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Design Study for an Astronaut's Workstation

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ABSTRACT

Restraints in space range between the simplicity of foot loops and the dissatisfaction of current restraints with a more welcome stabilization closer to the body's center of gravity. Although there is a line of upper thigh restraints, which come close to a terrestrial chair analogue, they are not currently implemented in design standards. In 1999 a team of architects and engineers at the University of Technology Munich developed a modular, foldable astronaut's workstation with integrated seat restraint. Prototypes were tested successfully on parabolic flights at NASA-JSC. In 2002 an exhibition model for the Space Station Mock-up at EADS Space in Bremen was ordered. Due to a limited budget, the original full aluminium design models had to be changed dramatically in construction to save costs. Nevertheless, the opportunity to rebuild the models for an exhibition has been taken, to study options to make the construction of the workstation much lighter. Although the limited budget did not allow to properly engineer some crucial details, the exhibition model allowed to test some alternative design approaches, resulting from the aftermath of the parabolic flights.

INTRODUCTION

After successful testing on parabolic flights of an astronaut workstation with integrated restraint system developed by the University of Technology Munich, several efforts have been undertaken to receive more research money for further development of the workstation. Due to political changes and the still prevailing reluctance of funding interdisciplinary work, no substantial research money could be gained. Thus, the offer of EADS in Bremen to built a design model for the permanent exhibition and ISS module mock-ups, at least allowed to work on some design iterations and test some detail ideas in principle. Given the low budget, the level of engineering and fine mechanics could not be developed to a high-end state. Nevertheless, the design knowledge developed that far, that a light-weight, flight-ready workstation could be built fairly quickly.

RESTRAINTS IN SPACE

On Earth we employ three basic restraint modes, which we use in daily life to perform tasks up to a very high precision and control. These are standing upright, sitting, and lying. Standing allows in combination with walking and leaning towards a very wide reach and good employment of our muscles for physical work. Sitting has a limited reach, but is good for mental and high precision work, especially in combination with a table. Lying is our preferred mode for relaxing and sleeping, since active muscular support of all members is minimized. Although the degree of fatigue and reach in these basic modes is decreasing, it has to be highlighted, that they are all dynamic. Also the change between these modes can be done fairly quickly and easily. Designs for chairs, tables and beds are strongly supporting that.

The absence of gravitational forces in a micro-gravity environment makes movement relatively easy. But stopping movement is slower than on Earth. Also, since much lower forces are needed to move the whole body mass, keeping still is also more demanding. Thus, to perform useful tasks like working on a glove box or on a laptop, restraints are needed to avoid uncontrolled body movement. Watching astronauts, who are using foot loops, which are fairly efficient for many tasks, one would nevertheless think, that a fixation near the waist or the center of gravity of the human body, would be a better and more natural restraint.

The Man-Systems Integration Standards NASA-STD-3000 (NASA 1995, revision B) identifies 3 basic types of body restraints:

1. **Handhold Restraint** - With the handhold restraint, the individual is stabilized by holding onto a handgrip with one hand and performing the reach or task with the other. This restraint affords a fairly wide range of functional reaches, but body control is difficult and body stability is poor.
2. **Waist Restraint** - A waist restraint (for example, a clamp or belt around the waist) affords good body

control and stabilization, but seriously limits the range of motion and reach distances attainable.

3. **Foot Restraint** - The third basic system restrains the individual by the feet. In Skylab observations and neutral buoyancy test, the foot restraints were judged to be excellent in reach performance, stability, and control. The foot restraint provides a large reach envelope to the front, back, and to the sides of the crewmember. Appreciable forces can often not be exerted due to weak muscles of the ankle rotators. Foot restraints should be augmented with waist or other types of restraints where appropriate.

This list leaves out all **Leg Restraints**, probably because none of them is in use at the moment. It is also pointing out some weaknesses of the systems, without being very systematic. The 'waist restraint' is the best restraint in terms of offering a fixation near the center of gravity of the human body, but the systems referred to are very awkward and indeed 'seriously limit the range of motion'. It is actually a problem of the NASA-STD-3000, that not the typological principles are evaluated, but 'currently used' systems, without further investigation on why they are used and why other known systems are not used. This would leave designers with a wider range of options to consider.

NASA's Crew Restraints Project (2003) seemed to take a more general look at restraints and mobility aids (R&MA's). The program set off to develop requirements and guidelines, which both do not exist for a multi-purpose crew restraint:

"The overall purpose of the NASA project is to develop requirements, guidelines, and conceptual designs, for an ergonomically designed multi-purpose crew restraint. NASA final deliverables include:

- Development of functional requirements
- Design concept prototype development
- Computer modeling evaluations of concepts
- Microgravity evaluation
- Implementation plan."

A survey of restraints was done reaching back to Skylab, but the survey and ergonomic evaluation of the systems does not go much in depth. All the information provided on the web-page is from early 2003 and the program seems to be stopped since then. Contacting the emails given on the page returned non-existing email addresses.

An electronic questionnaire returned the following 'General Comments on Restraints', listed under 'bad characteristics', while no good ones were listed:

- Set up time/break down time too long (could pose an emergency evacuation hindrance or frustration/ irritation to crew member)
- Restraint in aisle way (translation obstruction)
- Not useful for multiple tasks
- Flipping of restraint loops
- Take up too much storage space
- Cannot be readjusted quickly with ease
- Too complex
- Expensive
- Overdesigned/Underdesigned for tasks
- Breaking of structure where restraint is attached
- Uncomfortable - causes fatigue to crew body while in restraint system

This list basically reflects the common knowledge, that the ease of use of a restraint system is a prevailing factor. A reason, why handrails and foot loops are preferred by the astronauts whenever possible.

Dominoni and Ferraris (2003) make a more in-depth and systematic survey on the design of restraints, but limited to the currently available restraints on the ISS as listed in the document SSP 57020 (NASA, 2002). These are:

- Long Duration Foot Restraint (LDFR)
- Short Duration Foot Restraint (SDFR)
- Handrail
- Fixed Length Tether (FLT) and Adjustable Length Tether (ALT)
- Torso Restraint Assembly (TRA)

Dominoni and Ferraris (2003) point out, that a clearer distinction between restraints for long steady operations and for short 'stop and go' use should be made. Further the missing or unsatisfying integration of the interfaces, both to the human body and the standard rack system on the ISS are criticised. They recommend to more deeply study today's separation of 'complex but comfortable' restraints and as could be said 'simple but soring' ones. They propose to further study a closer integration of the personal restraint systems with the crew clothing system, of which a potential line of development started in Skylab, but has been abandoned since then.

Notable in all three sources is the complete absence of the identification of thigh restraints and 'chair-like' systems as proposed as early as Wernher von Braun's Collier spaceship illustrations as shown in figure 1, as used on Skylab and on MIR space station [figures 2 and 3]. A micro-gravity analogue to the chair, given its terrestrial ease of use and stabilization would actually be of great benefit to the stop-and-go tasks in a space station.

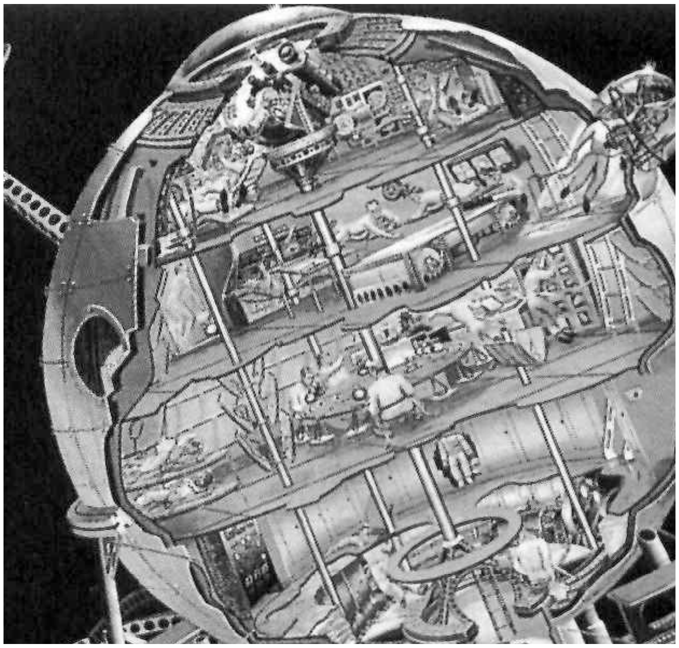

Figure 1: Rendering of the interior of the lunar spaceship's passenger sphere by Fred Freeman, based on a proposal of Wernher von Braun and published in Collier's 1952. Note the seats around the table in the middeck.

CHAIR-LIKE RESTRAINTS IN SPACE - Chair-like restraint systems in space are on one hand contradictory (One cannot use its weight to restrain like sitting on Earth in microgravity) on the other hand very obvious, since the neutral body posture in microgravity is close to a seating position and the body would be restrained close to its center of gravity. Naturally they do not work like chairs in gravity environments, but they can provide the same ease of use of ingress and egress with immediate fixation near the body's center of gravity, leaving full mobility and reach of the bodies upper part.

There are only 4 examples known to the author, which have actually been used in space or tested on parabolic flights. These are the Skylab Food Table Restraints, the MIR Seat Restraints, The Munich Space Chair and the Flexible on-orbit Workstation FLOW. The first two examples were fixed installations around the wardroom table. The Munich Space Chair was conceived as a flexible restraint, which could be mounted where needed. The FLOW workstation, initially was conceived as a modular wardroom table system, which could be packed away for launch, but quickly the potential for a more universal use was seen.

Skylab's Food Table Restraints - At Skylab's food table a foldable thigh restraint was used in addition to foot loops and cleat receptacles as shown in figure 2. The thigh restraints were attached to the upper part of the food table pedestal and provided the crewmen a means of stabilization in a semi-seated position while eating. These restraints were friction hinged at the table to permit elevation selection and out-of-the way stowage for access the food table pedestal doors, and at midpoint, to provide selection of the desired seating position (MSFC System Analysis and Integration Laboratory, 1974, page 118-120)

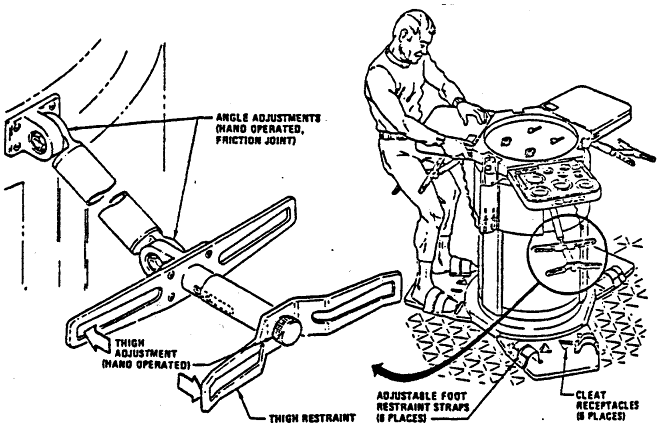

Figure 2 shows the food table restraints used in combination with foot loops in Skylab. (Source: MSFC System Analysis and Integration Laboratory, 1974, original caption: "Figure 102: Food Table Restraints. Each thigh restraint was fitted with a slide adjustment permitting confirmation to each individual crewmen's thighs.")

MIR Seat Restraints - On MIR station fixed stools as shown in figure 3 were used, which allowed the crew to clamp their thighs under the also fixed table, thus pressing the backside on the pads of the stool. Additionally a bar handle was fixed on the floor to fix one's feet. The legs are kept in bended position and muscles stretched. Except for the rotation around its vertical axis no further adjustment was possible.

Figure 3: Stools in the MIR station. Shown here it the MIR mock-up at the European Astronauts Center in Cologne.

Munich Space Chair - The Munich Space Chair (MSC) was tested on the MIR-Station. The MSC was invented in 1984 by Johann Huber, an architecture student, during a workshop on manned space flight at the Institute of Astronautics at the Technical University of Munich. He suggested to use an adaption of the most common fixation concept on Earth – the chair – as a restraint system in space. The concept was further developed by the university's aerospace engineering department and in 1995, more than 10 years after the invention of the space chair, the MSC was launched to space station MIR and installed inside the SPEKTR module.

The concept of the MSC is based on ergonomic aspects. It fixes a human body in its neutral 0-g position without the need for additional supports like belts. The human body is fixed on three points between the foot bar, the thigh plate and the seat plate. The astronaut only has to press his thigh against the thigh plate by stretching his foot and spanning his calf muscles, respectively. Due to the leverage of the thigh plate, the backside is pressed onto the seat plate. The whole lower part is fixed while the upper part of the body keeps its freedom. Depending only on the muscle employment of the astronaut, it is possible to "sit" on the chair being fixed very tightly, rather loosely or "free floating" within the three fixing points. Thus, the fixation can be easily varied for different tasks. Furthermore the MSC can be adapted to all body sizes. The system is fixed on the floor. The MSC can be folded, but is using considerable space and a certain time to be installed. Igenbergs, Naumann, Eckart and Pfeiffer (1997) concluded, that its best use is in applications of high precision, high hand pressure, or extended work in the neutral 0-g position.

Figure 4: Astronaut T. Reiter using the MSC during EUROMIR '95 (source: ESA)

Flexible On-Orbit Workstation FLOW - The modular table system with integrated restraint system named FLOW was designed by architecture students Björn Bertheau, Claudia Hertrich and Arne Laub during two space design semesters held at the Institute for Design and Product Development at the University of Technology in Munich (Vogler, 2000). Inspired by the flexibility of Future System's Space Station Wardroom Table („Meetings and Meals") described in Nixon, Miller and Fauquet (1989) and Hans Huber's Munich Space Chair restraint principle, the advantages of both were combined into a foldable table restraint combination, which can be carried like a personal briefcase. Different than the MSC the workstation table can be attached to the front seat tracks at the standard ISS payload rack and not to the ground, thus making it a universal working aid for astronauts, which leaves the 'floor' area clean. Further, the workstation flat-packs completely and can be moved out of the way within seconds. The seat tracks allow the height adjustment on the rack. Through fine adjustments of the seating plates, the workstation can be adjusted to individual body size. All plate angles can be adjusted by a press-button tilting mechanism, which is easy to use. For fixation of laptop, pencils, paper and other utilities on the working surface, a bungee cord system was developed, which pulls back the bungees under the table surface by a rotating spring mechanism, preventing the bungees from becoming ballistic. Thus the table can be either a clean flat surface or provide easy to use object fixation.

After completing a series of underwater tests to prove the principle, two prototypes were built. One to fulfill the safety requirements for the 2g phase of the parabolic flight, which required strong steel reinforcements, and one full aluminum prototype for microgravity use only and as close as possible to proper flight hardware. The handling and use of both models were tested on parabolic flights. The main results were:

- fast and easy ingress and egress
- all three assumed restrain modes work
- stays comfortable for small persons in large person's adjustment and vice versa
- good restraint of feet and hip while upper body stays flexible
- intuitive use of the workstation by people not introduced to it.
- easy handling of bungee fixation
- high marks on comfort
- good use while writing etc.
- easy handling while folded-up
- easy unfolding in microgravity

Figure 5 shows the designers testing the flight model with the Astronaut Mary Ellen Weber on a parabolic flight at NASA-JSC.

WORKSTATION FLOW DESCRIPTION

The parabolic test flight returned promising results and video takes as shown in figure 6 show the quick and easy ingress and egress, which is even more fluent than foot loops. The folding with the push button proved to work very well and quick. The basic geometry of the workstation proved to be ergonomically, even without individual adjustment. Testers used the workstation intuitively like a chair, without further instruction. None had problems with ingess or egress, just one tester needed to be advised to leave the feet on the floor, not to loose fixation in pitch direction. In the following the functional elements of the workstation are shortly described.

FUNCTIONAL ELEMENTS - The workstation basically consists of a working area and two seat plates as shown in figure 7. All of these surfaces are adjustable in 15° angular steps by a push button sprocket based mechanism. The plates are interconnected by a telescopic arm. The whole system attaches to the standard racks seat track over a handrail adapter.

Handrail adapter - The connection of the workstation system to the standard rack seat tracks has not been developed for the parabolic flight due to time constraints. It has been discussed to use handrails as an interface. A main identified problem is the low performance of the seat tracks under lateral forces, which would be enhanced by the leverage of the workstation.

Working Plate - The working plate is machined out of a full piece of aluminium. Side drillings on the upper and lower part take the push-button turning mechanism as shown in figure 8, which connect to the handrail on the upper part and the telescopic arm of the seat plates on the lower part. The thickness of the plate's side rim provides structural stability and allows to minimize the folding volume by taking in the seat plates as shown in figure 9.

Table top fixation system - As an alternative to the commonly used Velcro strips, a bungee fixation system has been developed. on the working surface. The system is integrated into the table top. The elastic cords are pulled out from the left side of the table top and clipped into the right side. To avoid excessive tension in the cords, which could be a hazard, a spring roll leading system has been developed, which enables the bungees only to be in tension in the last 2 cm before reaching the final fixation point. This system allows a safe and immediate retraction of the cords, once they are released and a clear surface is needed.

Figure 6: The four images show a video sequence of ingressing the workstation during a parabolic flight. Pictures are taken from a video in half a second intervals, resulting in a total of 2 seconds from approaching the workstation to being fully stabilized and restrained.

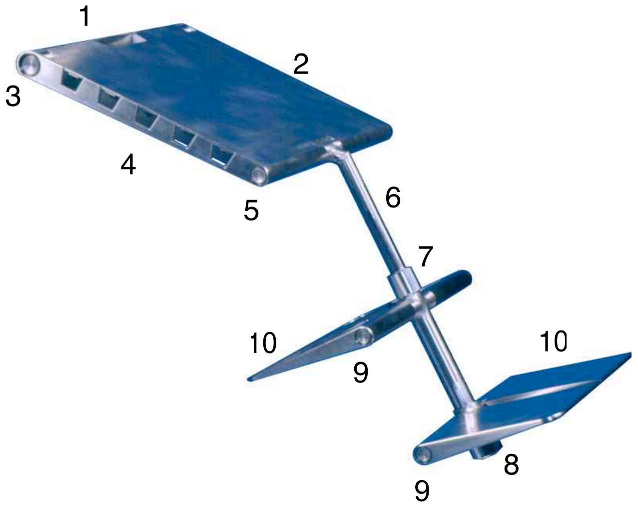

Figure 7 shows the functional elements of the workstation:
1 Handle
2 Table Top
3 Push-button turning mechanism for the working plate inclination
4 Elastic cord fixing grooves
5 Push-button turning mechanism for the restraint inclination
6 Telescopic seat arm
7 Length adjustment screw of seat plates distance to table top
8 Length adjustment screw of lower seat plate distance to upper seat plate
9 Push-button turning mechanism for seat plates
10 Seat plates.

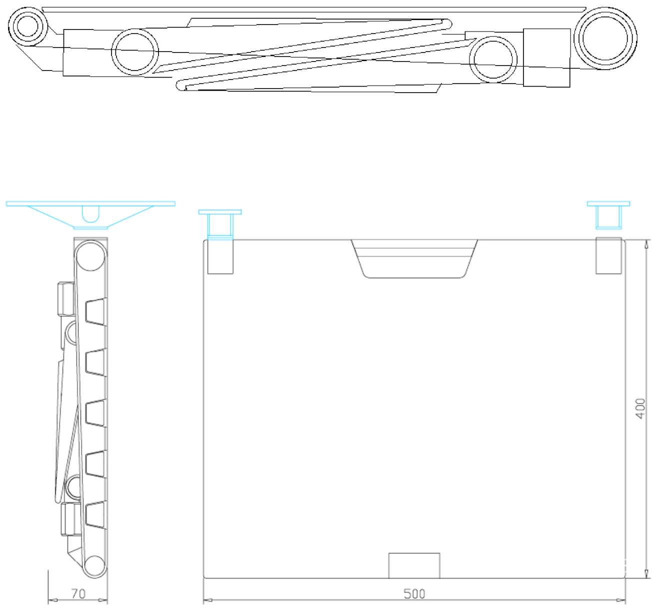

Figure 9 shows how the seat plates folded together to go beneath the table top.

Telescopic seat arm - Using the push-button mechanism on the lower end of the working plate, the telescopic seat arm, holding the two seat plates can be folded out into position. To adjust for different body sizes and allow maximum compactness when folded the seat plates can be moved along the telescopic arm. One friction-based screw above the upper seat plate allows the adjustment of the distance of the upper and lower plate to the table top and another hand operated screw allows to adjust the distance of the lower plate to the upper plate.

Seat plates - The seat plates also fold out from the telescopic arm by a push button mechanism, which allows 15° angular steps. For maximum compactness a groove is milled out in the center axis of the seat plate as shown in figure 10, which allows it to fold over the tube of the telescopic arm.

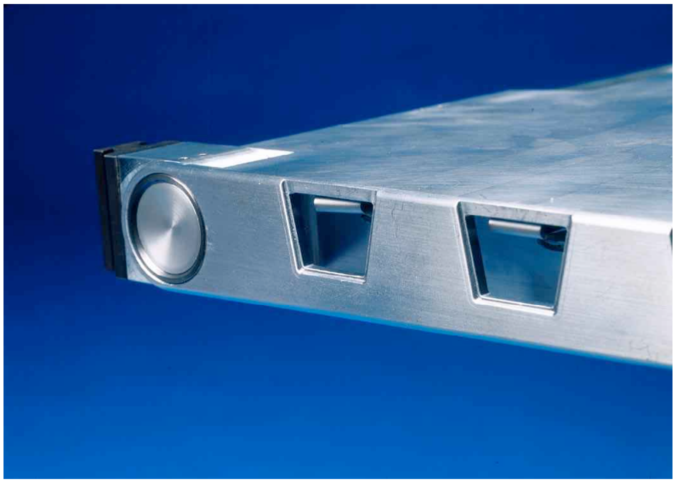

Figure 8 shows the push-button to turn the table top on the upper left side of the workstation. The openings on the side contain the elastic cords, which can be pulled out and fixed on the other side of the table top.

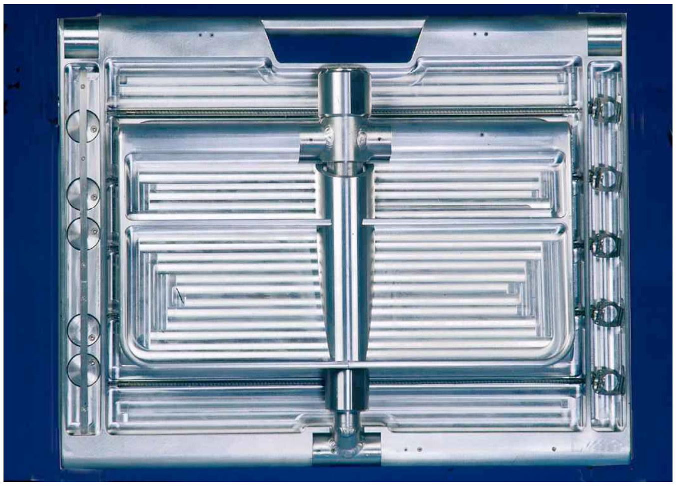

Figure 10 show the underside of the folded workstation with the elastic cord system and the groove in the seat plate to fold tightly to the tube of the telescopic arm.

DISCUSSED USES OF THE WORKSTATION - The workstation FLOW concept derives from an overall architectural study of the ISS Habitation module as shown in figure 11, where a table system for the galley was designed, which allowed the whole crew to have a meal or meeting together, but which could be removed, if not used.

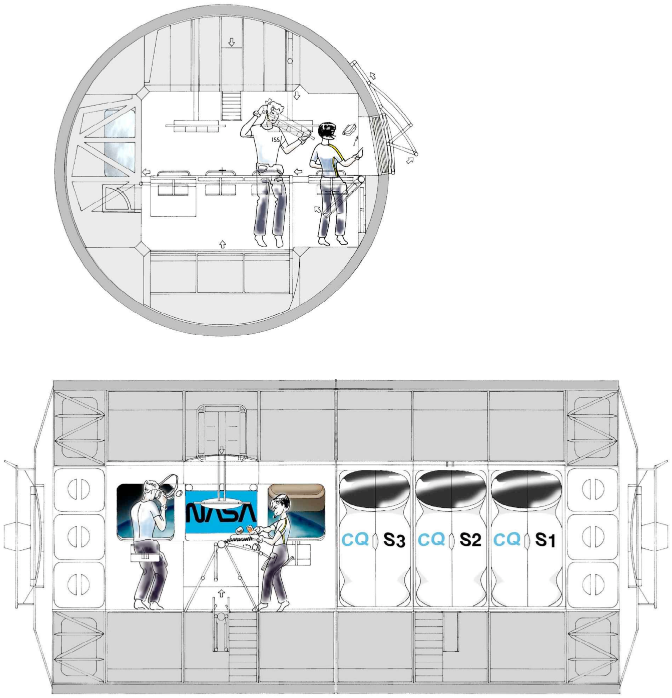

Figure 11 shows the arrangement of six workstations to a galley table in the habitation module of the ISS.

General Use as Modular Workstation System - Once the foldable workstation for the galley was conceived, it was an easy step to think of the table as a general modular workstation system, which can be folded up and carried along by the astronaut like a briefcase to where its next use was. Like that, each astronaut would carry along his/her personal workstation and restraint system, which could be set up very quickly and be planned according to the crew tasks. This mobile system would not only save weight, but also allow the astronaut to adjust the restraint system once to the personal dimensions and then be able to quickly set up a long-duration work situation with restraint, which is comfortable, but not complex.

Glove Box Restraint - In 2000, the University of Technology at Munich was contacted by the team building the Microgravity Sciences Glove box (MSG) at Astrium Bremen, who were planning to make a proposal to consider the FLOW principle as an alternative restraint for the glove box. The Long Duration Foot Loop restraint as shown in figure 12 for the glove box leaves the main mass of the body unrestrained and thus leading extra restraint forces into the glove box, where the astronaut additionally tries to stabilize himself by pressing the arms towards the glove box openings. A restraint like the FLOW principle would allow much more controlled movements of the upper body part, which would additionally have positive effects on the head movement, while using the microscope.

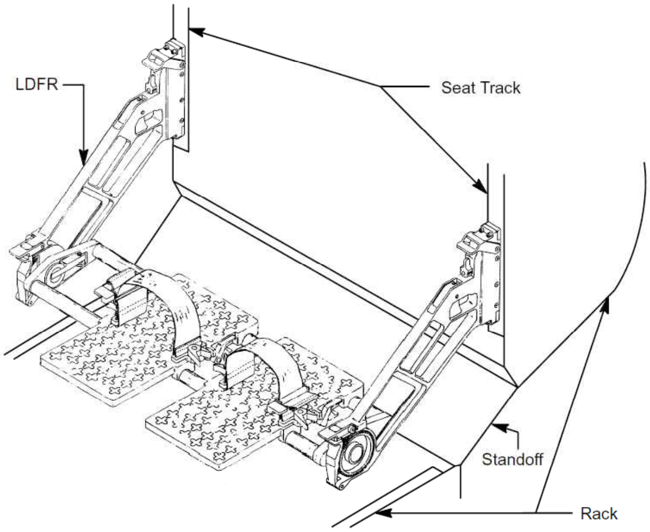

Figure 12 showing the LDFR used at the MSG.

Universal Experiment Platform - A request by Kayser-Threde in Munich to consider the restraint system for a reaction-time experiment to be flown on the shuttle, revealed further potential of the workstation system. If an adaptor to the table top is created, an universal experiment platform could be offered, where fully prepared experiment set-ups could be docked on, ready to be used by the astronaut. This would allow to offer an integrated system to scientists, who would not have to worry about proper restraint. Figure 13 shows a mock-up for a reaction experiment with laptop, joystick and push-buttons mounted to the table top.

The parabolic test flights also revealed, that the workstation could be used in a free floating state respectively by using foot loops. By clamping the seat plates with his legs the astronaut can fix the working plate in a stable working position as shown in figure 14.

At the end Kayser-Threde preferred to build an extra island solution to provide an experiment platform with the astronaut being strapped down to the mid-deck floor of the shuttle.

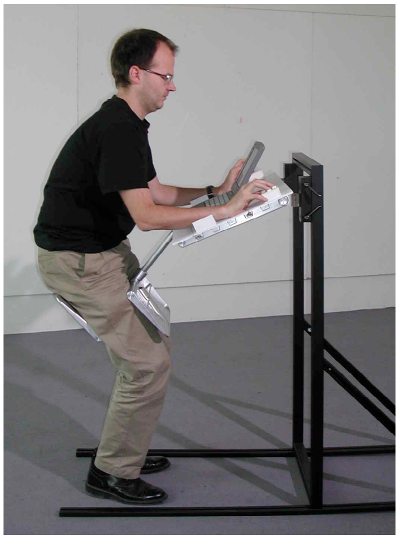

Figure 13 shows a mockup of a reaction experiment mounted on the table top of the workstation.

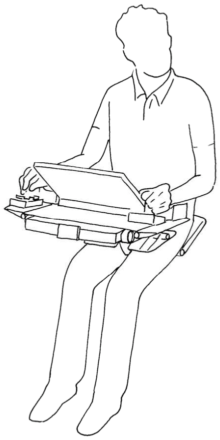

Figure 14 shows a free-floating working situation, where the table top is held into position by the seat plates. The astronaut can still use his legs and arms to move through the station.

Figure 15 showing the author using the workstation in free-floating mode during a parabolic flight. Note that the seat plates and telescopic arm have not been adjusted and still allow good short-term or 'stop-and-go' use of the workstation. Unfolding and egress took less than 10 seconds without adjusting the telescopic arm and without previous training.

DESIGN ITERATIONS OF THE FLOW CONCEPT

The offer by Astrium Bremen to build a new model of the FLOW workstation provided the opportunity to test some new design iterations and to reconsider some assumptions done before the parabolic test flights. The budget for the models, which had only to serve the purpose of the permanent exhibition and which should communicate the involvement of designers, did not allow any extensive mechanical and technical development. Indeed, much of the time had to be used to simplify the construction to cut down cost. The overall principle of the workstation proved to work very well in the parabolic flights and was subject to change. Four subsystems of the construction were changed, basically to save manufacturing costs, but also to test other construction possibilities to eventually safe weight. These changes were 1) the separation of the fully machined plates into a frame and infill system, which allowed easier manufacturing of the parts, but also other surface materials than aluminium to be in contact with the body parts; 2) the folding mechanisms original sprocket system had to be abandoned for cost reason and different options were explored; 3) The elastic cord desktop restraint system was abandoned purely for cost reasons; and 4) the rack connection with a handrail, not solved in the initial design was simulated, but could also not be led to a final solution.

RECONSIDERED SUBSYSTEMS - The low-cost version required several simplifications of the original design. Some of them could be well reconsidered for a flight prototype, since a considerable amount of weight can be saved. In the original design the inclination of the table top and the two restraint plates could be altered in 15 degree steps. Studies in drawings led to the test assumption, that the foldable workstation may as well work with one fixed combination of angles, which would save about 50% of costs and weight of the construction. Another alteration was to divide the original full aluminium-milled table- and restraint-plates into an aluminium frame and – for purpose of the exhibition – acrylic plates. This results into a softer and 'warmer' design for the restraint plates and, even more importantly, into an interchangeable tabletop, which would allow to offer an interchangeable well-restrained workstation, where different experiments could be set-up very quickly and cost-efficiently.

Frame – Plate separation - Early design studies and prototypes of the original workstation included a separation of the construction elements into frame and plates. This was abandoned, when the sprocket adjustment and tilting mechanism was introduced. The later concept of a potentially universal experiment platform and lower costs led the design team to re-consider this aspect for the exhibition model. As beautiful and elegant the full aluminium design prototype shown in figures 7-10 was, it had a slightly 'cold' touch by the full aluminium surfaces. The separation would allow to employ different materials for the surfaces. To fit into the current ISS colour concept white plates were chosen in combination with the aluminium frame, which has been blasted with glass beads to achieve a slightly silk-matt surface. The aluminium parts could be machined out of relatively small parts, thus reducing costs. The use of a less heat conductive material than aluminium would have a positive effect for the seating comfort. For the exhibition model white acrylic was used, for a space application powder-coated carbon fiber could be considered. To fix the table top plate a feather-based clip system was considered, which should allow stable fixation, but also easy exchange or turnaround of the table top. A spring-based bolt fitting the requirements could not be found in the time and so the fixation was replaced by Velcro for the final model. The seat plates were glued to the aluminium frame to avoid the visible screw heads and eventually for cost reasons. A layout of the parts is shown in figure 16.

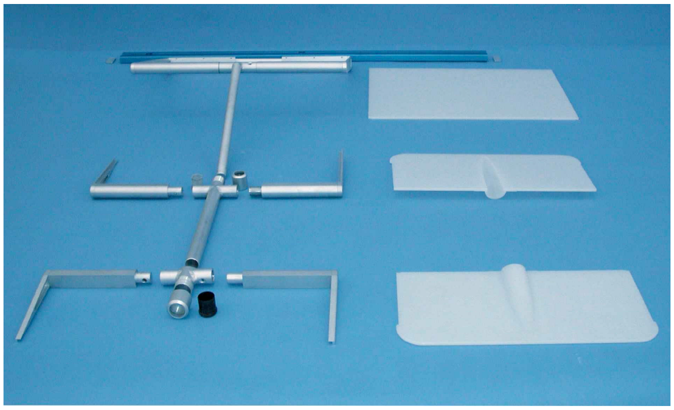

Figure 16 showing the separation into an aluminium frame construction and surface plates of the FLOW exhibition model. The plates were made out of white acrylic glass. Alternatively carbon fibre could be used.

Folding Mechanism - The sprocket adjustment and tilting mechanism of the original model was the most expensive single part of the original design. For the exhibition model two alternative principles were identified and considered: a friction-based solution and a spring-bolt solution.

Friction Based Mechanisms - A friction joint for angle adjustment would allow an infinitely variable adjustment of the angles, which would be best for individual adjustment of the workstation. On the other hand friction based mechanisms often are subject to wear and tend to loosen after a while. Systems using hand operated turnknob screws have been considered as well as bicycle-like quick-release levers acting on wedges as shown in figure 17. Although bicycle quick-release levers and sliding wedges are well known options, initial test showed that these mechanisms tended to gradually loosen and suffer material wear-out with the relatively soft aluminium.

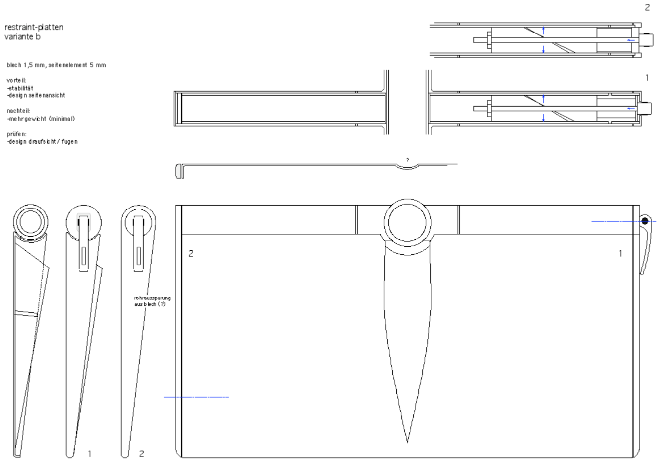

Figure 17: Plan and section of seat plate with quick-release lever for angle adjustment.

Bolt Based Mechanisms - In the time available a satisfying solution for a friction based adjustment could not be found and alternatives were considered. A bolt would actually lock the turning mechanism at a predefined position fairly stable. Unlike friction joints this would only allow gradual adjustment in about 15° steps, similar to the original sprocket system. To achieve a gradual adjustment elaborated fine mechanics would have to be employed.

The parabolic flight tests of the FLOW system showed a good use of the workstation for different people even without adjustment. The main adjustment needed for different body sizes were the table height and the distance of the seat plates to the table top. This led the design team to decide for one angular position for each plate only as shown in figure 18, which is based on the median angles of the neutral body posture in microgravity as shown in the Man-Systems Integration Standards NASA-STD-3000 (NASA 1995) These derived from measurements done on 12 individuals on Skylab. The deviations from the median angles are illustrated in figure 19 and show the relatively low deviation from the thighs to the body-centered vertical reference which is ±7°. Leg deviations down to the foot add up to ±21°. This is another indication for the reduced comfort in long-duration foot-restraint use.

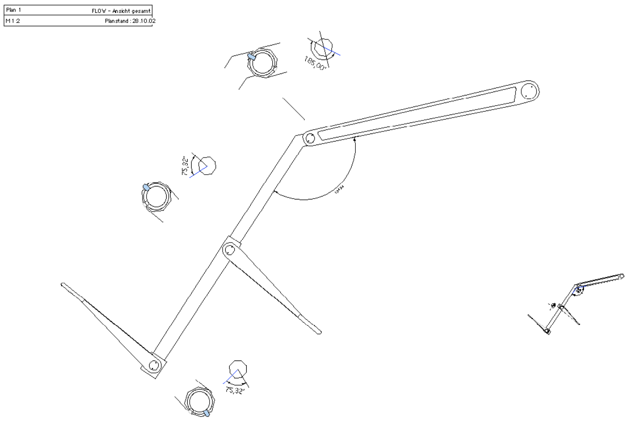

Figure 18: Fixed angular setting based on median angles of neutral body posture in microgravity.

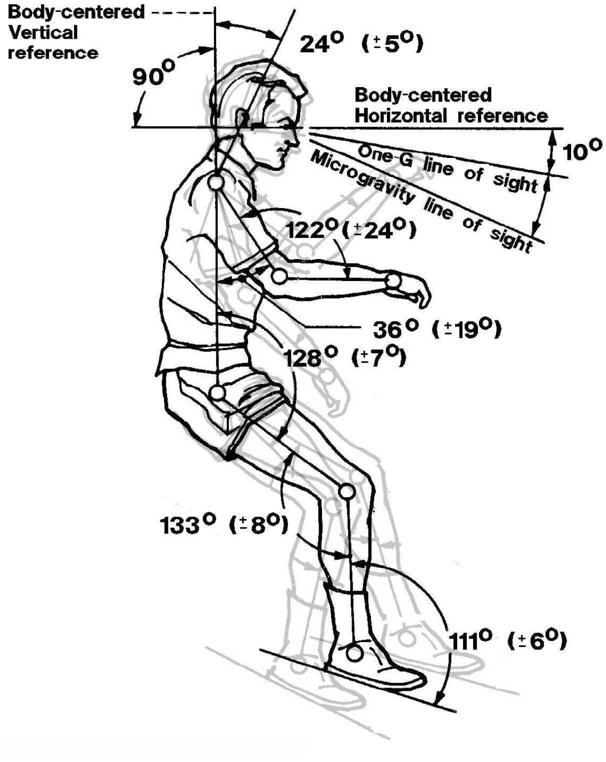

Figure 19 shows the deviation of the median angle from the neutral body posture measured on Skylab. (Source: NASA-STD-3000, deviations in grey added by author)

The spring bolts were placed at the turning joints on the left side of the telescopic arm, well visible as shown in figure 20. They have been kept relatively small for the exhibition model, but are likely to be larger in space, to be operated with EVA gloves as well. The fully deployed workstation is shown in figure 21.

Figure 20 showing push button fixation of the seat plate at a predefined angle.

Figure 21 showing deployed workstation in fixed angular position.

Desktop restraint - The bungee system of the original design has been replaced by simple Velcro strips attached to the table top as shown in figure 21. The new option to take the table top out of its frame and turn it around allows different set-ups, which can be flipped relatively quickly.

Rack connection - The seat track interface has not been elaborated further since existing systems where not available for testing and the structure of the exhibition racks did not allow substantial load on the seat tracks. As shown in figure 22 for the handrail a standard aluminium profile with similar dimensions was used. The profile was a 16 x 40 mm single-sided MayTec blue anodized aluminium profile. This profile and the correspondent standard adaptors of the MayTec system, which where fixed at the workstation, allow a quick and easy plug-in of the workstation into two holes in the center and a lateral movement by a sliding groove along the handrail. The adapters can be tightened to the handrail by a screw, which could prove redundant in microgravity, since the deviation of the angle could be kept relatively low by fine mechanics.

Figure 22 shows the workstation mounted in the BEOS exhibition at EADS Bremen.

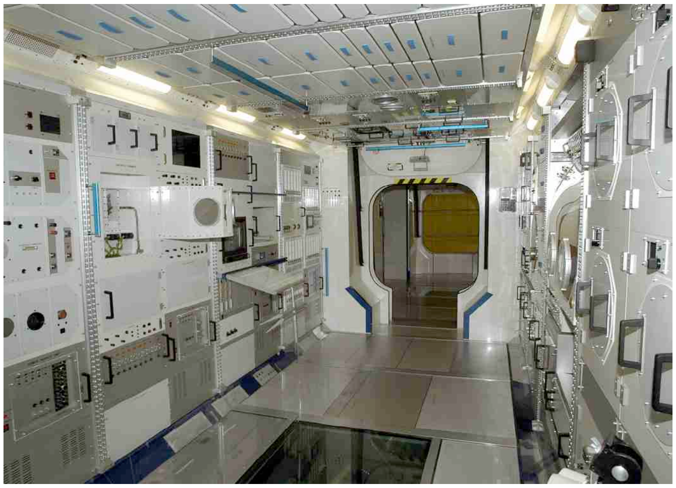

Figure 23 shows the half folded-workstation in a module mock-up. The workstation can be fully folded back to the rack, but also deployed the intrusion into the main passage way in the ceter of the module is minimal.

CONCLUSION

Today's activities in the International Space station are on a tight schedule and can be in majority characterized as stop-and-go activities, where foot loops provide a simple and quick restraint. For more complex operations like the control of the robot arm, NASA is experimenting with the lower leg restraint FRED. Current waist constraints, which provide good body stabilization are awkward to use and seriously limit the range of motion. The need for better restraint solutions is identified by NASA's Crew Restraint Project and other researchers. A micro-gravity analogue to the terrestrial chair, which provides high range of movement, simple and fast ingress and egress as well as a good and effortless fixation near the body's center of gravity stays still unidentified by many researchers though. Such systems have been proposed and used in spaceflight since the early days. The foldable workstation FLOW is the latest development of this line and adds high compactness, modularity and flexibility to the design. Parabolic test flights proved its function and showed foldout times of less than 10 seconds and ingress and egress times of less than 2 seconds. Thus the system not only provides good comfortable stabilization for high precision work, but also best 'stop-and-go' characteristics like a terrestrial office chair with briefcase dimensions, when folded. The production for an exhibition model provided the chance to even increase the flexibility of the design by introducing exchangeable table tops. The frame-infill system also allows to improve the feel and touch factor of the design by allowing colour and less heat conductive materials than aluminium. The adjustability of the original design is questioned and would have to be verified by further tests. By simplifying the tilting mechanisms approximately 3 kg of mass have been saved. The chair analogue upper thigh restraint is a valid restraint offering mostly improvements to existing restraints. They would also offer the advantage to act as chairs in low gravity environments as found on Moon or Mars, and thus could become a 'universal' chair.

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REFERENCES

Dominoni, A., & Ferraris, S. (2003). Design Restraints in Space Laboratories (SAE 2003-01-2435). 33rd International Conference on Environmental Systems (ICES), Vancouver, British Columbia, Canada, 7-10 July 2003, Warrendale, Pennsylvania, USA: Society of Automotive Engineers.

Igenbergs, E., Naumann, W., Eckart, P., & Pfeiffer, E. K. (1997). Munich Space Chair (MSC) - A Next Generation Body Restraint System For Astronauts. 12th Man in Space Symposium, June 8-13, 1997 Washington DC:

MSFC System Analysis and Integration Laboratory. (1974). MSFC Skylab Crew Systems Mission Evaluation (NASA TM X-64825). Washington DC: National Aeronautics and Space Administration.

NASA (1995). Man-Systems Integration Standards (NASA-STD-3000), Revision B. Houston, TX: NASA Johnson Space Center.

NASA (2002). International Space Station Program Pressurized Payload Accommodation Handbook, Revision A (SSP 57020 REV A). Houston, TX: NASA Johnson Space Center.

NASA (2003). Crew Restraints Project. Retrieved March 18, 2005, from http://iems.ucf.edu/crew/Default.htm

Nixon, D., Miller, C., & Fauquet, R. (1989). Space Station Wardroom Habitability and Equipment Study (NASA CR-4246). Washington, DC, USA: National Aeronautics and Space Administration.

Pfeiffer, E. (1996). Entwicklung, Erprobung und Bewertung einer Fixiereinrichtung für Astronauten. München: Herbert Utz Verlag.

Vogler, A. (2000). Micro-G-Architecture - A Transdisciplinary Education, Research and Product Development Project for Engineers and Architect (SAE 2000-01-2328). 30th International Conference on Environmental Systems, Toulouse, France, July 10-13, 2000, Warrendale, PA: Society of Automotive Engineers.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

R&MA'S: restraints and mobility aids

LDFR : Long Duration Foot Restraint

SDFR: Short Duration Foot Restraint

FLT: Fixed Length Tether

ALT : Adjustable Length Tether

TRA : Torso Restrain Assembly

MSG : Microgravity Sciences Glovebox

APPENDIX

	Footloops	**Skylab Food Table Restraints**	**MIR Seat Restraints**	**Munich Space Chair**	**FLOW**
Positive Characteristics	Light and cheap mounted anywhere, where needed fast fixation wide reach	Good stabilization Can be stowed away easily	Simple, clear system Quick fixation	Good and comfortable fixation for long-duration and high precision work	Good and comfortable fixation for long-duration and high precision work Fast ingress
Negative Characteristics	Foot muscles stabilize whole body, Difficult to used for high precision work	Only one dedicated use Only in combination with footloops	Uncomfortable Stay in the way when not used	Set up time, Relatively big storage volume Stays in the way, if not used	TBD
Interface with space station	4	2	2	4	8
weight	10	5	4	6	7
volume	10	8	5	4	8
modularity	7	4	2	4	8
flexibility	10	2	2	6	10
Simple to use	10	6	10	8	10
Ingress/egress time	9	8	9	9	10
Short-term comfort	8	8	6	10	10
Long-term comfort	4	6	1	10	10
Correct posture for tasks	4	8	2	10	10
reach	10	6	4	8	8
TOTAL (110)	**86**	**63**	**47**	**79**	**99**

Table 1: Comparative evaluation of upper thigh restraint systems compared to foot loops. Scores from 1-10 have been given on estimation by the author.