The Elmer A. Sperry Award
1993

for advancing the art of transportation

The Elmer A. Sperry Medal

The Elmer A. Sperry Award

The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.

In the words of Edmondo Quattrocchi, the sculptor of the Elmer A. Sperry Medal:

"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control of man's purposes."

Presentation of

The Elmer A. Sperry Award for 1993

to

Heinz Leiber
Wolf-Dieter Jonner
Hans Jürgen Gerstenmeier

for the conception, design and development of the Anti-lock Braking System for application in motor vehicles

by

The Board of Award under the sponsorship of the:

American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers
Society of Automotive Engineers
Society of Naval Architects and Marine Engineers
American Institute of Aeronautics and Astronautics
American Society of Civil Engineers

At the 1994 SAE International Congress & Exposition
Tuesday, March 1, 1994
Detroit, Michigan

THE HUMAN ACHIEVEMENT

The story of the Anti-lock Braking System (ABS) is also the story of three engineers: Heinz Leiber, Wolf-Dieter Jonner and Hans Jürgen Gerstenmeier. For two decades they resolutely pursued their vision of a higher safety standard without allowing themselves to be dissuaded by adversity and setbacks.

And it was indeed a long road from the vision to the practical reality: Leiber, Jonner and Gerstenmeier applied for almost 600 patents in connection with ABS development. This number illustrates how much painstaking work was needed to turn a great idea into a reality on the road.

The development of ABS required the special skills of each of the three award-winners working as a team. Heinz Leiber, using his background in precision mechanics, invented and developed the control strategy of the ABS System and also contributed to the design of its hydraulic unit and speed sensor.

From his experience with modelling and testing, Wolf-Dieter Jonner defined the physics of the vehicle ABS system. Through his efforts, numerous vehicle dynamic safety related features were incorporated into the algorithm.

Hans Jürgen Gerstenmeier, a specialist in electronics, made design contributions and implemented the algorithm into the electronic controller. He also defined numerous hardware and software safety features.

THE AWARD WINNERS

Heinz Leiber

Heinz Leiber, the most senior ABS design engineer among the three award winners, started work on an electronic Anti-lock Braking System as early as 1964. From 1953 to 1956 Leiber was trained as a precision mechanic near his birthplace and hometown Trossingen, Germany. Starting in 1956, he worked for three years as a technical draftsman in nearby Schwenningen before he transferred to the State Engineering School in Esslingen where he specialized in precision engineering. After completing his studies, Leiber's first job was in the development department of the Bosch subsidiary Teldix in Heidelberg, where he initially worked on the development of navigational systems. In 1964 Leiber began the development of ABS. In 1975 he transferred to the Automotive Development Center of Robert Bosch GmbH in Schwieberdingen as project leader for ABS. When ABS series production started in 1978, Leiber was promoted to development director for ABS, a position he held for seven years. During this time, he established contacts with all major automotive companies in the world and was instrumental in the establishment of a joint venture in Japan. In 1985 Leiber moved to Daimler-Benz AG to become a department director. Since 1988 he has been responsible for the entire area of automotive electrical and electronic systems at Mercedes-Benz AG. Leiber has already received numerous awards for his work on ABS including the Safety Award for Engineering Excellence from the U.S. National Highway Traffic Safety Administration in 1980. He also received the Porsche Prize from the University of Vienna in 1981 and the Aachen and Munich Prize for Technology and Applied Natural Sciences in 1991. Now 57, Leiber is married and has two children.

Wolf-Dieter Jonner joined the ABS team in 1966. After graduating from the Triberg Gymnasium, he studied general precision engineering at the Technical Institute in Furtwangen, Germany. In the ABS development department at Teldix, Jonner was primarily responsible for road and lab tests as well as the development of control algorithms. Jonner transferred to Bosch in Schwieberdingen in 1975. He was named department head in the ABS and traction control field at Bosch in 1980 and has been development director there

Wolf-Dieter Jonner

Hans Jürgen Gerstenmeier

since 1990. Jonner, now 52, is married and has two children.

After graduating from Heidelberg Gymnasium, *Hans Jürgen Gerstenmeier* studied communications engineering at the Technical University in Munich, Germany. In 1967, he returned to Heidelberg and took a job at Teldix where he initially worked in the area of navigational equipment and gyroscopes before he became solely responsible for the development of electronic control systems for ABS. In 1975, Gerstenmeier and his colleagues Leiber and Jonner moved to Bosch in Schwieberdingen to continue the development of ABS and later traction control. In 1983, Gerstenmeier became department head for electronic development for ABS and for traction control. Since 1988 he has been responsible for electronic control units for safety systems such as ABS and airbags as development director in Schwieberdingen. Now 52, Gerstenmeier is married and has two children.

In addition to the outstanding work by Leiber, Jonner and Gerstenmeier, ABS was made possible by a support team of exceptional and highly dedicated associates. Also indispensible to ABS's eventual success was the courage to take entrepreneurial risks. Such men as Fritz Krümmling, Teldix's Managing Director; Dr. Hans Bacher, member of the Bosch Board of Management; and Prof. Dr. Hans Scherenberg, member of the Daimler Benz Board, promoted the ABS idea despite all setbacks and defended its development against resistance and skepticism through personal commitment.

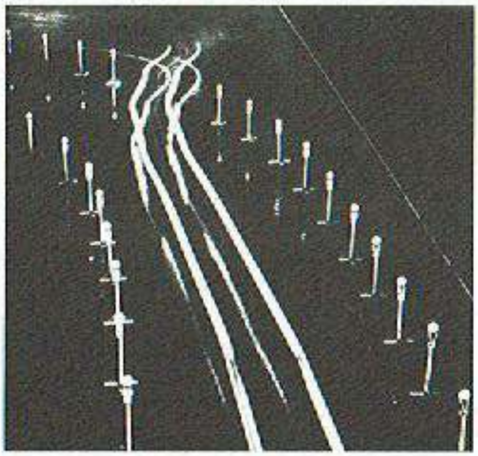
HOW THE PRESENT ABS OPERATES

ABS activates during panic braking when sudden dangerous situations and/or adverse ambient conditions overburden the driver and the vehicle. A classic example is an obstacle appearing suddenly on a slick road, a situation to which most drivers respond almost instinctively with panic braking. The wheels lock, losing their traction with the road, and the vehicle can no longer be steered.

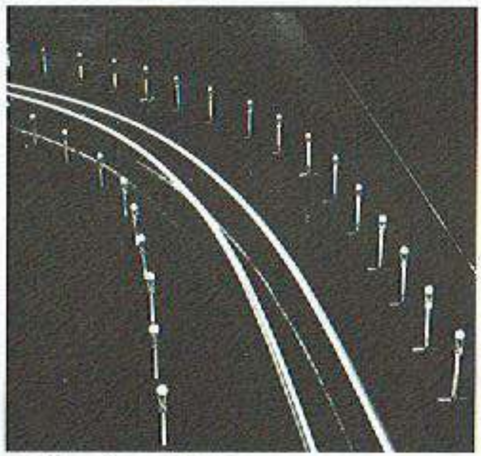
ABS automatically controls the braking effect in such a way that the wheels are prevented from locking in the first place. The result is not only a reduced stopping distance under most driving conditions, but the vehicle also stays on track and responds to the driver's steering commands. Thus ABS helps to prevent catastrophic accidents. The fully electronic Anti-lock Braking Systems of the current generation consist of speed sensors at the wheels, an electronic control unit (ECU) and a hydraulic modulator. In today's compact versions the hydraulic modulator and the electronics are integrated into one unit.

When the system operates, inductive sensors monitor the wheel speed, continually feeding this information to the ECU in the form of electrical signals which the latter constantly evaluates. If a wheel is detected tending towards locking, the electronically controlled hydraulic modulator activates. By means of solenoid valves, the pressure in the corresponding brake cylinder is initially kept constant even if the driver applies the brakes still harder.

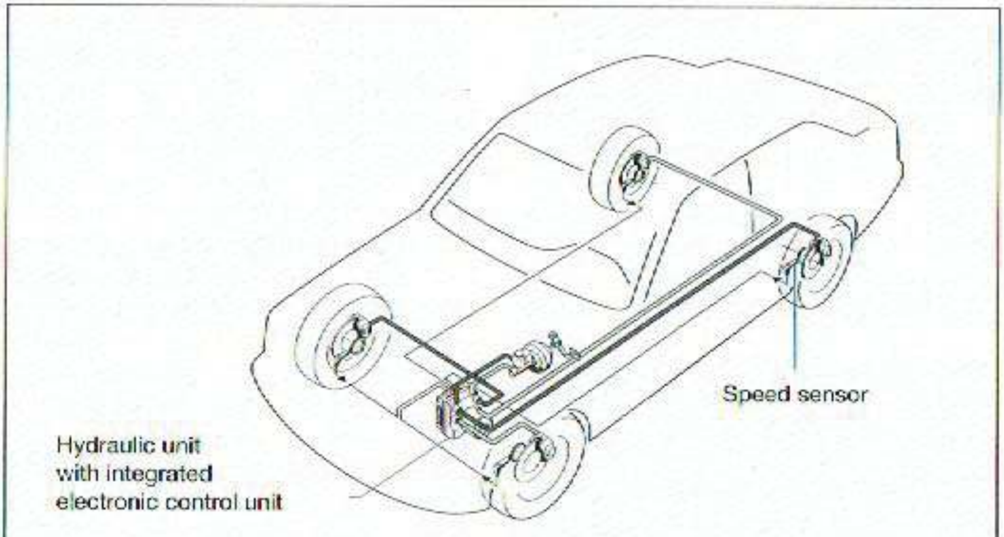
The solenoid valves are capable of reducing, holding or again increasing the



Braking effect without ABS:
The tracks show that the wheels have locked and the vehicle has broken away.



Braking effect with ABS:
The vehicle retains full steerability and keeps to its course even in the event of panic braking.



Present Anti-lock Braking System with 4 channels and 4 sensors.

brake pressure in rapid succession. Depending on the conditions of the road, this interplay can occur several times per second. It maintains, within a narrow range around an optimum value, the balance between the coefficient of friction between a tire and the road surface and the brake force.

In the process the front wheels are controlled individually and the rear wheels jointly. If the road surface is slippery on one side, the rear wheel braking on a slippery surface determines the common brake pressure for both of them. In this manner, the shortest possible stopping distance is achieved within reasonable physical limits. In other words: ABS assures that the tire grip is always maintained.

Therefore, a sudden braking action does not cause the driver to lose control of the vehicle. For added safety the ECU operates with two redundant microprocessors. These not only constantly control the entire system, they also monitor each other by comparing their separate outputs. If deviations between the two microprocessors occur, the entire ABS shuts itself off automatically and signals the malfunction to the driver via a warning light in the dashboard. At this point the brake system functions as a conventional system until the defect is corrected.

HISTORY OF THE ANTI-LOCK BRAKING SYSTEM

The current ABS system just described required a long period of development. As early as the 1920's, the first patents were granted for components of Anti-lock devices. In 1936, Bosch patented "a device to prevent the locking of the wheels of a motor vehicle". The basic idea was the same then as it is today: to keep the wheels from locking by easing the brake pressure. Solenoid valves had already been designated for this purpose in the 1936 patent. Pressure regulation was not the determining problem.


DEUTSCHES REICH

AUSGEGEBEN AM 16. FEBRUAR 1939

REICHSPATENTAMT

PATENTSCHRIFT

№ 671 925

KLASSE 63c GRUPPE 53

W 99472 II/63c

Robert Bosch G. m. b. H. in Stuttgart

Vorrichtung zum Verhüten des Festbremsens der Räder eines Kraftfahrzeuges

Patentiert im Deutschen Reiche vom 15. September 1936 ab

Tag der Bekanntmachung über die Erteilung des Patents: 2. Februar 1939

First Bosch ABS patent (1936)

Failure of the Mechanical Approach

The early ABS tests failed because the mechanical detection of a wheel's speed of rotation was too slow and too imprecise to serve as the basis for an ABS. Richard Bussien, therefore, commented in his automotive handbook in 1941: "So far the attempt to counter the danger of wheel locking through special devices has only had modest successes. An anti-lock regulator which protects brakes from locking under operating conditions would represent a giant step towards the safety of motor vehicle traffic." These were almost prophetic words because as later developments were to demonstrate, ABS was not dead. Rather, the idea lay dormant until Heinz Leiber picked it up again 28 years after the first Bosch patent had been filed. In 1964, while working as an engineer at the Bosch subsidiary Teldix GmbH in Heidelberg, Leiber initiated the development of a workable ABS, to be joined by Jonner in 1966 and Gerstenmeier in 1967.

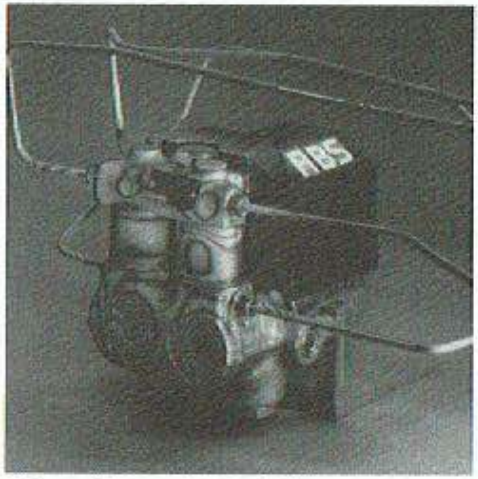
When the development of the modern ABS began in 1964, anti-lock braking systems equipped primarily with mechanical-hydraulic regulators were already in use in large airplanes in civil aviation and with mechanical-pneumatic regulators on some express trains. Early electronic systems were already being used in military planes. However, these were very costly and elaborate. At that time integrated circuits with a few transistors appeared on the market for the first time. Although fast-acting hydraulic valves were already in existence, they were too expensive for use in motor vehicles.

Initial Steps on the Road to a Fully Electronic ABS

Facing this situation, Leiber and his colleagues at Teldix in 1965 developed the first system that senses wheel rotation utilizing electro-mechanical wheel accelerometers and fast-acting solenoid valves. Even though this combination was able to prevent the wheels from locking, operating time was limited by hydraulic pressure capacity and the stopping distance longer than with a conventional brake system.

In 1966 the ABS team developed a friction wheel sensor which measured wheel rotation through contact with the brake disc. The acceleration signals from the sensors were evaluated by a mechanical control because at that time automotive experts still had little confidence in electronics. With this new system the design engineers succeeded in reducing stopping distance in comparison to locked wheels. This made a lasting impression on experts in the field.

In 1967 the three engineers experimented with accelerometers which were mounted directly on the wheel hubs. By means of slip rings, the signals from these sensors were transmitted to a small electronic device. It controlled the solenoid valves which were combined into a compact valve block. A recirculating pump with accumulator for the brake fluid solved the problem of the limited control time, a principle which to this day is being used worldwide for ABS. Although the system achieved a remarkable reduction in stopping distance during large-scale tests, while



Holographic examination of the Bosch ABS hydraulic unit shows distortion of the external surfaces caused by brake pressure.

maintaining good stability and steerability, problems with the durability of the pump motor and the hub sensors together with control weaknesses during extreme braking in curves, prevented the system from being developed to the production stage.

The First Generation: an Analog ABS

Past experiences were incorporated into a new system concept in 1969. The front wheels were equipped with a combination of rotational acceleration sensors and simple pulse generators, the rear axle only with a pulse generator. The ABS team combined the pump and solenoid valves into a compact hydraulic modulator. The control was fully electronic. Individual transistors were mounted on a circuit board with over a thousand components based on analog technology because integrated circuits suitable for automotive applications were not yet available. A full third of the components were designated for the safety circuit designed to shut off ABS in case of a malfunction. The control technology specified at that time is still the basis of nearly all anti-lock braking systems because the system yielded excellent results in test drives with respect to stopping distance and stability. In 1970/71, Teldix, together with Daimler-Benz, introduced the first generation ABS in passenger cars, trucks and buses and received an enthusiastic response from the world press and the industry.

Winter testing of Bosch ABS/ASR (traction control) in northern Sweden.

The basis for mass production appeared to have been found. In subsequent years, a significantly expanded ABS team concentrated on modifying all components to conform to production requirements. In 1972, the system had to undergo tough, large-fleet, winter testing on frozen Hornavan Lake near Arjeplog on the edge of the permafrost in northern Sweden. Since then this simple test site has mushroomed into a full-fledged technical application center logging up to 10,000 overnight stays by employees and customers.

However, these initial tests at the Arctic Circle were frustrating. Although ABS worked well in principle, endurance testing of individual components proved to be unsatisfactory. Thirty percent of the analog electronic control units failed in the winter test, as did other components, resulting in a longer stopping distance or even total failure of the brake effect.

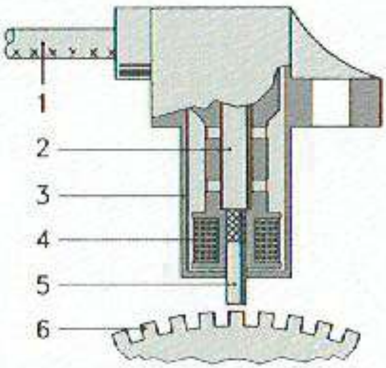
On the basis of these test results, quality experts modified the electronic system. Simultaneously, ABS for commercial vehicles was developed for series production, and studies were conducted to determine whether ABS was also suitable for motorcycles and for auto racing.

The second winter tests in 1973 yielded better results regarding reliability, but they still failed to satisfy its demanding requirements. The necessity to do so became obvious that same year when an American company launched a simple ABS for commercial vehicles. Its poor reliability led to a number of accidents that gave ABS a bad reputation worldwide. Teldix also delayed production plans for the first generation ABS by almost one year . Again it appeared that an impasse had been reached.

The Second Generation: a Digital ABS

Despite these setbacks, ABS development was ultimately resumed in 1974. A decisive factor in the crucial decision to proceed was the new prospect of using large-scale integrated circuits, adapted to the especially demanding environment of ABS. The ABS engineers realized that only this type of electronic controls combined with state-of-the-art control engineering would work with sufficient speed and precision. At first the ECU had to be digitized and set up in a test vehicle for optimization on a complex breadboard with over 1,000 integrated circuits. The integration of about 30,000 transistors on a silicon surface of $40mm^2$ finally created the basis for reliable electronic hardware. This pioneering work led to the use of the first digital LSI (large scale integration) circuits in motor vehicles. Because of the digital electronics, the mechanical accelerometers could be replaced by wheel speed sensors which developed signal pulses on the induction principle without making contact with the wheels. Finally a new control principle made it possible to reduce the number of solenoid valves per control channel from two to one.

Wheel-speed sensors: a) Wheel-speed sensor with chisel-type pole pin.
b) Wheel-speed sensor with round pole pin.



Wheel-speed sensor with round pole pin
1 Electric cable 4 Winding
2 Permanent magnet 5 Pole pin
3 Housing 6 Sensor wheel

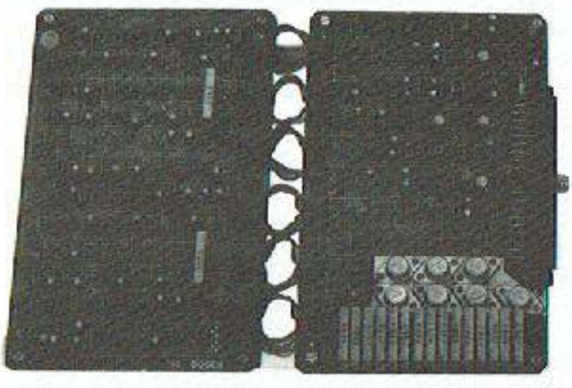
The wheel-speed sensors signal the wheel speed to the ECU. The pole pin (5) of the wheel-speed sensor is surrounded by a winding (4) and is located directly over the sensor ring (6), a gear wheel which is attached to the wheel hub. The pole pin is connected to a permanent magnet (2) whose magnetic field extends into the sensor ring. When the ring rotates, the pole is faced alternately by a tooth and a tooth gap. Consequently, the magnetic field changes repeatedly and induces a voltage in the winding which is tapped off at the winding ends. The frequency of the voltage serves as an exact measure for the wheel speed.

Integrating these improvements defined a new generation ABS in 1975. During this time, ABS development activities were transferred from Teldix to Bosch. (Since 1965, ABS had been developed separately by both companies, but now forces were joined and ABS could finally be introduced to the market). The digital circuits were developed by American Microsystems Inc., a U.S. joint venture partner, and the analog integrated circuits at the Bosch plant in Reutlingen.

In 1978, the go-ahead was finally given for series production: the new S-Class from Mercedes-Benz came equipped with ABS, soon to be followed by the new BMW 7 Series. Problems with reliability were a thing of the past, but now prohibitively high costs jeopardized the success of ABS. In a three-year project the team reduced by 1981 the costs to such an extent that ABS could now emerge not only as a technical achievement but also as an economic success.

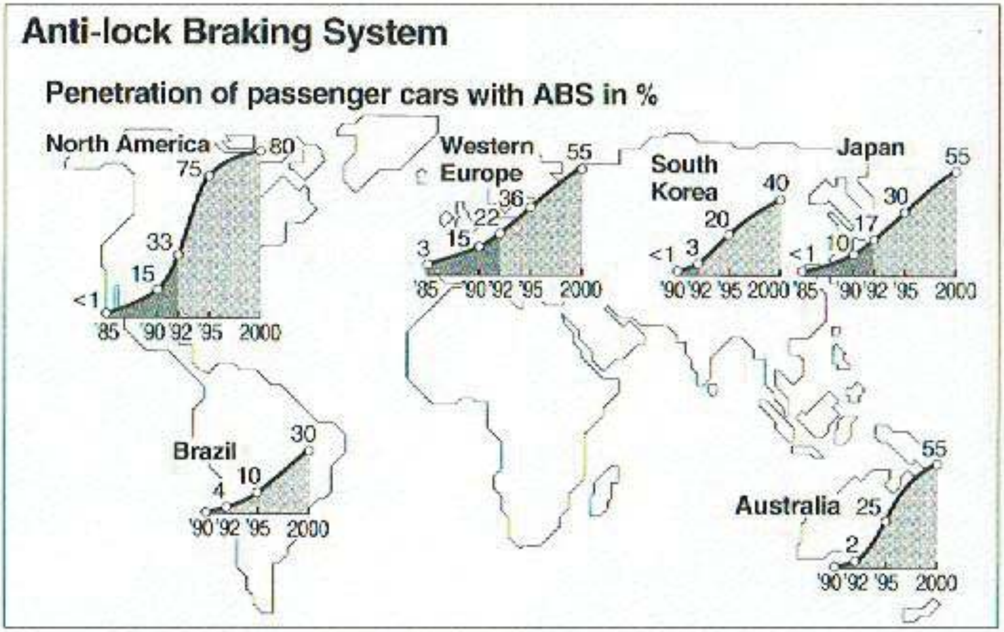
Further Developments

ABS development continues at Bosch. Subsequent engineering efforts there have focused on designing ABS units compatible with a wide range of motor vehicles from small cars, and even motorcycles, to large buses and trucks, and on making them lighter and more compact. Since 1988 a new generation of ABS combines its normal role, to reduce braking on a wheel that was locked, to that of "traction control", to reduce power on a driving wheel that is spinning.



Electronic control unit for ABS in 1972 ...

... and 1989

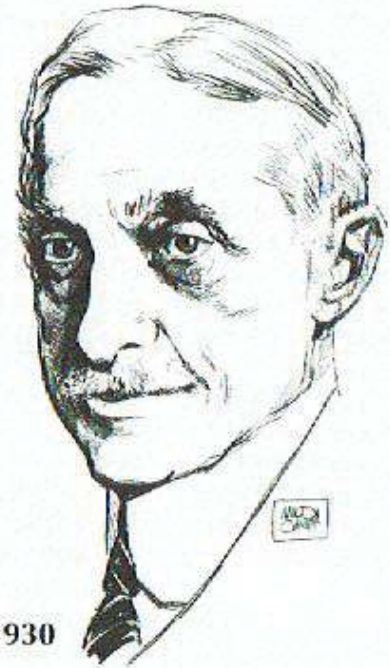


Market Response

Meanwhile, ABS is increasingly being regarded by motor vehicle manufacturers throughout the world as an essential component for their products. The largest market for the safety system is North America where, in 1993, fifty percent of all new vehicles were equipped with ABS, a share expected to grow to seventy-five percent by 1995. In Japan and Europe the number of vehicles equipped with ABS is growing annually by a double digit percentage rate. Automotive experts are projecting that worldwide every second new vehicle will be equipped with ABS as early as 1996, with an increase to seventy percent by the turn of the century.

To conclude: as noted early in this historical sketch, over 50 years ago an automotive authority foresaw that – if it were ever achieved – a device "which protects brakes from locking under operating conditions would represent a giant step towards the safety of motor vehicle traffic."

The surging demand for ABS gives dramatic witness to the achievement of just such a Giant Step. Meanwhile, the awards and citation presented at this time recognize that behind its arrival lies a long series of often small but significant steps in the practice of creative engineering.



Elmer A. Sperry, 1860-1930

After attending Cornell University in 1879-80, Sperry invented an improved electric generator and arc light and opened an electric company in Chicago. He invented electric mining equipment, locomotives, streetcars and an electric automobile. He developed gyroscopic stabilizers for ships and aircraft, a successful marine gyrocompass and gyro-controlled steering and fire control systems used on Allied warships during World War I. Sperry also developed an aircraft searchlight and the world's first guided missile. His gyroscopic work resulted in the automatic pilot in 1930. The Elmer A. Sperry Award was established in 1955 to encourage progress in transportation engineering.

The Founding of The Elmer A. Sperry Award

To commemorate the life and achievements of Elmer Ambrose Sperry, whose genius and perseverance contributed so much to so many types of transportation, the Elmer A. Sperry Award was established by his daughter, Helen (Mrs. Robert Brooke Lea), and his son, Elmer A. Sperry, Jr., in January 1955, the year marking the 25th anniversary of their father's death. An additional endowment to support the award was received in 1978 upon the death of Mrs. Lea. Additional gifts from interested individuals and corporations also contribute to the work of the Board.

Elmer Sperry's inventions and his activities in many fields of engineering have benefitted tremendously all forms of transportation. Land transportation has profited by his pioneer work with the storage battery, his development of one of the first electric automobiles (on which he introduced 4-wheel brakes and self-centering steering), his electric trolley car of improved design (features of its drive and electric braking system are still in use), and his rail flaw detector (which has added an important factor of safety to modern railroading).

Sea transportation has been measurably advanced by his gyrocompass (which has freed man from the uncertainties of the magnetic compass) and by such navigational aids as the course recorder and automatic steering for ships. Air transportation is indebted to him for the airplane gyro-pilot and the other air-navigational instruments he and his son, Lawrence, together developed.

The donors of the Elmer A. Sperry Award have stated that its purpose is to encourage progress in the engineering of transportation. Initially, the donors specified that the Award recipient should be chosen by a Board of Award representing the four engineering societies in which Elmer A. Sperry was most active:

The American Society of Mechanical Engineers
(of which he was the 48th President);

American Institute of Electrical Engineers
(of which he was a founder member);

Society of Automotive Engineers; and

Society of Naval Architects and Marine Engineers.

In 1960, the participating societies were augmented by the addition of the Institute of Aerospace Sciences. In 1962, upon merging with the Institute of Radio Engineers, the American Institute of Electrical Engineers became known as the Institute of Electrical and Electronics Engineers; and in 1963, the Institute of Aerospace Sciences, upon merger with the American Rocket Society, became the American Institute of Aeronautics and Astronautics. In

1990, the American Society of Civil Engineers became the sixth society to become a member of the Elmer A. Sperry Board of Award.

Important discoveries and engineering advances are often the work of a group, and the donors have further specified that the Elmer A. Sperry Award honor the distinguished contributions of groups as well as individuals.

Since they are confident that future contributions will pave the way for changes in the art of transportation equal at least to those already achieved, the donors have requested that the Board from time to time review past awards. This will enable the Board in the future to be cognizant of new areas of achievement and to invite participation, if it seems desirable, of additional engineering groups representative of new aspects or modes of transportation.

The Sperry Secretariat

The donors have placed the Elmer A. Sperry Award fund in the custodianship of The American Society of Mechanical Engineers. This organization is empowered to administer the fund and has generously agreed to assist in handling the Award procedures.

The fund has been placed in an interest bearing account, and earnings are used to partially cover the expenses of the Board. The principal account is augmented from time to time by donations from interested individuals and organizations.

The Elmer A. Sperry Board of Award Secretariat is administered by the American Society of Mechanical Engineers, which has generously donated the time of its staff to assist the Board in its work. The Secretary is appointed by the ASME from among its senior staff personnel.

The Elmer A. Sperry Board of Award welcomes suggestions from the transportation industry and the engineering profession for candidates for consideration for this Award.

ELMER A. SPERRY AWARDS

1955 to *William Francis Gibbs* and his Associates for development of the S.S. United States.

1956 to *Donald W. Douglas* and his Associates for the DC series of air transport planes.

1957 to *Harold L. Hamilton, Richard M. Dilworth and Eugene W. Kettering* and Citation to their Associates for the diesel-electric locomotive.

1958 to *Ferdinand Porsche* (in memoriam) and *Heinz Nordhoff* and Citation to their Associates for development of the Volkswagen automobile.

1959 to *Sir Geoffrey De Havilland, Major Frank B. Halford* (in memoriam) and *Charles C.Walker* and Citation to their Associates for the first jet-powered aircraft and engines.

1960 to *Frederick Darcy Braddon* and Citation to the Engineering Department of the Marine Division, Sperry Gyroscope Company, for the three-axis gyroscopic navigational reference.

1961 to *Robert Gilmore Letourneau* and Citation to the Research and Development Division, Firestone Tire and Rubber Company, for high speed, large capacity, earth moving equipment and giant size tires.

1962 to *Lloyd J. Hibbard* for application of the ignitron rectifier to railroad motive power.

1963 to *Earl A. Thompson* and Citation to his Associates for design and development of the first notably successful automatic automobile transmission.

1964 to *Igor Sikorsky and Michael E. Gluhareef* and Citation to the Engineering Department of the Sikorsky Aircraft Division, United Aircraft Corporation, for the invention and development of the high-lift helicopter leading to the Skycrane.

1965 to *Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook and Richard L. Loesch, Jr.* and Citation to the Commercial Airplane Division, The Boeing Company, for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720 and 727.

1966 to *Hideo Shima, Matsutaro Fuji and Shigenari Oishi* and Citation to the Japanese National Railways for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

1967 to *Edward R. Dye (in memoriam), Hugh DeHaven, and Robert A. Wolf* and Citation to the research engineers of Cornell Aeronautical Laboratory and the staff of the Crash Injury Research projects of the Cornell University Medical College.

1968 to *Christopher S. Cockerell and Richard Stanton-Jones* and Citation to the men and women of the British Hovercraft Corporation for the design, construction and application of a family of commercially useful Hovercraft.

1969 to *Douglas C. MacMillan, M. Nielsen and Edward L. Teale, Jr.* and Citations to Wilbert C. Gumprich and the organizations of George G. Sharp, Inc., Babcock and Wilcox Company, and the New York Shipbuilding Corporation for the design and construction of the N.S. Savannah, the first nuclear ship with reactor, to be operated for commercial purposes.

1970 to *Charles Stark Draper* and Citations to the personnel of the MIT Instrumentation Laboratories, Delco Electronics Division, General Motors Corporation, and Aero Products Division, Litton Systems, for the successful application of inertial guidance systems to commercial air navigation.

1971 to *Sedgwick N. Wight (in memoriam) and George W. Baughman* and Citations to William D. Hailes, Lloyd V. Lewis, Clarence S. Snavely, Herbert A. Wallace, and the employees of General Railway Signal Company, and the Signal & Communications Division, Westinghouse Air Brake Company, for development of Centralized Traffic Control on railways.

1972 to *Leonard S. Hobbs and Perry W. Pratt* and the dedicated engineers of the Pratt & Whitney Aircraft Division of United Aircraft Corporation for the design and development of the JT-3 turbo jet engine.

1975 to *Jerome L. Goldman, Frank A. Nemec and James J. Henry* and Citations to the naval architects and marine engineers of Friede and Goldman, Inc. and Alfred W. Schwendtner for revolutionizing marine cargo transport through the design and development of barge carrying cargo vessels.

1977 to *Clifford L. Eastburg and Harley J. Urbach* and Citations to the Railroad Engineering Department of The Timken Company for the development, subsequent improvement, manufacture and application of tapered roller bearings for railroad and industrial uses.

1978 to *Robert Puiseux* and Citations to the employees of the Manufacture Francais des Pneumatiques Michelin for the design, development and application of the radial tire.

1979 to *Leslie J. Clark* for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

1980 to *William M. Allen, Malcolm T. Stamper, Joseph F. Sutter and Everette L. Webb* and Citations to the employees of Boeing Commercial Airplane Company for their leadership in the development, successful introduction and acceptance of wide-body jet aircraft for commercial service.

1981 to *Edward J. Wasp* for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.

1982 to *Jorg Brenneisen, Ehrhard Futterlieb, Joachim Korber, Edmund Muller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler and Werner Teich* for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotives in heavy freight and passenger service.

1983 to *Sir George Edwards, OM, CBE, FRS; General Henri Ziegler, CBE, CVO, LM, CG; Sir Stanley Hooker, CBE, FRS (in memoriam); Sir Archibald Russell, CBE, FRS; and M. Andre Turcat, Ld'H, GG*; commemorating their outstanding international contributions to the successful introduction and subsequent safe service of commercial supersonic aircraft exemplified by the Concorde.

1984 to *Frederick Aronowitz, Joseph E. Killpatrick, Warren M. Macek and Theodore J. Podgorski* for the conception of the principles and development of a ring laser gyroscopic system incorporated in a new series of commercial jet liners and other vehicles.

1985 to *Richard K. Quinn, Carlton E. Tripp and George H. Plude* for the inclusion of numerous innovative design concepts and an unusual method of construction of the first 1,000-foot self-unloading Great Lakes vessel, the M/V Stewart J. Cort, which revolutionized the economics of Great Lakes transportation.

1986 to *George W. Jeffs, Dr. William R. Lucas, Dr. George E. Mueller, George F. Page, Robert F. Thompson and John F. Yardley* for significant personal and technical contributions to the concept and achievement of a reusable Space Transportation System.

1987 to *Harry R. Wetenkamp* for his contributions toward the development and application of curved plate railroad wheel designs.

1988 to *J. A. Pierce* for his pioneering work and technical achievements that led to the establishment of the OMEGA Navigation System, the world's first ground-based global navigation system.

1989 to *Harold E. Froehlich, Charles B. Momsen Jr. and Allyn C. Vine* for the in vention, development and deployment of the deep-diving submarine, Alvin.

1990 to *Claud M. Davis, Richard B. Hanrahan, John F. Keeley and James H. Mollenauer* for the conception, design, development and delivery of the FAA enroute air traffic control system.

1991 to *Malcom Purcell McLean* for his pioneering work in revolutionizing cargo transportation through the introduction of intermodal containerization.

1992 to *Daniel K. Ludwig* (in memoriam) for the design, development and construction of the modern supertanker.

1993 to *Heinz Leiber, Wolf-Dieter Jonner and Hans Jürgen Gerstenmeier* and Citation to their colleagues in Robert Bosch GmbH for the conception, design and development of the Anti-lock Braking System for application in motor vehicles.

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