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# Professor Yasusi Tanasawa's Achievements, the International Conference on Liquid Atomization and Spray Systems, and the Tanasawa Award

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**ABSTRACT** This paper describes Prof. Y. Tanasawa's achievements from 1935 to his death in 1992, which include measurements of drop size, expression of mean drop size and drop distribution, the photographic methods for investigating the atomization, research of various atomization methods and research of atomization mechanism. The history and the circumstances surrounding the establishment of ICLASS, ILASS, the journal and the Tanasawa Award are also discussed.

**Keywords:** Prof. Y. Tanasawa, ICLASS, ILASS, Tanasawa Award, Liquid Atomization,

## 1. Professor Yasusi Tanasawa's Achievements

Professor Yasusi Tanasawa was born in October, 1906 in Tokyo, Japan. This year is the commemoration for the centennial anniversary of his birth. He was educated at Daichi High School and graduated with a BSc in Mechanical Engineering from the University of Tokyo in 1929. Then he joined the Tohoku University, Mechanical Engineering, Thermo Engineering Department as a lecturer, where he worked on heat transfer problems, and other issues such as measurements of rate of heat transfer and measurements of thermo constants with Professor Shiro Nukiyama. In 1936 he acquired the higher degree of Doctor of Engineering from the University of Tokyo for pioneering contribution in the measurements of thermal constants in heat transfer.

After that, he changed his research subjects completely from "Heat Transfer Research" to "Liquid Atomization Research". Prof. Tanasawa's research was devoted to Liquid Atomization research for over 50 years until his death in 1992.

In 1934, Toyota Motor Co., (then known as Toyoda Automatic Loom Co.), began plans to manufacture their own motor vehicle, which would be the first car made in Japan. The following year, Prof. Tanasawa received a research request from Toyota Motor Co. about gasoline combustion and carburetor performance. Although other companies had successfully manufactured the carburetor, the breakup mechanism and size of fuel drops in the carburetor were yet unknown.

It was at this time that Prof. Tanasawa decided to study the research of Liquid Atomization and became devoted to this research. It was 1935.

In studying the carburetor, he first started with the research of air blast atomization.

His first mission was to determine "how to measure the liquid drop size".

Next, he needed to figure out "how to express the drop size distribution". Previous work on size distribution in powders and in solid particles suspended in liquids, had been shown in Rosin and Rammler distribution and a logarithmic probability distribution equation.

Professor Yasusi Tanasawa
(1906-1992)

Prof. Tanasawa, from his experiments with air blast atomization, came up with an expression for liquid drop size distribution:

$$f_n\left(x\right) = Ax^{\alpha}\, exp\left(-Bx^{\beta}\right)$$

Then it was "how to take photographs for high-speed phenomena". To enable him to take complete pictures of spray development with time, he developed very short flashes which could be obtained by the discharge of highly loaded condensers. He took many excellent pictures of liquid atomization.

These pioneering research results were published in the Japan Society of Mechanical Engineers (JSME) and other Japanese publications from 1938 to 1943. Unfortunately, these reports were written in Japanese only. The knowledge of Prof. Tanasawa's research did not leave the boundaries of Japan[1-14].

In the summer of 1944, the Imperial Japanese Navy Air Service asked Prof. Tanasawa to join in the development of a Jet Engine. It was one year before an atomic bomb was dropped on Hiroshima. It seemed to him that since Japan was already in the state of defeat, the development of a Jet Engine would be impossible. However, Prof. Tanasawa decided to cooperate in the development of a fuel injection nozzle and combustor for the "Ne-10" engine, which the Imperial Japanese Navy Air Service was already developing.

He made the combustion wind tunnel in his laboratory and was devoted to experimenting from early in the morning till late at night.

Although it began as a modified research of the "Ne-10" , in late 1944, he engaged in the research and development of a newly designed jet engine, the "Ne-20". He joined in the research of an optimum design for the swirl fuel injector and annular combustor.

Based on such basic research, the Ne-20 jet engine was completed in early March, 1945. Ground maximum thrust was 490 kg and the structure of this engine, as shown in Figure 1, fundamentally did not differ from the present highly efficient jet engine.

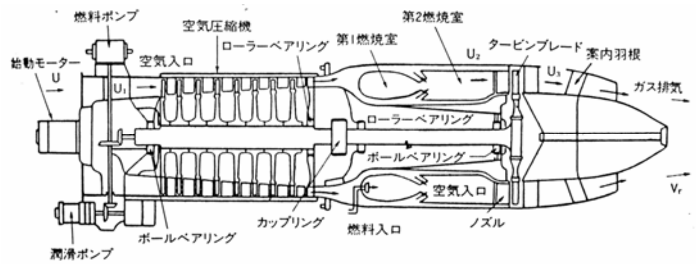


Fig.1 Ne-20 Jet Engine (1945)

It was a great surprise that the Ne-20 engine was completed in such a short period. This Ne-20 engine was attached to a jet airplane called "Kikka" and it made a test flight at Kisarazu airport near Tokyo on August 7, 1945. The test was successful for 12 minutes with a light load. It was the day after the atomic bomb was dropped on Hiroshima. A public test flight was conducted with a full load on August 11, 1945. However, it could not take off and Jet airplane rushed into the sea. The life of the first Japanese Jet Aircraft was finished and World War II ended on August 15, 1945.

After the war, Prof. Tanasawa's research results, the swirl atomizer, and gas turbine combustor were published from 1946 to 1951[15-23]. This research was useful in the development of a subsequent Japanese jet engine.

Prof. Tanasawa energetically devoted his life to research and education in "Liquid Atomization and Spray Systems" after World War II[24-26, 28-32, 34-40].

His book "Gas Turbine" written in Japanese, the first of its kind, enunciating theory, design and performance aspects of gas turbine combustors and fuel injectors, was published in 1954[27]. In 1956 he published his other important book "Fuel Atomization and Sprays, and Spray Combustion" which was also written in Japanese[33]. In this book, he describes the results which he obtained experimentally. These include the mechanism of disintegration of liquid jets, fuel spray characteristics, a simple theory of the swirl atomizer, experimental methods for assessment of fuel spray characteristics, droplet combustion, vaporization and ignition.

Professor Yasusi Tanasawa was clearly a pioneer in the research of "Liquid Atomization and Spray Systems", and arguably one who contributed more as a researcher and educator than any other.

He served as Dean of the College of Engineering, Tohoku University from 1965 to 1968. He showed his innovative leadership in making a new campus and reorganizing the faculty.

In 1970, he retired from Tohoku University and moved to Toyota Central Research and Development Laboratories Ltd. as president. There, in the face of the new problems of exhaust emissions, he made many exemplary contributions in the gasoline injector. He completed the technical foundation of the gasoline engine and the diesel engine of today's Toyota Motor Co.

As a professor he was able to devote himself entirely to research and education. Professor Yasusi Tanasawa passed away on July 27, 1992. He was 85 years old.

## 2. International Conference on Liquid Atomization and Spray Systems

In response to Prof. Tanasawa's pioneering work, many Japanese researchers took interest in fuel atomization and studied Liquid Fuel Atomization and Spray Systems. Previously, liquid atomization conferences had mainly been held at the Japan Society of Mechanical Engineers or the Japan Chemical Engineering Society. Later, many researchers requested specialized conferences in liquid atomization. Liquid atomization is an interdisciplinary subject covering a wide range of study fields. The Japan National Conference on Liquid Atomization started in 1972 under the sponsorship of the Japan Fuel Society (now the Japan Institute of Energy). Despite the lack of recognition in liquid atomization at the time, it was the enthusiasm of highly respected Prof. K. Yamasaki and Dr. K. Neya which was the driving force behind the realization of the Japan National Conference on Liquid Atomization. The conference has been held since then in Japan every year.

In 1974, Prof. T. Sakai and Prof. T. Kurabayashi, of Gunma University visited Dr. Paul Eisenkalm at the Imperial College in London and reported on the present status of liquid atomization research in Japan and the liquid atomization conference held every year in Japan. Dr. Eisenkalm praised the activity of Liquid Atomization Research in Japan and showed interest. Then he proposed holding the International Conference on Liquid Atomization and Spray Systems in Japan. His suggestion was accepted in Japan and preparation of an International Conference proceeded.

The first International Conference on Liquid Atomization and Spray Systems was held in August 1978, in Tokyo under the chairmanship of Prof. Y. Takashima, where 53 papers were presented and over 200 researches attended.

Since then, International Conferences organized by the International Conference of Liquid Atomization and Spray Systems(ICLASS) are held throughout the world every 3 years, successively in Asia, USA and Europe.

At the second ICLASS held in Madison, Wisconsin, USA in 1982, Dr. Eisenklam made three proposals.
The first proposal was:

How about forming three ILASS(Institute for Liquid Atomization and Spray Systems); ILASS-Far East, Europe and Americas to improve regional research activities and to exchange information among the ILASS?
The second proposal was:
How about publishing a journal on Liquid Atomization?
The third proposal was:
How about establishing an ICLASS scientific award? The title could be the "Tanasawa Award" in respect to Prof. Tanasawa, the pioneer of Liquid Atomization.

In 1982, Dr. Eisenklam initiated the establishment of ILASS-Europe and saw its formation with the first Annual General Meeting at UMIST 1983.

ILASS-Americas, the Institute for Liquid Atomization and Spray Systems, North and South America, was established in 1986 as an outgrowth of the International Conference on Liquid Atomization and Spray Systems.

Japan, Korea, Taiwan and China originally belonged to ILASS-Far East. ILASS-South Asia was established in 1985 in India, to include surrounding countries. ILASS-Asia which covers all Asian countries was established in 1989.

Each regional ILASS has annual conferences and issues newsletters. Each regional ILASS(Asia, Americas and Europe) is an organization of industrialists, researchers, academics, and students engaged in professional activities connected with the Liquid Atomization and Spray Systems.

As a central body of ILASS, the International Council of ILASS was organized in 1988 to coordinate the activities of ILASS and to deal with international issues. Professor Toshio Kurabayashi was elected as the first President of ILASS-International. The Constitution and Bylaws was written on the advice of Prof. Kurabayashi and Dr. Harold C. Simmons in 1991.

In 1985, through the efforts of Dr. Eisenklam, the first issue of a technical journal; "Atomization and Spray Technology"(AST) was published by Elsvier Applied Science Publishers.

A big shock came upon us in 1987. It was the sudden death of Dr. Eisenklam. Then, AST was discontinued in 1987 with Vol.3, No.4. However, a new journal; "Atomization and Sprays", commenced a bimonthly publication under editor in-chief of Prof. Norman Chigier as the official journal for ILASS-International by Begell House, Inc.

In recognition of the author(s) of the best paper presented at an ICLASS, the Tanasawa Award was founded and the first presentation was made at ICLASS-1988 in Sendai, Japan.

Special thanks to late Dr. Eisenklam for the realization of ICLASS, ILASS, the journal and the Tanasawa Award.

## 3. The Tanasawa Award

At the Second International Conference on Liquid Atomization and Spray Systems held in Madison, Wisconsin, USA in 1982, Dr. Eisenklam, of proposed that future conferences should have an international academic award. He suggested that it should be named the Tanasawa Award in commemoration of Professor Tanasawa's important pioneering contributions to the field of liquid atomization and spray systems.

In response to his proposal, the persons concerned in Japan decided that they should make preparations for the award at ICLASS 1988 as a target, and they asked Prof. Tanasawa's disciples to put it into practice, including the fund raising. This decision in Japan was reported at the third ICLASS in London by Prof. Takashima and was accepted.

After the Conference in London, the Committee for the Award was established in Japan and Prof. Kobayashi was nominated as chairman and Prof. Hiroyasu was nominated as secretary.

The entire fund to pay for the award was donated by the Toyota Motor Co. Ltd. Thanks to Dr. Shoichiro Toyoda, former president of Toyota Motor Co., and one of Professor Tanasawa's disciples.

The selection committee of the Tanasawa Award was organized to select the outstanding paper from each previous ICLASS. The committee consisted of nine members nominated throughout of the world. The administration committee of the Tansawa Award would like to thank the late Dr. Eisenklam for his farseeing proposal, and to Toyota Motor Co. Ltd., for its financial support.

This Award will continue as an authoritative award forever.

## 4. Measurements of Drop Size and Drop Distribution

Prof. Tanasawa, in his early stage of experiments used glass plates with a special liquid in which the drop would not dissolve but would remain stable and suspended to enable measurements of drop size. The drops were counted and measured using a microscope.

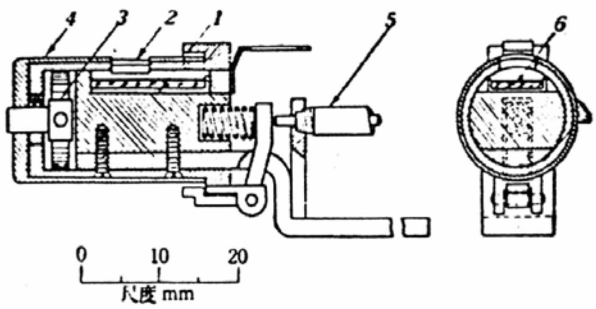


Fig. 2. Rotating shatter for drop measurement

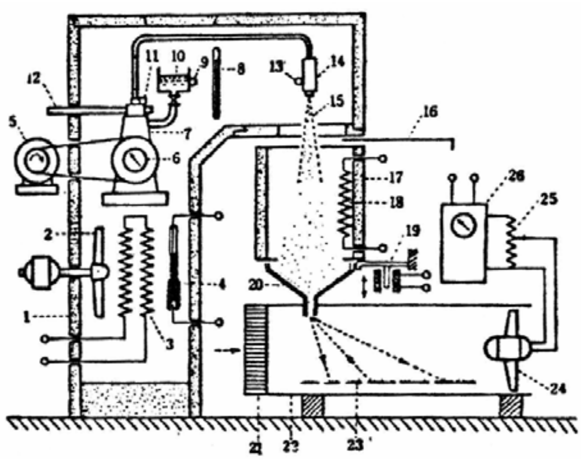

Fig. 3. Molten wax drop size analyzer

He made a special rotating shutter as shown in Fig.2. He tested several kinds of "immersion liquid," including lubricating oil with high viscosity, silicone oil, some surface-active agents. He was able to clarify a part of spray characteristics by means of a primitive method. However, he took special care regarding sampling error in drop distribution within unsteady time and space. He wanted to measure all the drops injected from the nozzle. He tried freezing the fuel drops in liquid nitrogen and the molten wax method. Molten wax which is heated before spraying, has values of surface tension, viscosity and specific gravity similar to the actual fuel. Wax drops solidify in the air and are all fed into a suction wind tunnel of very low air velocity and assorted according to size on the glass plates set on the floor of the tunnel. If the relation between the size of a drop and the position of the floor on which the drop falls are measured, we can determine the weight distribution of injected drops by simply measuring the weight of drops accumulated on the glass plates[38].

In 1962, Prof. Tanasawa and Hiroyasu[39,40] developed "the Drop Size Analyzer by Sedimentation". When drops of varying size fall in still air, each drop assumes a terminal velocity proportional to its size. This principle is used in a drop-size-analyzer for checking the output of atomizers. The upper chamber encloses the atomizer and release-control mechanism. The lower chamber contains a weighing and recording apparatus. A vertical duct about 1 m in diameter and 8 m high connects the chamber as shown in Fig.4. The analyzer can measure drops between 5 and 250 microns in size.

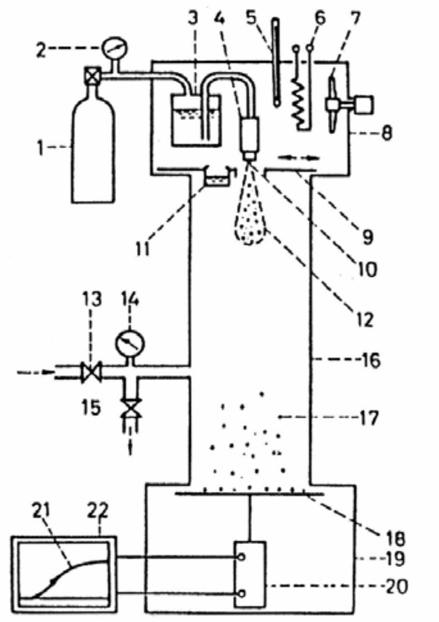


Fig. 4. Drop size analyzer by sedimentation

## 5. Expression of Mean Drop Size and Drop Distribution

Since drops in spray cover a wide range of sizes, it would be useful to know the relationship between the drop sizes and the frequency of their occurrence in a spray. P. Rosin and E.Rammler presented drop size distribution equations for powders and solid particles in 1927 and 1933. However, this formula is faulty in that the number frequency dn/dx of drops became infinite, when drop size x becomes small. Then, Prof. Tanasawa proposed the following formula.

$$f_n\left(x\right) = Ax^{\alpha}\, exp\left(-Bx^{\beta}\right)$$

where, $f_n(x)$=dn/dx and is a mathematical expression for the number of drops n of a size x in a given size range dx. A and B are constants, and α and β are experimental constants, which depend on the type of atomizer and properties of fuels, but usually β=1. Constants A and B are expressed;

$$A = B^{\alpha+1} \big/ \Gamma\left(\alpha+1\right),\quad B = \left[\alpha+4 \big/ \alpha+3\right]\left[1 \big/ x_{32}\right],$$

where $x_{32}$ is the Sauter mean diameter.

This equation can be rewritten into the chi-square distribution, if we put $\phi = 2\left(\alpha+4\right)$,

$\chi^2 = 2Bx$ . Where, $\chi^2$ is the chi-square distribution and $\phi$ is degree of freedom in the chi-square distribution[39].

## 6. The Photographic Method for investigating the Atomization

The photographic method for investing the atomization of liquid sprays has been quite important. There are two ways of photographing high-speed phenomena; one is by means of a high-speed cine-camera, the second consists of illuminating the object with a very short and intense flash while the camera shutter is open. High speed phenomena for a drop of, say 20 microns diameter, moving with a velocity of, say, 100m. per sec. and allowing the passage of 20 microns during the photographic exposure time (which means 100 per cent deformation on the picture), the time exposure will be $20/(1000 \cdot 100 \cdot 10^3)=2 \cdot 10^{-7}$ sec. This means that the time of exposure should be not greater than 0.2 microseconds. Such a short exposure time could not be obtained with a cine-camera at the time(1935). Such short flashes could only be obtained by the discharge of highly loaded condensers, and Prof. Tanasawa used the Marx circuit as shown in Fig.5 for short flashes. He made a flash lamp with a $10^{-6}$ to $10^{-7}$second duration and took numerous spray photographs for analyzation.

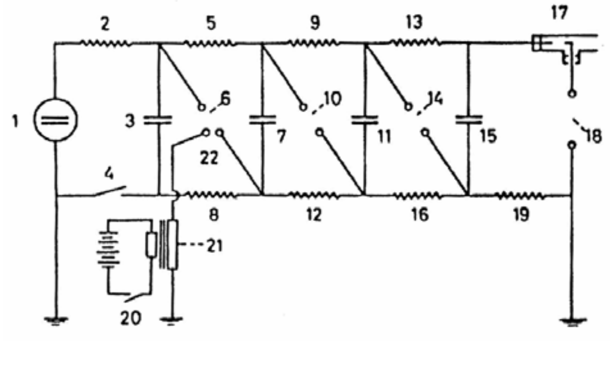


Fig. 5. Marx circuit for short flashes

## 7. Research of Various Atomization Methods

Since 1936, Prof. Tansawa conducted extensive studies on various methods of atomization;

(1) by dripping (1941- )
(2) with circular nozzle or orifice (1936- )
(3) with nozzle of special shape (1954- )
(4) by swirling flow (1940- )
(5) by impingement (1940- )
(6) by vibration (1040- )
(7) with gas (or vapor) blast nozzle (1936- )
(8) with rotating disk (1936- )
(9) with rotating nozzle (1943- )
(10) by electrostatic or dynamic force (1940- )
(11) by evaporation or condensation (1955- )

## 8. Research of Atomization Mechanism

Observations of liquid jet disruption were made by means of high-speed spark photography, and the length from the orifice to the break-up point of the jet was measured and is shown on Fig.6 as a function of the initial jet velocity. The discharge velocity of the jet was gradually increased and following stages of jet disintegration were observed:

(1) Dripping,
(2) Smooth flow region
(3) Transition flow
(4) Wavy flow region
(5)(6) Spray

He introduced non-dimensional number; $Sb = \mu / \sqrt{\sigma \rho D}$ , he called this number stability number and he showed he stage of jet disintegration in relation to Reynolds number and Stability number as shown in Fig.7. Furthermore, he introduced new number; Jet number Je, like a Weber number .

$$Je = \frac{\rho D v^2}{\sigma} \left( \frac{\rho_a}{\rho} \right)^{0.55}$$

If Je<0.1; dripping, Je≒0.1-10; smooth flow, Je≒10-400; wavy flow and Je>400; spray.
Where μ: viscosity, σ; surface tension, ρ; density, D; inner diameter of orifice, v; jet velocity.

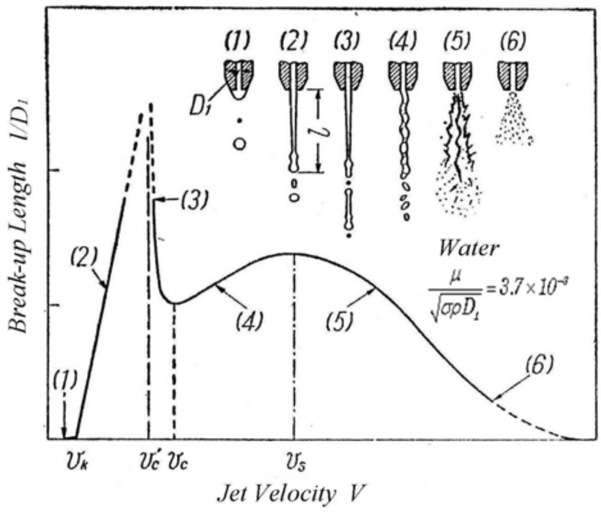


Fig.6. Relationship between break-up length and jet velocity

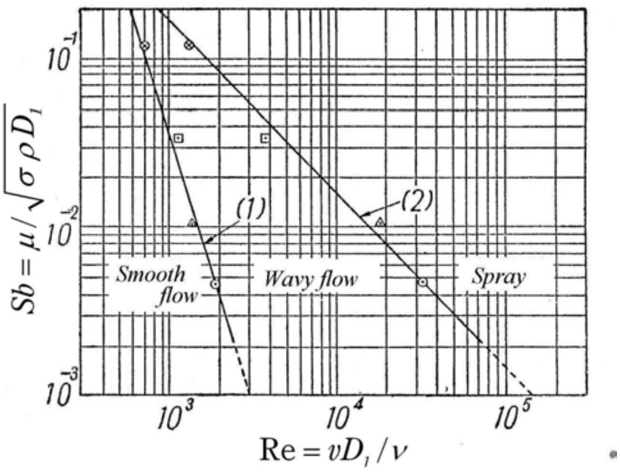


Fig. 7. Stages of jet disintegration in relation to Reynolds number and Stability number

## 9. Summary

Liquid atomization is an interdisciplinary subject covering a wide range of study fields. Therefore, there are the greatest problems in preparation of a conference, or community at an international level. However, Prof. Tanasawa's pioneering research in liquid atomization and spray systems and Dr. Eisenklam's useful proposals were completed the realization of ICLAA, ILASS, the journal and the Tanasawa Award.

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