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Participation by Research and Industry

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Preface

These notes are prepared to give an impression of considerations and activities in Denmark related to ESRO and ESA, roughly in the period 1964 to 1990. In a number of chapters we consider early space-related research in Denmark, the initial phase of the ESRO era and the following period, including the phase of transition from ESRO to ESA when Denmark seriously considered leaving the space co-operation. A chapter gives examples of activities in the ESA era within space science and astronomy, Earth Observation and microgravity, followed by a final one dealing with the national management of optional programmes and the involvement by industry.

In drafting the notes we have taken advantage of the work carried out in the Introductory Studies[1] carried out to secure and place in order the archives of the Danish Space Research Advisory Committee. In this connection excerpts of individual documents (mostly minutes of meetings, letters and reports) were taken. To a great extent they form the basis for many of the points made in the notes.

1 Mackintosh, J. and P. Gudmandsen, Danish History Project, Introductory Studies, Final Report, June 2001, 44 pp. Ministry for Science, Technology and development, Copenhagen. This work was supported by a grant from the ESA History Extension Project.

Contents

1 Early Space-related Research

The launch of the Danish microsatellite Ørsted on 23 February 1999 to measure the Earth's magnetic field may be regarded as the culmination of a long series of investigations that began in 1842 with the monitoring of the Earth's magnetic field on one of the bastions of the fortification of Copenhagen.[2] This activity was suggested by Hans Christian Ørsted, the discoverer of electromagnetism in 1820. It lasted only for twenty years, but was resumed by the Danish Meteorological Institute in 1891 and is maintained since then except for a brief interval in the period 1901 – 06. With its participation in the International Polar Year, 1882 – 83, the institute established a geophysical observatory in Godthåb (Nuuk), Greenland, followed by the establishment of a permanent observatory in 1926 in Godhavn (Qeqertarsuaq), Greenland, with continuous monitoring of the Earth's magnetic field.

In a way the satellite Ørsted also represents another continuation of traditions at the Danish Meteorological Institute. Since 1889 work has been carried out to improve the accuracy of the measurement of the magnetic field (Vilhelm Hjort and Adam Poulsen). Construction of improved and new magnetometers was undertaken (Dan Barfoed la Cour and Viggo Laursen) and later exploited in a number of observatories during the International Polar Year (1932/33) and the International Geophysical Year (1957/58) including the observatories in Greenland (Godhavn, Thule and Julianehåb (Qaqortoq)).[3] The tradition was revived in recent years at the Danish Meteorological Institute and the Danish Space Research Institute, leading to construction of magnetometers for rocket and satellite measurements. This work formed the basis for the instruments onboard the Ørsted satellite.

Other research related to the magnetosphere of the Earth involved studies of the *aurora borealis* and the ionosphere. The first scientific record of an aurora was made in the late 16th century by the Danish astronomer Tycho Brahe who studied the sky from his observatory on the island of Hven in Øresund.[4] Systematic observations over several years were carried out by the Danish vicar in Godthåb (Andreas Ginge) and published in 1788 by the Royal Danish Academy of Sciences and Letters.[5] He showed that aurorae are associated with magnetic disturbances and that they depend on the time of the night. Later observations were made from the same locality in the period 1865 – 1882 (Samuel Kleinschmidt) and in the period 1882 – 1883 (Adam Poulsen) which led to the understanding of the formation of aurorae as electrons that react with the upper atmosphere (Adam Poulsen, 1894). The tradition was followed by other intensive studies in Greenland during the Second Polar Year (1932/33), (Johannes Olsen), in the period 1952 – 1956 (Knud Lassen), during the International Geophysical Year (1957/58) and again in the International Quiet Sun Year (1964/65).

Ionospheric research was initiated in 1951 by the Danish National Committee of the *Union Radio Scientifique Internationale* (URSI) by the establishment of an ionosonde in Godhavn. It is a ground-based vertically directed radar covering a wide range of frequencies with radio wave reflections from the ionosphere dependent upon the electron concentration. This work may be regarded as a follow on to theoretical work on radio wave propagation in the ionosphere by P.O. Pedersen[6], Professor at the Polytechnical College in Copenhagen.[7] It was initiated by his assistant, (and successor) Professor Jørgen Rybner, Chairman of the Committee and led to the establishment of the Ionosphere Laboratory at the Technical University of Denmark. Stations were later established in Narssarssuaq, South Greenland (in 1957) and Thule, Northwest Greenland (in 1966), so that simultaneous observations could be made in the auroral oval (midnight and midday sectors) and in the central Polar Cap. A result of these long term

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2 "Meteorologisk Institut gennem hundrede år, 1872-1972" (Meteorological Institute through one hundred years), Copenhagen 1972, pp. 269-309.

3 *ibidem*. pp. 311-316.

4 *ibidem*. pp. 199-224.

5 Det Kongelige Danske Videnskabernes Selskab, Copenhagen, founded in 1742,

6 P.O. Pedersen, 1927. "The propagation of radio waves along the surface of the earth and in the atmosphere", Danmarks Naturvidenskabelige Samfund, Copenhagen.

7 The College of Advanced Technology was founded in 1829 by Hans Christian Ørsted. Later it was renamed Technical University of Denmark.

measurements was the discovery of the so-called Slant-E feature, a scatter trace in ionograms caused by plasma instabilities.[8]

Other measurements were added, such as recordings of Very-Low-Frequency signals created in the ionosphere as well as measurements of Polar Cap Absorption by means of so-called *riometers*[9], that measure the absorption caused by high-energy particles that enter the ionosphere and which result in a reduction of the cosmic background radiation caused by solar events. This work developed successively into an international network of stations along the auroral oval to study the migration of these absorption phenomena, organised by the Meteorological Institute (Peter Stauning).

These activities are good examples of how research that originally aimed at understanding radio wave propagation for the purpose of predicting high frequency communications gradually turned into a study of the physics that control the mechanisms observed.

In the period 1969 – 1970 the Ionosphere Laboratory launched a series of high-altitude balloons in Narssarssuaq for X-ray measurements in a joint programme with the Max-Planck-Institut für Aeronomie, Germany, organised in the framework of the Solar Particle and Radiation Monitoring Organisation with simultaneous balloon ascends in Kiruna, Sweden, and Narssarssuaq.[10]

A special activity is worth mentioning. Shortly after the launch of Sputnik 1 in October 1957 the Microwave Laboratory under the Danish Academy of Technical Sciences began recording the high-frequency signal emitted from the satellite. It was the result of a rush activity of constructing a suitable receiver, although it diverted from the work already scheduled to the dismay of the board of the laboratory. However, it was worthwhile since it made satellite observations (as well as the laboratory) known to the public partly because reports appeared at intervals on the Danish radio and TV. At a later moment, it was realised that the signal recordings contained interesting information about the electron concentration of the ionosphere that could be derived from the so-called Faraday rotation of the radio waves propagating through the ionosphere.[11] (It is interesting to note that the same effect was recently observed at the much higher frequency of the ERS Synthetic Aperture Radar in the area of the southern auroral oval over Antarctica).

8 Olesen, J.K. and J. Rybner, 1958. Slant E disturbances at Godhavn and its correlation with magnetic activity, Agardograph 34. P. Stauning and J.K. Olesen, 1989, Observations of the unstable plasma in disturbed polar E-region, Physical Scripta, Vol. 40. pp. 325-332.

9 "Meteorologisk Institute gennem hundrede år, 1872-1972" (Meteorological Institute during one hundred years) Copenhagen 1972, p. 241.

10 Taagholt, J. 1972." Danish arctic ionosphere research", 'Arctic', J. Inst. North America, Vol. 25, No. 4, pp. 251-262.

11 Sørensen, E.V., 1961. "Magneto-Ionic Faraday Rotation of the Radio Signals on 40 Mc from satellite 1957α (Sputnik I). IRE Trans. Antennas and Propagation, Vol. AP-9, pp. 241-247.

2 Initial ESRO/ELDO Considerations

In the 1960s when the discussion of the formation of ESRO/ELDO took place in Europe the Ionosphere Laboratory was already engaged, together with Norwegian scientists, in research on the auroral oval using sounding rockets. A meeting of Norwegian, Swedish and Danish scientists was held in May 1960 on the initiative of Bjørn Landmark, Norwegian Defence Research Establishment (NDRF), with a view to use of the launch site at Andøya, northern Norway for the experiments. In spite of the general enthusiasm the outcome became a Danish-Norwegian co-operation with the first launch of a series of four rockets with payloads built by NDRF and the Ionosphere Laboratory in May 1961. The final Swedish attitude towards the project was determined by internal considerations as to the development of ESRO, as it was diplomatically expressed.[12]

In fact, at that time Swedish scientists had already participated in initial discussions at various meetings and tried to create a national space programme. These include the meeting at the Royal Society, London, on 29 April 1960 where a discussion took place *inter alia* about launch sites in Europe, and according to Stjiernstedt.[13] Danish and Norwegian scientists were present at this meeting and at the following meeting in Paris on 23 and 24 June where the European Space Research Study Group (GEERS) (after the French version of the name) was established. From the list of participants[14] it appears that Denmark was represented by professor J.K. Bøggild.[15] Denmark was also represented at the more official meeting held in Meyrin, Switzerland, 28 November – 1 December, where COPERS was established (the French abbreviation for the Preparatory Commission to Study the Possibilities of European Collaboration in the Field of Space Research). It appears that the Danish representative had reservations to the so-called 'Meyrin Agreement' which was signed on 1 December.[16]

In autumn 1960 the UK Ambassador to Denmark approached the Danish government about the British launcher programme 'Blue Streak' which was suggested to form the basis for the development of a European launcher. It was followed by a visit by the UK Minister for Aviation, Peter Throneycroft. Following this the government asked the Danish Technical Research Council[17] for advice and a delegation was sent to the conference in Strasbourg 30 January to 3 February 1961. The delegation included representatives from the Ministry of Foreign Affairs and the Ministry of Education as well as the PTT and the Technical University of Denmark.

Prior to the conference, Professor K. Refslund[18] visited relevant British industries and launch installations in order to explore to what extent Danish technical sciences and industry could contribute to the launcher development. He found it difficult to see an involvement of Danish industry in such a complicated system and referred especially to the lack of suitable test facilities in Denmark which he found important. He also concluded that a participation in the project would not have great value for Denmark.

Shortly after his return a meeting of the Council was held on 19 January 1961 with a wide attendance of scientists and officials from various ministries. Apparently they were impressed by the scale of the project and referred to smaller rockets that could be purchased much more cheaply. Reference was made to the American offer previously issued to launch European satellites with American launchers from US launch facilities. The representative of Danish industry, Carl Schrøder[19,] declared that Danish industry presently had

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12 Rybner, J. and O. Holt, 1963. "The scientific goals of the Danish-Norwegian Rocket Project", in "Norwegian-Danish Rocket Research", Ionosphere Laboratory Report, No. 14, pp. 12-16. J. Taagholt, 1972. Danish arctic ionosphere research, 'Arctic'. J. Inst. North America, Vol. 25, No.4, pp 251-262.

13 Stiernstedt, J, 1999. "Sweden in Space", ESA SP-1248, 237 pp.

14 Krige, J. and A. Russo, 2000. "A History of the European Space Agency, 1958-1987", Vol. I, Figure 1-1, p. 31.

15 Professor at Niels Bohr Institute of Theoretical Physics, Copenhagen University.

16 Krige, J. and A. Russo, 2000. *op. cit.*, p. 38.

17 The Danish Technical Research Council was established by government resolution in 1946 to advise the Ministry of Education on research policies and to support and promote technical-scientific research and economic research to the benefit of Danish industry and agriculture. In June 1960 a sub-committee was formed to handle space research related to the Scandinavian ionosphere research.

18 Professor in fluid mechanics at the Technical University of Denmark, Lyngby, and member of the Council.

19 Co-Founder and Managing Director of 'Radiometer', a company for the development and marketing of electronic measurement equipment.

no interest in taking part in the development whereas in the longer term there could be interest in contributing with components for rockets and satellites. The meeting also considered the aspects of the proposed co-operation for the development and exploitation of satellites negotiated in Europe at the many meetings the year before.

Danish interests including telecommunication, navigation and meteorology were listed. Gunnar Pedersen[20] declared some interest in the proposed satellite co-operation, referring to the hesitation expressed by European authorities as to the tendency towards a US monopoly on transatlantic telecommunications. He also referred to the Danish responsibility for telecommunications to Greenland. He mentioned the possibility of political problems if the activity involved NATO since this would imply that the little co-operation that had been established in telecommunication with Eastern European countries would cease. The meeting ended inconclusively by stating that more information was needed. Considering the special nature of this issue the Chairman raised the question whether a special permanent group should be formed to consider and advise on space matters.

During spring 1961 there were many meetings and informal discussions concerning the participation in ESRO and ELDO, including also Scandinavian consultations. Based on these deliberations a letter was sent by the Council to the Ministry of State, dated 13 March 1961, dealing with the Blue Streak proposal.[21]

The letter mentions the great benefits that may be obtained from participating in large-scale advanced projects 'which as a matter of principle Denmark should not stay out of'. It goes on to briefly describe considerations for the formation of ESRO from which great benefits were foreseen and to the Scandinavian co-operation that was already established. It states furthermore that time did not permit in depth studies of the British proposal but ends anyhow with a negative attitude because 'there seems to be a disproportion between the financial engagement and the benefit to Danish science, industry and telecommunications'. Additional arguments were:

- With the then state of Danish industry the possibility that it would be capable of delivering components to the programme within the first five years foreseen was regarded as slight
- In case of a Danish participation it was foreseen that a number of engineers and researchers would be stationed in England and France to follow (and contribute to) the work. In that case there was a great risk that these people, valuable to Danish industry, would not return to Denmark afterwards.
- There was a risk that the proposed launcher developed under the Blue Streak programme would not be suitable for the launch of future satellites.

The latter argument refers to the ongoing development in the USA where combustion was changed from liquid to solid fuel – according to information gathered previously during consultative travels to the USA. Furthermore, it reflects on the possibility of co-operation with the USA in launcher development at a lower cost although it is admitted that no guarantee had been obtained

The letter is – perhaps not intentionally – somewhat manipulative in its formulation in that it compares the amount of 5 million DKK[22] foreseen for the Scandinavian co-operation in a five year period, 50,000 DKK for participation in the preparations of ESRO and the very much larger amount of 19 million DKK distributed over five years for Blue Streak, all presented within a few lines. With the letter the Council 'wears belt and braces' by stating that there might be political reasons for accepting the British proposal. It also states that if the proposal is accepted it should have no consequences for funding other research that may result from future deliberations by the Council.

The last statement stems from an intervention by the Ministry of Foreign Affairs advocating that participation in the Blue Streak programme could be important from a political point of view especially if the United Kingdom and Denmark became members of the Common Market. This attitude raised some concern in the Council which saw the contribution to this programme being pursued at the expense of the otherwise well founded proposal regarding ESRO. In the end, the government decided to follow the proposition by the Council and Denmark did not participate in ELDO – but obtained observer status.

The question raised by the Chairman at the meeting referred to above, led after some consultations to the establishment of the Danish Space Research Committee in June 1961. Dr. Haldor Topsøe, a leading

20 Director General of the Danish PTT.
21 Danish Technical Research Council, Annual Report 1960-62, Attachment A.11, 49-51.
22 Danish Kroner. One Accounting Unit or one Euro is approximately equal to 7.5 DKK.

industrialist[23], was asked to chair the committee with a membership representing universities, the Ministry of Education[24], the PTT, the Meteorological Institute and the Defence Research Establishment as well as industry. The Committee was an advisory body and would refer to the Danish Technical Research Council. It held its first meeting on 1 July 1961. (For the sake of brevity the Committee will in what follows be referred to as the Space Committee or just the Committee).

The Committee got a flying start with nine meetings in the period up to April 1962, some with an interval of only one week, interleaved with informal consultations.

The discussions at these meetings went very much on the same lines as before i.e. on subjects such as the scientific and application interests in Denmark and the interest by Danish industry. But also the question of whether Denmark should host ESTEC was dealt with at length.

There was little doubt as to the advantages from a science point of view in joining ESRO although there were no plans for activities at that time beyond what was already happening within the Danish-Norwegian sounding rocket programme. In fact, this programme maintained – for good reasons – a high priority in the view of the Committee. Consequently, Members of the Committee were asked to outline planned and future research issues, which resulted in interesting propositions. In addition to the existing sounding rocket experiments, the meteorologists wanted to establish a receiving station to take advantage of the US series of meteorological satellites of the TIROS series, and they wanted to study aurora events in Greenland by means of ground-based radar and to measure atmospheric parameters at 30 – 90 km altitude by rockets. The latter proposal received indirect support from an independent proposal by a university laboratory that wanted to participate and develop the necessary payloads. At that time there were no plans for astrophysical and cosmic radiation projects as stated by one of the members.

The situation of Danish industry had naturally not changed in the short span of time so that the interests and chances for industry to contribute to the advanced technology of launchers and satellites were regarded as very small. In the longer term, however, sufficient experience would become available. In response to the discussion taking place in COPERS as to in-house research at ESTEC it was argued that a great deal of the technical developments should as a matter of principle be carried out in industry and research laboratories in the member countries.

The telecommunication authorities aired again their anxiety as to the creation of monopolies in the field of satellite telecommunication but found that participation in the launcher programme did not have any relationship to this problem – as was already argued in an earlier meeting. They had arrived at that conclusion after having travelled to the United States visiting various companies and having received commercial proposals of possible solutions from some American companies. Another subject was raised, namely that of the establishment of a satellite receiving station as an important factor in international competition in the telecommunication market, but a decision was not considered necessary at that moment in time.

The meeting (again) took note of the American offer to launch European satellites with NASA launchers and from American launch sites although it was clear that the offers could not be taken as guaranteed. It was argued that this solution would be much cheaper than to develop a European launcher.

The question about hosting ESTEC was dealt with at several meetings but the issue was concluded negatively. There were arguments for a Danish proposal from the side of the Technical University of Denmark[25], the Meteorological Institute and the Defence Research Establishment who foresaw the inspiration and spin-off effects in research and technology that undoubtedly would result as an advantage whereas negative issues were raised from industry and the administrations who feared the 'brain drain' that would result. In fact, it was considered a very serious issue in view of the lack of qualified engineers in most fields at that time. The Danish Atomic Energy Research Establishment at Risø that was established some years before was used as a frightening example. A minor point was raised regarding the rather hectic building activity that took place at that time in Denmark, including the construction of the new Technical University in Lundtofte/Lyngby. Construction of another major research facility would undoubtedly

23 Founder and Managing Director of 'Haldor Topsøe A/S', a chemical development and consulting company.

24 The Ministry was at that time responsible for all education in Denmark including the universities and for publicly-financed research.

25 This is contrary to a statement made by the Rector of the Technical University in previous elaborations, but now it was scientists who spoke.

aggravate the situation and ‘heat the economy’. The Committee had a discussion on what it considered the best place for ESTEC and England was proposed. The reasoning behind this was that if placed in The Netherlands as offered by this country the centre could be strongly influenced by Philips which was considered undesirable.

A letter to the Ministry of Education dated 17 April 1962[26] outlines in some detail the issues dealt with during the many meetings. Thus, reference is made to possible developments that 'open new technical possibilities in the fields of telecommunications, navigation and meteorology in addition to space sciences’. Observations from rockets and satellites are referred to specifically. It is interesting to note that the recommendation for joining ESRO is made in spite of the fact that the issues of placing the ESRO facilities and establishments did not follow the intentions of the Committee who preferred a central facility for the sake of efficiency to be placed in England. An important issue was raised in the letter which stresses the point that participation in ESRO required that a corresponding activity take place at the national level in order that public services, research and industry in Denmark be able to take full advantage of the membership and the developments that would take place. For this purpose a special 'Follow-on Research Appropriation' was proposed.[27] The government followed the recommendation of the Committee. Denmark signed the ESRO Convention and the membership was ratified by parliament in December 1964. Also, an ESRO ‘Follow-on Research Appropriation’ was subsequently included in the State Budget.

In an interview in December 2000 Haldor Topsøe stated that when these negotiations took place he did not have great hopes for the involvement of Danish industry.[28] It was largely a manufacturing industry with little tradition of advanced development and research. He felt on the other hand that considering the scientific traditions in the country it was an obligation for Denmark to participate in the large-scale scientific research made possible participating in organisations like ESRO. No doubt, these considerations guided him and thereby the Space Committee – reflected in some of the documents in the files of the Committee.

In retrospect, it is to be regretted that the Committee did not see the chances offered by having a very advance development unit such as ESTEC in the country – and especially at that moment in time. In contrast to the universities and some research institutes the industry and the administrations were apparently more concerned with their immediate problems than long-term considerations as to the advancement of technology in Denmark. However, the chances for Denmark to host ESTEC were probably slight considering the offers that were given by other countries and the fact that Danish delegates seem not to have been very active players at the meetings that led to the establishment of ESRO. This is perhaps understandable when considering the level of space research in Denmark and that no high-level policy was defined at that time.

It was only in the course of the meetings referred to above that more concrete proposals were put on the table at the request of the Committee.

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26 Danish Technical Research Council, Annual Report 1960-62, Attachment A. 10, 48.

27 A similar appropriation was introduced when Denmark became a member of CERN in Meyrin (Geneva, Switzerland) some years before.

28 Mackintosh, J. and P. Gudmandsen, 2001, Danish History Project, Introductory Studies, Final Report, Interview with Haldor Topsøe, pp. 11-13.

3 The ESRO Era 1964 – 1972

After the hectic period of meetings and the decision of the government that Denmark should sign the ESRO Convention, the Space Committee met about twice per year to review the situation and to support ongoing and forthcoming activities by way of the ESRO Follow-on Appropriation. The Committee is an advisory body to the Ministry of Education recommending the apportionment of the funds available based on proposals received.

In the beginning the recommendations to the government by the Committee were largely based on the ongoing Norwegian-Danish co-operation of rocket soundings of the magnetosphere and the interests of scientists in general to extend the activity to include satellites. In fact, during the first few years the Ionosphere Laboratory was the only applicant for financial support. Being a university laboratory its activities were very largely based on this support.

In order to widen the circle of potential applicants an information note was issued in March 1964 to 62 Danish entities covering a wide field of industries and laboratories that could be interested in ESRO research and development activities and/or could be suppliers of services to ESRO. The letter mentioned also the ESRO Follow-on Appropriation agreed by the parliament, designed to support activities related to scientific undertakings as well as engineering and commercial developments on shorter or longer terms.

The result was not very encouraging. Only 14 institutions answered, of which ten declared no interest – at least for the time being. The four institutes that indicated an interest were university laboratories and the Geodetic Institute which showed a general interest without a specific proposal. Thus, the Committee was left with the information that was already at hand from its own membership in April 1962.

Another attempt was made in 1964 by DANSPACE representing a group of Danish industries. It was formed as a counterpart to the EUROSPACE organisation that was established in 1962 in connection with preparatory work related to satellite telecommunication undertaken by CETS[29], formed in that year. 26 companies and seven research establishments were contacted but the result confirmed the earlier understanding of the Committee that the greatest benefit would be obtained by the Danish research community through its participation in the scientific programmes. The formation of the group did indicate an increasing interest by industry leading to larger involvement at the time of the formation of ESA.

In the following sections we shall briefly describe the activities in the field of research and industry but also in the field of telecommunications that was considered already in the initial discussions about participation in the Blue Streak/ELDO programme.

3.1 Involvement of Danish research institutions

In the initial phase the only space-related activity was that carried out by the Ionosphere Laboratory at the Technical University of Denmark as described previously. Another proposal was presented to the Space Research Committee by the Institute of Fluid Mechanics, Technical University of Denmark, concerning research in atmospheric physics with instruments on sounding rockets. Astronomical Laboratories at the University of Copenhagen and the University of Aarhus presented ideas related to visual astronomical observations from satellites. The latter turned out to fit the proposed programme of a Large Astronomical Satellite or was inspired from the lengthy discussions in the Launching Programme Advisory Committee (LPAC). To the dismay of the astronomers it did not materialise because the programme was abandoned for financial reasons.

The activities of the Ionosphere Laboratory were a natural extension of the many years of ground-based measurements in Greenland. They were included in the Norwegian-Danish rocket campaign that was extended at a certain time to include also a NASA team. The Memorandum of Understanding which was required by the American authorities apparently gave some problems in NASA, which was concerned that

29 French acronym for the European Conference on Satellite Communications, established formally in 1963 as a forum for the discussion of European interests in satellite communications.

Denmark in contrast to Norway did not have an official space organisation to deal with.[30] A solution was found and the MOU was signed by the Ministry of Education in May 1964 on the recommendation of the Space Committee.

The co-operation was very smooth and may be characterised as a success from the many successful launches and the results obtained. Scientific payloads were developed in Danish and Norwegian laboratories and integrated in rockets that were launched at the Norwegian launch site in Andøya. 22 rockets with Danish payloads were fired in the period 15 August 1962 to 1 October 1968 with an additional one in 1980[31] with excellent data recording and analysis.

An important asset of the Ionosphere Laboratory was the Instrument Department established for design and manufacturing of the payloads.[32] A great deal of expertise was accumulated in the course of time to the extent that the Chairman of the Space Committee expressed his surprise to see 'how much electronic circuitry could be accommodated in a small space'. In fact, it was the first time that compact electronic equipment was made in Denmark.

At a certain time the space available at the premises of the Technical University of Denmark became too small and funds were allocated so that the Instrument Department could move outside the university to a larger locality. At the same time new and advanced equipment was purchased so that the Department became one of the most advanced outfits of its type in Denmark. The sum involved was so large by the standards of the day that it became headlines in one of the largest Copenhagen newspapers.[33] However, it proved to be a worthwhile investment since it enabled the Laboratory to participate in the first ESRO satellite with the S71C experiment and to assist the Kiruna Geophysical Observatory (KGO) in the design and manufacturing of the electronic control and telemetry parts of its experiments on ESRO 1, S71D.

The latter equipment was developed on a contract with KGO, a contract which raised some discussion on principles: what is the contractual situation of a publicly-owned laboratory and who covers any loss that may occur? This was a new situation in Denmark, and was resolved in this particular case by the Space Committee assuming the contractual and financial responsibility – with permission from the Ministry of Education on the basis of the annual appropriations. The question arose in full when the Laboratory in 1965 gave a bid on an Invitation to Tender from ESRO for payloads to the ARCAS rockets to be launched in Greece. Danish industry was invited to bid but apparently did not have the necessary capabilities. The Laboratory did not win the contract, however – the bid was 2% higher than that of a competitor.

This incident initiated a Danish intervention in ESRO (IPC) in a discussion of the geographical distribution of contracts. There were two lines of thinking. On the one hand, the economy of the ESRO shall be safeguarded but on the other, it is important that when distributing contracts between its member countries, countries with little experience in space technology should have an advantage, and in fact one of the strong arguments in Denmark for joining ESRO was the ‘technological push’ that would result from the membership. Consequently, it was suggested that a bidder should have the opportunity to reconsider its bid if the original bid was within say 10% of the lowest bid received. This rule was not introduced but the intervention did cast light on the problem of especially the smaller member countries and of a newcomer such as Denmark at that time. This incidence was probably one reason, in addition to others, for the reluctance when the continued membership of ESRO was later discussed in Denmark.

In the same context, the question of fair bidding was discussed by the Space Committee. Although there was no Danish commercial entity that could compete at that time – or even had the experience in writing a good proposal – it was nevertheless found important that any bid from a publicly-owned institution be made on the same terms as those applied in a private company regarding hourly rates and overhead etc. – a rule that has been adhered to since.

In an attempt at widening the range of scientific activities Professor Bernard Peters was invited to join the Space Research Committee in 1962 on a proposal by the chairman.

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30 A.W. Frutkin, Head of the Department of International Affairs at NASA was concerned 'that the Danish cooperative agency was not a national body equal to NASA or the Norwegian Space Committee'. p. 131 in *Making Sense of Space*, J.P. Collett (ed.), Scandinavian University Press, Oslo 1995

31 *ibidem*. Appendix: Section entitled "Sounding rocket payloads integrated in Norway", pp. 348-355.

32 It was led by Ove E. Petersen, an electronics engineer, who had acquired experiences in the field of miniaturisation during an extended stay in the USA.

33 Berlingske Tidende, 1966.

Inspired by a visit to a Dutch research group he suggested that cosmic rays would be an important future research objective.[34] In his presentation he stressed that 'in the initial phase (of any new research field) it was desirable to concentrate on few special subjects selected on their scientific merits'. Furthermore, 'the selection should be made on the basis that it contributes to the subject in a significant way'. He indicated that a co-operation with the Dutch group could be of advantage. This became the start of a new activity he also advocated as a Danish delegate to the ESRO Scientific and Technical Committee (STC).

In his capacity as Vice-Chairman of STC Prof. Peters wrote a letter of concern to the Chairman (R. Lüst), dated 1 December 1965. The background was that at that time ESRO responded favourably to an approach by CETS. As a scientist he feared that programmes would not be guided by scientific arguments and – perhaps the important point – that 'substantial commercial interests [would] have a more or less direct influence on priorities in the execution of contracts which ESRO places with industry'.[35] It is interesting to note that the Space Committee was apparently not informed about the views expressed in this letter which was written at a moment in time when discussions as to application programmes also appeared on the national scene.

With the new research activity proposed by Peters, the Ionosphere Laboratory was reorganised in three departments, one related to the ground-based measurements in Greenland, another to outer space and the instrument development group. With this wider scope a co-ordination of the work became an issue and Professor Hans Lottrup Knudsen[36] who took charge of the Ionosphere Laboratory after Professor Jørgen Rybner suggested in 1965 that a space research institute be established as an independent entity directly under the Ministry of Education and with its own allocation in the State Budget. This was effected by November 1966 and Peters was named director of the Danish Space Research Institute.[37]

The science activities related to the ground-based observations in Greenland were later (1968) transferred to the Geophysics Department of the Danish Meteorological Institute which had earlier been responsible for the station operations. It took some time to secure the necessary funding partly because the Institute at that time was reporting to the Ministry of Defence. During the discussions that took place in this connection – partly raised because the Ionosphere Laboratory took a large share of the Follow-on Appropriation – it was agreed by the Space Committee that the Greenland area has a special scientific interest because of its position relative to the auroral zone. But, as pointed out by the representative of the PTT[38] there was no reason for continuing ionosphere research for the sake of communications. Also, the Committee Chairman expressed the view that the extensive data collection carried out should lead to publication of scientific results. These interventions clearly indicate that the scientists had not been very clever in 'selling their ideas' but they also reflect on the lack of understanding within funding agencies that in some cases long-term observations are needed to arrive at valuable results.

This is just another example of the interest in science expressed by the chairman, Dr. Haldor Topsøe. Undoubtedly, he played an important role in inviting Professor Peters to join the Committee that led to the establishment of the Danish Space Research Institute. With the experiences from the two surveys of scientific and industrial interests carried out and the applications for support received by the Committee he came to the conclusion that a change in reporting should be made. The Committee was initially established by the Danish Technical Research Council but since the activity was directed towards science it appeared more rational to the Committee to report to the recently established Danish Natural Sciences Research Council. After a number of negotiations this was effected by April 1970 but since the ESRO programmes still contained a strong technical component the new Space Committee included two members elected by the Danish Technical Research Council. In retrospect, this change appears somewhat curious because at that time the discussions as to the membership of ESRO had already begun and an important aspect was especially the applications programmes and the increasing involvement by industry. Therefore, it is not surprising that the point that caused a change in the affiliation once more created a change when the Space Committee in January 1973 reported directly to the Ministry of Education – now including two representatives of the Natural Sciences Research Council.

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34 Letter to the chairman, Dr. Haldor Topsøe, 28 February 1964.
35 Krige, J. and A. Russo, 2000. *op. cit.*, pp. 280-281.
36 Professor in Electromagnetic Theory, Technical University of Denmark.
37 From 1 March 1967.
38 Børge Nielsen, Chief of Department, PTT.

The Space Committee followed the development of the ESRO programmes based on reports from Danish delegates. In one case (spring 1968), the Committee became worried about the development of an ESRO satellite. The Committee expressed its concern as to the delay of TD1 and TD2 due to the position on contractual matters by the Italian delegation and it was decided to ask the government to intervene because it was felt that if a compromise was not found it could be crucial for the survival of ESRO. Danish laboratories were involved in these payloads. Nevertheless, the government decided not to interfere and a solution was found at ESRO.

Another national problem arose late in 1968 concerning an American research programme that included the launch of a number of rockets near the Thule Air Base in northwest Greenland. All American research programmes in Greenland had to be approved by the Danish government and in this case permission was not granted ‘for political/psychological reasons’ caused by the disaster of an H-bomb loaded B-52 aircraft in coastal waters near Thule (Uummannaq) in January 1968.[39] Scientists from the Ionosphere Laboratory were involved in the American programme and appealed therefore to the Committee who approached the Ministry for Greenland giving all evidence and the scientific prospects of the programme that was related to ongoing Danish research of the ionosphere. The demarche ended positively.

3.2 Involvement of industry

Two of the members of the Space Research Committee represented industry and through their soundings with colleagues and especially the Association of Industries in Denmark it was found that there was little interest in participating in the development of space technology in the early days of ESRO. Most Danish industry was of the manufacturing type with little tradition of research and development. Exceptions were some electronics firms that developed radio and television sets, telecommunications equipment and mobile telephone and a few that were engaged in the development and manufacturing of electronic measurement equipment. The latter did see a potential in exploiting their expertise but felt that they did not have manpower with sufficient expertise. An argument put forward was that it was difficult to see how the work could lead to series production in a later phase. This attitude was confirmed by replies to a questionnaire, mentioned above, that was issued in March 1964.

The result of this attitude became clear when it was realised that the return coefficient for Denmark only reached 0.385. Also, it appears that a major 'return' was in connection with the building of the ESTEC facilities in Noordwijk, Holland, where a Danish architect won the competition and a building company a contract for construction work. The architect was Preben Hansen who applied the same principles as when building the Danish Atomic Research Establishment in Risø some years before. The flexibility of laboratory facilities was probably a deciding factor, as was the case when plans for the Risø establishment were accepted.

An exception was an institution under the Academy of Technical Sciences (Elektronikcentralen). Although in principle a research and development outfit it had for a number of years contracts concerning support engineers placed at ESTEC. Being perhaps the most advanced electronic establishment at the time with experience in building payloads for rockets and in microwave techniques the institution was consulted by Danish industry and the Space Committee.

However, Danish industry did make an effort by establishing a network under the name of DANSPACE, mentioned earlier. At a certain moment the network involved ten electronic companies that was kept informed about contractual possibilities and met at irregular intervals to exchange experiences.[40] When the Association of Electronic Manufactures was formed in 1966, including a permanent secretariat, this activity was strengthened and led to increased awareness of space.[41] When the question of Denmark’s adherence to ESA arose, this association played an important role in the attempts to convince the Ministry of Education of the advantages of continued membership.

Although the Space Research Committee showed a great interest in the involvement of Danish industry in the ESRO work it was guided – and still is – by the principle of no direct involvement in the contractual relationship between ESRO and industry. This was implemented so that the Ministry could not be accused of

39 Taagholt, J., 2002, Thule Air Base 50 år (years), Grønland, No. 2-3, pp.84-87.

40 Interview with Ove E. Petersen, 8 January 2002.

41 Mackintosh, J and P. Gudmandsen, 2001, Interview with Frede Ask, Danish History Project, Introductory Studies, Final Report, pp. 21-22.

favouring specific companies. In contrast to several other ESRO member countries the Committee responded to the Ministry of Education rather than to the Ministry of Industry, which is one reason for this relatively passive attitude at the national level. It should be mentioned that this attitude was fully supported by the industry's representatives on the Committee. However, when contracts were negotiated at the ESRO level the Danish official representatives were advocating the interests of industry.

3.3 Telecommunications

When the Blue Streak programme was presented, one of the important issues raised was the importance of having access to a launcher to place telecommunications satellites into orbit. It was argued that an organisation that could launch a telecommunications satellite was likely to obtain a monopoly. For a while this view was accepted by the Danish Technical Research Council. The Danish Postal Telecommunication Administration was represented on the Space Research Committee and undertook to study this issue in depth. Investigations including visits to Germany, the United Kingdom and Canada and the U.S.A. convinced them and representatives of the Great Northern Telegraph Company[42] that the great expenses foreseen for the launcher development could not be justified from the point of view of telecommunications. Also, the question of establishing a ground station for future satellite systems was not found pressing from a competition point of view.

In parallel, the Administration participated in European co-operation through the European Conference of Postal and Telecommunications Administration (CEPT), formed in 1959, where it led a working group on satellite communication. On the occasion of the July 1963 CETS the Administration urged – with two letters to the Space Research Committee at three weeks interval – that the attitude of Danish industry towards the development of satellite systems should become clearer.

Thus provoked, the Space Committee turned once more to the question of involvement by Danish industry but came again to the conclusion that there was no interest. More specifically it was expressed by a representative from the electronics industry, as his personal opinion, that: (1) Danish industry is not capable of undertaking development in connection with space projects as proposed, (2) Danish industry will be able to manufacture many of the elements involved assuming that specifications and knowhow are made available, (3) it is uncertain whether such manufacturing will be financially attractive in the shorter term, (4) Danish industry should follow the developments in the field carefully but otherwise take an waiting attitude.

In spite of this rather meagre response, a conference was organised by the Committee on the subject in July 1964. The Ministry of Foreign Affairs reported from a meeting of the Space Technology Committee that European countries did not expect to be able to contribute essentially to the development of satellite communication systems in the 'interim period' until 1970. The work planned for this period had the purpose of reinforcing European industry, however. It is symptomatic of the situation that the outcome of the conference was a recommendation that a group of university laboratories study the techniques involved including the Microwave Laboratory and Radio-technical Research Laboratory (systems studies), both of the Danish Academy of Technical Sciences, the Ionosphere Laboratory (electronics design and technology) and the Laboratory of Electromagnetic Theory (antennas), Technical University of Denmark. An application for financial support was submitted shortly after to the Space Committee – now with the involvement of the telecommunication authorities (systems) and the Technology Department of the Technical University of Denmark (structures) – with a view to funding from the Follow-on Appropriation.

Reports from the studies include a detailed survey of the technologies that are involved in telecommunications satellites but did not point at specific companies that eventually could undertake development work. Clearly, at that time most research and development was carried out in university laboratories and in those of the Academy of Technical Sciences.

In parallel, the Telecommunication Administration joined the Scandinavian Telecommunications Satellite Committee established in December 1961 with the purpose of making experiments in the use of satellite communications. The Committee went into co-operation with radio astronomers in building a combined receiving station/radio telescope at Råö, north of Gothenburg, Sweden, operating on a time-sharing basis. The station started in November 1964 based on an agreement with NASA concerning the US satellite testing

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42 Great Northern Telegraph Company, Copenhagen, is a Danish company, founded in 1869, which established and operates telecommunication lines over a great part of the world, including transsiberian and transatlantic cables and cables to Greenland.

programme that ensured access to satellite transponders. The Scandinavian co-operation continued after the tests were concluded (June 1967) resulting in establishment of a joint operational satellite receiving station at Tanum, on the west coast of Sweden, inaugurated in 1971.[43] It is interesting to note that “this earth station brought no contracts for Scandinavian industry. The responsible authorities opted for minimum risk and minimum price and purchased equipment from established firms abroad”.[44] This was in line with the general attitude of the Danish Telecommunication Authorities (reporting to the Ministry of Public Works) that has no mandate to support the national industry.

43 When clearing the ground for the station well preserved stone engravings from the Bronze Age were uncovered.
44 "Making Sense of Space", J.P. Collett (ed.), Scandinavian University Press, Oslo 1995, p. 171.

4 The Transition from ESRO to ESA

It was of repeated concern to the Space Committee that the industrial involvement was so low but also that the scientific programmes appeared to have relatively little benefit for Danish science. In addition, it was felt that the progress in the discussion of application programmes was too slow, although the French proposal for Europeanisation of the Meteosat programme formalised in September 1972 was a step in the right direction. It was therefore agreed to recommend that Denmark should leave the organisation at the time of expiry of the ESRO Convention. The government was warned accordingly in a letter already in November 1968 with some views as to the future of European space research motivated by the ESA Council meeting at ministerial level in Bonn later in the same month.[45]

The letter reviews the launcher situation and points to the fact that several member countries insisted that as a matter of principle European satellites should be launched by European launchers. It points to the possibility of having European satellites launched by American launchers which would be a cost-effective solution, although it is admitted that there was no firm offer from the USA as to the launch of application satellites. Apparently it was not known that US offers in space and other fields of technology did not include launching European communications satellites.[46]. It concludes that from a Danish viewpoint European satellites should be launched at the lowest possible cost, assuming equal performance and reliability.

Discussing the activities in CETS that included plans for an experimental television satellite the Committee concluded that this programme definitely should be carried out in the framework of ESRO. This applied also to the proposed development of meteorological satellites. Reference is made to Intelsat[47] which was responsible for the establishment of 'the necessary telecommunications satellites'. In this context it is pointed out that until then Danish industry had had 'a rather passive attitude towards technical developments in the field of satellites and that deliveries of satellite equipment have been modest'.

It was stated that since its establishment in 1964 ESRO had concentrated on fundamental research and that all projects had exceeded the agreed budgets. On the other hand it was mentioned with satisfaction that in the course of time the attitude of ESRO had gradually changed towards application projects and reference was made to meteorological and aeronautical systems to be worked out on the basis of additional appropriations.

Based on these rather negative points the letter concludes that continued membership after 1972 could not be recommended. However, it is pointed out that some projects embarked upon could not be concluded before the expiration of the ESRO Convention and that two-to-three year extension may be foreseen. However, the letter does include a caveat by saying that the attitude of the Committee could change if applications programmes were to obtain a more pronounced position in the future.

Still, there was a year for further considerations and the Space Committee undertook a number of inquiries with interested parties: universities, research institutions and industry. In general, the responses were positive with the researchers pointing to the fact that participation in ESRO programmes enabled participation in projects that were very much larger than could be established nationally. Industry pointed to the improved situation concerning ESRO contracts and the return coefficient during the previous years and made a comparison with the Danish participation in CERN from which no contracts were obtained. It was pointed out in one case that the knowhow obtained through contracts was just as important as the financial value of the contract. Furthermore, the exercise of meeting well-defined goals within a fixed time frame appeared to be new to Danish industry and research laboratories and was regarded an asset.

Also, consultations were made with Swedish and German authorities to learn their attitude.

In spite of the positive reactions the decision was not changed and, after approval by the parliament the Danish government advised ESRO by the end of 1970 that Denmark would leave ESRO with effect from 31 December 1971. However, Denmark would continue within the programmes that were not concluded by

45 Mackintosh, J and P. Gudmandsen, 2001, Danish History Project, Introductory Studies, Final Report, Danish Technical Research Council 1960-69, Appendix 2, pp. 39-44.
46 Johnson, S.B., "The Secret of Apollo", The John Hopkins University Press, Baltimore 2002, p. 164.
47 International Telecommunications Satellite Consortium, established in 1964.

that time. Internally, the government wanted to 'keep the door open' in case of a positive development in the ongoing negotiations.

Although Denmark is a country with a comparatively small BNP and therefore a small contribution to ESRO (about 2%) this decision did create some activity on the side of ESRO – maybe because the Executive was afraid of a domino effect since France announced the same attitude (although for other reasons).

In October 1970 the Director General of ESRO, Hermann Bondi, participated in a meeting of the Space Committee where he described current and future programmes of ESRO. Especially he addressed the COS-B and HEOS programmes where an improvement would be made regarding Danish industry. In response, the Committee expressed its concern and concluded that presently there was insufficient background for decisions of longer-term involvement but that Denmark was inclined to participate in the scientific programmes until the end of 1972.

A number of other ESRO people came to Denmark in the course of 1971 and 1972 to meet with people who had been involved in ESRO programmes or contracts, to explain the situation in ESRO and to determine in what way the involvement by Danish industry could be increased. In an interview with an Danish official reference was made to the 'amusing situation when ESRO officials came to Copenhagen' at that time. 'There was no end to all the good things that would be done to remedy the prevailing situation'.[48]

Another attempt at changing the attitude of the Danish authorities was a call for a larger meeting in The Royal Danish Academy of Sciences and Letters in Copenhagen[49] in April 1971 where the ESA Council Chairman, Professor Giampietro Puppi, with a delegation of ESRO officials described the plans for a continued space activity in Europe. The meeting was part of a tour to the capitals of the ESRO member states. In his talk he touched on the discussion about the science programme as a mandatory or an optional programme, an item that proved to be essential for the Danish attitude.

The government's decision stirred up the situation in ESRO but also at the national level. A number of industrial companies addressed the Minister of Education (April 1971) outlining the great advantages that were obtained and those that would likely be obtained in the future. But they also stressed that a presumption for a continued membership was that the geographical distribution of contracts was improved. A letter was sent by the Danish Association of Electronics Manufacturers in October 1971 to the new Minister of Education with approximately the same arguments. According to a rumour circulating at that time, top people from industry contacted a number of the ministers in a true 'door-knocking lobby action' wearing them down in the end.

Views expressed in two annual reports from the Danish Space Research Institute (sent to the Ministry of Education) may also have played a role in the final decision. In the report covering 1970-71, page 6, the following statement was made (translation by the author):

> *'As to the long-term programme of the Institute it should be considered that Denmark is going to leave the European space research cooperation. Although the Institute is developing in a satisfactory way some damage may result in the longer term. The European co-operation will have to be replaced by bi-lateral agreements, ESRO research grants that have been exploited greatly will have to be replaced by other sources, but perhaps more important it may prove difficult to maintain the personal contacts with many active space research groups at their present level'.*

Similarly, words of concern were expressed in the annual report for 1971-72:

> *'At the beginning of 1972 Denmark left the European Space Research Organisation. Denmark had been a member of this organization from the start (1964) and had made active use of all opportunities offered by this membership. The institute has participated in eight experiments on five different ESRO satellites (of which three have been launched). It has also participated in numerous experiments on ESRO sounding rockets. Our share in the ESRO scientific programme had therefore been considerably in excess of the Danish share of the expenses of the organisation (2,13%). The decision to leave the European Space Organisation, while all the other nine member states are in the process of greatly increasing and developing their co-operation, was a setback*

48 Mackintosh, J. and P. Gudmandsen, 2001, Danish History Project, Introductory Studies, Final Report, Interview with Per Grønborg, p. 30.

49 Det Kongelige Danske Videnskabernes Selskab, Copenhagen, founded in 1742.

> *for the institute, and especially a threat to its future scientific development. It is to be hoped that in view of these detrimental effects on future research and in view of the strong interest in the ESRO membership expressed by industry and engineering circles, this decision will be reversed.* [50]

Under the impression of the arguments advanced and perhaps also pressure from industry the decision was reversed by the government – opening an new era for Denmark.

50 These two statements are interesting when comparing with information given by Niels Lund of the Danish Space Research Institute in an interview (see fn 53). At the time when Denmark considered leaving ESRO 'Bernard Peters was approached by Danish industry for support of the campaign undertaken to ensure membership (of ESA) – he refused to sign a statement that expressed that the effect (of leaving ESRO/ESA) would be to the death of Danish space research'. 'He had the idea that the institute should develop an expertise and technology that were so good that it would be invited to participate in most larger programmes'.

5 The Era of the European Space Agency

5.1 The Danish Space Research Advisory Committee and the ESA Follow-on Research Appropriation

The Space Committee (the abbreviated version of the official title of the Committee) advises the Ministry of Education (now the Ministry of Science, Technology and Innovation) as to the financial contributions to various optional ESA programmes covered by the annual appropriation in the State Budget. This advice is based on ESA documents, reports by delegates to various ESA boards and industrial interests expressed by members of the Committee. Also, it advises the Ministry on the application of the ESA Follow-on Appropriation. A great deal of the space-related activity is carried out by public laboratories, mostly at universities, which are therefore dependent upon the additional support that could be obtained by this fund and in most cases the support is crucial for the work undertaken. The advice is based on an evaluation of proposals by a subcommittee and presented to the full Committee for approval before being issued to the Ministry.

The deliberations of the Committee were carried out in a relaxed atmosphere and in no case was a vote necessary. Views were presented reflecting the different interests of the scientists and the industry people with the Chairman finally arriving at a conclusion accepted by the members. Two examples illustrate that.

When the Swedish Space Corporation in the 1980s invited Denmark to participate in their Tele-X programme, industry expressed an interest whereas there were no other interests stated. The Chairman[51] therefore concluded that 'since Denmark pays ESA to build the satellites for us there is no point in embarking on that ourselves'. This was in line with the general attitude towards research and development in telecommunications – and there were no other places to go to raise the additional money. However, it is worth noting that the Danish contribution to the telecommunication programmes of ESA is relatively high, Table 1, reflecting the interests of industry.

Another, more complex, example came up when discussing adherence to the Columbus, Ariane-5 and Hermes programmes in the period 1985-87. Scientists advocated that the Columbus programme should be considered as a prestige project that would be of importance mostly for human-physiological research. Industrial investigations under microgravity conditions could just as well be performed using unmanned satellites with artificial intelligence and robotic technology that would be a technological challenge in itself. These views were in line with the series of protests that were aired by scientists in the USA when the Space Station Freedom was proposed, expressing the fear that the very large investments necessary would endanger future scientific and applications satellite programmes. The criticism was partly appeased when NASA proposed the polar orbiters and the same happened in Europe when ESA invented the Polar Platform programme. After several meetings the Committee agreed to participate at a 1% level. To the dismay of industry it was, however, impossible to accommodate the participation in the other two programmes with the funds available although it was generally agreed – based on experience and especially the Challenger disaster – that Europe should seek independence in access to space. The Ariane-5 and Hermes programmes were characterised as technological/industrial programmes and the Ministry for Trade and Industry was approached, but initially refused. Nevertheless, industry cleverly managed after some months to change the decision so that Denmark could adhere to the programmes with a 0.5% contribution each. The Ministry imposed two conditions: (1) Royalties should be paid of future production and (2) the knowhow acquired should be made freely available to Danish companies. Thus, a broader disagreement in the Committee found a solution.

An impression of the Danish financial contributions to ESA Programmes may be obtained from Table 1, compiled for the period 1972-1995, as derived from the Annual Reports of the Space Committee[52] and the State Budget.[53] Annual Reports were initiated only in 1984 but the table includes the accumulated expenses for the previous period 1972 to 1983.

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51 Ib Lønberg, Deputy Director General, the Danish PTT, Chairman 1982-88.
52 See the bibliography at the end of the report.
53 State Budget, 1984, § 09.04.53.01, 1993, §20.73.13 and 1994, §19.15.12.

Table 1: Danish financial contributions to ESA Programmes, 1972 – 1995

Year	Mandatory	Optional	Telecom	Earth Obs.	Spacelab/ Columbus	Ariane	Total	Follow-on Appropriation	
	MDKK*	MDKK	MDKK	MDKK	MDKK	MDKK	MDKK	MDKK	%
1972-1983	249,7	317.7	103.0	55.3	94.3	65.1	567.4	-	-
1984	41.8	53.4	18.0	12.4	9.8	13.2	95.2		
1985	40.6	48.1	14.2	8.7	11.1	4.1	88.7	6.5	8.3
1986	41.3	53.0	13.8	20.2	15.4	3.6	94.3	6.7	7.1
1987	44.1	54.2	15.8	24.0	11.5	2.9	98.3	7.4	7.6
1988	47.4	55.3	7.3	19.1	19.8	9.1	102.7	7.7	7.5
1989	50.9	65.2	5.6	21.1	17.1	21.4	116.1	8.1	7.0
1990	55.7	78.7	10.4	15.5	20.0	32.8	134.4	8.2	6.1
1991	60.1	97.9	18.4	10.3	31.8	37.4	158.0	7.9	5.0
1992	65.6	117.8	19.1	23.7	34.8	40.2	183.4	8.6	4.7
1993	70.4	117.5	13.0	24.3	43.0	35.6	**187.9	8.6	4.6
1994	69.1	112.6	19.0	21.0	43.5	27.5	**181.7	11.5	6.3
1995	71.2	102.7	7.6	21.4	48.1	23.8	***173.9	11.7	6.7

** Million DKK, * *Including 1.6 million DKK for GSTP, *** Including 1.8 million DKK for GSTP*

The column for the optional programmes is the sum of the funds listed under the individual programmes in the subsequent columns whereas the column labelled Total is the sum of the mandatory and the optional contributions.

It is interesting to note the increase in contributions to the optional programmes that begins in 1989 as the major programmes take shape at ESA. The contributions to the Telecommunications programmes have varied a great deal, with a general decrease over time.

The Danish contribution has been and still is about 1% of the ESA budget, which is half of the GNP-contribution of the country. Of this, the mandatory contribution takes about 41.7% on average and the optional programmes 58.3%. It is found that these numbers largely reflect the distribution of funds between space-oriented research in Danish research laboratories. For the period 1984-1995 the numbers are 38.9% for Space Sciences and Astronomy and 54.5% for the Applications programmes (Microgravity-related research and Earth observation) with the remaining 6.6% allocated to Communications and Technological developments.

It is noted that the funds for follow-on research vary between 4.6% and 8.3% of the total Danish contribution to ESA in the course of time with an average of 6.3% for the period 1984-1995.

An impression of the activities funded by the ESA Follow-on Appropriation may be obtained from Figs. 1 and 2 which have been derived from the same source.

It is seen that priorities were placed on space sciences and astronomy, on life sciences and Earth Observation. The majority of the space research activities were directed towards astronomy so the total amount spent on outer space research becomes about 40 million DKK. The life sciences research is related to Spacelab, Eureka and the International Space Station but other microgravity studies were also funded including smaller programmes on crystal growth and plant growth experiments in a microgravity environment.

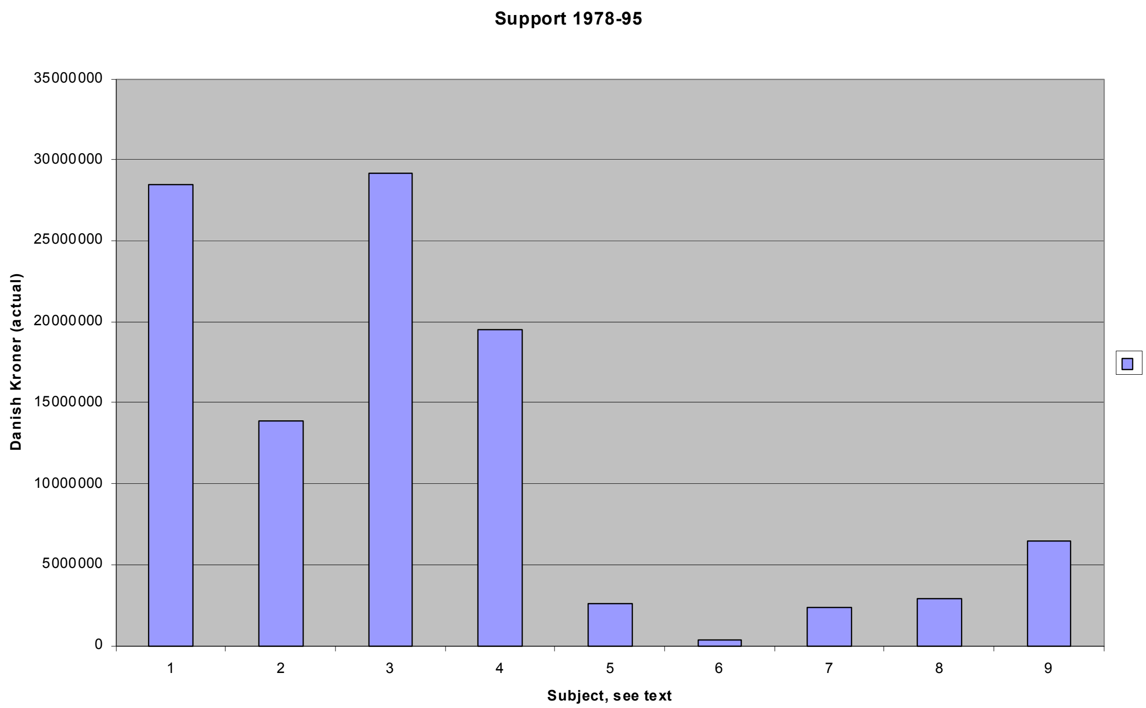

Fig. 1: Allocation of funds from the ESA Follow-on Appropriation in various fields of research. The items numbered are 1: Space Sciences, 2: Astronomy, 3: Life Sciences, 4: Earth Observation, 5: Geodesy/Earth Gravity, 6: Communications, 7: Crystal Growth, 8: Plant Research, 9: Technology.

Of the total microgravity spending of about 34.4 million DKK about 15% or 5.2 million DKK were spent on these undertakings. Similarly, of the two related programmes, Earth Observation and geodesy, the latter obtained a support corresponding to 12% of the total sum of 22.2 million. DKK. It is interesting to note that the subject of Communications received only small support, reflecting the relatively small activity in this field in Denmark, but industry also showed a relatively small interest in obtaining grants – and only during the first years.

Another picture of the activities is obtained from Fig. 2 that shows the development over the years 1978 to 1995 based on the same information. The relatively large peaks are due to the establishment of various facilities or large experiments. Thus, the 'peak' in 1980 for Earth Observation is due to the purchase of the first digital image processor in Denmark. Likewise, the 'peak' in 1985 is related the establishment a 'Life Sciences Centre' whereas the step function in 1988 is due to the large activity at the Danish Space Research Institute in connection with production of telescopes for the Russian-French mission GRANAT.

It is noted that the Annual Reports include short descriptions of the work carried out based on the support obtained. A review of these shows clearly that the ESA Follow-on Appropriation has been of the utmost importance to Danish research institutions as will appear from the sections to follow. Although the amount of money allocated every year on the State Budget is relatively small – corresponding to an average of 6.3% of the total ESA contribution, with variations from year to year – it enabled Danish scientists to participate actively in space research and developments in connection with ESA. In addition, the broad interpretation of the objectives of the funds made it possible for them to participate in activities with other agencies and in international space-related research projects. An important issue is that activities could be supported over a longer period than is normally the case with Danish research foundations. In almost all cases the additional expenses that often occur because of programme and launch delays could be covered. It is worth noting that the funds indirectly played a role in the way that scientists and engineers representing Denmark on various programme boards and technical committees could participate actively. Through their work that was often supported by the Follow-on Appropriation they were able to play an influential role in formulating the ESA programmes.

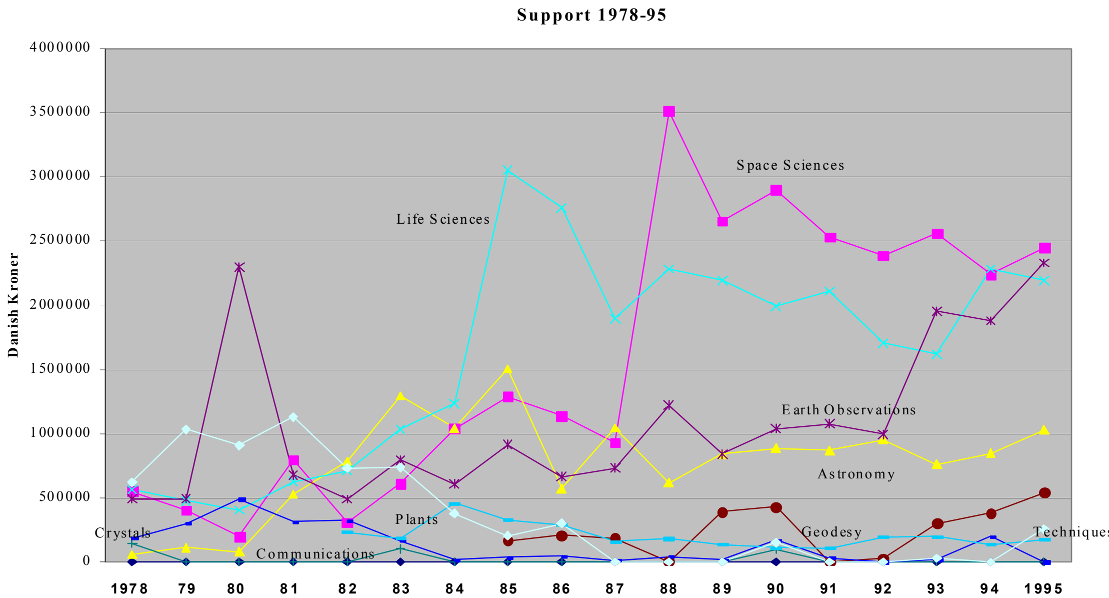

Fig. 2: Allocation of funds from the ESA Follow-on Appropriation versus time in various fields of research

5.2 Research supported by the ESA Follow-on Appropriation

Space research

Fundamental space research is almost entirely carried out by or in connection with the Danish Space Research Institute established in November 1966. As described previously it is an offspring of research carried out at the Technical University of Denmark related to ionosphere phenomena within the auroral oval that crosses northern Norway and the Greenland area. This research included ground measurements, rocket campaigns and early satellite missions in ESRO. The Institute continued the last two activities and expanded its interests and expertise in the course of time with a specific scientific view. In the period considered, the Institute was headed by Professor Bernard Peters from March 1966 until March 1979 followed by Professor Herbert Shopper (until October 1996).

At the outset, it can be said that a statement made by Professor Peters and referred to in the interview with Niels Lund[54] (who worked with Peters even before he was made Director of the Institute) appears to have been fulfilled. It is reflected in a presentation by Peters given on the occasion of an open-house event in October 1979 from which we have extracted some paragraphs.[55]

Professor Peters suggested to answer three questions related to space research:

- Why do we have a space research institute?
- Are we really able to contribute with something new in natural sciences and technology that is comparable with that of organisations that are very much larger?
- Isn't space research too expensive in comparison with research carried out in other disciplines?

'In answering the question whether Denmark should be in the field of space research one should ask oneself how do we make progress otherwise? This happens at universities or research institutions where scientists – and often a few scientists – concentrate on certain unexplained phenomena and try to develop methods for discovery and measurement. Such a laboratory could be placed in Denmark just as well as in California and there is no reason to believe that a modern,

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54 Mackintosh, J and P. Gudmandsen, 2001, Danish History Project, Introductory Studies, Final Report, Interview with Niels Lund, pp. 14-16.

55 Peters, Bernard, "Hvorfor har vi et Rumforsknings Institut i Danmark?" (Why do we have a space research institute in Denmark?), Brochure with Notes in connection with an open house feature at the Danish Space Research Institute, 25 October 1979, 7 pp. Translated from Danish by the author.

well-equipped laboratory in Denmark could not contribute to science at a level comparable with laboratories elsewhere'.

'As to the cost, space research does cost a great deal of money for satellites, launch, ground stations etc. that would not be affordable in a small country. But do we really need that? If we develop a useful idea about how we may achieve new and unknown results from space observations, experience shows that there are many research groups in other countries that would like to participate with analysis of the ideas, constructing experiments, carrying out the actual experiments and participating in the analysis of the results – and just as important, to share the costs. Most experiments carried out by the Danish Space Research Institute have been co-operative experiments that were of great benefit to the institute not the least because they could be carried out within budgets which are normal for experimental research activities in Denmark. Thus, we may conclude that fundamental research in space is not more expensive than other research fields such as solid state physics, nuclear physics and even microbiology'.

'The Danish contribution to the ESA space programme is about 2% but it is not exaggerated when we claim that our part of the European space experiments is almost three times as valuable. Furthermore, it is perhaps not unfair to say that the contributions by the Danish Space Research Institute are respected and lead to other co-operation in new projects. This is also true when considering projects outside Europe where the institute participates. We may conclude that Denmark now has a research institute that is considered competent not only in Europe and America but also in Japan, India and China'.[56]

These lines may be regarded as a sort of a testament that summarises the state of the institute as an active and recognised partner in an international co-operation to further the research on the ionosphere, the near-Earth magnetosphere and outer space with satellite, rocket and balloon missions.

The list of ESA and international satellite missions in which the Institute has participated or is participating with instruments and/or data analysis is long and we shall only consider some of them that may demonstrate the diversity of the Institute.[57] In doing so we have taken advantage of annual reports from the Institute, the first one covering the period November 1966 to March 1967 and additional information from Flemming Hansen of the Institute.

An interesting case is that of the GOES mission carried out during the ESRO era. In 1970 the Institute proposed measurements with a particle spectrometer and VLF[58] measurements in competition with other parties. Before the final decision by the Science Board Professor Peters suggested to the other proposers that whoever was selected should share data with the other parties. With this 'musketeers oath' the Institute was ensured data for its research which turned out to be helpful since the Kiruna Group won and faithfully shared data after a thorough screening.[59] With this geostationary satellite it was planned to carry out balloon and rocket measurements in Scandinavia at the place where the magnetic lines from the satellite reach the ground. Unfortunately, the satellite, GEOS 1, did not reach the geostationary position required but

56 Additional philosophical thoughts expressed the view of Peters 'that the Danish Space Research Institute should continue its development during the coming decennia to maintain its international status. No doubt this may be accomplished but whether the society at large shares this view shall be investigated. Although space research is an important activity to mankind and that we want to participate one may ask the question: Is this really necessary? Perhaps there are other problems that are more pressing! It is naive to state that the society cannot expand its culture and knowledge without the institute. No doubt this is possible, but we do not stand outside the community, we are part of it'.
'Finally, as a word of warning in order not to be misunderstood: Increased knowledge about nature is important for the development of our culture. However, new knowledge does not ensure that the knowledge acquired may be to the benefit of mankind. This cannot be achieved with fundamental research alone'.

57 For the period 1967 to 1990 the list of satellite missions reported in the annual reports comprise (no superscript = ESA, superscript A = Argentinian, D = German, DK = Danish, R = Russian/Soviet, S = Swedish and U = US satellites, with launch dates, month and year, in parentheses): ESRO-1 (10/68), HEOS A2 (01/72), GEOS-I (04/77) and II (07/78), HEAO-3U (09/79), Giotto (07/85), Viking^{S} (02/86), Hipparcos (08/89), Granat^{R} (12/89), Eureca (08/92), Exosat (05/83), ISO (11/95), SOHO (12/95), Astrid^{S} (12/1998), XMM-Newton (11/99), Ørsted^{DK} (02/99), Champ^{D} (07/00), SAC-C^{A} (11/00), Integral (10/02).

58 Radio waves at Very Low Frequencies.

59 Hultquist, Bengt, *Space, Science and Me,* ESA SP-1269, 2003, p 70.

nevertheless delivered very useful data from its elliptical orbit far into the magnetosphere. Its successor, GEOS 2, launched shortly afterwards did reach its orbit, but the planned ground measurements were not carried out.

In 1983 the Institute proposed to design an X-ray telescope to be flown on EURECA for launch with the US Space Shuttle in 1988. The telescope was accepted the following year and the design began in 1985 under the name of WATCH (Wide-Angle Telescope for Cosmic Hard X-rays). The purpose of the instrument that was an improved version of one developed previously and flown in balloon missions from Svalbard in 1980 was to detect and determine the direction from which X-rays appear in order to guide other optical and X-ray detectors with finer spatial resolution towards the X-ray source. It constituted a major effort mechanically and electronically. However, due to the Challenger accident the mission was delayed until 1992 and then flown with success. While waiting for the launch another flight opportunity arose in connection with the French-Soviet satellite mission, GRANAT, but this required that four identical instruments be supplied to constitute a wide-field monitor for other on-board X-ray telescopes. The production of these telescopes in a period of two years was a great challenge to the Institute – also financially, which required a special grant from the Space Committee (see Fig. 2). The flight models were delivered in time for a launch that was delayed to December 1989, followed by successful operation of three of the units until 1991. A great number of glints were recorded during this period. With the experiences gained from the design of WATCH the Institute could engage itself in another joint development of an advanced X-ray telescope under the name of SODART[60] to be included in the future SPECTRUM-RÖNTGEN-GAMMA mission by ESA, a cornerstone in the Horizon 2000 plans.

The list could have included a Soviet/Russian satellite named Spectrum-X. The institute was heavily involved in designing instrumentation for this satellite, but unfortunately in the period of the collapse of the Soviet system. Later it proved impossible to find the necessary funds in Russia and internationally to ensure the launch of the satellite. This is another example of the disappointments one meets in the space business and, according to Flemming Hansen, “a miracle is needed in order to get the satellite into orbit”.

These undertakings required development of advanced production and test facilities at the Institute including development of suitable sources for qualification and calibration of components and assemblies. The workshop and laboratories of the Institute became a very advanced facility, able to handle a number of different materials and manufacturing large quantities of specific elements – perhaps the most advanced in Denmark at that time.

The Institute has developed a number of magnetometers for space and rocket applications, thus extending the ‘tradition’ from the early days of research in Denmark referred to in the introduction. In addition to the X-ray telescopes other sensors have been developed often in co-operation with other parties, the idea being that access to data from a satellite mission require a contribution that could be a sensor or support electronic units or design of the ground segment with data handling and analysis software.

Early rocket campaigns were continued by the Institute with the objectives of measuring the electron density of and the electric fields in the ionosphere, VLF noise in connection with auroras, magnetic fields and particle distributions. In total 40 rockets were launched within the Scandinavian Co-operative Agreement or in co-operation with other parties from France, U.S.A. and Japan, from ESRANGE, Northern Norway, Greenland, Texas and Northwest Territory, Canada. A number of the early launches were within the ESRO programme or in support of ESRO satellite missions. In most cases one or several of the payloads were constructed at the Institute.

Activities with stratospheric balloons are reported for the period 1967 to 1979. They were carried out to test new instrument developments with a view to future satellite measurements of the electric field in the ionosphere, cosmic ray isotopes (electric charge of high energy particles) and a single one for measuring galactic noise. The work was carried out in co-operation with Saclay.[61] The flights were carried out in France and in the Nordic area. Thus, in one campaign 10 balloons were flown from Norway over Iceland to Greenland and Canada collecting in total 1200 hours of valuable measurements of the electric field in the ionosphere. A proposal by the two partners to NASA concerning the HEAO mission gave rise to a number of balloon flights in the USA. The satellite HEAO-3 was launched in September 1979 with a cosmic ray spectrometer developed by the two partners and analysis of the data acquired continued until 1984. Later

60 Soviet-Danish Röntgen Telescope developed with Russian scientists.
61 Centre à l'Energie Atomique in Saclay, France.

balloon flights were carried out in collaboration with the California Institute of Technology with detectors developed jointly in the HEIST project.[62] Still another flight was carried out in the Nordic area together with the University of Bergen, Norway to measure electric fields and X-rays associated with Japanese ground measurements in Antarctica on conjugate magnetic lines.

The annual reports from the Institute list a great number of publications by scientists of the Institute based on analysis of data acquired by various missions. In addition, the Institute has a great activity of internal and external meetings and conferences with invited and internal speakers. For a number of years the Institute has benefited from visits by foreign scientists. Scientists from the Institute have taken a genuine interest in the work of ESA's Science Programme Board. Thus, valuable contributions were given to the definition of the Horizon 2000 programme that was accepted by the ESA Council in 1985.

'Nobody does space science who's not an optimist' said Dr. David Southwood recently.[63] The Danish Space Research Institute is an example of optimism. On the other hand, the activities of the Institute show that the situation is not as awkward as it was described in another way concerning the individual scientist: 'essential prerequisites for working in space are a good deal of patience and a good health so the scientist lives long enough to see his/her satellite experiment flying'. The programmes have invariably suffered from delays but the Institute has shown the ability to turn these into something useful.

Astronomy

In the ESRO era the Astronomical Observatory of Copenhagen University took a great interest in the work related to the Large Astronomical Satellite (LAS) and the less ambitious Ultra-Violet Astronomical Satellite (UVAS) for stellar astronomy in the ultra-violet region. Neither of them materialised in the end for financial reasons. However, with the launch of the International Ultra-violet Explorer, IUE in January 1978, new interest arose for exploiting observation times on the satellite and analysis of data. This work was supported by the ESA Follow-on Appropriation during a number of years – often based on relatively small allocations.

With the approval of the astronomical satellite HIPPARCOS additional activity arose with the preparation of data analysis procedures. Beginning gradually in 1980 it became a large project with studies of a number of aspects in 1985 continuing on a slightly lower level, after the launch of the satellite in 1989 with analysis of actual data. The work which was undertaken within a consortium of British, Danish and Swedish scientists resulted in a catalogue of highly accurate position data of more than 100 000 stars and in the additional TYCHO project of more than one million stars.[64] From a modest initial sum the support rose to about 700000 DKK per year, totalling about 10 million DKK, see Fig. 2. To this sum should be added the contributions by other members of the consortium.

It should be mentioned that the Danish Space Research Institute participated in the HIPPARCOS project and supported Danish and Swedish scientists in their analysis of data with computer time.

Earth Observation

It seems that satellite remote sensing in relation to ESRO/ESA came to Denmark in early 1972 with a visit by Regier Tessier[65] who invited Danish scientists to participate in the forthcoming application programme of ESRO/ESA. He has a background in geology and through contacts in Denmark a meeting was organised in Copenhagen by the Director of the Geodetic Institute, Professor Einar Andersen, with participation from various research institutions. The meeting expressed a general interest in following the development of the new technology but in a *tour de table* it appeared that only one of the participants had any experience in

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62 High-Energy Isotope Spectrometer Telescope

63 *Nature*, Tightening the purse string, Vol. 415, 14 February 2002. p. 730.

64 The activity was headed by Dr. Erik Høg of the Astronomical Observatory, who received the Director of Science Medal in May 1999. The Hipparcos and Tycho Catalogues are available as ESA SP-1200 in 16 volumes.

65 Associated with the Directorate of Planning and Future Programmes of ESRO/ESA, Neuilly, France, headed by Dr. André Lebeau.

remote sensing, through airborne radio echo sounding of the Greenland ice sheet.[66] At that time it was generally believed that the discipline of geology would be the foremost application of the techniques and it was agreed that Professor Theodor Sorgenfrei[67] should be the Danish contact to ESRO/ESA with the present author[68] acting as his deputy. Unfortunately, Prof. Sorgenfrei died shortly after so that the author participated in the first remote sensing meeting at Neuilly, France, in July 1972. This became the beginning of his more than 20 years of involvement in ESA remote sensing programmes serving as a Danish participant and delegate to various study groups, advisory bodies and programme boards.

At that time Europe was in a learning process, which was understood by the ESRO/ESA executive. In an attempt to alert European scientists a questionnaire was drafted and issued to a great number of organisations to learn how scientists foresaw the application of data observed from space. The result was rather discouraging in that a great number of the replies referred to the type of data that was already available, i.e. aerial photography with fine-resolution data that could not be achieved from space with the techniques available at that time. It is only recently – about 30 years later that this could be achieved. Very few had experience with the multichannel data that became available after the launch of the NASA Earth Resources Technology Satellite (ERTS-1) in autumn 1972.[69]

Another step in the learning process was the definition of a research facility that would be able to supply data to scientists from various campaigns over selected test areas and could serve as a test bed for new instruments. This action that was named the European Remote Sensing Aircraft Facility (ERAF) was inspired by a similar NASA facility, but the proposal worked out appeared to offer a better solution in that the aircraft chosen was designed so that a change of equipment could be made rather easily. The platform was a Breguet aircraft for submarine detection purposes, developed by Dassault, France, and therefore had a very long endurance of 12 hours. Perhaps just as important was the fact that it was designed with a non-pressurised equipment bay in the lower part of the fuselage so that experimental equipment could rather easily be exchanged without modifying the aircraft. Experiences from the radio echo soundings in Greenland in fitting advanced antennas to aircraft clearly demonstrated the advantage of this configuration. Again, we were not very good at selling our ideas. When the proposal was presented to the ESA Council for approval it was turned down with reference to national aircraft that were available in various mapping agencies although none of them were suitable for the purpose – and were in fact never used.

The advent of ERTS in 1972 created some interest in Danish research institutions involved in disciplines such as geology, geography, agriculture, glaciology and sea ice. Samples of data were acquired and analysed to study the potentials of this new technology. The data were in the form of photographs for each of the three channels and in an attempt at exploiting the multichannel features an optical device for combining the three-channel images was purchased by the Danish Meteorological Institute. However, difficulties in registration of the three images made this instrument less useful. To all parties it became clear that in order to fully exploit this type of data in a professional way digital processing was – and is – a must.

This was also concluded by a newly formed study group based on a suggestion by Christian Rovsing who had been visiting A. Frutkin of the NASA Office of International Affairs, to explore the possibilities of acquiring data from the Greenland area.[70] Based on a grant from the Space Research Committee the company had carried out a study of the application to Greenland that supported the view. This informal group was named the Danish Landsat Users Group and had members from all disciplines mentioned above.

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66 Laboratory of Electromagnetic Theory, Technical University of Denmark, participated in the Expéditions Glaciologique International au Groenland (EGIG) in the period 1958-69 led by Expéditions Polaires Francaises (Paul-Emil Victor) with participation from institutes in Austria, Denmark, France, Germany and Switzerland. The work comprised construction of low-frequency radars for airborne sounding, and a number of campaigns over the Greenland ice sheet were carried out to compile a map of the ice thickness. The work was supported by Danish foundations and the National Science Foundation, USA. and was extended to Antarctica together with the Scott Polar Research Institute, Cambridge, England.

67 Professor of Technical Geology at the Technical University of Denmark.

68 Associate Professor, Laboratory of Electromagnetic Theory (later Electromagnetics Institute), Technical University of Denmark, later Professor in Microwave Techniques at the same university.

69 ERTS-1 was later renamed LANDSAT 1.

70 Being a part of Denmark there is a long tradition for research in the fields of geodesy, geology and glaciology in Greenland and monitoring of the sea ice conditions in Greenland waters. The establishment of the Commission for Scientific Research in Greenland (Komissionen for videnskabelige Undersøgelser i Grønland) in 1878 is an indication of that.

In view of its large area and the climatic conditions, remote sensing was considered a valuable candidate for research in Greenland and an application for the purchase of a digital image processor was therefore presented to the Commission of Scientific Research in Greenland and to the Space Committee. The chairman of the Commission, Professor Isi Foighel, took a special interest in the matter and worked out with the Ministry for Greenland that various ministries were invited to participate in funding the device which at that time was very costly indeed (3 million DKK). In parallel, the Commission undertook to carry out an investigation with 17 laboratories and industries as to the need for such a facility. Of these 11 presented projects that would take advantage of the facility and the remaining indicated a general interest. It is worth noting that 15 replies were related to work in the Greenland area. With contributions from various research funds[71] a computer with suitable analysis software was purchased from TRW, California, and installed in 1980 at the Electromagnetics Institute under the name of DK-IDIMS (Interactive Digital Image Manipulation System). The Commission donated the salary for an engineer in a three-year period that should support users from all categories in exploiting the possibilities. This proved to be a very important asset since many researchers at that time had very limited experience in handling digital data, and by this means the computer really served the purpose of introducing Danish science to application of remote sensing data. In some cases the support also included assistance in programming of theoretical models and for other applications that exploited such data.

In 1984 this computer system was replaced by one donated by IBM Denmark. In this connection a guest professor undertook to run a course on digital image analysis for the benefit of researchers and students – including several from outside the university – based on lecture notes that later appeared in book form.[72] The course was continued for a number of years as part of the curriculum of the university.

Experience soon showed that data acquisition over the Greenland area which was relying on the tape recorder onboard Landsat was too scant, also due to the frequent cloud cover of the area. In order to improve the situation the possibility of real-time acquisition by a suitably located receiving station was considered. The NOAA receiving station established by the Danish Meteorological Institute in Narssarssuaq, South Greenland, could not be used without major and costly modifications. In this context it was suggested by Asger Lundbak[73], responsible for the meteorological data acquisitions, that the best position for a receiving station would be in Iceland which would give data coverage of all of Greenland and a great part of northern Europe. The idea was presented to the Earth Observation Programme Board, but it turned out to be only wishful thinking.

With the same token an action was taken when it became known that Canada considered establishing a receiving station in the eastern part of the country. A position that was considered at Shoe Cove, Newfoundland, would have been ideal from a Greenland point of view. The Ministry of Foreign Affairs was approached in October 1974 to establish contact with the Canadian authorities to inform them of Danish interests, but with no result.

In the summer 1973 the Royal Norwegian Council for Scientific and Industrial Research suggested that a joint Nordic Landsat ground station be established in Tromsø, northern Norway, extending the activity of the telemetry station already there. The idea fostered by Knut Melby, head of the Space Activity Division of the Norwegian Research Council, was that scientists should jointly apply for support from existing funds for Nordic co-operative economic and cultural projects[74] to improve the possibilities for receiving multispectral scanner (MSS) data from the Landsat satellite already in orbit and those planned for. The idea was picked up immediately by the Landsat Users Group since experience had shown that very few data were acquired from Greenland since acquisition depended upon the NASA programming of the on-board recorders that had a limited capacity. The position of a station in Tromsø was almost ideal since all of Greenland would be covered for real time reception of data from the satellite, except for a small part in the north-western corner. The scientific activity in Greenland was limited at that time and could not justify the establishment of a station in Greenland so a joint project was ideal from a Danish point of view.

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71 Including the Space Research Committee (2 million DKK) and the Natural Sciences Foundation (0.5 million DKK).

72 Wayne Niblack, *An Introduction to Digital Image Analysis*, Strandberg Publishing Company, Birkerød, Denmark, 1985, 213 pp.

73 Geophysicist at Danish Meteorological Institute.

74 Instituted by the Nordic Council, a governmental cooperative body of Denmark, Finland, Iceland. Norway and Sweden.

A series of meetings was held in the summer and early autumn in the different countries to write up the scientific justifications for having access to Landsat data in support of an application with participation from Denmark, Finland, Norway and Sweden. The meetings were held in a positive atmosphere until a meeting in Helsingfors in spring 1974 where the Swedish representative, Stefan Zenker, informed the meeting that Sweden had decided to establish it own station in Kiruna with Swedish funding. The Swedish Space Corporation apparently acted on the same grounds as the Norwegian Research Council in maintaining activities in remote places of their countries, such as Tromsø and Kiruna where Esrange had earlier been transferred from ESRO to Sweden.[75]

The present author was the Danish representative in these negotiations advocating the many applications, foremost in Greenland. In a recent correspondence with Arvid Øvergaard he wrote:

> *'I still remember the tension that arose when Stefan – clearly very much embarrassed – informed us of the Swedish decision during a meeting in Helsingfors. Having participated in the many meetings in good faith I felt that we were let down by the Swedish Space Corporation. To you who was the prime mover in the exercise it must have been even worse and I recall your pale face when you ran to the nearest telephone to inform Knut Melby'.*

Sweden allocated the funds necessary partly from regional development funds for the area of Kiruna and in fact Norway did the same when it secured national funds for development of the Tromsø Telemetry Station in 1976 with a view to receiving data from the forthcoming American satellite SEASAT-A that was launched in 1978.[76] The station should support the Norwegian enforcement of the 200-mile economic zone claimed at that time. It was a very advanced project for the time involving the development in Norway of a digital computer, CESAR, for processing the synthetic aperture radar data acquired the station. 'The rumour in Denmark said that the two organisations ordered their receiving antenna from the same American company within a time frame that allowed delivery in Narvik by the same ship".

EARTHNET

The Landsat Users Group supported ESA's idea of establishing EARTHNET with a receiving station in Italy to ensure LANDSAT data for other research issues than those in Greenland (spring 1977). However, the Space Committee took the attitude that this sort of activity be regarded a routine activity and should therefore be funded from the ESA General Budget. At that time the ESA appropriations were rather strained which probably was another tacit argument. Since other delegations did not want to load the General Budget EARTHNET was established as an optional programme without Danish participation in spite of the interest and the fact that Danish users took advantage of the system. It was a relief to the Danish delegation when EARTHNET finally became financed from the General Budget in 1980.

In order to alert potential users, the idea of so-called National Points of Contact (NPOCs) was suggested with entities in the ESA member countries. With the contacts made in conjunction with the operation of the image analysis facility IDIMS and later versions, the Electromagnetics Institute assumed the responsibility for the Danish NPOC. In this context, a file of LANDSAT and later also ERS SAR data was established covering Denmark proper and Greenland.

SPACELAB

When the SPACELAB programme was introduced by the ESRO/ESA executive in 1973 it was presented to the ESA Remote Sensing Advisory Board as a laboratory where new ideas and especially new instruments including remote sensing equipment could be tested before being implemented for autonomous satellites. Work could be carried out onboard in what was presented as a 'shirt-sleeve' environment.

With the experiences of developing airborne equipment and the great cost of installation on an aircraft in mind this sounded very interesting indeed and was used as one of the arguments for the decision of the Space Committee to join the project. However, in the course of the development it turned out that they were promises without substance. As with aircraft, manned vehicles require extreme safety that results in great costs. A prerequisite for the laboratory environment was the availability of windows designed for transmission of radio signals to outside instruments. This proved to be a costly and difficult task.

75 Stiernstedt, J. *Sweden in Space*, ESA Publications Division, SP-1248, 2001, p..229.

76 *Making Sense of Space, The Norwegian History of Norwegian Space Activities*, J.P. Collett, 1995, pp. 254-257.

However, the decision had a positive effect since in order to get ideas for exploitation of SPACELAB a two-man team was asked to tour Canada and the USA in 1974 visiting a number of research and industry laboratories. It concluded, that the chances of using SPACELAB for testing remote sensing equipment were scant. Another point was that the inclination of the orbit of the Space Shuttle that should carry it would not give coverage of the Greenland area. Based on the observations made it was suggested that instead, development of techniques for using remote sensing data in general would be a good approach, including digital image processing. This conclusion was followed-up with a proposal to the Space Committee for work related to Greenland applications, a work that continued over several years and in fact was another lever for the purchase of the DK-IDIMS referred to previously.

SPOT

In 1977 France took a lead by suggesting, as prescribed in the ESA Convention, that a remote sensing satellite that was studied by CNES, Satellite Preparatoire de Observation de la Terre, SPOT, be *Europeanised*, i.e. to become an official ESA programme. As part of the exercise a French delegation came to Denmark – even twice – to introduce the programme to authorities and the research community. The idea was received with great interest and by Danish industry in particular. However, the experiences with LANDSAT data and the frequent cloud cover of Denmark as well as Greenland made some potential users reluctant to support the proposal. Literature had shown the potential of radar and the experience of the Electromagnetics Institute with a side-looking airborne radar had demonstrated the advantage of this technique in the Greenland environment. Moreover, at that time early information about SEASAT became available (and rumours about corresponding US military satellites) that indicated application of active microwave techniques from space independent of light conditions and clouds. Data from the NASA aircraft tests in 1974 with a multichannel microwave radiometer over the East Greenland Current which were available to the Electromagnetics Institute through a co-operation with NASA Goddard Space Flight Center demonstrated clearly the advantages of microwave techniques for large-scale sea ice observation.

Thus, the Greenland mantra again played a role so that the Danish delegate to the ESA Remote Sensing Committee adopted a wait-and-see attitude. It was resolved when France announced that she had decided to proceed with the programme as a national programme with participation by Belgium and Sweden.

In retrospect one cannot help wondering whether we would have had the ERS satellites if the French proposal had been accepted. However, the SPOT programme helped the ERS-programme on its way when the French delegation insisted upon the application of the SPOT platform for ERS as a condition to participate in that programme (although it was not very suitable for carrying the SAR antenna).

ERS

At the time when NASA's SEASAT programme became known in Europe the question of reception of data in Europe appeared in the Remote Sensing Advisory Group that recommended to the Programme Board that ways be found to effect this. At the same time the European Association of Remote Sensing Laboratories (EARSeL) had its first General Assembly (1977) in which a working group was formed under the name of SURGE (Seasat Users Research Group of Europe). The task of this group was to organise the application of data if actually received within the European area. The UK delegation to the Programme Board suggested that the RAE[77] Oakhanger Station in southern England be modified to receive the SEASAT data in real time very much supported by the EARSeL Chairman, the author, who happened also to be the Danish delegate. The Oakhanger station was ready in time for the launch of the satellite that took place in June 1978 and an agreement with NASA and ESA/Earthnet ensured that a series of data were acquired. Unfortunately, the satellite lived only 100 days so that most of the preparations made at European laboratories proved to be in vain – including the Danish ones. Fortunately, a large oceanographic programme in the Atlantic Ocean west of Scotland, under the name of JASIN (Joint Air-Sea Interaction Experiment), was planned before the SEASAT opportunity appeared and was in action in the period July-September 1978 so that a data validation for the Synthetic Aperture Radar (SAR) and the wind scatterometer on board the satellite could be made. Other data did give very valuable information as to future design and applications of space borne SAR, wind scatterometer and altimeter.[78] The short mission did serve the very important purpose of supporting the ideas of an ocean satellite built by ESA – but with a greater inclination so that all of Greenland would be covered.

77 Royal Aircraft Establishment.

78 Some of the results obtained are reported in Satellite Microwave Remote Sensing, (T.D. Allan, ed), Ellis Horwood Limited, 1983, 526 pp.

In 1978-79 ESA initiated a number of studies entitled Coastal Ocean Microwave Monitoring System (COMMS)[79] related to applications in which the Electromagnetics Institute, Technical University of Denmark, participated through a number of contracts based on its experience with microwave instruments and participation in the NASA NIMBUS Experiment Team since 1974 with microwave radiometry. Over time the institute had about 70 contracts including field campaigns and participated in various study groups mostly related to microwave radiometry, including the Multichannel Imaging Microwave Radiometer (MIMR)[80, 81] and present day work on MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) leading to the Earth Explorer SMOS mission (Soil Moisture and Ocean Salinity).

The financial aspects of the ERS programme faced difficulties. To the amazement of the Danish delegation they were only resolved by separating the industrial part of the programme (Phase C/D) from the exploitation phase (Phase E). Illogically, the programme was initiated – after several attempts at reaching the 90% financial level – without ensuring that the satellite actually could be utilised when launched. Politics is not always logical. Also, the problem of financing Phase E was resolved only when the four larger member states (D, F. I, UK) offered to establish the so-called Processing and Archiving Facilities (PAF's) dealing with the handling of the different instruments onboard the satellite. Still, when it was disclosed that the operation of the facilities should be covered by the programme the Danish delegation changed its mind so that the contribution was reduced to 1.35% in stead of the intended BNP of 2%, a level that was maintained at each new negotiation about the extension of the exploitation of the satellite in its nine-year life time.

With a view to future operational satellite missions ESA suggested to implement the so-called Broad-band Data Dissemination Network (BDDN) so that data could be distributed to users shortly after acquisition. The idea was to use a system that was already developed in Norway and implemented for surveillance of its coastal waters. However, with Norway at that time only having the status of associate to ESA the Swedish delegation insisted that a Swedish design which was on the drawing board should be used, so a decision was delayed until this could be properly presented. A receiving station was established by ESA in 1991 at the Danish Meteorological Institute and operated satisfactory after a series of compatibility problems. When actually in operation it proved to be very valuable for Danish users, demonstrating the concept of dissipation of processed SAR data with a delay of only one or two days for the polar and sub-polar areas within the coverage of the Kiruna Station. A catalogue of data was compiled but unfortunately, the schedules for acquisition and processing were not well defined to make systematic investigations possible.

As part of the promotion action by ESA the Programme of International Polar Ocean Research (PIPOR) was established as proposed by the mission manager, Guy Duchossois. Being labelled as an ocean and ice mission it was a logical way of promoting ERS and SAR data in particular. The programme included scientists in Denmark, France, Germany, Norway and United Kingdom and from Canada and the United States and was organised with two Co-Chairmen, one from Europe and another from the United States, and a Coordinating Office at the Alfred-Wegener-Institut für Polar- und Meeresforschung. A number of joint planning meetings took place, defining areas of interest, i.e. sea-ice frequented areas and data acquisition schemes.[82, 83]. Of special interest was the definition of two periods of acquisition with a three-day repeat cycle during the northern winter months, January-March, to study sea ice dynamics supported by special

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79 In parallel, another series of studies was carried out under the name of Land Application Satellite System (LASS).

80 MIMR was designed for inclusion in the Polar Platform for Earth Monitoring (POEM, a forerunner for ENVISAT), and being essentially a monitoring instrument it was included in the list of potential instruments for the METOP series of meteorological satellites. Although brought very far in the design phase, EUMETSAT decided not to include the instrument in the payload.

81 The Multi-frequency Imaging Microwave Radiometer Instrument Panel Report, ESA SP-1138, 1990, 39 pp. MIMR – The Multifrequency Imaging Radiometer, MIMR Science Advisory Group, SP-1245, 2001, 49 pp.

82 Programme for International Polar Oceans Research, 1985, ESA SP-1074.

83 Two of the meetings took place under rather serious winter conditions. One in New York City (Columbia University) at low temperatures and strong wind so that the conference room could hardly be heated. Another was in ESRIN when the Frascati area had frost and was covered by several centimetres of snow the night before the meeting.

ground activities.[84] A number of papers based on this programme were presented in a special issue of the International Journal of Remote Sensing in 1995.[85]

Sea Ice in Greenland waters

The Electromagnetics Institute, Technical University of Denmark, has taken part in all these activities based on financial support from the Space Committee over more than ten years, involved in projects designed to develop methods applicable to geophysical studies related to the Greenland area, ice sheet and especially sea ice. Examples of projects are the East Greenland Current Project, the Greenland Sea Project (carried out with four other Danish institutions and laboratories) and MIZEX 93.[86]

Image processing

Data from Landsat and the NOAA meteorological series of satellites are used extensively for sea ice and vegetation studies. In the context of the latter, the Geographical Institute of Copenhagen University has developed an image processing system with the acronym CHIPS (Copenhagen Image Processing System) that is being used extensively in projects in Senegal and other third-world countries. A special feature of this activity is that the system is freely available to co-operating partners in the countries in question but also to other groups, the idea being that in this way contacts are made with a wide circle of scientists and technicians. The development has been supported by a grant from the Space Research Committee and the system is continuously being upgraded.

Microgravity

With the Post-Apollo programme and the subsequent approval of the ESA Spacelab programme in 1973 interest arose in Denmark to explore the possibilities offered by a zero-gravity environment in the fields of crystal growth, biological research and various physiological research. These investigations continued in connection with the European Retrievable Carrier (EURECA) programme initiated in 1981.

It appears from Fig. 1 that in the period 1978-1995 Danish scientists received a substantial support for their research related to these programme with space medicine being the top scorer of all activities in the period. Space Medicine received a total of about 28 million DKK whereas the other research received relatively modest amounts of about 2 million DKK for crystal growth and about 3 million DKK for plant research.

Crystal growth

The research related to growth of organic crystal in a microgravity environment was initiated by the Physics Laboratory III at the Technical University of Denmark. It was labelled ES 332 and was operated in parallel with a French proposal, ES333. It included a temperature-stabilised oven that was developed and built by Terma Elektronik A/S in Aarhus which was ready for testing in 1980. Spacelab was launched in 1983 and the experiment must be characterised as successful. At that time the partners became involved in the development of the Solution Growth Facility as part of the Spacelab Follow-on Development Programme in which Terma Elektronik was prime contractor in the concept definition study for ESA. The experiments finally concluded with the launch of Spacelab in 1991 after a long delay due to the Challenger accident. In parallel, the Physics Laboratory exploited the NASA Long-Duration Exposure Facility on the Space Shuttle with organic platinum salts and calcium carbonate and calcium tartarate crystal growth, the latter two with success.

An investigation was undertaken by the Chemical Laboratory of the Royal Veterinary and Agricultural University of Copenhagen to study the mineralisation and the demineralisation in bones under zero-gravity conditions – more specifically crystallisation of calcium phosphate under microgravity conditions compared with that under terrestrial conditions. The studies exploited the Solution Growth Facility on EURECA when it was launched in 1991 and concluded in the 1993-94 framework.

84 They took place in 1992 and 1994. It was a nuisance to other users depending on the 35-day acquisition plans otherwise exploited and pressure was exerted to abandon the latter period. It was maintained but it is the irony of nature that in this period there was almost no sea ice to study in the Gulf of Bothnia – one of the operationally interesting areas – with plans for simultaneous ground studies.

85 *International Journal of Remote Sensing*, 1995, Vol. 16, No. 17, pp. 3221-3479. Guest Editor: Mark R. Drinkwater

86 Marginal Ice Zone Experiment with contributions from several countries.

Biological research

Two projects were undertaken in parallel with a view to exploiting the Botanical Facility on EURECA. One was proposed by the Institute of Molecular Biology and Plant Physiology at Aarhus University to study the effect of a microgravity environment on cell wall regeneration, cell division, growth and differentiation of plants from protoplasts[87] and tissue cultures. Initially, the study included selection of the best plant material and assisted ESTEC in specifying the plant growth facility in co-operation with the Botanical Institute of Trondheim University, Norway. It continued with the design of a plant growth chamber for the NASA Biorack for the International Microgravity Laboratory Space Mission (IML) in this case in co-operation with Chr. Michelsens Institutt in Bergen, Norway, and the Jutland Technical Institute, Aarhus, the latter being responsible for the construction of the facility. While waiting for resumption of the Space Shuttle flights after the Challenger accident contacts were made with the Soviet Biokosmos series of experiments. An experiment on Biokosmos-9 carried out in September 1989 in co-operation with a group at the University of Tübingen, Germany, demonstrated that the growth and development of plant protoplasts is reduced compared to that observed under terrestrial conditions. The experiments were resumed on Biokosmos-10 with equally good results. The IML-1 mission was flown in January 1992 which again demonstrated that the cells are unable to regenerate to full plants under low-gravity conditions. During the 14-day IML-2 mission in July 1994 the development of plant root structures was studied, leading to the statement that the perception of gravity lies in the root.

Other studies were undertaken by the Institute of Physiological Botany of the Royal Veterinary and Agricultural University of Copenhagen addressing the problem of auxin translocation and differentiation of tissues of protoplasts of pea plants under microgravity conditions. The group went into the problem of controlling the plant growth by means of controlling the atmosphere to study the effect of low oxygen and light on the senescence of intact plants and excised leaves. For this purpose the development of a solid-state sensor was undertaken in co-operation with the company Dansensor System A/S, Tølløse, Denmark, to control the content of oxygen and carbon dioxide in gas and fluid states.

Space medicine

With a view to exploiting the possibilities offered by Spacelab under the maxim of 'Man in Space' the Space Committee accepted in 1978 an application by Flemming Bonde-Petersen M.D. for initial studies of low-gravity human physiology. The application may be considered a natural development of research on the functions of the human body undertaken at the August Krogh Institute of Biochemistry and Physiology of Copenhagen University since early 1900 and was inspired by a visit to the Health Science Center, University of Texas which worked with NASA on the adaptation of the functions of the human body to microgravity conditions.[88]

The early studies involved work with test persons in simulated low-gravity conditions using head-down tilt of the test persons, with the first results being presented in 1979 at an ESA sponsored international symposium in Copenhagen on 'Human Cardiovascular[89] Adaptation to Zero Gravity'.[90] In addition to the international contacts made the meeting also raised interest with other medical researchers in Denmark who proposed various complementary studies.

In the following years further studies were supported by the Space Committee and continue today. In addition to low-gravity simulations by tilting the body they also included water immersion, negative and positive pressure of the lower body, neck suction and head-up tilt as well as parabola flights which give a few seconds of weightless conditions.[91] The research was pertaining to subjects such as cardiovascular physiology, the physiology of the lung, and endocrinology.[92] The latter is related to the water and salt balance of the body studied by water immersion of the test person. In total about 250 test persons have been subject to these experiments.

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87 A protoplast is an open cell without walls.

88 This section is based essentially on an article by Flemming Bonde-Petersen in the Annual Report of the Space Committee for 1987.

89 Pertaining to heart and blood-vessels.

90 ESA SP-1033,1981.

91 A Gulfstream jet aircraft of the Royal Danish Air Force,

92 Pertaining to the production of hormones that controls the blood concentration, the lower body functions including the function of the kidneys.

In order to be able to carry out these investigations the methodology had to be developed including construction of suitable instruments. Thus, a non-invasive method of measuring the heart function has been developed comprising an infrared photo-acoustic method which replaces the much heavier mass-spectrometer previously used. It is marketed under the name of Respiratory Measurement System (RMS). Apparatus for the different kinds of simulation experiments have also been developed. A special development is the Cycle-ergometer that was developed for use – and is being used – during space flights. The institute took a great interest in the design of Anthrorack

With the solid background obtained from its research the institute suggested a number of experiments to ESA that were accepted for the German D-2 mission on the Space Shuttle. They are: DK-17: ‘The central venous blood pressure in the transition from 1-G to zero gravity’; DK-22: ‘The water and salt balance during long space flights’; DK-35: ‘The respiratory function of the lung’ and DK-44: ‘The central and peripheral blood flow during rest, work and lower-body negative pressure’.[93] The institute should deliver the necessary measuring equipment developed in close contact with industry (AMIS A/S and later Innovision A/S).

Originally placed at the August Krogh Institute the facilities were later (1985) transferred to the Copenhagen University Hospital under the name of the Institute of Aerospace Medicine. In order to promote co-operation between research and industry the organisation changed its status in 1988 to a limited company under the name of DAMEC Research A/S with involvement by industry, but still associated with the Copenhagen University Hospital, and now headed by Peter Norsk M.D.

With its great involvement in the ESA Microgravity Programme and the many international contacts in mind the idea surfaced in 1988 to enlarge the activity of the institute to become an internationally recognised ‘User Support Centre for medical survey of astronauts during European space flights’. The Space Committee endorsed this idea by approving a large increase of the support so that additional investments could be done. This is the reason for the large sum allocated in 1988 reaching 3.5 million DKK and the rather high support the following year for further expansion and research, see Fig. 2. This work led to a close co-operation with the European Astronaut Centre at DLR in Cologne.

However, as pointed out by Flemming Bonde-Petersen[94]

> *‘Space research takes time. The preparations for a mission are extremely extensive. Patience is not only a virtue but also a necessity especially in connection with the many and unfortunate delays that occur’.*

And he goes on by describing in broad terms the planning of the work of the institute to reduce the impact of the delays. To this statement he could have added the words ‘very costly’, see Fig. 1. However, the activity resulted in many scientific publications and some Doctor theses and in addition to the D-2 mission DAMEC Research A/S was qualified to participate in the EURO-MIR 1995 mission and several experiments on the International Space Station. There appears to be a close co-operation between this company and the present Innovision A/S, Odense, Denmark

In parallel with the above-mentioned studies complementary laboratory work was carried out by the Medico-physiological Institute of the Copenhagen University to study the water balance of the body at gravity stress and simulated low-gravity conditions. They included studies of various physiological control systems on the internal environment of the body subject to slow tilting of a test person (homeostasis). Great renal sensitivity was discovered, leading to a study of the kidney function associated with endocrine changes under salt-water infusion during non-gravity conditions. This is related to the DK22 experiment on the D-2 mission.

Another activity was undertaken at the Otoneurological Laboratory at Copenhagen University Hospital of the vestibular-ocular[95] response to accidental active and passive movements of the head. It has a bearing on space motion sickness. In this context equipment and associated software has been developed to measure compensatory eye movements associated with turning of the head – partly associated with Anthrorack. Proposals to ESA and NASA were worked out, the latter in co-operation with a laboratory at the University of Southern California.

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93 The D-2 mission was flown in spring 1993 giving good but also surprising results. It was found that the mechanisms studied all behaved differently from what was expected from the Earth-based simulations carried out as part of the experiments. Peter Norsk in Berlingske Tidende, 26 April 1995.

94 Translation from Danish by the author.

95 The cavity of the inner ear and the eye.

Overall this selection of the most important (or costly) projects undertaken with support from the ESA Follow-on Appropriation shows a very great activity that has scored well in terms of the number of accepted experiments on Spacelab and the International Space Station. In several applications for support to the Space Committee it was argued that the simulated experiments carried out on ground and the corresponding measurements on test persons in space (astronauts) may lead to a better understanding of the control mechanisms of the human body – the water and salt balance, the heart, the lungs and the kidneys, for instance. However, when addressing the question of the application of the space medicine research, Peter Norsk related his reply.[96]

> *'to fundamental research in general. The answer is that the community known today is the result of the questions asked by man: WHY? The human race differs from animals by abstract thinking and by curiosity, which is led by more than just needs and survival. The day when we no longer can afford fundamental research, culture and arts that do not have a clearly defined utility, on that day the development of the community ceases'.*

96 Berlingske Tidende, April 1993 (on the occasion of the D-2 mission); translation from Danish by the author.

6 ESA Optional Programmes and Involvement by Industry

During the ESRO era the overall industrial return coefficient for Denmark was very low, largely due to an immature industry. In the period of transfer from ESRO to ESA representatives of the latter organisation presented the Danish authorities with schemes that were likely to improve the situation of the Danish return coefficient. In fact these schemes were referred to as an argument in the proposal to the Danish government by the Space Committee. Also, it was advocated that through contracts with ESA Danish industry would be involved in technology that was more advanced than would be realistically the case at the national level. Management schemes of such contracts was seen as another asset.

In the course of time these schemes proved useful with return coefficients ranging around 1.0 for many years now. In 1990 it reached 0.90. At a certain moment in time the return coefficient became so high in a certain programme, however, that it was necessary to compensate for this by reducing contractual involvements in that programme. Industry felt that the allocations for ESA contracts should be increased 'in order to ensure that the expertise that rests with Danish companies, often acquired by way of ESA contracts was exploited to the maximum'.[97] It should be understood that such an unfortunate problem arises from the principle adopted by the delegations to ESA that the industrial return coefficient be calculated for each optional programme. A change of this principle suggested by the Danish delegation to ESA could not find support in spite of the fact that many of the negotiations taking place in various programme boards due to complaints by certain member states on the issue could be avoided by determining the overall return coefficient for a number of programmes and specified time period. At any rate, in the case of a Danish 'over run' it is a question of small money compared to those contributed by the larger member countries and the problem appears somewhat ridiculous in the context of the total of ESA contracts.

By the same token a Danish company found that a contract went to a company in another country which did not have the experience in the field in question, in order to adjust for a low return coefficient.[98] Similar surprises also turned up at the national level though. When EUMETSAT was formed in 1986[99] the Danish Meteorological Institute adhered to its convention that involve a contribution at the BNP level for the construction and operation of follow-on satellites to Meteosat-1 and 2. Through contacts with ESTEC a company expected to be involved in the latter and invested in a clean room to be able to meet the stringent delivery terms. However, the Meteorological Institute did not succeed in securing the necessary funds from the Ministry of Defence in time and since the Space Committee felt unable to support what it considered an operational service, Denmark adhered with only a symbolic contribution. The result was that the company was not considered when the industrial work was contracted out.[100]

The annual appropriation from the government has always been lower that what corresponds to a Danish contribution at a BNP level, in the range of 1.8 – 2 %. Thus, participation in new optional programmes becomes a matter of priorities, the interest of Danish industry in the technology involved and the estimate of the chances of obtaining contracts within the individual programmes. A decision is made by the Space Committee based on a proposal worked out by a subcommittee that includes officials of the ministry and the industry representatives on the Committee who liase with interested parties. (More correctly we should say that the Space Committee advises the ministry on the matter, but an advice has never been turned down. This applies also to the apportionment of the annual Follow-on Appropriation).

Denmark has participated in most ESA optional programmes but often with a contribution of 1% or even 0.5%. It was often argued by industry that it was important to participate in the initial study phase, Phase A, even at a low level, to give industry an opportunity to judge the quality of the technology involved in later phases. It was considered a sort of an admission ticket to later phases of the programme in question. By the same token, participation has been proposed concerning the many technological and preparatory

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97 Mackintosh, J. and P. Gudmandsen, 2001. Interview with Knud Pontoppidan and Frank Jensen, Danish History Project, Introductory Studies, Final Report p. 37.

98 *ibidem*, Interview with Chresten Overbech, p. 33.

99 Krige, J. Crossing the Interface from R&D to Operational Use, The Case of the European Meteorological Satellite, *Technology and Culture*, 2000, Vol. 41, pp. 27-50

100 Mackintosh, J. and P. Gudmandsen, 2001. Interview with Johannes Jacobsen, pp. 35-36.

programmes ESA has suggested through the years with a series of cleverly labelled names and contents, such as EOPP (Earth Observation Preparatory Programme).

Special cases are programmes like ASTP (Advanced Science and Technology Programme) where direct negotiation takes place between an institute or industrial partner and ESA about a special development. Funds are allocated for this purpose on the annual budget of the Committee but only spent on the basis of an application from the party interested as a result of a successful negotiation with ESA. However, lacking an industrial policy, handling of these applications is somewhat difficult and requires some iterations to match the tasks to the available funding.

Other cases were the Ariane and the Hermes programmes. The size of these programmes were such that they could not be accommodated within the government appropriations but since they could be characterised as engineering or industrial types of programmes rather than research the payments were made from funds made available by the Ministry of Trade and Industry over a number of years.

At a certain moment (April 1985) it was argued that the ESA industrial contracts could be regarded as a government subsidy to industry and that industry therefore should contribute to the Danish ESA budget. The idea was adopted from similar considerations in Sweden where a contribution of 7% was suggested. Industry argued that ESA contracts in general were so advanced and demanding that often it had to relax on overheads and in that way actually contributed the contracts. If it were a matter of savings on the government budget industry would prefer that the Danish contributions be reduced by the 7%. Later in the year the idea was abandoned.

An impression of the involvement of Danish industry may be obtained from an investigation carried out in 1987 of the indirect economical effects (spin-off) of ESA contractual work[101] based on the period 1977 to 1986. The investigation was carried out by the Louis Pasteur University in Strasbourg which had carried out a similar study for ESA from which the Danish activities could be extracted. In addition, interviews were undertaken with seven institutions and companies which held contracts with ESA in order to check their understanding of the effects of the contractual work, more specifically four categories of products were considered:

- technological benefits, i.e. sales of products, components or services that are technologically derived from the work done for ESA
- commercial benefits, i.e. increase of sales without any determinable technological innovation (international co-operation, industrial networks established etc.)
- organisation and method benefits, i.e. improvement of technological knowhow, new management methods, etc.
- the work factor benefits, i.e. improvement of personnel knowhow, creation of staff of highly qualified engineers (reach new complex contracts and maintaining teams in an intensive R&D environment).

The organisations approached included software and hardware companies, a research company and a university institute. In the period in question ESA contracts amounted to about 70 MAU (million accounting units) i.e. about 75% of the total Danish contribution to ESA (this may be regarded as an overall return coefficient) and the total amount of indirect benefits in the years 1977-1991 were estimated at 336 MAU, i.e. a ratio of 4.8:1.

The study also considered the revenue aspects of the activity and came to the conclusion that the total increased revenue based on the benefits was approximately equal to the total amount paid to ESA by the Danish government.

When presented to the Space Research Advisory Committee it was received with some reluctance. ‘Fortunately, paper is patient’ as one participant expressed it and later the Committee dismissed the report on the grounds that ‘the investigation does not fulfil the most elementary requirements of an analysis of the economy’. However, whether this is correct or not it is worth mentioning that in interviews carried out in 2000 with Danish companies still working with ESA the benefit coefficient was rated much higher in several

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101 Université Louis Pasteur, Bureau d’Économique Theorique et Appliquée, December 1987: ‘The indirect economic impact of ESA’s contracts on the Danish Economy’. pp. 41, 5 Appendices, pp. 28. Filed under 1112-52/87.

cases, although based on qualitative considerations.[102.] A figure of ten was quoted in one case (Alcatel Space Denmark) where international business in 1999 was much larger than ESA contracts by a factor of about ten.[103] One R&D company (TICRA) was founded in 1971 in connection with an antenna design contract with ESA with many more contracts to follow through the years. It is now acting in a much wider field of consulting and sales of special software in electromagnetics, thus offering another example of a success story.[104]

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102 Mackintosh, J. and P. Gudmandsen, 2001. Interview with Christian Rovsing, Danish History Project, Introductory Studies, Final Report. pp. 17-20.
103 *ibidem*. Interview with Chresten Overbeck, pp. 33-34.
104 *ibidem*. Interview with Knud Pontoppidan and Frank Jensen, p. 37.

7 Conclusions

Considering the evolution of space science and technology in Europe one cannot help thinking of the wise men who in the period around 1970 tried hard to save what had already been achieved in ESRO and succeeded in persuading their governments to continue the efforts in what became the European Space Agency. Based on the experiences gained from ESRO they could draft a convention that has proved its value over many years.[105] With its emphasis on application programmes it became possible to persuade – at the last moment – the Danish government to adhere to the convention. As will appear from the many lines above it was of benefit to Danish space research and to applications of remote sensing technology in meteorology and Earth Observation by introducing advanced techniques and methods to an extent that in most cases would not have been developed in national programmes. The many related activities at universities carried out under ESA contracts or with national funding were important for the education of research students and 'young scientists'. Also, Danish industry took advantage of the many possibilities that were offered in the development of advanced techniques and management methods. Those who succeeded agree that ESA contracts increased their knowhow. Although less than one tenth of the Danish contribution to ESA programmes, the so-called ESA Follow-up Appropriation managed by the Ministry of Research on advice from the Space Research Advisory Committee was and is an asset that 'ensures that the membership may be exploited in a productive way to the advancement of Danish research and industry'.[106]

105 Reflections on this issue may be found in *ICON*, Journal of the International Committee for the History of Technology, Vol. 6, 2000, pp. 50-66: 'Decision Processes at the European Space Agency' by P. Gudmandsen.

106 Mackintosh, J. and P. Gudmandsen, Danish History Project, Introductory Studies, Final Report, June 2001. Interview with Henrik Grage, pp. 26-29.

8 Sources

A great deal of the information that has been used in writing this report has been derived from the files of the Danish Space Research Advisory Committee including minutes of its meetings. This has been made possible through the introductory studies that were carried out with support from the ESA History Extension Project that secured these archives and placed them in order.[107]

Other sources were:

Annual Reports of the Space Committee, 1978-1994, that include short descriptions of the projects that were supported by the Space Committee through the annual ESA Follow-on Appropriation.

Annual Reports from the Danish Space Research Institute, 1968-1992, some of them issued as bi-annual reports.

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107 Mackintosh, J. and P. Gudmandsen, Danish History Project, Introductory Studies, Final Report, June 2001. 44 pp. Available from the Ministry of Science, Technology and Innovation, Bredgade 43, DK-1360 Copenhagen.