JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

All KC events will be approved for public using NASA Form 1676.

This synopsis provides information about the Knowledge Capture event below.

Topic: Origins and Early History of Underwater Neutral Buoyancy Simulation of Weightlessness for EVA Procedures Development and Training – Winnowing and Regrowth

Date: September 10, 2013 **Time:** 11:30-12:30 pm **Location:** JSC/B5S/R3102

DAA 1676 Form #: 29744

This is a link to all lecture material and video \\js-ea-fs-03\pd01\EC\Knowledge-Capture\FY13 Knowledge Capture\20130910 Charles_History of Underwater Neutral Buoyance_Part 2\For 1676 Release & Public Review

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

Assessment of Export Control Applicability:

This Knowledge Capture event has been reviewed by the EC5 Spacesuit Knowledge Capture Manager in collaboration with the author and is assessed to not contain any technical content that is export controlled. It is requested to be publicly released to the JSC Engineering Academy, as well as to CASI for distribution through NTRS or NA&SD (public or non-public) and with video through DVD request or YouTube viewing with download of any presentation material.

* This PDF is also attached to this 1676 and will be used for distribution.

For 1676 review use_Synopsis_Charles_Winnowing and Regrowth_9-10-2013.pdf

Presenter: John Charles

Synopsis: The technique of neutral buoyancy during water immersion was applied to a variety of questions pertaining to human performance factors in the early years of the space age. It was independently initiated by numerous aerospace contractors at nearly the same time, but specific applications depended on the problems that the developers were trying to solve. Those problems dealt primarily with human restraint and maneuverability and were often generic across extravehicular activity (EVA) and intravehicular activity (IVA) worksites. The same groups often also considered fractional gravity as well as weightless settings and experimented with ballasting to achieve lunar and Mars-equivalent loads as part of their on-going research and development. Dr. John Charles reviewed the association of those tasks with contemporary perceptions of the direction of NASA's future space exploration activities and with Air Force assessments of the military value of man in space.

Biography: Dr. John Charles was a child of the early space age, and clearly remembers playing "John Glenn" while lying on his back in the dusty playground of his elementary school, in the launch posture with his legs up and over some handrails. A scientific interest in weightlessness led him to a career in the space life sciences, and a lifelong fascination with spaceflight in general has kept him in the library stacks and on-line archives researching little known aspects of spaceflight history. Charles earned his bachelor of science in biophysics at The Ohio State University and his doctorate in physiology and biophysics at the University of Kentucky. He has been at the Johnson Space Center since 1983, where he investigated the cardiovascular effects of space flight on Space Shuttle astronauts and on crewmembers of the Russian space station Mir. He was mission scientist for the NASA research on American astronauts on Mir, on John Glenn's Space Shuttle flight, and on STS-107, Columbia's last mission in January 2003. Charles is now the chief of the International Science Office of NASA's Human Research Program and leads space life sciences planning for the joint U.S./Russian one-year mission on the ISS. He is a fellow of the Aerospace Medical Association and a full member of the International Academy of Astronautics, has published over 60 scientific articles, and has received several professional awards.

EC5 Spacesuit Knowledge Capture POCs:

Cinda Chullen, Manager
cinda.chullen-1@nasa.gov
(281) 483-8384

Vladenka Oliva, Technical Editor (Jacobs)
vladenka.r.oliva@nasa.gov
(281) 461-5681

Origins and Early History of Underwater Neutral Buoyancy Simulation of Weightlessness for EVA Procedures Development and Training - Part 2

Winnowing and Regrowth

Spacesuit Knowledge Capture Series
September 10, 2013

John B. Charles, Ph.D.
john.b.charles@nasa.gov

Methods of weightlessness simulation for human-centered purposes

(Wunder, Duling & Bengele, in McCally, 1968)

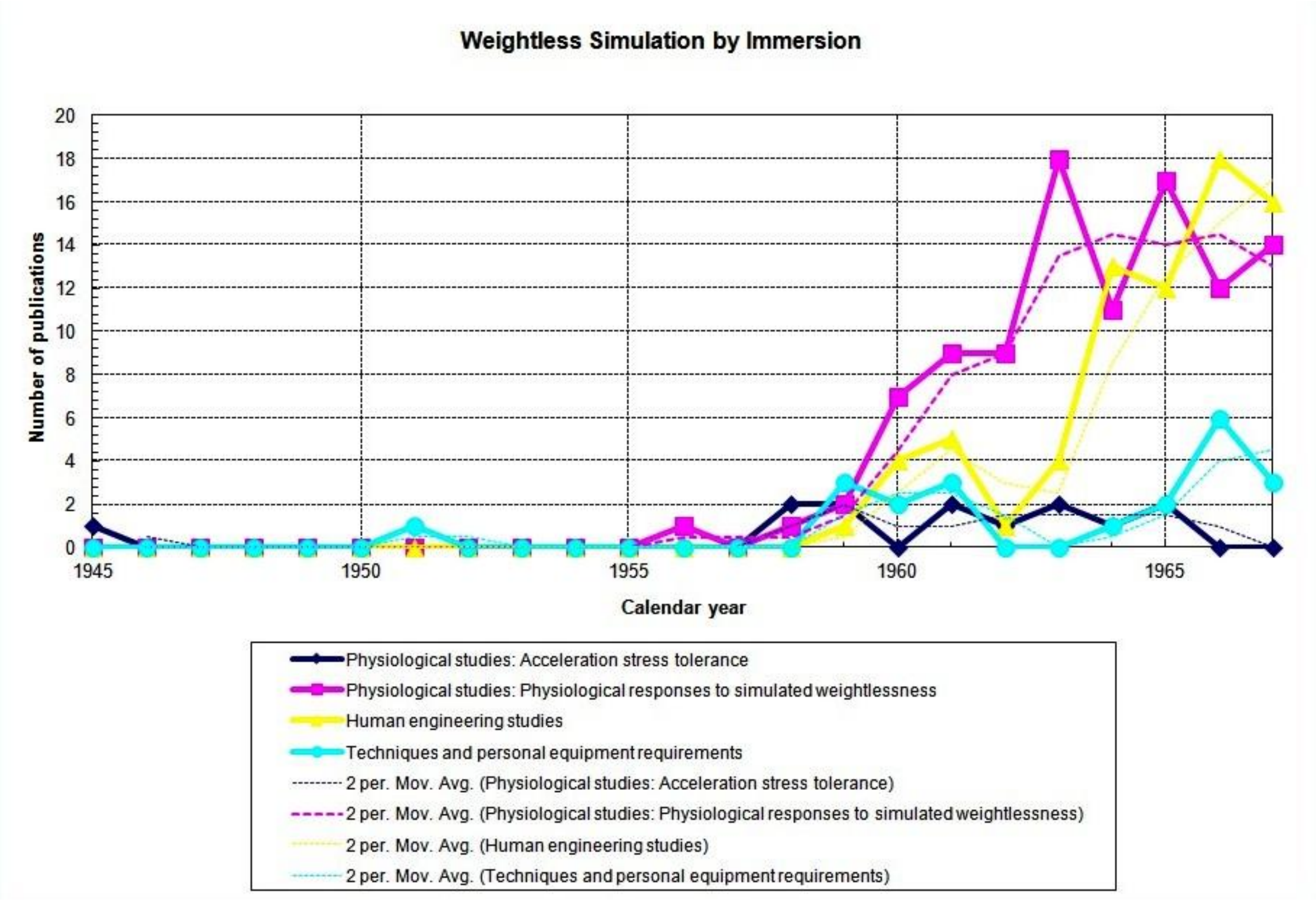
Direct reduction of mechanical force in a localized area		
	Denervation (cutting the nerves)	Physiological
	Tenotomy (cutting the tendon)	
	Plaster casts (immobilization)	
Reduction by mechanical support of forces required to oppose gravity		
	Bedrest (hypokinesia, hypodynamia)	Physiological
	Immersion and buoyant support (neutral buoyancy)	Physiological, human engineering
	Tumbling devices (impeded settling)	Psychophysiological
Elimination of friction and ground reaction forces		
	Overhead suspension (off-loading)	Physiological, human engineering
	Air-bearing devices (eliminate ground reactive forces)	Human engineering

Neutral buoyancy (NB) task analysis

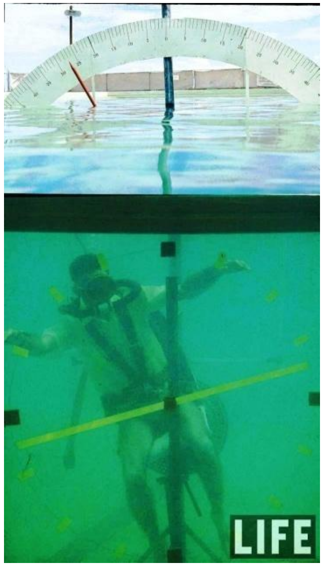
<table>
<tr><th rowspan="4">Type of study</th><th colspan="2">Physiological</th><th colspan="2">Human Engineering</th><th rowspan="3">Techniques and Personal Equipment Requirements</th></tr>
<tr><th rowspan="3">Acceleration stress tolerance</th><th rowspan="2">Responses to simulated weightlessness</th><th colspan="2">Human performance capabilities</th></tr>
<tr><th>EVA</th><th>IVA</th></tr>
<tr><th colspan="4">Weightlessness simulation</th></tr>
<tr><td>Activity</td><td>Passivity</td><td>Hypodynamia</td><td colspan="2">Orientation, manipulation, translation, etc.</td><td>Enabling</td></tr>
<tr><td>Volume</td><td>N/A</td><td>N/A</td><td>N/A</td><td>Confined</td><td>As required</td></tr>
<tr><td>Restraints</td><td>N/A</td><td>N/A</td><td colspan="3">As required</td></tr>
<tr><td>Pressure garment (real or simulated)</td><td>N/A</td><td>N/A</td><td>Required</td><td>Incidental</td><td>Air-filled vs. water-filled</td></tr>
</table>

Weightless Simulation Using Water Immersion Techniques - Annotated Bibliography

Duddy, Kalos, Caswell & Vogt, LMSC, Dec. 1967



Early whole-body NB studies



1957 Grover J.D. Schock, CPT USAF
Holloman AFB
outdoor pool with windows
El Paso YMCA? or New Mexico
School for Visually Handicapped,
Alamogordo?
LIFE JREyerman Space Frontiers

1962: Graveline observes immersion subject at Wright-Patterson AFB. (LIFE Oct. 2, 1964, pp. 102-3)

Levine, Raphael B. , Lockheed Aircraft Co., Marietta, GA (1960, 1963)

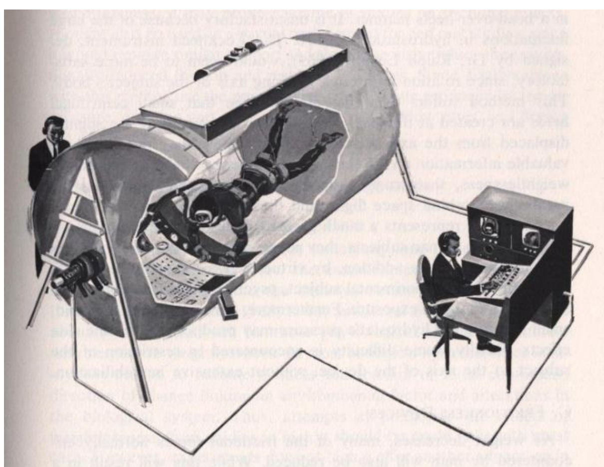


FIG. 6. Schematic view of Lockheed null-gravity simulator (tumbler). Note buoyancy adjustment gear and centering cables (Levine, 1963).

Immersion at Brooks AFB (LIFE on-line archives, Ftriz Goro, undated)

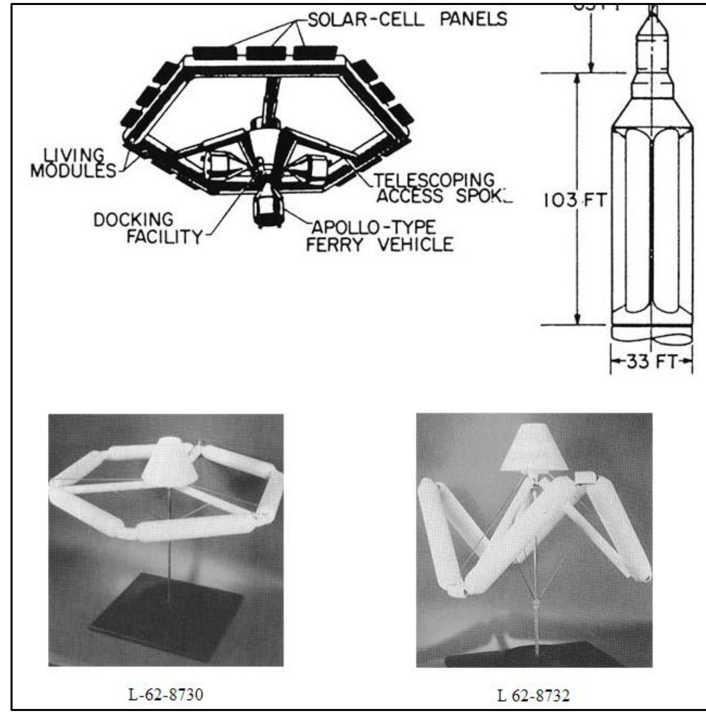
Limited orientation, manipulation, translation, etc.

NB for human factors engineering, 1962-1966

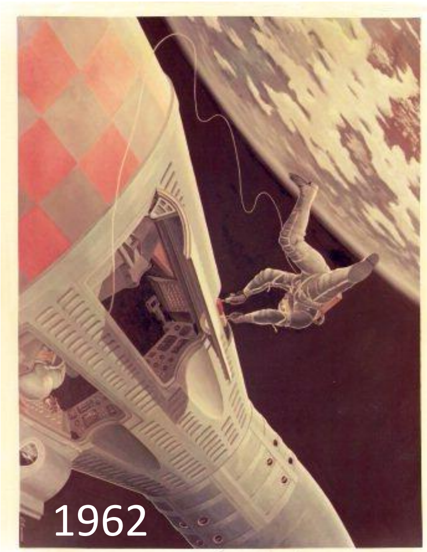
Provider	Customer	Location	Notes	1959-60	1963	1964	1965	1966
(USN)	(NASA)	(Pool, LaAFB; NAB Little Creek)	SCUBA training					
(LaRC)	(LaRC)	(LaRC)	SSRG: proposed, rejected					
ERA	LaRC	Pool, LAFB	Airlock demo			1x		
	LaRC, MSC	Pool, McDonogh	Airlock, OWS, Gemini EVA					
General Dynamics	USAF	San Diego	flexibility, mobility		?			
Boeing	Boeing	Angle Lake, WA	Misc.					
		Seattle, WA	0GER					
(USN)	(MSC)	(Carpenter: Sealab 1, 2)	Manipulation, restraints					
General Electric	USAF	Aquarama, Philadelphia	MOL					
	MSFC	MSFC NBTF (a/k/a blast forming pits)	AAP					
	USAF, NASA	USN UDT base, Buck Island, USVI	MOL, AAP OWS & lunar					
Garrett AiResearch	LaRC	Los Angeles	EVA maintenance					
MSFC	MSFC	MSFC NBTF (a/k/a blast forming pits)	Early AAP					
MSC	MSC	Hangar 135, Ellington AFB	Misc. (ex.: GT-8 HHMU)					
			Total	0	2	3	6	5-6?

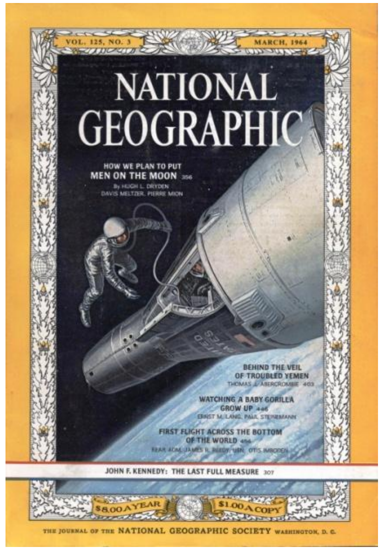
NB support and analysis needs identified by early-mid 1960s

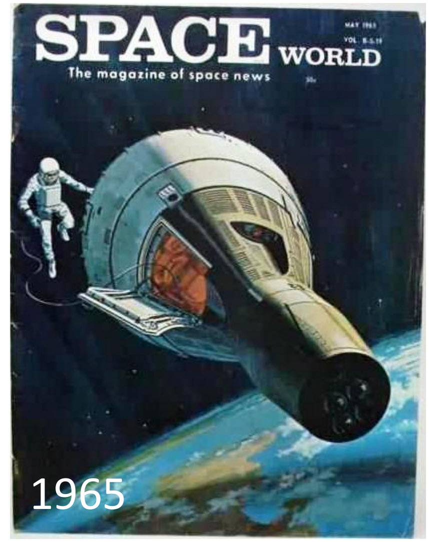
- Space station concepts (NASA)
  - IVA
- Gemini (NASA)
  - EVA
- MOL (USAF)
  - EVA, IVA
- S-IVB OWS (NASA)
  - EVA, IVA



Gemini EVA

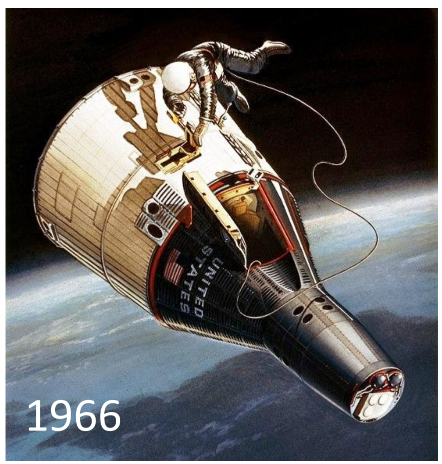

1962

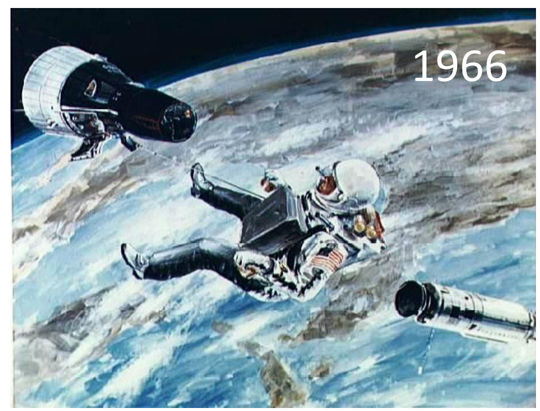

VOL. 125, NO. 3
MARCH, 1964
NATIONAL GEOGRAPHIC
HOW WE PLAN TO PUT
MEN ON THE MOON 356
By HUGH L. DRYDEN
DAVIS MELTZER, PIERRE MION
BEHIND THE VEIL
OF TROUBLED YEMEN
THOMAS J. ABERCROMBIE 403
WATCHING A BABY GORILLA
GROW UP 446
ERNST M. LANG, PAUL STEINEMANN
FIRST FLIGHT ACROSS THE BOTTOM
OF THE WORLD
JOHN F. KENNEDY: THE LAST FULL MEASURE 307
$8.00 A YEAR
$1.00 A COPY
THE JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D. C.


SPACE WORLD
The magazine of space news
1965


1966

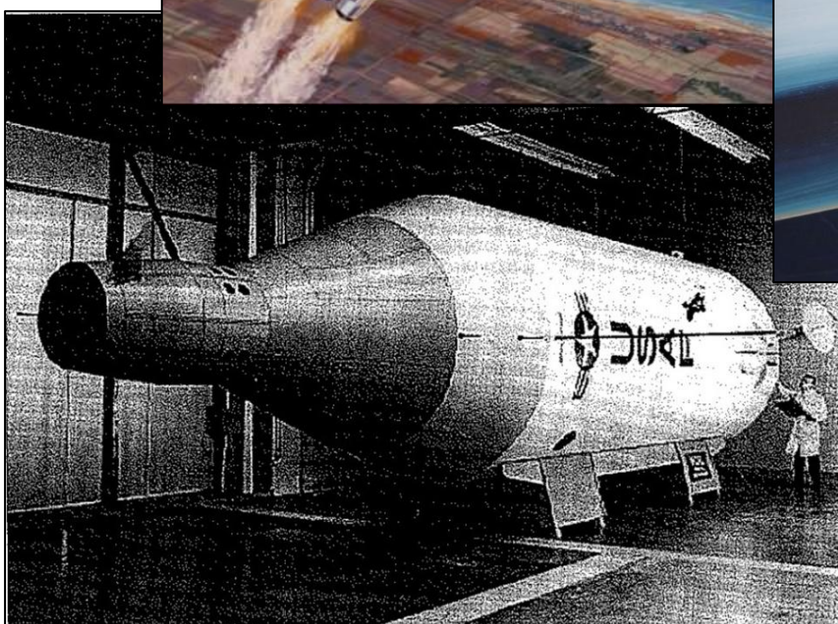

1966


UNITED STATES
1966

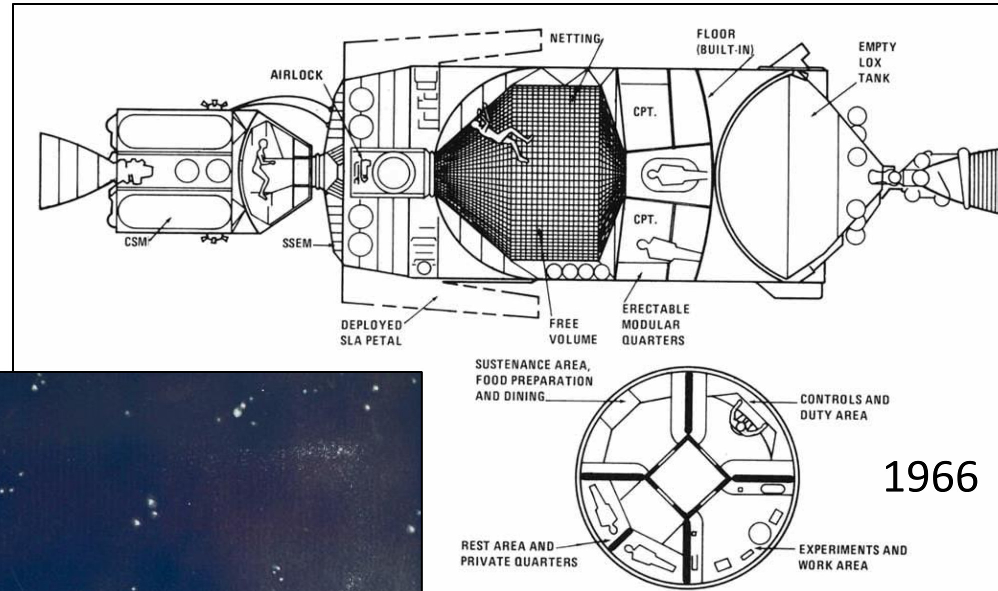

1966


Smithsonian
1988

Manned Orbiting Laboratory (MOL)
USAF, 1963-1969



S-IVB Orbital Workshop ("wet workshop") NASA AAP (1965-1969)



1966

1968

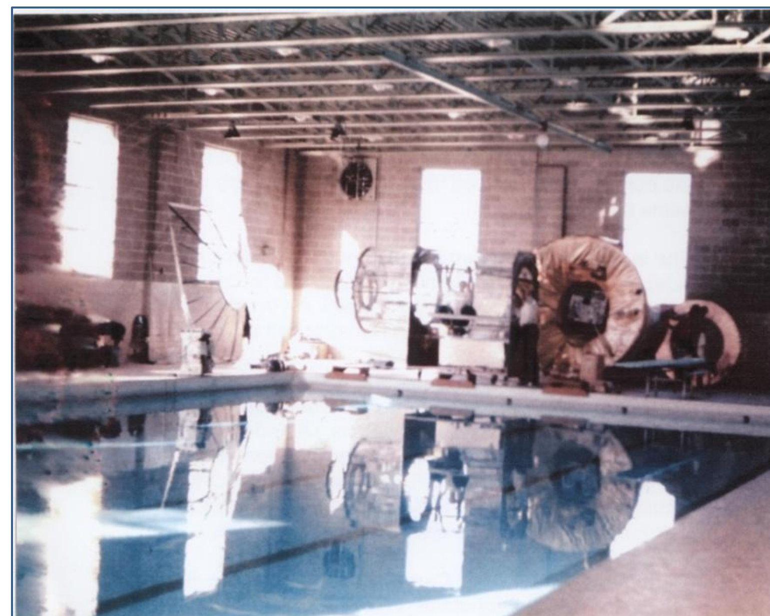
Environmental
Research
Associates

Environmental Research Associates

- Cadet Pool
  - McDonogh School
    Owings Mills, MD
  - 1964-1968*

- Above-ground cylindrical tank
  - Baltimore
  - 1969ca*

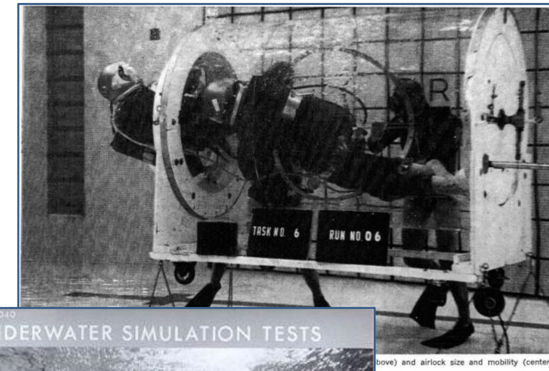
Length		Width or Diam.	Depth (max)	Volume (deep end only)	
total	deep end				
75 ft	16 ft	~35 ft	11 ft	6K ft^3	46K gal.
23 m	5 m	~11 m	3.3 m	174 m^3	174Kℓ
		~15 ft	~7 ft	1.2K ft^3	9.3K gal.
		4.6 m	2.1 m	35 m^3	35Kℓ

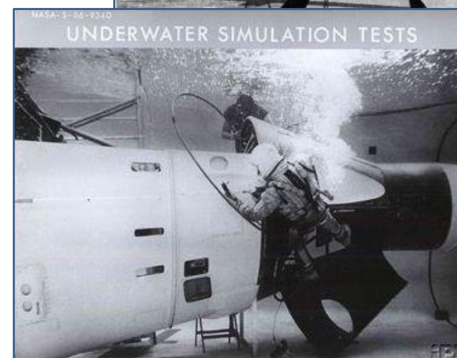


* Discontinued due to NASA requirement for on-site decompression chamber

Environmental Research Associates

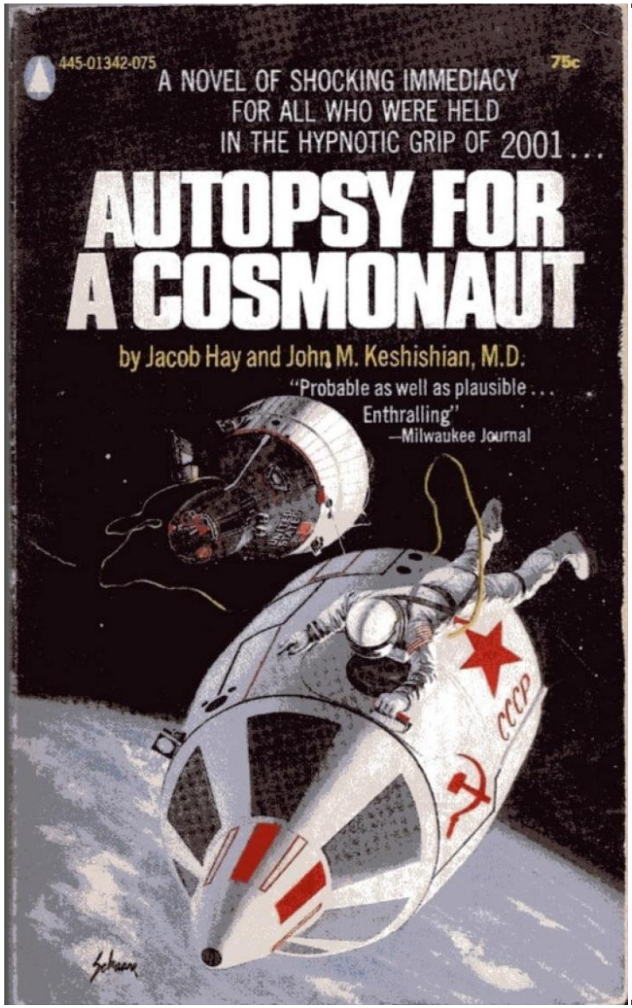
- NB for 0-g simulation
  - EVA (USN Mk IV Mod-0 FPS)
    - Airlock (“LRC-Mod II” mockup)
      - 48”D x 72”L, 3 hatches (36”; 32”; 28”x42” oval)
      - 1-g vs. 0-g (C-131) vs. 0-g (NB)
    - Gemini (Mk IV; G2C, G4C)
      - 9: descriptive (forensic)
      - 10, 11: predictive
      - 12: crew training
    - AAP OWS AM (G2C?)
      - descriptive, predictive
  - IVA
    - Restraints, task analysis





Environmental Research Associates

ERA in popular culture



AUTOPSY FOR A COSMONAUT 85

"Even gynecologists," Sam said flatly, and produced the effect he wanted. The conversation turned to the merits of the evening's restaurant and whether it rated a return visit.

Always there was the intensive training, gruelling and totally unrelenting in its pressures. Sam thought it was probably an adaption of the Berlitz method of language teaching by "total immersion." But it seemed to be working, and at the end of a month he was beginning to feel almost natural in the cramped confines of the spacecraft simulators, and the myriad switches and dials and their functions were becoming familiar, as was the feel of his rushed-to-completion space suit.

He discovered the eerie sensation of weightlessness during a series of parabolic flights aboard a cavernous Air Force K-135 cargo plane, dipping and soaring, then dipping again to allow him to float free for half a minute or more at a time while technicians, braced between deck and roof, restrained him from flying too high and coming down with a crash when gravity was restored. Afterwards, there was a mystery-shrouded flight for Sam and Dan Golding to Andrews Air Force Base just outside Washington, where their T-38 was met at the runway's edge and they were whirled through the dark Maryland countryside to a boys' military academy northwest of Baltimore and its closely guarded indoor swimming pool, containing a specially fitted mock-up of the Gemini spacecraft. Here, for nearly two weeks, Sam was to learn and practice the techniques of extravehicular activity in the closest possible approach to prolonged weightlessness, underwater. The underwater methods had been developed when it became apparent on the early flights involving EVA that the parabolic flights were not enough, and the new methods were fully justified in the very successful Gemini 12 mission.

Floating in his weighted pressure suit, Sam mastered the operation of opening the hatch above his couch and egressing from the mock-up to perform initially simple but increasingly more complex chores outside, after which he would return to the mock-up and close the hatch. In the process he gained experience in maneuvering his body on his tether, although he was aware that NASA and McDonnell engineers were working on a new development for Gemini 12-A that might sharply reduce the tether's importance. If it worked out, it would be installed aboard the underwater mock-up and Sam would face yet another session submerged.

Back at Houston again, he and Pitt went through the rigors

General Electric Missile & Space Division, Valley Forge, Pa.

Date	Facility	Location	Activity
1965	City Aquarium ("Aquarama")	Philadelphia, Pa.	USAF MOL
1966-1967	Underwater Test Facility (abandoned USN UDT training base)	Buck Island, VI	USAF MOL (1966) NASA AAP S-IVB OWS (1967) Lunar surface (1966)
1966-1967	Neutral Buoyancy Test Facility (a/k/a: metal-forming tank, explosive-forming tank)	MSFC, Huntsville, Ala.	Early NASA AAP S-IVB tests
1968-1970?	Neutral Buoyancy Facility	Valley Forge, Pa.	Human test, evaluation; design, development of crew procedures, interfaces

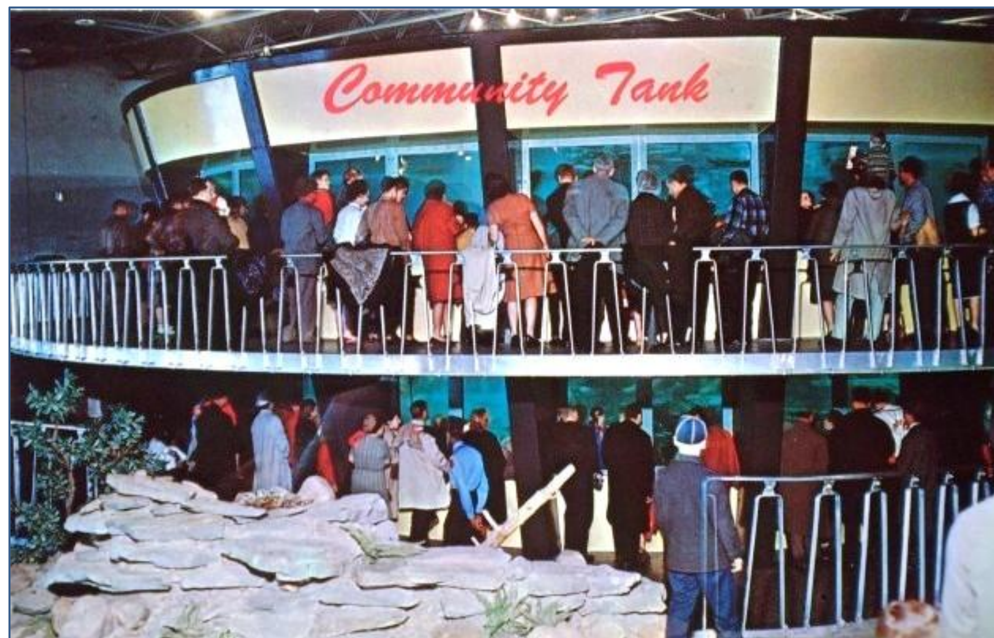
General Electric at Aquarama

- City Aquarium
  - "Aquarama Theater of the Sea"
  - Philadelphia, Pa.
  - Salinity 1-2%
  - 70°F
  - B. 1962- D. 1969
- 1965 only

Major axis	Minor axis	Depth	Volume	
60 ft	22 ft	10 ft	10.3K ft^3	77.6 K gal.
8.3 m	6.7 m	3 m	294 m^3	294K ℓ


4-C San Antonio Light Sunday, February 24, 1963

ZOO LEAGUE IN ACTION — Based on the current trend, Noah would have to enlarge his ark to official bowling lane specifications if he wanted all the animals to come aboard today. The tenpin game seems to be the rage of zoo, aquarium and back yard as well as the bowling center. Among the latest members of the menagerie league is Lucky (left) a star performer at Philadelphia's Aquarama. Like his counter-part, Flippy, of the Miami Seaquarium, Lucky uses the approach of diving deep into his pool for momentum and releases the ball just as he reaches the surface. Helping the water-logged bowler in the photo above is Chief Halftown (center), a member of the Brunswick advisory staff, with Aquarama star Babette Knapp and head trainer Dell Winders.



General Electric at Aquarama

Astronaut capabilities for handling, adjusting, maintaining experiments

- Maintenance, tool design
- Storage
- Ground/space systems interface
- Crew time availability, eating, rest cycles
- Restraints
- Pressure suit limitations, etc.

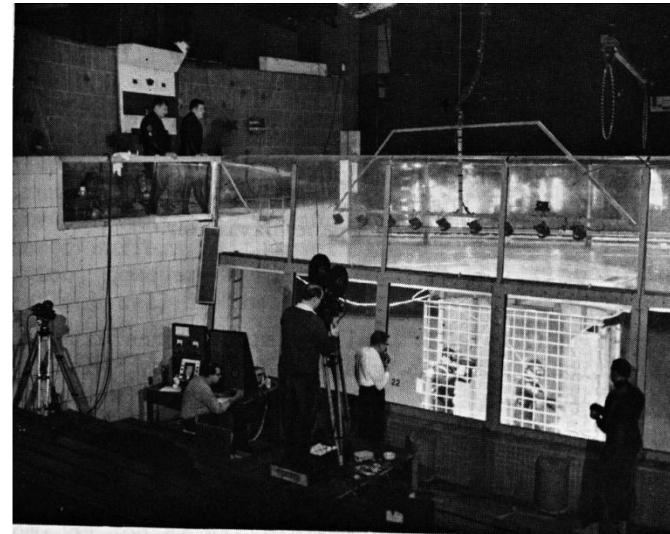
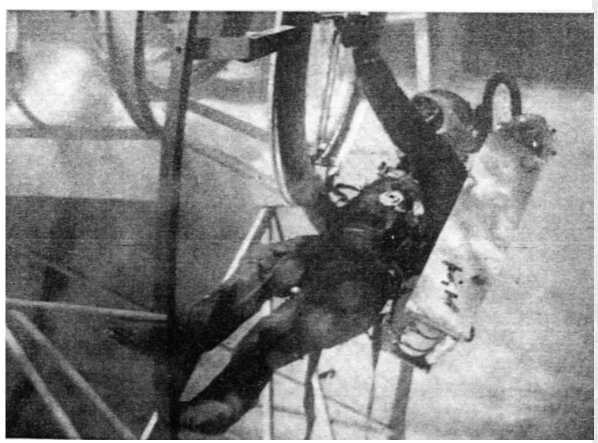
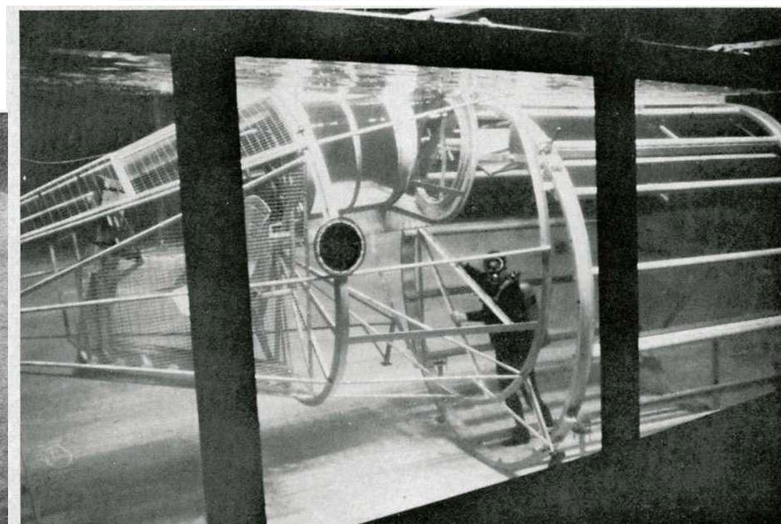


Fig. 1. Overall view of the test facility.

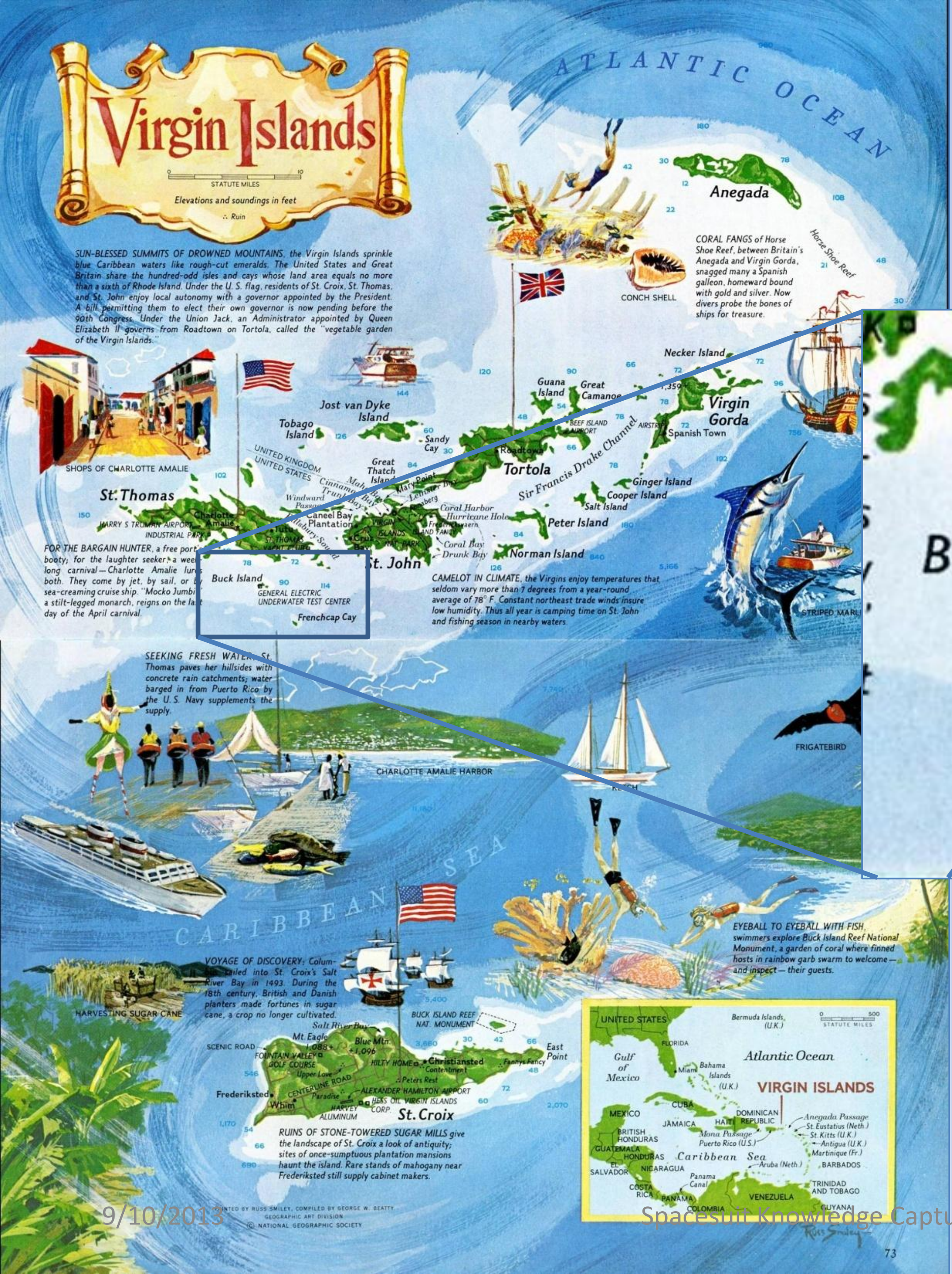
Fig. 3. A subject using the Toe Trap.





UNDERWATER tests conducted by GE at the Philadelphia Aquarama employ hardware simulating the Gemini capsule, left, an adapter section and the MOL canister, right. Tunnel between capsule and canister appears at top center in adapter section.

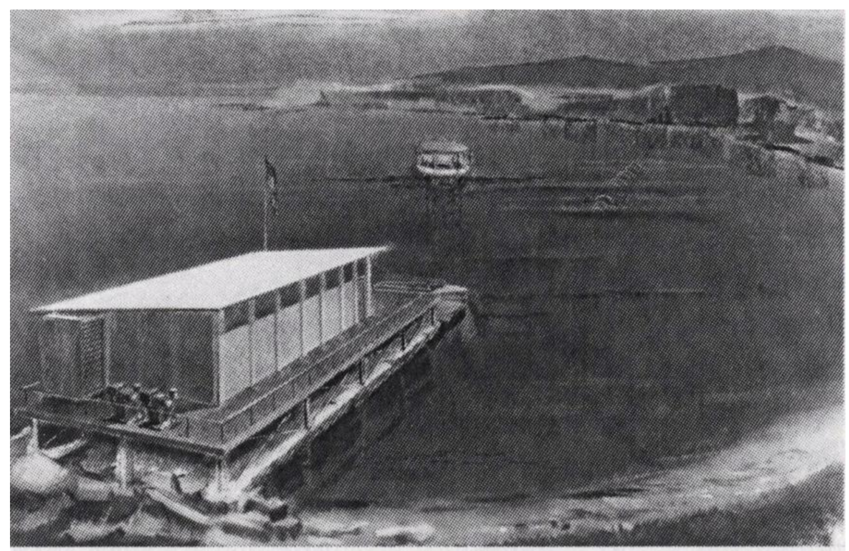
General Electric in the Virgin Islands



General Electric in the Virgin Islands

General Electric at Buck Island

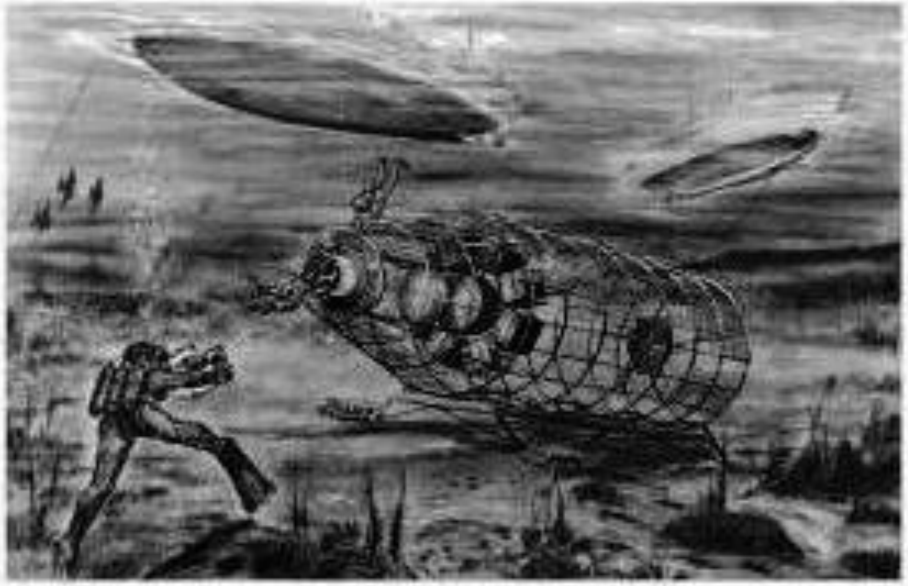
- Immediate need for large area to permit whole-task simulation—nonsegmented in time, geometry, metabolic cost—of manned space operations in zero, partial gravity
- Natural environment mandatory
  - minimize facility investment
  - maximize cost effectiveness
  - produce timely results
- Several locations investigated
  - Only Buck Island met all requirements: volume, water & weather conditions, accessibility
- Small operations building constructed on foundations of former pier in protected cove
  - site of former USN UDT training area
- Supports water immersion studies 100 yards from shore, 30 ft depth
  - Dec.1966-Jan. 1967: preliminary feasibility studies in S-IVB stage mockup
  - Feb. 1967: S-IVB passivation tasks, equipment transfer tasks investigated



Underwater Test Facility,
Little Buck Island, USVI,

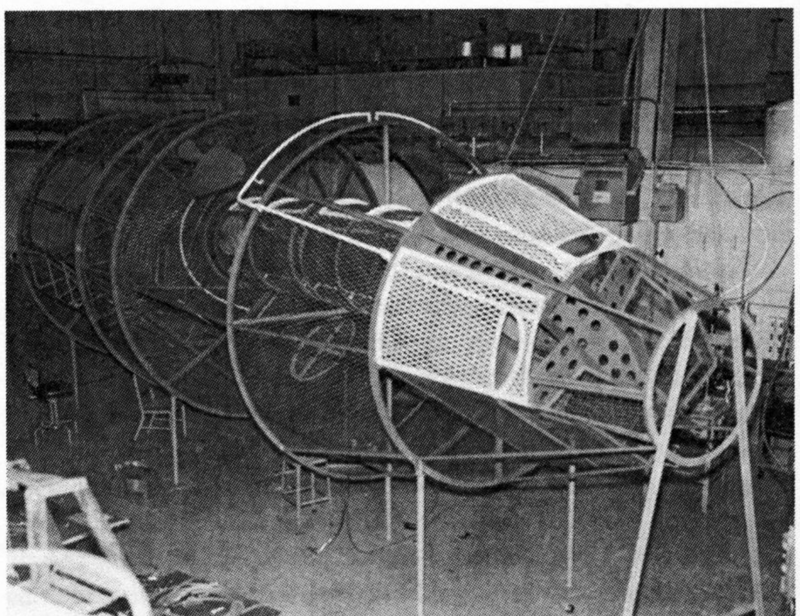
General Electric at Buck Island

- NB for 0-g simulation
  - MOL
    - Suited EVA, IV transfers
  - S-IVB OWS
    - Cargo handling
- NB for lunar-g mobility analysis

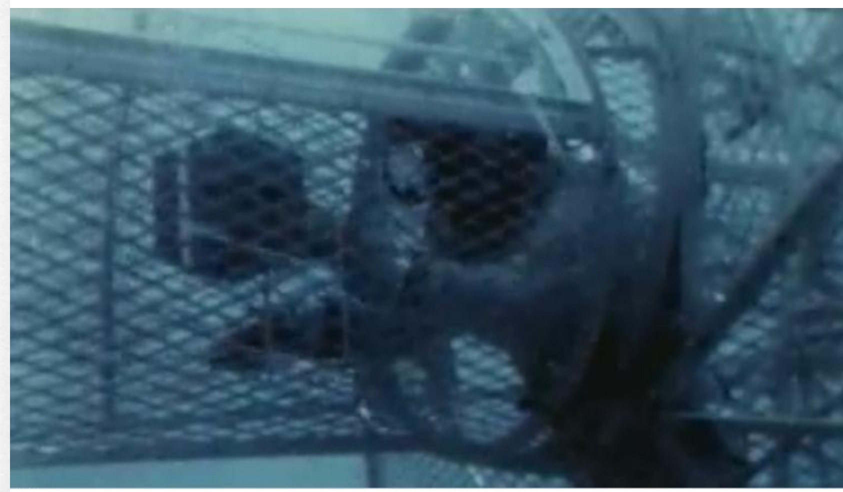


SIV-B Simulator for the Orbital Workshop Program, Renamed Skylab

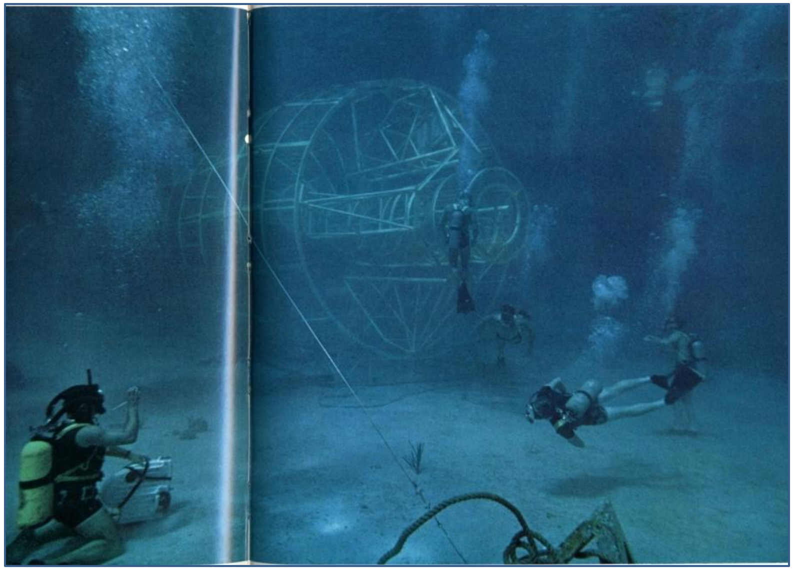
GE, Buck Island: MOL Mockup,



Gemini-B/Manned Orbiting Laboratory, at King of Prussia



GE, Buck Island: S4B OWS Mockup



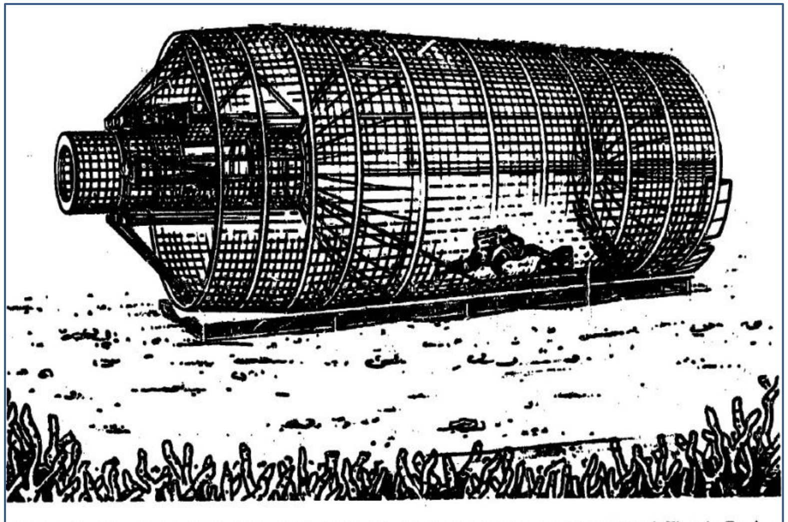
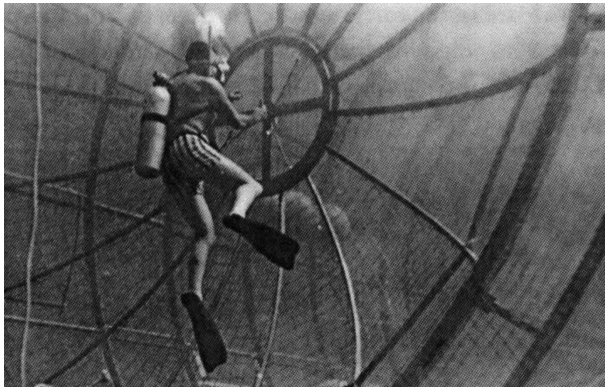
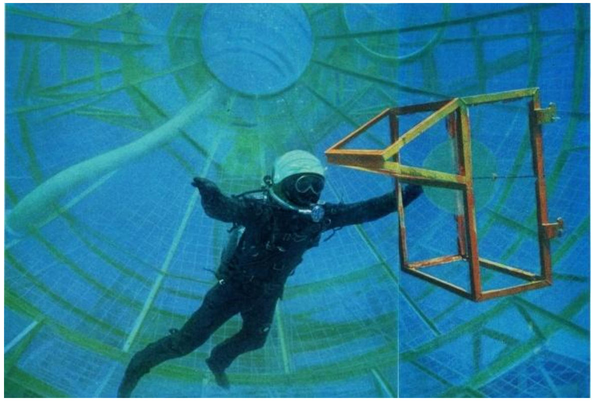
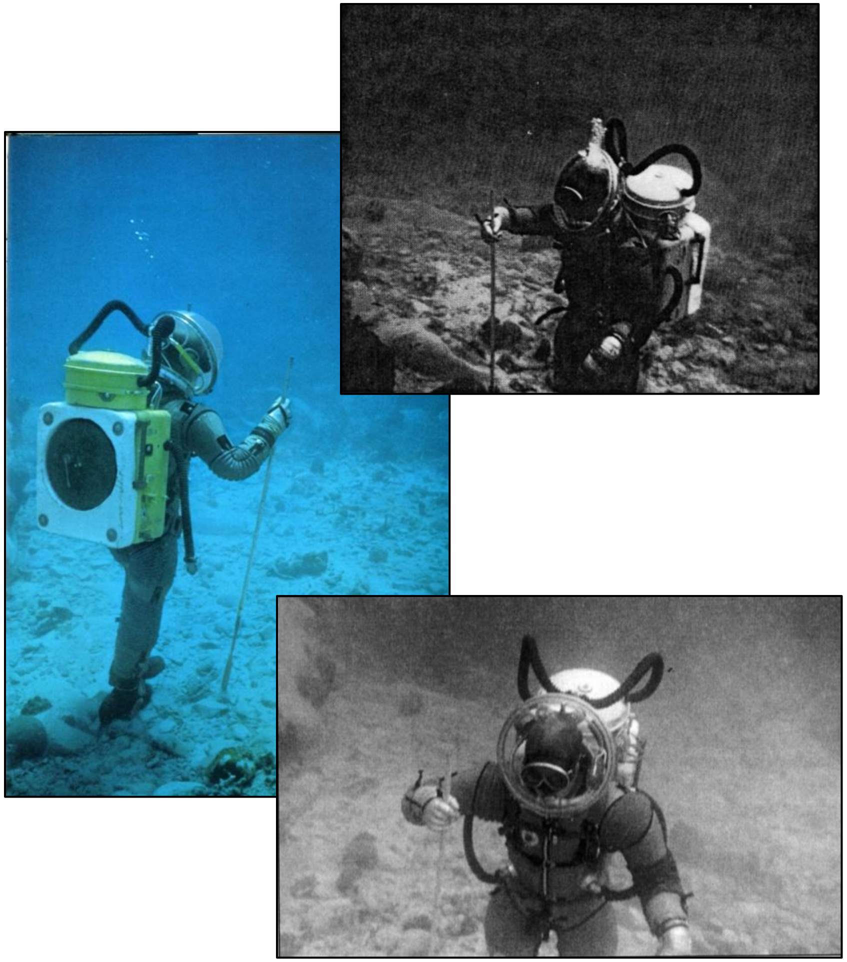


FIGURE 6.—Underwater simulation mockup of the AAP orbital workshop as used by General Electric Co. in 1966–67 tests.





GE, Buck Island: lunar mobility



- Lunar traverse tasks
  - 1/6-g equivalent
  - Special underwater course
  - 2 pressure-suited subjects
- Data recorded
  - Task times
  - Subjective comments
  - Drag measurements for
    - Equipment models
    - Suited, non-suited subjects
      - During erect, prone transport

General Electric at MSFC

- Neutral Buoyancy Test Facility
  - 2 in-ground tanks
    - 90°F
  - Instrumentation building
  - Dressing-room van
- 1966-1967
- Mass handling, maintenance, force-generation, restraints

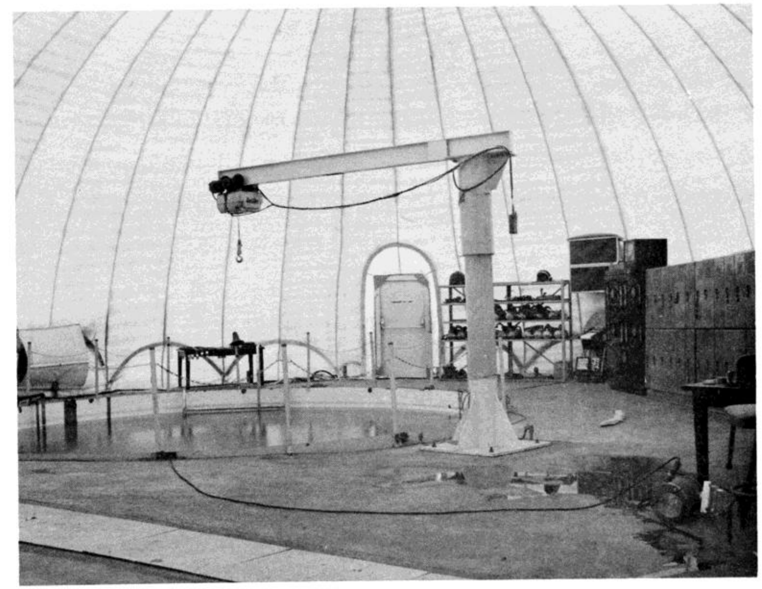


Figure 5.1-1. Neutral Buoyancy Simulation Facility

	Diameter	Depth	Volume	
large	25 ft	15 ft	7363 ft^3	55K gal.
	7.6 m	4.6 m	208 m^3	208K ℓ
small	15ft	12 ft	2120 ft^3	16K gal.
	4.6 m	3.6 m	60 m^3	60K ℓ

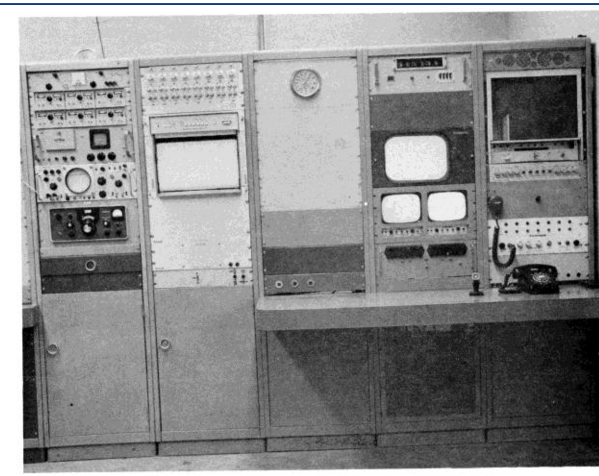


Figure 5.2-1. Instrumentation Facility

General Electric at Valley Forge

Length	Width	Depth	Volume	
60 ft	28 ft	25 ft	42K ft^3	314K gal.
18.3 m	8.5 m	7.6 m	1.2K m^3	1.2M ℓ

- 90°F water, 95°F air temp.
- 1969: seeking support for Investigations of space maintenance and repair

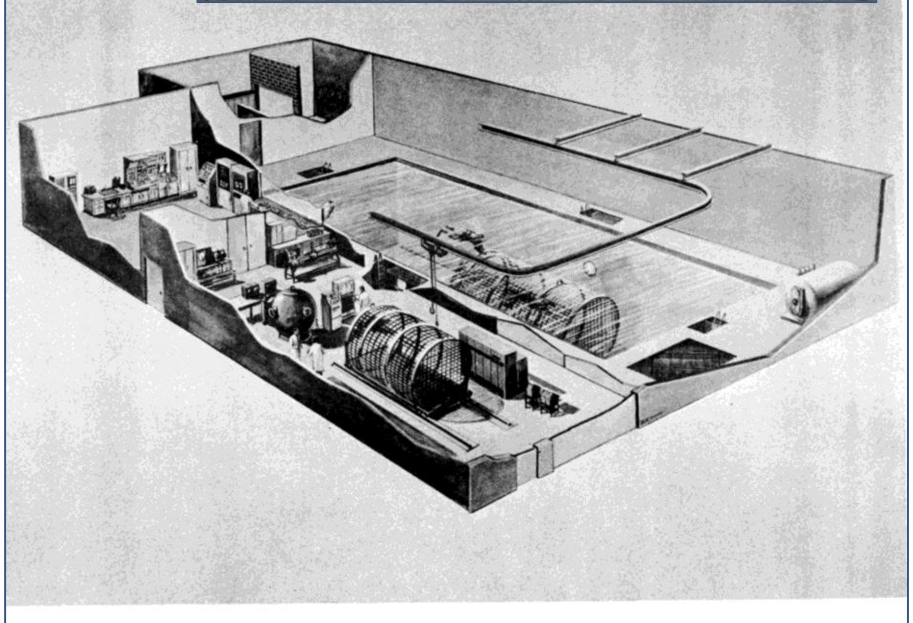
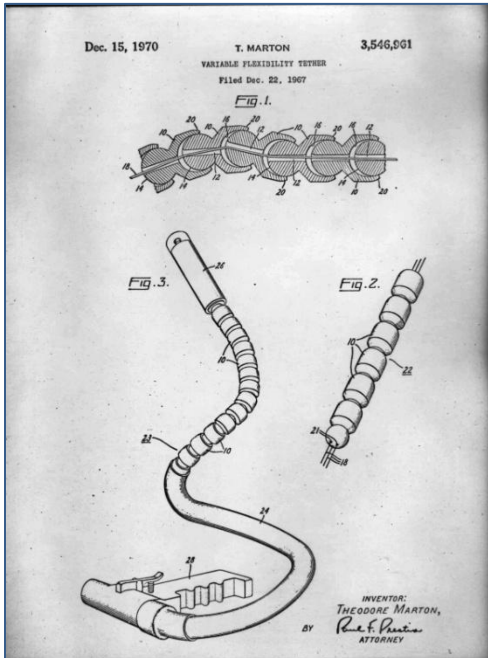
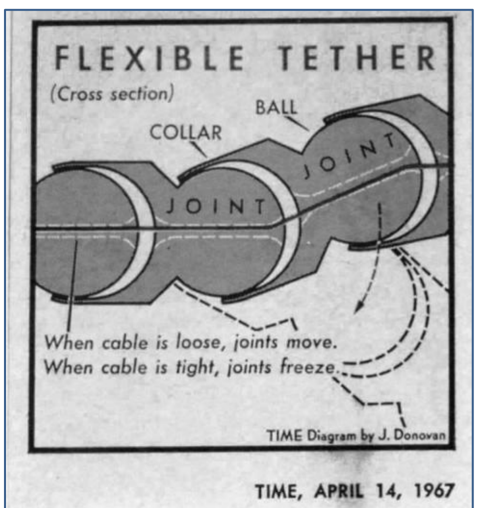


Figure A-1. General Electric Neutral Buoyancy Facility

Flexible Tether: Theodore Marton/GE MSD

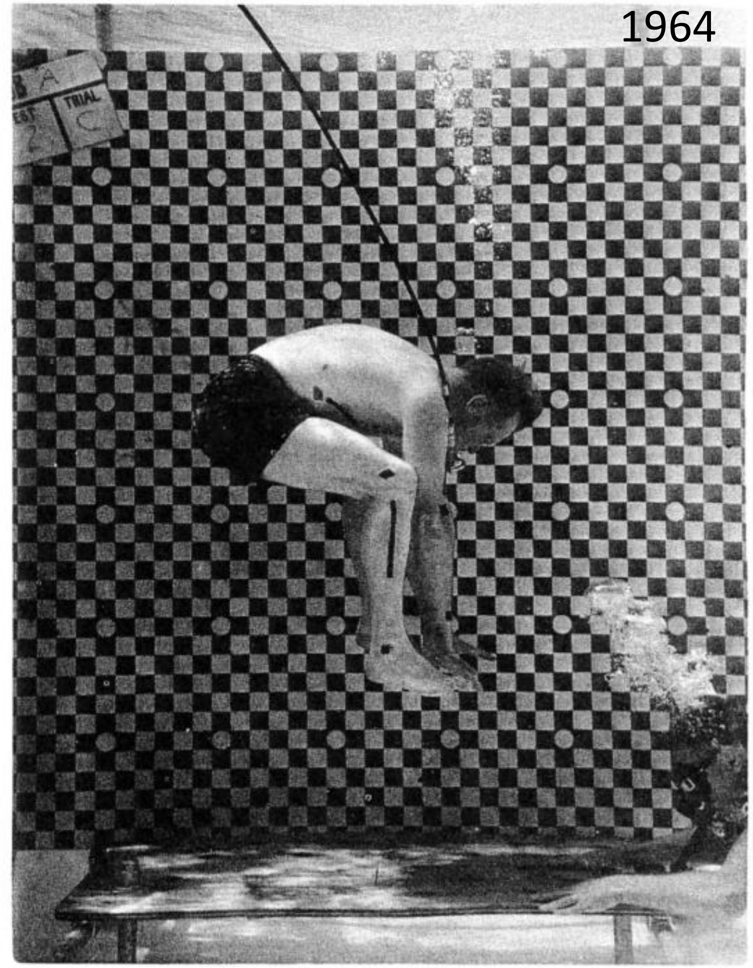




GENERAL DYNAMICS

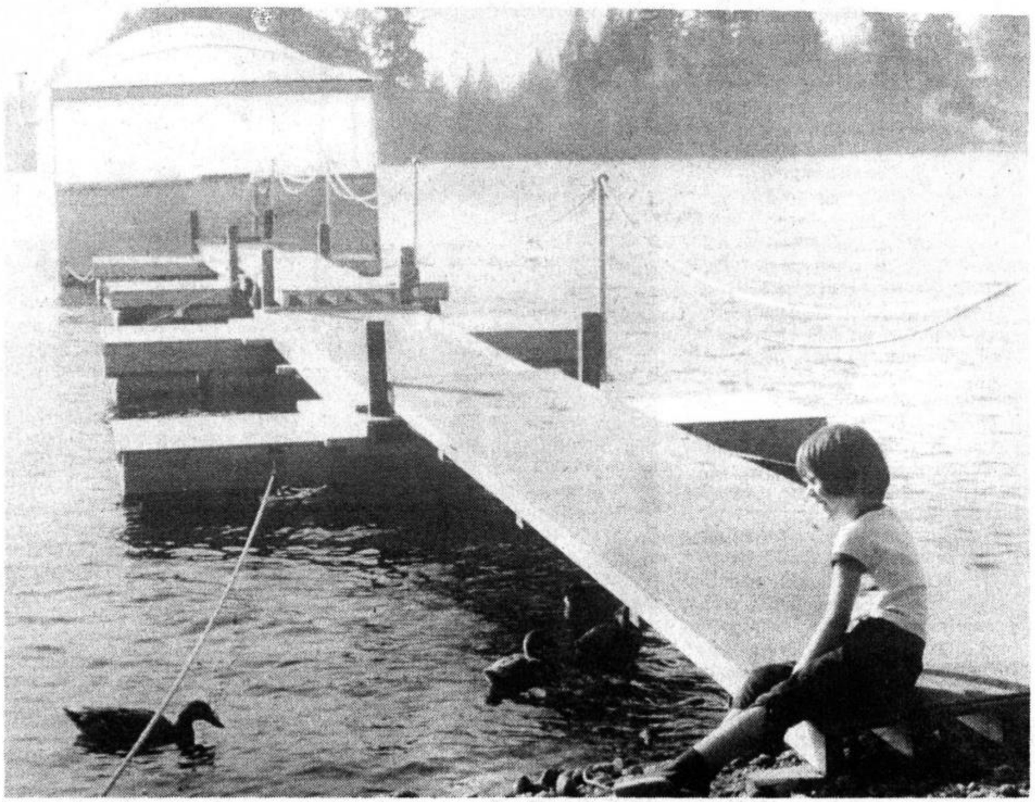
General Dynamics

- San Diego
  - What? Where?
- EVA
  - 1966: water-pressurized suits (EVA?)
    - Per Carpenter, July 1966
- IVA
  - 1964: Mobility and flexibility
    - Astronautics Div., Life Sciences Section
    - For AMRL, WPAFB



Boeing

- 1964: Jack Chaffee's home on Angle Lake



It may not look sophisticated, but this was Boeing's first neutral-buoyancy facility, located at former employee Jack Chaffee's Angle Lake home. A small group of employees from the "Bioastronautics" organization used petty cash to design and construct the facility and equipment used in underwater studies simulating weightlessness in space. Chaffee's daughter posed in this photo, taken sometime in 1964.

Boeing

- Plant II, Bldg. 2-01, Seattle, Washington
- 1964-1965 only?
- One tank or two?

Diameter	Depth	Volume	
25 ft	20 ft	10K ft^3	73K gal.
7.6 m	6 m	228 m^3	228K ℓ

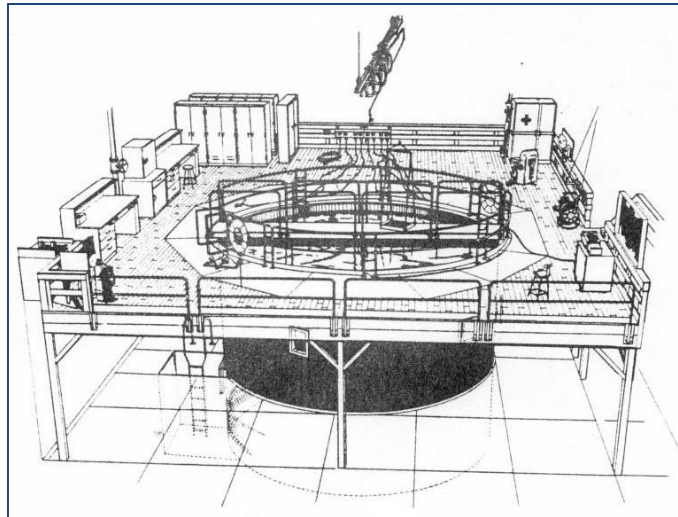
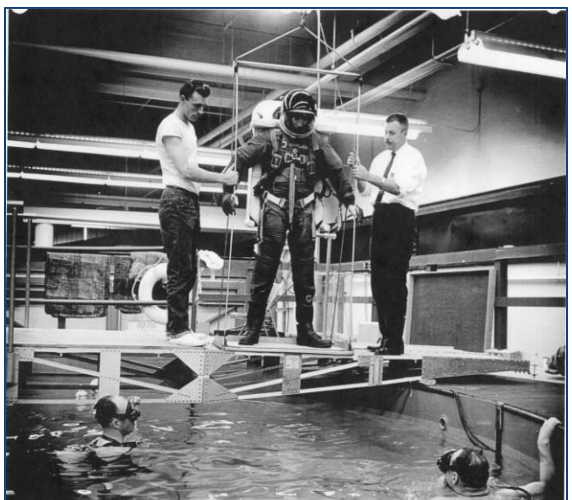
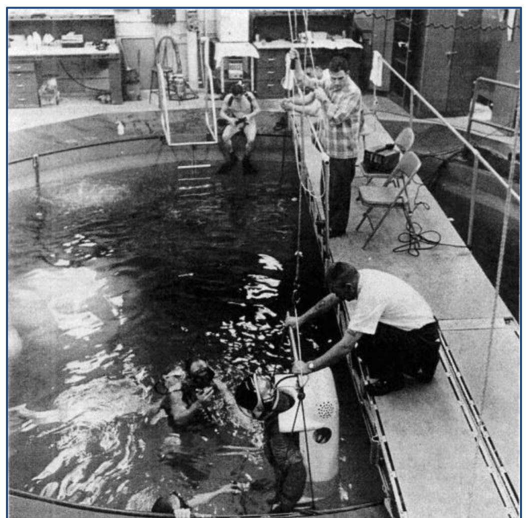
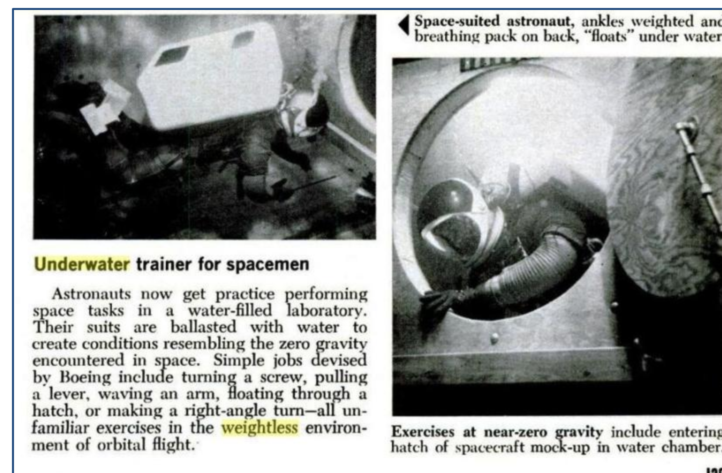


Figure 1: NEUTRAL-BUOYANCY FACILITY







Space-suited astronaut, ankles weighted and breathing pack on back, "floats" under water.

Underwater trainer for spacemen

Astronauts now get practice performing space tasks in a water-filled laboratory. Their suits are ballasted with water to create conditions resembling the zero gravity encountered in space. Simple jobs devised by Boeing include turning a screw, pulling a lever, waving an arm, floating through a hatch, or making a right-angle turn—all unfamiliar exercises in the weightless environment of orbital flight.

Exercises at near-zero gravity include entering hatch of spacecraft mock-up in water chamber.

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Garrett AiResearch

Garrett AiResearch

- Facility
  - 190th Street and Crenshaw Boulevard, Torrance, California
- Dates
- Activities
  - EV 0g maintenance, assembly
    - 6 dof simulator
    - Neutral buoyancy
  - Sponsor: LaRC

Diameter	Depth	Volume	
30 ft	20 ft	14K ft^3	105K gal.
23 m	12 m	400 m^3	400K ℓ

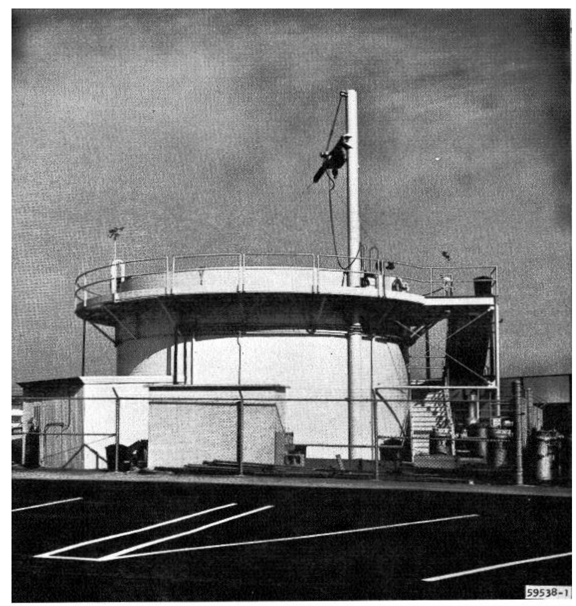
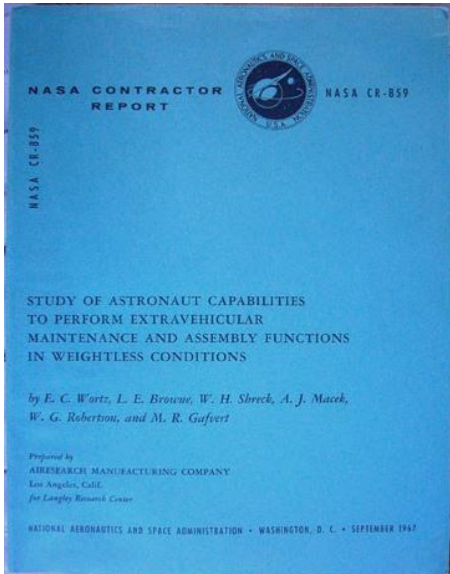


Figure 2-2. Underwater Testing Facility

Garrett AiResearch


NASA CONTRACTOR REPORT

NASA CR-859

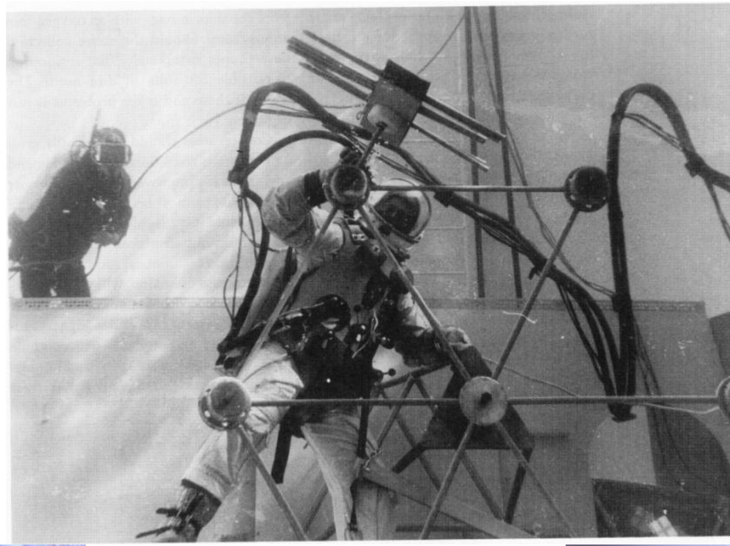
NASA CR-859

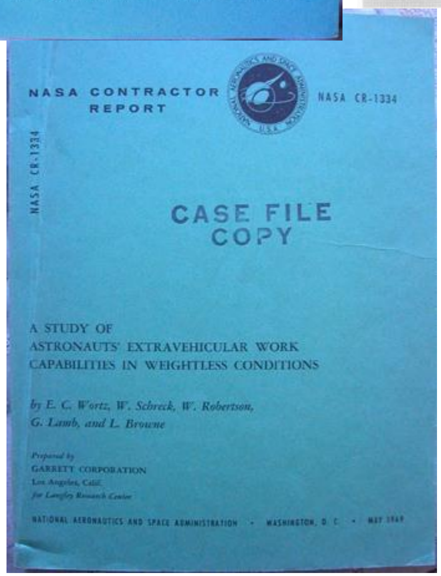
STUDY OF ASTRONAUT CAPABILITIES
TO PERFORM EXTRAVEHICULAR
MAINTENANCE AND ASSEMBLY FUNCTIONS
IN WEIGHTLESS CONDITIONS

by E. C. Wortz, L. E. Browne, W. H. Shreck, A. J. Macek, W. G. Robertson, and M. R. Gafvert

Prepared by
AIRESEARCH MANUFACTURING COMPANY
Los Angeles, Calif.
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1967




NASA CONTRACTOR REPORT

NASA CR-1334

NASA CR-1334

CASE FILE COPY

A STUDY OF
ASTRONAUTS' EXTRAVEHICULAR WORK
CAPABILITIES IN WEIGHTLESS CONDITIONS

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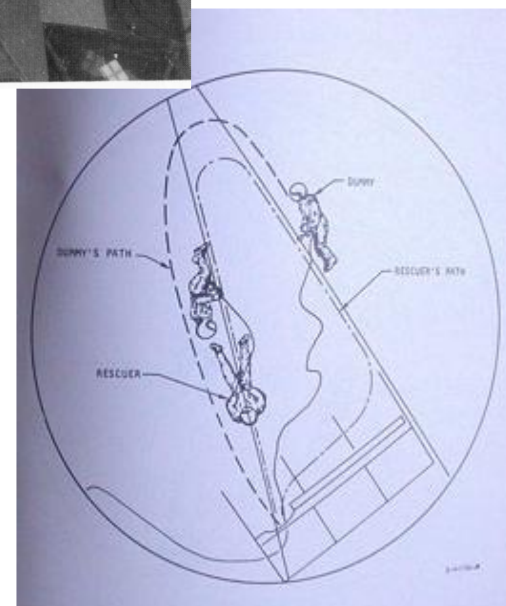


Figure 4-87. Concept 3--Exploratory Crew Rescue

NASA MSFC

Marshall Space Flight Center

- Facility
  - Blast-forming pits
  - Xx’ dia x xx’ deep
- Dates: ~1966
- Activities
  - EVA

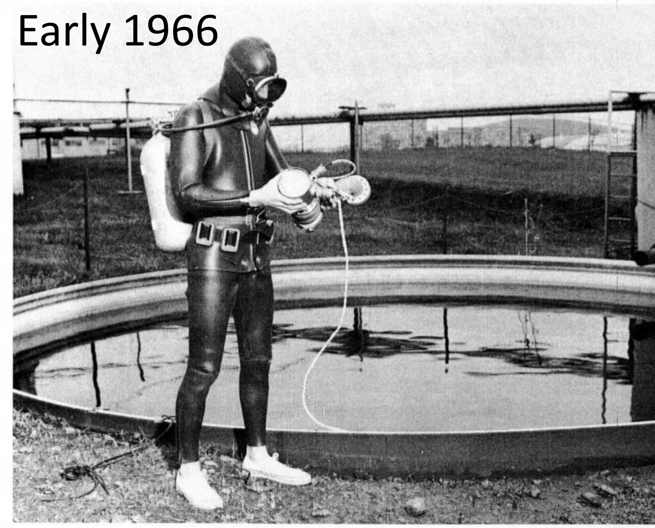


FIGURE 14 - 25' x 15' Deep Neutral Buoyancy Submersion Tank, and Subject with Rocket Engine Valve

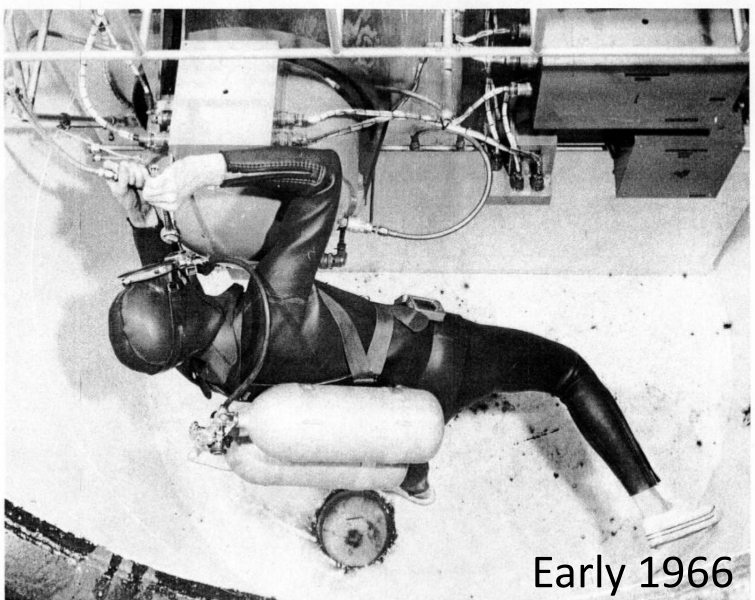
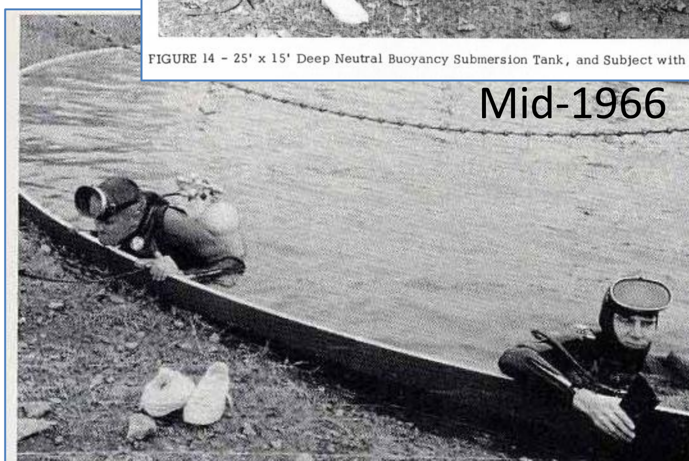


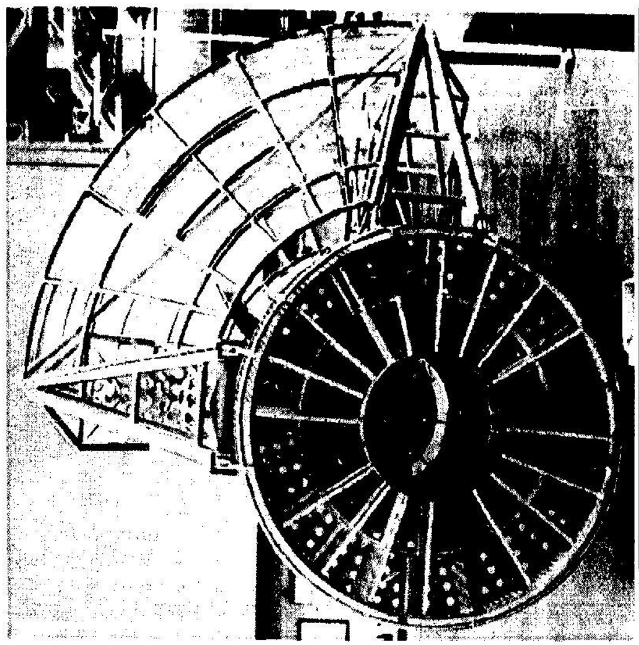
FIGURE 13 - Socket Wrench Tests of Space Vehicle Guidance Component Removal



During the second year of the informal program, Marshall director Wernher von Braun's support enabled Cooper and his team to carry out their trials in a larger tank (above;

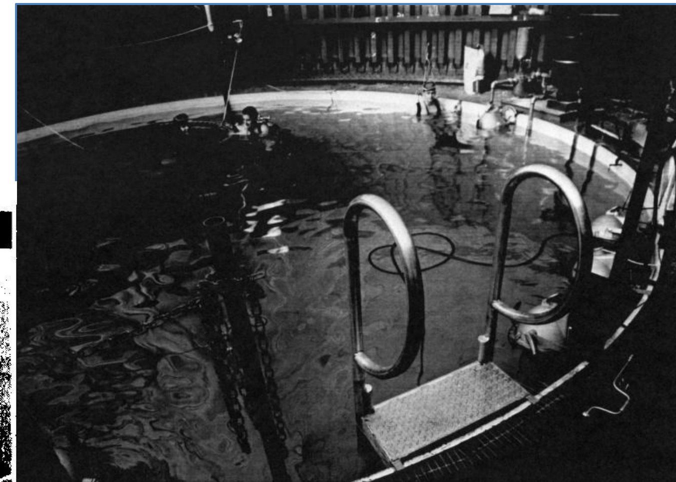
Marshall Space Flight Center

- Above-ground tank
- 1967
- Activities
  - AAP



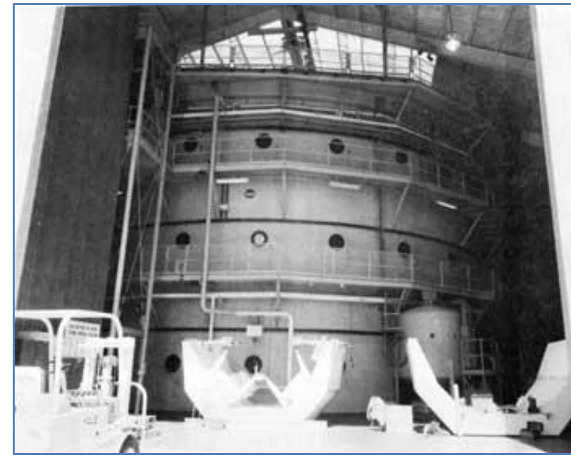
UPI Telephoto

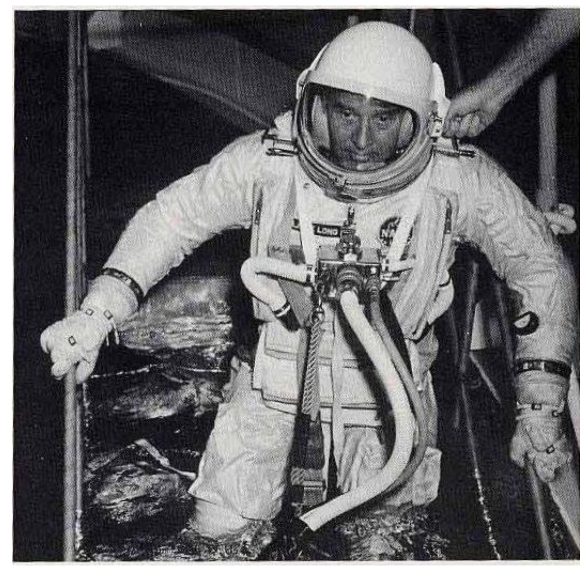
SPACE AIRLOCK — A model of an airlock, designed by McDonnell Company in St. Louis, to allow astronauts to transfer from spacecraft into an orbiting station, has been built for underwater training of the Apollo astronauts. Holes in the model will allow it to sink to the bottom of a large water tank where the astronauts will get a simulation of weightlessness while working the airlock.



Marshall Space Flight Center

- Neutral Buoyancy Simulator
  - Bldg. 4705
- Dates: 1968-1990
- Activities
  - EVA: AAP, Skylab training, repair; HST repair.





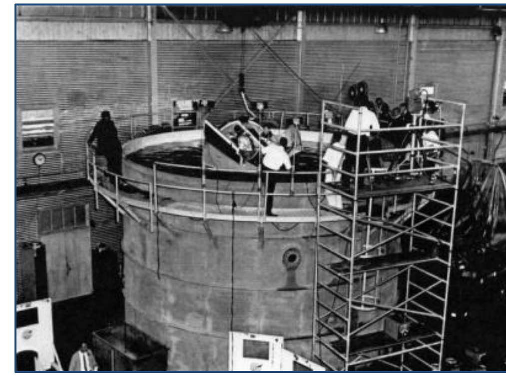
Diameter	Depth	Volume	
75 ft	40 ft	187 K ft^3	1.4 M gal.
23 m	12 m	5.3K m^3	5.3M ℓ

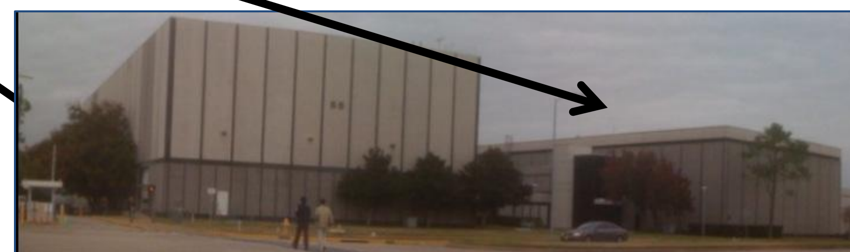
NASA MSC, JSC

Manned Spacecraft Center

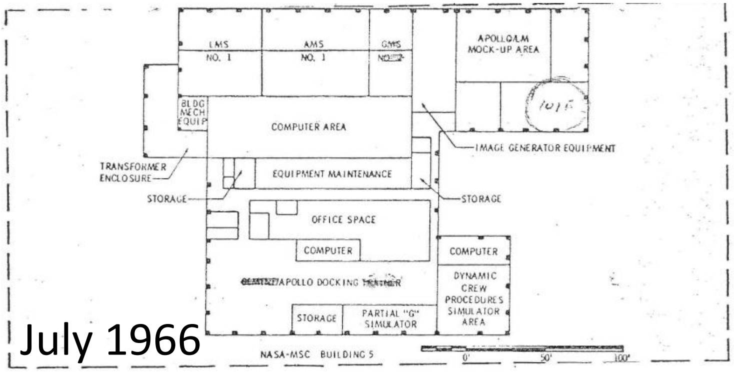
- Facilities
  - Water egress training tank
    - 1964-67: Ellington AFB, Hangar 135
  - Water Immersion Facility
    - 1967-78: Bldg. 5
    - 1978-9: Bldg. 260
- Activities
  - Apollo EVA
    - Contingency LM-CM transfer
    - J-mission film retrieval
    - LM, lunar surface fam
- Early Shuttle misc.

Diameter	Depth	Volume	
30 ft	16 ft	11K ft^3	85K gal.
9 m	5 m	320 m^3	320K ℓ

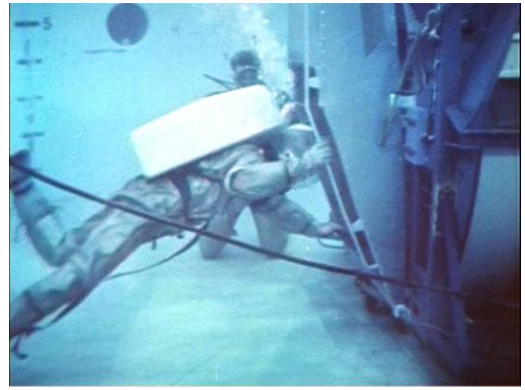


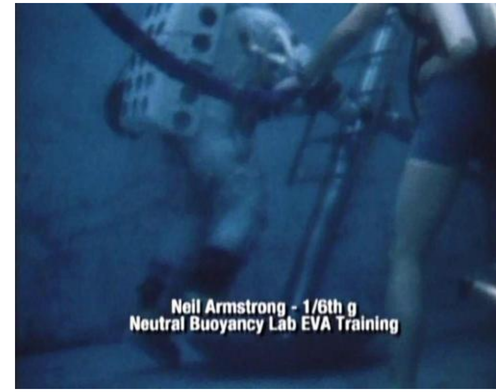


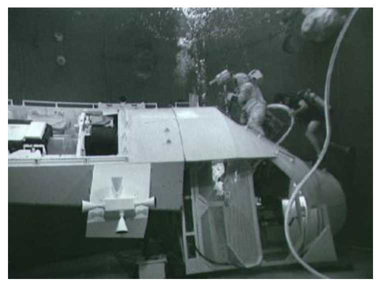
WIF, MSC Bldg. 5, 260

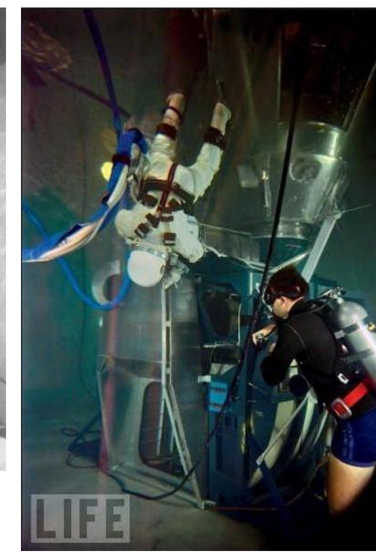


July 1966



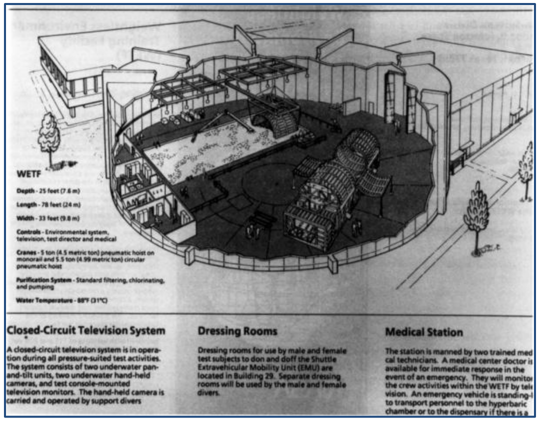




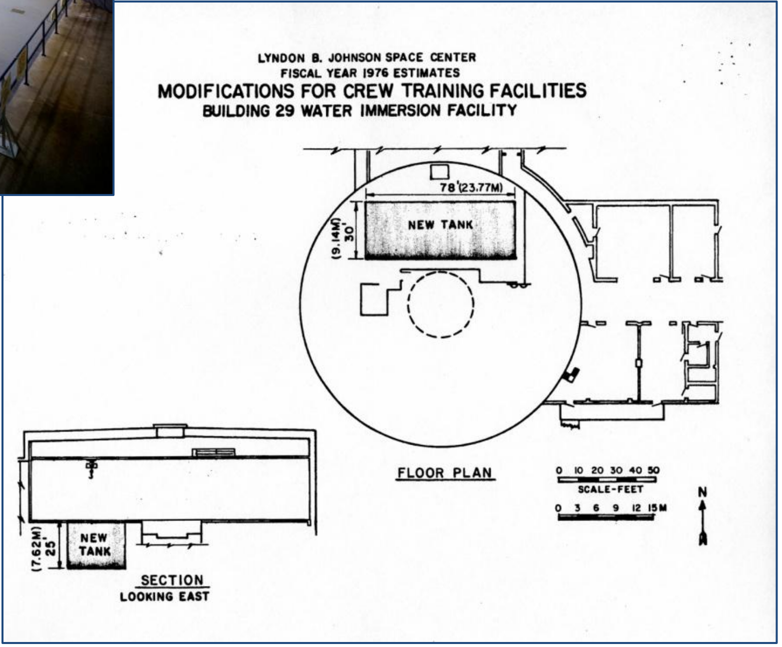


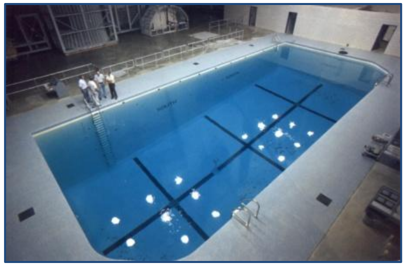
Johnson Space Center

- Weightless Environment Training Facility
  - Bldg. 29
  - 1979-1992
- Activities
  - EVA
    - 0g: STS, ISS
  - Orbiter egress training



Length	Width	Depth	Volume	
78 ft	33 ft	25 ft	64K ft^3	481K gal.
24 m	10 m	8 m	1822 m^3	1.8M ℓ





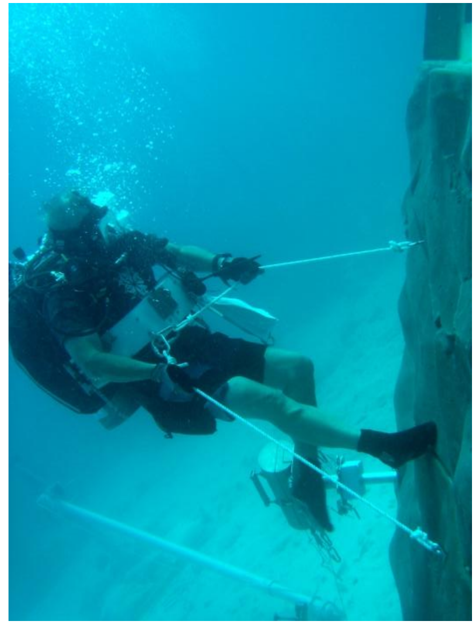
Johnson Space Center

- Neutral Buoyancy Laboratory
  - Sonny Carter Training Facility, Ellington Field
  - Since 1992
- Activities
  - EVA
    - 0g: STS, ISS, MPCV
    - Fractional g
  - Orbiter egress training

Length	Width	Depth	Volume	
202 ft	102 ft	39 ft	808K ft^3	6M gal.
61.5 m	31 m	12 m	23K m^3	23M ℓ

Johnson Space Center

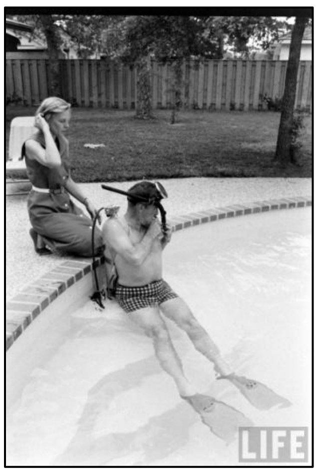
- NURC
  - NEEMO
  - 2001-2013
- Activities
  - EVA
    - Fractional g



NASA's embrace of NB

May 1959: "Original 7" SCUBA training at Langley AFB Officers Club pool, Norfolk, VA

May 1960: "Original 7" water survival training by UDU-2, USN Amphibious Base, Little Creek, Norfolk, VA

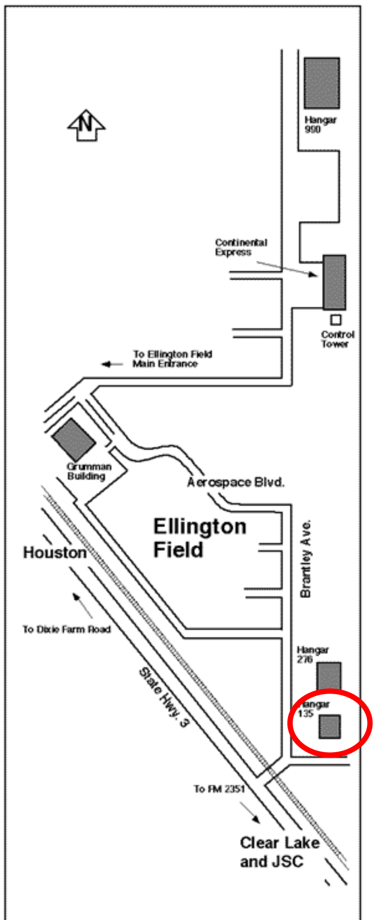


1964: Schirra at home

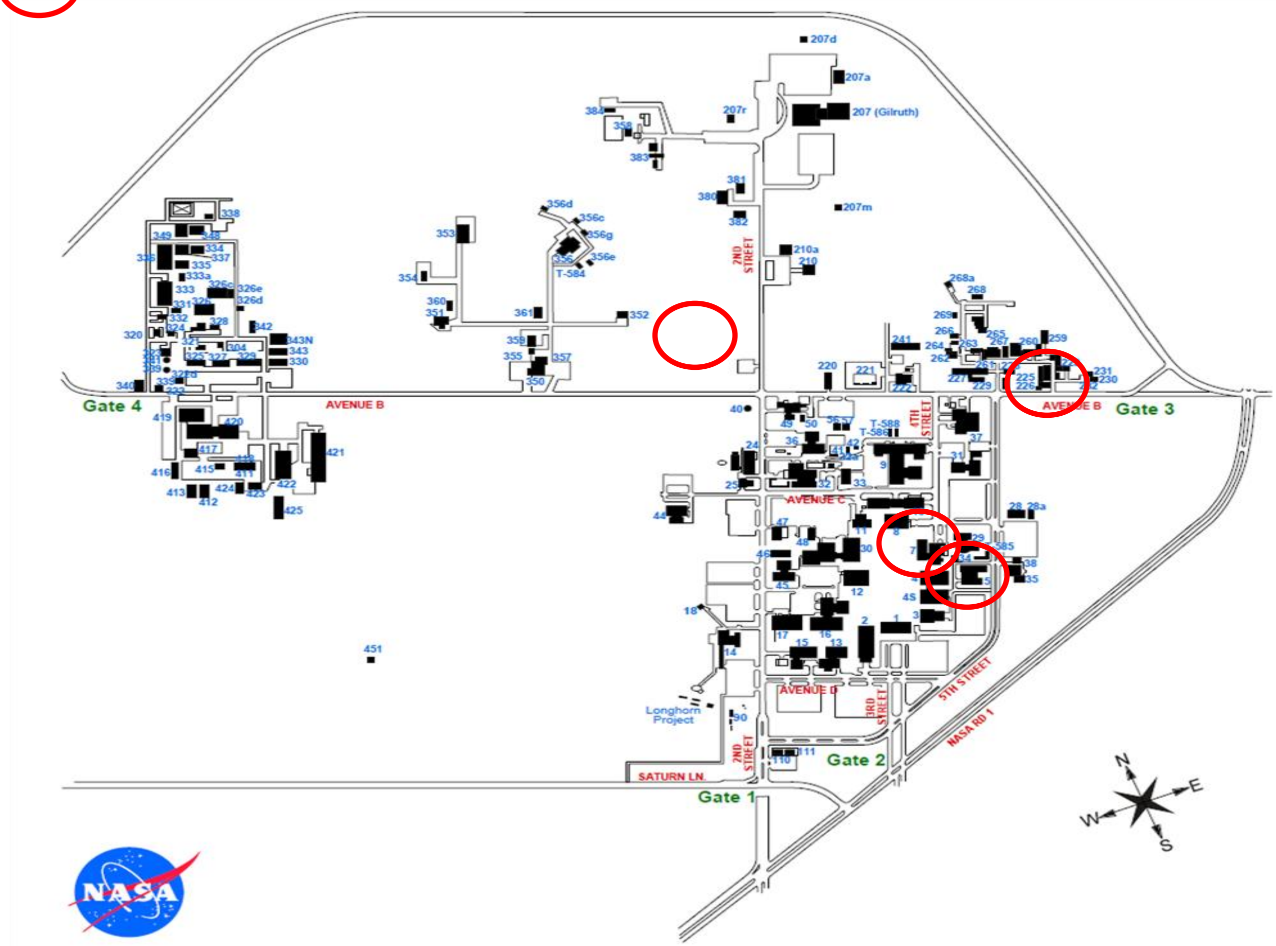
Carpenter,
1964: Cousteau at MIT
1964: Sealab I
1965: Sealab II

April 1967: NAUI SCUBA training , US Naval Base, Key West, FL

MSC-JSC Immersion Facilities



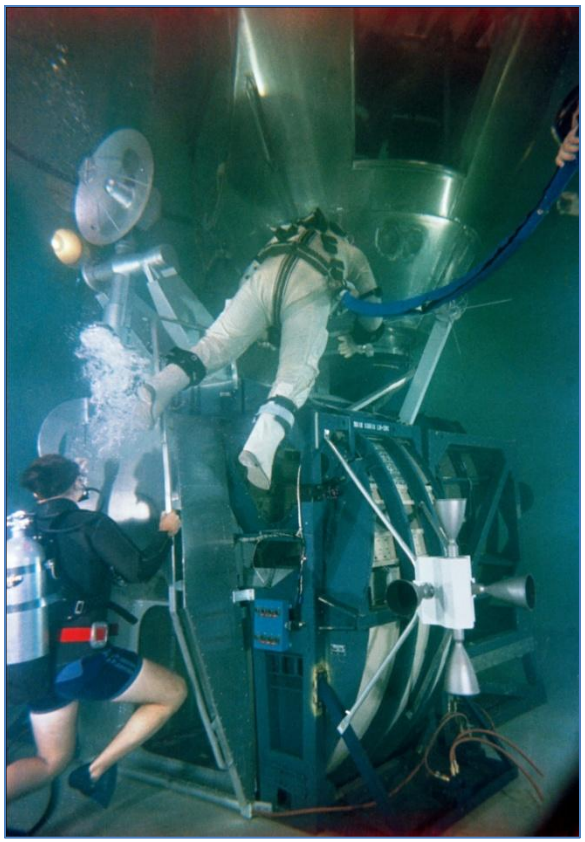
NBL



Rapid adoption of NB by mainstream NASA

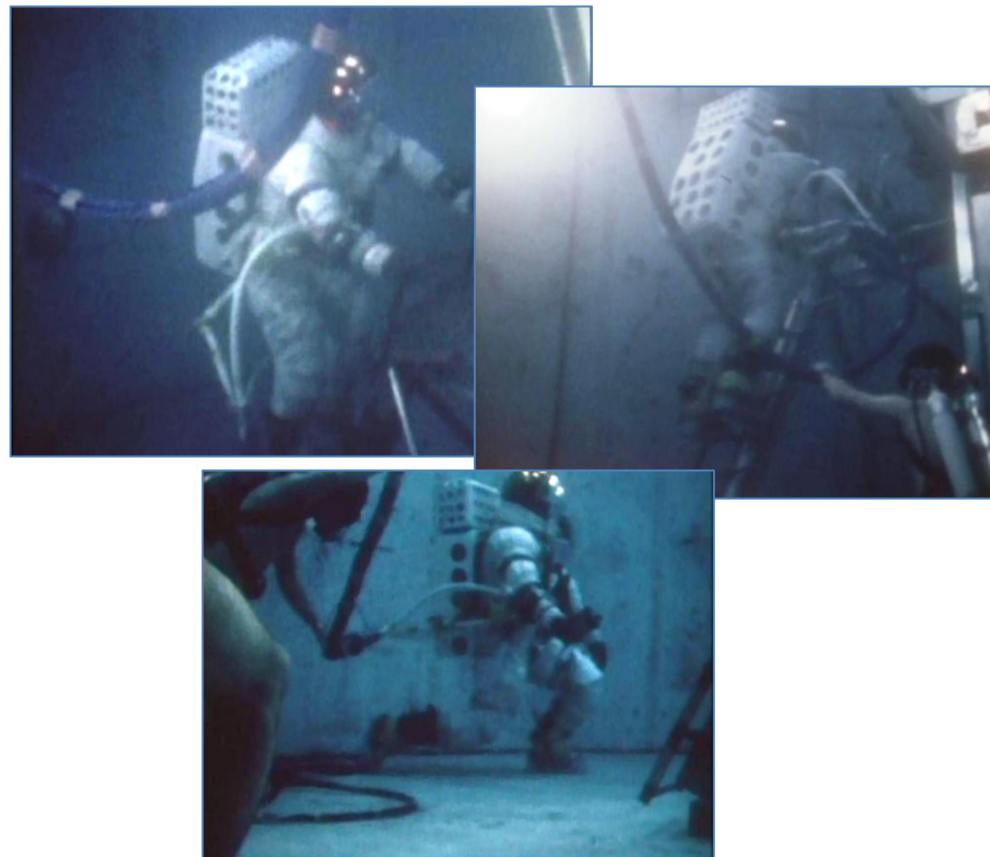
1967: Scott Carpenter, simulated contingency EVA transfer from Apollo LM to CM

(S67-50581)



1969 April 10: Neil Armstrong, 1/6-g familiarization (Apollo 11 L-97 days)

2002 edition of Apollo 11 DVDs from Spacecraft Films.



Astronaut's early opinions of NB training

Carpenter: What he learned and felt during Sealab II convinced him underwater one of best ways to simulate problems in space. Underwater training **excellent approach to working in tractionless situation** and will yield info enabling better EVA equipment: hand holds and tethers.

Cernan: "Since I had likened spacewalking to swimming in zero gravity, the agency rented a swimming pool as a training are for astronauts. Among the first ones in the tank, dressed in space suits, were me and Buzz Aldrin, who would do the EVA on the final Gemini flight…"

Scott: "…I made my way out to a large water tank at the back of [MSC], where the Flight Crew Support Division had prepared a simulated zip-gun exercise not unlike those I had been practicing on the air-bearing table. Whereas movement on the air-bearing table was in two dimensions, this exercise was in three. It involved me lowering myself into a roughly 20 x 20-feet circular water tank with the zip gun and attempting to maneuver myself around 10 feet underwater. I did not have the benefit of underwater equipment— this was a relatively simple experiment and **it worked reasonably well**—but I did not find the exercise uncomfortable since I had spent so much of my athletic life swimming.

Collins: "…in the wake of Gene Cernan's difficulties [on Gemini-9] … proposals were made to duplicate all my [Gemini-10] EVA tasks in a water tank and analyze any difficulties which might develop. Fortunately or unfortunately, John and I simply didn't have time to drop what we were doing, with only a month left to go, and **chase this red herring underwater**. We pleaded our case with Mathews and his people. Our strongest argument was the simplicity of my equipment, all of which could be donned inside the cockpit before depressurizing. The only thing I had to do, in the way of preparation, after I left the cockpit, was to attach a nitrogen line to the side of the spacecraft. The connection was made just aft of the cockpit, and there was a handrail located conveniently nearby … If I did it right, the mechanism locked itself into place; if I missed, the collar on the umbilical end snapped forward and had to be recocked—a two-handed operation. But this was the only tricky part, and even that was not a life or death matter, … So underwater simulations were conducted, and the conclusion was that I might have trouble with this task, and then again I might not. John and I received this news with straight faces (sometimes I had trouble with it in the zero-G airplane, and sometimes I didn't) and pressed on with our simulator work."

Aldrin: "In retrospect, **neutral buoyancy was the breakthrough**. We improved, in an evolutionary way, foot restraints that were absolutely critical; feet have to be anchored, not temporarily attached… Well, that came along at the same time as neutral buoyancy. I think that's one of the major things that we got out of the whole Gemini program, the neutral buoyancy training that gave us the opportunity to exercise three-dimensional freedom, similar to scuba diving, in a neutral buoyancy tank. It was outstanding training for spacewalking."

Worden: "Although **work in the water tank for the EVA was useful**, I found that our **zero-G airplane training was even better**. … **We learned a lot more in that airplane than we ever did underwater**. The water tank was a good place to test some procedures, but not to practice moving objects around. … **The water tank could also be quite misleading**, as NASA engineers found out when deciding the best way to bring the film cassettes back in. …"

Carpenter as NASA NB mentor

1960 May: **Astronauts train on scuba techniques with US Navy UDT at Little Creek, Va., at suggestion of Carpenter.**

1962 May: Carpenter piloted MA-6 mission.

1963 Jan.: Carpenter assigned to lunar excursion training.

Early 1964: Carpenter declined Gemini flight assignment, investigated **Cousteau, US Navy Sealab Projects**.

1964 Feb.: Carpenter, Conrad as p.o.c. for Grumman LEM designers; Carpenter listed in "Apollo Flight [branch]" of CB.

1964 March: Carpenter in geology field training, Grand Canyon, Ariz.; Carpenter, Conrad, White, Slayton evaluated Grumman LEM mockup.

1964 April: Carpenter in geology field trip to Alpine, Tex.; CB memo shows Carpenter *alone* in "Special Projects: pressure suits and US Navy project liaison."

1964 May: **NASA, USN announced Carpenter to join four-man team of Navy divers for final week [20-27 July] of three-week underwater experiment off coast of Bermuda this summer. SeaLab I, 40-foot undersea laboratory, to be lowered to 192 feet on July 6, remain submerged for three weeks.**

1964 June 26: **Carpenter depart MSC for Bermuda, Sealab I, until Aug.**

1964 July: **Carpenter listed as on leave from CB to US Navy, Sealab program.**

1964 July 16: **Carpenter broke left arm in motorcycle accident in Bermuda.**

1964 Aug. 6: **Astronaut Office, Special Projects: Carpenter – USN project liaison.**

1964 Sep.21: Carpenter Executive Assistant to MSC Director Gilruth, for indefinite period.

1965 Jan. 19: Carpenter in LCC, Cape Kennedy, for GT-2, unmanned sub-orbital.

1965 Feb.: **Carpenter listed on CB roster as US Navy liaison, special projects.**

1965 May 30: Carpenter collected photopolarization data during solar eclipse.

1965 July: **Carpenter expected to lead first diving team on Sealab II, christened last week Long Beach Naval Shipyard: 57 feet long, 10 men, depth 210 feet.**

1965 Aug.: **Sealab II mission.**

1965 Sep.: Carpenter listed in "Apollo Branch" under McDivitt, chief; "Interim Astronaut Assignments", with more permanent assignments to follow ~mid-November: **Special Projects: Carpenter**; office, Bldg. 2 [later Bldg 1], Room 935.

1966 Feb.: Carpenter, chief, Advanced Programs Branch, Astronaut Office (includes all 5 Group 4 sci-astros).

1966 Mar.: Carpenter presented CB perspective on radio astronomy at IEEE conference, New York.

1966 Apr.: **3rd International Conference On Hyperbaric Medicine "…panelists were Commandant Cousteau, Dr. Christian Lambertson, of University of Pennsylvania School of Medicine and Commander Scott Carpenter…"**.

1966 May: Astronaut Office Re-org – effective with move to Bldg. 4 3rd floor mid-May 1966; no effect on technical assignments and responsibilities: Carpenter, chief, "Flight A".

1966 June: **Carpenter will not be diver for Sealab III, but will serve as consultant on program.**

1966 July 28?: **Carpenter visited McDonogh en route to MSC from General Dynamics, San Diego.**

1966 Sep.: **Carpenter to visit GE Philadelphia, Valley Forge.**

1967 Jan.: **Astronaut Technical Assignments: Carpenter, "USN/ *Under-water Zero-G*".**

1967 May: **Carpenter, USN/*Underwater 0-g*.**

1967 TBD: **Carpenter A5L demonstrated EVA transfer between LM and CM underwater, in water tank in Bldg. 5. [AWST cover photo sometime in 1967.]**

1967 Aug. 10: Carpenter left NASA.

NB for human factors engineering, 1966-1970

Provider	Customer	Location	Notes	1966	1967	1968	1969	1970
ERA	LaRC, MSC	Pool, McDonogh	Airlock, OWS, Gemini EVA					
		Tank, Baltimore	Misc.					
Gen. Dyn.	USAF	San Diego	flexibility, mobility					
Gen.Elec.	USAF, MSFC	USN UDT base, Buck Island, USVI	MOL, AAP OWS & lunar					
		MSFC NBTF (a/k/a blast forming pits)	AAP					
MSFC	MSFC							
		NBS, MSFC						
MSC	MSC	Hangar135, Ellington AFB	GT-8 fam?					
		Bldg. 5, MSC	Apollo EVA, IVA; AAP					
(USN)	(MSC)	(Key West, Fla.)	(SCUBA training for astronauts)					
WPAFB	WPAFB	?	Erectable assembly					
Lockheed	Lockheed	?	?					
Ham-Std.	USAF	Pool, Central Conn. State College	Unassisted 0-g suit don,doff		1x			
Douglas, MDAC	USAF	Bolsa Ave., Huntington Beach, CA	USAF MOL IVA, EVA?					
LaRC	LaRC	TBD at LaRC	Mass handling studies					
Gen. Elec.	Gen. Elec.	UWTF, Valley Forge, PA	Misc.					
				5	8	5	6	5

S4B OWS evaluations

ERA (1966)

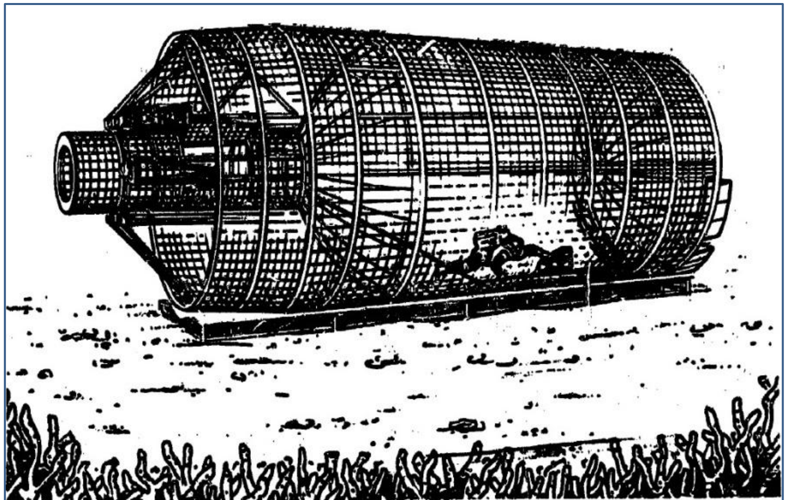
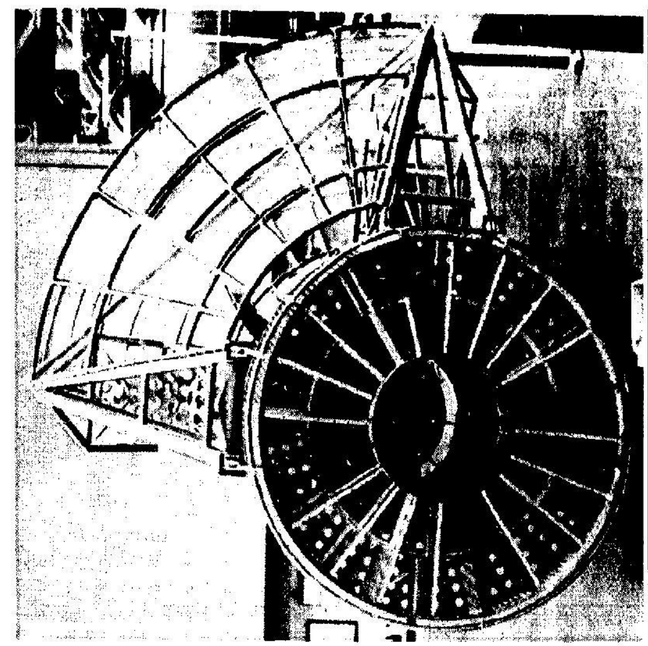


FIGURE 6.—Underwater simulation mockup of the AAP orbital workshop as used by General Electric Co. in 1966–67 tests.

GE (1966-67)

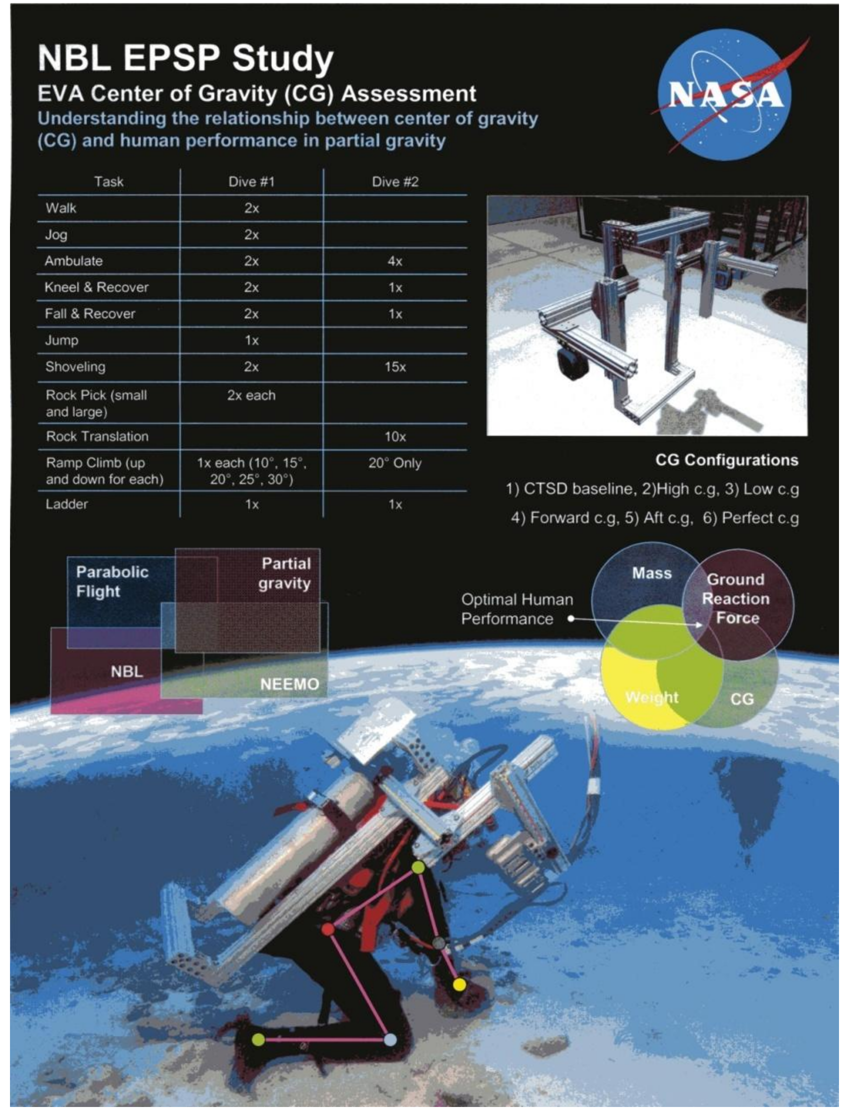
MSFC (1966ff)



UPI Telephoto

SPACE AIRLOCK — A model of an airlock, designed by McDonnell Company in St. Louis, to allow astronauts to transfer from spacecraft into an orbiting station, has been built for underwater training of the Apollo astronauts. Holes in the model will allow it to sink to the bottom of a large water tank where the astronauts will get a simulation of weightlessness while working the airlock.

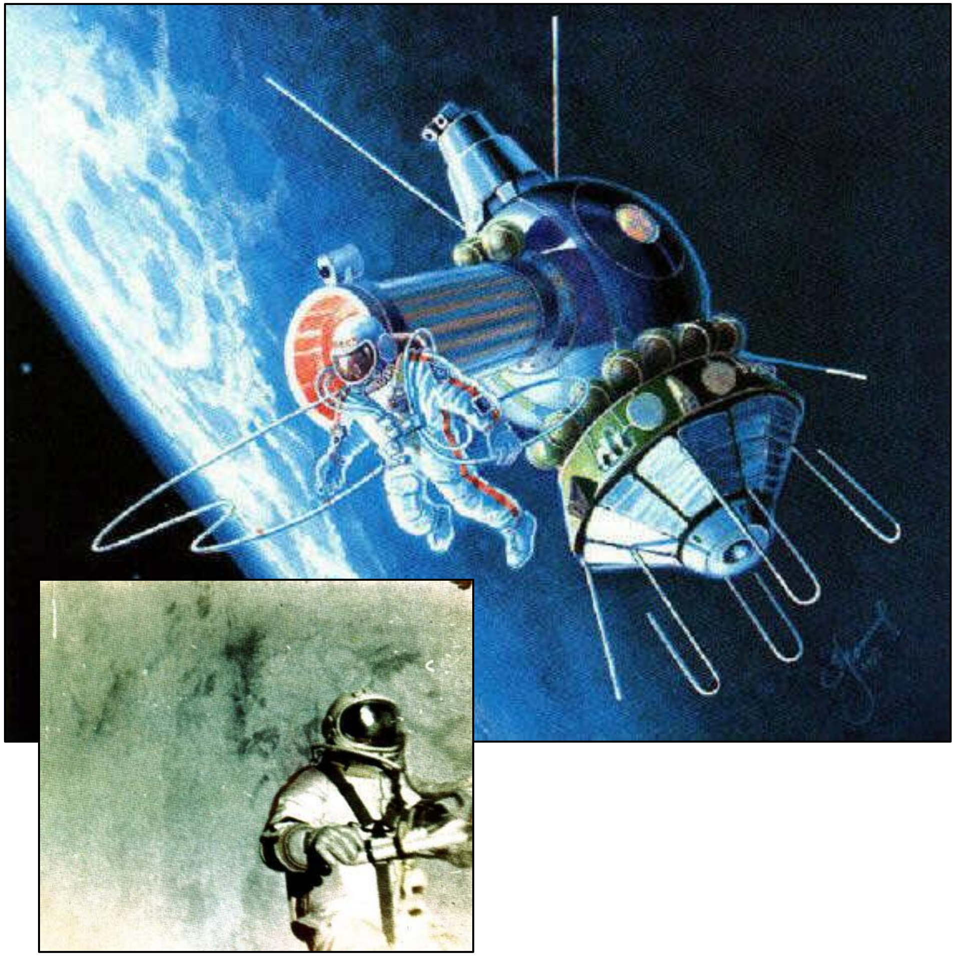
Lunar surface 1/6-g simulations




CCCP

What about Soviet use of NB?

March 1965: Voskhod-2, first EVA



Jan. 1969: Soyuz 4-Soyuz 5 docking, EVA partial crew exchange

Soviet NB activities: pre-Hydrolab

Not yet…	In discussion…
• <u>1961 early</u>: Zvezda SK-1 spacesuit with integral flotation collar tested in [Zvezda?] water tank. • <u>1964 June 9 (Tue.)</u>: Performance specification for Zvezda's Berkut EVA garment, airlock signed. **No hydrolab training had yet been introduced**. • <u>1965 March 18 (Thu.)</u>: Voskhod 2 launched; Leonov's EVA used Zvezda's Berkut garment and airlock. **No hydrolab training had yet been introduced**. Leonov described 200 parabolas in Tu-104 training flights, **no mention of neutral buoyancy**.	• <u>1968 Aug 15</u>: At UN Conference on Exploration & Peaceful Uses of Outer Space in Vienna, **Leonov** read **Gagarin's** paper which emphasized similarity between experiences of Soviet astronauts and of crews of deep-sea exploratory craft. **He said all actions taken in Soviet space vehicles were tried first in underwater craft**. • <u>1968 Dec.</u>: "**Soviets have conducted extensive zero-gravity crew exercises with Soyuz descent capsule [sic], simulating weightlessness in water tanks [sic]**. Cosmonauts with self-contained underwater breathing equipment practiced entry and exit through compression chamber [BO?]. They also mounted external equipment carried from capsule and simulated rescue maneuvers for crew members in trouble outside spacecraft. Exercises viewed as preparation for forthcoming EVAs." [BO, orbital module for Soyuz 4-5 transfer, January 1969? Or descent module for Zond missions?] • <u>1967-1968</u>: Zvezda's Orlan garment developed (1967) and tested (1968). **Unspecified hydrolab used for testing specially modified version of Orlan (weighted for neutral buoyancy; hoist for immersion and emersion; simplified LSS; pool-side pressurization, venting, cooling system)**. • <u>1970 Oct</u>.: Sevastyanov in MSFC NBS with Schweickart for simulated Skylab ATM film change-out • <u>1970 Dec.</u>: GCTC **Hydrolab** approved as part of 1970-1975 "Five-year Plan."

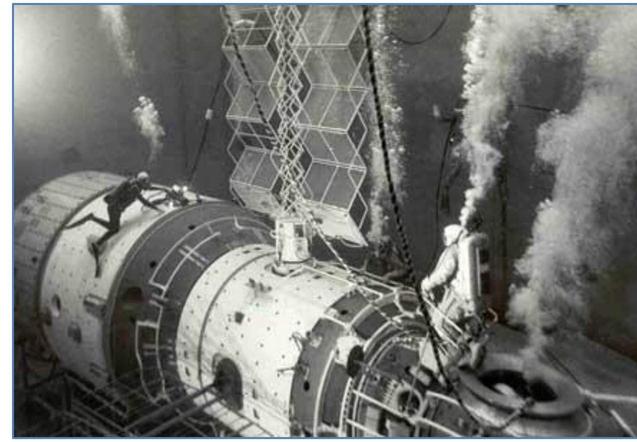
Neutral buoyancy in early Soviet piloted space program

- No unambiguous information on neutral buoyancy training prior to 1980
  - 1980: GCTC Hydrolab opened
  - Kamanin diaries lament failure to develop NB throughout 1970s
- No significant demand for EVA training before 1980

Soviet NB activities

- GCTC Hydrolaboratory
  - “Vykhod” (“Exit”) Facility
  - Opened 28 Jan. 1980

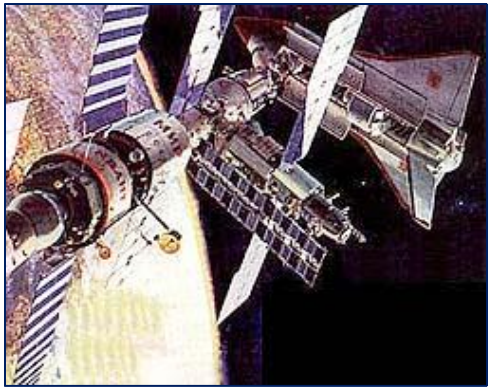
Diameter	Depth	Volume	
75 ft	39 ft	173K ft^3	1.3M gal.
23 m	12 m	4.9K m^3	4.8M ℓ



Activities: EVA at Salyut-7, Almaz-T, Mir, Buran, ISS.

GCTC Hydrolaboratory historical NB activities summary (at a glance)

Retired or obsolete modules and compartments maintained in parking lot behind Hydrolaboratory (JBC, October 2011)



Soviet NB activities in creation of hoax?

Lloyd Mallan, 1966: "Russia´s Space Hoax" claimed Soviet space walk, rest of space program faked.

James Oberg, “Space World,” 1975: “Mallan is right when he says that most of the Leonov spacewalk movies are not genuine. They are shots **underwater** [emphasis added], shots from wire-suspension training sets, shots in simulations and practices. The Russians were often careless in describing the sources of these films. The spacewalk itself was real.“ http://www.jamesoberg.com/phantoms.html (JBC, 7Sep13)

Chinese space walk: NB invoked by hoaxers?

“Confirmed Discrepancies in CCTV’s Live Broadcast of Shenzhou VII Launch”
By Shi Yu, Epoch Times Staff, Nov 18, 2008

“CCTV ran a live broadcast of the Shenzhou VII spacecraft launch to mark the second phase of the Chinese Communist Party (CCP)’s Project 921 at the end of September. This video footage, however, contains many unexplainable physical phenomena. These anomalies from the broadcast, which include **bubbles in space**, no evidence of the earth’s atmosphere, and the lack of background noise usually hear [sic] in space communication, call into question the legitimacy of the mission itself. Upon analyzing this footage, **some even suspect the live broadcast was a fraud that employed an analogue video taken under water to simulate conditions in space**.” [emphasis added]

Open historical questions: Pre-NASA MSC activities

- How did contractors decide to get into NB business? How did they fund NB facilities? What made them decide to get out of NB business?
- How were various efforts supported? (NASA contracts, even self-funded)
- How many NASA contracts were awarded? To whom? By whom? Did some NASA field centers award multiple contracts in parallel? Did some NASA centers award parallel contracts to competing contractors?
- What were the functional relationships between the various GE efforts?
- What was the story with General Dynamics? How did they become Carpenter's pre-ERA recommendation?
- What topics received contracts for study? (generic: airlock, mass-handling, passive retrieval; specific: Gemini ops, AAP ops)
- How many high-fidelity spacesuits were in use in the 1960s? (Arrowhead Mk. 4, G2C, G3C, G4C, A5L, A6L, A7L) Who used them? Who provided them? Were they loaners rotating among users, or were they dedicated to one user?
- How was suit-pressurization decided? (NASA fiat)
- How many tanks did MSFC have? (2 before NBS) Who used them? (in-house, GE)
- How many Soviet NB tanks were there, and where were they, and when?

Open historical questions: NASA-era activities

- How did MSC NB mockups for AAP end up at MSFC NBS? (NBS existed, WIF too small, but how was it negotiated? Lake Logan pact?)
- How many SIVB OWS mockups were there? Where? (ERA, GE, MSFC) How many did George Mueller see? (At least 2) Why did it take him 2 years after ERA demo to decide against Wet Workshop concept?

Final thoughts…

State of NB history

- Cataloguing
  - Published official documentation
    - Almost complete
  - Popular press
    - Well-established
  - Oral histories
    - Only beginning
    - Time-critical
- Analysis
  - Rudimentary to date
  - Daunting in scope
- Narrative
  - Entertaining, informative
  - Benefits from a wealth of material
- Much more to come

Esther Marton (2008)

Sam Mattingly (2012)

BACKUP

Techniques and personal equipment requirements, still to be analyzed: Water-pressurized or air-pressurized EVA suits?

	Water-filled	Air-filled
Safety (residual interior air)		✓
Center of gravity (ballast distribution)	✓	
Comfort (insulation from water)		✓
Ease of breathing		✓
Intra-suit support	✓	
Limb mobility (volume change)		✓
Approximation of in-space EVA mobility		✓
	General Dynamics Astronautics, San Diego: R.L.Wolf, 1964 Boeing, Project OGER. 1964 General Electric, Valley Forge, PA: Dick Scoles, ca. 1965	LaRC, Trout et al., ERA, Loats et al., 1964 MSFC, 1966 MSC, 1967- Lockheed, 1967 WPAFB, 1967 LaRC, 1969

NB for human factors engineering, 1960-1970 TO BE UPDATED

Provider	Customer	Location	Notes	1962	1963	1964	1965	1966	1967	1968	1969	1970
(LaRC)	(SSRG)	(LaRC)	Proposed, rejected									
ERA	LaRC	Pool, LAFB	Airlock demo			1x						
	LaRC, MSC	Pool, McDonogh	Airlock, OWS, Gemini EVA									
Gen. Dyn.	USAF	San Diego	flexibility, mobility									
Boeing	Boeing	Angle Lake, WA	Misc.									
		Seattle, WA	0GER									
Gen.Elec.	USAF	Aquarama, Philadelphia	MOL									
	USAF, NASA	USN UDT base, Buck Island, USVI	MOL, AAP OWS & lunar									
AiResearch	LaRC	Los Angeles	EVA maintenance									
MSFC	MSFC	MSFC blast forming pits.	AAP									
		NBS, MSFC	AAP									
MSC	MSC	H.135, Ellington AFB	Misc.									
		B.5, MSC	Apollo EVA, IVA, AAP									
WPAFB	WPAFB	?	Erectable assembly									
Lockheed	Lockheed	?	?									
Ham-Std.	USAF	Pool, Central Conn. State College	Unassisted O-g suit don,doff						1x			

NB: the first wave TO BE UPDATED

Dates of use	Location	User	IVA? (wetsuit)	EVA? W	EVA? A	Notes
(1963)	(LaRC)	(Space Station Research Group)				(Proposed by Otto Trout, rejected by Robert Osborne)
1963?-1964?	San Diego	General Dynamics for WPAFB	x			Flexibility, mobility
1963	Angle Lake, WA	Boeing	?			Flexibility, mobility
(March 1964)	(Houston)	(NASA MSC)			x	(Slayton memo to GPO; no follow-up)
(1964 Apr)	(Bermuda)	(NASA MSC)				(Carpenter TDY to USN for Sealab)
1964-1965	Seattle	Boeing			x	OGER
1964 (1x)	Officers' Club Pool, LaAFB	NASA LaRC for ERA			x	Airlock demo
1964-1966	McDonogh School, Owings Mills, MD	ERA for NASA LaRC			x	Airlock; AAP OWS, Gemini
1965	Aquarama, Philadelphia	General Electric	x			USAF MOL IVA studies
1965-1968	NASA MSFC metal-forming tanks (2?)	NASA MSFC	x			Early AAP studies
1965?	Los Angeles	AiResearch for LaRC		?		EVA maintenance

1963-1965

- All appeared simultaneously (more-or-less)
  - Dates of origin often not clear from historical record
- No significant synergy or even mutual acknowledgment among groups

NB: the second wave TO BE UPDATED

Dates of use	Location	User	IVA? (wetsuit)	EVA? W	EVA? A	Notes
1963?-1964?	San Diego	General Dynamics for WPAFB	x			Flexibility, mobility
1963	Angle Lake, WA	Boeing				Flexibility, mobility
1964-1965	Seattle	Boeing			x	OGER
1964 (1x)	Officers' Club Pool, LaAFB	NASA LaRC for ERA			x	Airlock demo
1964-1966	McDonogh School, Owings Mills, MD	ERA for NASA LaRC			x	Airlock; AAP OWS, Gemini
1965	Aquarama, Philadelphia	General Electric	x			USAF MOL IVA studies
1965-1968	NASA MSFC metal-forming tanks (2?)	NASA MSFC	x			Early AAP studies
1965?	Los Angeles	AiResearch for LaRC				EVA maintenance
1966, 1967-1978	NASA MSC (Hangar 135) Bldg. 5, then Bldg. 260	NASA MSC			x	Apollo EVA, IVA
1966-1967	USN UDT base, Buck Island, USVI	General Electric		x		MOL (1966), OWS (1967)
1967	?	WPAFB			x	Erectable assemblies
1967	?	Lockheed				TBD
1967-1980?	Huntington Beach, CA	Douglas, McDonnell-Douglas, Boeing				USAF MOL IVA, EVA?
1967 (1x)	Central Connecticut State College pool	Hamilton Standard	x			Unassisted 0-g suit don/doff
1968-1997	Neutral Buoyancy Simulator	NASA MSFC			x	AAP/Skylab, STS, HST, misc.
1968?-1970	Water Immersion Simulator	NASA LaRC	x			Mass handling studies
1969-??	Underwater Test Facility, Valley Forge	General Electric				Misc.

NB: the third wave TO BE UPDATED

Dates of use	Location	User	IVA? (wetsuit)	EVA?		Notes
				W	A	
1976-1980	MIT Alumni Pool (Bldg. 57), Cambridge	MIT Space Systems Lab.			x	
1980-1997	WETF (JSC Bldg. 29)	NASA JSC			x	STS, ISS
1980-ongoing	**Hydrolab, Star City**	**GCTC**	**x**		**x**	**Salyut, Mir, ISS**
1980-1993?	Huntington Beach, CA	McDonnell-Douglas, Boeing			x	SSF, ISS
1986-ongoing	**Underwater Astronaut Trainer**	**US Space and Rocket Center, Huntsville**	**x**	**?**		
1987-1993?	Neutral Buoyancy Test Facility, Moffet Field	NASA ARC			x	Hard suit
1992?-?	Les Mureaux, France	Aerospatiale	x	?	?	Hermes
1992-ongoing	**Neutral Buoyancy Research Facility, U.Md. (Bldg. 382)**	**U.Md. Space Systems Lab**			**x**	**Suit development**
1993-1996?	Neutral Buoyancy Test Facility, Le Bourget, France (1997: transferred to Turin)	ESA	?	?		Columbus development
1995?-?	Weightless Environment Test System, Tsukuba	JAXA	?	?		Kibo development
1997-ongoing	**Neutral Buoyancy Lab, Houston**	**NASA JSC**			**x**	**STS, ISS, exploration, other**
1997-ongoing	**Neutral Buoyancy Test Facility, Turin, Italy**	**ALTEC**				**MPLM development**
2001-2013?	Aquarius, NURC, Key Largo, FL	NOAA, NASA		x		Exploration
2005?-ongoing	**Neutral Buoyancy Facility, EAC**	**ESA**	**?**	**x**		**Columbus, misc.**
2006-2007?	Kearsely HS pool, Kearsely, MI	Kearsely HS and CAP		x		Assembly demos (Chris Cassidy observed)
2008-ongoing	**CART, Beijing**	**Chinese Astronaut Research & Training Center**			**x**	**Shenzhou**

ALTEC?

Selected references

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- Hypodynamics and Hypogravics, Michael McCally, Academic Press, 1968.
- Simulation of Gemini Extravehicular Tasks by Neutral-buoyancy Techniques, NASA TN D-5235, June 1969, Otto F. Trout, Jr. (LaRC), Gary P. Beasley (LaRC), Donald L. Jacobs (MSC) http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690018646_1969018646.pdf.