the surface 23 is merely a geometric refinement of the piston recess.



Id., Fig. 10.

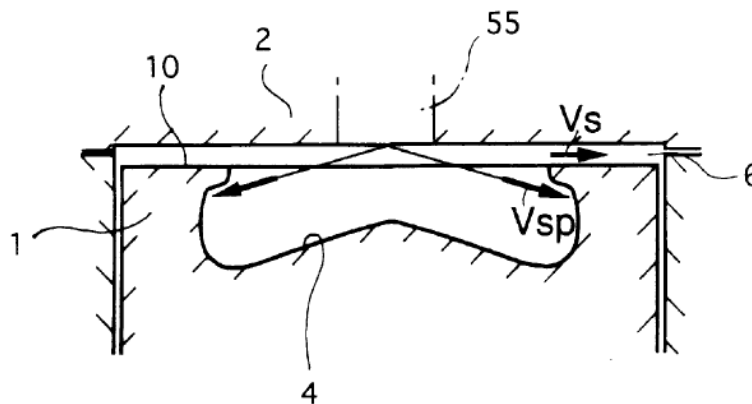
75. As I explain below, the combinations of features that the '238 Patent recites in the challenged claims were not innovative as of the effective filing date, as demonstrated at least by the prior art teachings in Ishida (EX. 1005), Takatomo (EX. 1006), Gatellier (EX. 1007), Iijima (EX. 1008), and Oota (EX. 1009).

B. Summary of the Prosecution History

76. When examination of the '238 Patent began, the applicant initially amended the specification. EX. 1011, 103–12. The applicant also canceled all original claims and added new claims 11–30. *Id.* 85–8.

77. The Examiner then mailed a non-final Office Action which rejected all of the claims. *Id.*, 38–9. In the Office Action, the Examiner rejected claims 11, 12, 16–24, and 26–30 under 35 U.S.C. § 102(b) as being anticipated by U.S. Patent No. 6,161,518 to Nakakita *et al.* (“Nakakita,” EX. 1012) with the Examiner stating “[n]ote Figures 1, 4 and 7 and column 9, line 28 through column 10, line 39.” *Id.*, 41; *see id.*, 43.

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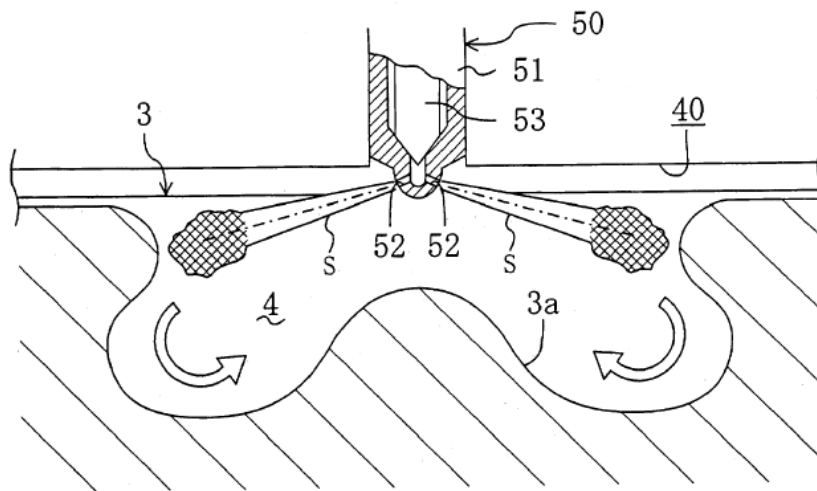


EX. 1012, FIG. 1.

78. The Examiner also rejected claims 11–15, 18–25, and 27–30 under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent Application Publication

No. 2003/0217732 to Kataoka *et al.* (“Kataoka,” EX. 1013) with the Examiner stating “[n]ote Figure 3.” EX. 1011, 41; *see id.*, 43.

FIG. 3



EX. 1013, FIG. 3.

79. The Examiner also rejected claims 11, 12, 16–24, and 26–30 under 35 U.S.C. § 102(e) as being anticipated by U.S. Patent Application Publication No. 2004/0123832 to Quigley *et al.* (“Quigley,” EX. 1013) with the Examiner stating “[n]ote Figures 2 and 4 and paragraphs 0016–0019.” EX. 1011, 41; *see id.*, 43.

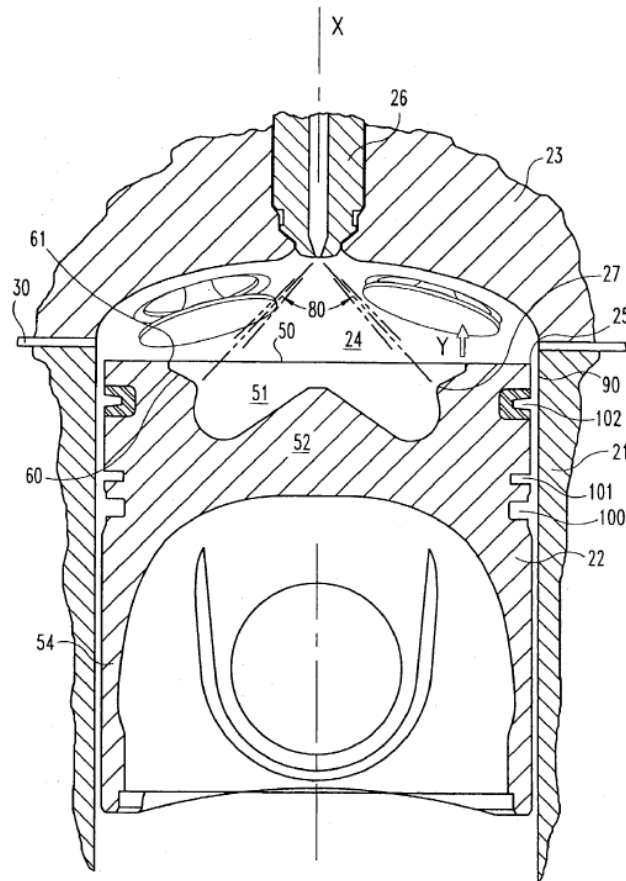


Fig. 2

EX. 1013, Fig. 2.

80. In response to the Examiner's rejections in the non-final Office Action, the applicant amended claim 1 as follows (where I understand the underlined text was added and the strikethroughed text was removed):

Claim 11 (Currently Amended): A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space, wherein the piston ~~has~~ has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction, and a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius so that an injection jet impinging ~~in this region~~ the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and the surface is substantially planar and has an extent-ascending gradient in the recess edge direction such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.

EX. 1011, 30.

81. The Applicant also canceled claims 19–21 and 28–30. The applicant did not indicate any other amendments were made to the claims. Along with these amendments, the applicant stated:

The amendments to Claim 11 are based upon the features disclosed in paragraphs [0026] and [0028] of the Specification, two of which were found in now canceled Claims 19 and 20. The claimed geometry allows the directly injecting engine to operate with both a homogenous operator and a conventional combustion operation by ensuring that the injection jet impinges at the piston recess for optimal intermixing of fuel and air independently of the injection time point as described at paragraph [0009] of the Specification. The three cited references do not show or suggest the claimed geometry in amended Claim 11.

Nakakita et al's piston does not have a surface with an ascending gradient. The Kataoka et al piston does not have a substantially planar surface anywhere in the recess. The Quigley et al piston does not have the claimed surface adjoining the elevation in terms of an ascending gradient. Nothing in the teachings of the cited documents would have led to the present invention.

Id., 33.

82. The applicant included no further discussion of the amendments, Nakakita, Kataoka, or Quigley.

83. The Examiner then mailed a Notice of Allowability allowing claims 11–18 and 22–27. *Id.*, 18. The Notice of Allowability did not include any comment from the Examiner on the claims or how they allegedly were innovative in view of the prior art (including Nakakita, Kataoka, and Quigley).

84. It is my understanding that the Examiner did not consider Ishida, Takatomo, Iijima, or Oota during the prosecution of the '238 Patent.

C. Person of Ordinary Skill in the Art

85. I understand that there are multiple factors relevant to determining the level of ordinary skill in the pertinent art, including the educational level of active workers in the field at the time of the alleged invention, the sophistication of the technology, the type of problems encountered in the art, and the prior art solutions to those problems.

86. In determining the characteristics of a hypothetical person of ordinary skill in the art of the '238 Patent at the time of the claimed invention, I considered several things, including the type of problems encountered in this field, and the rapidity with which innovations were made. I also considered the sophistication of the technology involved, the educational background and experience of those actively working in the field, and the level of education that would be necessary to understand the '238 Patent. Finally, I considered myself back in the relevant period of time and considered the state of the art and the level of skill of the persons working in this field at that time.

87. It is my opinion that the subject matter of the '238 Patent is piston recess design for a piston of an internal combustion engine. Based on the materials I have considered (including the prior art cited herein), my own knowledge and experience, and the level of skill required to design a piston recess for a piston of an internal combustion engine, I have come to the conclusion that the characteristics of

a person of ordinary skill in the art of the '238 Patent would hold at least a bachelor's degree in mechanical engineering, and two or more years of experience in mechanical engineering and/or internal combustion engine system design. This hypothetical person would be capable of performing various design tasks and would understand the basic mechanical features and operation of an engine system; this hypothetical person would also have an appreciation for combustion processes and air-fuel mixture considerations associated with an internal combustion engine. I believe these understandings are demonstrated, for example, by the prior art I discuss herein. A person could also have qualified as a person of ordinary skill in the art with some combination of (1) more formal education (e.g., an M.S. or Ph.D.) and less technical experience or (2) less formal education and more technical or professional experience in the fields listed above.

88. Although my qualifications and experience exceed those of the hypothetical person having an ordinary level of skill in the art, my analysis and conclusions herein are from the perspective of a person of ordinary skill in the art as in the 1995–2010 timeframe, unless otherwise noted.

IX. OVERVIEW OF THE REFERENCES RELIED UPON BY PETITIONER

A. Ishida

1. Overview

89. Similar to the '238 Patent, Ishida is directed to a “combustion chamber for a direct-injection diesel engine.” EX. 1005, p. 2. While Ishida is not in English, I have considered the certified translation of Ishida which a POSITA would have understood as providing the teachings of Ishida. Ishida states that its combustion chamber is “configured so that fuel is injected from a fuel injection nozzle toward a side wall of a combustion chamber at the top of a piston.” *Id.*

90. First, Ishida describes a “typical combustion chamber for a conventional direct-injection diesel engine is a spherical combustion chamber B with a lip (generally known as a squish lip) L, as shown in FIG. 1, at the top of a piston P.” *Id.*

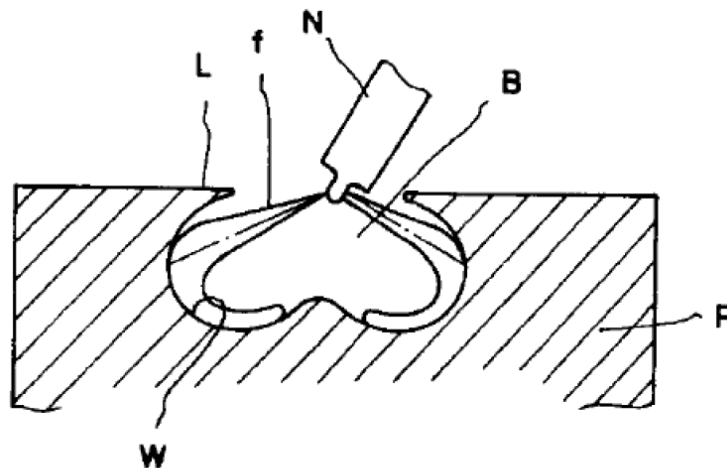


FIG. 1

Id., FIG. 1.

91. Ishida explains that in the typical combustion chamber (i.e., in a prior design), “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” *Id.*, p. 3. “HC” is the abbreviation for hydrocarbons (e.g., methane, propane, etc.). Thus, one problem Ishida seeks to solve is flow of the injected fuel downward into the cavity. Ishida states that “[i]t is an object of the present invention to overcome this problem with combustion chambers having a lip in direct-injection diesel engines by providing a combustion chamber for a direct-injection diesel engine configured so that fuel is injected from a fuel injection nozzle toward a side wall of a combustion chamber at the top of a piston, characterized in that a lip is formed at the peripheral edge of the combustion chamber inlet, and fuel from the fuel injection nozzle is set so as to impact the side wall of the combustion chamber at approximately a right angle.” *Id.*

92. Ishida discloses that “FIG. 2 is a longitudinal cross-sectional view of the combustion chamber for a direct-injection diesel engine in the present invention, in which 1 is a piston in the direct-injection diesel engine, a combustion chamber 3 with a lip 2 is formed around the peripheral edge of the inlet in a portion of the top 11, and the side wall 31 is sloped outwardly so that the injected fuel F from the fuel injection nozzle 4 impacts the side wall at approximately a right angle R.” *Id.*, 4.

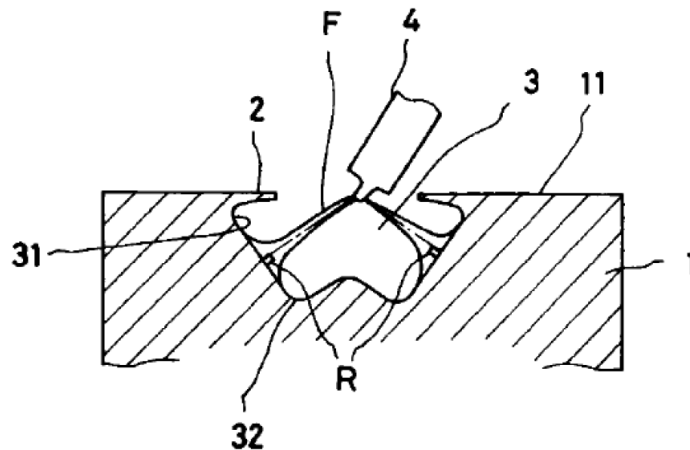


FIG. 2

Id., FIG. 2.

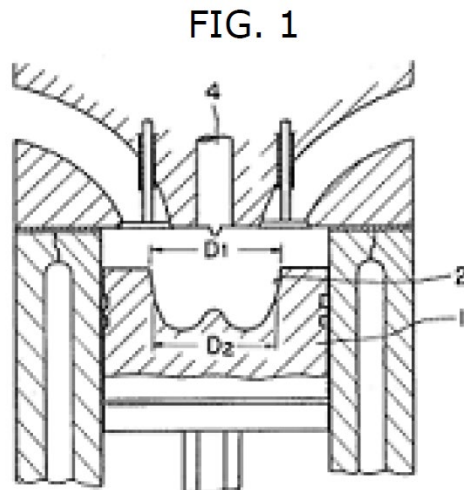
93. Ishida explains that “[b]ecause the combustion chamber 3 in the present invention is configured as described above, the injected fuel F makes an impact that causes it to rebound at the side wall 31 of the combustion chamber 3.” *Id.*, 4. Ishida further explains “[b]ecause this significantly reduces the proportion of fuel in the combustion chamber reaching the bottom 32 along the side wall 31, together with the effect of the lip 2, white smoke, odors, HC, etc., are significantly reduced.” *Id.* Ishida therefore has a mechanism of impinging the side wall 31. A POSITA would have understood that the degree to which this impingement occurs would vary with, for example, injection timing and injection pressure, but fundamentally this mechanism is always active regardless of injection timing and injection pressure.

B. The Ishida-Oota Combination

1. Overview of Oota

94. Similar to the '238 Patent, Oota is directed to “combustion chamber of a direct injection diesel engine.” EX. 1009, p. 1. While Oota is not in English, I have considered the certified translation of Oota which a POSITA would have understood as providing the teachings of Oota.

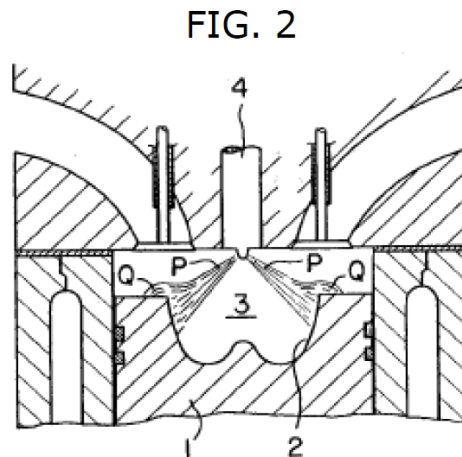
95. Oota states that a “combustion chamber in a conventional direct-injection diesel engine has a space formed by a recess 2 at the top of the piston 1, as shown in FIG. 1, and the combustion chamber 3 usually increases in diameter from the bottom to the top of the recess 2.” *Id.* As shown in Figure 1, below, Oota discloses that the “the inner diameter D_1 of the combustion chamber inlet in the figure is larger than the inner diameter D_2 of the central portion ($D_1 > D_2$).” *Id.*



Id., FIG. 1.

96. Oota also states that “FIG. 2 shows fuel being injected in this known combustion chamber 3” and that the “fuel (P) injected from the nozzle 4 into the combustion chamber 3 is partly blown upward toward the top of the piston 1 (as shown by Q in the figure).” *Id.* Oota explains that “[t]his fuel Q blown upward causes incomplete combustion, resulting in increased diesel black smoke and reduced combustion efficiency.” *Id.* While some of the flow in Oota that contacts the side wall 2 flows upward, a portion of the flow is directed onto the top of the piston 1 (without first flowing off the side wall 2). A POSITA would have understood that this portion that is directed onto the top of the piston 1 would “result[] in increased diesel black smoke and reduced combustion efficiency.” Specifically, fuel adhering to the top of the piston would be combusted in a manner that would have generated significant black smoke. This understanding is evidenced by, for example, Takatomo. *See* EX. 1006, 8:10-15 (“In summary, according to the present invention, the strength of the lip can be ensured, and even in an operation region with a long injection period, the fuel spray can be prevented from remaining on the top surface of piston and the bottom of cavity before and after top dead center, thereby achieving an excellent effect in reducing the amount of discharged HC.”); *see also, id.*, 3:50-59 (“the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated”).

Thus, reducing the portion of the fuel that is directed onto the top of the piston 1 in the design of Figure 2 of Oota would have been desirable.



EX. 1009, FIG. 2.

97. Oota explains that “[i]n addition, diesel engines are required to reduce NOx in exhaust gas, and there is a trend toward delaying the fuel injection timing.” *Id.* Oota also explains that “the disadvantage of delaying the injection timing is that black smoke increases.” *Id.* Oota provides that “[i]t is an object of the present invention to improve the open-chamber type combustion chamber and realize a combustion chamber for a diesel engine with a structure and effect different from those of squish lip type combustion chambers that prevents damage due to thermal stress.” *Id.*

2. The Combination of Ishida and Oota was Predictable

98. Counsel has informed me that the teachings of a reference may only be used to establish unpatentability where the reference is analogous art to the patent

application (or, as here, a claim of the '238 Patent where the reference is analogous art to the '238 Patent). Counsel has informed me that the reference and the patent application or patent (here the '238 Patent) are analogous art where the reference and the patent application or patent (here the '238 Patent) are directed to the same field of endeavor and to solving the same problem.

99. The field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. For example, the '238 Patent states that “[a]n object of the present invention, therefore, is to provide a directly injecting internal combustion engine, in which the shape of the piston recess is configured such that the internal combustion engine can be operated by both a homogeneous and a conventional combustion process.” *Id.*, 1:44–48. The '238 Patent provides that “[t]his object has been achieved, according to the invention providing that a surface of the piston recess which adjoins the elevation in the direction of the recess edge is connected to the elevation vi a radius in such a way that an injection jet impinging in this region and injected at the earliest possible time point is distributed both in the direction of the elevation and in the direction of the recess edge, and in that the surface adjoining the elevation in the direction of the recess edge has an extent in the direction of the recess edge such that an injection jet injected at the latest possible time point impinges onto the surface, the injection jet injected at the latest possible time point being distributed both in the direction of the elevation and in the direction of the

recess edge.” *Id.*, 1:49–61. Ishida and Oota are analogous art directed to the same field of endeavor as the ’238 Patent. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Oota states that “[t]he present invention relates to a combustion chamber of a direct injection diesel engine.” EX. 1009, p. 1.

100. The ’238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Specifically, the ’238 Patent states that “[t]he solution according to the invention ensures that the injection jet always impinges on the piston recess such that the injected fuel can be intermixed optimally with the air located in the combustion space, specifically independently of the time point of injection.” EX. 1001, 1:62–6. The ’238 Patent explains that “[p]articularly the fact that an injection jet injected at the latest possible time point always impinges onto the surface adjoining the elevation ensures that the momentum of the impinging injection jet is not nullified, i.e., with the result from nullification that it could no longer be used optimally for mixture formation, which, in turn, would entail an increased formation of black smoke.” *Id.*, 1:66–2:5. Ishida and Oota are directed to the same problem as the ’238 Patent. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.”

EX. 1005, p. 3. Oota states that “[t]he combustion chamber of the present invention is configured as described above to prevent fuel blow-up in conventional open-chamber combustion chambers and to obtain a combustion chamber with high combustion efficiency, no generation of diesel black smoke, and no NO_x emissions.”

EX. 1009, p. 3.

101. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida and Oota because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

102. While Ishida's piston includes a lip, lipless piston designs were well known and conventional. Indeed, the design choice of whether or not to include a lip was a question that was considered in concert with other design variables such as where injected fuel impinges on the piston, desired cost of the piston, cost and manufacturing considerations, and risk of cracking portions of the piston depending on desired operating conditions of the piston.

103. Ishida teaches that its lip provides an effect that, “together” with impingement on the side wall, provides desirable combustion. A POSITA, guided by the principle that piston design concerns more than simply seeking the most desirable combustion, would have recognized that while removal of the lip may make combustion less desirable in some situations, it also would make the piston

more desirable in some respects. Specifically, factors such as cost and durability are significant in the design of a piston. A POSITA would have recognized that the lip of Ishida would have been relatively expensive to include in the piston design. Specialized machining or casting would have been required to form the lip. Additionally, finishing (i.e., polishing) the piston of Ishida would have been difficult because of the lip. These difficulties would have significantly increased the cost of the piston. Moreover, a POSITA would have recognized that the lip of Ishida would have been particularly prone to cracking. For example, thermal stresses would have concentrated at the lip due to its relatively thin and protruding profile. *See* EX. 1008, 1:33–37 (discussing thermal stress in piston design). Additionally, the lip is particularly located in a region that gets relatively hot due to the location of combustion in Ishida’s combustion chamber. A lip also presents a portion that is prone to damage when pistons are installed and serviced. Thus, removal of the lip would have provided certain advantages to a POSITA.

104. Oota teaches a lipless design that is not subject to these shortcomings of the lip of Ishida. A POSITA would have understood that the drawbacks described in Oota (increased diesel black smoke and reduced combustion efficiency) are largely, if not entirely, due to the overspray Oota teaches occurs onto the top surface of the piston. This understanding is evidenced by, for example, Takatomo. *See* EX. 1006, 8:10-15; *see also, id.*, 3:50-59. This oversprayed fuel would not mix well with

air and instead would adhere to the top surface of the piston, resulting in undesirable generation of smoke. Ishida avoids such overspray by impinging the fuel on the side wall at all injection timings. Thus, the drawbacks of Ishida's lip and the drawbacks of Oota's lipless design would be avoided by removing the lip, as taught by Oota, and impinging the side wall across all injection timings, as taught by Ishida. Moreover, the lipless design of Oota was economically beneficial relative to the specially-machined lip of Ishida. A POSITA would have therefore found it obvious to modify Ishida to remove the lip in pursuit of decreased cost and/or increased durability.

105. Moreover, a POSITA would have had a reasonable expectation of success in such a modification of Ishida because Oota teaches that such a modification was already done (i.e., lipless pistons were a known design alternative). Indeed, this modification of Ishida would require only application of known engineering approaches taught by Oota, which would have been obvious to a POSITA when considering Ishida. Finally, a POSITA would have been motivated by Oota to make such a modification of Ishida in order to decrease risk of the piston cracking and avoid increased cost and complexity associated with the lip. When used in Ishida, which consistently impinges the side wall, the lipless design of Oota would not experience the significant overspray depicted in Oota (because Oota does not teach the same side wall impingement as in Ishida).

C. The Ishida-Gatellier Combination

1. Overview of Gatellier

106. Similar to the '238 Patent, Gatellier is directed to a “direct-injection internal-combustion engine.” EX. 1007, ¶[0001]. Gatellier states that the “development of combustion systems for internal-combustion engines must meet requirements such as emissions reduction, torque and specific power increase, combustion noise reduction, while remaining compatible with endurance criteria.” *Id.*, ¶[0003]. Gatellier explains that “[e]ngineers currently have a wide range of possible modifications allowing these objectives to be reached” and that “[t]hey can change, for example, design or adjustment parameters, like the shape of all or part of the combustion chamber, such as the bowl, provided in the upper part of the piston, in order to facilitate air/fuel mixing.” *Id.*, ¶¶[0004]–[0005]. Gatellier teaches that these engineers “can also change the compression ratio, certain parameters of the injection system (pressure, control law, etc.) and of the fuel jets (number of holes, diameter, etc.), the pressure charging adjustment, the EGR (exhaust gas recirculation) ratio or the intake temperature.” *Id.*, ¶[0006].

107. Gatellier explains that “[u]nfortunately, it is increasingly difficult to improve one of these points without deteriorating another one” and a “well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶¶[0007]–[0008]. Gatellier states that “[t]he problem is even more

difficult to solve when endurance criteria have to be taken into account.” *Id.*, ¶[0009]. Gatellier explains that “[t]his is for example the case for the liquid fuel or the soot in the vicinity of the cylinder walls, whose presence, harmful to the lubricant stability, depends on the nappe angle of the injection nozzle, on the shape of the bowl or on the timing and on the injection pressure” and “[a]djustment of these parameters unfortunately has a harmful effect on the combustion, leading to an emissions increase and/or to a reduction in the full load performances and/or to a noise increase.” *Id.*, ¶[0010].

108. In describing prior designs, Gatellier states that “[t]hese combustion chambers are delimited on one side by the upper wall of the piston, which comprises a conical or truncated shaped part referred to as teat, pointing towards the cylinder head and having the same axis, at the center of a circular cup or bowl.” *Id.*, ¶[0011]. Gatellier discloses that the “fuel is injected through a multijet nozzle in line with each cylinder, with a very wide nappe angle of the order of 140 to 160” and that “[t]he angle at the top of the teat is suited to the nappe angle of the injection nozzle so that the fuel jets are injected substantially along the slopes of the cone, then diverted thereby and by the rounded shape of the cup towards the top of the cylinder, thus vaporizing without ever touching the walls of the cylinder and therefore without affecting its lubrication.” *Id.* Gatellier explains that “[o]f course, the pistons have to be quite close to the top dead center (TDC) thereof for this effect to be obtained”

and “[o]nly a limited latitude is therefore available for selection of the fuel injection times.” *Id.*

109. Gatellier explains that “[t]his latitude constitutes a drawback that is by no means insignificant since it is also well-known that early and late fuel injections afford many advantages” and “[t]hus, a pilot injection before the top dead center and the main injection allows the combustion noise to be reduced.” *Id.*, ¶[0012]. Gatellier states that “[r]egeneration of the particle filters, which is initiated, according to a known technique, by raising the exhaust temperature, requires a fuel injection shortly before opening of the exhaust valves” and that “[a] fuel injection during expansion or during the exhaust phase can also be useful to obtain favourable exhaust conditions allowing regeneration of the NO_x traps.” *Id.* Gatellier explains that “[s]ince combustion systems generally use injection nozzles with nappe angles ranging between 140° and 160°, the adjustment range of these injections is reduced to limit problems of lubricant dilution by fuel or soot.” *Id.*, ¶[0013]. Gatellier states that “[i]n order to overcome this limitation, the present invention proposes an engine developing a combustion allowing very varied injection conditions.” *Id.*, ¶[0014].

110. Additionally, Gatellier teaches that “[u]sing an injection nozzle with a relatively narrow nappe angle offers a great latitude for selection of the fuel injection times while avoiding the drawbacks linked with the wide dispersion of the fuel injected, notably as regards wetting of the cylinder walls.” *Id.*, ¶[0017]. Gatellier

explains that “[t]his type of injection nozzle is well-suited to the combustion mode referred to as homogeneous combustion.” *Id.*

111. Gatellier teaches that “[a]ccording to a process of the invention for improving the latitude of operation of a direct-injection internal combustion engine comprising at least one cylinder, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on one side by the upper face of the piston comprising a teat pointing towards the cylinder head, it is characterized in that it consists:...for low and average loads, in injecting the fuel into each cylinder through an injection nozzle with a nappe angle less than or equal to $2\text{Arc}r g \frac{CD}{2F}$,...where CD is the diameter of the cylinder and F is the distance between the point of origin of the fuel jets from the injection nozzle and the position of the piston corresponding to a crankshaft angle of 50 in relation to the top dead center (TDC) so as to obtain a long mixing time of the fuel with the air admitted before combustion of this mixture,...for high loads, in injecting the fuel through the same injection nozzle with the same nappe angle, so as to obtain stratified mixing of the fuel with the air and a progressive combustion.” *Id.*, ¶¶[0042]–[0045].

112. Gatellier states that “FIG. 1 diagrammatically shows an internal-combustion engine provided with a fuel injection nozzle with a narrow nappe angle and a piston surface of carefully designed profile affording a greater latitude as

regards selection of the possible injection times.” *Id.*, ¶[0048]. Gatellier explains that “[w]ith reference to FIGS. 1 and 2, an internal combustion engine provided with a fuel injection nozzle, of Diesel type for example, comprises at least one cylinder 1 of axis XX with a cylinder head 2, air intake means and burnt gas exhaust means, in the present case respectively one or more intake valves 3, one or more exhaust valves 4, a piston 5 sliding in cylinder 1 and a fuel injection nozzle 6 such as a multijet nozzle, preferably arranged in line with axis XX of the cylinder.” *Id.*, ¶[0052]. Gatellier also provides that the “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060].

part 9 of upper face SP of piston 5.” *Id.*, ¶[0064].

114. Gatellier explains that its “face comprises a teat 7 whose axis is coaxial to the axis of the fuel nappe coming from injection nozzle 6, which points towards cylinder head 2 at the center of a cup or bowl 8 whose axis is also coaxial to the axis of the fuel jet nappe from nozzle 6.” *Id.*, ¶[0061]. Gatellier discloses that “[t]he concave part of this bowl is pointed towards this cylinder head 2 and it opens onto a substantially horizontal part 9 of said piston.” *Id.*

115. Gatellier states that “[t]he fuel injection nozzle has a small nappe angle α_1 , nappe angle α_1 , being selected at most equal to 120° and preferably ranging between 40° and 100° .” *Id.*, ¶[0054]. Gatellier explains that this “nappe angle is so selected that the walls of the cylinder are never wetted by the fuel for any position of the piston ranging between $+50^\circ$ and $+\alpha$ or between -50° and α , where α represents the crankshaft angle for the injection phase selected in relation to the top dead center (TDC), this angle α being greater than 50° and less than or equal to 180° to obtain a homogeneous type combustion.” *Id.*, ¶[0055]. Similarly, Gatellier states that its “invention thus allows to obtain a great latitude for the selection of the injection times since the injection nozzle as defined above allows to obtain a fuel jet nappe that will not wet the cylinder walls for an injection ranging between the positions of the piston corresponding to a crankshaft angle ranging between 50° and $+\alpha$ or between -50° and 31α , where α represents the crankshaft angle for the injection phase

selected in relation to the top dead center (DC), this angle α being greater than 50° and less than or equal to 180° .” *Id.*, ¶[0058].

116. Gatellier states that “[t]he angle at vertex a_2 of teat 7 is substantially suited to the nappe angle a_1 , of injection nozzle 6 so that the fuel is injected substantially along flank 11 of the teat when the piston is in the neighbourhood of the top dead center (TDC).” *Id.*, ¶[0063]. Gatellier explains that the “shape of bowl 8 is compatible with the nappe angle a_1 , selected” and “[i]t is so designed as to allow, in the conventional type operating mode (for any position of piston 5 up to $\pm 30^\circ$ in relation to the top dead center (TDC) for example), to obtain the desired effect of diversion of the injected fuel towards the cylinder head (along the concave part thereof towards the outside of the bowl) and its vaporization without wetting the cylinder walls.” *Id.*, ¶[0067].

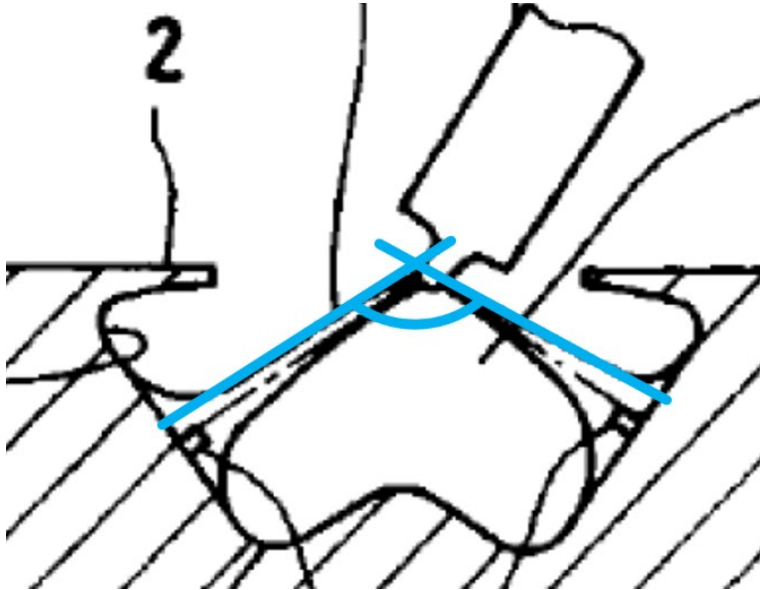
2. The Combination of Ishida and Gatellier was Predictable

117. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida and Gatellier are analogous art directed to the same field of endeavor as the '238 Patent. For example, Gatellier is directed to a “direct-injection internal-combustion engine according to the invention, comprising at least one cylinder with a cylinder head, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on

one side by the upper face of the piston comprising a teat pointing towards the cylinder head and arranged at the center of a concave bowl....” EX. 1007, ¶[0015]. Gatellier discloses that its “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060]. Ishida states that its “invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2.

118. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida and Gatellier are directed to the same problem as the '238 Patent. Specifically, Gatellier states that “[u]nfortunately, it is increasingly difficult to improve one of these points [(compression ratio, certain parameters of the injection system (pressure, control law, etc.), certain parameters of the fuel jets (number of holes, diameter, etc.), pressure charging adjustment, exhaust gas recirculation ratio, intake temperature)] without deteriorating another one.” EX. 1007, ¶[0007]; *see id.*, ¶[0006]. Gatellier explains that “[a] well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶[0008]. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3.

119. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida and Gatellier because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.



Id., FIG. 2 (annotated).

120. First, a POSITA would have understood that Ishida's Figure 2 depicts an injection angle of approximately 120°. I have annotated this injection angle in Ishida above. This injection angle is easily determined from Figure 2 by comparing the furthest extent (leftmost blue line) of one spray cone to the opposite extent (rightmost blue line) of the other spray cone. Thus, Ishida on its own utilizes an injection angle that is "between 50° and 120°." Second, use of injection angles "between 50° and 120°" was typical. Specifically, a POSITA would have understood

that fuel injection nozzles, like that of Ishida, conventionally have injection angles within the broad range of 50° to 120° . Indeed, a POSITA would have understood that injection nozzles, like that of Ishida, conventionally have injection angles between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier. Thus, a POSITA would have understood that the injection nozzle of Ishida has an injection angle between 0° and 120° (or preferably between 40° and 100°). In other words, while Ishida does not explicitly provide its injection angle, injection nozzles are conventionally understood to have injection angles between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier.

121. Additionally, a POSITA would have found it obvious to modify the injection nozzle of Ishida to have an injection angle between 0° and 120° (or preferably between 40° and 100°) as in Gatellier. First, Ishida and Gatellier use their injection nozzles for the same purpose (injecting fuel). Second, Ishida does not teach that the injection nozzle includes any structure that would preclude an injection angle between 0° and 120° (or preferably between 40° and 100°). Third, a POSITA would have understood that there are certain types of applications where an injection angle between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier, is preferred, such as applications where the diameter of the piston and the length of the straight portion of the cavity require an injection angle between 0° and 120° (or preferably between 40° and 100°) for impingement on the straight portion at target

injection timings. The injection angles of Gatellier would provide enhanced performance and flexibility of an engine (e.g., to handle additional load conditions, etc.). Moreover, Gatellier's goal is to avoid wetting the wall of the cylinder (*see* EX. 1007, ¶¶[0046], [0055], [0058], [0067]), and a POSITA would have recognized that Gatellier's injection nozzle is instrumental in that effort. Thus, a POSITA would have recognized that implementing Gatellier's injection nozzle in Ishida would have beneficially reduced wall wetting. When considering issues common in the field, such as facilitating combustion at desired injection timings and avoiding wall wetting, a POSITA would have been motivated to utilize Gatellier's injection angle to tailor a fuel injector for a target application. A POSITA would have understood that the foundational side wall impingement approach of Ishida would be retained when utilizing the injection angles taught by Gatellier.

122. In view of the similarities between the fuel injectors described in Ishida and Gatellier and the lack of Ishida to describe any structure which would prohibit use of a slightly different injector, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida. Modifying one known component (an injector) to have characteristics of another conventional component would have been a routine and standard engineering approach.

D. The Ishida-Iijima Combination

1. Overview of Iijima

123. Iijima states that its “invention relates to a piston for internal combustion engines which has a combustion chamber in a top surface thereof.” EX. 1010, 1:6–9. In describing the “Related Art,” Iijima describes a “piston for internal combustion engines which has a combustion chamber in a top surface thereof, for example, a piston for diesel engines which has a re-entrant type combustion chamber (a combustion chamber having an opened portion of a diameter smaller than a maximum inner diameter of the combustion chamber, and a comparatively deep recess) in a top surface thereof....” *Id.*, 1:11–27. Iijima explains that “[s]uch a structure is effective when an engine output is at a normal level but, when the level of an engine output is increased high, a high thermal load is imparted to the piston, so that the temperature of the cross-sectionally angular portion (edge portion) excessively increases.” *Id.*, 1:28–32. According to Iijima, “[t]his would cause inconveniences to occur which include cracks ascribed to a decrease in the high temperature strength of the material of the piston, the thermal deformation thereof and a high thermal stress put thereon” and “[t]herefore, the durability of the combustion chamber decreases.” *Id.*, 1:33–37. Iijima also describes how “when the combustion chamber is formed...by shaving off the wall thereof from the inner side of the edge section of the cross-sectionally angular portion thereof, the edge of the

cross-sectionally angular portion still remains” and “[t]herefore, heat points readily occur on the edge, and a sufficiently much improvement of the durability of the piston cannot be expected.” *Id.*, 2:28–37.

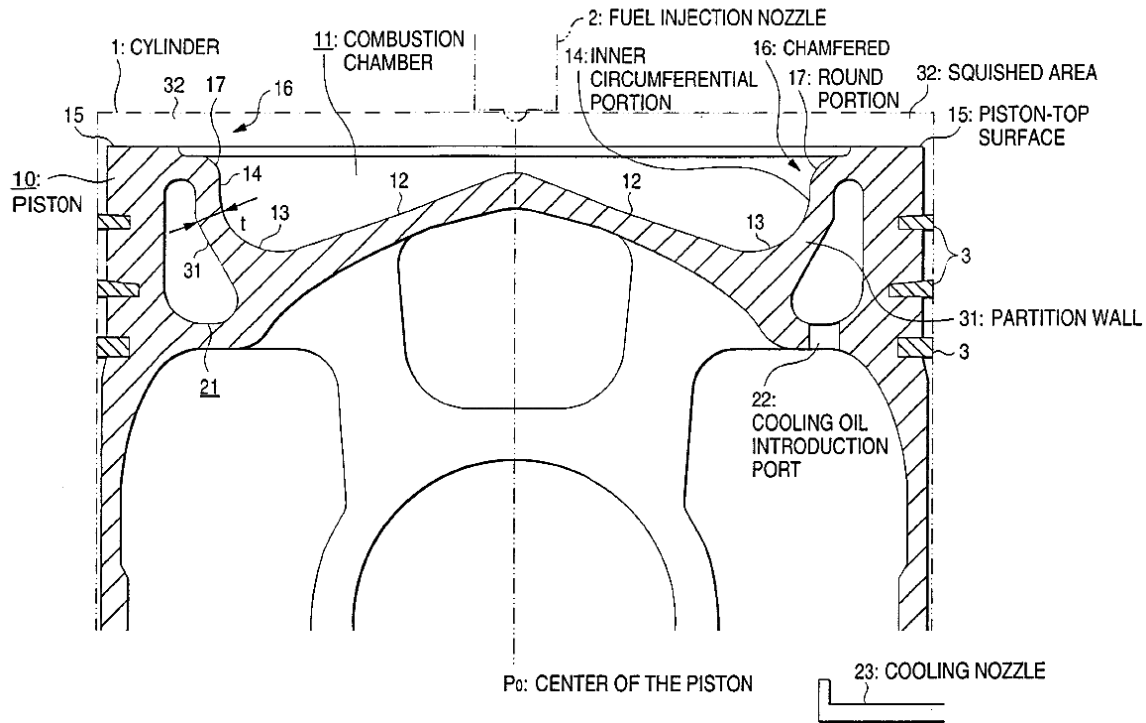
124. In describing its invention, Iijima discloses a “combustion chamber formed by recessing the same top surface, and in an outer circumferential wall of the combustion chamber with a cooling cavity the inner diameter of a lower portion of an inner circumferential surface of which is set smaller than that of an upper portion thereof, wherein a cross-sectionally angular portion defined by an upper edge portion, at which the combustion chamber is opened in the interior of a cylinder, of an inner circumferential surface of the combustion chamber and a piston-top surface is chamfered greatly in conformity with the cross-sectional shape of the upper portion of the inner circumferential surface of the cooling cavity to such an extent that the thickness of an upper portion of an inner circumferential wall of the cooling cavity does not greatly vary.” *Id.*, 2:47–67.

125. Iijima states that “[w]hen the high-pressure injection of a fuel (at, for example, 1500 Kg/cm^o to 2500 Kg/cm², and at 2000 Kg/cm² to be exact) is carried out, the fuel is atomized, so that the mixing of the fuel with the air can be done satisfactorily even when a whirling current is not generated.” *Id.*, 3:54–58; *see id.*, 9:1–8. Iijima also states that “the edge section of the re-entrant portion is not strictly required.” *Id.*, 3:58–59.

126. Iijima explains that heat points are areas “in which the temperature rises excessively.” *Id.*, 3:32–35. Iijima explains that formation of heat points on a piston cause problems. Specifically, heat points cause “inconveniences including the occurrence of cracks due to a decrease in the high temperature resistance of the material of the piston, the thermal deformation of the piston and the thermal stress put thereon.” *Id.*, 3:35–42. Iijima explains that formation of heat points decreases durability of the combustion chamber. *Id.*, 6:24–27. Additionally, heat points cause deformation. *Id.*, 6:54–57.

127. Iijima states that “FIG. 1 shows a piston for diesel engines to which the invention is applied.” *Id.*, 5:1–2. Iijima explains that FIG. 1 shows a piston 11, a combustion chamber 11, and a fuel injection nozzle 2. *Id.*, 5:2–12. Iijima explains that “[t]he combustion chamber 11 is formed to a shallow bowl-like toroidal shape, and provided with a conical portion 12 inclined downward as it extends from the center Po of the piston 10 toward the outer circumference thereof, and an inner circumferential surface portion 14 extending from an outer circumference of the conical portion 12 so as to be opened in the interior of a cylinder 1 via an arcuate portion 13.” *Id.*, 5:41–47.

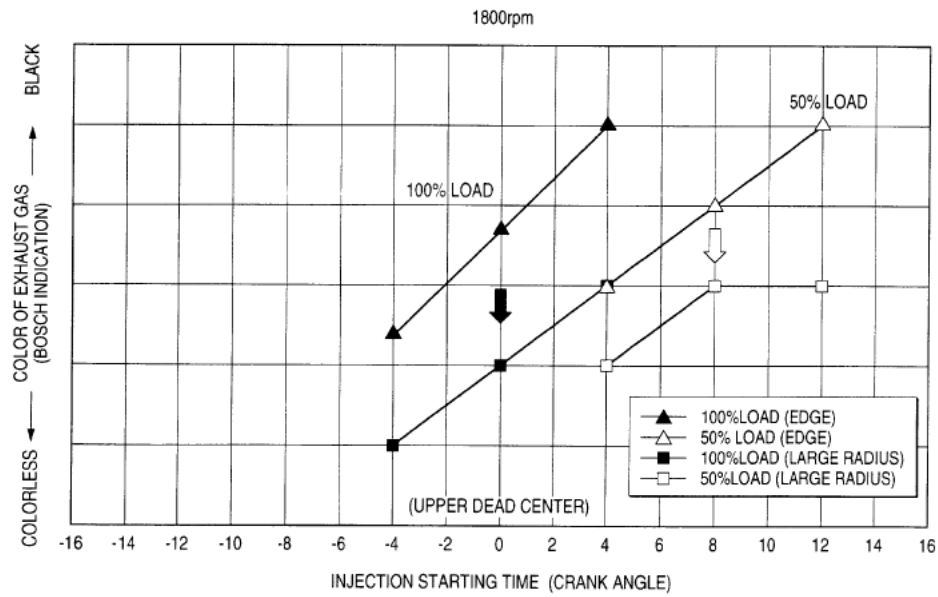
FIG. 1



Id., FIG. 1.

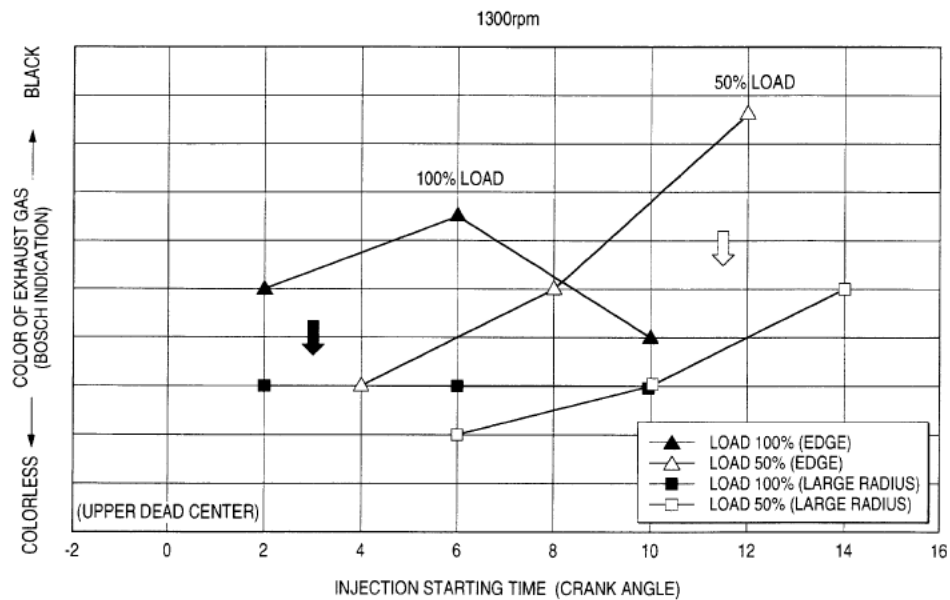
128. Iijima states that “[a]n angular portion defined by the inner circumferential surface 14 and top surface 15 of the piston 10 is greatly chamfered 16” and that the “chamfered portion is formed to a comparatively large radius 17.” *Id.*, 6:54–61. Iijima provides that “FIGS. 3 and 4 show the exhaust performance improving effect in a case where the cross-sectionally angular portion defined by the upper edge portion of the inner circumferential surface 14 of the combustion chamber 11 and the top surface 15 of the piston 10 and forming an edge (comparative example) is greatly rounded (this mode of embodiment).” *Id.*, 7:45–49.

FIG. 3



Id., FIG. 3.

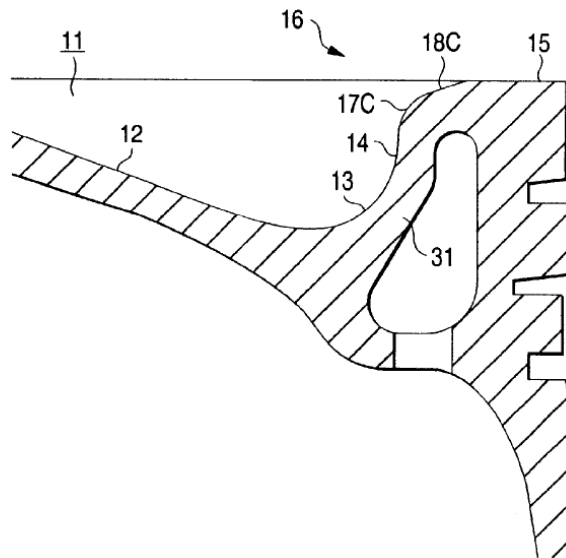
FIG. 4



Id., FIG. 4.

129. Iijima states that a “chamfered portion shown in FIG. 7 is identical with that shown in FIG. 6 in which an inner portion of an acute angle is rounded 17” and that “[n]amely, the chamfered portion is provided with a rounded portion 17C curved gradually in the inward direction as this rounded portion extends from a circumferential surface portion 14 toward a piston-top surface 15, and a conical surface portion 18C formed on the outer side of the rounded portion and inclined so that the height thereof increases gradually as the conical surface portion extends outward toward the piston-top surface 15.” *Id.*, 8:27–36.

FIG. 7

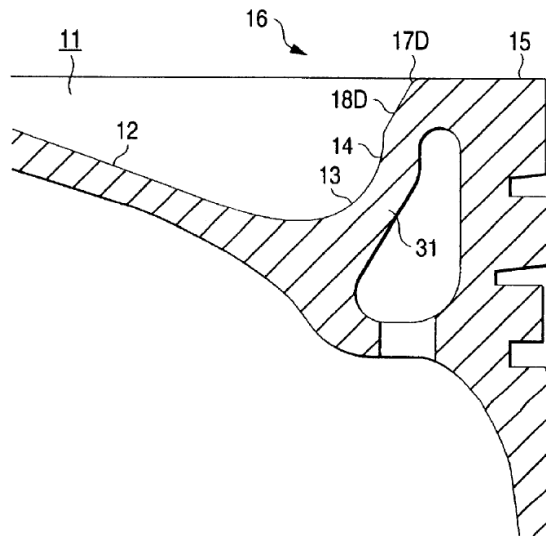


Id., FIG. 7.

130. Iijima explains that a “chamfered portion shown in FIG. 8 is provided with a conical surface portion 18D extending incliningly in the outward direction so that the height thereof increases gradually from a circumferential surface portion 14 toward a piston-top surface 15, and a rounded portion 17D formed on the outer side

of the conical surface portion and bent gradually outward in an arcuately curved manner toward the piston-top surface 15.” *Id.*, 8:37–44.

FIG. 8



Id., FIG. 8.

131. Iijima explains that “[a]s is understood from FIGS. 7 and 8, providing rounded portions 17C, 17D on the cross-sectionally angular portions of acuter angles is effective in preventing heat points from occurring.” *Id.*, 8:45–48.

2. The Combination of Ishida and Iijima was Predictable

132. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida and Iijima are analogous art directed to the same field of endeavor as the '238 Patent. For example, Iijima states that its “invention relates to a piston for internal combustion engines, and more particularly to a piston for internal combustion engines which has a combustion chamber in a top surface thereof.” EX. 1008, 1:6–9. Ishida states that its “present

invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2.

133. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida and Iijima are directed to the same problem as the '238 Patent. Specifically, Iijima states that “[w]hen the high-pressure injection of a fuel (at, for example, 1500 Kg/cm^o to 2500 Kg/cm², and at 2000 Kg/cm² to be exact) is carried out, the fuel is atomized, so that the mixing of the fuel with the air can be done satisfactorily even when a whirling current is not generated.” EX. 1008, 3:54–58. Iijima also states that “the edge section of the re-entrant portion is not strictly required.” *Id.*, 3:58–59. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3.

134. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida and Iijima because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

135. A POSITA would have understood that edges of lips, like the lip 2 of Ishida, formed on a top surface of a piston are conventionally rounded, as taught by Iijima. Additionally, a POSITA would have found it obvious to modify the lip 2 of

Ishida such that its edges are rounded, as in Iijima. A POSITA would have understood that there are certain types of applications where rounded edges, as taught by Iijima, are preferred, such as applications where formation of heat points, and therefore cracking, is likely to occur. Moreover, rounding edges was a conventional and commonly understood design choice routinely incorporated into design of a piston. Rounded edges would have been conventionally understood to be desirable because they are more durable and less prone to cracking or warping during operation (e.g., due to temperature changes, etc.). Further, rounded edges would have been desirable because they provide lower risk of damaging the piston recess when pistons are installed and serviced.

136. In view of the similarities between the piston recesses described in Ishida and Iijima, and the lack of Ishida to describe any structure which would prohibit use of a rounded edges, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida. Moreover, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida.

E. The Ishida-Gatellier-Iijima Combination

1. The Combination of Ishida, Gatellier, and Iijima was Predictable

137. As I also discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida, Gatellier, and Iijima are

analogous art directed to the same field of endeavor as the '238 Patent. Gatellier is directed to a “direct-injection internal-combustion engine according to the invention, comprising at least one cylinder with a cylinder head, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on one side by the upper face of the piston comprising a teat pointing towards the cylinder head and arranged at the center of a concave bowl....” EX. 1007, ¶[0015]. Gatellier discloses that its “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060]. Iijima states that its “invention relates to a piston for internal combustion engines, and more particularly to a piston for internal combustion engines which has a combustion chamber in a top surface thereof.” EX. 1008, 1:6–9. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2.

138. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida, Gatellier, and Iijima are directed to the same problem as the '238 Patent. Gatellier states that “[u]nfortunately, it is increasingly difficult to improve one of these points [(compression ratio, certain parameters of the injection system (pressure, control law, etc.), certain parameters of the fuel jets (number of holes, diameter, etc.), pressure charging adjustment, exhaust gas recirculation ratio, intake temperature)]

without deteriorating another one.” EX. 1007, ¶[0007]; *see id.*, ¶[0006]. Gatellier explains that “[a] well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶[0008]. Iijima states that “[w]hen the high-pressure injection of a fuel (at, for example, 1500 Kg/cm^o to 2500 Kg/cm², and at 2000 Kg/cm² to be exact) is carried out, the fuel is atomized, so that the mixing of the fuel with the air can be done satisfactorily even when a whirling current is not generated.” EX. 1008, 3:54–58. Iijima also states that “the edge section of the re-entrant portion is not strictly required.” *Id.*, 3:58–59. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3.

139. When seeking to solve the problem of the ’238 Patent, a POSITA would have predictably considered Ishida, Gatellier, and Iijima because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the ’238 Patent.

140. As I discussed in Section IX.C.2, a POSITA would have understood that Ishida depicts an injection angle of approximately 120° and that fuel injection nozzles, like that of Ishida, conventionally have injection angles within the broad range of 50° to 120°. Additionally, a POSITA would have found it obvious to modify the injection nozzle of Ishida to have an injection angle between 0° and 120° (or

preferably between 40° and 100°) as in Gatellier. As I discussed in Section IX.D.2, a POSITA would have found it obvious to modify the lip 2 of Ishida such that its edges are rounded, as in Iijima.

141. In view of the similarities between the piston recesses described in Ishida, Gatellier, and Iijima, and the lack of Ishida to describe any structure which would prohibit use of a slightly different injector, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida. Moreover, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida.

F. The Ishida-Takatomo Combination

1. Overview of Takatomo

142. Similar to the '238 Patent, Takatomo is directed to “piston for an engine in which a cavity for direct supply of fuel spray is formed at the top of the piston.” EX. 1006, 2:2–3. While Takatomo is not in English, I have considered the certified translation of Takatomo which a POSITA would have understood as providing the teachings of Takatomo.

143. Takatomo states that “in a low-compression-ratio engine matched for use as a turbosupercharger engine as described above, the fuel that collides with the side wall and bounces back does not ignite, or due to the delay in evaporation of the fuel adhering to the side wall, the fuel reaches the bottom of the combustion chamber

with a lower temperature and liquefies, and is exposed to the flame and floats as unburned fuel in the cavity, and then is discharged during exhaust stroke, which gives rise to a blue-white smoke (HC) with an irritating odor.” *Id.*, 3:3–11. Takatomo therefore is focused on improving combustion while also reducing HC emissions. Takatomo explains that “[f]or this reason, a diesel engine with lowered compression ratio has not yet been adopted, even though it can reduce friction and improve output by increasing supercharging ratio.” *Id.*, 3:12–14. Takatomo further explains that “in order to obtain a supercharged engine with a low compression ratio, the state (evaporation, dispersion and distribution) of the fuel supplied to the cavity must be controlled to a good state, and accurate ignition must be performed for flame propagation.” *Id.*, 3:15–19.

144. Importantly, Takatomo states that “[o]ne proposal based on this type of problem is ‘COMBUSTION CHAMBER FOR DIRECT-INJECTION DIESEL ENGINE’ (Japanese Unexamined Utility Model Application Publication No. S 58-102720) proposed by the present applicant.” *Id.*, 3:20–23. Japanese Unexamined Utility Model Application Publication No. S 58-102720 corresponds to Ishida. EX. 1005, p. 1. Thus, a POSITA would have understood that the “proposal” discussed by Takatomo is Ishida. In other words, Takatomo describes Ishida and Takatomo is evidence of the teachings in Ishida. In other words, a POSITA would have understood Ishida in the manner described by Takatomo. Moreover, a POSITA

would have understood that Takatomo is from the same applicant as Ishida, Isuzu Motors. A POSITA would have found this additional link between Ishida and Takatomo relevant in understanding how the teachings of Takatomo apply to, and would have been implemented in Ishida, as I discuss below with respect to the auto-timer.

145. In describing Ishida, Takatomo states that “[i]n the proposal, a cavity is recessed on a top surface of a piston, a lip radially protruding inward is formed around the periphery of an opening that forms an entrance to the cavity, a side wall of the cavity is formed to be perpendicular to the fuel spray line of a fuel injection nozzle, and a conical protruding portion for generating a toroidal stirring flow is formed in the center of the bottom of the cavity.” EX. 1006, 3:23–29. Thus, Takatomo acknowledges that Ishida aims to atomize fuel and spread these impinging droplets as a thin film on the side wall of the piston recess, and then confine that thin film (and thus the atomized fuel) within the piston recess. Takatomo further describes Ishida stating that “[b]y the collision of the fuel with the side wall at a right angle, a part of the injected fuel, fuel particles are further broken down into smaller pieces, and the remaining part of the fuel on the side wall adheres to the side wall and spreads in the form of a thin film, and then the lip is intended to confine in the cavity the fuel crushed by the side wall, the fuel evaporated, and the fuel adhering in the form of a thin film.” *Id.*, 3:30–35. This ‘collision’ is the impingement taught

by Ishida, and would occur at all injection timings including those that are “as early as possible.” Takatomo states that “[i]n other words, in the proposal, the atomization of fuel spray is promoted to generate a mixture gas necessary for ignition and flame propagation; on the other hand, depending on the strength of stirring flow, the fuel in the form of thin film and the vapor present near the side wall peel off from the side wall side, and are transported to the center side of the cavity to propagate the flame and improve combustion.” *Id.*, 3:35–42.

146. Takatomo then states that there are problems associated with “the use of the aforementioned proposal [(Ishida)] in the aforementioned engine with a low compression ratio and a high supercharging.” *Id.*, 3:44–46. Specifically, Takatomo states that “[i]t is necessary [in Ishida] to improve the mechanical strength of the lip against the fuel pressure of the engine with low compression ratio and high supercharging.” *Id.*, 3:47–49. Takatomo also explains that “[a]t the maximum output point of the engine [of Ishida], the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” *Id.*, 3:50–53. Takatomo teaches that “if the maximum output point [in Ishida] is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip),

so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:54–63. In other words, while the mechanism of Ishida (impinging the side wall) is maintained, at certain injection timings, a portion of the injected fuel is misplaced and misdirected onto the top of the lip and the top of the piston, resulting in generation of excessive HC. This adherence onto the top of the piston is likely exacerbated by the piston being lower in position relative to the injector at these injection timings. Efficacy of the arrangement of Ishida is therefore limited, as taught by Takatomo, at these injection timings, indicting a design limitation of Ishida. Specifically, Ishida was incapable of facilitating clean (i.e., without generation of an excessively large amount of HC (blue-white smoke) combustion even when operating according to its fundamental characteristic of impinging the side wall.

147. When late injection timings are utilized in Ishida, including an injection timing “as late as possible,” Ishida envisions direct and effective impact of the side wall. These positions include an optimal position of the piston near TDC where the fuel spray most directly impacts the side wall. While other forces interact with the injected fuel spray, the dominant interaction is the impact with the side wall and the subsequent ‘rebounding’ described by Ishida.

148. According to Takatomo, as a result of these problems in Ishida, “an auto-timer or the like for automatically adjusting the injection timing is required as an additional device.” *Id.*, 3:64–65. An “auto-timer” is a device that automatically

adjusts injection timing. It accounts for the delay of the injection pressure wave/pulse travelling through the fuel line between the injection pump and the fuel injector. The pressure wave is time dependent so it takes more crank angles to reach the injector at high engine speeds compared to lower engine speeds. An “auto-timer” facilitates operation of an engine at a wide range of actual injection timings. EX. 1017, 4-7. Thus, Takatomo strongly suggests that in various operating conditions, the piston of Ishida experiences a wide range of actual injection timings that are subsequently optimized by the auto-timer. This is apparent from Takatomo’s statements regarding the maximum output point, the fuel adhering to the top surface of the piston, and undesirable performance at various actual injection timings. Typically, an auto-timer optimizes injection timing relative to piston position, such as TDC. In other words, the auto-timer advances or delays injection timing based on variables such as engine speed and engine load so that the injection timing is optimized based on those variables. Sekiguchi describes an example of such an auto-timer. *See* EX. 1016, 1:7–25, 2:8–52. Use of an auto-timer is desirable because it prevents uncontrolled, excessive early injection, such as the undesirable injections in Ishida identified by Takatomo, which cause fuel to adhere to a top surface of the piston. In other words, Takatomo teaches that the base piston design of Ishida would have been incapable of effective operation across the full spectrum of injection timings and therefore required use of an auto-timer to address these shortcomings.

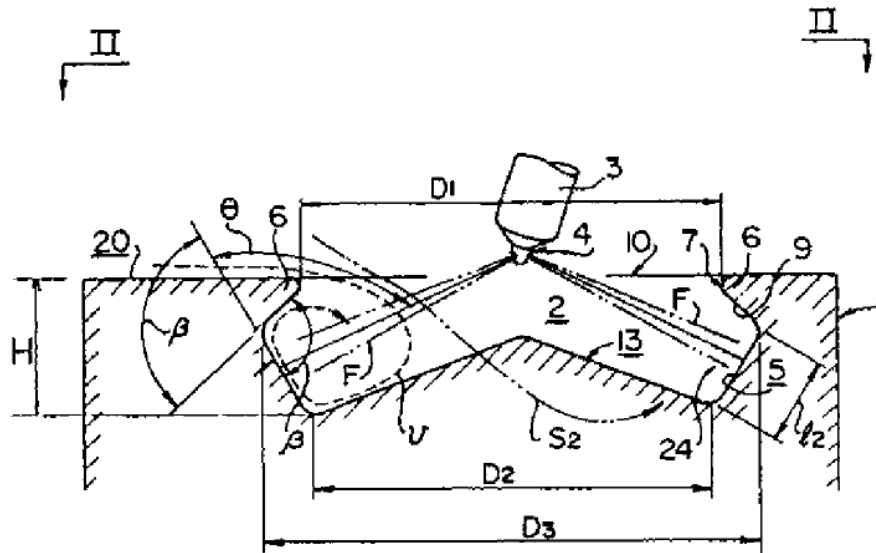
The auto-timer ensures consistent impingement of the side wall in Ishida's piston and therefore ensures that Ishida's dual-direction fuel distribution mechanism ((i) inwards and towards the elevation and (ii) outwards and towards the recess edge) functions as intended regardless of the injection timing.

149. A POSITA would therefore have understood based on Takatomo that even though impingement of the side wall is performed consistently in Ishida, optimal operation of Ishida's engine is not possible across a wide array of injection timings encountered during operation of the engine. For example, Takatomo teaches that without an auto-timer, the quality of combustion (i.e., cleanliness (in terms of HC), efficiency, etc.), which is the result of fuel distribution and mixing with air, is sub-optimal in Ishida (i.e., Ishida's piston geometry alone is insufficient to produce combustion at a desirable quality consistently). A POSITA would therefore have understood that while the fuel-side wall interaction was a constant in Ishida, quality of combustion undesirably varied with timing.

150. Takatomo discloses a "typical piston 1 adopted for a small direct injection diesel engine" that includes "a cavity 2 recessed in an axis direction on a top surface 20 of the piston" where the "cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2." *Id.*, 4:40–45. Takatomo explains that "the fuel spray is injected radially outward and obliquely downward from each nozzle to an opposing side wall or

corner.” *Id.*, 4:45–49. Takatomo states that “[e]ach side wall 5 of the cavity 2 is formed at an inclination angle θ in a certain range with respect to a fuel spray line F from the nozzle” and that “[i]n other words, each side wall 5 forms an inclined surface facing obliquely upward.” *Id.*, 4:50–53. The side wall 5 of Takatomo is substantially planar (i.e., when the piston is viewed in cross-section) and has an ascending gradient (i.e., towards an edge of the cavity 2).

FIG. 1



Id., Fig. 1.

2. The Combination of Ishida and Takatomo was Predictable

151. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida and Takatomo are analogous art directed to the same field of endeavor as the '238 Patent. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type

diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–42. Takatomo also states that “the cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5.

152. As I also discussed in Section IX.B.2, the ’238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida and Takatomo are directed to the same problem as the ’238 Patent. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–53. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*,

3:53–59. This “very early timing before the top dead center” includes “as early as possible” in Takatomo. During these early injections in Takatomo, the side wall is impinged by the injected fuel. Moreover, this statement in Takatomo provides a teaching that a POSITA would have understood as meaning that when optimizing for high-speed and/or high-load applications, injection timing is advanced so that it becomes effectively earlier at low speeds. Moreover, this statement teaches that fuel is injected from a very early timing to a late timing. Finally, Takatomo states that the auto-timer is necessary because Ishida is otherwise incapable of desirably operating across this wide range of injection timings. Specifically, Takatomo explains that without the auto-timer, Ishida experiences the problem of fuel being injected on top of the piston which results in undesirable HC generation.

153. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida and Takatomo because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

154. While Ishida only expressly depicts injection at a single injection timing (where the side wall is impacted at a right angle), a POSITA would have understood from Ishida that injections are performed across a wide range of injection timings, as I discussed in Section IX.A.1, above. Specifically, a POSITA would have understood that Ishida operates with fuel injections at a variety of injection timings

including very early injection timings and very late injection timings. Takatomo specifically explains that Ishida was operated in such a manner. For example, Takatomo states that Ishida was operated with a “very early [injection] timing before the top dead center to a late [injection] timing after the top dead center.” EX. 1006, 3:54–63. Thus, Takatomo confirms what a POSITA would have already understood from Ishida – that Ishida is operated with multiple injections that occur across a wide range of injection timings (from very early injection timings to late injection timings).

155. Additionally, Takatomo also describes setting the “maximum output point” as the “optimal timing” which results in “the dynamic injection timing [being][] advanced in the case of low-speed rotation.” *Id.*, 3:54–63. In other words, Takatomo is describing how injection timing becomes effectively earlier at low speeds after optimizing for high-speed and high-load performance (i.e., maximum output).

156. Very early injection timings, as used in Ishida and described by Takatomo, would have been understood by a POSITA to include injections as “early as possible.” Similarly, late injection timings, as used in Ishida and described by Takatomo, would have been understood by a POSITA to include injections as “late as possible.”

157. At very early injection timings in Ishida, injected fuel contacts the top surface of the piston. However, due to Ishida's fundamental principle of operation, the fuel still impinges the side wall at these injection timings.

158. For at least these reasons, a POSITA would have understood, as evidenced by Takatomo, that Ishida was operated across a broad spectrum of injection timings including very early injection timings and late injection timings.

159. Finally, Takatomo also states that "an auto-timer or the like for automatically adjusting the injection timing is required as an additional device" in Ishida. *Id.*, 3:64–65. Thus, a POSITA would have understood in view of Takatomo that Ishida was operated across a wide range of injection timings for example, due to varying engine conditions. A POSITA would have also understood that these operations would benefit from incorporation of an auto-timer to adjust the injection timing from what it otherwise would be. This would have motivated a POSITA to incorporate the auto-timer into Ishida.

160. Incorporation of the auto-timer into Ishida, as taught by Takatomo, would accomplish controlled injection (avoiding undesirable striking of the upper surface of the piston and subsequent HC generation) at early injection timings and late injection timings. When modified to include an auto-timer as taught by Takatomo, Ishida's fundamental operating principle of impinging the side wall (and subsequent rebounding of the fuel off of the side wall) would have optimally

functioned across the entire operational map of the engine. Where an early injection timing is desirable, the auto-timer may adjust injection timing to ensure controlled injection in a manner that primarily impinges the side wall 31 (the core principle of Ishida). Similarly, where a late injection timing is desirable, the auto-timer may adjust injection timing to ensure controlled injection in a manner that primarily impinges the side wall 31 (the core principle of Ishida). Thus, the auto-timer ensures repeated desirable operation of Ishida's piston. Regardless of when the injection occurs (such as early or late), impingement of the side wall 31 causes rebound and distribution of the fuel. At late injection timings, a POSITA would have understood that the auto-timer ensures maintaining injection at an optimal injection timing.

161. Additionally, Takatomo provides an explicit solution (incorporation of an auto-timer) to an identified problem in Ishida. A POSITA would have found it obvious in view of Takatomo to implement that solution (the auto-timer) in Ishida for at least that reason. This solution (again, taught by Takatomo) would enable desirable operation of Ishida across a wider range of engine operating conditions by actively managing injection timing. Through this modification of Ishida, the intended operation of Ishida (impingement of the side wall by the injected fuel) is ensured across the engine's entire operational map. Moreover, a POSITA would have had a reasonable expectation of success in such a modification because Takatomo teaches that such a modification was already done. Finally, a POSITA

would have been motivated to make such a modification of Ishida in order to avoid the problems identified by Takatomo and ensure desirable operation of the piston of Ishida in various operating conditions and across many injection timings. This modification ensures consistent impingement of the side wall 31 while providing the benefit of ensuring desirable operation of the engine of Ishida across a wide variety of operating conditions of the engine.

G. The Ishida-Oota-Takatomo Combination

1. The Combination of Ishida, Oota, and Takatomo was Predictable

162. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida, Oota, and Takatomo are analogous art directed to the same field of endeavor as the '238 Patent. For example, Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Oota states that “[t]he present invention relates to a combustion chamber of a direct injection diesel engine.” EX. 1009, p. 1. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–2. Takatomo also states that “the cavity 2 has a

quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5.

163. As I also discussed in Section IX.B.2, the ’238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida, Oota, and Takatomo are directed to the same problem as the ’238 Patent. Specifically, Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. Oota is directed to the same problem as the ’238 Patent. Oota states that “diesel engines are required to reduce NO_x in exhaust gas, and there is a trend toward delaying the fuel injection timing” and “the disadvantage of delaying the injection timing is that black smoke increases.” EX. 1009, p. 2. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–3. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:53–9.

164. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida, Oota, and Takatomo because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

165. While Ishida's piston includes a lip, lipless piston designs were well known and conventional. Indeed, the design choice of whether or not to include a lip was a question that was considered in concert with other design variables such as where injected fuel impinges on the piston, desired cost of the piston, cost and manufacturing considerations, and risk of cracking portions of the piston depending on desired operating conditions of the piston.

166. Ishida teaches that its lip provides an effect that, "together" with impingement on the side wall, provides desirable combustion. A POSITA, guided by the principle that piston design concerns more than simply seeking the most desirable combustion, would have recognized that while removal of the lip may make combustion less desirable in some situations, it also would make the piston more desirable in some respects. Specifically, factors such as cost and durability are significant in the design of a piston. A POSITA would have recognized that the lip of Ishida would have been relatively expensive to include in the piston design. Specialized machining or casting would have been required to form the lip. Additionally, finishing (i.e., polishing) the piston of Ishida would have been difficult

because of the lip. These difficulties would have significantly increased the cost of the piston. Moreover, a POSITA would have recognized that the lip of Ishida would have been particularly prone to cracking. For example, thermal stresses would have concentrated at the lip due to its relatively thin and protruding profile. *See* EX. 1008, 1:33–37 (discussing thermal stress in piston design). Additionally, the lip is particularly located in a region that gets relatively hot due to the location of combustion in Ishida’s combustion chamber.

167. Oota teaches a lipless design that is not subject to these shortcomings of the lip of Ishida. A POSITA would have understood that the drawbacks described in Oota (increased diesel black smoke and reduced combustion efficiency) are largely, if not entirely, due to the overspray Oota teaches occurs onto the top surface of the piston. This understanding is evidenced by, for example, Takatomo. *See* EX. 1006, 8:10-15; *see id.*, 3:50-59. This oversprayed fuel would not mix well with air and instead would adhere to the top surface of the piston, resulting in undesirable generation of smoke. Ishida avoids such overspray by impinging the fuel on the side wall at all injection timings. Thus, the drawbacks of Ishida’s lip and the drawbacks of Oota’s lipless design would be avoided by removing the lip, as taught by Oota, and impinging the side wall across all injection timings, as taught by Ishida. Moreover, the lipless design of Oota was economically beneficial relative to the specially-machined lip of Ishida. A POSITA would have therefore found it obvious

to modify Ishida to remove the lip in pursuit of decreased cost and/or increased durability.

168. Moreover, a POSITA would have had a reasonable expectation of success in such a modification of Ishida because Oota teaches that such a modification was already done (i.e., lipless pistons were a known design alternative). Indeed, this modification of Ishida would require only application of known engineering approaches taught by Oota, which would have been obvious to a POSITA when considering Ishida. Finally, a POSITA would have been motivated by Oota to make such a modification of Ishida in order to decrease risk of the piston cracking and avoid increased cost and complexity associated with the lip. When used in Ishida, which consistently impinges the side wall, the lipless design of Oota would not experience the significant overspray depicted in Oota (because Oota does not teach the same side wall impingement as in Ishida).

H. The Ishida-Gatellier-Takatomo Combination

1. The Combination of Ishida, Gatellier, and Takatomo was Predictable

169. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida, Gatellier, and Takatomo are analogous art directed to the same field of endeavor as the '238 Patent. For example, Gatellier is directed to a “direct-injection internal-combustion engine

according to the invention, comprising at least one cylinder with a cylinder head, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on one side by the upper face of the piston comprising a teat pointing towards the cylinder head and arranged at the center of a concave bowl....” EX. 1007, ¶[0015]. Gatellier discloses that its “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060]. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–2. Takatomo also states that “the cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5.

170. As I also discussed in Section IX.B.2, the ’238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida, Gatellier, and Takatomo are directed to the same problem as the ’238 Patent. Specifically, Gatellier states that “[u]nfortunately, it is increasingly difficult to improve one of these points [(compression ratio, certain parameters of the injection system (pressure, control law, etc.), certain parameters of the fuel jets (number of

holes, diameter, etc.), pressure charging adjustment, exhaust gas recirculation ratio, intake temperature)] without deteriorating another one.” EX. 1007, ¶[0007]; *see id.*, ¶[0006]. Gatellier explains that “[a] well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶[0008]. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–3. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:53–9.

171. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida, Gatellier, and Takatomo because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

172. A POSITA would have understood that Ishida depicts an injection angle of approximately 120° and that fuel injection nozzles, like that of Ishida, conventionally have injection angles within the broad range of 50° to 120° . For example, Gatellier teaches that injection nozzles, like that of Ishida, conventionally have injection angles between 0° and 120° (or preferably between 40° and 100°). Thus, a POSITA would have understood that the injection nozzle of Ishida has an injection angle between 0° and 120° (or preferably between 40° and 100°). In other words, while Ishida does not explicitly provide its injection angle, injection nozzles are conventionally understood to have injection angles between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier.

173. Additionally, a POSITA would have found it obvious to modify the injection nozzle of Ishida to have an injection angle between 0° and 120° (or preferably between 40° and 100°) as in Gatellier. First, Ishida and Gatellier use their injection nozzles for the same purpose (injecting fuel). Second, Ishida does not teach that the injection nozzle includes any structure that would preclude an injection angle between 0° and 120° (or preferably between 40° and 100°). Third, a POSITA would have understood that there are certain types of applications where an injection angle between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier, is preferred, such as applications where the diameter of the piston and the length of the straight portion of the cavity require an injection angle between 0° and 120° (or

preferably between 40° and 100°) for impingement on the straight portion at target injection timings.

174. In view of the similarities between the fuel injectors described in Ishida and Gatellier and the lack of Ishida to describe any structure which would prohibit use of a slightly different injector, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida.

I. The Ishida-Iijima-Takatomo Combination

1. The Combination of Ishida, Iijima, and Takatomo was Predictable

175. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida, Iijima, and Takatomo are analogous art directed to the same field of endeavor as the '238 Patent. For example, Iijima states that its “invention relates to a piston for internal combustion engines, and more particularly to a piston for internal combustion engines which has a combustion chamber in a top surface thereof.” EX. 1008, 1:6–9. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–2. Takatomo also states that “the

cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5.

176. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida, Iijima, and Takatomo are directed to the same problem as the '238 Patent. Specifically, Iijima states that “[w]hen the high-pressure injection of a fuel (at, for example, 1500 Kg/cm² to 2500 Kg/cm², and at 2000 Kg/cm² to be exact) is carried out, the fuel is atomized, so that the mixing of the fuel with the air can be done satisfactorily even when a whirling current is not generated.” EX. 1008, 3:54–58. Iijima also states that “the edge section of the re-entrant portion is not strictly required.” *Id.*, 3:58–59. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–3. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface

of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:53–9.

177. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida, Iijima, and Takatomo because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

178. A POSITA would have understood that edges of lips, like the lip 2 of Ishida, formed on a top surface of a piston are conventionally rounded, as taught by Iijima. Additionally, a POSITA would have found it obvious to modify the lip 2 of Ishida such that its edges are rounded, as in Iijima. A POSITA would have understood that there are certain types of applications where rounded edges, as taught by Iijima, are preferred, such as applications where formation of heat points, and therefore cracking, is likely to occur. Further, rounded edges would have been desirable because they provide lower risk of damaging the piston recess when pistons are installed and serviced.

179. In view of the similarities between the piston recesses described in Ishida and Iijima, and the lack of Ishida to describe any structure which would prohibit use of a rounded edges, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida. Moreover, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida.

J. The Ishida-Gatellier-Iijima-Takatomo Combination

1. The Combination of Ishida, Gatellier, Iijima, and Takatomo was Predictable

180. As I also discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Ishida, Gatellier, Iijima, and Takatomo are analogous art directed to the same field of endeavor as the '238 Patent. Gatellier is directed to a “direct-injection internal-combustion engine according to the invention, comprising at least one cylinder with a cylinder head, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on one side by the upper face of the piston comprising a teat pointing towards the cylinder head and arranged at the center of a concave bowl...” EX. 1007, ¶[0015]. Gatellier discloses that its “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060]. Iijima states that its “invention relates to a piston for internal combustion engines, and more particularly to a piston for internal combustion engines which has a combustion chamber in a top surface thereof.” EX. 1008, 1:6–9. Ishida states that its “present invention relates to a combustion chamber for a direct injection-type diesel engine (referred to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a

top surface 20 of the piston.” EX. 1006, 4:40–2. Takatomo also states that “the cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5.

181. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Ishida, Gatellier, Iijima, and Takatomo are directed to the same problem as the '238 Patent. Gatellier states that “[u]nfortunately, it is increasingly difficult to improve one of these points [(compression ratio, certain parameters of the injection system (pressure, control law, etc.), certain parameters of the fuel jets (number of holes, diameter, etc.), pressure charging adjustment, exhaust gas recirculation ratio, intake temperature)] without deteriorating another one.” EX. 1007, ¶[0007]; *see id.*, ¶[0006]. Gatellier explains that “[a] well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶[0008]. Iijima states that “[w]hen the high-pressure injection of a fuel (at, for example, 1500 Kg/cm^o to 2500 Kg/cm², and at 2000 Kg/cm² to be exact) is carried out, the fuel is atomized, so that the mixing of the fuel with the air can be done satisfactorily even when a whirling current is not generated.” EX. 1008, 3:54–58. Iijima also states that “the edge section of the re-entrant portion is not strictly required.” *Id.*, 3:58–59. Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in

significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–3. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:53–9.

182. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Ishida, Gatellier, Iijima, and Takatomo because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

183. As I discussed in Section IX.C.2, a POSITA would have understood that Ishida depicts an injection angle of approximately 120° and that fuel injection nozzles, like that of Ishida, conventionally have injection angles within the broad range of 50° to 120°. Additionally, a POSITA would have found it obvious to modify the injection nozzle of Ishida to have an injection angle between 0° and 120° (or preferably between 40° and 100°) as in Gatellier. As I discussed in Section IX.D.2,

a POSITA would have found it obvious to modify the lip 2 of Ishida such that its edges are rounded, as in Iijima.

184. In view of the similarities between the piston recesses described in Ishida, Gatellier, Iijima, and Takatomo, and the lack of Ishida to describe any structure which would prohibit use of a slightly different injector, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida. Moreover, a POSITA would have had a reasonable expectation of success in making such a modification of Ishida.

K. The Takatomo-Gatellier Combination

1. The Combination of Takatomo and Gatellier was Predictable

185. As I discussed in Section IX.B.2, the field of endeavor of the '238 Patent is piston recess design. EX. 1001, 1:44–2:5. Takatomo and Gatellier are analogous art directed to the same field of endeavor as the '238 Patent. Takatomo states that “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–2. Takatomo also states that “the cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed approximately on an axis of the cavity 2.” *Id.*, 4:42–5. Gatellier is directed to a “direct-injection internal-combustion engine according to the invention, comprising

at least one cylinder with a cylinder head, a piston sliding in this cylinder, gas intake and exhaust means, a combustion chamber delimited on one side by the upper face of the piston comprising a teat pointing towards the cylinder head and arranged at the center of a concave bowl....” EX. 1007, ¶[0015]. Gatellier discloses that its “combustion chamber is delimited on one side by cylinder head 2 and, on the opposite side, by upper face SP of piston 5.” *Id.*, ¶[0060].

186. As I also discussed in Section IX.B.2, the '238 Patent is directed to the problem of how to optimally mix fuel and air in a combustion space. Takatomo and Gatellier are directed to the same problem as the '238 Patent. Takatomo states that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” EX. 1006, 3:50–3. Takatomo also states that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (the upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:53–9. Gatellier states that “[u]nfortunately, it is increasingly difficult to improve one of these points [(compression ratio, certain parameters of the injection system (pressure, control law, etc.), certain parameters of the fuel jets (number of holes,

diameter, etc.), pressure charging adjustment, exhaust gas recirculation ratio, intake temperature)] without deteriorating another one.” EX. 1007, ¶[0007]; *see id.*, ¶[0006]. Gatellier explains that “[a] well-known example is the improvement of the following compromise: NO_x emissions/particles emissions.” *Id.*, ¶[0008].

187. When seeking to solve the problem of the '238 Patent, a POSITA would have predictably considered Takatomo and Gatellier because they extensively describe existing solutions to the same problem and are within the same field of endeavor as the '238 Patent.

188. A POSITA would have understood that fuel injection nozzles, like that of Takatomo, conventionally have injection angles within the broad range of 50° to 120°. Indeed, a POSITA would have understood that injection nozzles, like that of Takatomo, conventionally have injection angles between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier.

189. Additionally, a POSITA would have found it obvious to modify the injection nozzle of Takatomo to have an injection angle between 0° and 120° (or preferably between 40° and 100°) as in Gatellier. First, Takatomo and Gatellier use their injection nozzles for the same purpose (injecting fuel). Second, Takatomo does not teach that the injection nozzle includes any structure that would preclude an injection angle between 0° and 120° (or preferably between 40° and 100°). Third, a POSITA would have understood that there are certain types of applications where an

injection angle between 0° and 120° (or preferably between 40° and 100°), as taught by Gatellier, is preferred, such as applications where the diameter of the piston and the length of the straight portion of the cavity require an injection angle between 0° and 120° (or preferably between 40° and 100°) for impingement on the straight portion at target injection timings.

190. In view of the similarities between the fuel injectors described in Takatomo and Gatellier and the lack of Takatomo to describe any structure which would prohibit use of a slightly different injector, a POSITA would have had a reasonable expectation of success in making such a modification of Takatomo.

X. ANALYSIS OF THE REFERENCES RELIED UPON BY PETITIONER

A. Claims 1-3, 5, and 6 are anticipated by, or minimally obvious over, Ishida

1. Claim 1

191. Claim 1 recites:

1. [i] A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space, [ii] wherein the piston has a piston recess, which, in a central region thereof, has an elevation

extending in a cylinder head direction, and [iii] [a] a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius [b] so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and [iv] [a] the surface is substantially planar and has an ascending gradient in the recess edge direction [b] such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.

- i. **“A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space,”**

192. As I have explained in Section IX.A.1, Ishida discloses a directly injecting internal combustion engine that includes at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space. Specifically, Ishida discloses “a combustion chamber for a direct injection-type diesel engine (referred

to below simply as a direct-injection diesel engine).” EX. 1005, p. 2. Ishida also discloses “FIG. 2 is a longitudinal cross-sectional view of the combustion chamber for a direct-injection diesel engine in the present invention, in which 1 is a piston in the direct-injection diesel engine, a combustion chamber 3 with a lip 2 is formed around the peripheral edge of the inlet in a portion of the top 11, and the side wall 31 is sloped outwardly so that the injected fuel F from the fuel injection nozzle 4 impacts the side wall at approximately a right angle R.” *Id.*, p. 4.

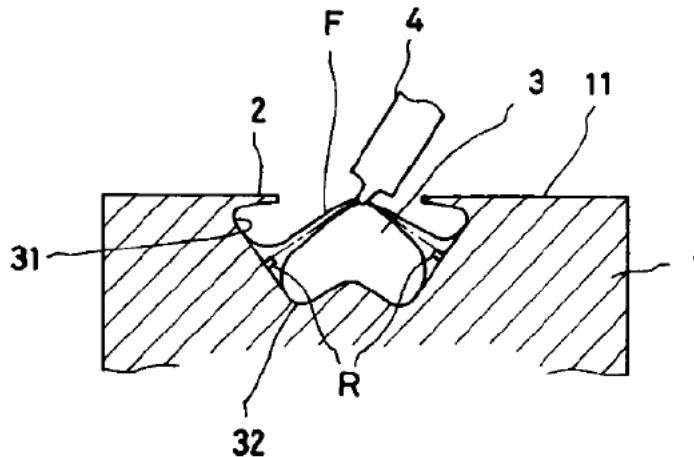


FIG. 2

Id., FIG. 2.

193. A POSITA would have understood that direct-injection diesel engines, like that of Ishida, include a cylinder which includes a combustion space. The combustion space is the area of the cylinder where combustion occurs. The piston of Ishida, and its combustion chamber 3, traverses this combustion space. The piston described of Ishida executes an oscillating movement within this combustion

chamber. As described in Heywood, for example, pistons in such engines execute oscillating movements during combustion. *See* EX. 1015, 41–43. Ishida also discloses a fuel injection nozzle 4. EX. 1005, p. 4. The fuel injection nozzle 4 injects fuel into the combustion space of the cylinder in which the piston executes the oscillating movement.

194. Therefore, Ishida discloses a “directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space,” as recited in claim 1.

ii. “wherein the piston has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction, and”

195. Ishida discloses that its piston (the piston 1) has a piston recess (the combustion chamber 3), which, in a central region thereof, has an elevation extending in a cylinder head direction. The combustion chamber 3 of Ishida is a recess in the piston 1 and therefore a piston recess. Ishida depicts that its combustion chamber 3 has a central peak (which could also be termed a conical portion or “hump”) that is an elevation. I have highlighted the elevation in Figure 2 of Ishida below.

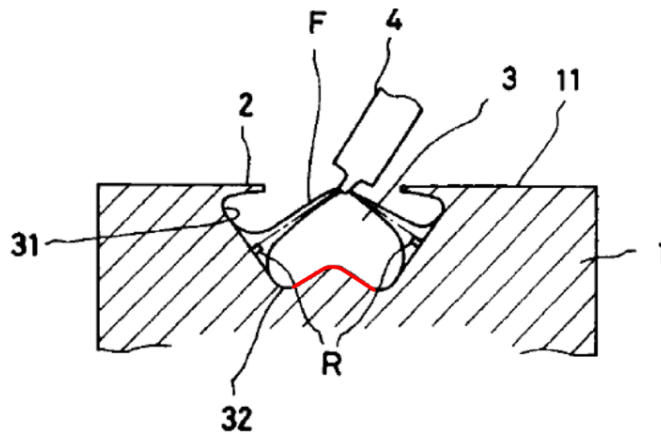


FIG. 2

Id., FIG. 2 (annotated).

196. As shown in Figure 2, Ishida teaches that its elevation is conical or peak-shaped and is positioned in a central region of the combustion chamber 3. The central region of the combustion chamber 3 only includes a single elevation (the elevation I have annotated above).

197. The '238 Patent depicts a cylinder head 3 in Figure 1, which I provide below. The '238 Patent provides that "FIG. 1 shows an internal combustion engine 1 which has a crankcase 2 and a cylinder head 3." EX. 1001, 2:42–3.

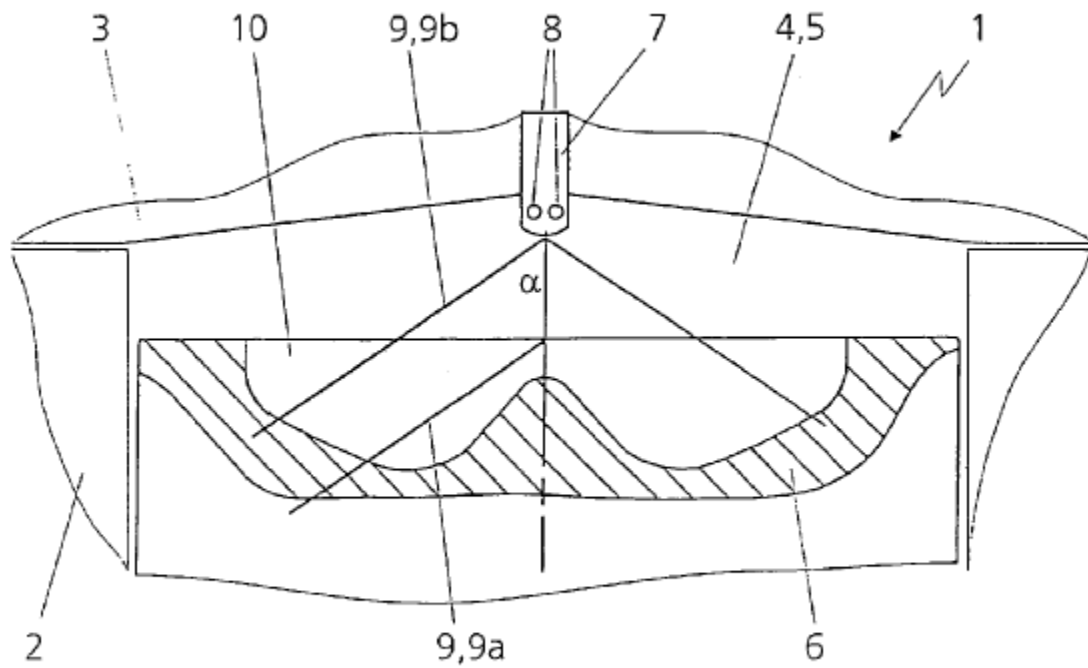


Fig. 1

Id., Fig. 1.

198. I have illustrated below an example of a “cylinder head direction” in Figure 1 of the '238 Patent.

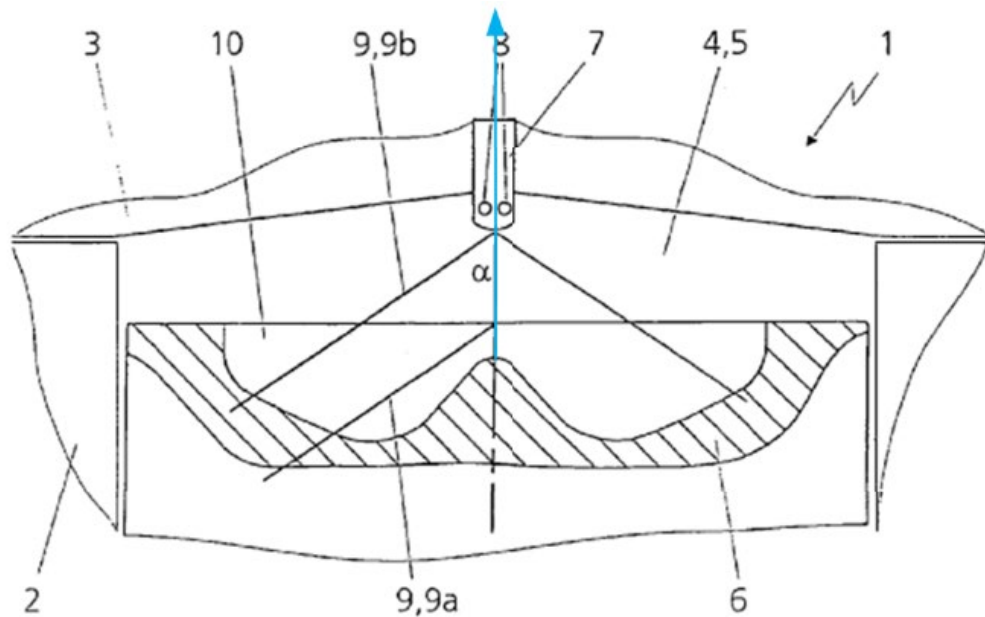
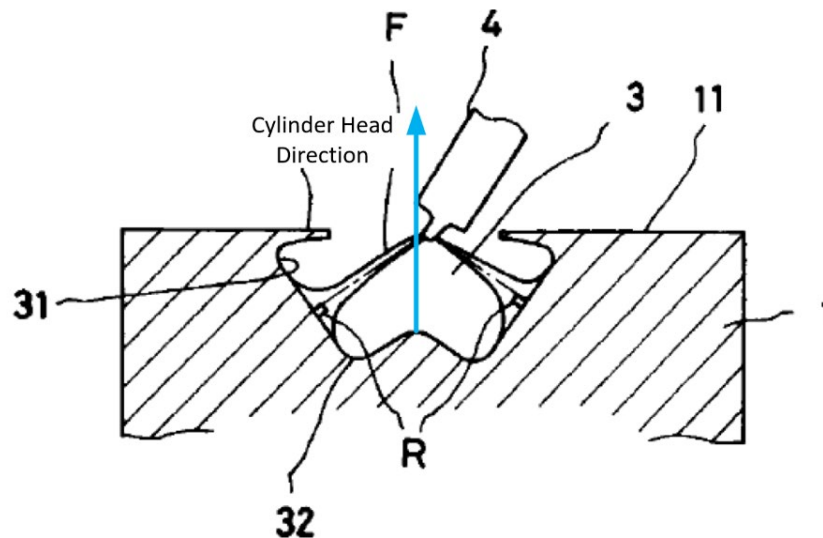


Fig. 1

Id., Fig. 1 (annotated).

199. The elevation of Ishida that I identified above extends in a cylinder head direction because the elevation extends towards the cylinder head. While the cylinder head is not shown in Ishida, a POSITA would have understood the engine of Ishida to include a cylinder head above the piston. Engines like that of Ishida commonly include cylinder heads above cylinder blocks within which their cylinders are included. For example, Heywood, which represents the understanding of a POSITA in this regard, teaches that cylinder head extends above each of the cylinders, and therefore each of the pistons. EX. 1015, 46. Below I have illustrated an example of the cylinder head direction in which the elevation extends. Therefore,

Ishida discloses that “the piston has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction.”



Id., FIG. 2 (annotated).

iii. “[a] a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius [b] so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and”

(a) “a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius”

200. Claim 1 recites that the surface adjoins the elevation and is connected to the elevation via a radius. Thus, claim 1 requires that the surface adjoins the elevation despite the radius being located between the elevation and the surface.

201. The '238 Patent states that “[a]s can be seen in FIG. 2 and FIG. 3, the elevation 11 has adjoining it in the direction of a recess edge 12, that is to say the end of the piston recess 10, a surface 13 which is connected to the elevation 11 via a radius 14 so that the injection jet 9a injected at the earliest possible time point impinges onto the surface 13 at an impingement point 15 and is distributed both in the direction of the elevation 11 and in the direction of the recess edge 12.” EX. 1001, 3:7–15.

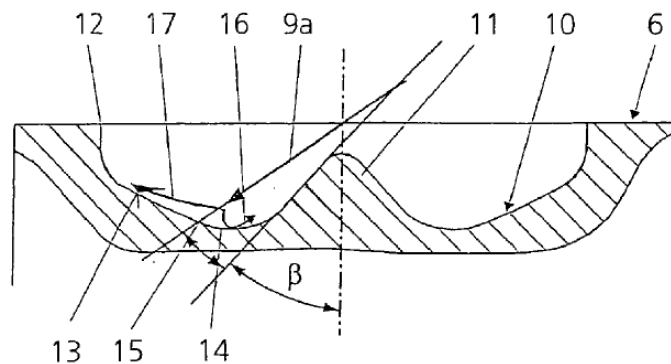


Fig. 2

Id., FIG. 2.

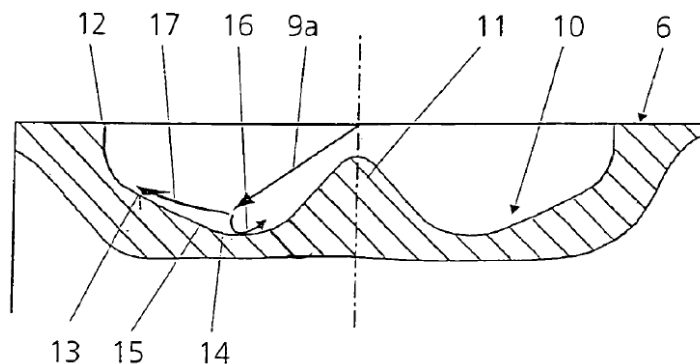


Fig. 3

Id., FIG. 3.

202. The combustion chamber 3 (the piston recess) taught by Ishida includes a surface (the side wall 31 – annotated in blue below) that adjoins the elevation (the central peak) and is connected to the elevation via a radius.



EX. 1005, FIG. 2 (annotated).

203. Above, I annotated the ‘surface’ of the combustion chamber 3 in blue and the ‘radius’ in pink. The radius is a curved surface that is connected to the elevation. The surface (blue) adjoins the elevation in a recess edge direction. The surface (blue) is flat and is impinged by the injected fuel.

204. The recess edge direction is a direction towards the recess edge. In Ishida, the recess edge is an edge (specifically a peripheral edge) of the combustion chamber 3. Specifically, the recess edge is an edge of the lip 2. This edge extends to along a top surface of the piston. The combustion chamber 3 of Ishida also includes a surface extending from the recess edge downward towards surface (blue). A POSITA would have understood that the top edge is the recess edge because the recess extends to the top edge.

205. Therefore, Ishida discloses a “surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius.”

(b) “so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and”

206. The '238 Patent depicts an elevation 11 in Figure 2, which I provide below. The '238 Patent provides that “[a]s can be seen in FIG. 2, the piston recess 10 has in its central region an elevation 11 extending in the direction of the cylinder head 3.” EX. 1001, 3:1–3.

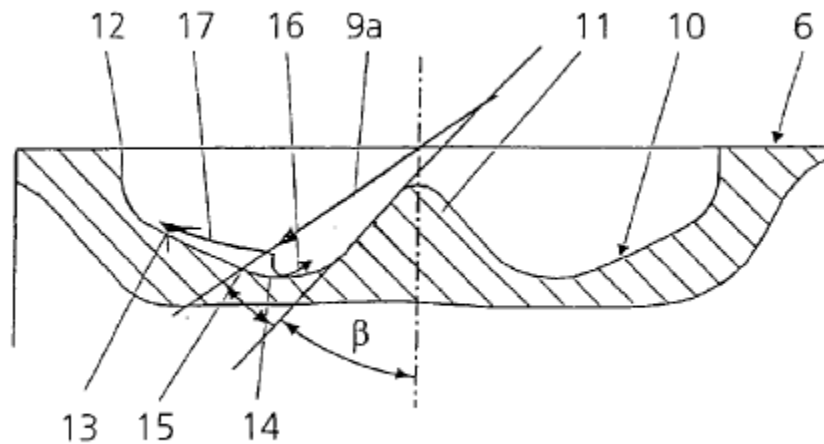
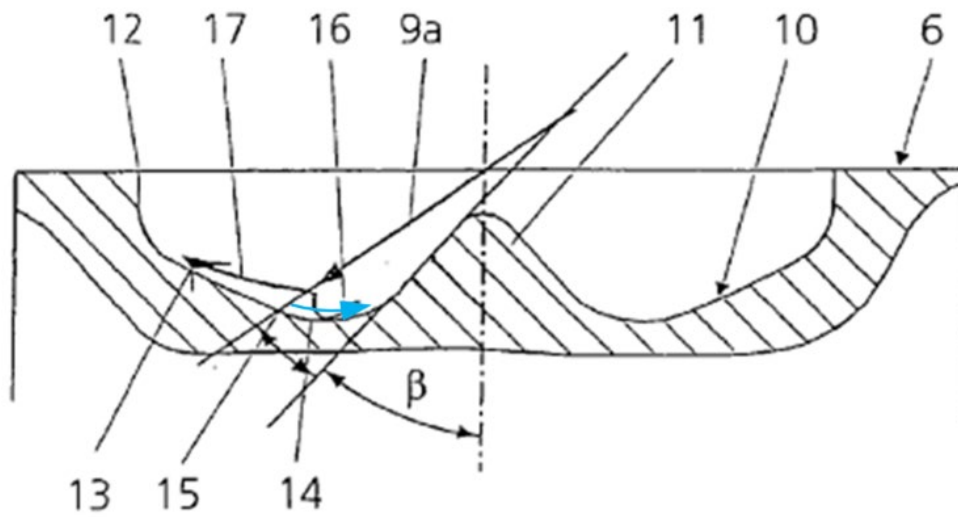


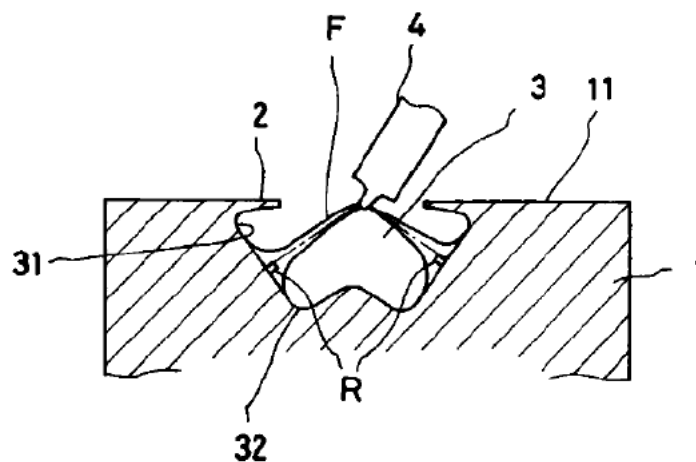
Fig. 2

Id., Fig. 2.

207. I have illustrated below an example of an “elevation direction” in Figure 2 of the '238 Patent.



208. Ishida teaches that an injection jet (fuel) impinges the surface of its combustion chamber 3. Ishida shows this injection jet in Figure 2. Figure 2 of Ishida depicts the piston at or near top dead center based on the position of the injector 4 relative to the piston 1.



Id., FIG. 2.

209. A POSITA would have understood that injection in Ishida occurs across a variety of injection timings. These injection timings include injection timings before what is shown in Figure 2 (including injections as “early as possible”), and injection timings after what is shown in Figure 2 (including injections as “late as possible”).

210. Claim 1 does not define what “injected as early as possible” means. The term “early” is relative. For example, when a first injection occurs before a second injection, the first injection is early relative to the second injection regardless of how much time elapses between the first injection and the second injection. Additionally, rather than the term “early” relating one injection to another injection, the term “early” also, in some contexts, refers to the time that elapses between an injection and top dead center. For example, “early” may connote a separation of a certain number of degrees in injection timing between an injection and top dead center. The separation might be, for example, 10 degrees or more.

211. Aside from claim 1, the '238 Patent and the prosecution history of the '238 Patent also do not define when “injected as early as possible” means.

212. In discussing the concept of early homogenization, the '238 Patent states that “[w]hen early homogenization is to be achieved within the combustion space of an operating internal combustion engine, in particular a diesel internal combustion engine, then injection time points of approximately 130 to 30° before

the top dead center of the piston must be selected, since, at this time point, the combustion space pressure is still relatively low, so that the injected fuel can penetrate very deeply into the combustion space.” EX. 1001, 1:25-36. The '238 Patent does not link this discussion to being “injected as early as possible.”

213. As discussed above, Ishida does not provide a specific injection timing for its depicted injection. A POSITA would have understood that Ishida is necessarily applicable to injections occurring during the compression stroke. Specifically, because Ishida operates a conventional diesel combustion process where injection occurs during the compression stroke, as described by Heywood (EX. 1015, 57, 59 (“[a]t about 20° before T[D]C, fuel injection into the engine cylinder commences”)), and because Ishida’s piston is used in this process, a POSITA would have understood that Ishida is applicable to injections occurring during the compression stroke. These injections necessarily include injections that are “as early as possible.” Specifically, these injections in Ishida would have been understood to include injection timings before TDC.

214. When describing the prior design of Figure 1, Ishida states that “injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc.” EX. 1005, p. 3. These issues, which Ishida aims to overcome, are most significant at early injection timings. Early

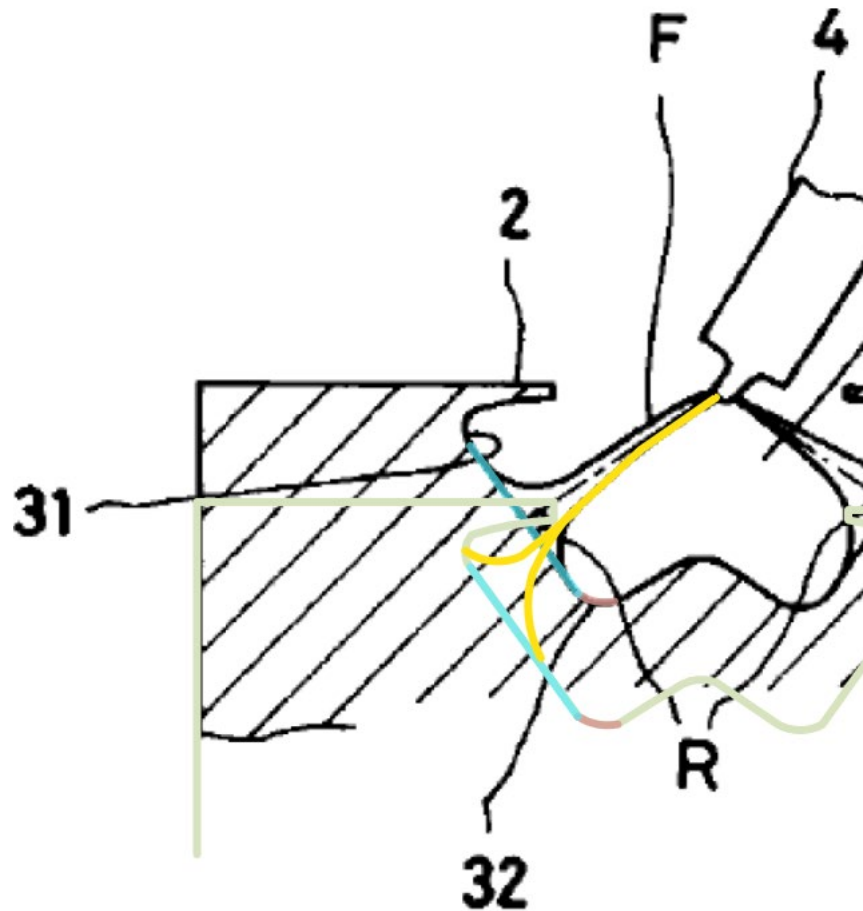
injection timings provide additional time for the fuel to flow towards the bottom of the combustion chamber and collect there, which would result in the problems identified by Ishida. These early injection timings also provide the opportunity for the fuel to interact unfavorably with cooler surfaces or has insufficient time to mix and vaporize properly before ignition, which also would result in the problems identified by Ishida. Thus, in the context of the prior design, Ishida explains that early injection occurred.

215. In the context of its design, Ishida states that “[b]ecause the combustion chamber 3 in the present invention is configured as described above, the injected fuel F makes an impact that causes it to rebound at the side wall 31 of the combustion chamber 3” and “[b]ecause this significantly reduces the proportion of fuel in the combustion chamber reaching the bottom 32 along the side wall 31, together with the effect of the lip 2, white smoke, odors, HC, etc., are significantly reduced.” EX. 1005, p. 4. While its design reduces the problems experienced in the prior design, its design would still be used for similar injection timings to those the prior design was used for. In other words, because Ishida teaches its prior design was used for early injections, a POSITA would have understood that Ishida’s design was similarly used for early injections.

216. The specific piston geometry (including its lip 2 and side wall 31 that is outwardly sloped towards an edge of the piston) taught by Ishida in its design is

always present (regardless of when injection occurs). In other words, the piston geometry of Ishida does not change during operation of the engine. Moreover, the piston geometry taught by Ishida necessarily interacts with the fuel spray for all injections, including early injections. Ishida does not contemplate injection where its side wall 31 does not interact with the fuel spray (such as injections where all of the fuel fails to interact with the piston at all). Rather, the fundamental principle of Ishida's operation requires fuel to interact with the side wall 31, so it follows that whenever fuel is injected in Ishida, the fuel necessarily interacts with the side wall 31. The side wall 31 of Ishida's specific piston geometry is explicitly designed to facilitate impact of the fuel on the side wall 31 (e.g., at approximately a right angle). This impact occurs at any injection timing, including the early injections (and the earliest as possible injection) during the compression stroke and late injections (e.g., near top dead center) (and the latest as possible injection), taught by Ishida. Nothing in Ishida limits this impact to only injections near top dead center or late injections. Rather, a POSITA would have understood that one of the benefits of Ishida's design is that impacting the side wall 31 slows flow of the fuel to the bottom 32 which is crucial to providing the benefits taught by Ishida. When the piston is earlier in the cycle than shown in Figure 2, it is lower in the cylinder. I have annotated Figure 2 of Ishida below to depict the piston (light green) at a position that is earlier than is shown by Ishida and is as "early as possible." At this earliest as possible position of

the piston (light green), the spray cone (gold) from the injector still impinges the side wall 31 (blue). This portion of the spray cone (gold) is still distributed both in an elevation direction (towards the central peak) and in the recess edge direction (towards an edge of the combustion chamber 3).



217. Early injections typically provide deeper-penetrating sprays into a relatively lower-pressure environment which often makes it more likely for fuel to flow to the bottom of a piston recess. However, Ishida's design avoids this issue through impingement of the side wall 31 at early injections. In other words, Ishida's

design provides a protective mechanism against fuel reaching the bottom 32 prematurely, and this mechanism provides specific advantages during early injections which would otherwise over-penetrate and collect at the bottom of the piston recess, as was the case in the prior design discussed by Ishida.

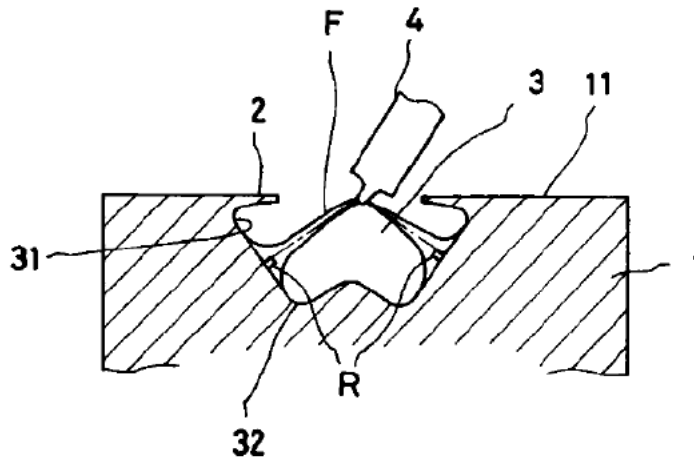


FIG. 2

Id., FIG. 2.

218. Specifically, impingement of the side wall 31 causes flow in both directions along the side wall 31, as shown by Ishida. One of these directions (i.e., the elevation direction) is towards the bottom 32 and therefore towards the elevation (central peak). This elevation direction flow harnesses a significant component of the momentum of the spray and causes the flow towards the center of the combustion chamber 3, where the elevation is located. The other of these directions (i.e., the recess edge direction) is towards the lip 2 and therefore towards the edge of the combustion chamber 3. This interaction of fuel injected against an

inclined side wall was known, as demonstrated by Park. *See* EX. 1014, 8-9 (Figure 6, below, illustrates “[d]ifferent impact angle cases...in the order of decreasing impact angle.”).

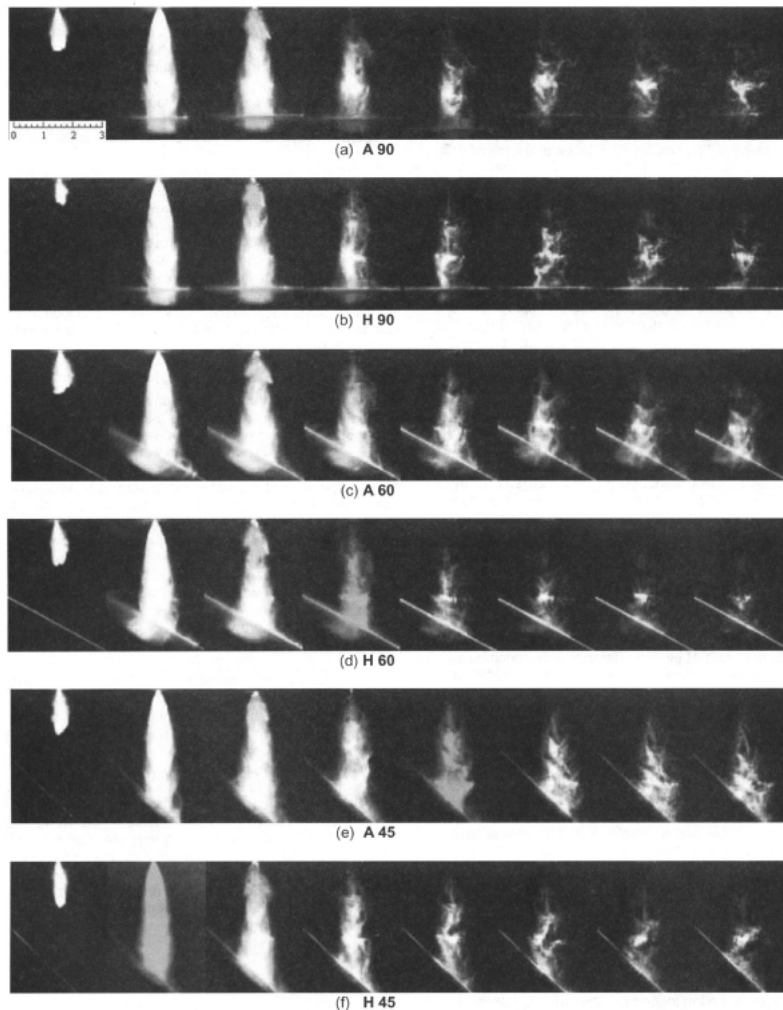
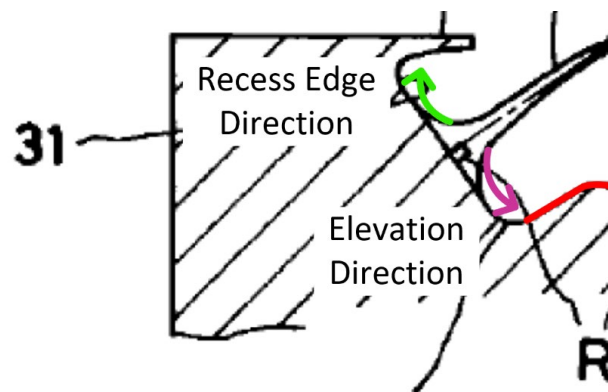


Figure 6. High-speed laser light-sheet Mie scattering visualization ($t_i=0.4\text{ms}$, $\Delta t=0.5\text{ms}$).

Id., 9.

219. Ishida explains that impacting of the fuel on the side wall 31 causes ‘rebounding.’ Specifically, Ishida states that “[b]ecause the combustion chamber 3 in the present invention is configured as described above, the injected fuel F makes

an impact that causes it to rebound at the side wall 31 of the combustion chamber 3.” EX. 1005, p. 4. This rebounding is what causes the distribution in the two directions described above and what provides distribution of the fuel. Below, I depict these two directions (recess edge direction (green) and elevation direction (purple)) in Figure 2.



Id., FIG. 2 (annotated).

220. If “injected as early as possible” requires injection earlier than depicted in Figure 2 of Ishida, a POSITA would have found performing such injections obvious. Varying injection timing was well known, especially in view of Ishida, and varying injection timing would still achieve the dual direction distribution of the fuel spray upon which Ishida is premised. For example, selecting earlier injection timings enables growth of a plume of the injected fuel to propagate towards a future location of the side wall as the piston moves upwards. It was conventional and well known to a POSITA that timing is selectable and a POSITA would have found it obvious to select (e.g., via an optimization process) a timing that is tailored for a target

application and/or to minimize the negative outcomes taught by Ishida (e.g., formation of white smoke or odors). These timings would be selected such that the jet impinges on the surface (blue), as taught by Ishida. Optimizing variables for a particular application was a well-known and conventional aspect of piston design.

- iv. **“[a] the surface is substantially planar and has an ascending gradient in the recess edge direction [b] such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.”**
- (a) **“the surface is substantially planar and has an ascending gradient in the recess edge direction”**

221. As an initial matter, I note that “substantially planar” is not described anywhere in claim 1. Additionally, this term is not used in the '238 Patent. The '238 Patent states that “FIG. 4 shows that the surface 13 adjoining the elevation 11 in the direction of the recess edge 12 is of essentially planar design and has an ascending gradient in the direction of the recess edge 12” and “[i]n other words, the surface 13 forms a plane which is at a constant angle γ to the injection jet 9 over the entire maximum injection duration.” EX. 1001, 3:33–38. I provide Figure 4 below.

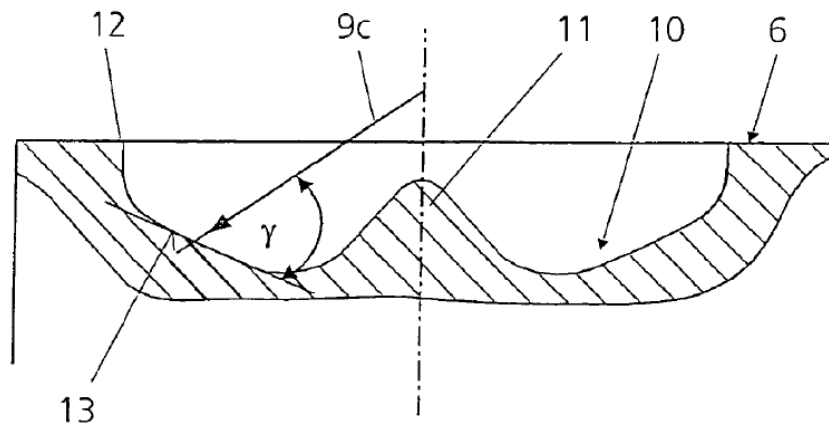


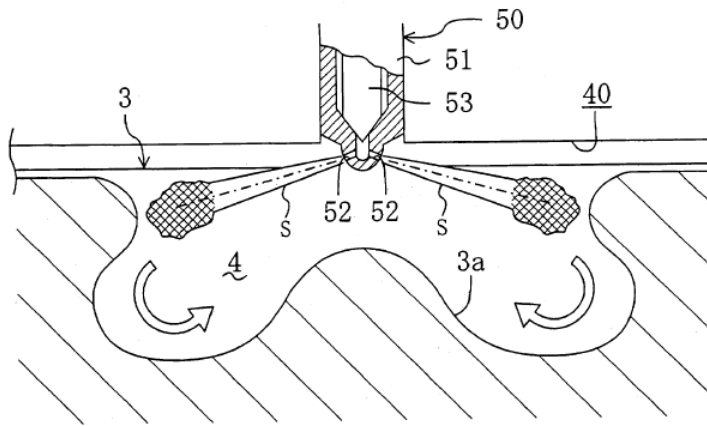
Fig. 4

Id., Fig. 4.

222. The '238 Patent does not explain if “essentially planar” is the same as “substantially planar.” The '238 Patent also does not explain what is meant by “substantially.” For example, the '238 Patent does not explain if a surface that is slightly curved is “substantially planar.” Similarly, the '238 Patent does not explain if a straight surface with a curved portion is “substantially planar.”

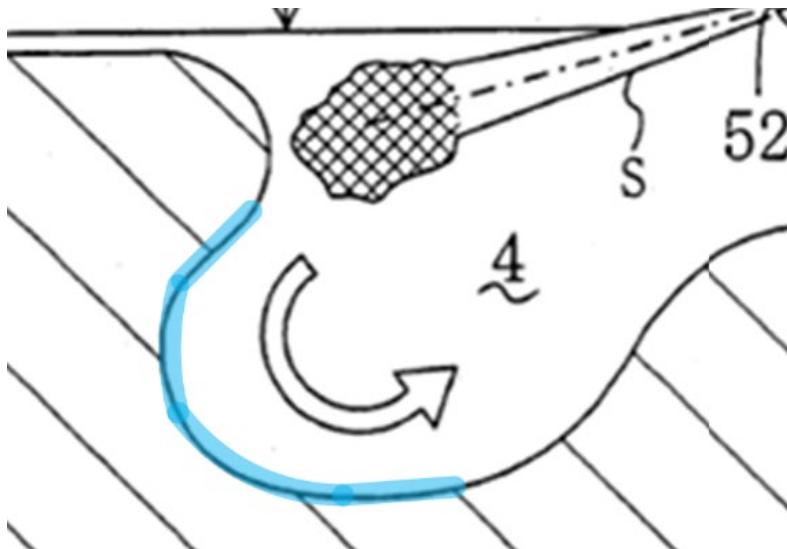
223. When the application that resulted in the '238 Patent was being examined by the Patent Office, a rejection was made in view of Kataoka. In describing how claim 1 differed from Kataoka, the applicant stated that “[t]he Kataoka et al piston does not have a substantially planar surface anywhere in the recess.” EX. 1010, 33 (emphasis in original). Below is an image from Kataoka.

FIG. 3



EX. 1012, FIG. 3.

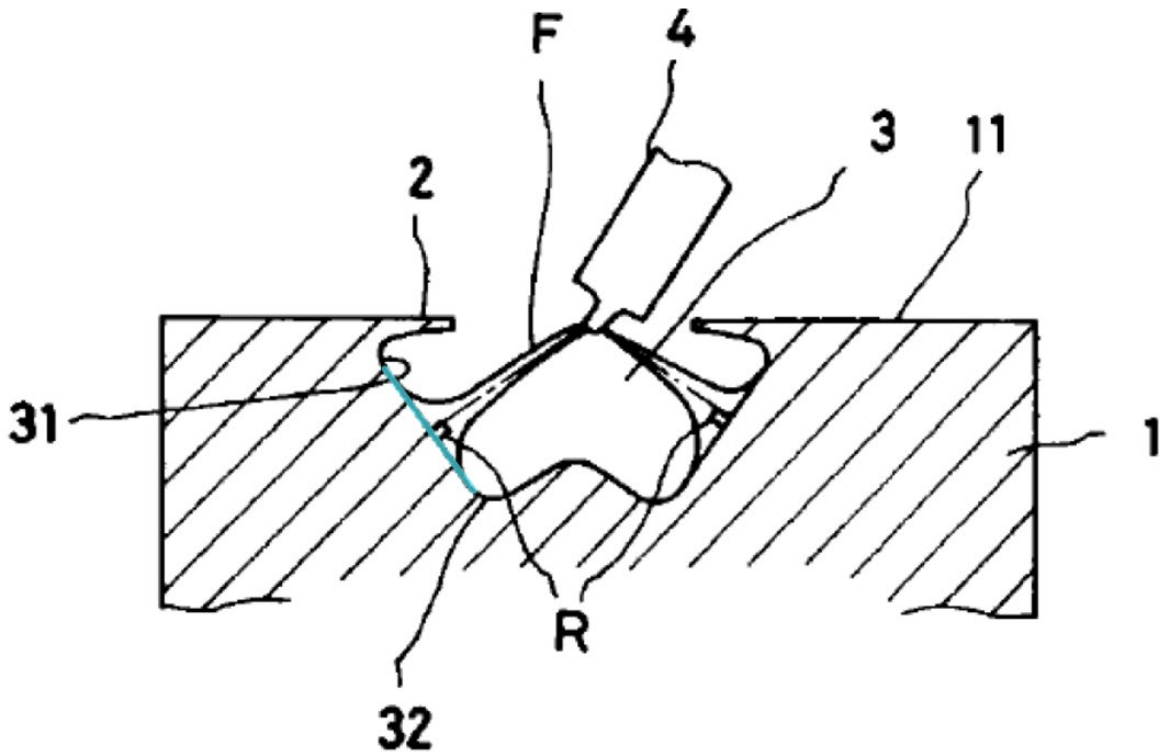
224. In Kataoka, the ascending surfaces are rounded. I highlight these surfaces below.



Id. (annotated).

225. In contrast to the rounded surfaces of Kataoka, Ishida teaches that its side wall 31 is disposed along a straight and inclined line in the cross-sectional view

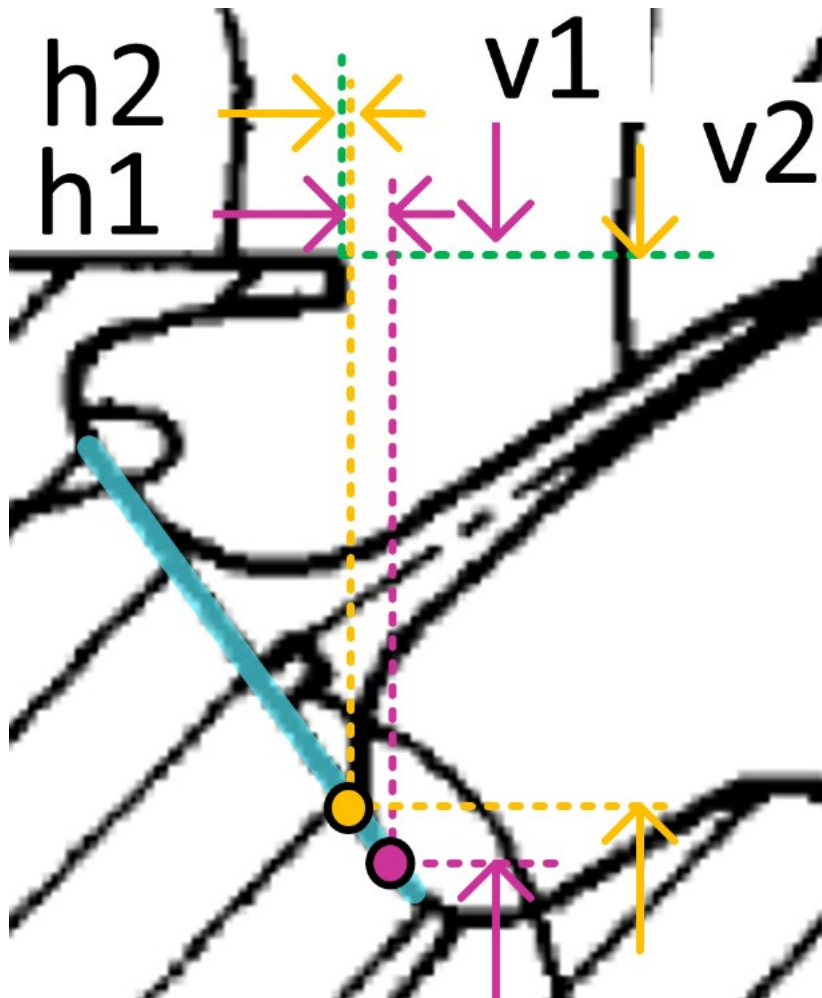
of Figure 2. A straight line is substantially planar. I have highlighted that straight and inclined line below in blue.



Id., FIG. 2 (annotated).

226. The side wall 31 of Ishida has an ascending gradient in the recess edge direction (a direction towards an edge of the combustion chamber 3). This is due to the upward and outward slope of the side wall 31. Specifically, at locations increasingly closer to the recess edge in the horizontal direction, the side wall 31 is increasingly closer to the recess edge in the vertical direction. I have illustrated Figure 2 of Ishida below to explain my understanding of the ascending gradient. Specifically, the first location (purple) is a first horizontal distance h_1 and a first

vertical distance $v1$ from the recess edge, and the second location (gold) is a second horizontal distance $h2$ and a second vertical distance $v2$ from the recess edge. The second horizontal distance $h2$ is less than the first horizontal distance $h1$, so the second location is closer to the recess edge in the horizontal direction. Similarly, the second vertical distance $v2$ is less than the first vertical distance $v1$, so the second location is closer to the recess edge in the vertical direction. Thus, the side wall 31 of Ishida has an ascending gradient in the recess edge direction (a direction towards an edge of the combustion chamber 3).



Id., FIG. 2 (annotated).

- (b) **“such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.”**

227. I note that “injected as late as possible” is not described anywhere in claim 1. Additionally, this term is not defined in the ’238 Patent.

228. The ’238 Patent describes that because “it is not possible to operate the internal combustion engine with a homogeneous combustion process (which uses early injection) over its entire characteristic map, the piston recess must be designed both for homogeneous and for conventional mixture formation.” *Id.*, 1:38-43. Homogenous mixture formation is typically associated with ‘early’ injection timings (as taught by Ishida) and conventional mixture formation is typically associated with ‘late’ injection timings. These ‘late’ injection timings would have been understood by a POSITA to typically be near TDC in diesel engines like that of Ishida. *See* EX. 1005, p. 4.

229. In this regard, the ’238 Patent states, “FIG. 1 depicts two different injection jets, to be precise an injection jet 9a, which is obtained when the piston 6 is at a top dead center, and an injection jet 9b, which is obtained in the case of fuel injection at the latest possible injection time point.” EX. 1001, 2:54–58. These

injection jets 9a, 9b are described by the '238 Patent as “illustrated merely as axes of an injection cone being distributed within the combustion space 5.” *Id.*, 2:58–60.

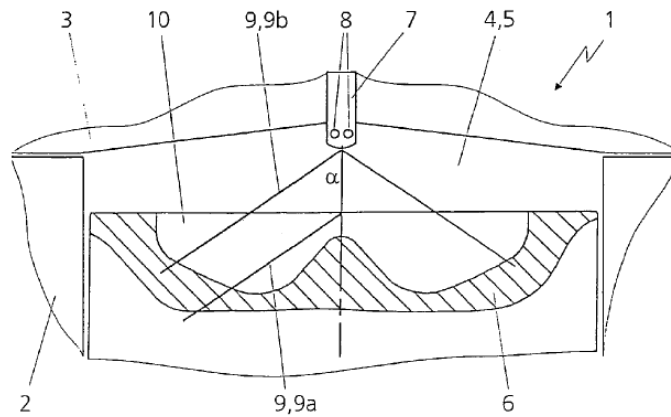


Fig. 1

Id., Fig. 1.

230. When viewing the jets 9a, 9b, a POSITA would have understood that they must occur at different injection timings. The '238 Patent states that the jet 9a occurs at top dead center. Thus, the jet 9b must not occur at top dead center. The '238 Patent explains that the jet 9b occurs “at the latest possible injection time point” which therefore also is not at top dead center. Accordingly, a POSITA would have understood that the “latest possible injection time point” would encompass injection timings slightly after top dead center because jet 9b is purportedly later in time and shown when the piston is below top dead center.

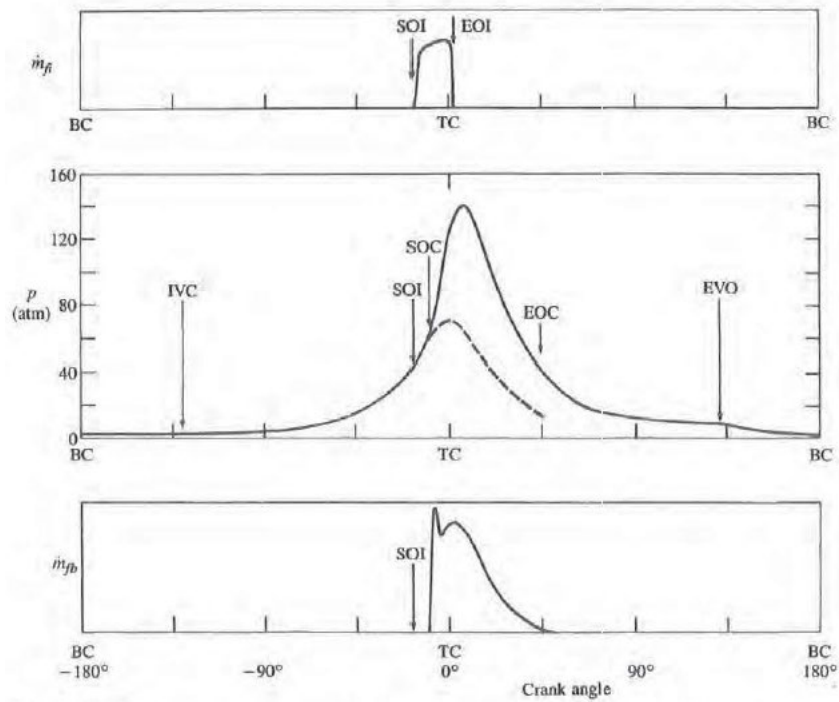
231. The '238 Patent also states, “FIG. 6 illustrates the injection jet 9b injected at the latest possible time point” and “[i]n this case, the surface 13 has an

extent in the direction of the recess edge 12 such that the injection jet 9b injected at the latest possible time point impinges onto the surface 13.” EX. 1001, 3:62–66.

232. As I discussed in Section X.A.1.iii.b, injection in Ishida occurs across a wide range of injection timings. These injection timings include injection timings after what is shown in Figure 2. Moreover, Ishida does not provide a specific injection timing for its depicted injection. A POSITA would have understood that Ishida is necessarily applicable to “as late as possible” injections.

233. At its core, Ishida teaches impingement of its side wall 31 using the injection jet. This impingement would occur at any injection timing utilized in Ishida and is not limited to only early injection timings or late injection timings. When injection occurs in Ishida, the side wall must (and is) impinged. For example, the rebounding principle (at the side wall) is described generally by Ishida and would have been understood by a POSITA as occurring when the fuel is injected “as late as possible.”

234. In direct-injection diesel engines, combustion can sometimes continue after top dead center for a short period of time. This continuance of combustion often occurs at high loads to complete fuel delivery. For example, Heywood, in describing a compression-ignition (diesel) engine, provides that SOI (start of injection) occurs very near TC (top dead center), as shown in the figure from Heywood below.



EX. 1015, 60; *see id.*, 196.

235. A POSITA would have understood that Ishida teaches a fundamental principle, impingement of the sidewall, that is applicable across all injections in Ishida's engine. In other words, this side wall impingement is necessarily applicable to injections that are "as late as possible" and "as late as possible."

236. When describing the prior design of Figure 1, Ishida states that "injected fuel f from the fuel injection nozzle N reaches the bottom of the combustion chamber along the spherical inner wall surface N, resulting in significantly worse white smoke, odor, HC, etc." EX. 1005, p. 3. In addition to being most significant at early injection timings, these issues are also problematic at late injection timings that are managed sub-optimally.

237. The specific piston geometry (including its lip 2 and side wall 31 that is outwardly sloped towards an edge of the piston) taught by Ishida in its design is always present (regardless of when injection occurs). Thus, the piston geometry taught by Ishida necessarily interacts with the fuel spray for all injections, including late injections. The side wall 31 of Ishida's specific piston geometry is explicitly designed to facilitate impact of the fuel on the side wall 31 (e.g., at approximately a right angle). This impact occurs at any injection timing, including the late injections where Ishida is utilized. Nothing in Ishida limits this impact to only injections near top dead center or early injections. Rather, a POSITA would have understood that one of the benefits of Ishida's design is that impacting the side wall 31 slows flow of the fuel to the bottom 32 which is crucial to providing the benefits taught by Ishida.

238. Impingement of the side wall 31 causes flow in both directions along the side wall 31, as shown by Ishida. One of these directions (i.e., the elevation direction) is towards the bottom 32 and therefore towards the elevation (central peak). This elevation direction flow harnesses a significant component of the momentum of the spray and causes the flow towards the center of the combustion chamber 3, where the elevation is located. The other of these directions (i.e., the recess edge direction) is towards the lip 2 and therefore towards the edge of the combustion chamber 3.

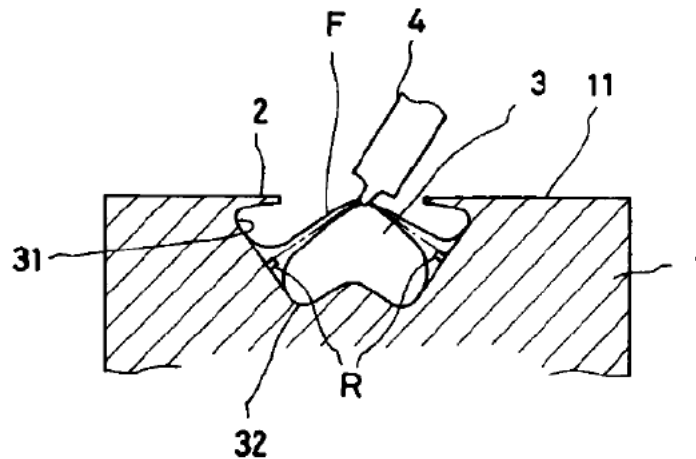
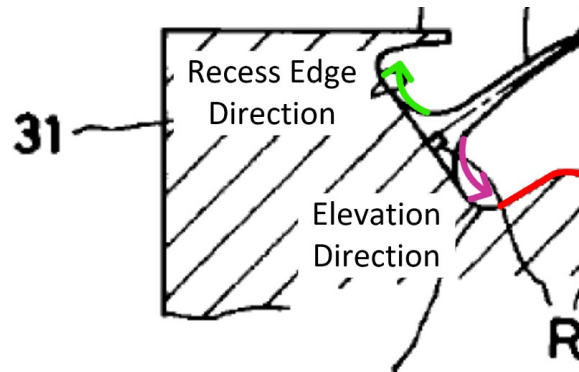


FIG. 2

Id., FIG. 2.

239. Ishida explains that impacting of the fuel on the side wall 31 causes ‘rebounding.’ Specifically, Ishida states that “[b]ecause the combustion chamber 3 in the present invention is configured as described above, the injected fuel F makes an impact that causes it to rebound at the side wall 31 of the combustion chamber 3.” *Id.*, p. 4. This rebounding is what causes the distribution in the two directions described above and what provides distribution of the fuel. Below, I depict these two directions (recess edge direction (green) and elevation direction (purple)) in Figure 2.



Id., FIG. 2 (annotated).

240. If “injected as late as possible” requires injection later than depicted in Figure 2 of Ishida, a POSITA would have found performing such injections obvious. Varying injection timing was well known, and varying injection timing would still achieve the dual direction distribution of the fuel spray upon which Ishida is premised. It was conventional and well known to a POSITA that timing is selectable and a POSITA would have found it obvious to select (e.g., via an optimization process) a timing that is tailored for a target application. These timings would be selected such that the jet impinges on the surface, as taught by Ishida. Optimizing variables for a particular application was a well-known and conventional aspect of piston design.

2. Claim 2 – “The directly injecting internal combustion engine as claimed in claim 1, wherein a surface connected to the recess edge adjoins the surface of the piston recess.”

241. Ishida teaches that the side wall 31 is connected to the lip 2 via a radius and a surface extender the top 11.

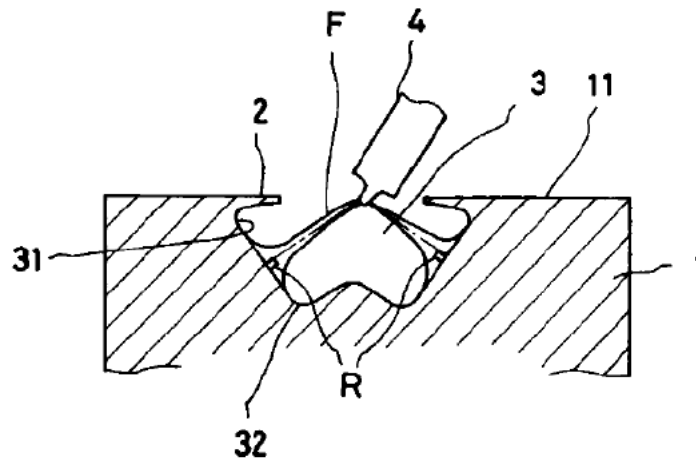


FIG. 2

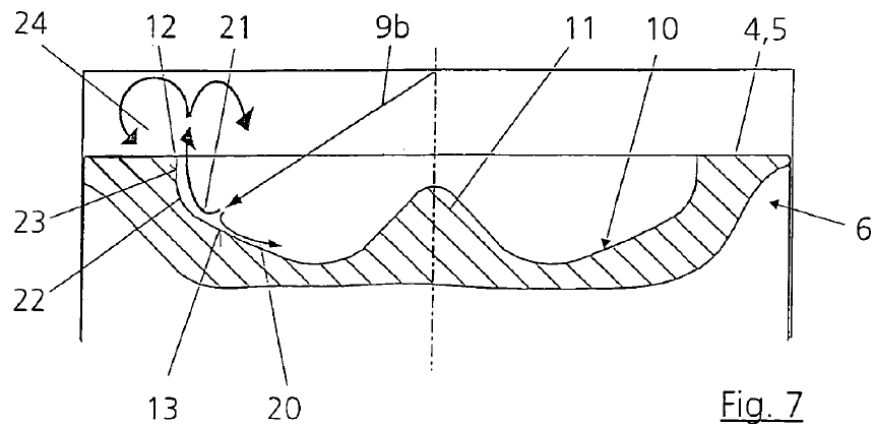
Id., FIG. 2.

242. These features are disclosed in Figure 2 of Ishida. Below, I annotate in Figure 2 a surface (purple) that is connected to the recess edge (green) and adjoins the surface (blue) of the piston recess.



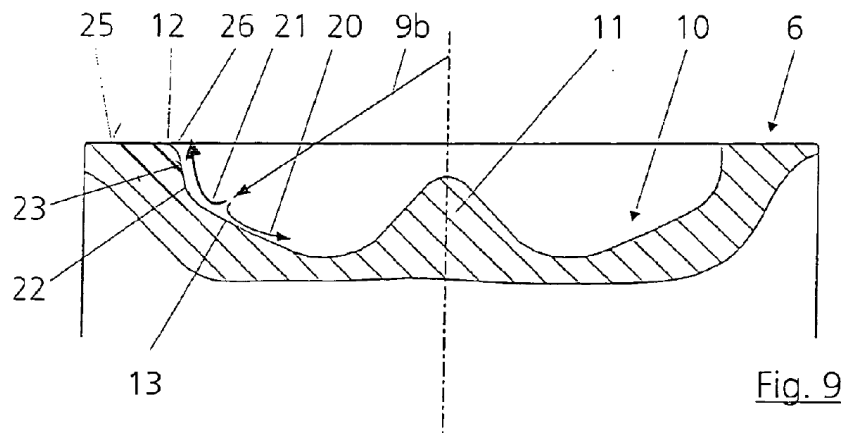
Id., FIG. 2 (annotated).

243. This interpretation of the surface adjoining the surface of the piston recess is consistent with corresponding discussion in the '238 Patent. *See* EX. 1001, 4:8–9 (“It is apparent from FIG. 7 that the surface 13 has adjoining it a surface 23 connected to the recess edge 12 via a radius 22.”). The '238 Patent discloses that the surface 23 adjoins the surface 13 despite the radius 22 being located therebetween.



EX. 1001, FIG. 7.

244. The '238 Patent illustrates the surface 23 in Figure 9 with the radius 26 between the surface 23 and the recess edge 12. EX. 1001, 4:20–7. Thus, the surface 23 connected to the recess edge 12 adjoins the surface 13 of the piston recess despite the radius 26 being present between the surface 23 and the recess edge 12.



EX. 1001, FIG. 9.

3. Claim 3 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

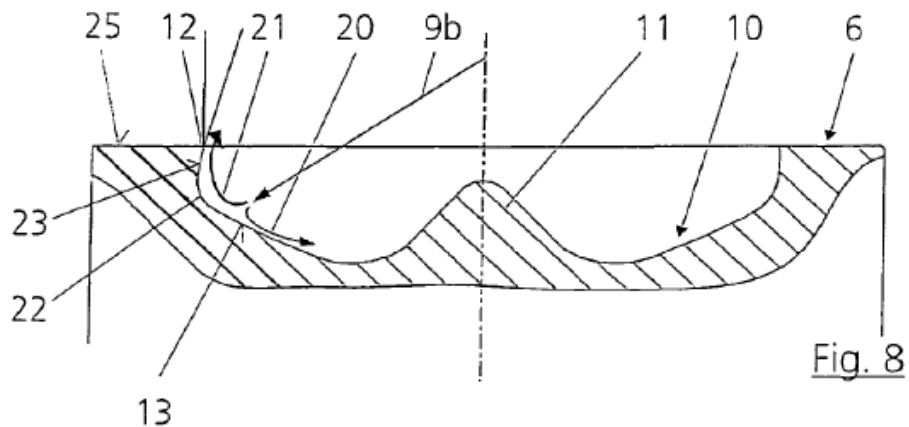
245. These features are disclosed in Figure 2 of Ishida. Below, I annotate in Figure 2 the surface (purple) that is connected to the recess edge (green) and that is connected via a radius (cream) to the surface (blue) of the piston recess.



EX. 1005, FIG. 2 (annotated).

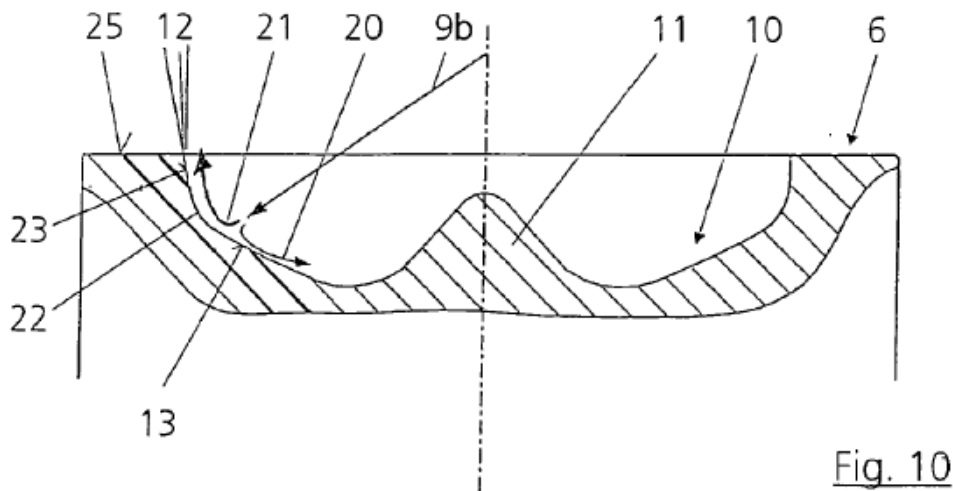
4. Claim 5 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

246. As an initial matter, I note that the '238 Patent does not provide any definition for “form[ing] an acute angle with an upper surface of the piston.” In this regard, the '238 Patent states that “[i]n the embodiment according to FIG. 8, the surface 23 connected to the recess edge 12 forms an acute angle with the upper surface 25 of the piston 6.” EX. 1001, 4:22–24.



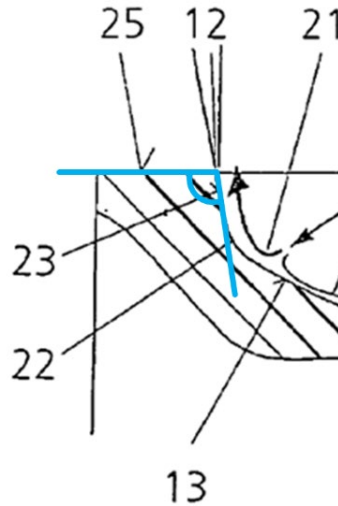
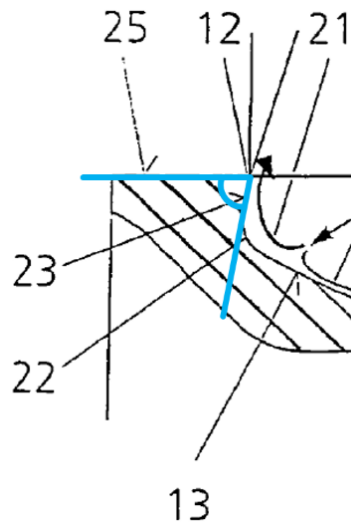
Id., Fig. 8.

247. In a related context, the '238 Patent states that “FIG. 10 illustrates an embodiment in which the surface 23 connected to the recess edge 12 forms an obtuse angle with the upper surface 25 of the piston 6.” *Id.*, 4:28–30.

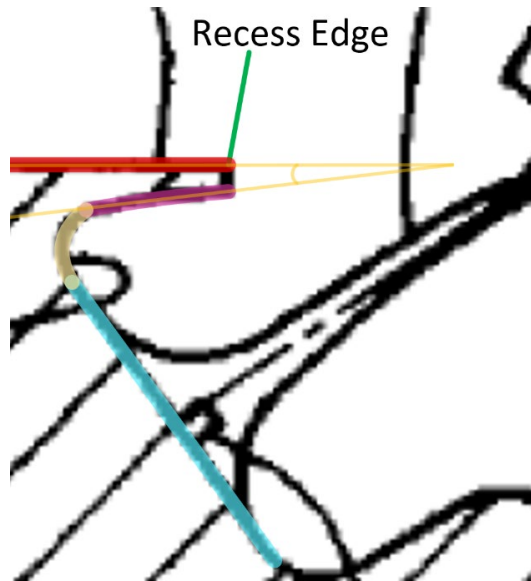


Id., Fig. 10.

248. Using Figure 8 along with Figure 10 and the corresponding discussion in the '238 Patent, the most reasonable interpretation is that both the acute and obtuse angles are measured counterclockwise from the upper surface 25 and about the recess edge 12 where the upper surface 25 adjoins the surface 23 along an edge and not a radius, as I have shown in my annotation of Figures 8 and 10 of the '238 Patent, below.



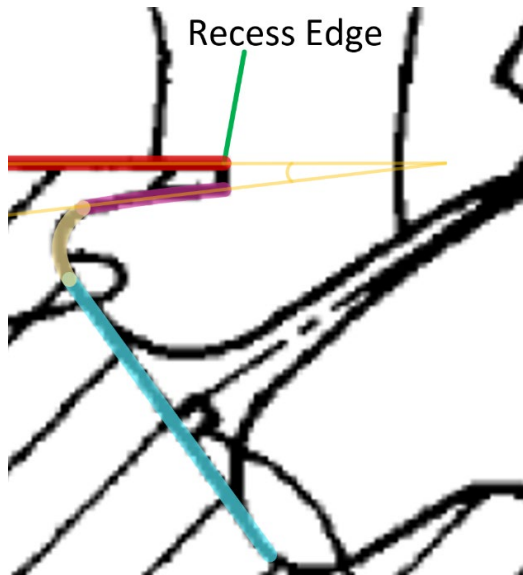
249. These features are disclosed in Figure 2 of Ishida. Below, I annotate in Figure 2 the surface (purple) connected to the recess edge (green) that forms an acute angle (orange) with an upper surface (red) of the piston.



EX. 1005, FIG. 2 (annotated).

- 5. Claim 6 – “The directly injecting internal combustion engine as claimed in claim 5, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”**

250. These features are disclosed in Figure 2 of Ishida. Below, I annotate in Figure 2 the surface (purple) connected to the recess edge (green) is connected via a radius (cream) to the surface (blue) of the piston recess.

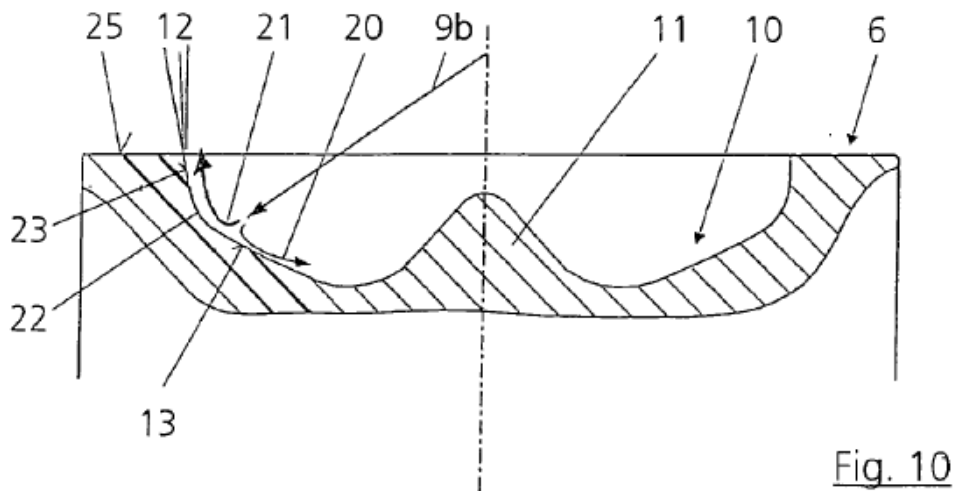


Id., FIG. 2 (annotated).

B. Claims 7 and 8 are obvious over Ishida and Oota

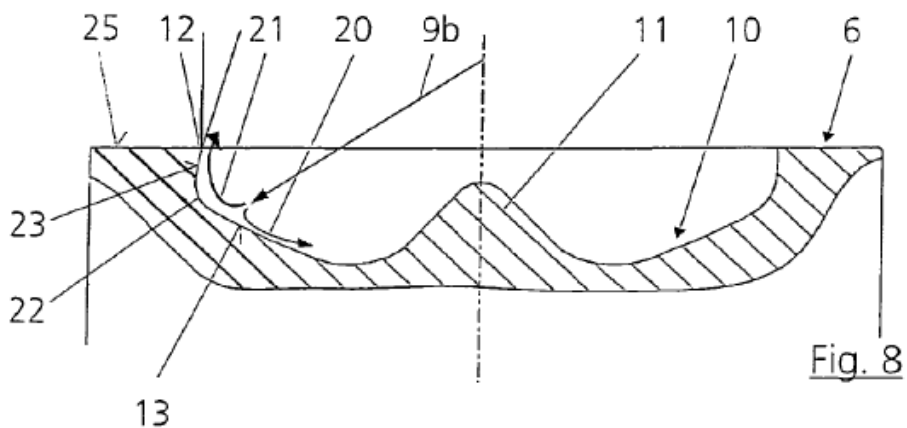
- 1. Claim 7 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an obtuse angle with an upper surface of the piston.”**

251. As an initial matter, I note that the '238 Patent does not provide any definition for “form[ing] an obtuse angle with an upper surface of the piston.” In this regard, the '238 Patent states that “FIG. 10 illustrates an embodiment in which the surface 23 connected to the recess edge 12 forms an obtuse angle with the upper surface 25 of the piston 6.” *Id.*, 4:28–30.



Id., Fig. 10.

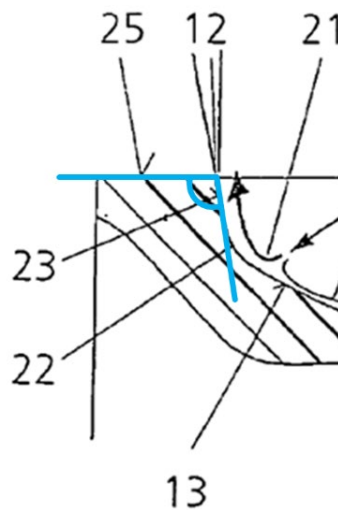
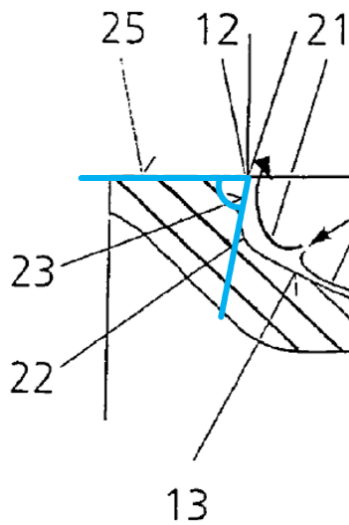
252. In a related context, the '238 Patent states that “[i]n the embodiment according to FIG. 8, the surface 23 connected to the recess edge 12 forms an acute angle with the upper surface 25 of the piston 6.” EX. 1001, 4:22–24.



Id., Fig. 8.

253. Using Figure 8 along with Figure 10 and the corresponding discussion in the '238 Patent, the most reasonable interpretation is that both the acute and obtuse angles are measured counterclockwise from the upper surface 25 and about the

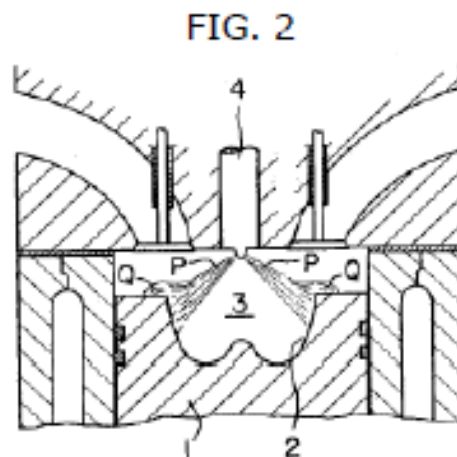
recess edge 12 where the upper surface 25 adjoins the surface 23 along an edge and not a radius, as I have shown in my annotation of Figures 8 and 10 of the '238 Patent, below.



254. Ishida does not disclose that the surface (purple) connected to the recess edge (green) forms an obtuse angle with an upper surface (red) of the piston because of the edge (orange) therebetween.



255. As I discussed in Section IX.B.2, lipless piston designs were well known and conventional. One example of such a lipless piston design is taught by Oota in its Figure 2 which Oota describes as a “known combustion chamber.” EX. 1009, p. 1.



Id., FIG. 2.

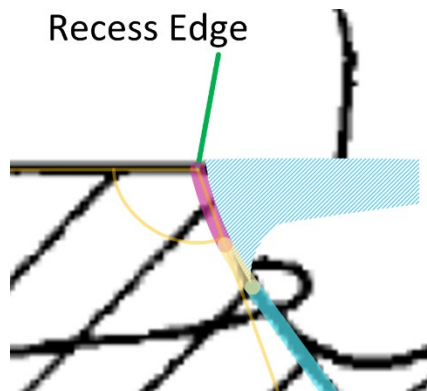
256. The lipless design of Figure 2 includes a simple open-chamber piston recess 3. A POSITA would have understood that a lipless design like that of Oota is less expensive than the lipped design of Ishida and is less prone to cracking (e.g., due to thermal stress) than the lipped design of Ishida. Unlike in Ishida, Oota teaches overspraying fuel onto the top surface of the piston, as shown in Figure 2. A POSITA would have understood that this overspray is principally responsible for the negative characteristics described by Oota (increased diesel black smoke and reduced combustion efficiency). Ishida teaches impingement of the side wall in a manner that would decrease overspray of fuel onto the top surface of the piston. Thus, a POSITA would have understood that removing the lip of Ishida, thereby using the lipless design of Oota, while impinging the side wall as taught by Ishida, would have avoided the negative characteristics described by Oota while providing the benefits associated with removing the lip (decreased cost and increased durability).

257. When designing an engine and, specifically, a piston, a POSITA is faced with a multitude of design choices. Many of these choices require considering the consequences of increased complexity against the benefits of simplicity. Similarly, many of these choices balance increased cost against increased performance. Lipless designs like that of Oota were well known and fundamental in piston design. A POSITA would have been well aware of these designs and understood how to implement them in Ishida. A POSITA would have seen the lipless

design of Oota as a straightforward design permutation that would have been obvious to implement in Ishida.

258. The piston recess in Ishida terminates at the upper surface 11 of the piston 1 when the lip 2 of Ishida is removed as taught by Oota. An edge is formed between an uppermost peripheral edge of the side wall 31 where it meets the flat top surface 11 of the piston. Additionally, this uppermost portion or termination of the side wall 31 at the piston's top surface is a "surface connected to the recess edge."

259. I have prepared below an annotation showing Ishida with the lip removed. The blue cross-hatching shows the lip being removed. With the lip removed, the side wall in Ishida transitions along a radius gradually upward to the recess edge. The side wall slopes outwards and upwards from the bottom towards the recess edge.

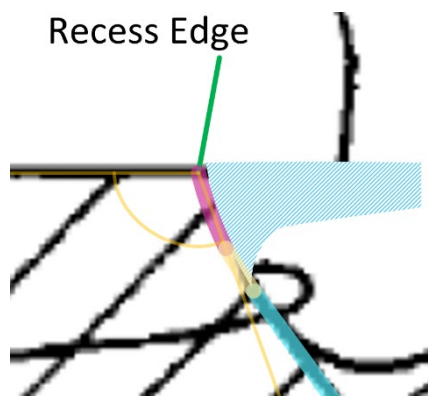


260. As shown above in my annotation, the side wall joins the top surface at an angle that is obtuse (greater than 90 degrees). This obtuse angle is a fundamental geometric consequence of an open bowl shape with an outwardly flared wall meeting

a flat top surface. Moreover, use of an obtuse angle would have been obvious to a POSITA because there are only three options for an angle – obtuse, acute, and normal (i.e., at 90 degrees). In view of such limited options, a POSITA would have found it obvious to implement any one of those options in order to tailor a piston for a target application.

2. Claim 8 – “The directly injecting internal combustion engine as claimed in claim 7, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

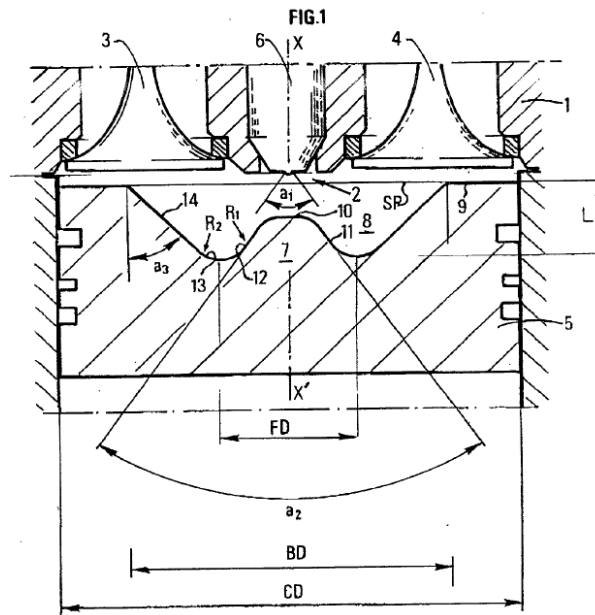
261. In the modification of Ishida I discuss in Section X.B.1 with respect to claim 7, a radius is included when the lip is removed. Specifically, as shown in the annotation below, the surface (purple) is connected to the recess edge (green) and is connected via a radius (cream) to the surface (the side wall - blue) of the piston recess.



C. Claims 9-13 are obvious over Ishida and Gatellier

1. Claim 9 – “The directly injecting internal combustion engine as claimed in claim 1, wherein an injection angle of the injection nozzle is between 50° and 120°.”

262. As I discussed in Section IX.C.2, Ishida alone depicts in its Figure 2 an injection angle of approximately 120°. Also, a POSITA would have understood that injectors like that of Ishida commonly have injection angles of “between 50° and 120°.” Finally, Gatellier provides an example of an injector that a POSITA would have selected and implemented in Ishida to tailor the engine of Ishida to target applications. Specifically, Gatellier discloses an internal combustion engine that includes “a fuel injection nozzle 6 such as a multijet nozzle, preferably arranged in line with axis XX’ of the cylinder.” EX. 1007, ¶[0052]. Gatellier states that the “fuel injection nozzle has a small nappe angle a_1 , nappe angle a_1 , being selected at most equal to 120° and preferably ranging between 40° and 100°.” *Id.*, ¶[0054]; *see id.*, ¶[0057], claim 3, claim 4.



Id., FIG. 1.

263. Gatellier explains that the “nappe angle is so selected that the walls of the cylinder are never wetted by the fuel for any position of the piston ranging between $+50^\circ$ and $+\alpha$ or between -50° and $-\alpha$ where α represents the crankshaft angle for the injection phase selected in relation to the top dead center (TDC), this angle α being greater than 50° and less than or equal to 180° to obtain a homogeneous type combustion.” *Id.*, ¶[0055]. This is a benefit Gatellier teaches that would have been understood to enhance the performance and flexibility of the engine by avoiding wetting of the walls of the cylinder (which would have been understood to decrease performance of the engine).

264. In designing an engine, a POSITA would have understood that the injection angle of the injector is one variable that is selectable to optimize the engine

for a target application. Injectors were ubiquitous and selecting an injector having one injection angle instead of another injector having a different injection angle would have amounted to nothing more than simple substitution of a readily interchangeable component of the engine. This modification to Ishida is nothing more than a design choice.

265. As I discussed in Section IX.C.2, it would have been obvious to replace the injector 4 of Ishida with the injection nozzle 6 of Gatellier. This would have provided the flexibility to use injection angles that are not explicitly disclosed in Ishida, which would have provided the flexibility to desirably utilize Ishida's engine in various applications where those injection angles are desirable. For example, the injection nozzle 6 of Gatellier would have been beneficial in resolving the known issues associated with injection timing and wall wetting that Gatellier is premised on solving.

266. Because "between 50° and 120°" as recited in claim 9 falls within "at most equal to 120°" and also overlaps with "between 40° and 100°," as disclosed by Gatellier, claim 9 is obvious in view of Ishida and Gatellier.

2. Claim 10 – "The directly injecting internal combustion engine as claimed in claim 9, wherein a surface

connected to the recess edge adjoins the surface of the piston recess.”

267. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 2 which is addressed in Section X.A.2, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

3. Claim 11 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

268. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 3 and 6 which are addressed in Sections X.A.3 and X.A.5, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

4. Claim 12 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

269. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 5 which is addressed in Section X.A.4, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

5. Claim 13 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface

connected to the recess edge forms an obtuse angle with an upper surface of the piston.”

270. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 7 which is addressed in Section X.B.1, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

D. Claim 4 is Obvious Over Ishida and Iijima

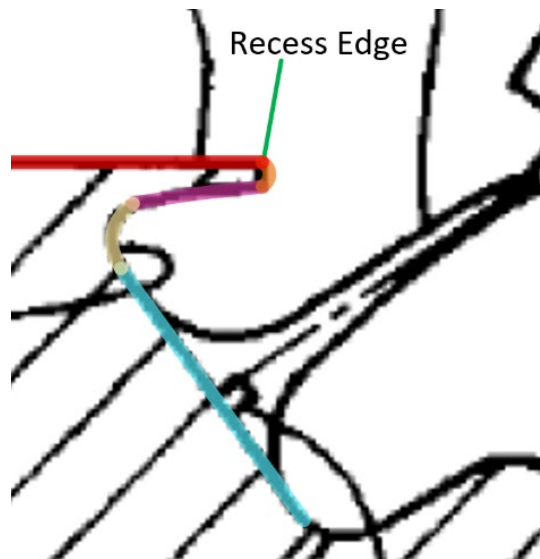
- 1. Claim 4 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.”**

271. As I have explained in Section IX.D.2, a POSITA would have found it obvious to modify edges to reduce risk of cracking. One of these modifications is to round these edges, as taught by Iijima.

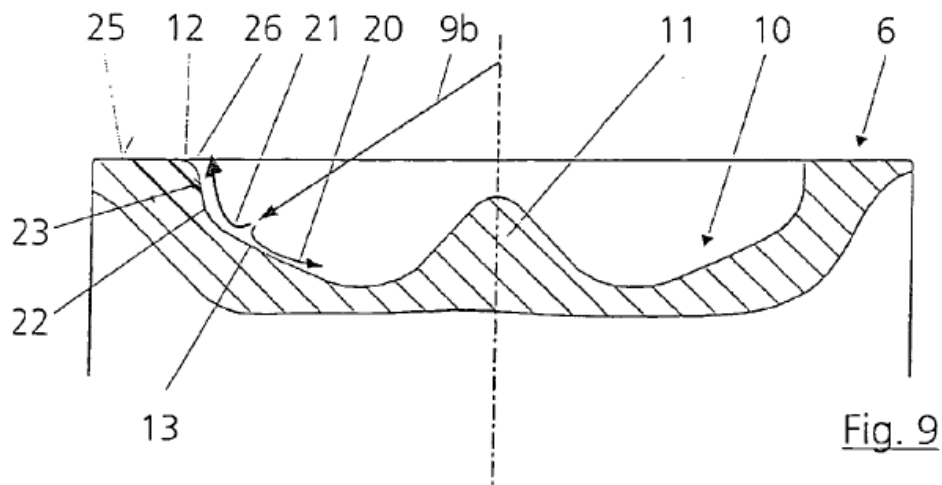
272. In Ishida, a POSITA would have understood that the lip 2 is prone to cracking due to its sharp edge. This cracking may be due to thermal stresses or, for example, damage during installation or servicing of a piston. The lip 2 may not crack in all applications (such as low load applications, for example). However, in seeking to enhance the useful life of Ishida’s engine and facilitate operation in additional applications (such as medium and high load applications, for example), a POSITA would have understood that applying the teachings from Iijima to Ishida would have

provided the benefit of reduced risk of cracking. Moreover, this modification of Ishida would not change its fundamental principle of side wall impingement.

273. In my annotation, I have modified Ishida to include a radius (orange) so that the surface (purple) connected to the recess edge (green) merges in a radius (orange) into an upper surface (red) of the piston.”



274. This interpretation of the surface connected to the recess edge merging in a radius into an upper surface of the piston is consistent with corresponding discussion in the '238 Patent. *See* EX. 1001, 4:26–27 (“The '238 Patent provides that “[i]n the embodiment according to FIG. 9, the surface 23 merges at a radius 26 into the upper surface 25 of the piston 6”). The '238 Patent discloses that the surface 23 adjoins the surface 25 despite the radius 26 being located therebetween.



EX. 1001, FIG. 9.

E. Claim 14 is Obvious Over Ishida, Gatellier, and Iijima

- 1. Claim 14 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.”**

275. I have provided my analysis of Ishida and Iijima with respect to these limitations which are also included in claim 4 which is addressed in Section X.D.1, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

F. Claims 1-3, 5, and 6 are obvious over Ishida, as evidenced by Takatomo

1. Claim 1

- i. “A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an**

**oscillating movement, and an injection nozzle for
injection of fuel into the combustion space,”**

276. I have provided my analysis of Ishida with respect to these limitations in Section X.A.1.i, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations.

**ii. “wherein the piston has a piston recess, which, in
a central region thereof, has an elevation
extending in a cylinder head direction, and”**

277. I have provided my analysis of Ishida with respect to these limitations in Section X.A.1.ii, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations.

**iii. “[a] a surface of the piston recess adjoining the
elevation in a recess edge direction is connected
to the elevation via a radius [b] so that an
injection jet impinging the surface and injected
as early as possible is distributed both in a
elevation direction and in the recess edge
direction, and”**

**(a) “a surface of the piston recess adjoining
the elevation in a recess edge direction is
connected to the elevation via a radius”**

278. I have provided my analysis of Ishida with respect to these limitations in Section X.A.1.iii.a, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations.

**(b) “so that an injection jet impinging the
surface and injected as early as possible is**

**distributed both in a elevation direction
and in the recess edge direction, and”**

279. I have provided my analysis of Ishida with respect to these limitations in Section X.A.1.iii.b, above.

280. As I discussed in Section IX.F.2, Takatomo describes Ishida as a prior solution. Takatomo explains that as a result of problems in Ishida, “an auto-timer or the like for automatically adjusting the injection timing is required as an additional device.” EX. 1006, 3:64–65. Thus, an obvious modification of Ishida in view of Takatomo is to incorporate an auto-timer into Ishida. This modification overcomes a deficiency in Ishida explicitly identified by Takatomo. A POSITA would have had a reasonable expectation of success in making such a modification because Takatomo teaches that this modification “is required.”

281. As I discussed in Section X.A.1.iii.b, a POSITA would have understood that Ishida is necessarily applicable to injections occurring during the compression stroke, and these injections necessarily include injections that are “as early as possible.” During these injections, even with an auto-timer, the fuel would impinge the side wall 31 and be distributed (e.g., towards the recess edge and towards the central peak) as described in Ishida.

282. Again, if “injected as early as possible” requires injection earlier than depicted in Figure 2 of Ishida, a POSITA would have found performing such

injections obvious. Varying injection timing was well known, and varying injection timing would still achieve the dual direction distribution of the fuel spray upon which Ishida is premised. It was conventional and well known to a POSITA that timing is selectable and a POSITA would have found it obvious to select (e.g., via an optimization process) a timing that is tailored for a target application. These timings would be selected such that the jet impinges on the surface (blue), as taught by Ishida. Optimizing variables for a particular application was a well-known and conventional aspect of piston design.

iv. **“[a] the surface is substantially planar and has an ascending gradient in the recess edge direction [b] such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.”**

(a) **“the surface is substantially planar and has an ascending gradient in the recess edge direction”**

283. I have provided my analysis of Ishida with respect to these limitations in Section X.A.1.iv.a, above.

(b) **“such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.”**

284. As I discussed in Section IX.F.2, Takatomo describes Ishida as a prior solution. Similarly, as I discussed in Sections IX.F.2 and X.F.1.iii.b, it would have been obvious to incorporate an auto-timer into Ishida for at least the reason that the deficiency in Ishida identified by Takatomo would have been overcome.

285. As I discussed in Section X.A.1.iv.b, a POSITA would have understood that Ishida is necessarily applicable to “as late as possible” injections. During these injections, even with an auto-timer, the fuel would impinge the side wall 31 and be distributed (e.g., towards the recess edge and towards the central peak) as described in Ishida.

286. Again, if “injected as late as possible” requires injection later than depicted in Figure 2 of Ishida, a POSITA would have found performing such injections obvious. Varying injection timing was well known, and varying injection timing would still achieve the dual direction distribution of the fuel spray upon which Ishida is premised. It was conventional and well known to a POSITA that timing is selectable and a POSITA would have found it obvious to select (e.g., via an optimization process) a timing that is tailored for a target application. These timings would be selected such that the jet impinges on the surface (blue), as taught by Ishida. Optimizing variables for a particular application was a well-known and conventional aspect of piston design.

2. Claim 2 – “The directly injecting internal combustion engine as claimed in claim 1, wherein a surface connected to the recess edge adjoins the surface of the piston recess.”

287. I have provided my analysis of Ishida with respect to these limitations in Section X.A.2, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

3. Claim 3 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

288. I have provided my analysis of Ishida with respect to these limitations in Section X.A.3, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

4. Claim 5 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

289. I have provided my analysis of Ishida with respect to these limitations in Section X.A.4, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

5. Claim 6 – “The directly injecting internal combustion engine as claimed in claim 5, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

290. I have provided my analysis of Ishida with respect to these limitations in Section X.A.5, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

G. Claims 7 and 8 are obvious over Ishida and Oota, as evidenced by Takatomo

1. Claim 7 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an obtuse angle with an upper surface of the piston.”

291. I have provided my analysis of Ishida and Oota with respect to these limitations which addressed in Section X.B.1, above. Takatomo is not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

2. Claim 8 – “The directly injecting internal combustion engine as claimed in claim 7, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

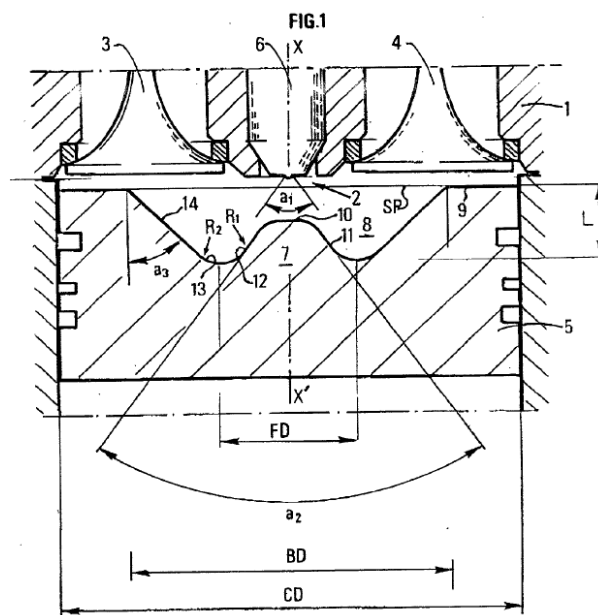
292. I have provided my analysis of Ishida and Oota with respect to these limitations where are addressed in Section X.B.2, above. Takatomo is not relied

upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

H. Claims 9-13 are obvious over Ishida and Gatellier, as Evidenced by Takatomo

1. Claim 9 – “The directly injecting internal combustion engine as claimed in claim 1, wherein an injection angle of the injection nozzle is between 50° and 120°.”

293. Gatellier discloses an internal combustion engine that includes “a fuel injection nozzle 6 such as a multijet nozzle, preferably arranged in line with axis XX’ of the cylinder.” EX. 1007, ¶[0052]. Gatellier states that the “fuel injection nozzle has a small nappe angle α_1 , nappe angle α_1 , being selected at most equal to 120° and preferably ranging between 40° and 100° .” *Id.*, ¶[0054]; *see id.*, ¶[0057], claim 3, claim 4.



Id., FIG. 1.

294. Gatellier explains that the “nappe angle is so selected that the walls of the cylinder are never wetted by the fuel for any position of the piston ranging between $+50^\circ$ and $+\alpha$ or between -50° and $-\alpha$ where α represents the crankshaft angle for the injection phase selected in relation to the top dead center (TDC), this angle α being greater than 50° and less than or equal to 180° to obtain a homogeneous type combustion.” *Id.*, ¶[0055].

295. In designing an engine, a POSITA would have understood that the injection angle of the injector is one variable that is selectable to optimize the engine for a target application. Injectors were ubiquitous and selecting an injector having one injection angle instead of another injector having a different injection angle would have amounted to nothing more than simple substitution of a readily interchangeable component of the engine.

296. As I discussed in Section IX.C.2, it would have been obvious to replace the injector 4 of Ishida with the injection nozzle 6 of Gatellier. This would have provided the flexibility to use injection angles that are not explicitly disclosed in Ishida, which would have provided the flexibility to desirably utilize Ishida’s engine in various applications where those injection angles are desirable. For example, the injection nozzle 6 of Gatellier would have been beneficial in resolving the known

issues associated with injection timing and wall wetting that Gatellier is premised on solving.

297. Because “between 50° and 120°” as recited in claim 9 falls within “at most equal to 120°” and also overlaps with “between 40° and 100°,” as disclosed by Gatellier, claim 9 is obvious in view of Ishida and Gatellier, as evidenced by Takatomo.

2. Claim 10 – “The directly injecting internal combustion engine as claimed in claim 9, wherein a surface connected to the recess edge adjoins the surface of the piston recess.”

298. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 2 which is addressed in Sections X.A.2 and X.F.2, above. Takatomo and Gatellier are not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

3. Claim 11 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

299. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 3 and 6 which are addressed in Sections X.A.3, X.A.5, X.F.3, and X.F.5, above. Takatomo and Gatellier are not relied upon for modifying that analysis with respect to these limitations. Additionally, the

modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

4. Claim 12 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

300. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 5 which is addressed in Sections X.A.4 and X.F.4, above. Takatomo and Gatellier are not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

5. Claim 13 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge forms an obtuse angle with an upper surface of the piston.”

301. I have provided my analysis of Ishida with respect to these limitations which are also included in claim 7 which is addressed in Sections X.B.1 and X.G.1, above. Takatomo and Gatellier are not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

I. Claim 4 is Obvious Over Ishida and Iijima, as Evidenced by Takatomo

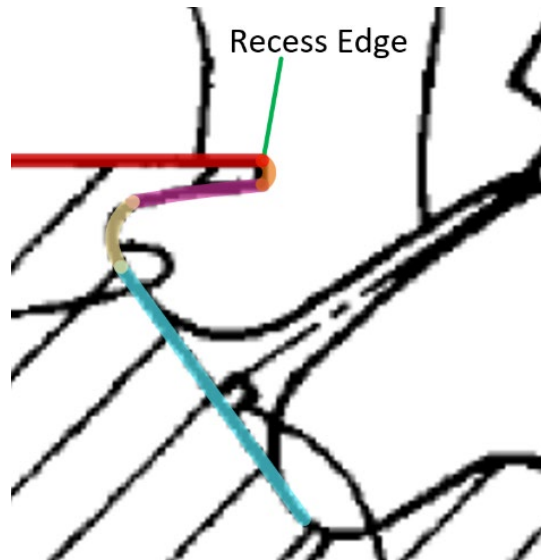
1. Claim 4 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface

connected to the recess edge merges in a radius into an upper surface of the piston.”

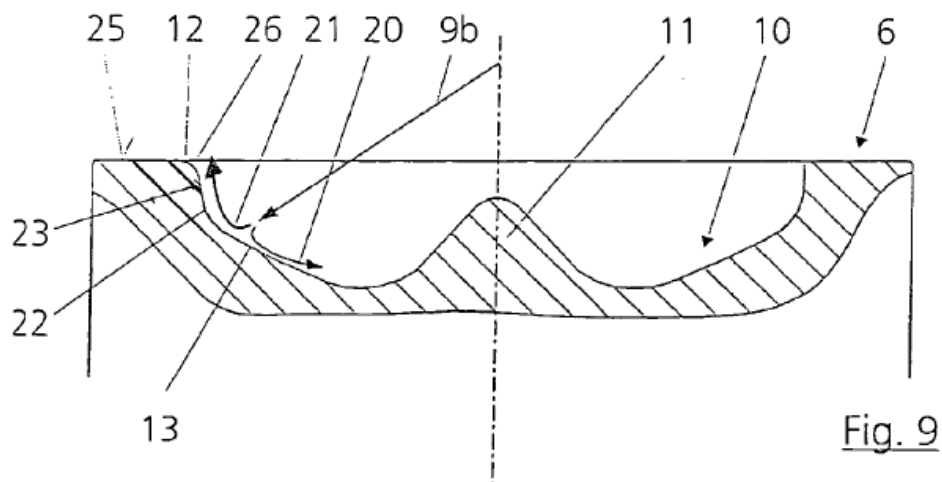
302. As I have explained in Section IX.D.2, a POSITA would have found it obvious to modify edges of a piston recess to reduce risk of cracking. One of these modifications is to round these edges, as taught by Iijima.

303. In Ishida, a POSITA would have understood that the lip 2 is prone to cracking due to its sharp edge. This cracking may be due to thermal stresses or, for example, damage during installation or servicing of a piston. The lip 2 may not crack in all applications (such as low load applications, for example). However, in seeking to enhance the useful life of Ishida’s engine and facilitate operation in additional applications (such as medium and high load applications, for example), a POSITA would have understood that applying the teachings from Iijima to Ishida would have provided the benefit of reduced risk of cracking.

304. In my annotation, I have modified Ishida to include a radius (orange) so that the surface (purple) connected to the recess edge (green) merges in a radius (orange) into an upper surface (red) of the piston.”



305. This interpretation of the surface connected to the recess edge merging in a radius into an upper surface of the piston is consistent with corresponding discussion in the '238 Patent. *See* EX. 1001, 4:26–27 (“The '238 Patent provides that “[i]n the embodiment according to FIG. 9, the surface 23 merges at a radius 26 into the upper surface 25 of the piston 6”). The '238 Patent discloses that the surface 23 adjoins the surface 25 despite the radius 26 being located therebetween.



EX. 1001, FIG. 9.

J. Claim 14 is Obvious Over Ishida, Gatellier, and Iijima, as Evidenced by Takatomo

- 1. Claim 14 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.”**

306. I have provided my analysis of Ishida and Iijima with respect to these limitations which are also included in claim 4 which is addressed in Section X.I.1, above. Takatomo and Gatellier are not relied upon for modifying that analysis with respect to these limitations. Additionally, the modification of Ishida in view of Takatomo discussed above with respect to claim 1 does not impact my analysis.

K. Claims 1–6 Are Obvious Over Takatomo

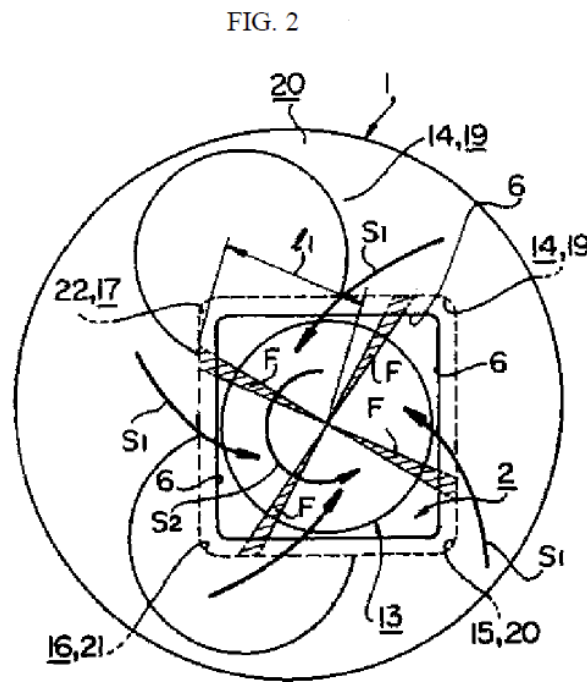
- 1. Claim 1**

- i. “A directly injecting internal combustion engine, comprising at least one cylinder which has a combustion space in which a piston executes an oscillating movement, and an injection nozzle for injection of fuel into the combustion space,”**

307. As I have explained in Section IX.F.1, Takatomo discloses a directly injecting internal combustion engine. Specifically, Takatomo teaches a “piston for an engine in which a cavity for direct supply of fuel spray is formed at the top of the piston.” EX. 1006, 2:2–3.

308. Takatomo does not state that its piston oscillates. However, a POSITA would have understood that the piston of Takatomo executes an oscillating

movement in a combustion space of a cylinder because such an arrangement is conventional in internal combustion engines like that described in Takatomo. *See id.*, Fig. 2.



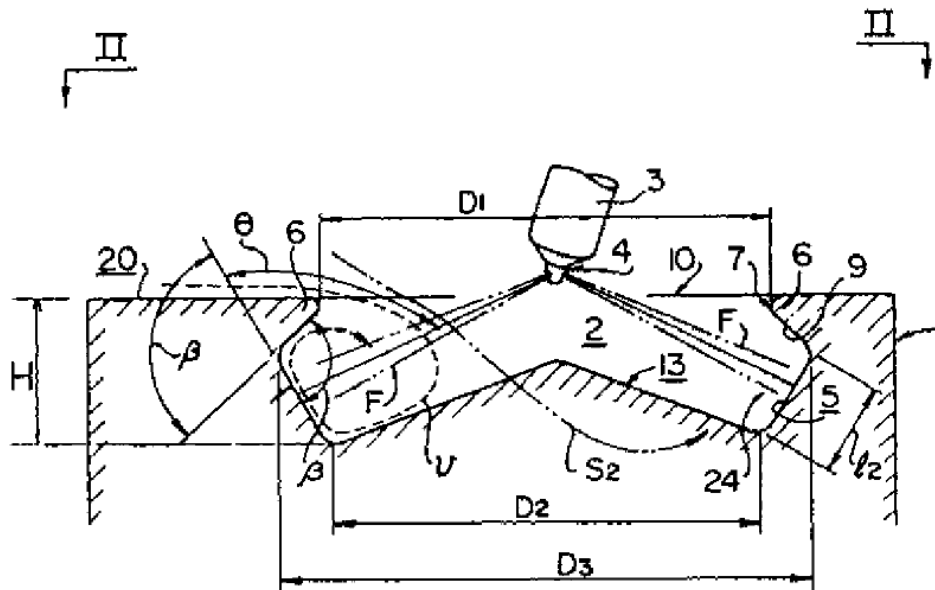
Id.

309. I have also described in Section VI the different strokes that a piston travels during operation of an internal combustion engine. The piston executes an oscillating movement during this travel (i.e., due to rotation of the crankshaft). Thus, a POSITA would have understood that the piston of Takatomo executes an oscillating movement.

310. Takatomo discloses an embodiment where “the cavity 2 has a quadrilateral horizontal cross section, and a fuel injection nozzle 3 is disposed

approximately on an axis of the cavity 2.” EX. 1006, 4:43–5. Takatomo states that a “nozzle portion 4 of the fuel injection nozzle 3 is provided with the same number of open nozzles as the number of corners of the cavity 2 at equal intervals in a circumferential direction, and the fuel spray is injected radially outward and obliquely downward from each nozzle to an opposing side wall or corner.” *Id.*, 4:45–49.

FIG. 1



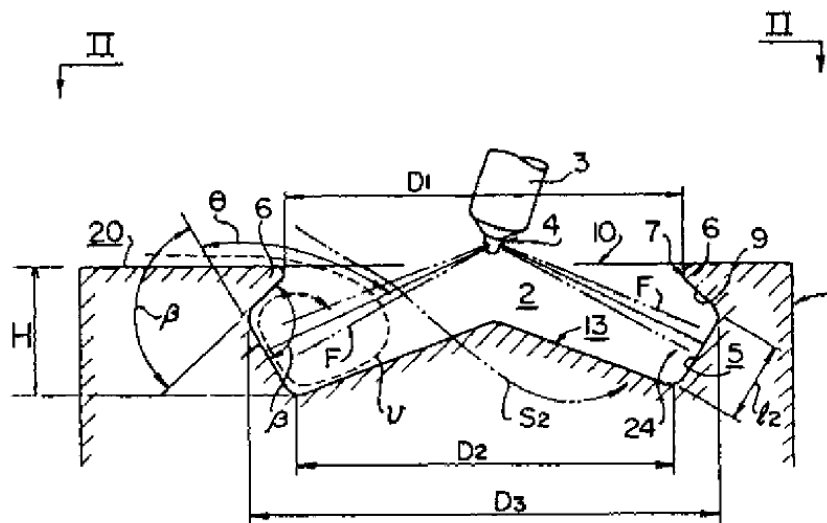
Id., FIG. 1.

311. Thus, Takatomo discloses an injection nozzle for injection of fuel into the combustion space.

- ii. “wherein the piston has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction, and”

312. Takatomo states “[a]s shown in Figs. 1 and 2, in a typical piston 1 adopted for a small direct injection diesel engine, a cavity 2 recessed in an axis direction on a top surface 20 of the piston.” EX. 1006, 4:40–3. Takatomo also provides that a “bottom surface 11 of the cavity 2 is formed by a conical protruding portion 13 that protrudes on a central axis O_2 of the cavity 2 with respect to the horizontal plane.” *Id.*, 4:58–60. Takatomo explains that “the apex of the protruding portion 13 is located near the middle position in the height direction of the cavity so as to generate a toroidal swirling flow in the cavity 2.” *Id.*, 5:1–3. The cavity 2 of Takatomo is a recess in the piston and therefore a piston recess.

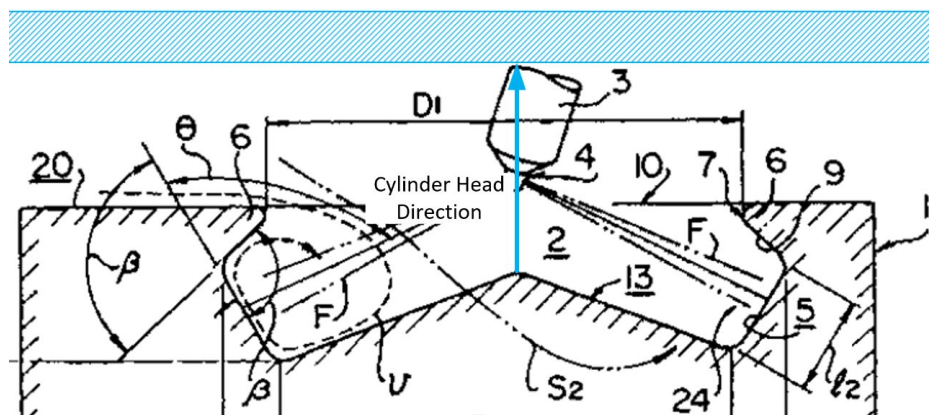
FIG. 1



Id., FIG. 1.

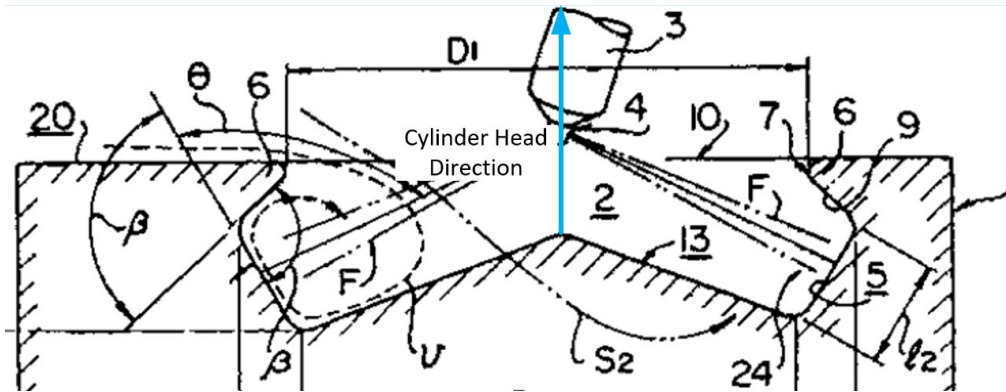
313. Thus, Takatomo discloses a piston that has a piston recess, which, in a central region thereof, has an elevation extending in a cylinder head direction.

314. Takatomo does not show a cylinder head in its figures. However, a POSITA would have understood that an engine, like that of Takatomo, includes a cylinder head, as I discussed in Section VI. *See* EX. 1015, 44, 46. Engines like that of Takatomo commonly include cylinder heads above cylinder blocks within which their cylinders are included. A POSITA would have understood that the cylinder head is located above the piston and cylinder. Thus, the POSITA would have understood that Takatomo includes a cylinder head above the piston and that the protrusion 13 extends in a direction towards the cylinder head. Below, I have prepared an annotation of a portion of Figure 1 of Takatomo showing a cylinder head direction and where the cylinder head (blue crosshatching) would be located (at one position of the piston).



Id., FIG. 1 (annotated).

315. As I discussed in Section X.A.1.ii, a POSITA would have understood “a cylinder head direction” as being any “direction” that is towards a “cylinder head,” regardless of how slight that direction is towards the cylinder head. I annotated only one such cylinder head direction below.



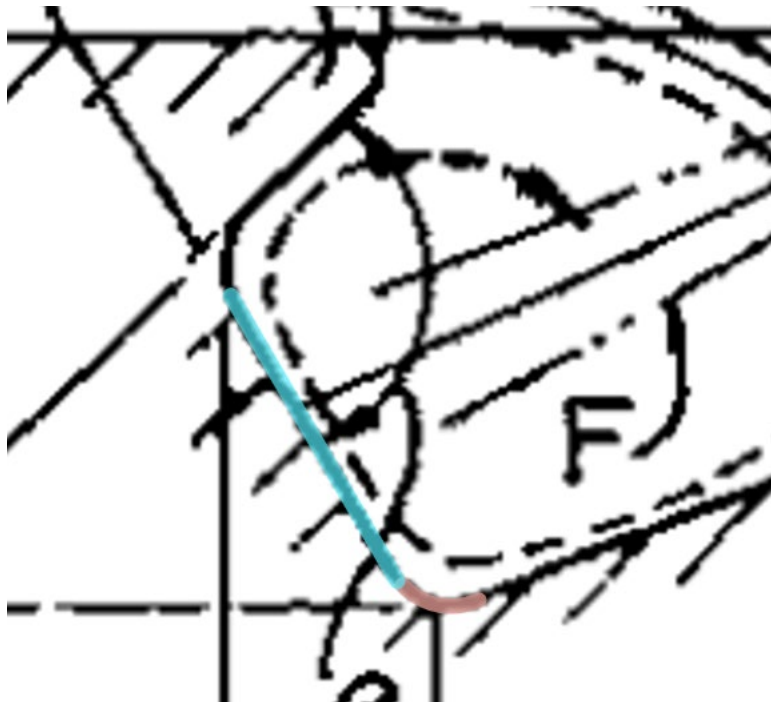
Id., FIG. 1 (annotated).

- iii. **“[a] a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius [b] so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and”**
 - (a) **“a surface of the piston recess adjoining the elevation in a recess edge direction is connected to the elevation via a radius”**

316. According to Takatomo, “the side wall 5 and the lip lower surface 9 are smoothly connected by an arc with a curvature that enables a squish flow V generated by the lip 6 at the end of compression stroke to peel off from the lip lower

surface 9 side and reverse to the bottom surface side of the cavity 2, and the connecting portion between the bottom surface and the bottom of the protruding portion 13 is also smoothly connected by an arc.” *Id.*, 5:15–21. Takatomo explains how ‘rounding’ surfaces forms ‘arcs.’ *Id.*, 5:5–10, 5:21–4, 5:46–55. A POSITA would have understood that the arc described by Takatomo is a radius, as described in the ’238 Patent. *See* EX. 1001, 3:8–15; 4:26–7.

317. Takatomo discloses that a surface (side wall 5 – blue) of its piston recess (cavity 2) adjoins its elevation (protrusion 13) in a recess edge direction (a direction towards an edge of the cavity 2) and is connected to the elevation (protrusion 13) via a radius (pink).

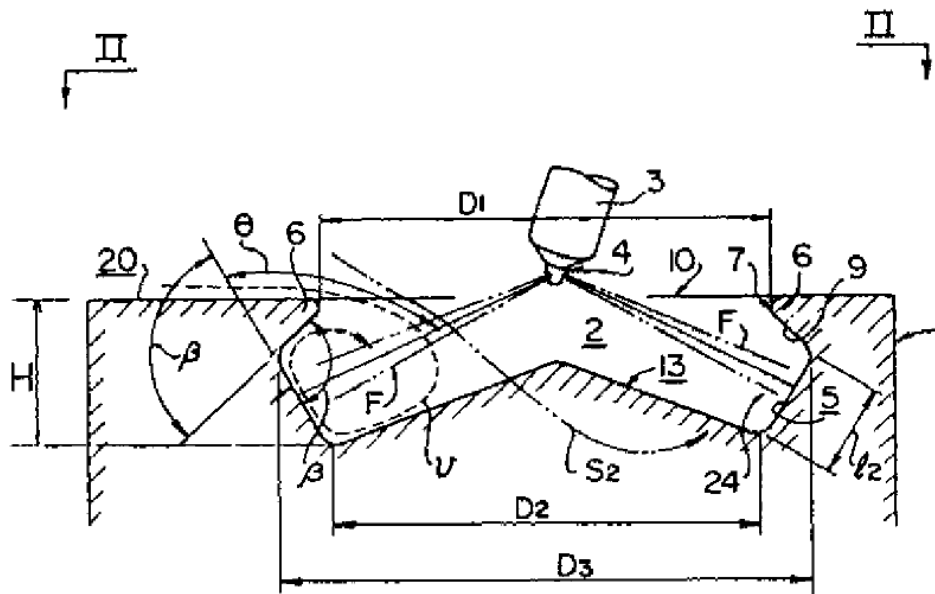


Id., FIG. 1 (annotated).

- (b) “so that an injection jet impinging the surface and injected as early as possible is distributed both in a elevation direction and in the recess edge direction, and”

318. Takatomo provides that a “nozzle portion 4 of the fuel injection nozzle 3 is provided with the same number of open nozzles as the number of corners of the cavity 2 at equal intervals in a circumferential direction, and the fuel spray is injected radially outward and obliquely downward from each nozzle to an opposing side wall or corner.” *Id.*, 4:45–9.

FIG. 1

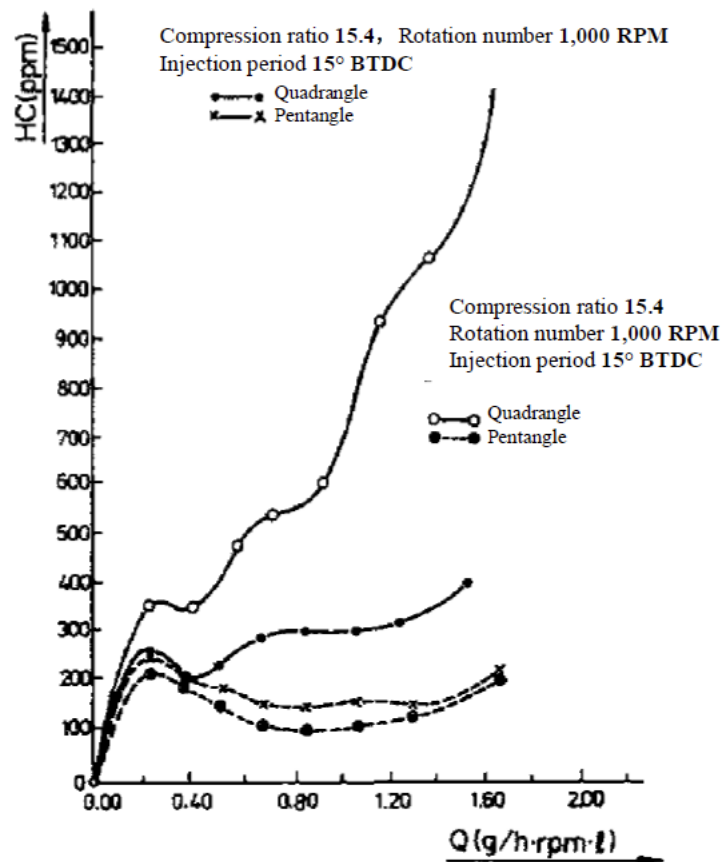


Id., FIG. 1.

319. Takatomo states that “Fig. 5 shows that when the number of rotations and the compression ratio are fixed and the injection timing is changed, the amount of discharged HC decreases when the injection timing is set to about 18° before top

dead center.” EX. 1006, 7:10–3. Takatomo thus describes how hydrocarbons are discharged at a lower rate at certain injection timings (such as about 18°) before top dead center. Takatomo also discloses that “[a]s is apparent from the results above, the pentagonal cavity with the aforementioned configuration is suitable for a low-compression-ratio engine, and when the compression ratio ϵ is set to about 15.4 and the injection timing of fuel is set to about 18° (BTDC), steady ignition and flame propagation combustion are ensured.” *Id.*, 7:19–24.

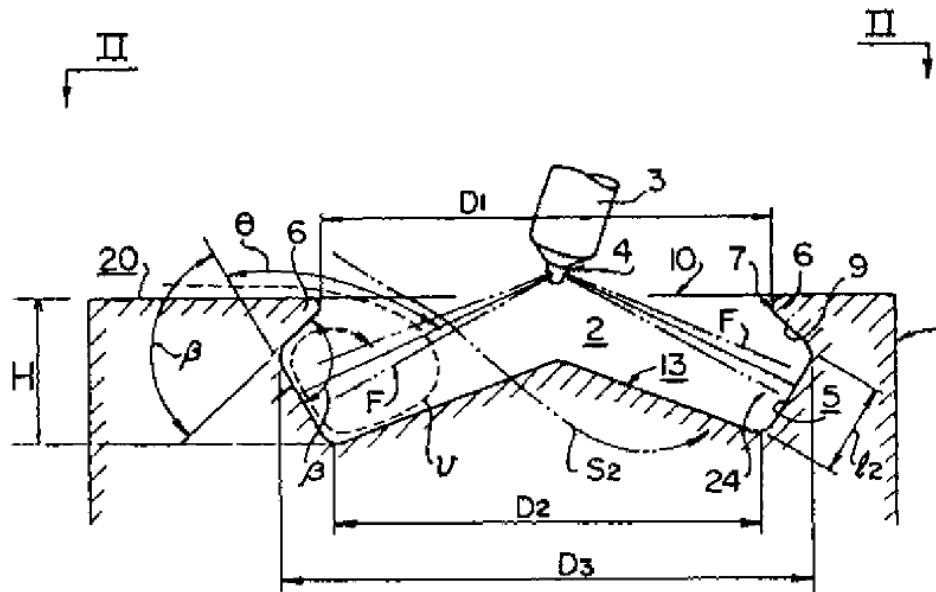
FIG. 5



Id., FIG. 5.

320. Figure 1 of Takatomo depicts the piston at a position that a POSITA would have understood is both before top dead center and after top dead center due to the reciprocation of the piston. In other words, because the piston travels vertically upward and downward in the view shown in Figure 1, and because the piston is not shown in Figure 1 as being at top dead center, Figure 1 depicts the piston at positions that are both before top dead center and after top dead center.

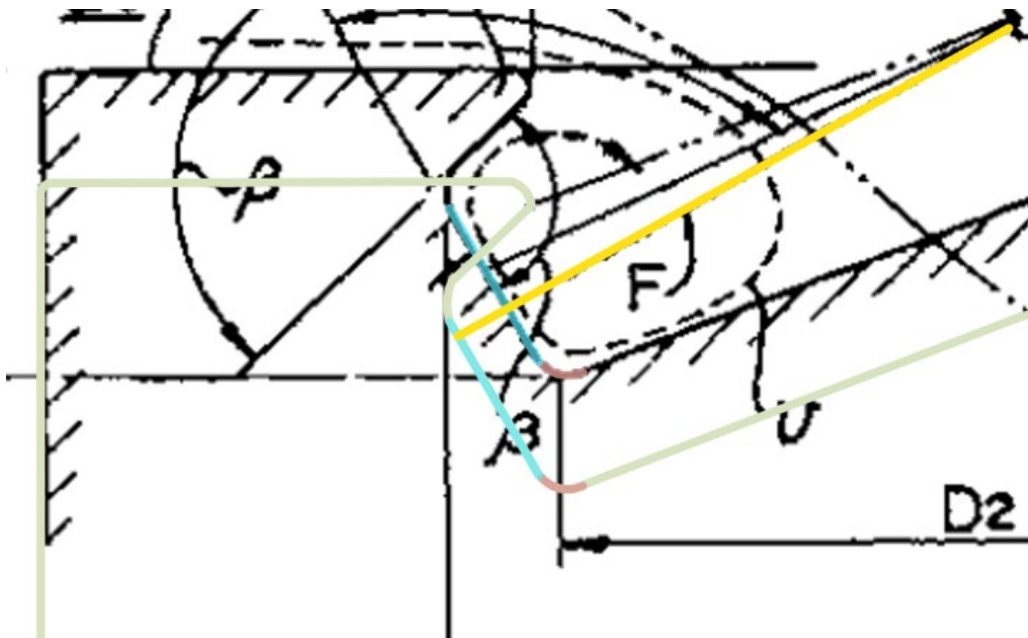
FIG. 1



Id., FIG. 1.

321. In Figure 1, the injection jet impinges the surface (side wall 5 - blue) and is distributed both in an elevation direction (a direction towards the protrusion 13) and in a recess edge direction (a direction towards an edge of the cavity 2). Thus, Takatomo discloses an injection before top dead center where the injection jet

impinges the surface (side wall 5 - blue) and is distributed both in an elevation direction (a direction towards the protrusion 13) and in a recess edge direction (a direction towards an edge of the cavity 2), and an injection after top dead center where the injection jet impinges the surface (side wall 5 - blue) and is distributed both in an elevation direction (a direction towards the protrusion 13) and in a recess edge direction (a direction towards an edge of the cavity 2).



Id., FIG. 1 (annotated).

322. When the piston is earlier in the cycle than shown in Figure 1, it is lower in the cylinder. I have annotated Figure 1 of Takatomo above to depict the piston (light green) at a position that is earlier than is shown by Takatomo and is as “early as possible.” At this earliest as possible position of the piston (light green), the spray cone F (gold) from the injector still impinges the side wall 5 (blue). This portion of

the spray cone F (gold) is still distributed both in an elevation direction (towards the protrusion 13) and in the recess edge direction (towards an edge of the cavity 2)..

323. A POSITA would have understood how to perform injections at various injection timings. For example, in reference to Figure 5 of Takatomo, as discussed above, Takatomo describes setting the injection timing to be a certain injection timing before top dead center. If “injected as early as possible” requires injection earlier than depicted in Figure 1 of Takatomo, a POSITA would have found performing such injections obvious. Varying injection timing was well known (as recognized by Takatomo). It was conventional and well known to a POSITA that timing is selectable and a POSITA would have found it obvious to select a timing that is tailored for a target application. In view of Takatomo, such timings would be selected such that the jet impinges on the side wall 5 (blue), as taught by Takatomo.

324. Takatomo states that “[a]n engine that is optimally matched at the maximum output point in this way exhibits a tendency that in a range where the speed is low and the load is light, i.e., the pressure of supercharger is low, the compression pressure, the temperature and the temperature of combustion chamber (cavity) become low.” *Id.*, 2:13–7. Takatomo explains that “[i]n general, the fuel injected from an injection nozzle usually collides with a side wall of a piston, bounces back, and is completely burned in the flame, and the fuel that adheres to the side wall is also completely evaporated or carbonized by the flame.” *Id.*, 2:17–3:2.

Takatomo explains that “[h]owever, in a low-compression-ratio engine matched for use as a turbosupercharger engine as described above, the fuel that collides with the side wall and bounces back does not ignite, or due to the delay in evaporation of the fuel adhering to the side wall, the fuel reaches the bottom of the combustion chamber with a lower temperature and liquefies, and is exposed to the flame and floats as unburned fuel in the cavity, and then is discharged during exhaust stroke, which gives rise to a blue-white smoke (HC) with an irritating odor.” *Id.*, 3:3–11. Takatomo explains that “[f]or this reason, a diesel engine with lowered compression ratio has not yet been adopted, even though it can reduce friction and improve output by increasing supercharging ratio.” *Id.*, 3:11–3.

325. Takatomo then describes the problems of previous engines. Specifically, Takatomo provides that “[a]t the maximum output point of the engine, the number of rotations is high, the fuel injection amount is also large, and the angular velocity of injection pump is large, so the dynamic injection timing is significantly delayed.” Takatomo further explains that “if the maximum output point is set as the optimal timing, the dynamic injection timing is advanced in the case of low-speed rotation, and from a very early timing before the top dead center to a late timing after the top dead center, the fuel is injected and adheres to the top surface of piston (upper surface of lip), so an excessively large amount of HC (blue-white smoke) is generated.” *Id.*, 3:51–60. A POSITA would have understood from

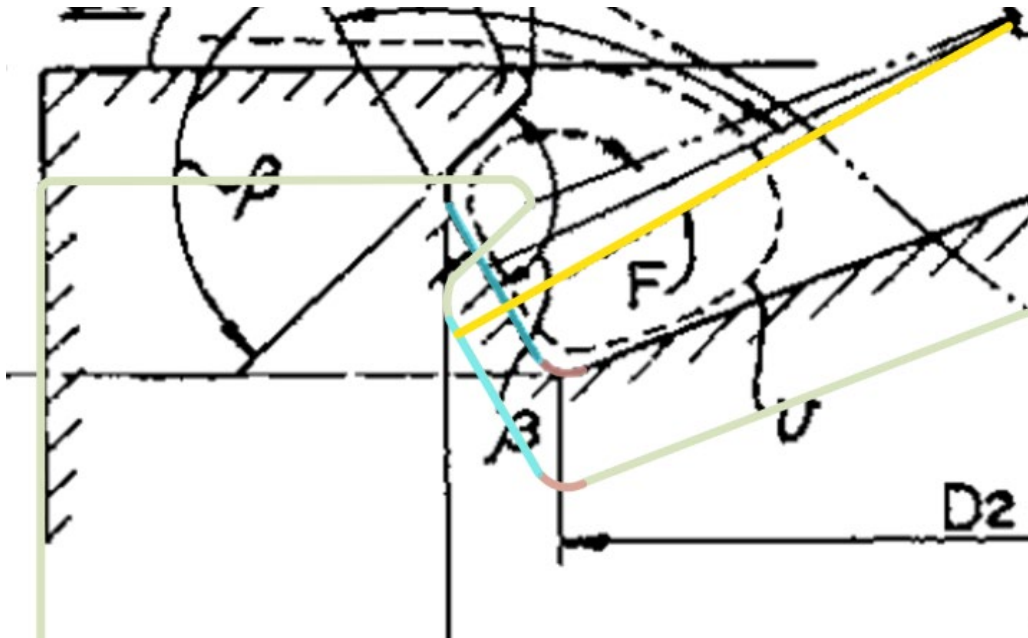
Takatomo that impingement on the side wall 5 (blue) is desirable because it reduces adhering of the fuel to the top of the piston, thereby avoiding the negative consequences (HC generation, etc.) Takatomo teaches are associated with fuel adhering to the top of the piston.

326. Takatomo states that “[w]hen the side wall 5 of the cavity 2 recessed on the top surface of the piston is formed at an inclination angle θ of 90° - 110° with respect to the fuel spray line F from the axis side of the cavity, the lip 6 is formed at the periphery of the opening of the cavity 2 so that the intersection angle β between the lower surface 9 of the lip 6 and the side wall 5 is in the same range as that of the inclination angle θ , and the protruding end 7 of the lip 6 is rounded to form an arc, the connecting portion between the side wall 5 and the lip lower surface 9 is located radially outward relative to the connecting portion between the side wall 5 and the protruding portion 13.” *Id.*, 5:44–9. Takatomo also states that “[a]s a result, the fuel spray F does not adhere to the upper surface of the lip 6 even at low speed and light load.” *Id.*, 6:1–2.

327. According to Takatomo, the “configuration” where the fuel spray F impinges the wall 5 provides that “the strength of the lip is ensured, and additionally the spray at the start of injection before top dead center and at the end of injection after top dead center collide with the protruding end and lower surface of the lip, smoothly guided to the straight portion of the side wall and flows into the cavity

while the fuel injection injected near the top dead center collides with the inclined surface of the side wall and is appropriately reversed and diffused.” EX. 1006, 4:20–

7. A POSITA would have understood that when the spray “collide[s] with the protruding end and lower surface of the lip,” as taught by Takatomo, the spray (within the yellow region) still impinges on the side wall 5 (blue). In other words, because the fuel is sprayed in a cone of droplets, each of which has its own trajectory and energy, a portion of the fuel (as shown below in gold) does not contact the lip and instead impinges on the side wall (blue). The relatively narrow lip would not block flow of all of the fuel to the side wall. By colliding with the side wall, a portion of the fuel is directed in the recess edge direction (e.g., upwards and outwards) and a portion of the fuel is directed in the elevation direction (e.g., downwards and inwards). The statement in Takatomo that the spray is “smoothly guided to the straight portion of the side wall” indicates that the side wall provides significant guiding of the flow towards the recess edge direction. The guidance is a result of direct impingement and redirection by the lip. The inward flow in the elevation direction is aided by the radius (pink) and would splash or expand towards the elevation due to turbulent breakup.



Id., FIG. 1 (annotated).

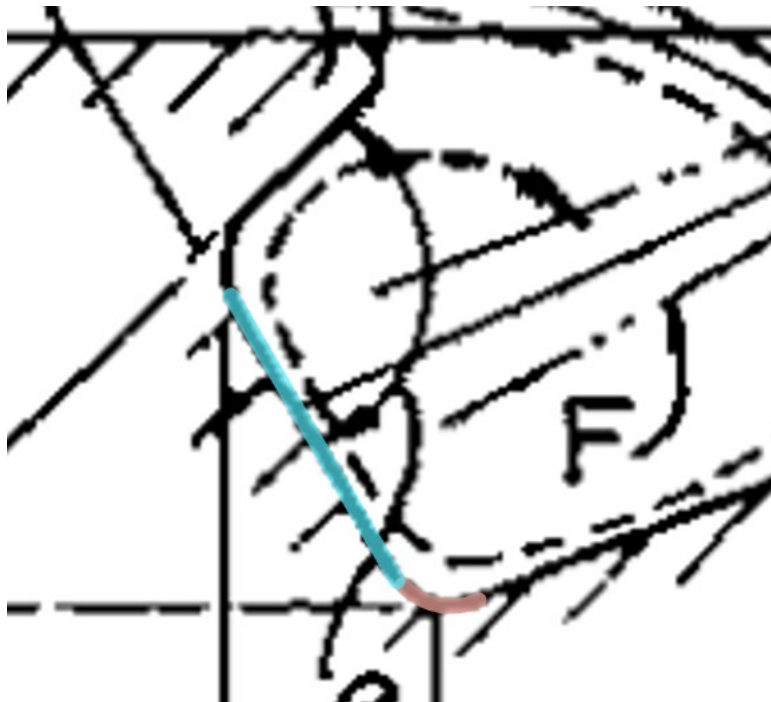
328. A POSITA would have understood from Takatomo that the timing of injection is selectable and would select a timing that is tailored for a target application and where the jet impinges on the side wall 5 (blue), as taught by Takatomo. One example of this tailoring would have been to achieve a desired balance between discharge of HC and load. *See* EX. 1006, 6:49-58. Takatomo discloses that an injection jet impinging the surface and injected at any timing before top dead center is distributed both in an elevation direction and in the recess edge direction.

- iv. “the surface [a] is substantially planar and has an ascending gradient in the recess edge direction [b] such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed

both in the elevation direction and in the recess edge direction.”

(a) “is substantially planar and has an ascending gradient in the recess edge direction”

329. Takatomo discloses that “each side wall 5 forms an inclined surface facing obliquely upward” and that “[t]he inclination angle θ of the side wall surface is approximately a right angle with respect to the fuel spray line F from the fuel injection nozzle 3, specifically an inclination angle in the range of 90° - 110°” EX. 1006, 4:50–8. The side wall 5 (blue) that adjoins the elevation (protrusion 13) is a portion with a discrete length that is disposed along a straight line when the piston is viewed in cross-section and has an ascending gradient in the recess edge direction (a direction towards an edge of the cavity 2).



- (b) **“such that an injection jet injected as late as possible impinges onto the surface, the last-mentioned injection jet being distributed both in the elevation direction and in the recess edge direction.”**

330. *See* Sections X.A.1.iv.b, X.F.1.iv.b.

331. Takatomo states that “fuel injection injected near the top dead center collides with the inclined surface of the side wall and is appropriately reversed and diffused.” EX. 1006, 4:19-26. Thus, Takatomo teaches that injection occurs near top dead center, which is late injection. Indeed, a POSITA would have understood that FIG. 1 of Takatomo depicts the piston at a position that is near top dead center. As I noted above, when the fuel inject impinges the side wall in Takatomo, a portion of the fuel is distributed towards the recess edge (upward and outward) while another portion is distributed towards the elevation (inward and downward). Takatomo discloses that an injection jet injected as “late as possible” impinges onto the surface and is distributed both in the elevation direction and in the recess edge direction. A POSITA would have understood from Takatomo that the timing of post-injection (i.e., after top dead center) is selectable and would have selected a timing that is tailored for a target application and where the jet impinges on the side wall 5 (blue), as taught by Takatomo. Takatomo discloses that an injection jet injected as “late as possible” impinges onto the surface and is distributed both in the elevation direction and in the recess edge direction.

2. Claim 2 – “The directly injecting internal combustion engine as claimed in claim 1, wherein a surface connected to the recess edge adjoins the surface of the piston recess.”

332. Takatomo discloses a surface connected to the recess edge (an edge of the cavity 2) adjoins the surface of the piston recess (cavity 2). Below, I annotate a surface (purple) that is connected to the recess edge (green) and adjoins the side wall 5 (blue) of the piston recess.



333. This interpretation of the surface adjoining the surface of the piston recess is consistent with corresponding discussion in the '238 Patent. *See* EX. 1001, 4:8–9.

3. Claim 3 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface

connected to the recess edge is connected via a radius to the surface of the piston recess.”

334. In my annotation, I annotate the surface (purple) that is connected to the recess edge (green) and that is connected via a radius (cream) to the side wall 5 (blue) of the piston recess.



4. Claim 4 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.”

335. In my annotation, the surface (purple) connected to the recess edge (green) merges in a radius (orange) into an upper surface (red) of the piston.



336. This interpretation of the surface connected to the recess edge merging in a radius into an upper surface of the piston is consistent with corresponding discussion in the '238 Patent. *See* EX. 1001, 4:26–27.

5. Claim 5 – “The directly injecting internal combustion engine as claimed in claim 2, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

337. Takatomo discloses that the surface (purple) connected to the recess edge (green) forms an acute angle with an upper surface (red) of the piston.



6. Claim 6 – “The directly injecting internal combustion engine as claimed in claim 5, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

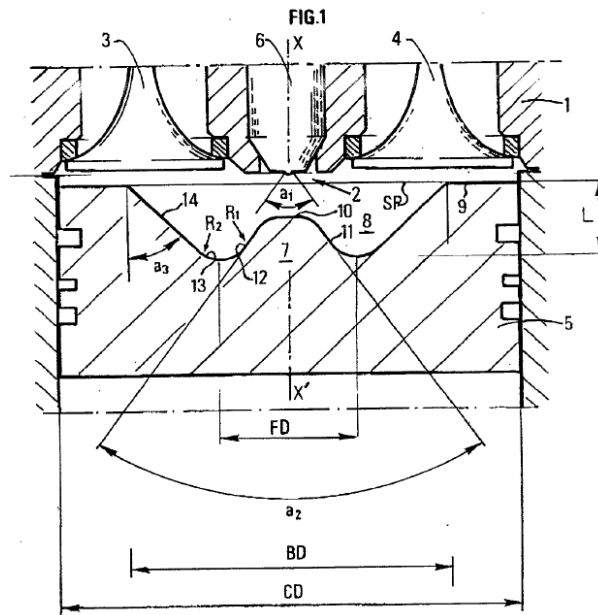
338. In my annotation, I annotate the surface (purple) that is connected to the recess edge (green) and that is connected via a radius (cream) to the side wall 5 (blue) of the piston recess.



L. Claims 9–12 and 14 Are Obvious Over Takatomo and Gatellier

- 1. Claim 9 – “The directly injecting internal combustion engine as claimed in claim 1, wherein an injection angle of the injection nozzle is between 50° and 120°”**

339. Gatellier discloses an internal combustion engine that includes “a fuel injection nozzle 6 such as a multijet nozzle, preferably arranged in line with axis XX’ of the cylinder.” EX. 1007, ¶[0052]. Gatellier states that the “fuel injection nozzle has a small nappe angle a_1 , nappe angle a_1 , being selected at most equal to 120° and preferably ranging between 40° and 100°.” *Id.*, ¶[0054]; *see id.*, ¶[0057], claim 3, claim 4.



Id., FIG. 1.

340. Gatellier explains that the “nappe angle is so selected that the walls of the cylinder are never wetted by the fuel for any position of the piston ranging between $+50^\circ$ and $+\alpha$ or between -50° and $-\alpha$ where α represents the crankshaft angle for the injection phase selected in relation to the top dead center (TDC), this angle α being greater than 50° and less than or equal to 180° to obtain a homogeneous type combustion.” *Id.*, ¶[0055].

341. In designing an engine, a POSITA would have understood that the injection angle of the injector is one variable that is selectable to optimize the engine for a target application. Injectors were ubiquitous and selecting an injector having one injection angle instead of another injector having a different injection angle

would have amounted to nothing more than simple substitution of a readily interchangeable component of the engine.

342. As I discussed in Section IX.C.2, it would have been obvious to replace the fuel injection nozzle 3 of Takatomo with the injection nozzle 6 of Gatellier. This would have provided the flexibility to use injection angles that are not explicitly disclosed in Takatomo, which would have provided the flexibility to desirably utilize Takatomo's engine in various applications where those injection angles are desirable. For example, the injection nozzle 6 of Gatellier would have been beneficial in resolving the known issues associated with injection timing and wall wetting that Gatellier is premised on solving.

343. Because "between 50° and 120°" as recited in claim 9 falls within "at most equal to 120°" and also overlaps with "between 40° and 100°," as disclosed by Gatellier, claim 9 is obvious in view of Takatomo and Gatellier.

2. Claim 10 – "The directly injecting internal combustion engine as claimed in claim 9, wherein a surface connected to the recess edge adjoins the surface of the piston recess."

344. I have provided my analysis of Takatomo with respect to these limitations which are also included in claim 2 which is addressed in Section X.K.2, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

3. Claim 11 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge is connected via a radius to the surface of the piston recess.”

345. I have provided my analysis of Takatomo with respect to these limitations which are also included in claim 3 which is addressed in Section X.K.3, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

4. Claim 12 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge forms an acute angle with an upper surface of the piston.”

346. I have provided my analysis of Takatomo with respect to these limitations which are also included in claim 5 which is addressed in Section X.K.5, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

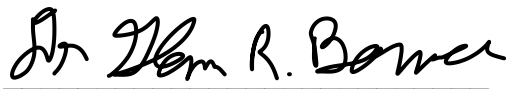
5. Claim 14 – “The directly injecting internal combustion engine as claimed in claim 10, wherein the surface connected to the recess edge merges in a radius into an upper surface of the piston.”

347. I have provided my analysis of Takatomo with respect to these limitations which are also included in claim 4 which is addressed in Section X.K.4, above. Gatellier is not relied upon for modifying that analysis with respect to these limitations.

XI. CONCLUSION

I hereby declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of the Title 18 of the United States Code.

Dated: 3 June 2025

By: 

Dr. Glenn R. Bower Ph.D., PE

APPENDIX A

Dr. Glenn R. Bower

Home Address

**5475 Meadowvale Road
Barneveld, WI 53507
(608) 924-3408**

Office Address

**1550 Engineering Drive
Madison, WI 53706
(608) 576 3979**

Academic Experience

2024 -	Teaching Associate Professor	UW-Madison Mechanical Engineering
2021 – 2024	Scientist III	UW-Madison Engine Research Center
2021 – 2024	Teaching Faculty III	UW-Madison Mechanical Engineering
2005 - 2021	Senior Scientist	UW-Madison Engine Research Center
2003 - 2021	Faculty Associate	UW-Madison Mechanical Engineering
1995 - 2005	Associate Scientist	UW-Madison Engine Research Center
1997 – 2003	Associate Faculty Associate	UW-Madison Mechanical Engineering
1992 – 1994	Post-Doctoral Researcher	UW-Madison Engine Research Center

Professional Registration

Registered Professional Engineer in Wisconsin #29717

Education

Assoc. of Science	University of Wisconsin-Center Richland	1985
BS ME	University of Wisconsin-Platteville	1987
MS	University of Wisconsin-Madison	1989
PhD	University of Wisconsin-Madison	1992

Instructor

Introduction to Competitive Manufacturing	ME 314
Engineering Design Projects	ME 349
Interdisciplinary Experiential Design Projects I	ME 351
Interdisciplinary Experiential Design Projects II	ME 352
Thermodynamics	ME 361
Fluid Dynamics	ME 363
Internal Combustion Engines	ME 469
Undergraduate Mechanical Engineering Projects	ME 291
Independent Study	ME 299
Mechanical Engineering Projects I	ME 491
Mechanical Engineering Projects II	ME 492
Hybrid Vehicle Powertrains - Characteristics and Models	ME 601
Advanced Independent Study	ME 699

Student Project Advisor

SAE Baja Advisor	1994 – Present
Hybrid/Autonomous Vehicle Advisor	1997 – Present
Society of Automotive Engineer Advisor	1998 – Present
Formula SAE Advisor	2000 – Present
Formula SAE Electric Advisor	2015 - Present
SAE Snowmobile Challenge Advisor	2001 – Present
SAE Formula Hybrid Advisor	2006 - 2011

Patents

Hybrid Braking System – US Pat. Application Number 09/302,766 (with Mike Koplin)

Awards and Distinctions

SAE Autodrive Challenge II – Advisor of the Year Award (2024)
SAE Clean Snowmobile Rules Committee (2022-2025)
SAE Formula Electric Safety Committee (2018 to present)
Collegiate Events Chair/Organizer for the Small Engine Technology Conference (2018)
University of Wisconsin Madison, Best Student Organization Advisor Award (2018)
Hybrid Session Chair/Organizer for the Small Engine Technology Conference (2009-2015)
Polygon Outstanding Instructor Award (2008-2012)
Pi Tau Sigma Outstanding Lecturer Award (2008)
NSF Long Term Outstanding Faculty Advisor (2006)
The Bollinger Academic Staff Distinguished Achievement Award (2005)
NSF Outstanding Faculty Advisor (2000)
SAE Faculty Advisor Award (2001, 2008, 2014)
UWC-Richland Outstanding Alumni Award (2001)

Professional Consulting in Engineering Legal Proceedings (last 6 years)

Retained by Foley and Lardner LLP, 2025 to Present.

Hired expert witness on behalf of Nissan Motor Co. Ltd.

Longhorn Automotive Group LLC v. Nissan Motor Co., Ltd.
United States District Court for the Eastern District of Texas
(Case No. 2:24-cv-00397-JRG)

Retained by Fox Rothschild LLP, 2023 to 2024, *Declaration testimony*.

ZPE LICENSING INC. vs. ZZPERFORMANCE LLC and UZOMA IWUAGWU, United
States District Court for the Western District of Michigan,
Case No. 1:22-cv-00857-RJJ-PJG

Retained by Foley and Lardner LLP, 2023 to 2024, *Declaration testimony*.

Hired expert witness on behalf of Cummins and PACCAR

Ray Hintz Transport, Inc. vs. Cummins Inc. and PACCAR Inc., United States District Court
for the Eastern District of Wisconsin, Case No. 2:22-cv-00803-PP.

Retained by Hogan Lovells US LLP, 2022 to 2023, *Declaration testimony*.

Hired expert witness on behalf of Mercedes-Benz USA, LLC

Mercedes-Benz USA LLC vs. Westport Fuel Systems Canada, Inc.,
Patent Trial and Appeal Board Cases, 2 total

Retained by Kantrowitz Goldhamer & Graifman, P.C. and Thomas P. Sobran, P.C, 2021 to present,
Declaration testimony.

*Joseph Amato, James B. Moore, George Sandoval and Ian Connolly, vs. Subaru of
America, inc., and Subaru Corporation*,
Civil Action No. 2:18-cv-16118-JHR

Retained by Wisconsin Attorney General Josh Kaul, 2021, *Declaration testimony*.

Hired expert witness on behalf of Attorneys Guy Cardamone and Tracey Lencioni

State of Wisconsin vs. Richardson
Case No: 2018CF 001783

Retained by Foley & Lardner LLP, 2020 to 2021

Hired expert witness on behalf of Cummins Filtration Inc.

Cummins Filtration Inc. vs. Donaldson Company, Inc.,
Patent Trial and Appeal Board Cases, 3 total

Retained by Brown Robert, LLP, 2020, *Declaration testimony*.

Hired expert witness on behalf of Kodiak Research LTD.

BRP-Powertrain, et al. vs. Gregory Everett, United States District Court for the Eastern District of Wisconsin, Case No. 14-CIV-1189-LS.

Retained by Merchant Law Group LLP, 2020 to Present, *Declaration & Deposition testimony*.

Dane Ashley Bruce Tress vs. FCA Canada Inc., and FCA US LLC, Canada, Court File Number: QBC 469 of 2018.

Retained by Sterne, Kessler, Goldstein & Fox P.L.L.C., 2019 to 2021, *Declaration & Deposition testimony*.

Hired expert witness on behalf of Volkswagen Group of America, Inc.

Volkswagen Group of America, Inc. vs. Michigan Motor Technologies, LLC Patent Trial and Appeal Board Cases, 6 total.

Retained by Haug Partners, 2019 to 2020, *Declaration testimony*.

Hired expert witness on behalf of Bentley Motors

Bentley Motors Limited and Bentley Motors, Inc. vs. Jaguar Land Rover Limited, Patent Trial and Appeal Board Case, IPR2019-01502.

Retained by Leland T. Schmidt & Assoc., P.C., 2019 to 2020, *Declaration testimony*.

State of Michigan in the Circuit Court for the County of Macomb, Case No: 2018-002831-NO , v Hon: Diane M. Druzinski.

Retained by Merchant Law Group LLP, 2019 to Present, *Declaration testimony*.

Alfred Julius Otto vs. FCA Canada Inc., and FCA US LLC, Canada, Court File Number: QBC 2415 of 2015.

Retained by Lawton & Cates, S.C., 2018 to 2019, *Declaration & Deposition testimony*.

Hired expert witness on behalf of MDS Enterprises, Inc.

MDS Enterprises, Inc., vs. Mid-State Truck Services, Inc, et al, Jefferson County, Wisconsin Circuit Court, Case No. 2017CV000488

Retained by Faegre Baker Daniels, LLP, 2018 to 2019, *Declaration testimony*.

Hired expert witness on behalf of Polaris Industries, Inc.

Ex Parte Reexamination of U.S. Patent No. 8,827,028

Retained by Quinn Emanuel Urquhart & Sullivan, LLP, 2017 to 2018

Hired expert witness on behalf of Hyundai

Michigan Motor Technologies LLC vs. Hyundai Motor Company, Hyundai Motor Group, Hyundai Motor Technical Center, Inc., US District Court, Eastern District of Michigan, Case No. 2:17-cv-12901.

Retained by McGuireWoods LLP , 2017 to 2019.

Hired expert witness on behalf of Stihl Inc.

Electrojet Technologies, Inc., vs. Stihl Inc., US District Court, Eastern District of Virginia Alexandria Division, Case 2:17-cv-00224 (RAJ-DEM).

Retained by Carlson Caspers LLP, 2017 to 2019, *Declaration testimony*.

Hired expert witness on behalf of Polaris Industries, Inc.

Arctic Cat Inc. vs. Polaris Industries, Inc., Patent Trial and Appeal Board Case, IPR2017-00199.

Retained by Carlson Caspers LLP, 2017 to 2020, *Declaration and Deposition testimony*.

Hired expert witness on behalf of Polaris Industries, Inc.

Polaris Industries, Inc. vs Arctic Cat Inc., US District Court, District of Minnesota, Civ. No. 15-cv-04475 (JRT/LIB). & *Polaris Industries, Inc. vs Arctic Cat Inc.*, US District Court, District of Minnesota, Civ. No. 15-cv-04129 (JRT/LIB).

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- 2024 “Rapid Development of an Autonomous Vehicle for the SAE AutoDrive Challenge II Competition”, (with Sriram Ashokkumar, et. Al.), April 2024, SAE 2024-01-1980
- 2019 “The Effect of Ethanol Fuels on the Power and Emissions of a Small Mass-Produced Utility Engine”, (with Saager Paliwal), Novmber 2019, SAE 2019-32-0607.
- 2014 “Development of a Miller Cycle Powersports Engine”, (with Jeffrey Blair), November 2014, SAE 2014-32-0090.
- 2014 “The Effect of a TiO₂ Coating With the Addition of H₂ Gas on Emissions of a Small Spark-Ignition Engine”, (with Saager Paliwal, Alex S. Bare, Katherine J. Lawrence, Marc Anderson), November 2014, SAE 2014-32-0034.
- 2011 “Clutchless Shifting of an Automated Manual Transmission in a Hybrid Powertrain”, (with Jon L Breen), September 2011, 2011-01-2194.
- 2009 “Initial Design and Refinement of a High-Efficiency Electric Drivetrain for a Zero-Emissions Snowmobile”, (with Ethan K. Brodsky, Nicholas J. Rakovec, Kevin R. King, Daniel J. Bocci, Jared Olsen, Adam R. Schumacher), November 2009, SAE 2009-32-0108 / 20097108
- 2008 “Design and Construction of a High Efficiency Electric Drivetrain for a Zero-Emissions Snowmobile”, (with Ethan Brodsky) October 2008, T2M Annual Conference Proceedings.
- 2008 “Improving Upon the Best Available Technology: A Clean Flex Fuel Snowmobile”, (with Nicholas Rakovec, Michael Maney, Brian Olenski) September 2008, SAE 2008-32-0049.
- 2007 “Design and Testing of a Prototype Hybrid-Electric Split-Parallel Crossover Sports Utility Vehicle”, (with Elizabeth Casson, Daniel Bocci, Daniel Mehr, Rebecca Gunn, Ethan Brodsky) April 2007, SAE 2007-01-1068.
- 2006 “Integration of Hybrid-Electric Strategy to Enhance Clean Snowmobile Performance”, (with Eric Schroeder, Ethan Brodsky, Adam Schumacher), November 2006, 06SETC-10.
- 2006 “Wisconsin’s Hybrid Team Reincarnates its EV1”, Electric & Hybrid Vehicle Technology International: 2005 Annual Review, January 2006.
- 2005 “University Challenge”, Electric & Hybrid Vehicle Technology International: 2004 Annual Review, January 2005.
- 2004 “Design and Testing of a Prototype Midsize Parallel Hybrid-Electric Sport Utility Vehicle”, (with Julie G. Marshaus, Nick L. Wolf, Kathryn .M. Orgish), October 2004, SAE 2004-01-3062
- 2003 “Design and Development of the University of Wisconsin’s Parallel Hybrid-Electric Sport Utility Vehicle”, (with Jason Helgren, Ethan Brodsky, Julie G. Marshaus), March 2003, SAE 2003-01-1259 & SAE Transactions.
- 2002 “Clean, Quiet, Environmentally Friendly Snowmobile”, (with Julie G. Marshaus, Jake Allen, Anthony Bauer, Chris Martinek, Matt Martinek, Nick Boyarski, Fred Mauerman, Dave Trettin), October 2002, SAE 2002-01-2763.
- 2002 “ Design and Optimization of the University of Wisconsin’s Parallel Hybrid-Electric Sport Utility Vehicle”, (with Ryan Rowe, Jennifer Topinka, Ethan Brodsky, Julie G. Marshaus), March 2002, SAE 2002-01-1211.
- 2001 “Safety Aspects Related to the Development of a Full Aluminum Frame for the Year 2000, 1500 Series Chevy Suburban”, (with Julie G. Marshaus, Mike Gall, Jennifer Topinka), November 2001, IMECE 2001/ AMD – 25442.

- 2001 "Development of the University of Wisconsin's Parallel Hybrid-Electric Sport Utility Vehicle", (with Julie Marshaus, Asha Ramnarine, Amanda Pertzborn, Ethan Brodsky, Mike Gall, Jennifer A. Topinka), SAE 2001 Special Publications.
- 2000 "Optimizing the University of Wisconsin's Parallel Hybrid-Electric Aluminum Intensive Vehicle", (with Jonathan A. Butcher, Joseph Bayer, Michael Koplin, Neel Vasavada, Herman Wiegmen), SAE Paper 2000-01-0593.
- 1999 "The Development of the University of Wisconsin's Parallel Hybrid-Electric Aluminum Intensive Vehicle", (with Michael Koplin, Matthew P. Thiel, Jonathan A. Butcher, Brian L. Swensen), SAE Paper 1999-01-0613.
- 1998 "Engine Cycle Analysis", (with Jim McFarland), Hot Rod Magazine, April 1998.
- 1998 "Design of a Charge Regulating, Parallel Hybrid Electric FutureCar, (with Patrick D. Maguire, Jed T. Van Heimbürg, Daniel J. Nickchen, Aaron Sullivan, Wayne D. Milestone), SAE Paper 980488.
- 1997 "In-Cylinder Measurement and Modeling of Liquid Fuel Spray Penetration in a Heavy-Duty Diesel Engine", (with L.M. Ricart, J. Xin, and Rolf Reitz), 1997 SAE Spring Fuel & Lubricants Meeting.
- 1997 "Effects of Biodiesel Blended Fuels and Multiple Injections on DI Diesel Engine Emissions", (with C.Y. Choi and R.D. Reitz), SAE Paper 970218.
- 1994 "Cylinder-Averaged Histories of Nitrogen Oxide In a DI Diesel Engine with Simulated Turbo-Charging", (with R.J. Donahue and G.L. Borman), SAE Paper 942046.
- 1994 "Two-Dimensional Flame Temperature Distribution of Diesel Combustion using the Two-Color Method", (with M. Grunwald and D.E. Foster), Proceedings from the Central States Section of the Combustion Institute.
- 1993 "Emission Tests of Diesel Fuel with NOx Reduction Additives", (with D. Tree, R. Donahue, D. Shamis, and D. Foster), SAE paper 932736.
- 1993 "The Effect of Split injection on Soot and NOx Production in an Engine-Fed Combustion Chamber", (with D. E. Foster), *SAE Transactions*, 932655.
- 1993 "The Effect of Split injection on Fuel Distribution in an Engine-Fed Combustion Chamber", (with D. E. Foster), *SAE Transactions*, 930864.
- 1992 "The Effect of a Split injection on Early Combustion in an Engine-Fed Combustion Chamber", Ph.D. Thesis, University of Wisconsin-Madison.
- 1991 "A Comparison of the Bosch and Zuech Rate of injection Meters", (with D. E. Foster), SAE paper 910724.
- 1990 "Data from a Variable Rate Shape High Pressure Injection System Operating in an Engine Fed Constant Volume Combustion Chamber", (with D. E. Foster), SAE paper 902082.
- 1990 "Characteristics of a Variable Rate Shape High Pressure Injection System", (with D. Foster), Proceedings from the ILASS National Conference.
- 1989 "Investigation of the Characteristics of a High Pressure Injector", (with D. E. Foster), SAE paper 892101.
- 1989 "Interrogation of a High Pressure Injector", (with D. E. Foster), Proceedings from the Central States Section of the Combustion Institute.
- 1988 "Physical Mechanisms for Atomization of a Jet Spray: A comparison of Models and Experiments", (with S. Chang, M. Corradini, M. El-Beshbeeshy, J. Martin, and J. Krueger), *SAE Transactions*, 881318.

Invited Presentations

- 2024 SAE Formula Electric Workshop, “Designing Your Accumulator”, September 2024
- 2023 SAE Formula Electric Workshop, “Accumulator Design Considerations” & “Tips for a Successful Formula SAE Team”, September 2024
- 2016 “Automotive Powertrain Trends for Meeting Pending CAFE Standards”, University of Wisconsin-Platteville, Renewable Energy Industrial Advisory Board Meeting, April 2016.
- 2015 “The UW Competitive Car Programs and the Bucky Wagon’s Green Makeover”, Detroit Alumni Association Founder’s Day Meeting, June 2015
- 2013 “The Bucky Wagon Green Makeover”, Wisconsin Alumni Association, September 2013.
- 2011 “The UW Competitive Car Programs and the Bucky Wagon’s Green Makeover”, Sacramento Alumni Association Founder’s Day Meeting, May 2011
- 2011 “The UW Competitive Car Programs and the Bucky Wagon’s Green Makeover”, San Francisco Alumni Association Founder’s Day Meeting, May 2011
- 2010 “The UW Competitive Car Programs and the Bucky Wagon’s Green Makeover”, Orange County Alumni Association Founder’s Day Meeting, March 2010
- 2010 “The UW Competitive Car Programs and the Bucky Wagon’s Green Makeover”, Houston Alumni Association Founder’s Day Meeting, March 2010
- 2009 “Hybrid Powertrain Architectures: Components and Controls”, Diesel Engine Research Consortium, June 2009
- 2008 “Design and Construction of a High Efficiency Electric Drivetrain for a Zero-Emissions Snowmobile”, October 2008, T2M Annual Conference
- 2008 “Hybrid Powertrain Architectures: Components and Controls”, Master of Engineering in Engine Systems, August 2008
- 2008 “Energy Use in Transportation Choices, Trade Offs & Decisions”, Country Village Retirement Home, February 2008
- 2007 “Energy Use in Transportation Choices, Trade Offs & Decisions”, Walworth Rotary Club, February 2007
- 2007 “Moovada, Wisconsin’s Cross-Over Vehicle” East Madison Rotary Club
- 2006 “Integration of Hybrid-Electric Strategy to Enhance Clean Snowmobile Performance”, SAE Small Engine Technology Conference, November 2006
- 2006 “Hybrid Technology”, Hybrid Fest, July 2006
- 2006 “Wisconsin’s Challenge X Project”, Johnson Controls Inc. Press Conference
- 2006 “Update on Midwest Baja 2006”, SAE Milwaukee Section
- 2006 “Cars of the Future”, Madison’s Optima Club
- 2005 “New Lightweight Applications in Transportation”, Aluminum Extruders Council Management Conference
- 2004 “Wisconsin’s Challenge Project”, Borg-Warner
- 2003 “Wisconsin’s Hybrid Vehicle Program”, Delphi Corporation
- 2003 “Wisconsin’s Hybrid Vehicle Program”, DANA Corporation

- 2002 "Developing an Effective Hybrid Team" – FutureTruck Fall Workshop
- 2001 "UW-Madison's Hybrid Vehicle Program", LandRover - Birmingham, UK
- 2001 "A Substantive Design Challenge for Students", NSF Design, Service and Manufacturing Grantees and Research Conference.
- 2000 "Automobiles of the Future", Engineer's Day 2000.
- 2000 "Cars of the Future", Madison Rotary Club.
- 1998-2001 Guest Speaker – Aluminum Associations Automotive Seminar – Livonia, MI.
- 1999 "UW-Madison Hybrid, Aluminum Intensive Vehicle", ASME Conference, Cincinnati.
- 1996 "Introduction to Heat Release and Data Acquisition on internal Combustion Engine", Hi-Techniques, Inc.
- 1994 "The FTIR as a Diagnostic Tool for internal Combustion Engines", Nicolet Analytical, Inc.
- 1993 "Emission Tests of Diesel Fuel with NOx ~Reduction Additives", Texaco Additive Research.
- 1993 "The Effect of a Split Injection on Early Combustion in an Engine-Fed Combustion Chamber", Oak Ridge National Laboratories.
- 1992 "The Effect of a Split Injection on Early Combustion in an Engine-Fed Combustion Chamber", Ford Motor Research.
- 1991 "Operating in an Engine Fed Constant Volume Combustion Chamber", Presentation for Army Research Office personnel.
- 1989 "Preliminary Results from the Engine-Fed Spray Chamber", Army Research Office Review.
- 1988 "Experimental Techniques for Studying Diesel Sprays", Mercury Marine Engineering Group.
- 1988 "Experimental Data on Diesel Sprays in a Cold High-Density Atmosphere", (with J. Naber), ARO/ERC Workshop.
- 1988 "An Overview of the Experimental Study of Diesel Sprays", ASME Student Meeting, UW-Platteville.

Community Service

- 2006, 2009, 2012 Organizer of Baja SAE International Competition in Wisconsin
- 2006 – 2014 SAE Milwaukee SAE Nominating Committee Representative
- 2000 – 2005 EMS Instructor – Southwest Technical College
- 2000 Imagination Destination Coach – Barneveld Elementary School
- 1999 – 2020 Mentor to Barneveld High School SuperMileage Team
- 1998 – 2020 Intermediate Level Emergency Medical Technician
- 1995 – 2004 Assistant Chief of Barneveld Area Rescue Squad, Inc.
- 1992 – 2000 EMT Assistant instructor for MATC and SWTC
- 1991-93 President of Friends of Deer-Grove EMS
- 1991-92 Personnel Coordinator for Deer-Grove EMS
- 1990 – 1998 Emergency Medical Technician-Basic
- 1983 President of Richland County 4-H Junior Leaders Assoc.