The ISS Symposium Turns 50:
Trends and Developments of Inertial Technology during Five Decades

J.F. Wagner[1], **M. Perlmutter**[2]

[1] University of Stuttgart, Deutsches SOFIA Institut
Pfaffenwaldring 29
70569 Stuttgart
GERMANY

[2] Civitanavi Systems Ltd
19 Peckham Hill Road
Sherborn, MA 01770
USA

Inertial Sensors and Systems 2015
Karlsruhe, Germany

Abstract

In 1965, the German Institute of Navigation founded the “Fachausschuss 8”, which was a committee with the task of bringing together scientists and users of gyro technology. From the beginning, the gatherings of this commission served to present and to discuss current research topics and typical applications of inertial systems. The first meeting took place in Hamburg with 58 participants from two countries. It was followed by a series of successful conferences, and after about 12 years, the annual, well-recognized international “Symposium Gyro Technology” had emerged. Meanwhile every year approximately 180 participants from 20 countries meet to inform themselves of research, innovative developments, and new applications of inertial sensors and systems. Considering the last 50 years, an enormous change of technology characterizes inertial sensors. Whereas mechanical gyros dominated the first conferences, now optical sensors and MEMS can be found in most applications. Strapdown systems replaced classical inertial platforms; electronic components substituted mechanical ones; and aiding devices like GNSS receivers complement in many cases inertial systems. In parallel, inertial sensors became much less expensive and more reliable. Against this background, it is remarkable how this yearly conference could cover all these changes being documented in the existing proceedings of more than 800 papers up to now. The intention of this paper is to portray the history of the “Symposium Inertial Sensors and Systems” and to characterize the technology developments, changes, and trends as well as applications of inertial technology during five decades. Based on the proceedings, this is done by considering different technologies and gyro types with respect to their importance and frequentness including their first mention.

1. An Annual International Symposium Emerges

“The purpose and objective of this committee of experts should be firstly to inform about the state of the art of navigation procedures and devices based on gyros, namely starting with the civil maritime transport. […] Therefore, we have at the beginning the gyro compass in the sense of a north indicator. Subsequently, we would like to extend our efforts to the horizontal platform and the inertial navigation, also in the context of aerospace. […] Likewise, the usage of gyro devices and procedures shall be addressed on land, on land in the sense of surveying, and finally also in the sense of surveying below ground. Here, it will be necessary to address open questions and problems both by [basic] science and research as well as [application-related] investigations.”

With these statements (translated to English), Gerhard Zwiebler, being president of the German Hydrographic Institute (DHI), opened on June 1, 1965 the first full assembly of the

“Fachausschuss 8”, a newly founded special committee of the German Institute of Navigation (DGON). The reason for establishing this commission was the circumstance that the DGON, which developed some years before from an association for radio location, intended to extend its competence to the full range of navigation technology. Accordingly, the committee had the purpose of bringing together scientists and users of gyro technology for a wide range of navigation applications [1].

The initial meeting of the “Fachausschuss 8” in June 1965 took place at the residence of the DHI in Hamburg and was attended by 58 experts from Germany and UK. Until 1970, altogether 7 full assemblies followed, which were hosted by industrial companies und research institutions. The number of participants climbed to an average level of 75 persons from up to five countries. In 1971, this development together with changes in the structure of the DGON led to a conversion of the assemblies into a regular scientific conference, the “Symposium über Kreiseltechnik”, which had no longer only invited presentations but public calls for papers. Due to the further increasing internationality of the meetings, the official language changed from German to English and accordingly the conference name became “Symposium Gyro Technology” in 1979. Simultaneously, the conference settled down at the University of Stuttgart, where all meetings took place until 2006; since 2007, the University of Karlsruhe / KIT hosts the conference. Over the years, the meetings showed a further increasing number of participating nations reaching more than 20, whereas the number of attendees leveled out at 150 to 200 [1].

As indicated above, classical mechanical devices like the gyro compass, the gyro theodolite, and inertial platforms dominated the first meetings. They formed, however, only the first fields of attention. Other sensor types like the dynamical/dry tuned gyro (DTG), the laser and the fiber optical gyro (FOG) as well as microelectromechanical (MEMS) devices appeared. Furthermore, strapdown systems replaced meanwhile in most cases classical platforms; electronic components substituted mechanical ones; and satellite navigation (GNSS), radar or photogrammetric devices typically complement inertial systems today. In parallel, new applications of navigation systems emerged, and inertial sensors became much less expensive and more reliable. Due to this technological development, the name of the conference was altered to “Inertial Sensors and Systems” in 2011.

It is remarkable how the symposia could cover all these changes. One reason for this ability is certainly the organizational steadiness of the conference as indicated above. Another reason might be that the statements of Dr. Zwiebler turned out to be a very sound basis for the scope of the meetings, although they had never been written down in something like a symposium charter. They can be structured as follows:

- Inform about the state of the art of
  - gyro devices and systems,
  - inertial navigation devices and systems,
  - navigation procedures based on this technology.
- Consider applications from
  - ships,
  - aerospace vehicles,
  - land vehicles,
  - surveying.
- Bring together experts from
  - basic science,
  - commercial applications.

In the following, Section 2 considers in more detail the history of the conferences; and Section 3 addresses the technical development of gyro devices and inertial navigation as covered by the meetings. Most of the details of Section 2 were taken from archives of the University of Stuttgart, which were completed by documents of the DGON [1], whereas Section 3 is based on the proceedings of all years [2].

2. The History of the Symposium

2.1. From a National Working Group to an International Conference

Stimulated by J.G.F. Bohnenberger's invention of the gyro with cardanic suspension in 1810 and the subsequent work of J.B.L. Foucault on gyroscopes four decades later, the theory of the gyro became a classic area of physics during the 19th century. First technical applications followed at the beginning of the 20th century [3]. German scientists like F. Klein, A. Sommerfeld, and M. Schuler from the University of Göttingen and R. Grammel from the today's University of Stuttgart as well as German enterprisers like H. Anschütz-Kaempfe and W. v. Siemens were closely involved in this process. Later, in Germany a world's leading industry developed for the gyro compass and for flight control instruments.

The end of the Second World War meant also the end for most of these German activities. Nevertheless, the restitution of an orderly political situation in Germany during the following years gave the possibility to tie in with the rich tradition of gyro technology. Against this background and due to a DGON information event on inertial navigation with more than 400 participants in January 1965 [4], F. Matezky and P. Christoph from the DHI suggested a commission of experts to promote the exchange of experience between gyro specialists of the post-war generation in the middle of the 1960s. After the approval of this proposal by the DGON, G. Zwiebler, who graduated from the Technical University of Berlin and was specialized in applied physics as well as in nautics, tried to find possible fellows for this commission. Among them was Kurt Magnus, the leading German scientist in gyro technology, who was already integrated again in the international gyro research community at that time [5]. As a physicist, he was a former PhD student of M. Schuler, was deported as a rocket specialist to the Soviet Union between 1946 and 1953, and succeeded R. Grammel as professor for mechanics at the today's University of Stuttgart in 1958. Furthermore, G. Zwiebler contacted in Western Germany research groups of mine surveying, technical offices of the public administration, several traditional companies like Anschütz (Kiel), C. Plath (Hamburg), and Bodenseewerk (a subsidiary of the former Askania-Werke in Überlingen) as well as the new enterprises Litton (Freiburg) and Teldix (Heidelberg), which were founded with the involvement of companies from USA. Based on these preparations, the first meeting of the "Fachausschuss 8" could start as described in Section 1.

Looking at Annex A, which lists the first symposium and all the following conferences until today, three development phases of that series can be distinguished:

A Initial segment, 1965 - 1971,
B Consolidation segment, 1972 - 1978,
C Steady segment, since 1979.

The symposia of the initial segment had mostly special mottos like "gyro compass developments" (1^{st} meeting), "gyros for surveying" (3^{rd} meeting) or "inertial platforms" (5^{th} meeting). All papers were invited, and they were accompanied by a tour through the laboratories, fabrication facilities etc. of the symposium host, which changed from meeting to meeting. The number of attendees and presentations was roughly constant, and the number of participating nations increased (already two of six papers of the 1^{st} meeting were non-German contributions); see Fig. 1 to 3, the numbers of 1970 and 1971 are partially missing. Furthermore, it turned out that one meeting per year was the right measure for exchanging experience while upholding the quality of the papers and discussions.

The transition to the consolidation segment had several reasons. Firstly, the DGON changed their organizational structure leading to the replacement of the "Fachausschuss 8" by a small subcommittee of the main scientific board of the DGON. Secondly, the scientific group around K. Magnus, who took the symposium chair at the 4^{th} meeting and who joined the Technical University of Munich in 1966, turned to new subjects of applied me-

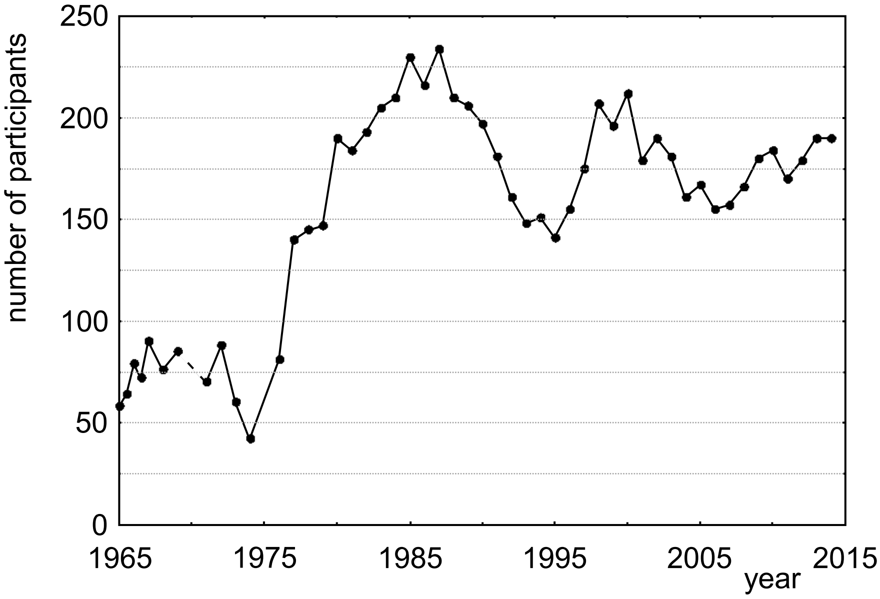

Figure 1. Number of symposium participants.

chanics like multibody dynamics, whereas optics and electronics became more and more important for inertial navigation. Thirdly and most important, the business of gyro technology in Germany became increasingly international. Against this background, the DGON intensely strived for the future orientation of the symposium in 1971.

It is the merit of Helmut Sorg, a former PhD student of K. Magnus at the University of Stuttgart and being specialized in electrical and mechanical engineering, that this crisis could be overcome. He took the chair after the symposium of 1971 and introduced still existing organizational measures to meet the altered conditions and to stabilize the meeting organization. The first three actions were

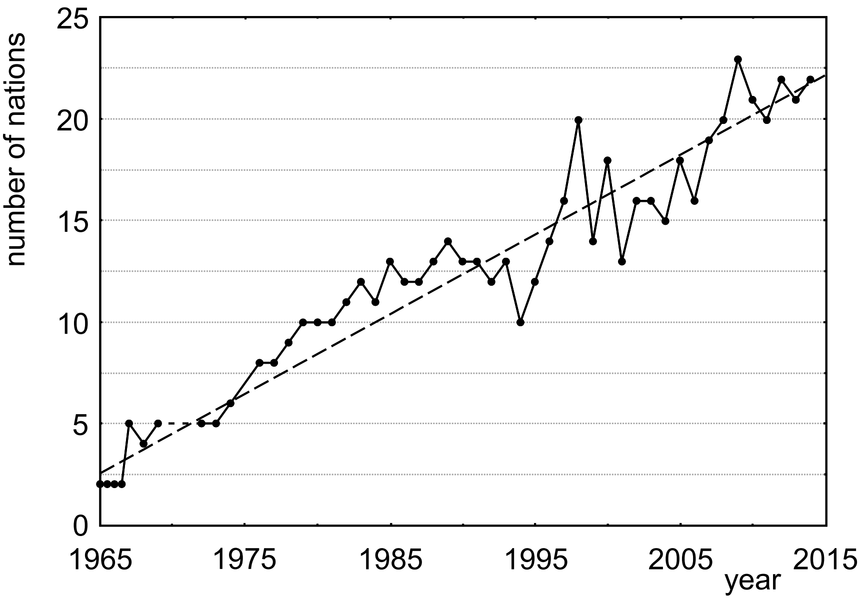

Figure 2. Number of participating nations with trend line.

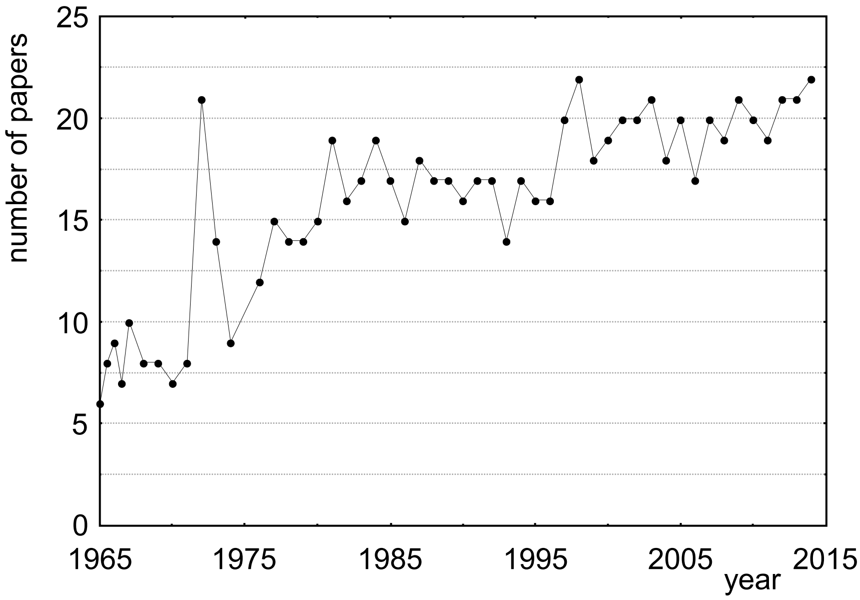

Figure 3. Number of papers presented.

- establishing a program committee,
- preparing the conferences by a public “Call for Papers”,
- admitting English papers.

The symposium of 1972 with 80 participants including from the USA and an escalating number of 21 presentations (Fig. 3) demonstrated the success of these changes. Nevertheless, the crisis was not over, the numbers of participants and papers decreased again, and the year 1975 had no meeting at all. Subsequently, H. Sorg established English as the only conference language, the Institute A for Mechanics at the University of Stuttgart, where he was meanwhile Professor for gyro and inertial technology, gradually took over the management of the conferences. Finally, the meetings took always place at the University of Stuttgart in September. This was the beginning of the third, the steady segment of the conferences, being characterized by a strongly rising number of attendees up to more than 200 (Fig. 1). In addition, the increase of internationality continued, and it is remarkable that this tendency remains unabated until today (Fig. 2).

2.2. Political and Other Changes

Since 1979, the organizational conditions of the conferences are practically constant. This opens the possibility to analyze how the meetings reacted to other circumstances like global politics and technical advances.

The 1970s and the 1980s were the last decades of the Cold War. Accordingly, the conferences at that time were characterized by high precision sensors and systems, which often had a military background. Accordingly, the attendees of these meetings came mostly from member states of the NATO. The political changes of the late 1980s, however, led to significant changes. H. Sorg realized immediately that the important gyro community in Eastern Europe was now able to attend the symposium. Forethoughtfully he invited not only scientists from these countries but also he provided facilitations of travel thus making it possible for them to quickly attend the conferences. From 1991, participants from the former Warsaw Pact participated in the meetings and thus made them truly international events.

In addition to Fig. 2, Table 1 exemplifies this aspect. Based on the records of participants being still retained for many years, it lists for selected conferences with large attendance the percentage of different nations with respect to the number of participants. The table illustrates the increasing importance of smaller countries (the most significant smaller nations are Sweden and Switzerland, which were already present at the meetings of the 1960s), whereas two traditional nations, United Kingdom and USA, currently play a minor part. France and Germany, however, maintained more or less their position.

Table 2 shows another aspect of the change from more military to more civil applications. Before the end of the cold war the part of attendees from industry (mainly big manufacturers) was continuously very high. Meanwhile universities and research institutions became again as important as during the initial segment (also with a surprisingly constant level). In addition, the number of small and medium enterprises increased, which may be an effect probably due to the availability of especially cheap MEMS gyros. On the other hand, user groups from airlines, military, and public authorities, which all have initiated the establishment of the symposium, form meanwhile only a very small group of attendees.

Figure 1 contains also interesting details for these decades. The highest numbers of participants arise just before the end of the cold war. They are followed by a deep drop, but the increasing internationality and the accumulated demand of exchange with the countries from Eastern Europe could compensate this effect in the middle of the 1990s. A second, less significant drop is visible at the beginning of the 2000s and coincides with the collapse of the Dot-com Bubble, which seems a plausible explanation due to the increased importance of civil applications and smaller enterprises. Meanwhile the number of participants seems to have recovered.

The stability of the series of conferences after 1979 appears also by the fact that the intermediate immense changes from mechanical systems to optical gyros, MEMS gyros, and electronics could be covered. This aspect is analyzed in more detail in Section 3.

Table 1. Nationalities with particular high attendance; percentages for selected years.

Military alliance, country	1967	1979	1989	2000	2009
NATO (of 1991)	97	95	89	69	70
France	2	8	12	8	16
Germany	93	63	54	46	40
UK	2	12	11	6	4
USA	0	10	7	6	2
Warsaw Pact (of 1991)	0	0	0	13	8
Russia	0	0	0	8	6
Other countries	3	5	11	18	28

Table 2. Profession of the attendees; percentages for selected years.

Profession	1967	1979	1989	2000	2009
Industry	60	79	80	68	68
Research	27	13	12	29	29
Users (airlines, military, …)	13	8	8	3	3

In 2007, Helmut Sorg passed, on account of his age, the chair of the symposium on to Gert Trommer, a professor of electrical engineering at the University of Karlsruhe, a very experienced engineer in industrial developments, and a participant at the conferences for many years. This change and the relocation to Karlsruhe proceeded very smoothly, and the success of the symposium seamlessly continued as Fig. 1 to 3 show. The conferences seem to have not been adversely influenced from the move and G. Trommer did a great job continuing on the tradition set by his predecessor.

Table 3 lists all the symposium and program committee chairmen up to now. Also, it should be mentioned that in total 23 persons, engineers and physicists, supported the

Table 3: Chairs of the symposium and the program committee.

Symposium chair		Program committee chair	
Gerhard Zwiebler	1965 - 1966	Manfred Pütz	1972 - 1995
Kurt Magnus	1966 - 1971	Walter Bernard	1996 - 2014
Helmut W. Sorg	1972 - 2006	Steffen Zimmermann	since 2015
Gert F. Trommer	since 2007		

conferences as symposium chairman, as its deputy or as member of the program committee (cf. Annex B), some of them for a very long time: H. Sorg (34 years), B. Stieler (33 years), W. Auch (28 years), M. Pütz and J. Steinwand (23 years), W. Bernard (18 years).

2.3. The Proceedings

Especially at the beginning, the DGON documented all conferences very carefully. The first meetings got detailed minutes, where even the technical discussions can be found. The presentations were recorded as a bundle of papers being attached to the minutes. These articles were distributed among the participants but not delivered to libraries. Nevertheless, some of them were selected for publication in the DGON quarterly “Ortung und Navigation” (see Annex A). In 1971, all papers together formed a special issue of this journal. One year later, special proceedings (with two volumes) were issued for the first time. In 1973, the DGON returned to the prior procedure (the reason for that is unknown); and from 1974 on, regular proceedings exist for all conferences. Some of them have special dedications to honor contributors to gyro technology.

During the last months, the authors were able to collect all papers of the symposium. This could be done based on the library stock of the former institute of H. Sorg, the institute of G. Trommer, and the support of the DGON. In case it is possible to resolve copyright matters, an anniversary edition of this material could be issued as a digital jubilee edition. The papers add up to more than 800 articles and form a unique archive of five decades of gyro and inertial development. The next section gives some insight in these documents.

3. Developments, Changes, and Trends of Inertial Technology

3.1. Technology Survey based on the proceedings

As mentioned in the previous section the initial symposia had mostly special themes for each meeting, selected by the conference organizers. All of the papers presented were invited. By the second decade (1970s) the papers seem to represent a variety of new ideas, technologies, and applications forming a hallmark of future conferences.

To get a slightly more organized and easier understanding of the developments, changes, and trends in the inertial technology as seen through these conferences, a survey at these topics one decade at a time is given (cf. also [6]):

The 1960s

Not surprisingly the gyros described in this decade were mechanical spinning wheel gyros, and many of the papers dealt with various gimbaled platforms. There were many civil engineering applications, and naturally stability of north seeking gyros was of great interest. It is fascinating to note that at this time it was thought that the naval environment was the most demanding – requiring 0.001 deg/h accuracy, followed by air and space – 0.01 deg/h, and followed by rockets requiring 0.1 to 0.01 deg/h. As the gyros discussed were mechanical devices, a great deal of research was reported on the various type of gas and ball bearings as this had a very strong influence on gyro performance and lifetime. Nevertheless, during the second conference and long before MEMS became customary inertial sensors, a paper was presented by H. Sorg, which contained basics about vibrating gyroscopes. Before the end of this decade and a few months before men walked on the moon, it was characteristically again H. Sorg, who presented a survey on two centuries of Gyro development. He described the origin of his fascination with gyros, described the origins of the directional gyro, the rate gyro, and the use of gyros in an artificial horizon. He quotes papers as far back as 1754 and points out that in a paper published in 1852 Foucault conceived the word gyroscope. He also pointed out that the early development of the gyroscope was characterized by the development of the artificial horizon and the gyrocompass for the navigation of ships. He graciously concludes his paper paying tribute to the development of the highest precision gyroscope at the time by Prof. Draper of the MIT Instrumentation Laboratory.

The 1970s

In the early 1970s the proceedings show the first mention of a strap-down system implementation as well as the use of thermal modeling and the implementation of Kalman filters. Systems were getting smaller and more efficient - from 45 kg and 1500 W in the 1960s to 18 kg and 500 W. The Mean Time Between Failures (MTBF) was increasing from 50 h to 100 h. A great deal of discussion continued on the merits of various types of bearings, and the first mention of 2 degree of freedom DTGs appears. With the participation of scientists from outside West Germany (BRD) there were even mention, discussion, and apprehension of competition (for precision mechanical gyroscopes) coming from foreign companies. During this time the proceedings contain the first paper on inertial grade accelerometers occurring simultaneously when the conference had presentations in both German and English. At the end of this decade (1979) the proceedings contain the first paper on Ring Laser Gyros (RLG) – about 14 years after the first experimental RLG was demonstrated in 1963. RLGs due to various qualities such as a true digital output were viewed by many presenters as the ideal gyro for strap-down inertial systems.

The 1980s

At the start of this decade the proceedings contain the first paper on the FOG – about 5 years after this gyroscope was demonstrated for the first time in 1975. (For comparison: 14 years was the time length between the demonstrations of the first RLG and the first paper on the topic at this conference.) Papers on RLGs, FOGs, and mechanical spinning wheel gyroscopes competed for attention in the conference during this decade. RLGs of various designs were proposed with ever improving performance and a variety of biasing mechanisms. There were papers proposing optical gyroscopes capable of measuring a 10^{-10}-fold of earth rate as well as the first mention of Nuclear Magnetic Gyroscopes (NMR). During this time, the proceedings contain various types of integrated, waveguide optic gyroscopes proposed to overcome the high price of optical fiber. In the middle of this decade, systems using the Global Positioning System (GPS) were mentioned as a means of aiding an inertial system. The papers contain a more frequent mention of Kalman filters as well as more and more emphasis on the software in various inertial navigation systems, the importance of software development, including verification as well as flight safety critical equipment. In addition, with the desire for greater reliability and due to lower sensor costs there were papers presented on various types of redundant systems with multiple (greater than 3) sensitive axis. At the end of this decade some contributions describe RLG based inertial navigation systems in production, implemented with Kalman filters running many states.

The 1990s

This decade was characterized by a bountiful number of papers on different gyro designs; and the proceedings contain the first papers on GPS/INS coupled designs. In addition, there were presentations of integrating inertial systems with both GPS and GLONASS – sometimes in the same system. On the systems side fault tolerant, highly reliable, “hard” systems with increasing emphasis on longer MTBF were mentioned. Predictions of sensor prices were low enough that the first papers appeared suggesting the use of inertial sensors in various type of Automated Guided Vehicles (AVGs). In 1991, there was the first paper that described the progress on inertial sensors based on the development of MEMS. Appropriately enough this first MEMS paper was presented by an engineer from Draper Laboratory, Cambridge, MA, USA, one of the pioneers in the development of the highest accuracy mechanical spinning wheel gyroscopes for various strategic applications. The paper predicted an Inertial Measurement Unit (IMU) of 2 cm^3 weighing 5 grams with a drift uncertainty of 10 deg/h or better, for short term navigation. The cost of such an IMU was projected to be $ 500 in quantities of 10,000 units and a price of less than $ 10 in quantities of 20 million units/year.

Early in this decade a paper was presented describing an IMU (named HD909) based on the Honeywell 1308 RLG. Productions of these IMUs started 3 years later in 1995 (named HG1700). In the following 20 years over 300,000 of these IMUs have been manufactured making this perhaps the highest volume tactical RLG based IMU ever produced. In parallel, several papers compared FOGs (the favored gyro of that decade) vs. RLGs (the favored gyro of the past decade) vs. DTGs (the favored gyros before RLGs) indicating that the choice was not obvious and each gyro had certain advantages.

Also early in this decade there was a presentation of the IEEE Gyro and Accelerometer Panel that had certain success in standardizing some of the nomenclature and testing methodology of inertial sensors. The meetings also started to have several presentations, virtually every year, on various resonating and vibrating gyroscopes (VIB) with hemispherical and tuning fork shapes. One such gyro named the Quapason using four quartz tines was quite successful in subsequent products. The proceedings also contain yet another proposal for a low cost autonomous navigation system in automotive vehicles.

The 2000s

The new century started with a rather large number of papers on various improvements to the performance, operation, and applications of FOGs as well as several papers on various GPS/INS integrated systems many based on FOG technology. More and more papers described tightly integrated GPS/INS configurations with FOGs and MEMS sensors.

This was also the decade when for the first time FOGs were qualified for use in space as well as submarine applications. It was also the time when symposium participants were reminded about how reliable Hemispherical Resonator Gyros (HRG) were in the difficult space like environment. Enthusiastic FOG scientists also tried to convince conference participants that Murphy’s Law does not apply to FOGs. Despite the large number of optical gyro technologies available, DTGs were still the preferred technology for use in Oil and Gas Exploration applications. There was also an update on the status of very large RLGs demonstrating performance about 4 orders of magnitude better than navigation grade instruments. MEMS based gyros were finding their way in automotive applications, and novel schemes were suggested for self-calibration of these gyros to greatly improve performance. In the middle of this decade there were also several papers presented on producing 3 orthogonal MEMS based gyros on a single chip raising the possibility of a truly low cost MEMS based IMU.

Furthermore, there were a couple of papers that summarized the marvelous past 100 years of gyro development at Anschütz as well as the long and spectacular history of the gyrocompass in marine applications. As more and more types of gyros were available and different nomenclature was used to describe the performance of MEMS gyros, the symposium participants were urged and reminded to use Allan variance characteristics in comparing and describing various inertial sensors.

Finally, it was in this decade when the first papers appeared describing various non GPS aiding of navigation systems as well as various tightly integrated GPS/INS systems and estimated performance results for use during GPS outages or in GPS denied environments.

The 2010s

This decade started with a historical presentation of the work of Johann Gottlieb Bohnenberger, the inventor of a “machine” (instrument) that is considered to be the first gyro with cardanic suspension and that formed the precursor of Foucault’s Gyroscope of 1852. This was then followed by a paper on the Gravity Probe B (GP-B) mission that showed a 4 order of magnitude superior sensitivity compared to the best, earth based, electrostatic gyro (10^{-5} deg/h). The GP-B was the first experiment designed to directly measure gravitational relativity as the main measurement effect.

At this first meeting of the decade the conference also started with a presentation about the ability of resolving rotation rates as small as 1 picoradians per second (with an integration time of less than 2 hours) using a large RLG instrument and concluded with a paper on measuring Earth’s rotation rate with a low cost MEMS gyroscope. In between these two presentations the contributions addressed a lot on novel MEMS based IMUs as well as described either novel or miniature FOG based systems.

The papers of subsequent conferences contain a number of applications describing MEMS based IMUs for pedestrian navigation and north-finding applications where a GPS signal cannot be assured. MEMS based inertial sensors of increasing higher accuracy were clearly becoming more readily available at low prices resulting in the presentation of a paper describing the commercial and military market of high performance, low cost inertial MEMS sensors and systems. FOGs continued to make great progress in improving performance and expanding their application. The attendees were fortunate to hear a seminal presentation by Herve Lefevre (perhaps the “uncle” of the FOG) on “The History of the Sagnac Effect”, a paper establishing critical “on orbit” heritage of FOG based satellite system and a paper describing FOG based systems for marine applications showing remarkable performance-approaching of 1 nm/month.

3.2. Different gyro types over the decades

The authors thought it would be interesting to look at the various gyro types described and mentioned in the papers presented during the past 50 years. As it is well known, the papers at this conference have been selected by an expert group appointed by the organizers. Thus, the type of gyros, navigation systems, and topics of interest are naturally influenced by this assessment process and committee. Due to the range of paper submissions as reflected by the composition of the symposium participants, there is nevertheless a strong correlation between the topics of the presentations, the type of gyros addressed, and the observed trends in this scientific field to provide a meaningful viewpoint. In Figure 4 the authors attempted to represent the different types of gyros as they have been discussed in the various presentations over the past 50 years. It was difficult to precisely categorize each presentation; so it was decided that if a system was described with one or two specific type of gyros it was considered for the diagram, however, if the presentation was simply one comparing many different gyro types like a survey paper it was not counted for this survey. In addition, the authors also considered in more detail the fractions of presentations mentioning four of the most recent gyro types namely RLGs, FOGs, HRGs/VIBs, and MEMS to see if a trend is visible (Figures 5 to 8). Looking at Figure 5, it appears that RLGs have passed the maturity phase and the paper rate is in decline. The dashed trend line is a Gaussian distribution plus a constant. It was chosen due to the fact

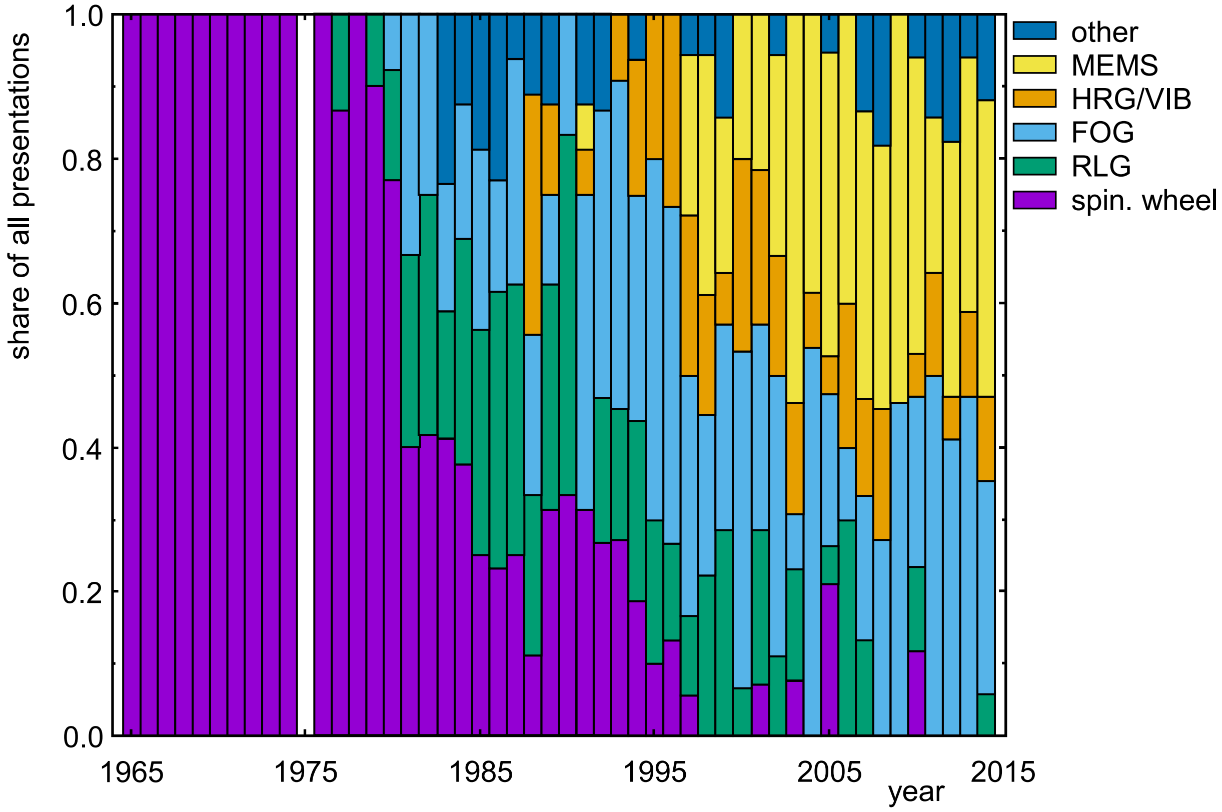

Figure 4. Different types of gyros as presented from 1965 through 2014.

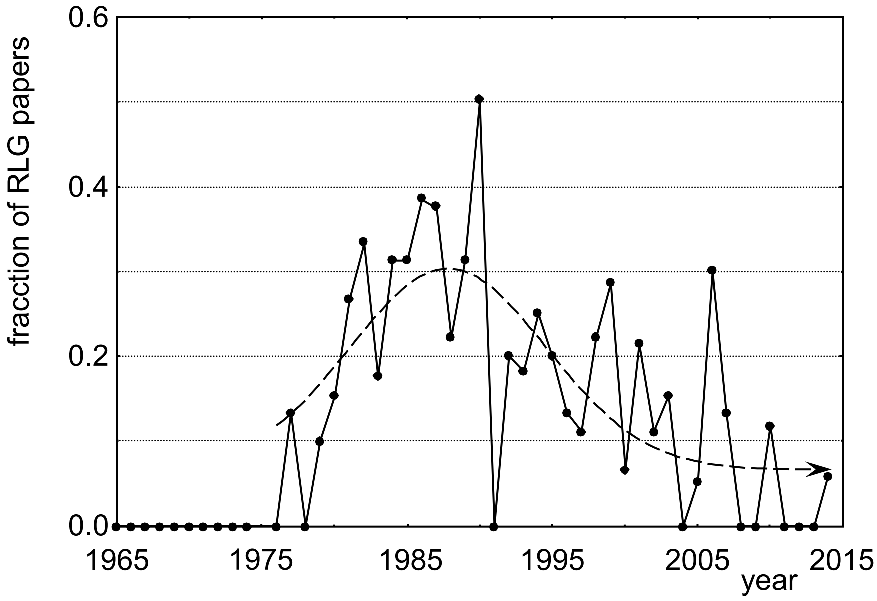

Figure 5. Frequency of presentations on RLGs from 1965 through 2014.

that the process of development and bringing onto the market RLGs is well advanced. Figure 6 representing the frequency of presentation of FOGs at all conferences seems to suggest that this technology has just reached maturity. The type of the trend line is the same like for RLGs. Figure 7 contain the same statistics for the HRGs/VIBs. An unambiguous trend is not visible. Finally looking at Figure 8 with the frequency of MEMS based presentations, it appears that this technology is in a rapid growth phase having not yet reached it technical limits. Therefore, just a straight line was used for the trend during the last years. (Remark: The trend lines were calculated using only those years beginning with the first presentation of the respective gyro type.)

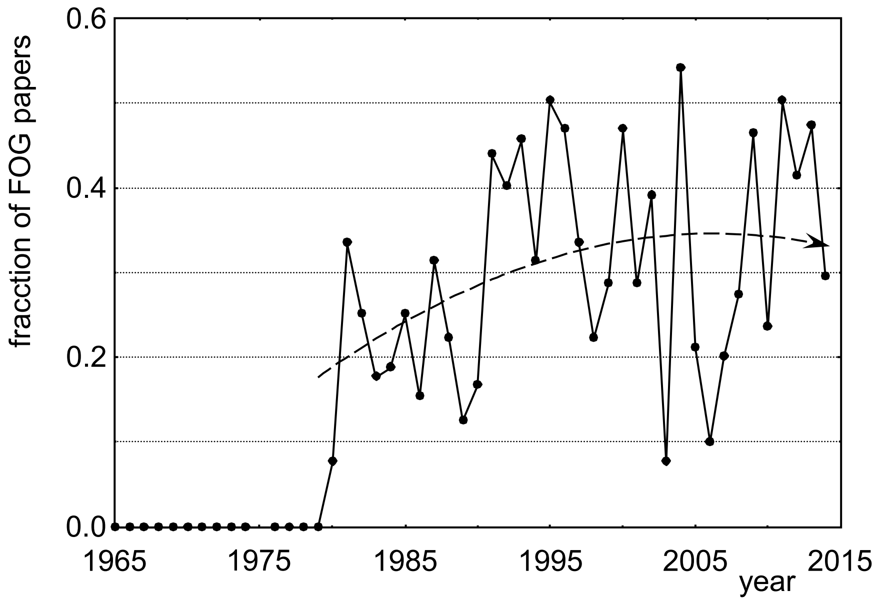

Figure 6. Frequency of presentations on FOGs from 1965 through 2014.

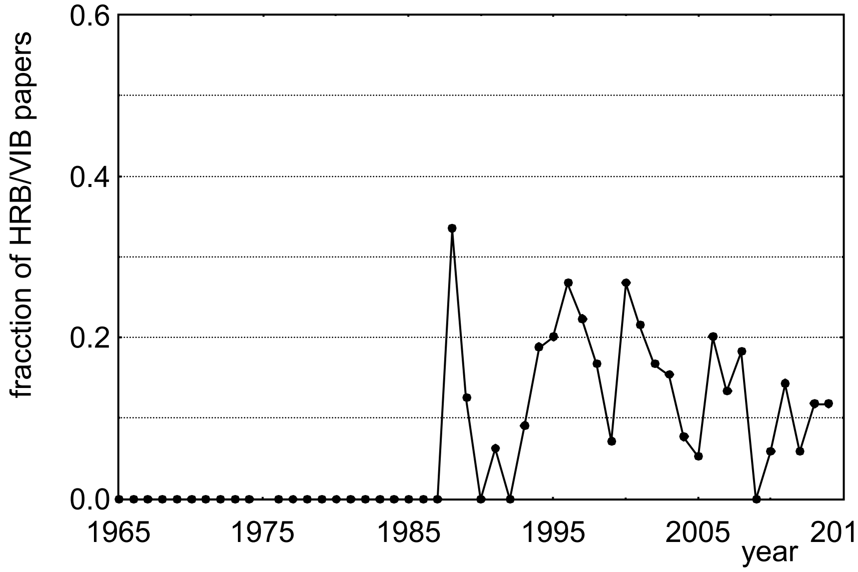

Figure 7. Frequency of presentations on HRGs/VIBs from 1965 through 2014.

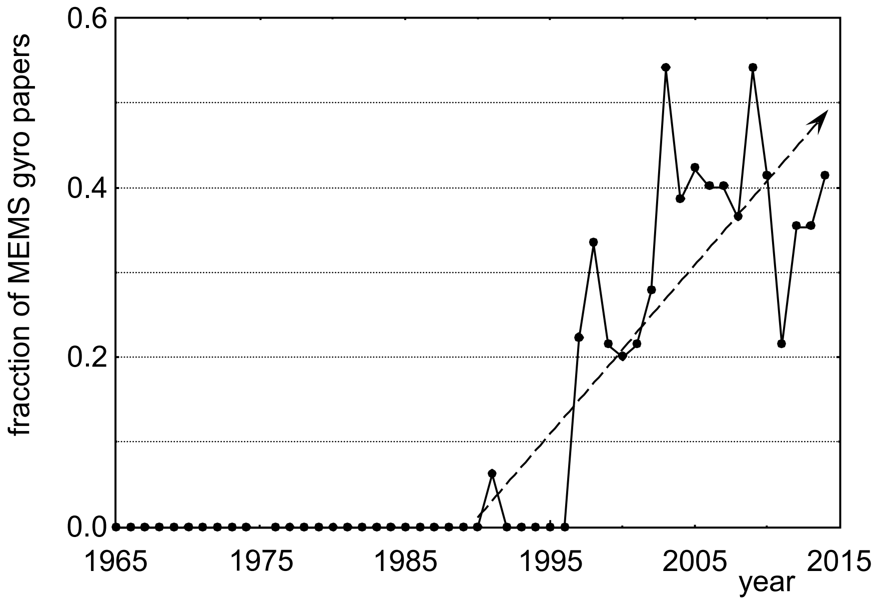

Figure 8. Frequency of presentations on MEMS gyros from 1965 through 2014.

4. Another 50 years?

"There is someone who should be singled out for his success in promulgating the international dissemination of the lore of inertial technology. That man is Dr. Helmut Sorg of the University of Stuttgart, Germany. Every year, for about 20 years, he organized the 'Symposium Gyro Technology' for the Deutsche Gesellschaft für Ortung und Navigation […], collecting papers (in English) into proceedings that are invaluable for the study of the field. I have referred to them liberally, and I recommend them to you."

With these words in his book on inertial technology [7], A. Lawrence draws a respectful balance of the first decades of the symposium in 1993, which should only be complemented by mentioning the former organization team of H. Sorg in Stuttgart as well as now G. Trommer and his team in Karlsruhe. Considering the years since the 1990s, it can be said that the character, the organization framework, and the technological return seems to be unchanged. Recorded by a continuously increasing library of proceedings, the conferences still mirror worldwide advancements and applications of inertial sensors and systems. Promoted by a traditionally face-to-face and familiar atmosphere, the meetings enable furthermore an easy networking and scientific exchange between the participants. It remains to be hoped that many successful conferences will follow in future.

Acknowledgments

The authors would like to thank several persons for their support in obtaining the necessary information about the symposium: Prof. H. Sorg, Dr. J. Steinwand, and H. Hummel (University of Stuttgart), Mrs. G. Lange (DGON, Bonn), Dr. W. Bernard (Diehl BGT Defence, Überlingen), Prof. F. Pfeiffer and Mrs. R. Schneider (Technische Universität München), Prof. G. Schweitzer (ETH Zurich), Dr. U. Mangold (Raytheon-Anschütz, Kiel), and D. Machoczek (Federal Maritime and Hydrographic Agency, Hamburg).

References

[1] Archives of the Symposium Gyro Technology, Archive of the University of Stuttgart, Sig. 201

[2] Collection of all papers from 1965 to 2014; addendum to the Archives of the Symposium Gyro Technology, Archive of the University of Stuttgart, Sig. 201

[3] J. Broelmann, “Intuition und Wissenschaft in der Kreiseltechnik”, Deutsches Museum, München, 2002

[4] K. Müller, “DGON-Kolloquium über Trägheitsnavigation am 15. Jan. 1965 in Düsseldorf”, in Ortung und Navigation 1965, Nr. 3, pp. 74 - 75

[5] H. Ziegler (ed.), “Gyrodynamics, Symposium Celerina, August 20 - 23, 1962”, Springer, Berlin et al., 1963

[6] E.T. Benser, “Trends in Inertial Sensors and Applications” in 2015 Int. Symp. on Inertial Sensors and Systems Proceedings, IEEE, Piscataway, NJ: 2015, pp. 1 - 4

[7] A. Lawrence, “Modern inertial technology”, Springer, New York et al., 1993

Annex A: List of all symposia

Year	Date	Local organizer, venue	Remarks
1965	June, 1 - 2	DHI, Hamburg	1st meeting of the “DGON-Fachausschuss 8”, proceedings were firstly an appendix to the minutes of the meeting, 2 papers published in the in the DGON journal *Ortung und Navigation* IV/65
	October, 19 - 20	Univ. of Stuttgart	1 paper published in *Ortung und Navigation* IV/65
1966	March, 29 - 30	Westfälische Berggewerk-schaftskasse, Bochum	1 paper published in *Ortung und Navigation* II/66
	October, 3 - 4	Teldix, Heidelberg	1 paper published in *Ortung und Navigation* I/67
1967	April, 18 - 19	Bodenseewerk, Überlingen	3 papers published in *Ortung und Navigation* III/67
1968	May, 16 - 17	Litton, Freiburg	3 papers published in *Ortung und Navigation* III/68
1969	March, 20	Techn. Univ. of Munich	3 papers published in *Ortung und Navigation* III/69
1970	February, 19 - 20	Techn. Univ. of Clausthal-Zellerfeld	8th and formally last meeting of the “DGON-Fachausschuss 8”
1971	May, 27 - 28	Anschütz, Kiel	Name changed to “Symposium über Kreiseltechnik”, all papers published in *Ortung und Navigation* III/71
1972	April, 12 - 14	Bodenseewerk, Überlingen	First papers in English, first regular proceedings, attendees from outside Europe
1973	April, 25 - 27	Westfälische Berggewerk-schaftskasse, Bochum	10 papers published in *Ortung und Navigation* II/73 and IV/73, 4 papers were only available as handouts
1974	April, 25 - 26	Teldix, Heidelberg	From now on regular proceedings
1975	(Autumn)	(Litton, Freiburg)	Symposium was cancelled
1976	March, 31 - April, 1	Techn. Univ. of Braunschweig	
1977	September, 28 - 29	Univ. of Stuttgart	All presentations in English, September is now symposium time frame, Institute A for Mechanics, Univ. of Stuttgart becomes co-organizer
1978	September, 18 - 19	Westfälische Berggewerk-schaftskasse, Bochum	Probably first attendees from Asia
1979	September, 25 - 26	Univ. of Stuttgart	Name changed to “Symposium Gyro Technology”, English is now conference language, in commemoration of Johannes Gievers
1980	September, 24 - 25	Univ. of Stuttgart	
1981	September, 23 - 24	Univ. of Stuttgart	Institute A for Mechanics, Univ. of Stuttgart becomes main organizer
1982	September, 15 - 16	Univ. of Stuttgart	Dedication: 70th Birthday of Kurt Magnus
1983	September, 14 - 15	Univ. of Stuttgart	
1984	September, 11 - 12	Univ. of Stuttgart	
1985	September, 24 - 25	Univ. of Stuttgart	

1986	September, 23 - 24	Univ. of Stuttgart	
1987	September, 22 - 23	Univ. of Stuttgart	In commemoration of Charles Stark Draper
1988	September, 20 - 21	Univ. of Stuttgart	
1989	September, 19 - 20	Univ. of Stuttgart	
1990	September, 25 - 26	Univ. of Stuttgart	In commemoration of Walter Wrigley
1991	September, 24 - 25	Univ. of Stuttgart	First attendees from the former Warsaw Pact
1992	September, 22 - 23	Univ. of Stuttgart	Increasing number of papers on civil applications of inertial systems
1993	September, 21 - 22	Univ. of Stuttgart	Decreasing number of attendees with military background
1994	September, 20 - 21	Univ. of Stuttgart	
1995	September, 19 - 20	Univ. of Stuttgart	Dedication: Manfred Pütz and Rainer Sindlinger
1996	September, 17 - 18	Univ. of Stuttgart	
1997	September, 16 -17	Univ. of Stuttgart	
1998	September, 15 - 16	Univ. of Stuttgart	
1999	September, 14 - 15	Univ. of Stuttgart	
2000	September, 19 - 20	Univ. of Stuttgart	
2001	September, 18 - 19	Univ. of Stuttgart	
2002	September, 17 - 18	Univ. of Stuttgart	Dedication: 90^{th} Birthday of Kurt Magnus
2003	September, 16 - 17	Univ. of Stuttgart	
2004	September, 21 - 22	Univ. of Stuttgart	
2005	September, 20 - 21	Univ. of Stuttgart	
2006	September, 19 -20	Univ. of Stuttgart	
2007	September, 18 - 19	Univ. of Karlsruhe	Institute of Systems Optimization, Univ. of Karlsruhe becomes main organizer
2008	September, 16 - 17	Univ. of Karlsruhe	
2009	September, 22 - 23	Univ. of Karlsruhe	
2010	September, 21 - 22	Karlsruhe Inst. of Techn.	Dedication: 200 years of gimbal mounted gyroscopes
2011	September, 20 - 21	Karlsruhe Inst. of Techn.	Name changed to “Inertial Sensors and Systems”
2012	September, 18 - 19	Karlsruhe Inst. of Techn.	Dedication: 100^{th} Birthday of Kurt Magnus
2013	September, 17 - 18	Karlsruhe Inst. of Techn.	Dedication: 100 years of the Sagnac effect
2014	September, 16 - 17	Karlsruhe Inst. of Techn.	
2015	September, 22 - 23	Karlsruhe Inst. of Techn.	

Annex B: Persons

Symposium chairs, co-chairs (until 1971) and members of the program committee: W. Auch, W. Bernard, P. Christoph, E. Fischl, W. Geiger, E. v. Hinüber, T. Löffler, K. Magnus, F. Matezky, U. Henke, M. Pütz, K. Schlichting, G. Schweitzer, R. Sindlinger, H. Sorg, J. Steinwand, B. Stieler, K.H. Stier, G. Trommer, J. Wagner, D. Wick, S. Zimmermann, G. Zwiebler.