Space 2006
19 - 21 September 2006, San Jose, California

AIAA 2006-7330

20 YEARS ON– THE SCI-ARC/NASA-AMES HABITABILITY MODULE PROJECT

David Nixon
Altus Associates, Architects, Los Angeles, California USA
and
Jun Okushi
Space Projects Group/Okushi Architects, Mito, Japan

ABSTRACT

This paper reviews a design project for the interior of the Space Station Habitability Module carried out by a student/faculty team at Southern California Institute of Architecture (SCI-Arc) supported by the Aerospace Human Factors Division at NASA-Ames Research Center from 1985 to 1988. At the time, NASA was planning to provide two full-length modules for the habitability of an 8 person crew on the Space Station. NASA later dropped both modules from the Station configuration for cost reasons. 20 years on, the paper revisits the SCI-Arc/Ames project, reviews the design processes involved and the physical products generated and offers lessons learnt that are relevant to the next cycle of design and development of human habitats for space exploration. The paper presents an overview of the SCI-Arc/Ames project which is fully described in two NASA reports published in the late 1980s and now available for downloading from the www.spacearchitect.org website.

I. INTRODUCTION

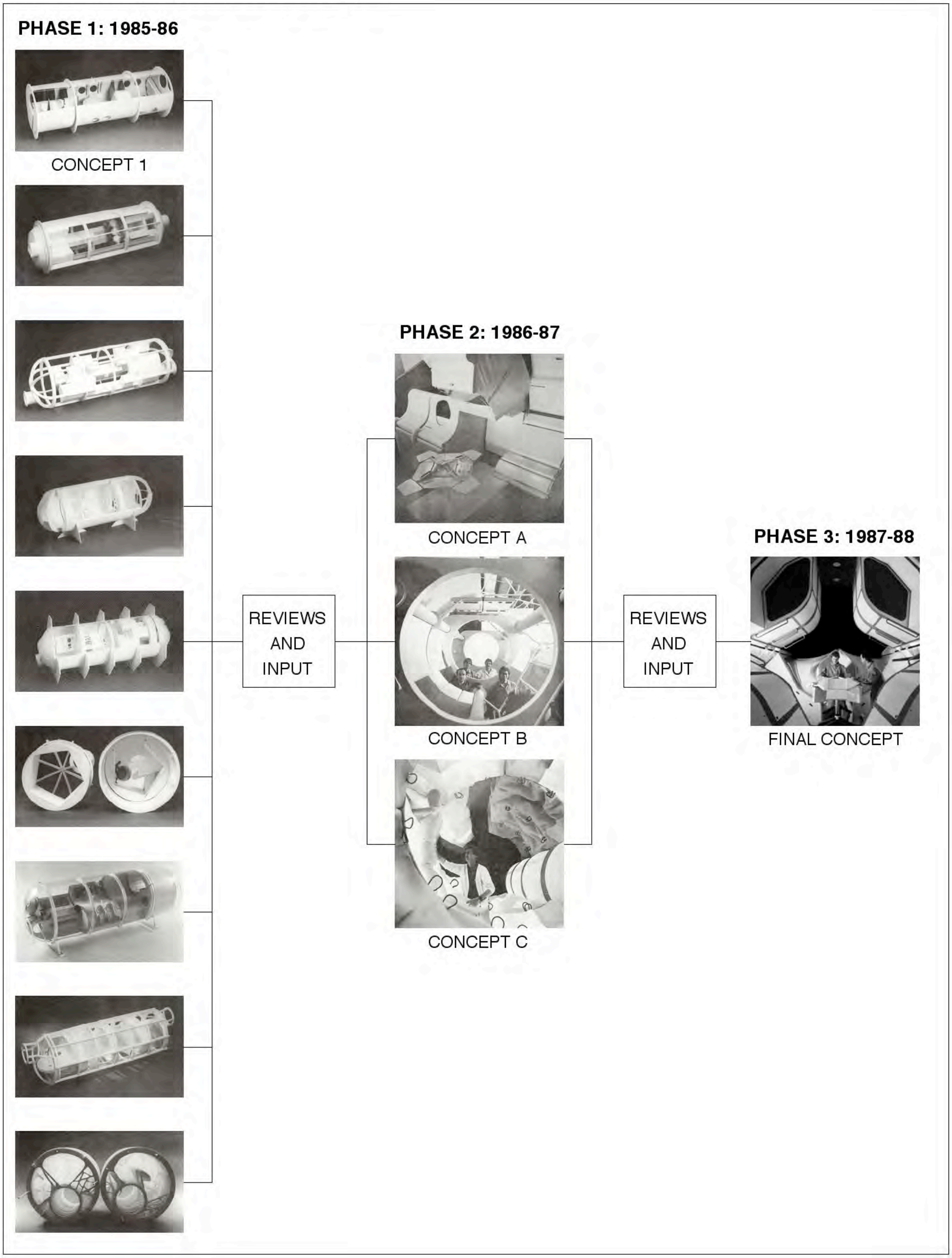
The original NASA Space Station Reference Design of 1984 contained guidelines for the design of the interior of the Station's pressurized modules. At the time, NASA was proposing two Habitability Modules – one for day shift and the other for night shift activities. The guidelines showed an interior layout for Habitability and Laboratory Modules based on a central access corridor running the length of each module with modular racks and compartments lining the corridor on each side, similar to the arrangement inside the European Space Agency's Spacelab modules in use at the time on Space Shuttle missions. As the Station development moved into Phase B, NASA contractors studied several alternative interior designs in which they arranged corridors, aisles, racks and compartments in different configurations. By this time, NASA had combined the two Habitability Modules into one for cost reasons, resulting in the need for an interior configuration with maximum rack and compartment capacity. A design emerged from the contractor studies called the '4-Stand-Off' configuration that offered maximum capacity and simplicity. It comprised a central corridor with a square cross-section. Racks and compartments of repetitive shape and size lined the four corridor sides down the module with little variation. It bore similarities to Europe's utilitarian Spacelab design for the Space Shuttle.

The SCI-Arc/NASA project began in 1986 at the time that NASA had just selected the '4-Stand-Off' configuration. Though the '4-Stand-Off' design resolved functional requirements very effectively, it was less desirable in terms of long-duration crew habitability (not a problem for Spacelab) and less successful in terms of human factors potential. In pursuit of maximum capacity, efficiency and economy, the design had overlooked architectural quality and variety. The Aerospace Human Factors Division at NASA-Ames Research Center decided to commission studies to investigate ways of improving the living standards inside the modules, leading to the project. It occurred between 1985 and 1988 and was performed by a student/faculty team at Southern California Institute of Architecture under a Cooperative Agreement with NASA-Ames Research Center. Much of the reference material used in the project was drawn from NASA and contractor progress documents of the time. The project is fully described in two NASA reports (Nixon, 1986, and Nixon, Miller, and Fauquet 1989) that can be downloaded from the www.spacearchitect.org website.

II. PROJECT STRUCTURE

The project consisted of three separate and consecutive phases. FIGURE 1 shows the project structure. Phase 1 occurred from 1985 to 1986 and comprised the development of 9 different concepts for the interior of the Habitability Module. Each student team member produced a design with plans, sections and a scale model. Review of the 9 concepts took place at the end of Phase 1 with input from NASA. Phase 2 took place between 1986 to 1987 and comprised the development of 3 different concepts for the Habitability Module interior. Students worked in teams with each team producing plans, sections and a full- scale mock-up of part of the module's interior. Review of

FIGURE 1: PROJECT STRUCTURE



the 3 concepts took place at the end of Phase 2 with input from NASA. Phase 3 occurred from 1987 to 1988 and comprised the development of a single concept for the wardroom portion of the Habitability Module. The project ended with a NASA and industry review at the end of Phase 3.

Phase 1 Design

Phase 1 began with research on accommodation requirements for the Habitability Module derived from anticipated crew activities. The crew activities were:

Meetings and Teleconferences
Planning and Training
Relaxation and Entertainment
Eating and Drinking
Food Preparation and Cooking
Exercises and Games
Housekeeping and Hygiene
Space Station Operations
Library and Study
Shift and Crew Handovers

The accommodation requirements identified all major equipment and outfitting items to be incorporated in the Habitability Module. Work continued on the development of design guidelines. These covered:

Crew Timelines and Activity Sequences
Activity Proximities and Compatibilities
Individual and Group Ergonomics

The Phase 1 Research provided the necessary information for the Phase 1 design.
This involved the development of 9 individual concepts for the Habitability Module interior. The aim of these was to propose and test alternative design approaches based on individual interpretations of the requirements and guidelines related to the Habitability Module volumetric constraints. The concepts ranged substantially in character from conventional and fixed configurations with dedicated activity volumes to experimental and multipurpose configurations with adaptable activity volumes. Each concept comprised longitudinal sections and transversal sections through the module and a scale model with the exterior skin cut away to show the interior arrangement.

Phase 1 Review

Review of the Phase 1 concepts involved the evaluation of each concept using a standard design analysis sheet developed for the purpose. The analysis process utilized 10 design factors. Each factor addressed a key issue essential for consideration at a conceptual level. Together, the design factors provided a comprehensive means of comparing and scoring the design concepts at this early stage of design development. The design factors were:

Communal Organization
Spatial Perception
Internal Circulation
Compartment Adaptation
On-Orbit Completion
Life-Cycle Modification
Ergonomic Utilization
Exterior Observation
Equipment Rationalization
Structural Inspection

FIGURE 2 shows a typical design analysis sheet for one of the concepts. FIGURE 3 shows a photograph of the model of the same concept. The wide central column contains comments on the design resolution of each of the 10 design factors. The intermediate column on the right indicates whether the resolutions resulted in a significant advantage or disadvantage or neither. The far right column scored the resolution in terms of a 5-point rating, ranging from optimum with a value of 1 to minimal with a value of 5. In the concept example shown in FIGURE 2, the design optimally resolved Spatial Perception, Internal Circulation and Exterior Observation (all scores of 1) but minimally resolved Compartment Adaptation (score of 5). TABLE 1 summarizes key aspects of the review results for all 9 concepts.

FIGURE 2: PHASE 1 ANALYSIS AND EVALUATION

DESIGNER:	CONFIGURATION:	CONCEPT:	
DESIGNER:	CONFIGURATION:	CONCEPT:	
DESIGNER:	CONFIGURATION:	CONCEPT:	
DESIGNER:	CONFIGURATION:	CONCEPT:	
DESIGNER:	CONFIGURATION:	CONCEPT:	
DESIGNER: JUN OKUSHI	CONFIGURATION: HORIZONTAL	CONCEPT: 9	

		BENEFIT	RESOLUTION (1 2 3 4 5)
COMMUNAL ORGANIZATION	Activity areas clustered along circulation spine. Activities separated into communal wardroom (active) functions and semi-private library/ workstation (passive) functions.	•	○●○○○
SPATIAL PERCEPTION	Direct utilization of anthropometric geometries and movement patterns in developing activity area configurations achieves interesting and exciting spatial environment.	A	●○○○○
INTERNAL CIRCULATION	Direct perimeter circulation path from module end to end.	A	●○○○○
COMPARTMENT ADAPTATION	Compartmental adaptability not clearly defined and requires extensive development. Extensive adaptability unlikely to be realized due to nature of concept.	D	○○○○●
ON-ORBIT COMPLETION	Internal skeletal and enclosure elements capable of on-orbit completion. Divisibility and itemization of internal configuration requires examination.	•	○○●○○
LIFE-CYCLE MODIFICATION	Internal enclosure elements and equipment may not be capable of life-cycle modification. Nature of life-cycle changes requires substantial clarification.	•	○○●○○
ERGONOMIC UTILIZATION	Considerable potential for effective ergonomic utilization of interior envelope elements and equipment. Requries further development.	•	○○●○○
EXTERIOR OBSERVATION	Windows potentially free of obstructions. Choice of window location fairly extensive. 360° anthropometric rotation requires windows clear of internal structure.	A	●○○○○
EQUIPMENT RATIONALIZATION	The unique nature of interior configuration combined with specialized approach to design of structure and envelope linings substantially limits possibility of rationalization.	•	○○●○○
STRUCTURAL INSPECTION	Elements and equipment could be designed to be detachable from module shell. Free-form communal area would aid accessibility - structural members may reduce it.	•	○○●○○

A = ADVANTAGE B = DISADVANTAGE 1 = OPTIMUM 2 = ACCEPTABLE 3 = AVERAGE 4 = DEFICIENT 5 = MINIMAL

FIGURE 3: EXAMPLE OF PHASE 1 CONCEPT

TABLE 1: SUMMARY OF PHASE 1 CONCEPT FEATURES

CONCEPT 1	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Constant Horizontal Multicolor Scheme with Flexibility of Window Arrangements End-to-End Overhead Translation Path Compartment Outfitting and Storage System Wardroom Table
CONCEPT 2	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Constant Horizontal Transparent and Enhanced Greenhouse Wall End-to-End Underfoot Translation Path Utilizes Platonic Solids Greenhouse and Workstation
CONCEPT 3	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Multi-Axial Interfaces Solid and Void Enhanced Interplay Central Spine Path Anthropometrics/Ergonomics-Driven Series of Dedicated Singular Function Zones
CONCEPT 4	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Constant Horizontal Generous Configuration of Internal Volumes Segmental Translation None (Overall Architectural Configuration) Multi-Functional Table/Workstation
CONCEPT 5	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Multiple Vertical Variable Volume Via Retractable Elements Off-Centric Spine Path Variable (Sliding Bulkheads) Sliding Bulkheads
CONCEPT 6	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Multi-Axial Interfaces Transformable Volume Achived by Retractable Racks Random Variable Stand-Off Configuration
CONCEPT 7	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Constant Horizontal Large Enhanced Curvilinear Elements Segmental Translation Interlocking Curvilinear Elements Large Curvilinear Elements
CONCEPT 8	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Multi-Axial Interfaces Enhanced Freeform Segmental Translation None (Large Bulkheads Configuration) Freeform Membrane Soft Surface Volume Envelope
CONCEPT 9	ORIENTATION SPATIAL PERCEPTION CIRCULATION MODULATION FEATURED ELEMENTS	Constant Horizontal 3-Way Enhanced-Curve Cellular Volume End-to End Underfoot Translation Path None (Large Bulkheads Configuration) Freeform Membrane Soft Surface Volume Envelope

FIGURE 4: PHASE 2 ANALYSIS AND EVALUATION

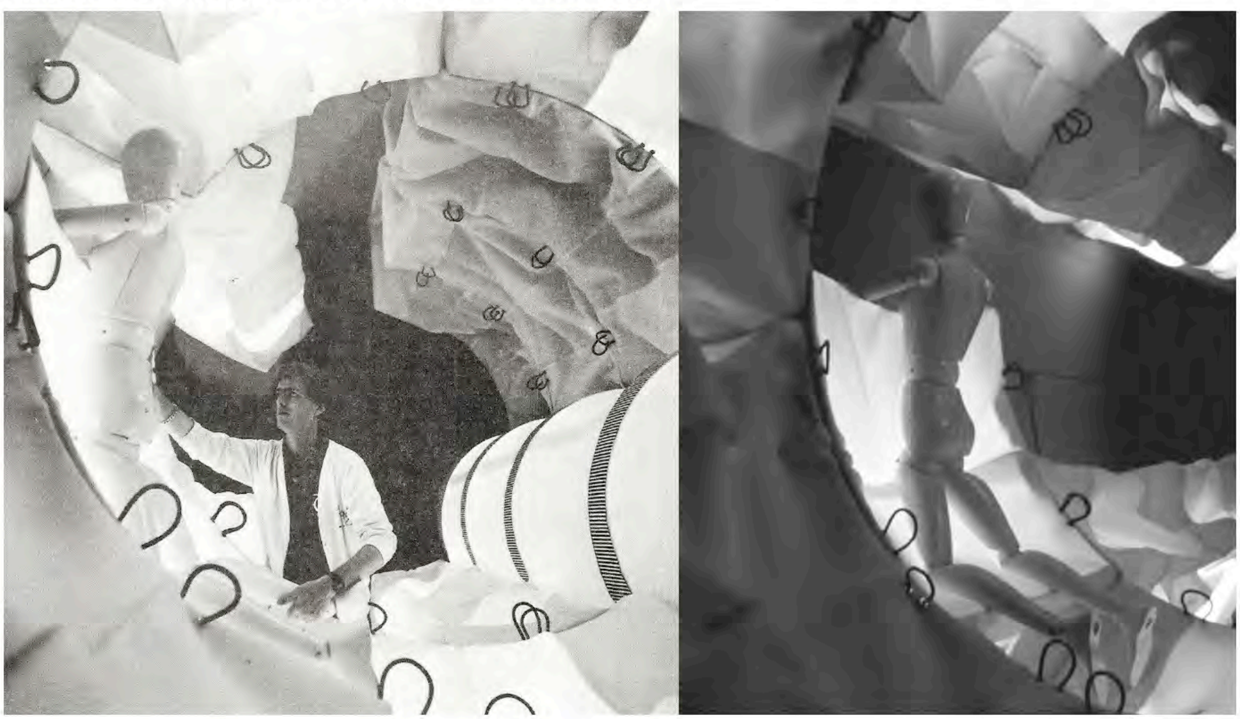
ARCHITECTURAL CONCEPT
ARCHITECTURAL SUBSYSTEMS
PERCEPTUAL QUALITY
ERGONOMICS
WARDROOM ACTIVITIES
ASSOCIATED FEATURES
ORIENTATION/TRANSLATION
CREW GROUP USES
UTILITY SYSTEMS

	EVALUATION 1	EVALUATION 2	EVALUATION 3	EVALUATION 4
	5 4 3 2 1	5 4 3 2 1	5 4 3 2 1	5 4 3 2 1
PRIMARY UTILITY CORES	○●○○○	●○○○○	●○○○○	●○○○○
UTILITY SYSTEMS DISTRIBUTION	○●○○○	○●○○○	●○○○○	○○●○○
SECONDARY STRUCTURE	○○○●○	○○○●○	○○○○○	○○●○○
UTILITY SYSTEMS ATTACHMENTS	○○○○●	○○○●○	○○○●○	○○○○●
PRESSURE WALL ACCESS	○○○○●	○○○○●	○○○○●	○○○○●

Utility core and distribution systems are clearly developed. Secondary structure attachments require study. Pressure wall accessibility a potential problem and requires some revision of rack and compartment geometries.

5 = OPTIMUM 4 = ACCEPTABLE 3 = AVERAGE 2 = DEFICIENT 1 = MINIMAL

FIGURE 5: EXAMPLE OF PHASE 2 CONCEPT



Phase 1 Result

Phase 1 completed with a series of conclusions and recommendations resulting from the Research, Design and Review stages. Major conclusions and recommendations were:

Conclusions;

a) Highly adaptable configurations perform effectively in responding to day-to-day activities and routines.

b) Crew perception and physical movement benefit from horizontal not vertical configurations.

c) Orbital completion, life-cycle modification and hull inspection are related design issues.

Recommendations;

a) Element and equipment compactness and miniaturization to minimize volumetric allocation and maximize available habitable volume.

b) Element and equipment multi-functionality and versatility to minimize performance inflexibility and maximize mass and cost efficiency of hardware.

c) Element and equipment ergonomic efficiency and their user friendliness to minimize operational inconvenience and maximize user comfort.

d) Element and equipment autonomy and self-containment to minimize systems interdependence and maximize individual functional durability

Phase 2 Design

Phase 2 began with the definition of the following objectives:

a) To simulate and evaluate the physical form and environmental characteristics of the wardroom and its constituent elements and equipment.

b) To generate and experiment with innovative architectural/industrial design alternatives for potential incorporation in full-scale mock-ups.

c) To obtain experience in the design and construction of full-scale mock-ups.

d) To apply anthropometric and group ergonomic design criteria to architectural interior configurations.

For cost and size reasons, Phase 2 focused on a part the Habitability Module that contained the wardroom and the 3 configuration concepts at full-scale, compared to the 9 scale-model concepts in Phase 1. The first task involved the fabrication of a shell to simulate portion of the Habitability Module of sufficient length to incorporate the wardroom. Shell dimensions were 2134mm (84") radius by 4877mm (192") long. The shell was open at each end. The three configuration concepts were:

Concept A

a) Approach – 4 perimeter stand-off spines that provided attachment and support for deployable and interchangeable modular racks and compartments and ergonomically adaptable workstations.

b) Features – 2 crew workstations, 1 wardroom table, 2 personal hygiene units, 2 library/study compartments, 2 ECLSS units, 8 fold-out sleeping compartments.

Concept B

a) Approach – A triangulated core with a central access corridor and 3 structural/utility spines providing support and attachment for specific and interchangeable modular elements and equipment.

b) Features – 2 galley food preparation stations, 2 galley hygiene stations, 2 'greenhouse' units (gloveboxes), 1 soft 'storewall' unit, 1 wardroom meeting table, radial storage compartments.

Concept C

a) Approach – An accessible off-center utility route and modular, curved-geometry racks and compartments providing anthropometrically-responsive, soft interior fascias for crew station functions

b) Features – Radial contoured racks/elements; continuous modular utility spine.

Phase 2 Review

Review of the Phase 1 concepts involved the evaluation of each concept using a standard design analysis sheet developed for the purpose, similar to that used in Phase 1. The analysis process utilized 57 design factors organized into 9 groups. Each factor addressed a key issue essential for design consideration. Together, the design factors provided a comprehensive means of comparing and the three full-scale wardroom concepts. The 9 design factor groups were:

Architectural Concept
Utility Systems
Architectural Subsystems
Perceptual Quality
Ergonomics
Wardroom Activities
Associated Features
Orientation/Translation
Crew Group Uses

FIGURE 4 shows a typical design analysis sheet for one of the 9 design factor groups for one of the concepts. FIGURE 5 shows photographs of the full-scale mock-up of the same concept. The 9 design factor groups are listed in the top horizontal bars. The design analysis sheet is for the Utility Systems factors group. The left column contains the Utility Systems design factors. The 4 identical columns on the right show the reviewer evaluations using a 5-point rating, ranging from optimum with a value of 5 to minimal with a value of 5. In the concept example in FIGURE 4, the design optimally resolved Primary Utility Cores, and Utility Systems Distribution but minimally resolved Utility Systems Attachments and Pressure Wall Access.

Phase 2 Results

Phase 2 completed with a summary of the most successful design features of the 3 full-scale concepts under their respective design factors. Chief among these were:

Architectural Concept-2 levels of crew accommodation and activity and functionally dynamic racks and compartments can make the most of a limited internal volume.
Utility Systems-Different ways of incorporating intra-module utility routes can include perimeter utility ducts, central utility spines and crew-accessible utility tunnels.
Architectural Subsystems-A single module of fixed shape and size can accommodate different rack and compartment geometries, increments and attachment methods.
Perceptual Quality-Fold-away compartments and variations of forms, surfaces, lighting and textures can improve the sense of interior spaciousness.
Ergonomics-Ergonomic interfaces between crewmembers and enclosures, consoles and surface must be responsive to crew anthropometric variables.
Wardroom Activities-The wardroom must be able to accommodate crew groups of different size engaged in different types of activity at different times of day.
Associated Features-Compartments and equipment items with deployable/retractable operational capabilities can fold and stow away when not in use to recover valuable volume.
Orientation/Translation-Well-defined orientation and translation routes inside the module can become integral and positive features of the architectural concept.
Crew Group Uses-Internal configurations must be able to accommodate a range of simultaneous activities with appropriate community/privacy gradients.

Phase 3 Design

Phase 3 began with the definition of the following objectives:

a) To consolidate and continue research into Space Station wardroom habitability based on relevant criteria drawn from pervious or parallel programs or studies.
b) To define and develop a feasible and innovative architectural/industrial design proposal for the configuration of the crew wardroom in the Habitability Module.
c) To contribute to the Space Station design effort by providing a life-size wardroom mock-up for use by NASA as a research tool for continuing habitability studies.

Phase 3 concentrated on the design and development of a single concept for the wardroom constructed as a full-size, medium-fidelity mock-up and based on a synthesis of criteria drawn from the following sources:

a) Research program requirements determined by the Aerospace Human Factors Research Division at NASA-Ames Research Center.
b) Appropriate recommendations derived from concepts developed in Phase 1 of the project.
c) Selected architectural and industrial design features drawn from concepts developed in Phase 2 of the project.

d) Selected architectural and industrial design features drawn from concepts developed at the beginning of Phase 3 of the project.
e) Appropriate data drawn from NASA contractor team studies during Space Station Phase B – Definition and Preliminary Design Phase.

The synthesis process and its position in the project sequence are shown in FIGURE 6.
The synthesized data resulted in the formulation of 20 major design guidelines for the development of the final concept. These Final Design Guidelines were:

1) Habitability Module 166” internal diameter and 464” effective length.
2) 8 person and dual shift Space Station crew organization.
3) Double height/dual level module accommodation configuration.
4) Compliance with Phase B rack and compartment fitting-out inventory.
5) Definitive configuration organization and activity adjacencies.
6) Feasible life-cycle modification and reconfiguration.
7) Flexible/modular rack and compartment longitudinal fit.
8) Adequate free wardroom volume for large crew group uses.
9) Clear module translation route and horizontal cueing.
10) Distinctive perceptual quality of interior environment.
11) Variable décor/finishes within interior environment.
12) Rationalized ECLS and utilities systems distribution.
13) Reduced number of full-depth structural stand-offs.
14) Improved functional and operational structural stand-off design.
15) Exercise compartments and galley food preparation facilities.
16) Planning/station operations and window/observation workstations.
17) Deployable/retractable dedicated crew activity compartments.
18) Advanced microgravity anthropometrics and ergonomics features.
19) Adaptable/extendable wardroom table and soft stowage system.
20) Folding/enclosing workstation operations techniques.

Final Concept Mock-Up

A full description of the final concept design and mock-up is given in the second of two NASA reports on the project (Nixon, Miller and Fauquet, 1989), details of which are given in the references. This section gives a brief description. The mock-up produced was equivalent to approximately 50% of the length of the Habitability Module and focused on the wardroom, galley and the exercise facility. The main features incorporated in the mock-up were:

a) 2 exercise compartments.
b) 1 command & control workstation.
c) 2 window workstations.
d) 1 soft stowage bag system.
e) 1 wardroom table.
f) 4 passive body restraints.
g) 4 galley racks.
h) 6 equipment racks.
i) A lighting system.

Mock-Up Photographs

FIGURE 7 shows a series of photographs of the mock-up of the final concept. The photographs are numbered 1 to 12. The photographs show:

1. View through 2 equipment racks into wardroom area.
2. Use of rowing machine in an exercise compartment.
3. Wardroom table with work surfaces fully angled.
4. Adjustable lighting mounted onto spines.
5. Wardroom table prototype with work surfaces stowed.
6. Soft stowage bag system.
7. View along module with galley in top foreground.
8. Wearable workstation prototype on NASA KC-135 flight test.

FIGURE 6: PROJECT SEQUENCE

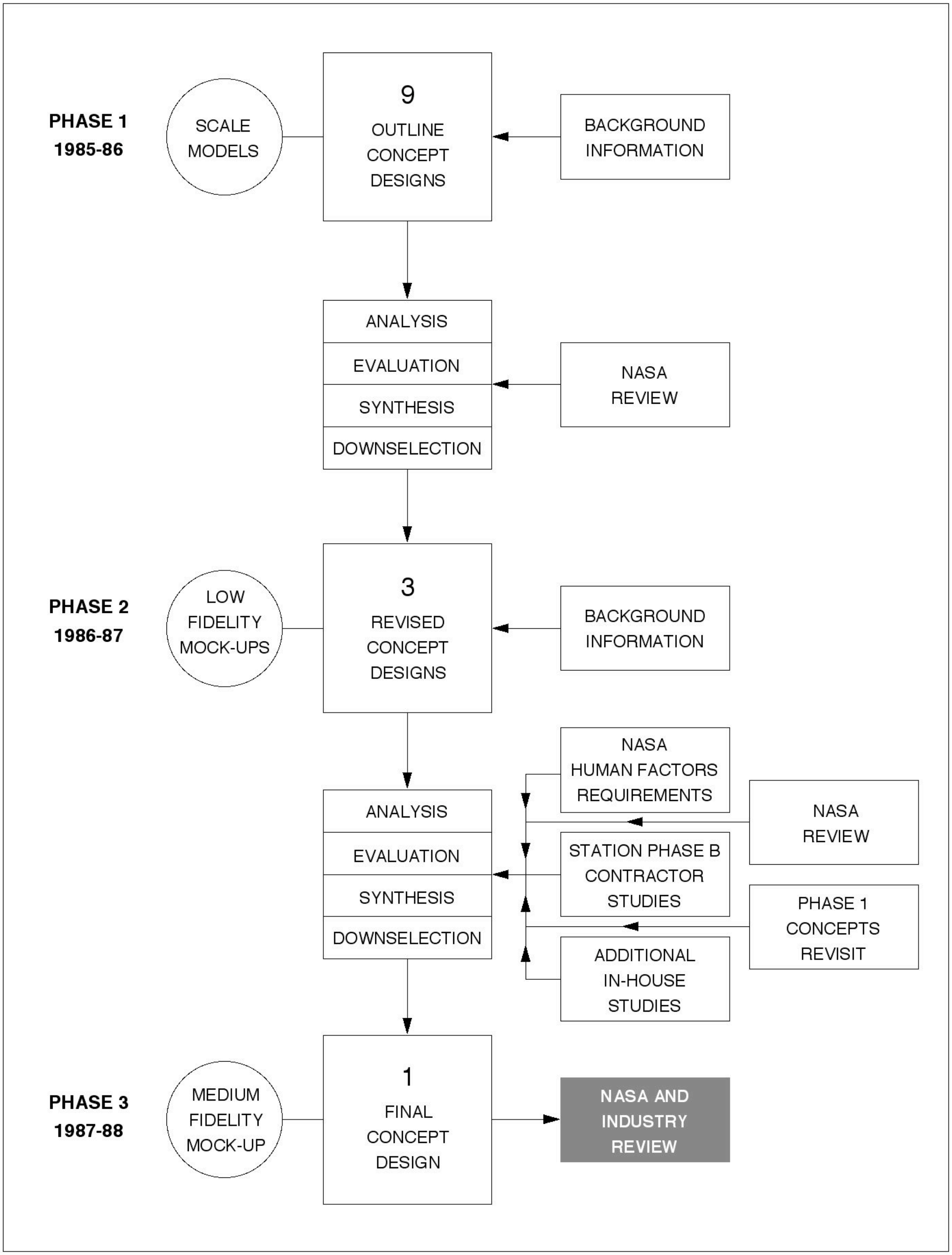


FIGURE 7: PHOTOGRAPHS OF MOCK-UP OF FINAL CONCEPT

9. Central wardroom area with table.
10. Curvilinear equipment racks in wardroom.
11. Window workstation with flat screen.
12. Bicycle ergometer in exercise compartment.

Phase 3 Results

NASA and aerospace industry representatives carried out a review of the mock-up at the end of Phase 3, following a presentation by the Phase 3 team. The reviewers did not use analysis sheets for the review, making comments directly to the team at the presentation. Phase 3 completed with a series of conclusions and recommendations. Chief among these were:

Life-Cycle Modification-Life-cycle reconfiguration and upgrading options are constrained by initial accommodation, stand-off and utilities design

Organization and Zoning-A dedicated buffer zone separating day and night accommodation increases noise attenuation and improves personal privacy.

Architectural Configuration-Dual level configurations improve operational and translational efficiency and generate enhanced perceptual interest.

Stand-Off Structural Systems-Demountable stand-off structure contributes to reduced physical obstruction and simpler on-orbit modification.

Utilities Distribution Systems-Variable depth stand-off structure contributes to rationalized utilities distribution and improved systems accessibility.

Rack and Compartment Sizes-Variable width racks and compartments contribute to improved organizational versatility and operational performance.

Rack and Compartment Functions-Deployable/retractable compartments provide valuable additional free volume and improved occupant performance.

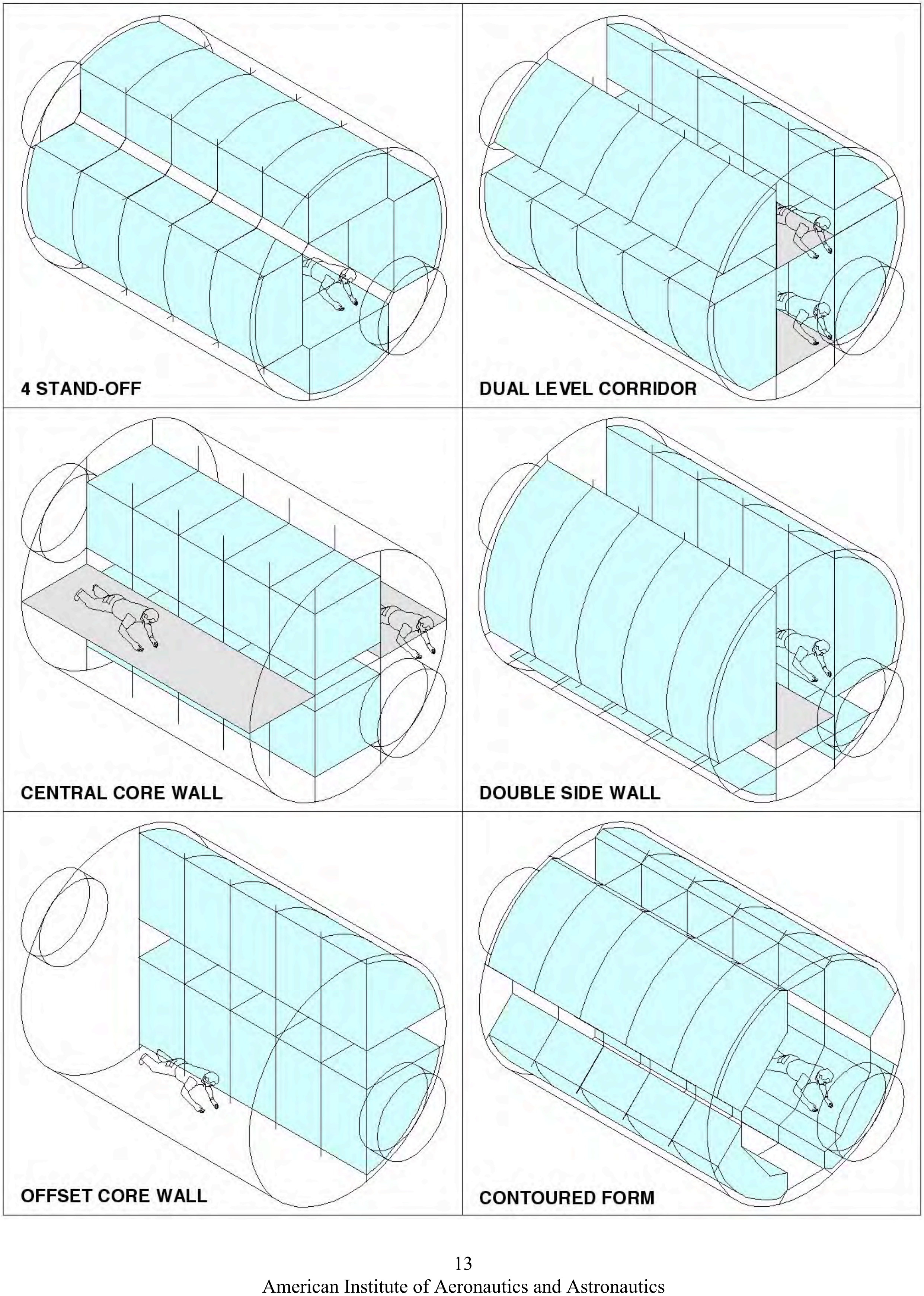
Crew Equipment Features-Adaptable and conformable crew equipment features improve workstation ergonomics and facilitate routine tasks.

III. CONCLUSIONS AND LESSONS LEARNT

This paper has summarized a design investigation carried out in the mid-1980s on an aspect of a major human space project – the International Space Station – that has been under construction in orbit since 1998. As such, the design outcome of the study is of historical interest as a record of one particular design approach to the challenge of providing a long term, livable environment inside a highly constrained volume. The International Space Station is a *fait accompli*. Human space endeavours have moved on to other horizons, notably the Shuttle replacement, a return to the Moon and eventually a human mission to Mars. Sooner or later, NASA will firmly commit itself to human exploration of the Moon and Mars and the cycle of design development will begin again. In conclusion, 20 years on, what main lessons were learnt from the SCI-Arc/Ames study that can benefit a new cycle of design effort?

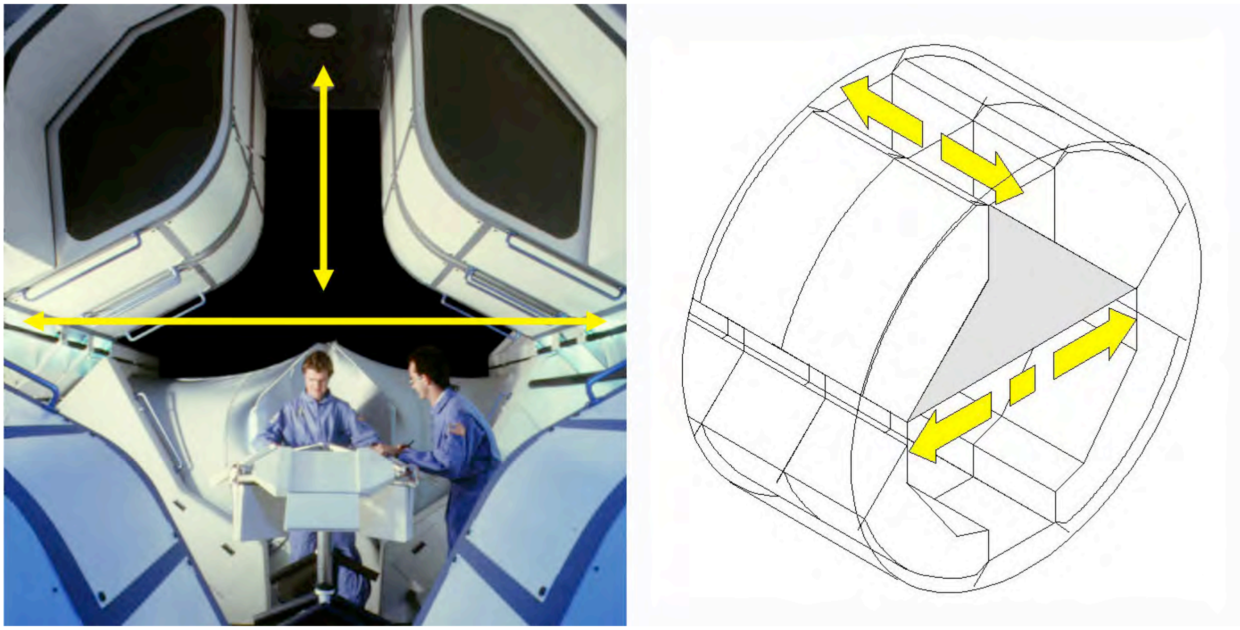
The first lesson has less to do with the design decisions taken and their architectural outcome in response to a particular design problem, but more to do with the value of systematic design enquiry using a series of measured steps of increasing fidelity accompanied by reviews to distill and refine a single end product from a group of initial ideas. Applying the same systematic, step-by-step approach to the development of the interior architectural configuration of the Space Station Habitability Module during Space Station Phase B in the 1980s could have resulted in design improvements to the livability of the 4 Stand-Off approach without loss of functional efficiency. FIGURE 8 shows the 5 major module interior concepts (4 Stand-Off, Dual Level Corridor, Central Core Wall, Double Side Wall, Offset Core Wall) at the time of Space Station Phase B, as well as the Contoured Form design produced in this study. It is evident from the concepts that a considerable variety of internal architecture solutions is possible within a common module geometry and size and that from crew anthropometric, ergonomic and perceptual as well as accommodation quality standpoints, several of the concepts were superior to the 4 Stand-Off design. For example, in the Contoured Form, the stand-offs are rotated to the 4 cardinal points in cross-section with the majority of utilities grouped through two 'wall' stand-offs, enabling the 'floor' and 'ceiling' stand-offs to be reduced in depth. This permits the introduction of an upper 'loft' level of accommodation and an increase in the free volume width across the module diameter. The result is greater internal spaciousness, first in the critical upper body zone where physical distance and longer sightlines between crew members occur from side to side across the module, and second in an upper crew translation and movement route that by-passes the group activities below and avoids conflict with them, as shown in FIGURE 9. The other design concepts can claim design ideas of equal merit but

FIGURE 8: MODULE INTERIOR CONFIGURATIONS



these were not put to the test by means of a systematic design enquiry with the early decision on the 4 Stand-Off configuration, at which point they were dropped.

FIGURE 9: INCREASING MODULE SPACIOUSNESS



The second lesson deals with the life cycle ability of module interiors to adapt to new requirements during their lifetime in response to new operational conditions or circumstances. This was of concern in this study. The Contoured Form demonstrates much potential for adaptability because, from the outset, it was conceived as an irregular and asymmetrical configuration unconfined by the rigid, modular geometry of the 4 Stand-Off approach. The essence of success here perhaps lies in the ability to reduce the dominance of the functional stand-offs on the module interior in such a way that permits the introduction of a variety of racks, compartments and linings and then allows them to be rearranged or changed-out during the life-cycle to create new architectural interiors as desirable or necessary. This remains an important consideration for the future of the International Space Station. Early on during design development, Station module interiors were outfitted to the fullest extent possible with racks as part of the 4 Stand-Off approach. This was necessary as the initial reduction of two Habitability Modules to one, and then the elimination of them entirely meant that the remaining modules had to be outfitted to full rack capacity. Today, the future utilization of the Space Station and the precise nature of the activities that will take place inside it are an open question.NASA's decision to descope the scientific research role of its portion of the Station combined with the receptiveness of the Russians to the idea of non-science uses and the emergence of space tourism as a vibrant market suggest that the Station's future may be quite different from that orginally intended. It is possible that the Station partners may privatize or commercialize it, wholly ot partly, both to reduce life-cycle operational costs at a time when expensive new projects demand available financial resources and to generate revenues from market-orientated applications in response to growing market interest. The result could be a need to remodel module interiors for other applications with the elimination of redundant racks and their replacement by quite different equipment and outfitting.

The third lesson concerns the value of building design concepts at flexible full-scale mock-up level to analyze and evaluate their advantages and disadvantages at "hands-on" and "walk-through" scale during the design decision process. Full-scale mock-ups are often used by the aerospace industry and several were built by NASA and its contractors during Space Station Phase B and Phase C/D to display module interiors. These ranged from low fidelity versions fabricated from foamboard to medium-to-high fidelity versions fabricated from aluminum. In most cases, they were built to demonstrate a design and engineering solution already proposed, rather than as a tool to help to analyze and evaluate different design concepts. The SCI-Arc/Ames mock-up was different. It was built from a kit of parts. The cylindrical module shell comprised a series of identical modular elements to enable the mock-up to be reconfigured, lengthened, shortened, dismantled or moved to a new location. The elements were designed and sized to enable manual construction of the mock-up using a simple elevated working platform, without need of a crane or lifting tackle. The mock-up shell was capable of assembly by four people. Elements that formed the lower portion of the mock-up that were required to be robust as they were taking live floor loads, were mobile and were easily moved across a flat floor by two persons. All module elements were sized to fit on flatbed trucks or inside shipping containers. This modular and mobile approach allowed the mock-up to be moved three times during the lifetime of the project – first from SCI-Arc to a new warehouse location in the Los Angeles area for final assembly and review, second from Los Angeles to NASA Johnson Space Center in Houston for display and finally from NASA Johnson Space Center to NASA Ames Research Center at Moffett Field, California for long-term storage.

REFERENCES

Nixon, D., "Space Station Group Activities Habitability Module Study," NASA CR 4010, 1986.
Nixon, D., Miller, C., and Fauquet, R., "Space Station Wardroom Habitability and Equipment Study," NASA CR 4246, 1989.

(Note: These reports are available in PDF format and can be downloaded from the www.spacearchitect.org website. On the home page, click on "publication" in the left hand column and scroll through the authors' names to locate the titles of the two reports).