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 – From 'Below Dignity' to 'Above It All'

Date: August 21, 2013 **Time:** 11:00-12:00 pm **Location:** JSC/B5S/R3102

DAA 1676 Form #: 29743

This is a link to all lecture material and video: \\js-ea-fs-03\pd01\EC\Knowledge-Capture\FY13 Knowledge Capture\20130821 Charles_History of Underwater Neutral Buoyancy_Part 1\For 1676 Review & Public Release

*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_From Below Dignity to Above It All_8-21-2013.pdf

Presenter: John Charles

Synopsis: An attempt to clarify some vague memories of underwater studies of astronaut capabilities in space led Dr. John Charles to become acquainted with Sam Mattingly, one of the pioneers in the field, and to greater insights into Mattingly's work simulating Gemini EVAs in the mid-1960s. Charles recounted major accomplishments by Environmental Research Associates (ERA), Mattingly's company for contracting with NASA Langley on several early studies. ERA's work was considered within the context of contemporary efforts to simulate weightlessness and the widespread development of neutral buoyancy facilities after ERA's successful demonstration for Gemini 12.

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

From "Below Dignity" to "Above It All"

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

Spacesuit Knowledge Capture Series
August 21, 2013

John Charles
NASA Human Research Program
john.b.charles@nasa.gov

Weightlessness

- A dominant aspect of ballistic spaceflight
  - No “weight” -- only inertial mass
    - No sedimentation
    - No convection
    - No hydrostatic pressure
    - No frictional ground-reaction forces
- Anticipated for a century before first human spaceflight
- Has been simulated in a variety of ways
  - No universally-applicable simulation
    - Each simulation has limited applicability

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

Weightlessness

Neutral buoyancy

Neutral buoyancy task analysis

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

Physiological

Responses to simulated weightlessness

limited orientation, manipulation, translation, etc.

Early whole-body water immersion studies

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

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

Limited orientation, manipulation, translation, etc.

Null-Gravity Simulation

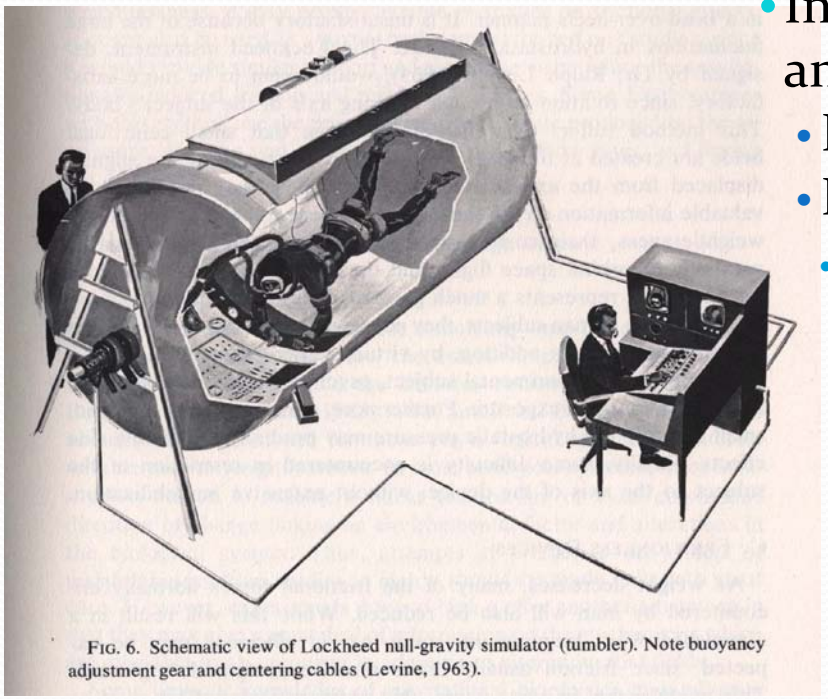


FIG. 6. Schematic view of Lockheed null-gravity simulator (tumbler). Note buoyancy adjustment gear and centering cables (Levine, 1963).

Combined tumbling and immersion devices for orientation in weightlessness

- Intended to neutralize otolith settling and somatosensory inputs
  - Fish
  - Humans
    - Levine, Raphael B. , Lockheed Aircraft Co., Marietta, GA (1960, 1963)
      - Disadvantages
        - Small residual centrifugal field at otolith
        - Small hydrostatic gradient alterations
        - Difficulty restricting subject to axis of rotation
        - Psychological limitations of confinement
        - Operational overhead

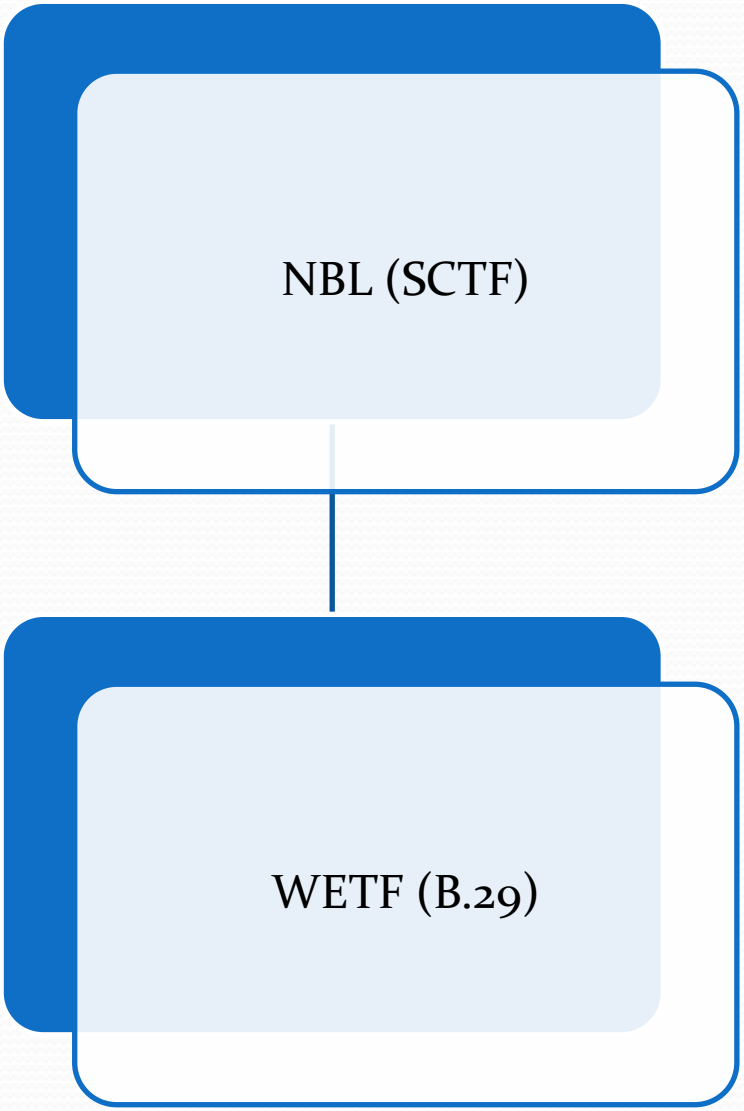
Human engineering

Human performance capabilities: EVA

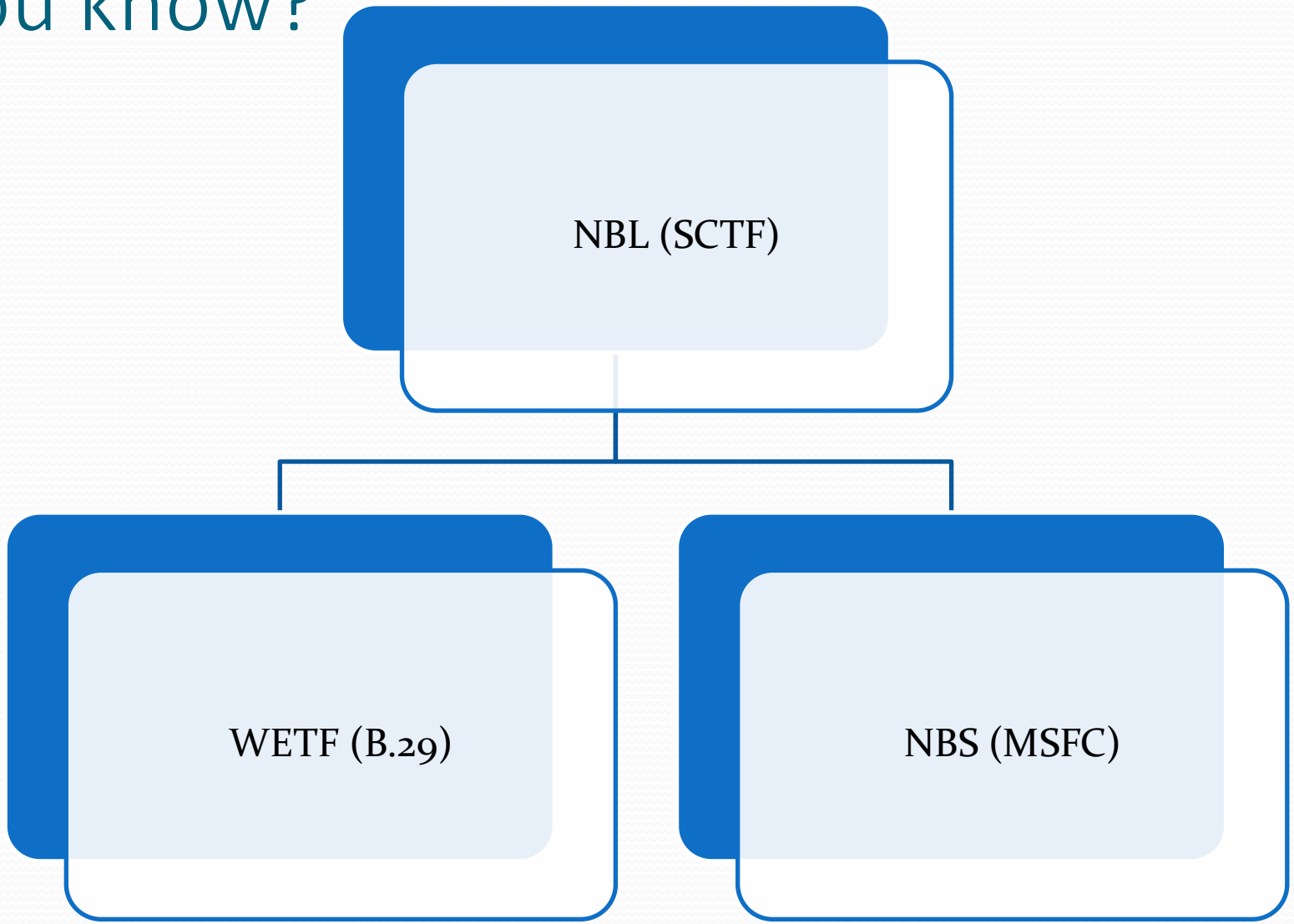
How many neutral buoyancy tanks do you know?

NBL (SCTF)

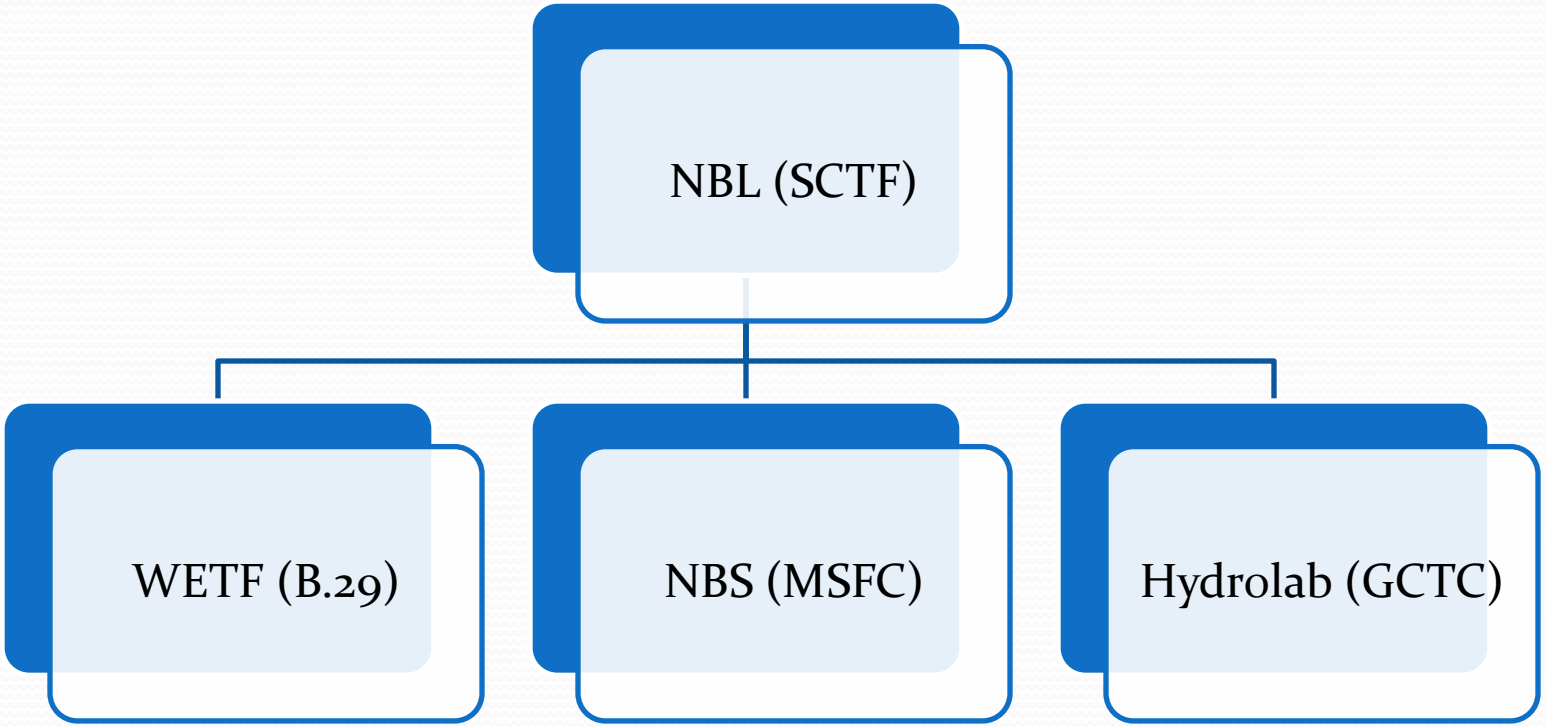
How many neutral buoyancy tanks do you know?



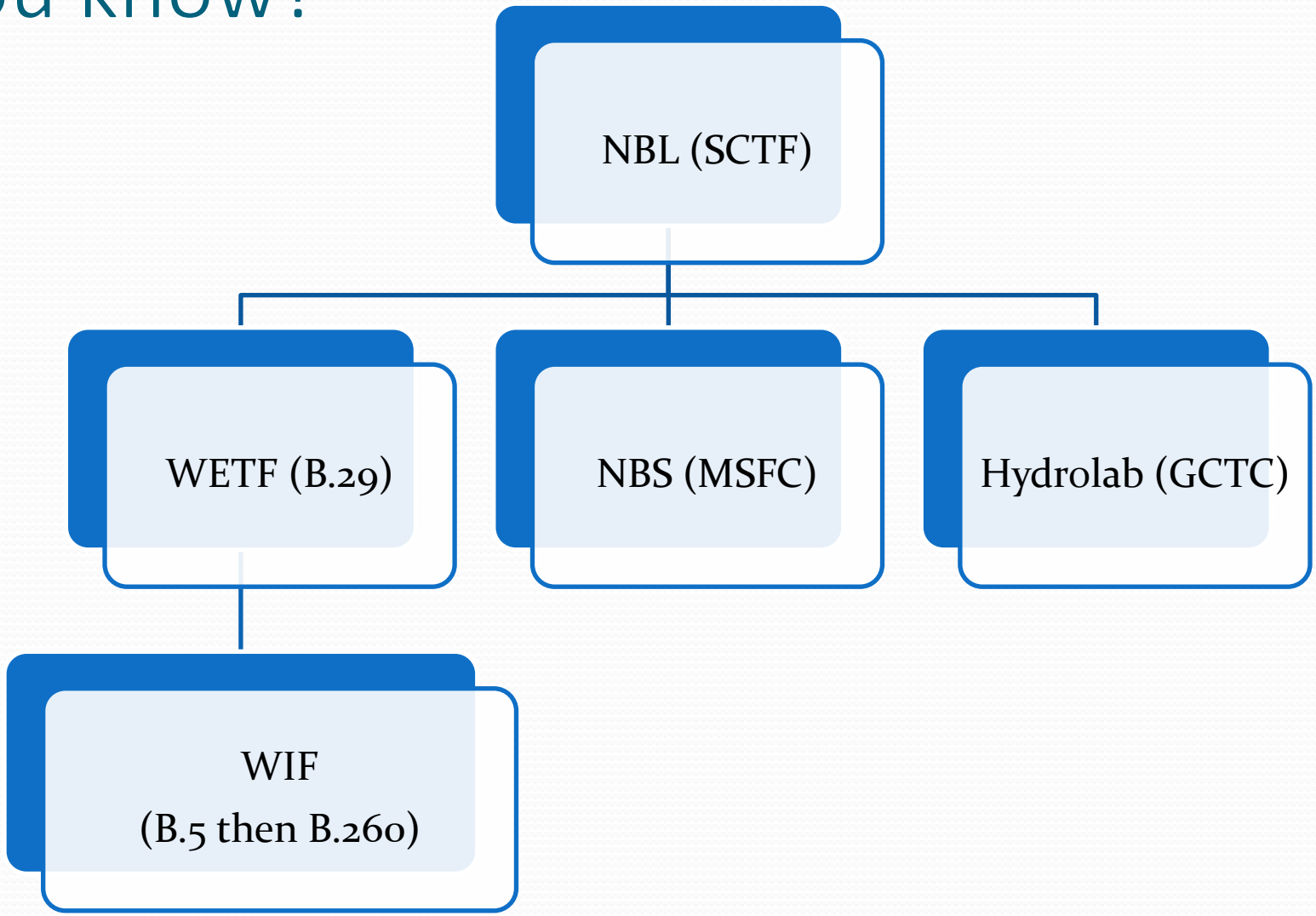
How many neutral buoyancy tanks do you know?



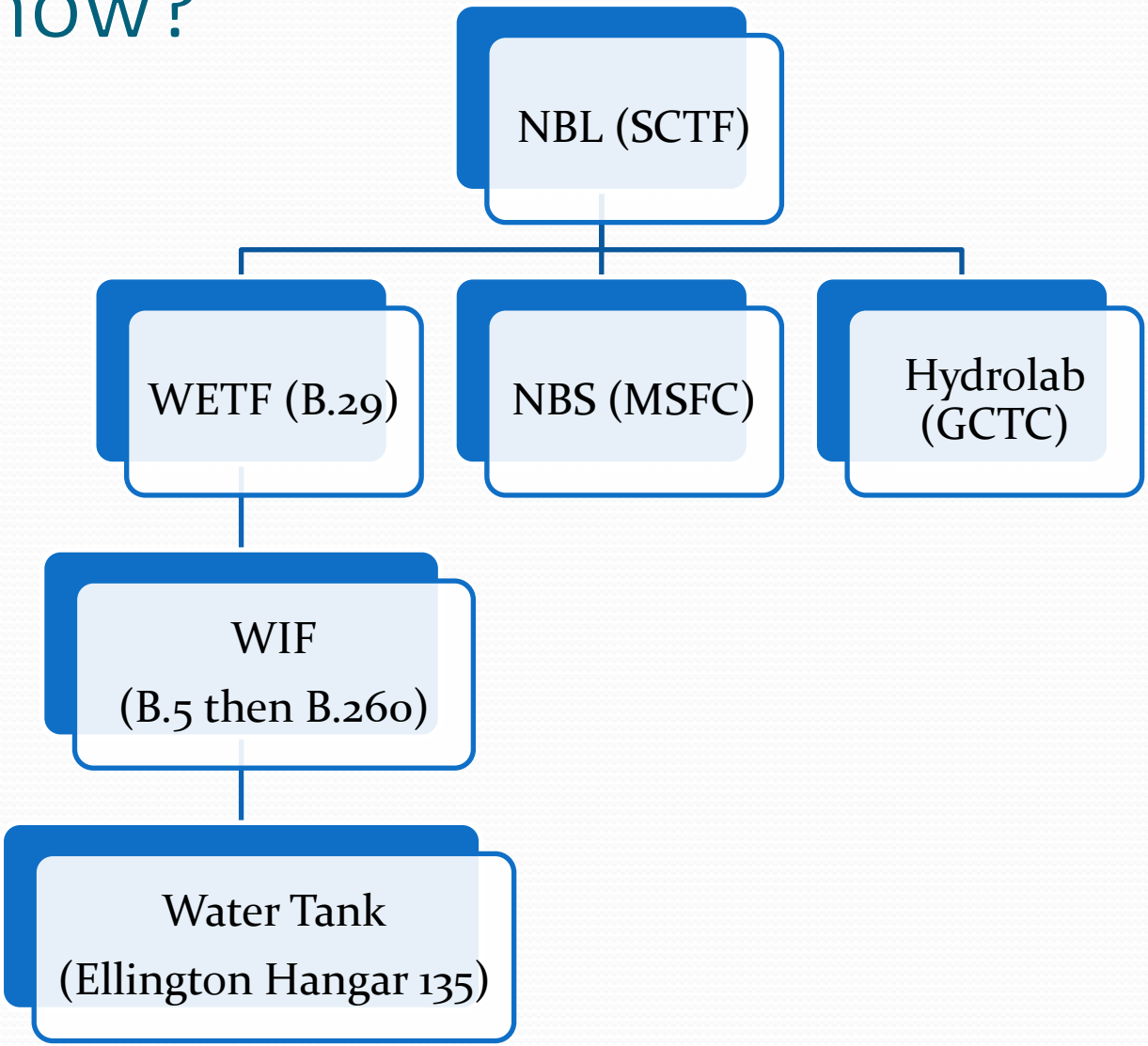
How many neutral buoyancy tanks do you know?



How many neutral buoyancy tanks do you know?



How many neutral buoyancy tanks do you know?



Neutral buoyancy: the first wave

Dates of use	Location	User	IVA? (wetsuit)	EVA?		Notes
				W	A	
(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

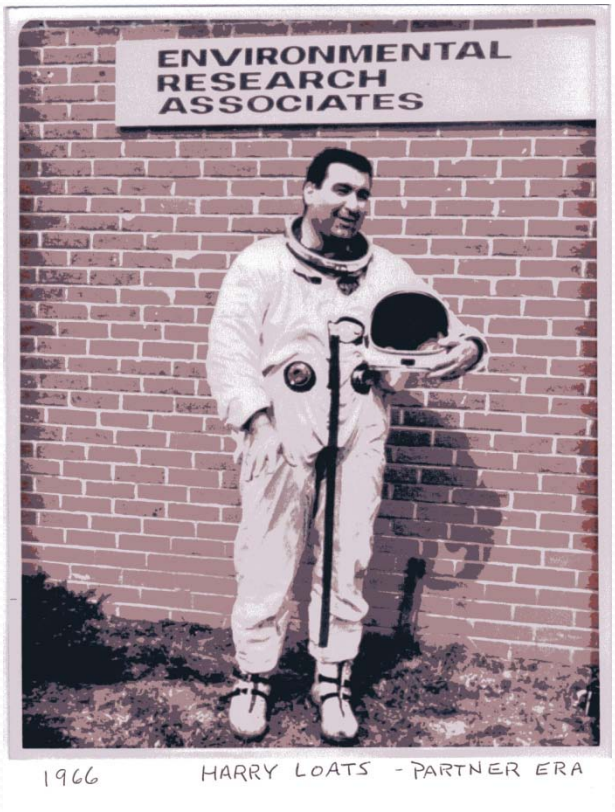
1963-1965

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

Case study

Environmental Research Associates

…a small research firm that became a pioneer in neutral buoyancy simulation of EVA almost by accident.



Harry L. Loats, Jr.
Co-founder and Chief Scientist

G. Samuel Mattingly
Co-founder and Senior Partner

Neutral buoyancy: 3 questions

1. How did ERA come to adopt neutral buoyancy as a technique for simulation of weightlessness in spaceflight?
2. How did neutral buoyancy become established as a dominant technique for weightlessness simulation?
3. How did ERA prevail over other early adopters of neutral buoyancy in the aerospace community?

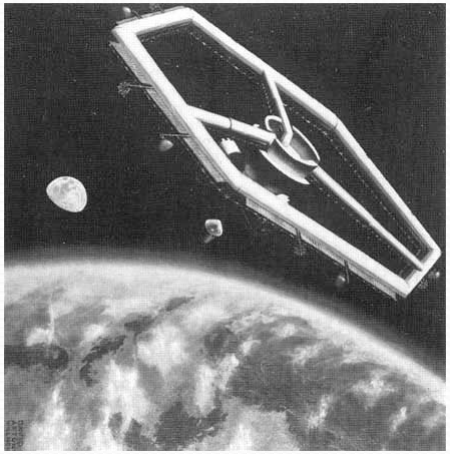
Background: ERA history relevant to neutral buoyancy (<1961)

- 1944-46: **Mattingly** US Army Air Corps as C-47 **flight engineer**,
- 1949: Mattingly worked for business **installing pool filtration systems**
- 1959: Flight Refueling, Inc. (FRI)
  - **Mattingly**, marketing; **Loats**, R&D; Watson Newhall, president
  - Mattingly and Loats convinced Newhall to extend FRI scope to **orbital rendezvous, docking for NASA**
    - Gained **entrée** to LaRC branch & assistant division chiefs, MSFC branch chiefs
    - But NASA contracts went to IBM and General Dynamics, not to FRI
  - FRI bought out by Aeronca, Loats stayed; Mattingly went to Pneumodynamics
- Pneumodynamics
  - US Navy contracts
  - Mattingly hired to bring in NASA contracts
  - Mattingly and Loats reconnected, Loats moved to Pneumodynamics
- 1962: Mattingly and Loats left Pneumodynamics, formed **Environmental Research Associates (ERA)** with expectations of 3 new contracts (NASA, AEC, Navy)

Background: ERA history relevant to neutral buoyancy (1961-1963)

- ~1961: Marquardt Corp. (Van Nuys) consulting contract (facilitated by Newhall) for marketing space uses of long cables to NASA, USAF
- Made contacts with USAF at Wright-Patterson AFB
- Connected with Paul Hill, Assoc. Chief, Applied Materials and Physics Division, LaRC, early space station planner
- Submitted unsolicited proposal to study **seals for erectable space station**
  - USP converted to RFP by LaRC
  - Bidders included Martin Co., General Dynamics and ERA
  - Contract awarded to ERA, 1963-1964, **Otto F. Trout,** contract monitor in Hill's division

Paul R. Hill (1909-1990)(1962 photo)



Background: ERA history relevant to neutral buoyancy (1963)

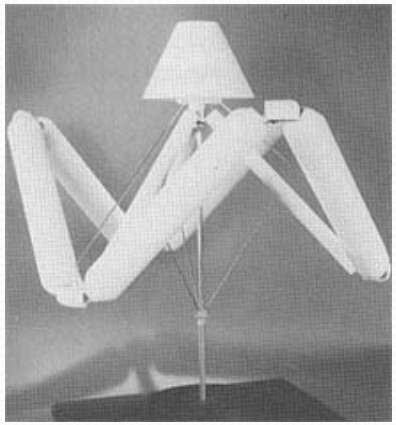
- 1963: ERA submitted USP to LaRC for use of cables in space
  - Art Vogeley, branch chief, refocused USP on EVA tether retrieval of incapacitated Gemini astronaut
    - Study scenario: **EVA astronaut** retrieval of Agena target vehicle at 1 mile (~1500 m) from **Gemini**
    - First Gemini funding to LaRC
  - Marquardt as prime, ERA as consultants
- ~1963: ERA ended consulting relationship with Marquardt

1962 McDonnell advertisement

Otto Trout's plastic airlock

- ERA study of **airlock** seals (1963–1964)
  - Technical contract monitor Otto F. Trout, Langley engineer
  - Reviewed seal materials, flange sizes and configurations
  - Concluded little available information on airlock usage as applied to lightweight structures such as an early space station
- Contract augmented to allow ERA to design conceptual airlock with various door and seal designs to be tested in Langley vacuum chambers
- Langley model shop built **full size cylindrical plastic model of airlock** for Trout to use in briefing Langley management
  - 4 feet (1.2 meters) diameter
  - 6 feet (1.8 meters) length
- Plastic airlock model only intended for demonstrations, not for use in vacuum chamber

Otto F. Trout (1966 photo)



Plastic airlock demo at LaRC (Jan. 1964, L-64-841)

Underwater neutral buoyancy epiphany for ERA & LaRC

- ~June 1963: Concurrent projects at LaRC for airlock design and Gemini astronaut retrieval led to considerations of space station airlock sizing
  - Necessary to determine ability to enter airlock, turn around, seal entry hatch, all in suit pressurized against vacuum
    - Testing to use Trout's plastic airlock for photography
    - Well-known lack of agility in pressurized suit in normal gravity
      - Necessary to simulate weightlessness
        - Underwater neutral buoyancy
          - Trout had proposed it previously (1963)
          - Immersion as proper weightlessness simulation not a consideration
          - **Least expensive option available**

NASA concept of EVA (1962)

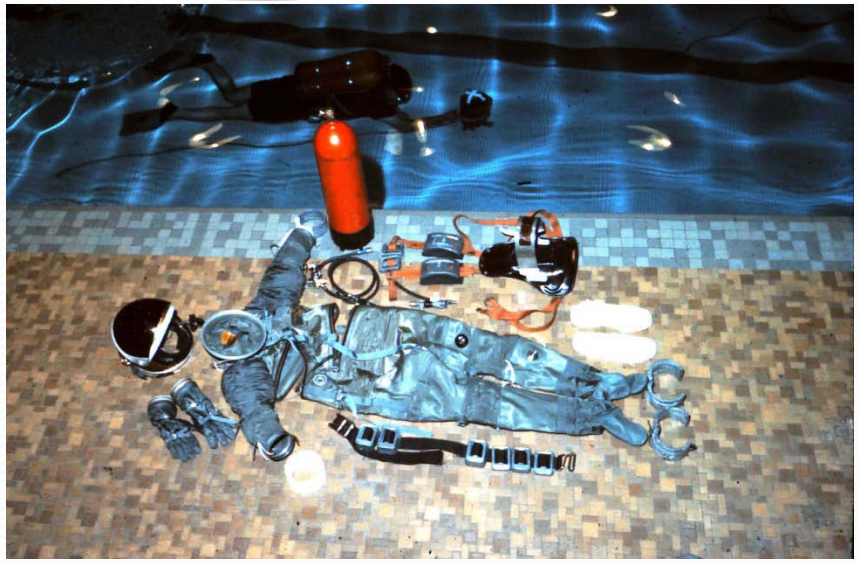
Neutral buoyancy: 3 questions

1. How did ERA come to adopt neutral buoyancy as a technique for simulation of weightlessness in spaceflight?

Least expensive option available

Pressure suit courtesy of US Navy

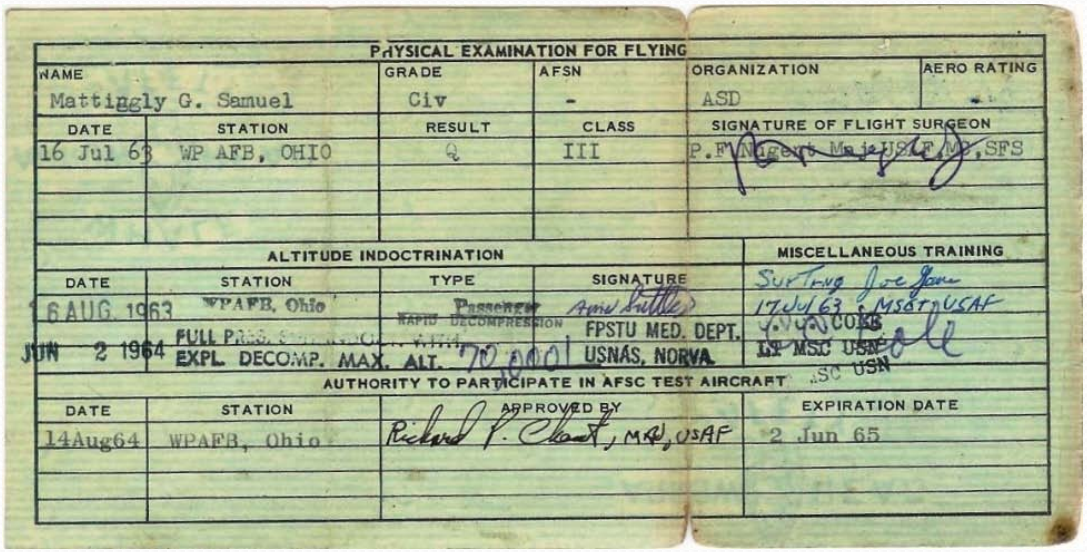
- Airlock study required pressurized "space suit"
- ERA contacted Navy High Altitude pressure suit school at nearby Norfolk Naval Base
  - Navy pilots trained in use of full pressure suits
  - Trained to egress ditched aircraft while wearing unpressurized suit
    - Small on-site pool for procedures training
    - Arrowhead suits
      - Out of service for flying
      - Still adequate for training
    - **ERA noted similarities underwater EVA simulation**
- Lt. Charles C. Cole, director, agreed to loan suit with appropriate training of Loats and Mattingly



- School not confident that pressurized Arrowhead suit could be made neutrally buoyant without excessive weights
  - Supported ERA by providing, maintaining several Arrowhead suits, associated hardware without contract

Mattingly training	
16 July 1963	Class III physical
16 Aug. 1963	Physiological training
2 June 1964	Pressure suit training
14 Aug. 1964	Aircraft test conductor qualification

Navy training and "SPACE"



PHYSICAL EXAMINATION FOR FLYING

NAME	GRADE	AFSN	ORGANIZATION	AERO RATING
Mattingly G. Samuel	Civ	-	ASD	

DATE	STATION	RESULT	CLASS	SIGNATURE OF FLIGHT SURGEON
16 Jul 63	WP AFB, OHIO	Q	III	P.F. Nugent Maj USAF MC, SFS

ALTITUDE INDOCTRINATION

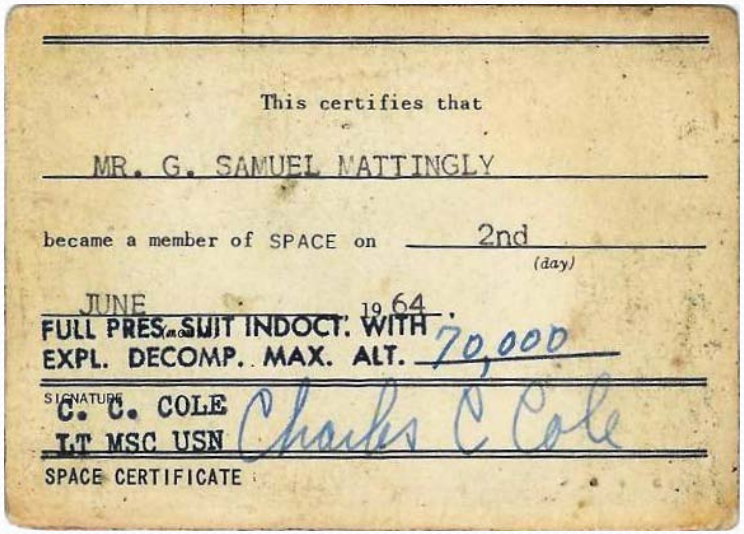
DATE	STATION	TYPE	SIGNATURE
6 AUG 1963	WPAFB, Ohio	Passenger RAPID DECOMPRESSION	FPSTU MED. DEPT. USNAS, NORVA
JUN 2 1964	FULL PRESS. SUIT INDOCT. WITH EXPL. DECOMP. MAX. ALT. 70,000		

MISCELLANEOUS TRAINING

SUPTNG Joe Jean 17Jul63 MSGT USAF
C.C. COLE LT MSC USN

AUTHORITY TO PARTICIPATE IN AFSC TEST AIRCRAFT

DATE	STATION	APPROVED BY	EXPIRATION DATE
14Aug64	WPAFB, Ohio	Richard P. Chant, MAJ, USAF	2 Jun 65



This certifies that

MR. G. SAMUEL MATTINGLY

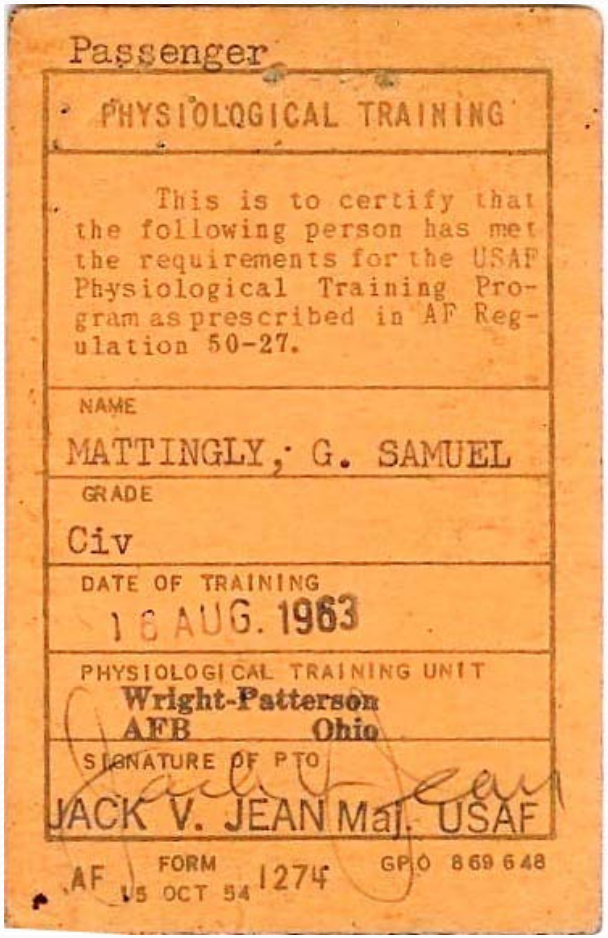
became a member of SPACE on 2nd (day)

JUNE 1964.

FULL PRES. SUIT INDOCT. WITH EXPL. DECOMP. MAX. ALT. 70,000

SIGNATURE
C. C. COLE
LT MSC USN Charles C Cole

SPACE CERTIFICATE



Passenger

PHYSIOLOGICAL TRAINING

This is to certify that the following person has met the requirements for the USAF Physiological Training Program as prescribed in AF Regulation 50-27.

NAME
MATTINGLY, G. SAMUEL

GRADE
Civ

DATE OF TRAINING
16 AUG. 1963

PHYSIOLOGICAL TRAINING UNIT
Wright-Patterson AFB Ohio

SIGNATURE OF PTO
JACK V. JEAN Maj. USAF

AF FORM 1274 15 OCT 54 GPO 869648

Navy's "Society of Pioneering Astronauts and Celestial Explorers"

Poor Man's Space Suit Possible for Tests

"The Navy's Mark IV pressure suit, pressurized at 2.0 psig, can be substituted for the Gemini 3C-8 suit at 3.5 psig for research projects involving psychomotor skills such as manual dexterity, dexterity with tools, speed of arm movement, gripping strength, pursuit tracking, and static and dynamic steadiness, an LTV Astronautics Div. study indicates. After extensive comparisons with each, R. D. Hughingson concludes that there is no significant difference between the suits, although the performance differences in each suit attributable to the pressurized or unpressurized condition were marked. This finding could relieve the demand for Gemini and Apollo suits for ground-based research, he says."

"Poor Man's Space Suit Possible for Tests," Missiles & Rockets, May 9, 1966, p. 21, Technical Countdown, Life Support.

Arrowhead version of B.F. Goodrich Mk.IV, worn by Wernher von Braun, MSFC (1967)

June 1964 test in Langley AFB Pool

- Trout was granted use of swimming pool at officers club at Langley AFB for a single 3-hour period
  - Plastic airlock was immersed
  - Mattingly suited up, weighted to approximate neutral buoyancy
    - No attention to d/o/f or rotational stability, only to total neutral buoyancy
      - Weighting included lead shoes, body-worn weights, and handheld dumbbells
- Test inconclusive
  - Mattingly passed through plastic airlock
  - Unable to demonstrate 6 d/o/f of weightlessness
- Program would require more time, planning
  - ERA to take possession of plastic airlock
  - Conduct program to evaluate simulation procedures
    - To include detailed underwater documentary photography

The McDonogh School connection

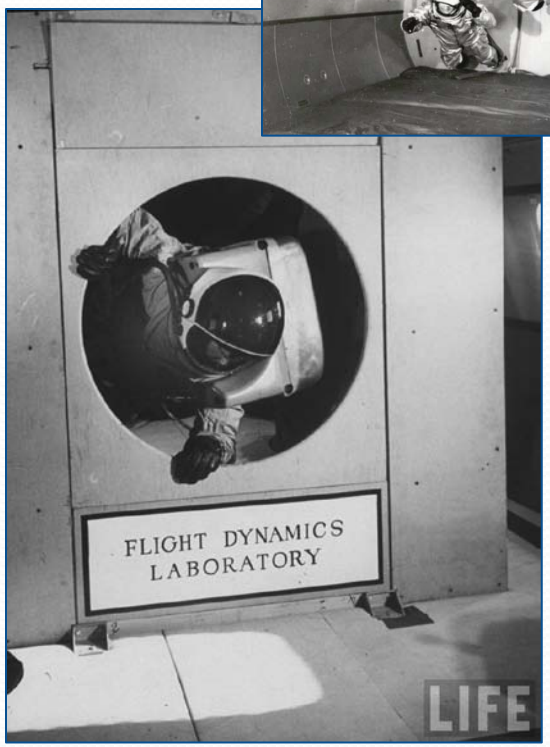
- June 1964: Next day after Langley exercise, Mattingly approached McDonogh School
  - Boys' military school, Owings Mills, MD
  - Near ERA offices in Randallstown, MD
- McDonogh had indoor pool for year-round use by swim team, Red Cross for swim instruction
  - Mattingly knew water quality would be adequate for photography
    - Had installed filtration system in previous business
- Robert Lamborn, Headmaster, agreed to ERA's use of pool, for same hourly rate as Red Cross, off-hours , no equipment to remain in pool building after use, no impact on other pool users
  - Intended to be short-term program, no formal lease, just gentleman's agreement that ERA would keep track of usage and pay monthly

July 18, 1964, test at McDonogh

- Several simulations evaluated Arrowhead full pressure suit in neutral buoyancy mode using bags of welding shot tied on to suit at various locations
- Less than 1 month after test in Langley pool, ERA made first formal neutral buoyancy test of airlock ingress and egress
- Trout acquired Milliken 16 mm gun camera from USAF
  - Exposed 400 feet (120 meters) of 16mm film in 12 minutes
  - ERA designed, built Plexiglas camera housing for underwater use
- Mattingly in suit, Loats as photographer safety diver, Trout as observer safety diver
- Film convinced Paul Hill to fund proposal for series of simulations to evaluate airlock features, sizes
  - Contract NAS1-4059
  - ERA hired several young SCUBA-experienced personnel, conducted simulations

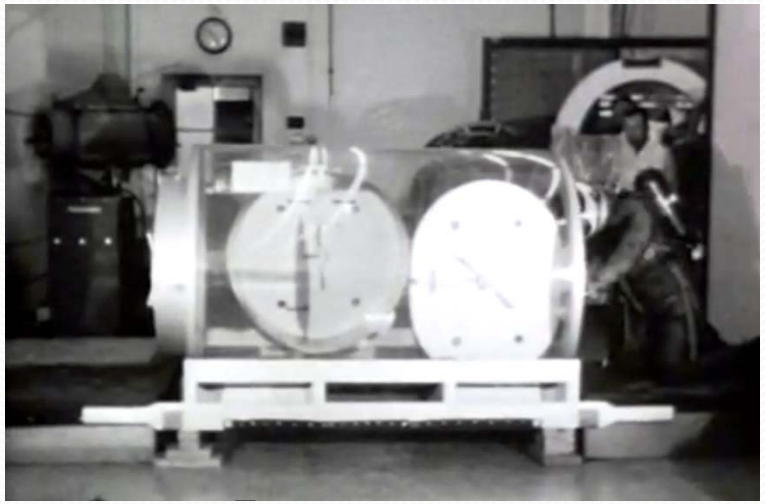
Comparison of neutral buoyancy, 1-g and 0-g

- Neutral buoyancy acceptance required comparison to 0-g in parabolic flight, 1-g baseline
- LaRC had no zero-g flight capability.
  - ERA contacted WPAFB, John C. Simmons
    - Studied human motion control in weightlessness using C-131
    - Impressed with ERA film
    - Arranged for Mattingly (former Army Air Corps flight engineer) to be qualified as test conductor for USAF 0-g flights
    - Provided C-131 for test of LaRC plastic airlock ingress and egress
    - no formal contract for performance



Comparison of neutral buoyancy, 1-g and 0-g

- ERA filmed simulations at 1-g, 0-g, neutral buoyancy
- Report generated September 1965, published January 1966
  - NASA Technical Note TN-D 3054, "A Water Immersion Technique for the Study of Mobility of a Pressure Suited Subject Under Balanced Gravity Conditions"
  - Neutral buoyancy good representation of 0-g, more cost effective than parabolic flight



Facility	Cumulative time/day	Manpower	Cost/hr
C-131	10 min	10	$5K
Pool	4-5 hr.	4-5	$10

Neutral buoyancy: 3 questions

2. How did neutral buoyancy become established as a dominant technique for weightlessness simulation?

Best value for the dollar

Meanwhile, back at MSC: "The only practical means of simulating…a reduced gravity environment…is by water immersion"—March 1964

- Gemini Extravehicular Operation (memo)
  - from CO/Asst Dir FCO [**Slayton**]
  - to GO/Mgr, Gemini Program Office
  - dated 24 March 1964.
  - Drafted by J.M. Bremer 3-18-64.
- "**The only practical means of simulating the overall effects of a reduced gravity environment for relatively long periods of time is by water immersion.** A fairly realistic simulation of some of the techniques and problems in accomplishing extravehicular activities can be accomplished by **submerging the Boilerplate No. 201** [delivered Dec. 1963] **in the Ellington Tank** [Hangar 135]. The **flight crews can then don SCUBA equipment and practice such tasks as egress, ingress, opening and closing the spacecraft hatches and maneuvering over the spacecraft** [and "Retrieve and Replace Equip in Adapter" from Chart III]. In addition, they can do **slow maneuvering by use of a simple underwater maneuvering pack**, which will represent fairly well the operational characteristics of an in-flight maneuvering pack."
- Also noted that an unrestricted 5 d/o/f EV space simulator is being tested by FCSD.

Possibly Lovell (left seat) & Gordon Harvey (ret. seat) - wk of 1/27-31/64 per LNR 2/5/64, pp 1,3 2/19/64 p.6

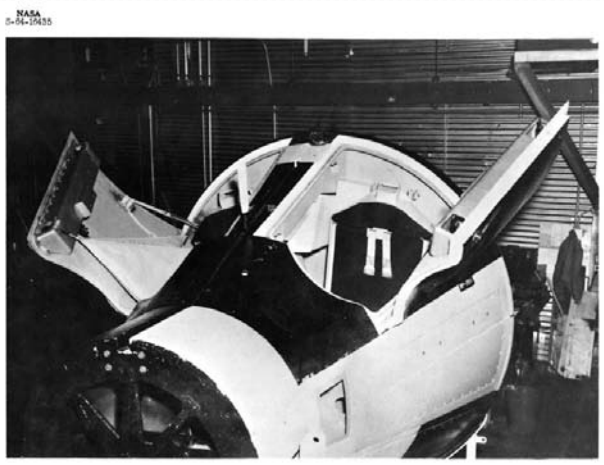
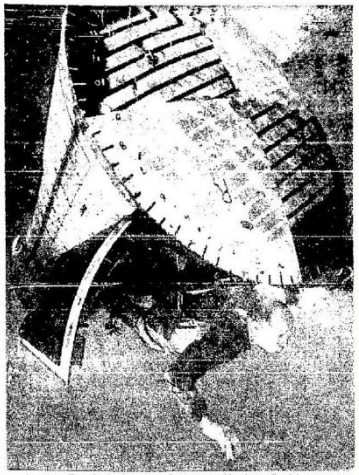


Illustration 1. Boilerplate 201



Astronaut Tom Stafford egresses from an upside down Gemini spacecraft during a training session at Ellington Air Force Base, Houston, Tex. The training exercise involved leaving a Gemini capsule which had overturned under water, and swimming to the surface. AP Wirephoto

May 4, 1966: Extravehicular Activities Training (briefing)

3.5-1 Briefings…

3.5-2 Air bearing platform…

3.5-3 Gemini Crew Station and Adapter Mockup…

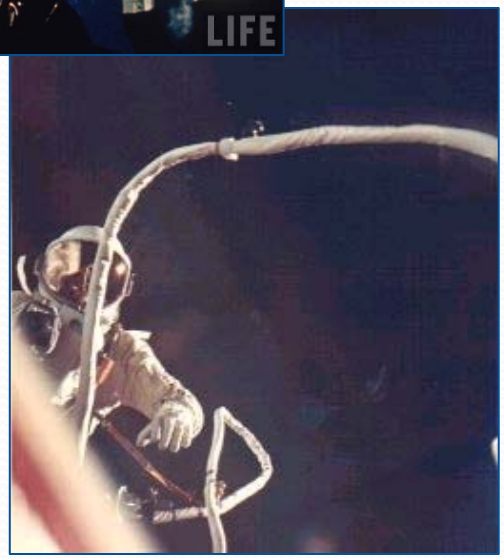
3.5-4 Boilerplate No. 2 in altitude chamber…

3.5-.5 Zero-g flights…

NASA PROGRAM GEMINI WORKING PAPER NO. 5048, MANNED SPACECRAFT CENTER, HOUSTON, TEXAS, MAY 4, 1966, PREPARED BY: Mission Training Section, Mission Operations Branch

Neutral buoyancy's demonstrated value

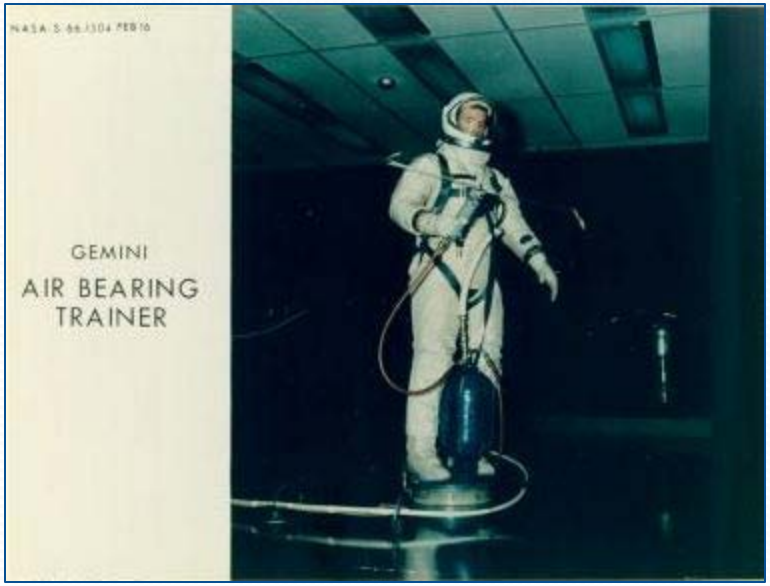
- Neutral buoyancy had demonstrated value in evaluating general EVA problems
  - Contract extension was negotiated at LaRC to broaden scope of simulation
  - Additional contract extensions continued program until July 1966
  - Presentation at NASA facilities, symposiums
- Meanwhile, one Soviet and two American EVAs were undertaken
  - Soviet EVA (Voskhod-2, March 1965) had serious problems not publicized for decades
  - 1st US EVA (Gemini-4, June 1965): brief, lightly-scheduled, successful, deceptive
  - 2nd US EVA (Gemini-9A, June 1966): not successful



NASA TN D-5235, June 1969

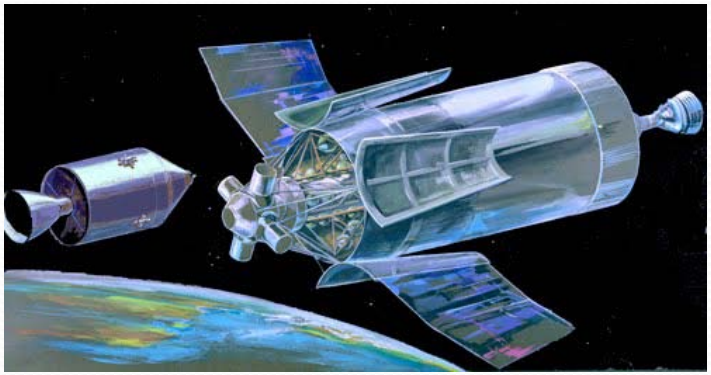
Below the dignity of an astronaut

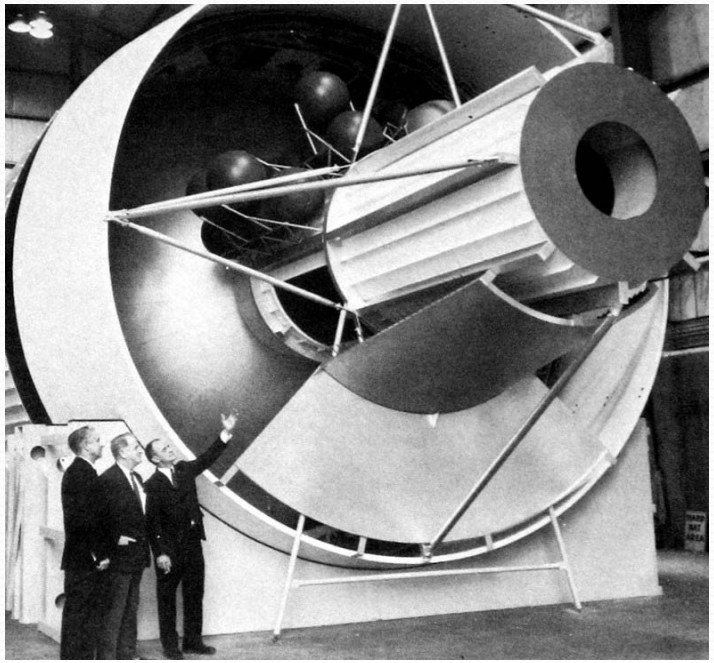
- Nonetheless, NASA planners considered EVA a done deal
  - Astronaut training was expected to be conducted in 0-g on KC-135 and on frictionless air-bearing platforms
- LaRC/ERA neutral buoyancy program was considered interesting but not necessary
  - Gemini Program Office, NASA MSC, not interested in further neutral buoyancy work
    - Underwater training was "below the dignity of an astronaut," according to Kenneth Kleinknecht, Gemini Program Deputy Manager



ERA's Wet Workshop demo

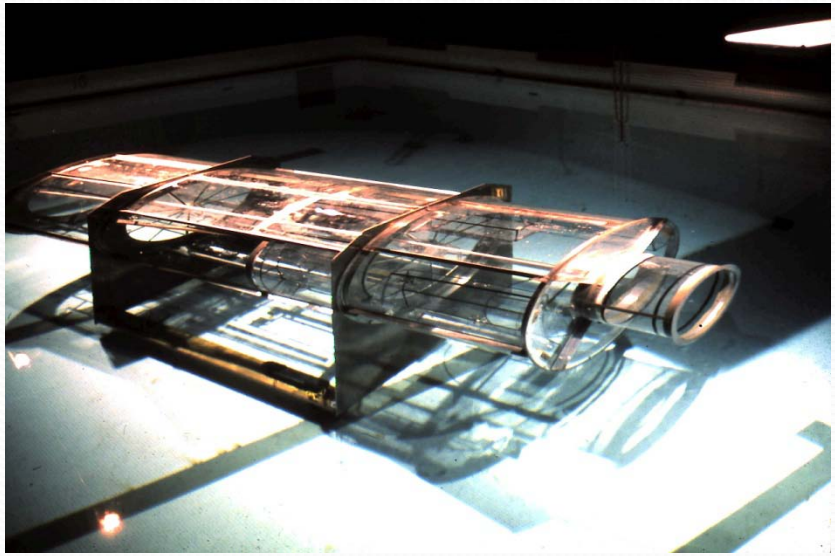
- June 1966: ERA nearing end of contract
  - LaRC not interested in extending
- Loats and Mattingly used last $10K for final demo
  - Test of MSFC proposition to convert SIVB stage into habitable volume by installing airlock in dome of LH2 tank –within 3 orbits!
- Invited all potentially-interested parties
  - NASA LaRC
  - NASA MSFC
  - NASA MSC
  - USAF
- Also June 1966: Gemini-9 EVA difficulties
  - Gemini Program Office took interest in neutral buoyancy for EVA training , encouraged by Robert Gilruth, MSC Director





ERA's Wet Workshop demo pays off

- ERA built aluminum frame mockup of LH2 tank dome and airlock per photo in trade magazine
  - Task included removal of 72 bolts holding dome cover
- Borrowed Black & Decker Torqueless Wrench from USAF
  - Same as MSFC planned to use for SIVB task
- Demonstrated difficulty—if not outright impossibility—of removing dome cover



ERA's Gemini-10 demo

- Don Jacobs, GPO, NASA MSC, observed demo, contacted ERA within days
  - Shipped adapter mockup in Gemini-10 configuration for EVA evaluation
  - Gemini-10: L-2½ wks
- EVA task involved attaching umbilical fitting from maneuvering gun to nitrogen valve on adapter
- June 30 (Thu.) - July 1 (Fri.), 1966: ERA neutral buoyancy simulation showed task doable but would require three hands to complete without incident
- July 18 (Mon.)-21 (Thu.): Gemini-10 mission
  - Mike Collins' EVA experience confirmed simulation
  - EVA task successfully completed

Carpenter's detour to McDonogh

- ~July 22 (Fri.): Shortly after Gemini-10, astronaut Scott Carpenter visited McDonogh unannounced
  - Detoured en route back to Houston from General Dynamics, San Diego
    - Observed GD neutral buoyancy
      - Water-filled pressure suits
    - Intended to recommend GD for future Gemini EVA training support
  - Did not know why detoured

- Donned SCUBA gear, observed ERA diver in Gemini suit attempting dome cover removal task
  - Diver removed only 3 of 72 bolts in 30 minutes (e.g., 12 hr for task)
    - Carpenter : "I can see that he is having trouble, but I can't see why."
  - Donned Gemini suit, attempted the dome cover removal task
    - Removed 1 of 72 bolts in 30 minutes (e.g., 36 hr for task)
- Impressed by difficulty of task and usefulness of underwater simulation
  - Reported to MSC that ERA's work at McDonogh had value

July 25 (Mon.), 1966: Gilruth endorsed ERA

- "I have given a great deal of thought recently to the subject of how best to simulate and train for extra-vehicular activities and have reached the conclusion that **both zero 'g' trajectories in the KC-135 and underwater simulations should have a definite place in our training program**.
  - KC-135 best suited for training in rapid movements between two points
  - **Underwater "far better" for study of positioning, hand holds, and initiation and termination of movements between points**.
- Recommended following actions "immediately":
  1. Astronaut participation in underwater testing at **Environmental Research Associates, Randallstown, Md**. Permit better evaluation of techniques involved, also some immediate testing for Gemini 11 and 12. Particularly important to have White, Cernan and Collins involved in these sims.
  2. FCSD "should **proceed immediately to develop an underwater simulator**. I have some specific ideas on how this should be done and would like to discuss this as soon as possible."

"Underwater simulation of extra-vehicular activity" (memo), from Director [RRG] to "CA/D.K. Slayton", signed "7/25/66".

Neutral buoyancy: 3 questions

3. How did ERA prevail over other early adopters of neutral buoyancy in the aerospace community?

Demonstrated competence and resourcefulness

July 26 (Tue.)-27 (Wed.), 1966: Post flight simulations of Gemini-9A EVA tasks

- Non-astronaut subject wearing one G2C suit provided by MSC
  - Cernan observed from close range and practiced similar tasks in a diver's wet suit and using scuba apparatus
  - 1 day after Gilruth memo!

NASA TN D-5235, June 1969.

July 29 (Fri.), 1966: Cernan post flight underwater simulation of Gemini-9A EVA tasks

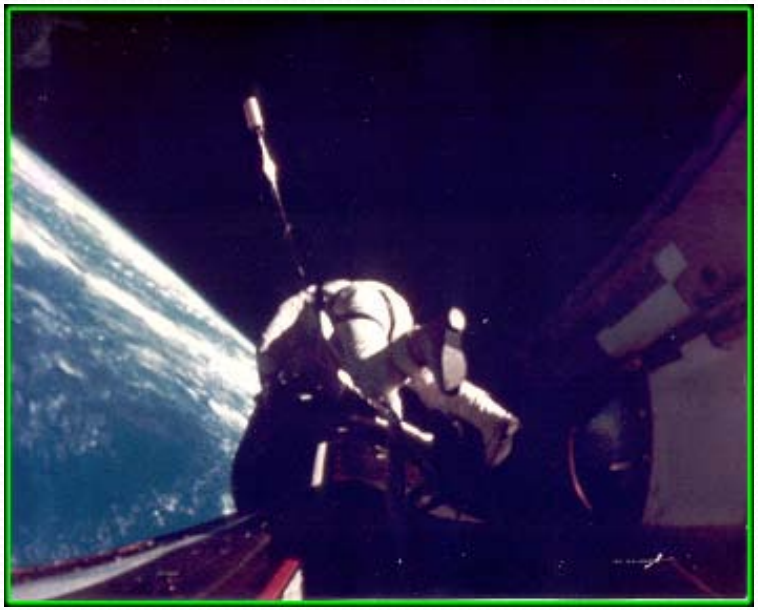
- R+53 days
- Used his G4C training pressure suit
- After observing similar tests performed by non-astronaut test subjects, ERA personnel George Hay and Bruce Tharp
- Noted similarity between neutral buoyancy and space experience
  - Reported simulation had value
  - Not universally accepted that AMU failure on EVA was *not* his fault.

ERA "in like Flynn" in July-August 1966

- 22 July (ca): Carpenter unannounced visit to ERA after being at General Dynamics—**departed impressed**
- 25 July: "Underwater simulation of extra-vehicular activity" (memo), from Gilruth, MSC Director to Slayton, Director, Flight Crew Operations"—**specified ERA**
- 29 July: Letter from General Electric Missile & Space Division, reiterating offer (May 24, maybe?) of neutral buoyancy capability at Virgin Islands
- 15 August: General Electric neutral buoyancy activities in Philadelphia Aquarium in work
- 16 August: MSC establishing on-site neutral buoyancy capability
- 24 August: Gilruth responded to GE: **already working with ERA**, etc.

Aug. 10 (Wed.), 1966: Gemini-11 EVAs simulated (L-33)

- G2C pressure suits
- Experiments included
  - attachment of 100-foot (30.5-m) tether line from Gemini docking bar to Agena target vehicle
  - D-16 power-tool experiment
  - manual work-station experiments at back of Gemini adapter section

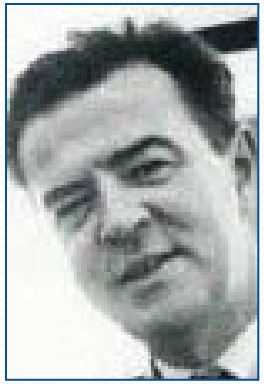


- No time in schedule for Gordon to train at McDonogh
- Motion-picture films of simulation were sent to MSC for review by astronauts prior to their flight
  - Never viewed films, per Gordon (2011)

NASA TN D-5235, June 1969

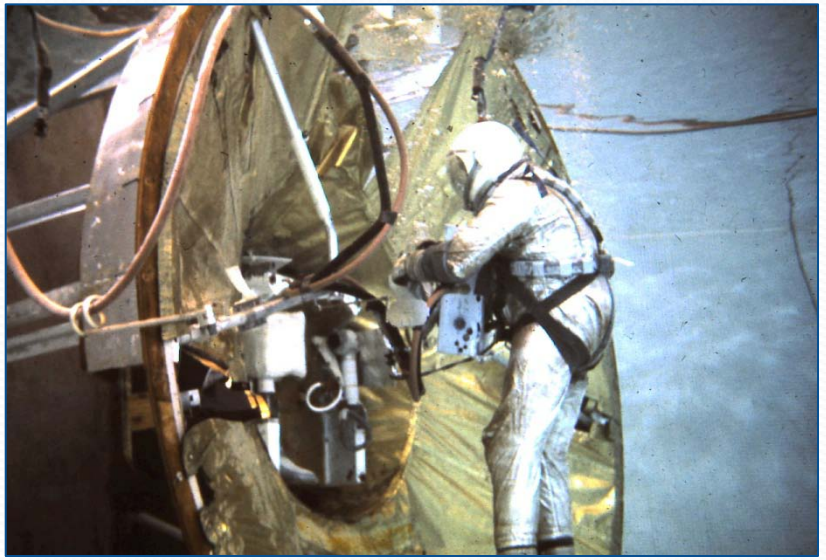
Sep. 11 (Sun.)-12 (Mon.), 1966: Aldrin's first training dives

- Charles Matthews, Gemini Program Manager, had petitioned Dr. Gilruth to have Gemini-12 Astronaut Buzz Aldrin include neutral buoyancy EVA training by ERA at McDonogh
  - Chief Astronaut Alan Shepard opposed adding neutral buoyancy into already-busy training schedule
  - Only relented on direct written orders from Dr. Gilruth
- **Aldrin became first astronaut to train for EVA in neutral buoyancy**



Charles W. Matthews (1968)

Alan B. Shepard (1969)



August 16 (Tues.), 1966: MSC Underwater Simulation Facility

- FCSD, with assistance of Engineering Division
  - Request Crew Systems Division supply necessary pressure suits, including mods, maintenance and suit techs
- Schedule not yet firm (nor was location specified—Bldg. 5??)
  - Tank modest: ~30 ft. dia., 15 ft. high
  - Available in 1-2 months [ca. mid-October-mid-November]
  - Suggest non-critical Gemini suits, or Mercury suits if necessary
- HI Johnson (Adv. Apps. Ofc.) and Louie Richard (Crew Station Branch, Mockup Section) to coordinate Submersion Facility for FCSD
  - Richard coordinates pressure suit requirements, mods.
- "Early tryouts" of mod suits can be made in Recovery Division's 25-ft.-tank in Bldg. 260
  - Arrangements already made to use this tank temporarily on non-interference basis

"Pressure Suit Support for Zero-G Submersion Facility" (memo), from CF/Chief, FCSD [WJN], to EC/Chief, Crew Systems Division, cc CF23/L.G. Richard, EC8/E.M. Tucker, CF/H.I. Johnson.

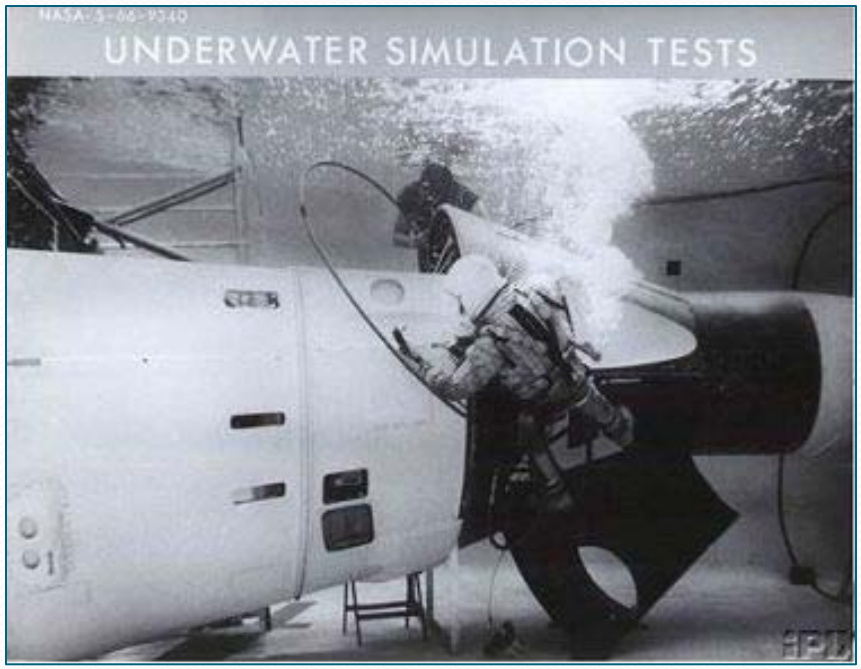
AMU off of Gemini-12

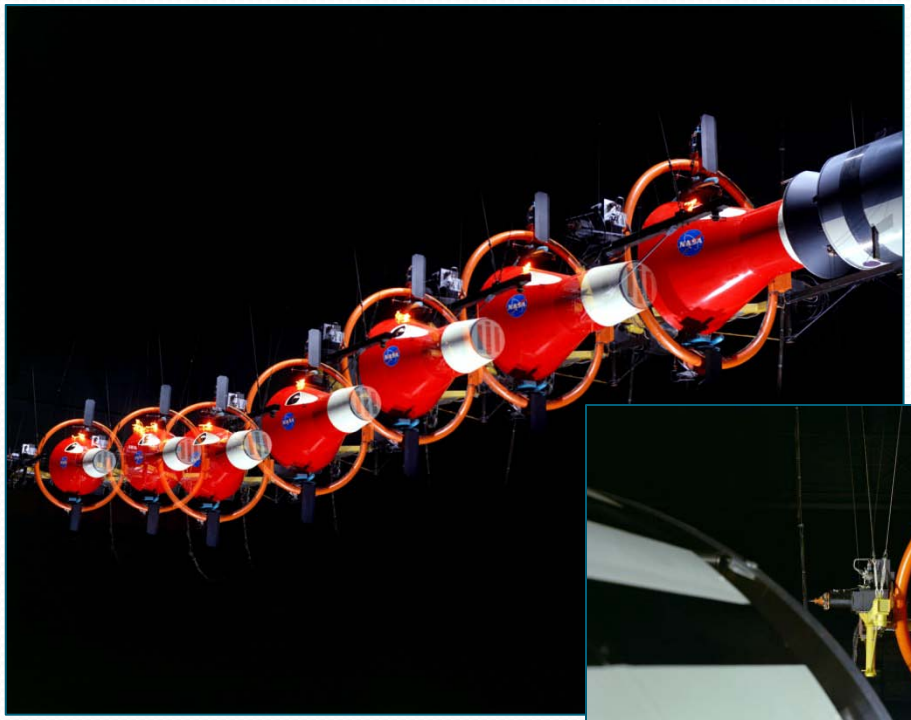
- Sep. 12 (Mon.): Aldrin training at McDonogh on Gemini-11 launch day
  - Break in preparations so Aldrin could watch on TV while suited, standing in 4-ft-deep area
  - Then proceeded with evaluation of AMU per original Gemini-12 EVA plan
  - Confident that task was doable, some restraints and hardware already redesigned, upgraded from Gemini-9
- Sep. 13 (Tues.): EVA Review Board was briefed on AMU at its first meeting
  - Gordon difficulties in-flight
  - AMU was dropped from Gemini-12

Figure 7.3-3. - Underwater simulation of AMJ preparations.

Aldrin's preparations

- Final version of Gemini-12 EVA hardware was incorporated into simulator

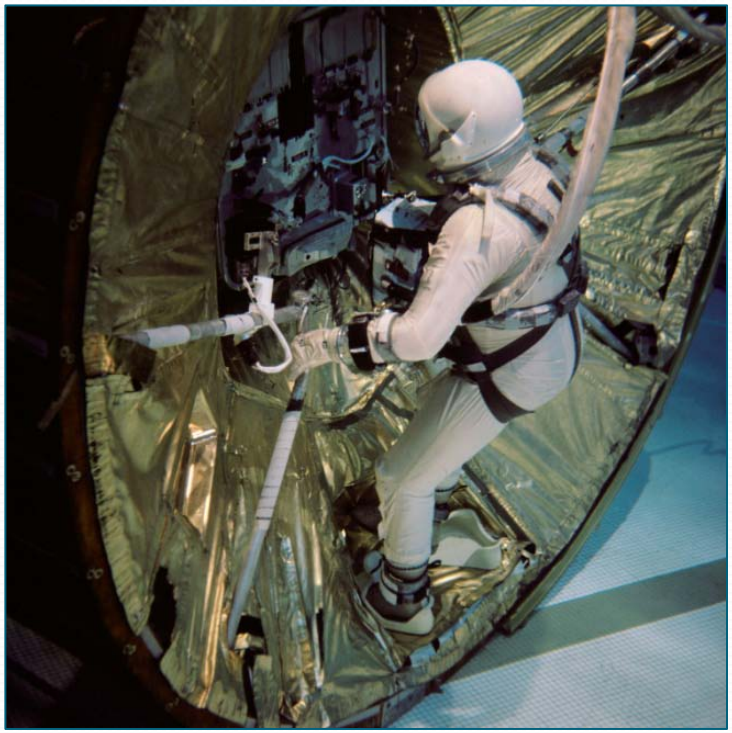


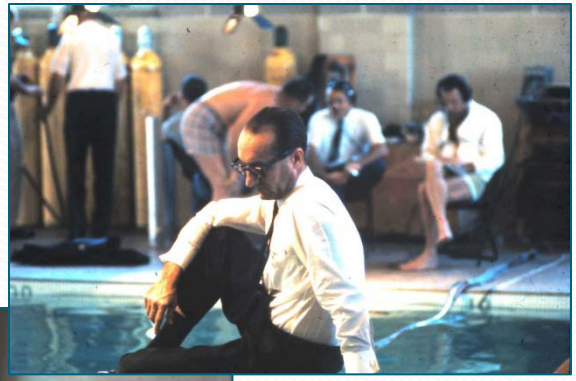


Gemini-Agena docking trainer, LaRC (1962-1964)

Aldrin's success

- Final version of Gemini-12 EVA hardware was incorporated into simulator
- Aldrin returned for additional training sessions
- Some sessions included astronauts Gene Cernan and Jim Lovell, Gemini-12 Command Pilot (unsuited) in radio contact with Aldrin underwater
- Observing NASA officials from Headquarters included George Mueller, Bill Schneider, and several others
- Aldrin's Gemini-12 flight EVA was considered totally successful



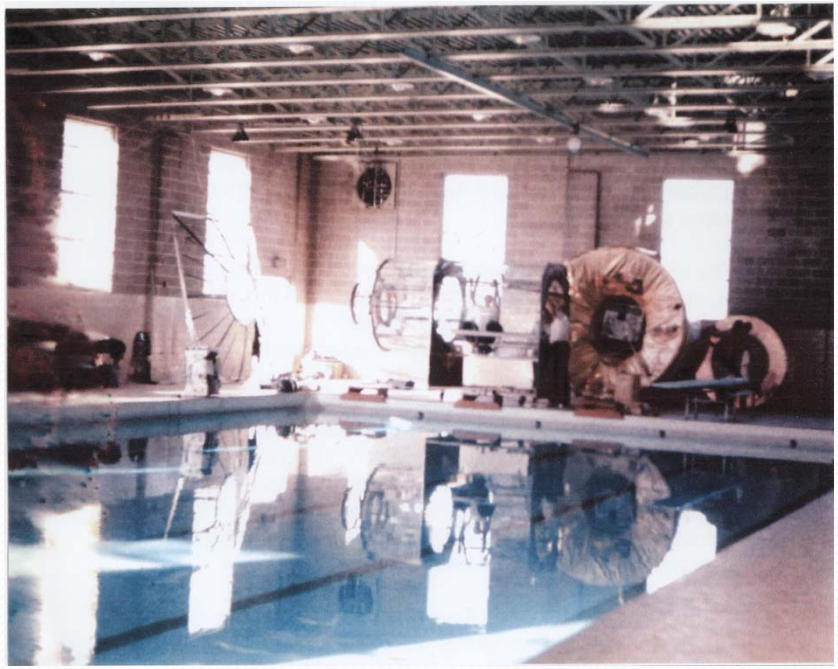


Why ERA?

- During this period major aerospace firms began studying neutral buoyancy simulation
  - Ellington AFB near MSC had a pool that was being used to practice egress from the Gemini capsule after splashdown
- Matthew's decision to request inclusion of neutral buoyancy training for Gemini 12 was engineering decision supported by human factors study
- Decision to use ERA/McDonogh facility probably resulted from consultations with astronauts Scott Carpenter and Gene Cernan
  - Carpenter
    - Recognized underwater expert within NASA for SEALAB
    - Had visited other aerospace firms (GD, GE) before ERA
  - Cernan first visited ERA after Gemini 9, at request of Dr. Gilruth.
- Probably not an easy decision
  - ERA was a very small firm with fewer than a dozen employees
  - Using rented pool on part-time basis
  - However, ERA had advantages
    - Two years experience in neutral buoyancy simulation
    - Produced comprehensive report

McDonogh's travails and ERA prevails

- Training sessions and equipment required flexibility from McDonogh and ERA
  - Gemini simulation equipment
    - Assembled in pool building
    - Removed from pool to deck at end of each session
    - Left on pool deck when not in use
  - Some sessions were conducted overnight
- ERA installed overhead handling structure
- ERA revised breathing air supply using ~40 "K" bottles also stored on pool deck
- Water temperature was 70°F
  - ERA restricted safety divers to 30-minute shifts to avoid hypothermia
- Additional divers were hired, trained in suit operation, maintenance
- At one point, in order to submerge entire mockup, water level was raised 14 inches by stopping up pool scuppers
- Three more Milliken cameras were submerged, ganged for continuous filming, each providing 12 minutes of coverage before it was hoisted out of water for film changing
- For color film of EVA simulation
  - 28-volt generator was brought in from Andrews AFB
  - group of landing lights was submerged
- Initially: couple of morning hours couple of days a week for 4-5 people
- Eventually: 15 ERA people and 15 visitors working 4-5 hr at a time.
- The McDonogh School managed to survive, and ERA established basis for future EVA training without ever competing for another contract.



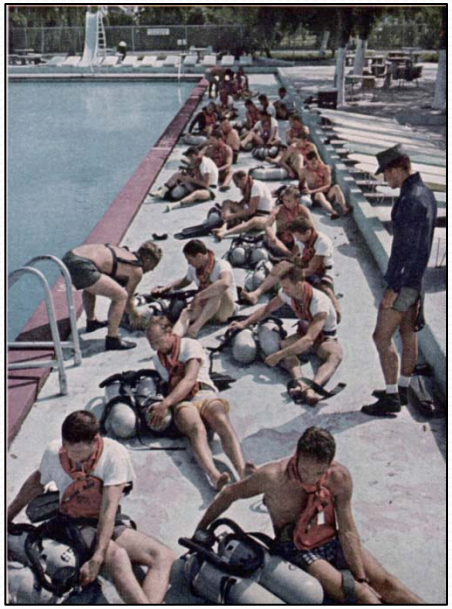
NASA's embrace of neutral buoyancy

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

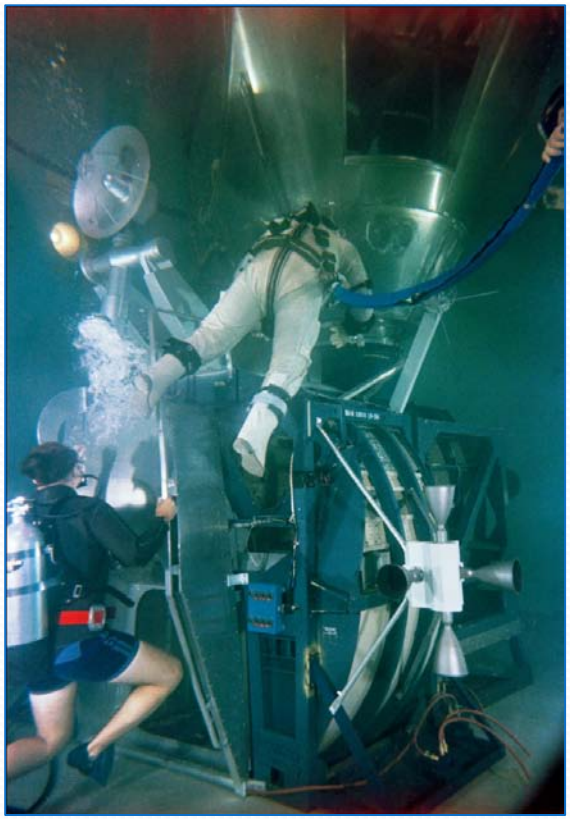
Carpenter,
1964: Cousteau at MIT
1964: Sealab I
1965: Sealab II



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

Rapid adoption of neutral buoyancy by mainstream NASA

1967: simulated contingency EVA transfer from 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.

Maybe it did, maybe it didn't

- At conclusion of Gemini program, mixed feelings about neutral buoyancy simulation
  - 1/3 of people involved said "I always knew that it was the right way to go"
  - 1/3 felt that it was useful but that restraints and handholds were more important
  - 1/3 felt that neutral buoyancy had nothing to do with success or failure of EVA, and that it was entirely result of restraints and handholds

Maybe it did, maybe it didn't

- New restraints, procedures
  - 12 mobility aids added to Gemini-12 following Gordon's Gemini 11 difficulties
    - 8 had not flown before in space
  - Gemini-12 included relaxed SEVA designed to let Aldrin become accustomed to suit, equipment prior to more demanding full-emergence EVA
- Underwater simulation
  - Duplicated actual extravehicular actions, reactions with high degree of fidelity
  - Any task which could be accomplished readily in underwater simulation would have high probability of success during actual EVA

Summary of Gemini Extravehicular Activity, NASA SP 149, 1967

Everybody gets a water tank

- Underwater training was judged to be sufficiently important to success in EVA that water tanks for astronaut training and procedures development soon appeared at several NASA and contractor facilities, and eventually in other countries as well.

Neutral buoyancy: the second wave

Dates of use	Location	User	IVA? (wetsuit)	EVA?		Notes
				W	A	
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, 1967-1980?	NASA MSC (Hangar 135) Bldg. 260, then Bldg. 5	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 O-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.

Neutral buoyancy: the third wave

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**

Techniques and personal equipment requirements

Water- or air-filled 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

Postscript

In early December 2009, Mattingly visit NBL to see how operations were conducted and to see what differences there were from ERA experiences in the McDonogh pool.

He met Chris Cassidy and Akihiko Hoshide before their EVA sim at submerged ISS mockup, and talked with technicians and divers particularly pleased with rapport.

NBL Director Ron Lee gave him NBL challenge coin #114. It is a marker on long road connecting routine work today with his early efforts almost half a century ago.

Almost Annual ERA Reunions

- August 2012: Mattingly, wife Nancy and son Randy, invited three ERA divers to meet JBC at his home in Ocean Pines, MD, for a small Eastern Shore crab feast.
- August 2013: Mattingly family invited 3 divers, JBC and Smithsonian Institution curator Mike Neufeld (plus wives) for a slightly larger crab feast.

Life imitates sim imitating life

July 16, 2013: EVA-23 terminated due to Parmitano EMU issue

- 2nd EVA within 1 week for Chris Cassidy (NASA) and Luca Parmitano (ASI) was terminated when water started to accumulate in Parmitano's helmet.
- Significant quantity of water , from unknown source, quickly became concern as it was entering Parmitano's eyes, nose, and mouth, so ISS flight director terminated EVA early.
- Parmitano headed straight back to Quest Airlock, while Cassidy grabbed EVA bags before returning to airlock himself to begin repress, with Luca no longer able to hear any communications due to water in his helmet.

  (July 16, 2013, Pete Harding , NSF.com)

Selected references

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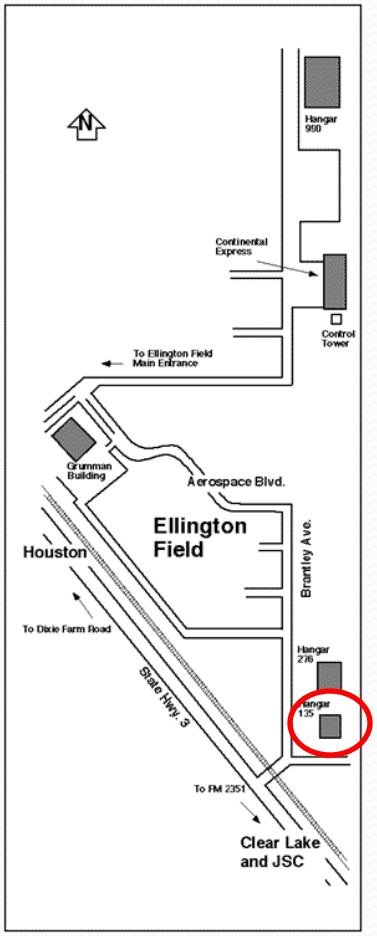
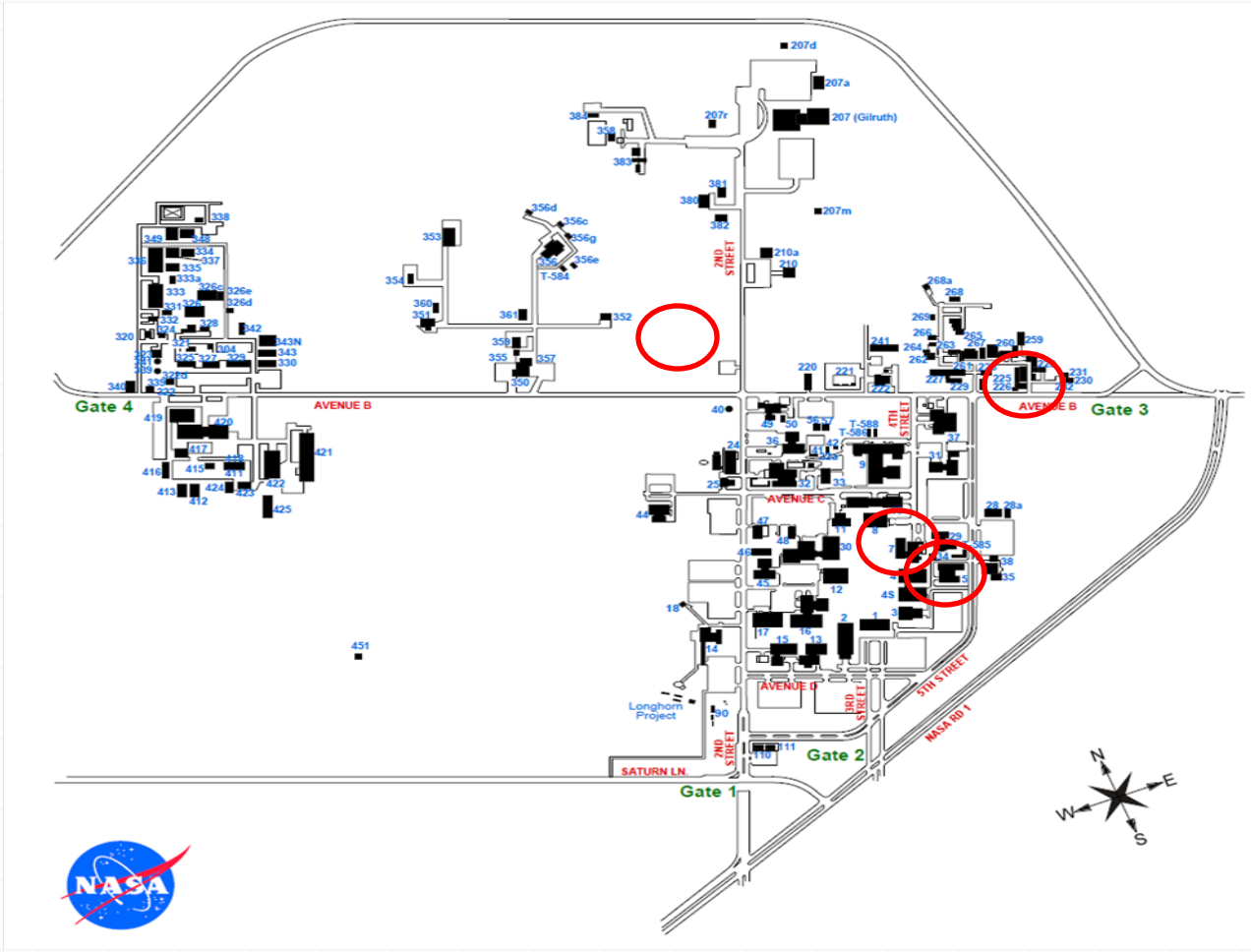
- Simulation of Gemini Extravehicular Tasks by Neutral-buoyancy Techniques, NASA TN D-5235, June 1969, Otto F. Trout, Jr. (LaRC), Gary P. Beasley (LaRC), Donald L. Jacobs (MSC) http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690018646_1969018646.pdf.

Add NBL

MSC-JSC Immersion Facilities





Synopsis

- An attempt to clarify some vague memories of underwater studies of astronaut capabilities in space led John Charles to an acquaintance with Sam Mattingly, one of the pioneers in the field, and to greater insights into Sam's work simulating Gemini EVAs in the mid-1960s. This lecture will recount major accomplishments by Environmental Research Associates (ERA), Mattingly's company for contracting with NASA Langley on several early studies. ERA's work will be considered within the context of contemporary efforts to simulate weightlessness and the widespread development of neutral buoyancy facilities after ERA's successful demonstration for Gemini 12.

Biography

- 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. John earned his B.S. 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 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 Shuttle flight and on STS-107, Columbia's last mission in January 2003. Dr. 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 US/Russian one-year mission on 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.