Personal Reflections / Observations

There are many documents describing the COLUMBUS program starting with initial ideas, many studies wrt program contents definitions (reducing the flight elements to one) and finally the formal documentation of the development, integration, verification and delivery of the remaining one flight element the Attached Pressurized Module (APM). I decided to write down some background information occurring behind the scene, which might be of common interest. Obviously my descriptions are not objective and other involved persons might have different opinions….

1. Configurations

Already during the final phase of the SPACELAB program some people at MBB-ERNO were thinking about a successor program. It resulted in a mini space station concept: just a pressurized SPACELAB module extended by a resource module. These ideas found interest first at the German delegation, then Italy got interested too so that MBB-ERNO and ALENIA were doing the first bi-lateral studies. After the successful SPACELAB flights and the financial success of selling a second SPACELAB flight system to NASA (FOP - Follow On Production) also other countries did show strong interest for a new manned space program extending the experiences gained so far so that ESA had only one choice to take over the management.

With big enthusiasm a visionary space station scenario was defined for first concept assessments:

- a free flying laboratory, which was visited by astronauts for maintenance and Payload exchange,
- a platform co-orbiting with NASA station Freedom,
- a service vehicle transferring astronauts to / from the NASA station docking to the free flying laboratory (strongly promoted by France / AEROSPATIALE due to similarities with HERMES),
- a small transfer vehicle for space-suited astronauts to visit the co-orbiting platform and the exterior of the free-flying laboratory based on Freedom,
- a long pressurized module permanently attached the space station Freedom ,
- a polar platform.

When more looking in the technical complexity and the programmatic impacts of such a complex scenario the number of flight elements had to be reduced to three. These items were considered feasible within Europe's know-how and economic capacity. From now on the COLUMBUS program entering the detailed definition / requirements definition phase consisted of the flight elements:

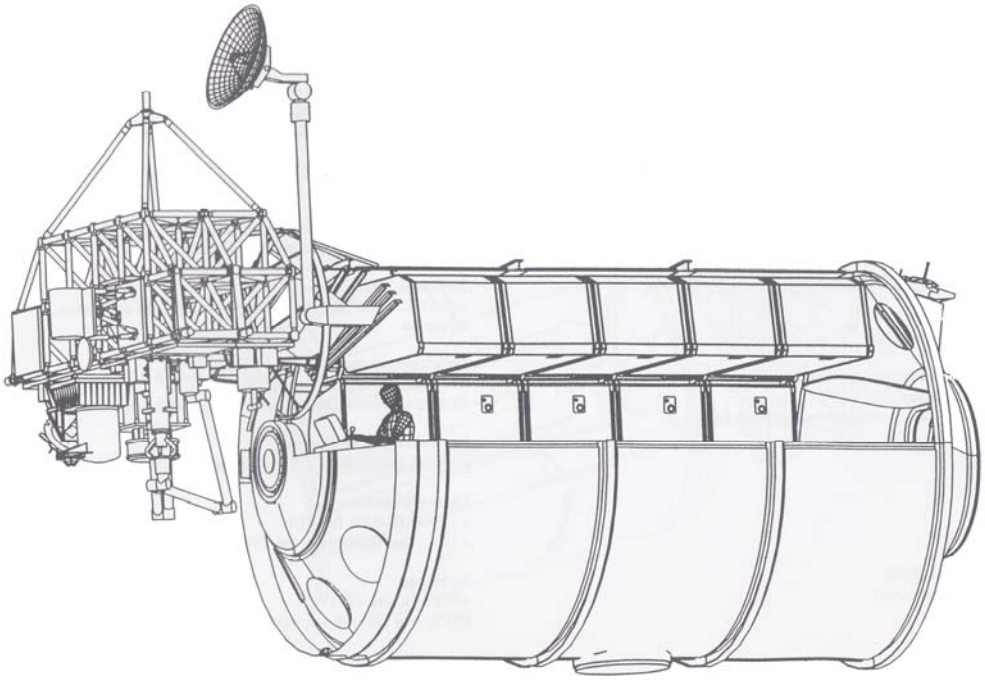
- Attached Pressurized Module (APM), no major change versus previous concept,
- Man-tended Free Flyer (MTFF), now flying to the space station for servicing and Payload exchange (3-5 year cycle) and in-situ by HERMES (180 day cycle),
- Polar Platform (PPF).

In parallel also NASA concluded that their station concept was too expensive and needed too many shuttle flights for building it up. Then the CHALLENGER accident caused even more serious discussions and de-scoping of the space station configuration. The technical changes and the revised schedule had also influences on the COLUMBUS program for which ESA had required a binding proposal for phase C/D in 1989.

The costs were quite above the ESA target as the different subcontractors were still not in favour of the MBB-ERNO approach with technical commonality (see section 2) and centralized parts procurement and the expected reductions were not implemented by the subcontractors. In the final proposal phase the COLUMBUS consortium high level management, which had not controlled the programmatic part of the proposal before final printing, did fall into panic and tried to define numerous cost reducing options but caused quite some confusion in the formal proposal so that an evaluation by ESA was practically impossible so that the proposal was refused by ESA.

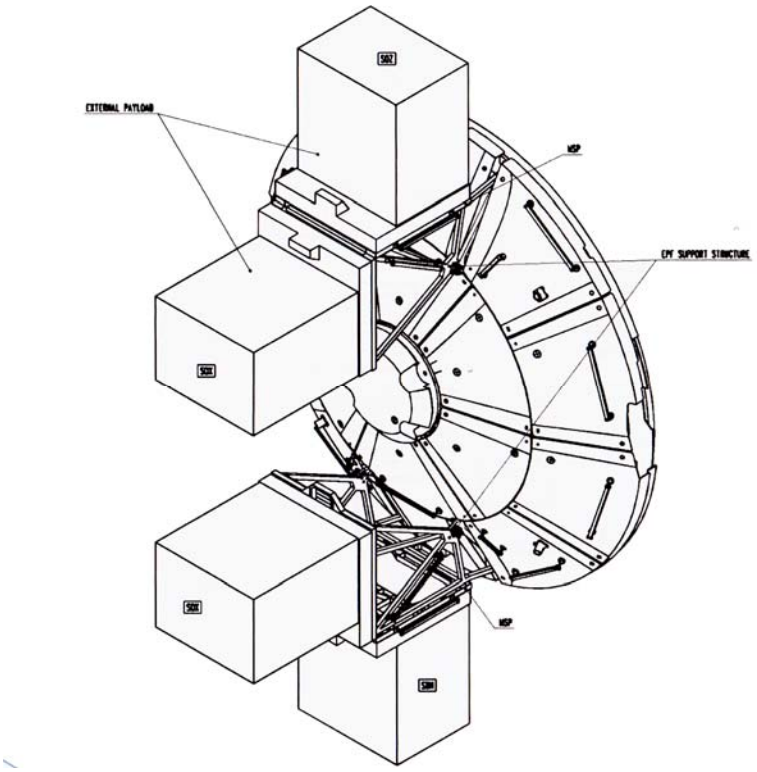
In the mean-time the economical situations in all countries had become worse - especially in Germany due to the reunification - so there was no interest to come by negotiations to an agreement and several delegations were fortunate to reduce / withdraw their commitments.
The COLUMBUS program contents were reduced step by step finally leaving only the APM entering phase C/D but also its configuration was cut-down and modified for cost saving reasons. A major one was the reduction of length but resulting in the advantage that it could now be launched including a first Payload complement by one Shuttle flight. Obviously the remaining concept – more or less SPACELAB with updated interior / functions – caused strong disappointment at the “old”, experienced team members (including me) as they had expected more challenging tasks.
It turned out that the COLUMBUS challenge was not so much in technical but management areas (see section 3).

In 1994 the Payload/Utilization Working Group requested reassessment and optimization of the APM for expanded utilisation capabilities taking into account the station modifications due to Russian involvement including the higher inclination orbit. Mainly external payload accommodation options with manipulator and improved pointing options were considered on their request. One concept was introducing a platform potentially based on EURECA initially placed on the station berthing port foreseen for the APM; the platform being later re-positioned on the end or side of the APM. Together with this extension a manipulator on the platform controlled from inside the APM with viewing on its operation was favoured by the Payload world. In addition a high speed data terminal communicating with DRS was to be studied.



External Payload Option

All these options were considered too expensive and rejected by ESA management but the ideas came back later on (now much more expensive due to the advanced status of the program though very much simplified); two structures added to the end cone for on-orbit payload accommodation became baseline of the APM (External Payload Facility EPF).



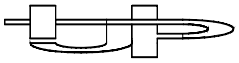
Final External Payload Configuration

Some time later also the accommodation of different concepts of high speed terminals on the APM were assessed but due to high impact rejected.

The conclusion on space programs implementation problems seems obvious; the contract starting point is governed by low costs in order to get the political agreement and later it is tried to improve the configurations by changes paying high costs and getting less performance. This behaviour is common at ESA as well as contractors.

2. Commonality

Already in the SPACELAB program commonality with the SHUTTLE was considered as advantage as one expects costs as well as risk reduction if one can rely on items, which are developed in a different program and only recurring / manufacturing costs are to be paid. The experiences made were not so favourable in all cases; it worked well for items, which were already in the manufacturing state whereas items still under development caused schedule impacts (though we were sometimes so clever to hide our problems behind commonality versus our customer / ESA).
The reason of these problems was seen in the fact that the Europeans had no formal control or even no transparency on the detailed status of these SHUTTLE-common items as NASA had no interest to discuss with us being considered as space-newbie's and did not allow intensive contacts with their contractors.



This disadvantage was considered irrelevant for commonality between the different COLUMBUS flight elements APM, MTFF and PPF as MBB-ERNO as prime contractor would be able to ensure the necessary control by proper contractual set-up with their subcontractors. The potential for cost saving due to commonality was seen for the Data Management Subsystem (incl. operating system software), Electrical Power and Guidance Navigation and Control subsystems.
The proposed principle was based on the following responsibilities:

- Element contractors deliver there specific requirements to the prime,
- Prime generates subsystem configuration(s) with commonality as far as considered advantageous and generates subsystem specification to be agreed by element contractors,
- Prime places contract with Common Subsystem Contractor Subcontractor (COSCO) for design and qualification of complete subsystem configuration (incl. element specific items),
- Element contractors place contracts with COSCO's element specific items (unit level verification and delivery).

The element contractors did not like this approach and stated it being impossible to take full element design responsibility under these conditions. All complaint at their delegates and these at ESA about this principle; especially BAE / Great Britain insisted on full responsibility.
Consequently the newly introduced ESA responsible for Station and Platforms Mr. Engstroem (before ARIANE responsible) requested a meeting with all parties at their headquarters in Paris. The MBB-ERNO COLUMBUS program manager Sami Gazey and I went there to explain our plan. From other sources I had heard the opinion that Mr. Engstroem is very strict and clear in wording if he considers something wrong and therefore I was a bit nervous having the duty to present our concept, the other element responsibles had warned us that they would rigorously fight against this commonality principle.

After some general discussions I had to stand up as first speaker. The presentation explained in detail the different task allocations / documentation flows to ensure that all involved needs were adequately covered.
Then the advantages expected for the program were shown with cost estimations where possible

- cost saving: only one systems engineering control authority per common subsystem subcontractor needed,
- risk reduction: only one subsystem to be developed,
- lower spares costs for operational phase for APM, MTFF and PPF.

The element contractors had no detailed presentations available and complaint in many words why such a "reduced" systems engineering responsibility is not acceptable to them; again BAE was the strongest opponent. As compromise the final proposal for phase C/D did contain two configurations:

- PPF "A" with commonality on COLUMBUS elements
- PPF "B" with commonality on SPOT-4/HELIOS and ERS-1.

Mr Engstroem was very objectively putting questions to the different parties in calm, Swedish behaviour and concluded that he considers the commonality approach as feasible and believes in the cost saving potential. I was really impressed by his way of chairing the meeting and we were flying home happily.

Finally weighting expected cost saving versus contractual risk on prime contractor site MBB-ERNO decided to implement formal commonality only for the Data Management Subsystem DMSS (MATRA).
The commonality for Electrical Power and Guidance Navigation and Control were not formally implemented because of the diverging arguments by the element contractors and the increased risk on the prime but these subsystem contractors were asked to implement common solutions for their deliverables to the different element responsibles in order to minimize costs and risk.

3. Technical Management/Organisations

After my study of Telecommunications at the Technical High school in Aachen (RWTH) I found my first job 1965 at ERNO in the Avionics group consisting of two persons in the main department Astrodynamics. Our initial task was the conceptual design of the data management and telecommunication aspects of the German Solar Probe HELIOS anticipated at that time.

ERNO had up to that time never led a space program with system responsibility but was a well-known subsystem supplier for satellite structures and thermal control (Azur, TD). As young engineer I did not know the upper level ERNO management and their plans for the company future but it seems it was recognized that only becoming responsible for a complete satellite would make the company future more successful and the German solar probe HELIOS could become this turning point.

As that project was in a very initial phase there was no integrated project team at ERNO and the working relationships between the different areas responsibles was quite inefficient as several were located at different locations in Bremen and the communication was limited to some meetings, telephone calls and transfer of drawings and longer text by manual mail coming two times a day.

The company had at that time a general consultancy contract with the American space company TRW in Los Angeles, very experienced because of their development of the PIONEER satellites for NASA. They did send a consultant to Bremen (Andy Parks) to do all to generate a successful proposal to the German Gesellschaft for Weltraumforschung (GFW). As first step he convinced the ERNO management to set-up an integrated HELIOS team located at one place. He worked daily with this core team (approx. 12 persons) like a trainer ensuring cooperation between all responsibility areas. Nowadays one would call it the HELIOS Systems Engineering team but the term “Systems Engineering” and its role was not known at ERNO at that time.
This guy was really a phenomena, he was originally an American lawyer but responsible for many proposals at TRW gaining a lot of experiences and feelings about satellite technical data, e.g. when reviewing data generated by us he questioned for instance weight or power consumption of a transmitter and analyzing the data again it was found that he was mostly right. He acted as successful team integrator and moderator and I think all members of the HELIOS team learnt a lot from him as they did show up later in other space system teams again. He used the term “Social Engineering” to motivate all to work together and help solving problems together. So a real team spirit (like a sports team) did build up by playing football together, arranging barbecues and rallies and last but not least to sit sometimes up to midnight in the “Kleiner Olymp” (a well known scene restaurant in the Schnoor area in

Bremen). For the C/D proposal the complete team went to L.A. to the TRW proposal centre and I was impressed by the professionalism of the experts and even the secretaries supporting us (any text prepared by us was properly typed over night).

Unfortunately ERNO did not win this proposal but not really due to technical reasons but price and no management experiences. Our competitor MBB changed their thermal concept of a double cylinder to the ERNO cotton reel (the biggest challenge for a solar probe going close 0.3 AU to the sun) showing it two weeks later at the industrial exhibition in Hannover. As for previous programs ERNO became subcontractor to MBB for structures and thermal control.

The next space system for which a binding phase C/D proposal was planned to be delivered was GEOS, the first ESA satellite on a geostationary orbit. The ERNO management had been strengthened by a Hans E.W. Hoffmann, a young engineer gaining first practical experiences as leader of the ERNO ELDO team, and so a competent team by transferring the related persons to the new GEOS system team was implemented; sometimes against the arguments of functional department managers. They wanted to keep their responsibility receiving complete subsystem contracts from outside ERNO which had worked well up to that time for them.

This time ERNO was leading the MESH consortium (Matra, ERNO, Saab, Hawker-Siddely) being responsible for the complete system design including management of subcontractors; it worked quite well even without external consultancies as previously for HELIOS. The binding proposal for phase C/D was judged in most points superior versus the competitive one in the ESRO evaluation except the geographical distribution.
This constraint is up to now a big hindrance for all European space programs as the different national space delegates insist to receive the same amount back the have committed to a program. The commitments are related even to phases of a program and in addition certain technical responsibilities are requested for the home space industries. Consequently sometimes strange situations occur e.g. when during a pre-phase the money allocation allows just a trip and one week work for a company as their field is considered not critical and relevant during this time.
As the ERNO GEOS proposal was not fully compliant in this area it was not selected by ESRO but contracted to the COSMOS consortium led by MBB; some insiders explained that it was just the time for COSMOS to get a new contract….

When there were indications that NASA had some financial problems in the realization of their challenging new manned space scenario consisting initially of a Space Shuttle and later of a permanently manned space station they contacted ESRO (the precursor of ESA) for potential co operations. The reaction of the Europeans was diverging but Germany was very optimistic and announced strong financial contribution. The first studies considered component responsibilities for Europe e. g. wings or landing gear and therefore some ERNO engineers worked within the American engineering teams in the states. Soon it became obvious that such design and development splitting over the ocean would be very risky due to its complicated interfaces and was abandoned therefore. The American and European space program responsibles and especially the German ministry for science and technology agreed after many meetings that only a complete element with a certain functional autonomy could be developed outside the states with manageable risk; the result was full development responsibility for the Space Shuttle Payload element (called Sortie Lab by the Americans) by Europe.

Personally I was frustrated about my activities at ERNO up to this time as there were only paper results and no real C/D program I could participate in. All experienced people I met somewhere stated that one can become only a "real" space engineer if one has had the responsibility for an item starting with the specification up to delivery and successful operation.
As I did not see an attractive future for me at ERNO I was searching for a new job in a different technical areas. The companies inviting me for an interview were AEG/ Hamburg, Siemens Eisenbahnsignaltechnik/Braunschweig and Bodenseewerk/Ueberlingen. All offered me an interesting job but they explained that they consider the space approach as being overloaded by documentation and therefore as too expensive and not useable for there activities and because of that my salary request could not be fulfilled fully. Due to these results I decided to stay with ERNO and that was my luck!

Beginning 1973 three phase B studies for SPACELAB (the American name Sortie was changed to show the new responsibility) were performed by the 3 consortia STAR, COSMOS and MESH. As Germany had committed for 50 % of costs the competition was narrowed down to two led by German Prime Contractors i.e. MBB for COSMOS and ERNO for MESH resulting in two proposals for phase C/D. During that time both designs were presented in parallel at NASA and ESA (becoming the new European space agency merging ELDO and ESRO). In order to avoid knowledge transfer the competitor teams had stay outside when the other presented their data. Obviously we as keen young engineers wanted always to find something out from the others whenever possible. I was one time successful at MSFC as the presentations were made in the central audience room being very big and crowded with NASA people so that I could slip in with some NASA guys drinking coffee outside. I heard their nasty comments about the MBB operations presentation and hoped that ours would be judged better by them. Then our presentation started and P.Natenbruck presented our operations concept - the nasty comments were nearly identical. It was obvious that at that time nobody in Europe had experiences with operation of a manned space system.

A more serious event was Mr. Causse (ESRO head of the Spacelab programme at that time) visiting us after the final phase B presentation in Nordwijk putting the question: "Do you want to commit suicide to propose an American data management computer?"
I was responsible for Spacelab Avionics at that time and therefore our Project Manager K.Berge requested to change immediately to a European one; I explained the reasons why the IBM AP101, which was designed and qualified already for the Space Shuttle, would be the best selection technically. It was requested to make immediately a trade-off finding by all means an European computer replacing the AP101. One must imagine that computers of that time had much less performances than present ones though being very big and needing much electrical power. We had discussions with LITEF, who proposed the Tornado flight computer as option, but technically it was not a good choice. Actually I cannot remember fully how the problem was solved for the proposal, a preliminary choice was made with the statement that the final selection would be made during phase C/D. Later on a trade-off was made by a group led by ESA/G.Bolton and me and ERNO data management experts visiting the related companies in order to find a European computer fulfilling best the Spacelab requirements:

-Siemens computer 300/16 bit ground computer to be redesigned for flight by Siemens,

-CTL Modular one/16 bit ground computer to be redesigned for flight by Dornier,

-CII Mitra submarine computer to be improved and redesigned for flight by CII,

-Dassault flight computer for Mirage fighter aircraft.

Understanding the complications of the tasks to be performed for a manned space program CII stopped the discussions with us stating that they have no interest any longer. The Dassault option seemed to become the winner when we made our last trip to Paris to negotiate finally with Dassault before they deliver a formal proposal. We were late in the evening and had to hurry-up not to miss our flights and it was already dark and strongly raining. At the exit of Dassault facilities there was a guy standing in the rain and Mr.Bolton asked me, if we could look again to a revised CII proposal though they were formally already out. We stopped and this person, the CII marketing manager personally known to Mr. Bolton, handed to each of us a paper package. This revised CII proposal was quite better than the other European options and therefore it was selected for implementation.
Looking backwards the selection of the Mitra can be explained only as result of "political engineering" under management pressure; several problems in the hardware and software areas would have been avoided, if the IBM AP101 would have been selected as proposed by us in the beginning.-

The phase C/D proposal evaluation by ESA did show some 10 points less for ERNO in the 600 range; as far as I remember disadvantages were:
- Computer selection not finalized,
- Less remote control compared with MBB concept though not required in the RFQ,
- No experiences as Prime Contractor.

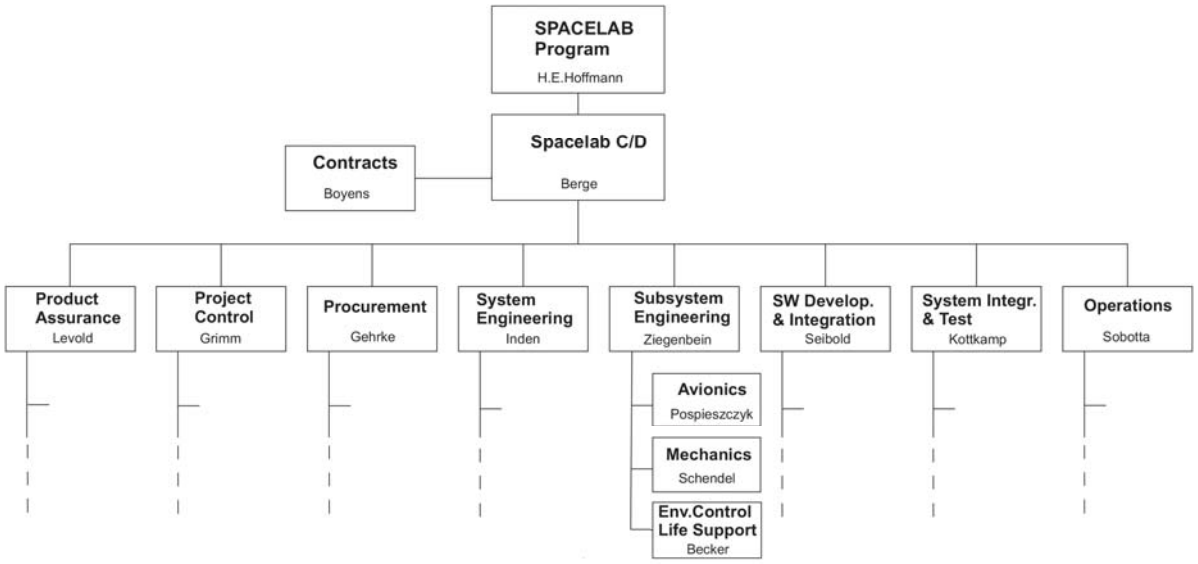
On the positive side the modularity of the Pressurized Segment was counted, which was strongly promoted by M.Fuchs being responsible for the initial Spacelab study phases. I worked several times together with M.Fuchs, he was even for some time my organizational boss, and therefore I know him as a strong creative personality fitting well in ERNO's reputation of the early times. Unfortunately ERNO became more and more an anonymous company where strong personalities were not so favoured and therefore he left and launched his own space company in Bremen becoming much more successful than the remaining space section of AIRBUS in Bremen.

Later on when I had really friends in the ESA Spacelab team they told me that also the location Munich was considered much more attractive than Bremen with its cultural provisions like theatres and nature environment for after-business activities.
Though the arithmetic advantage for MBB the contract was finally allocated to ERNO and there was a rumour that political SPD connections between the mayor of Bremen Mr.Koschnik and Science Minister of Germany Mr.Matthöfer had played a certain role as well as the unjust loss of the GEOS proposal.

After contract signature the ERNO prime contractor organization had to be implemented quickly but ERNO had not enough experienced manpower so that the mother company VFW/Fokker transferred man power to ERNO - some of them had not the announced quality/experiences and it seemed VFW/Fokker took the chance to decrease their VFW 614 resources as the aircraft could not be sold as expected.

Soon it turned out soon that the management weakness criticized in the proposal evaluation by ESA was a fact. The organization had too many branches/managers working on the

SPACELAB design evolution phase having their specific, often diverging opinions so that Mr. Berge was not able to keep all under control.



The core technical team of the previous phases was split into a "system team" headed by Mr. Inden and an "implementation team" headed by Mr. Ziegenbein. The system team got the responsibility for overall technical design especially the configuration and the implementation team was responsible for subsystem design and implementation control at the related subcontractor, the formal control ensuring SOW (Statement of Work) fulfilment as well as cost and schedule compliance was by dedicated subcontractor managers in the procurement branch headed by Mr. Gehrke.
The biggest failure was the splitting of SW development and integration as separate branch which was part of Avionics up to C/D proposal delivery. The new concept might be advantageous for a "software system" development project where hardware is mostly frozen but for the SPACELAB all had to designed and optimized together. Additionally the software activities were split in numerous entities contracted to different subcontractors in order to fine-tune the geographical distribution.
ERNO was supported by a McDonell Douglas (MDTSCO) team (head: Don Charhut, systems engineering: Dave Wensley) providing to each branch an experienced consultant except for Avionics and software.

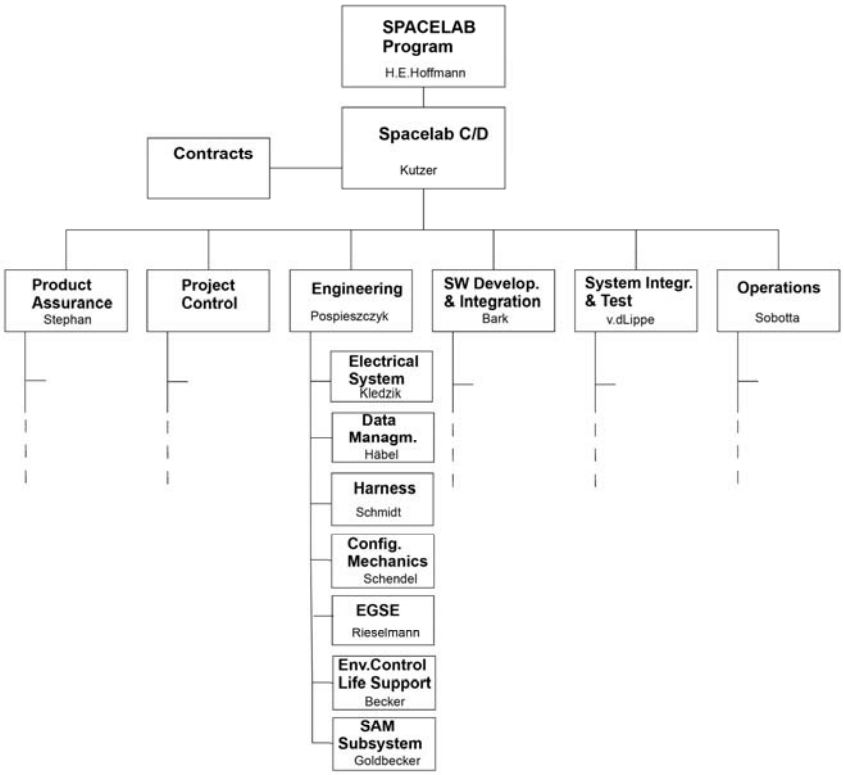
Looking backwards it is astonishing that this unreasonable organization structure could be implemented though ERNO was supported permanently by the MDTSCO consultancy team and short-term high-ranked advisers from outside (e.g. retired NASA managers as Dr. Rees).

It turned out that there were no clear responsibility/task descriptions for the different organization elements but also some personal characteristics did not fit together.
The working relations of the two engineering teams consisting of engineers mostly without "systems engineering" experiences were not fruitful, it culminated in the problem that the harness in the front section of Spacelab, which was designed in detail by the implementation team and its harness subcontractor AEG, did not fit in the volume foreseen by the systems team. The leaders of the two teams argued without agreement how to find a solution so that on management direction a Fokker task force was implemented for some weeks. They solved

the problem pragmatically by designing an extension at the bottom of the first rack to accommodate the harness. It was quite an ugly but proper fix which can be seen in any Spacelab version still available in museums (called "Schuh Karton").

Over time it became clear that the project was not proceeding very successfully in the initial phase so that Mr. Berge got an experienced deputy Mr. Kutzer who had managed already successfully space programs from the beginning up to the end (AZUR, HELIOS).
I guess that there were discussions on high management level on agency and ERNO side that improvements are required in order to make the project a success.
So the first major schedule delay caused by the DMS subcontractor SEL/Stuttgart was used as official argument to replace Mr. Berge by Mr. Kutzer and on ESA side Mr. Stoewer by Mr. Altmann.

The ERNO organization was streamlined to remove the issue of the two engineering organizations; also the frequent discrepancies between the subsystem managers and subsystem engineers needing formally project manager control was improved by integration of the subsystem mangers to the engineering organization. Some discipline managers of the initial organization found other roles within ERNO or other companies.
The software activities were not remarkably supported by MDTSCO so its status had become so critical that a complete TRW team was located in Bremen and the ERNO responsibles acting only formally.
All members of this revised organization were keen to make SPACELAB a success and found good personal relations within ERNO as well as with the agency counterparts and key subcontractor responsibles so that they could meet all required deliveries within the agreed cost and schedule. As consequence NASA felt confident to place the FOP (Follow-on Production) contract for manufacturing/delivery of a second flight unit and related documentation for an attractive price.

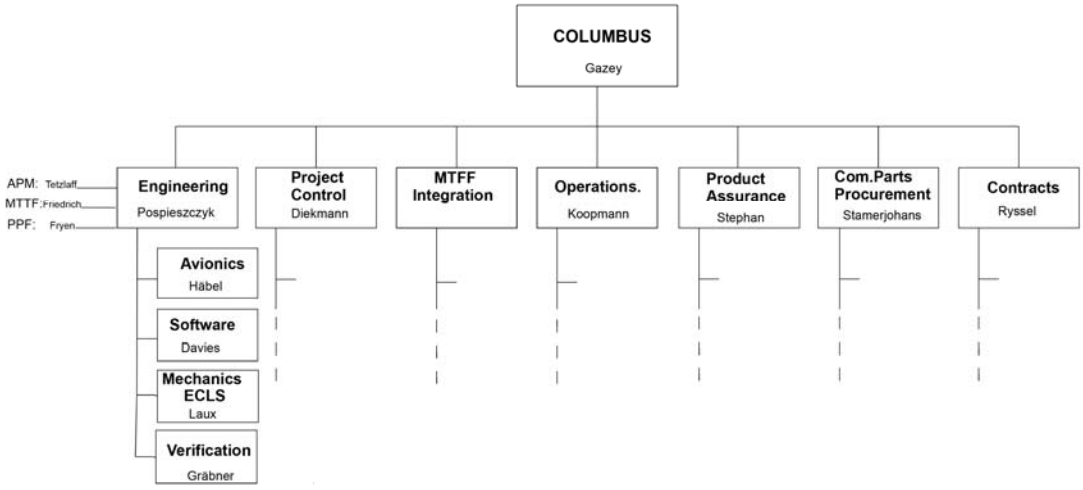


Already during the final phase of the SPACELAB program some people in Germany were thinking about a successor program. After the successful SPACELAB flights and the financial success of selling a second SPACELAB flight system to NASA (FOP - Follow On Production) also other countries did show strong interest for a new manned space program extending the experiences gained so far so that ESA had only one choice to take over the management.
The Columbus program passed through several study phases before it was considered mature to prepare a binding C/D proposal.
Based on the previous SPACELAB experiences and skilled personnel the COLUMBUS organization was set up taking into account the definition of the main responsibilities:

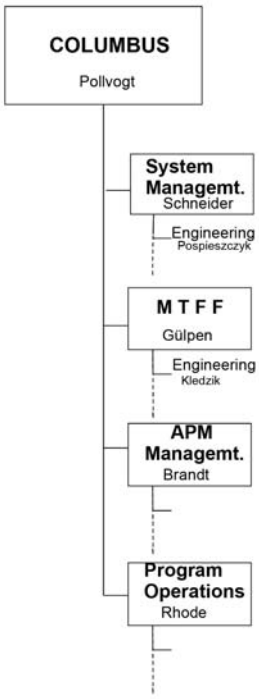
- MBB-ERNO as Prime Contractor is responsible for all overall activities and controls the subcontractors and delivery of the MTFF being build-up by the Pressurized Module delivered by Alenia and the Resource Module delivered by Dornier,

- APM delivery by Alenia,

- PPF delivery by BAE.



As described above already the C/D proposal though judged quite positive wrt technical contents was rejected by ESA due its high costs requesting also reduced program contents.
Now the MBB-ERNO functional department managers saw their chance to destroy the SPACELAB organization principle which they considered always as a separate unit giving them only small work orders for specific tasks. I remember well the meeting chaired by Mr.Ludwig, who had been promoted in the meantime from mechanical branch manager to the overall technics manager. It was stated in strong words that the technical department would now take over with complete redefined responsibilities and personnel. The following working meetings introduced the new Players(Schneider, Gülpen, Kledzik, Brandt) lead by Mr. Pollvogt. He was called back from the States where he acted as marketing and NASA contact. In this community I felt like having leprosy and heard strange arguments from some people, whom I had considered quite reasonable before. I think they would have liked to remove me also from COLUMBUS but this would have been a disadvantage to them because of positive reputation and contacts at ESA.
That was the time I resigned internally, which position never changed really up to my final retirement from Astrium; my working style did change to major extent i.e. daily overtime and weekend work at home were not valid any longer.
Taking into account also the Polar Platform split-off from the COLUMBUS program the following organisation was set up.



The unclear definition of the definition/responsibilies between "System Management" and the MTFF and APM organizations led to continuous quarrelling. Mr. Gülpen and Mr.Brandt tried with all power to make their roles as independent as possible whereas Mr.Schneider seemed to have no major interests in this dispute and therefore I had to run all discussions on this subject. One time one told me that his understanding of system responsibility was the right one as he did two semesters "germanistik"…..
After some time Mr.Schneider gave up and they allocated his position to me.
Several unpleasant events occurred at that phase; one time the MTFF team developed a "cheap" data management subsystem concept based on commercial boards. As I considered it a hopeless idea I tried to avoid the presentation of this idea in Nordwijk but finally I got the order to participate there. The presentation was done by an engineer with good technical knowledge but having no ideas about reliability/space radiation, costs and planning. During the presentation and the following question/answer phase I tried to avoid the sympathetic glances of the ESTEC people and at lunch time I was sitting at the ESTEC table refusing discussions on this subject. After that this idea was gone…
Another time was a system level MTFF review; one presentation was about a detailed data management interface issue on bit level. During the coffee break Mr.Longhurst (ESA Columbus Program Manager) and Mr.Selg (ESA COLUMBUS Systems Engineer) came to me asking my judgement about the material prepared by the MTFF team for this Review.
As we were knowing us already over years (one could call that even friendship) i gave them some explanations about the COLUMBUS organization and its drawbacks. They stated that they could not understand this because of the excellent performance of this company at SPACELAB and initial COLUMBUS times.

TBC

4. International Cooperation