

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

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

This synopsis provides information about the Knowledge Capture event below.

Topic: Launch, Entry & Abort, Intravehicular Spacesuits (presentation)

Date: April 10, 2013 **Time:** 3:30-5:00 pm **Location:** JSC/B5S/R3204

DAA 1676 Form #: 28501

The paper, CTSD-SS-3522 (DAA 1676 #28501)* can be found either on the DAA system or on the EC Share: \\139.169.94.174\data\EA\EC_SHR\Knowledge-Capture\FY13 Knowledge Capture\20130410 Thomas_LEA-Intra-Vehicular Spacesuits

Assessment of Export Control Applicability:

Ken Thomas' presentation of *Launch, Entry & Abort, Intravehicular Spacesuits* to "all" attendees will await the assessment of the export control reviewer. If required, attendees will be limited to authorized personal only.

It is requested the presentation 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 and the paper, *Launch, Entry & Abort, Intravehicular Spacesuits - CTSD-SS-3522*.

*The paper has been submitted separately for an export control review.

Presenter: Kenneth S. Thomas

Synopsis: Kenneth Thomas, senior spacesuit expert, will present information about Launch, Entry & Abort (LEA) spacesuits – part of an overall vehicle crew escape and survival system. These LEA spacesuits are worn during the launch and reentry to enhance crew survival. The U.S. has traditionally called these spacesuits Intravehicular Activity (IVA) spacesuits. The Russians refer to this type of spacesuit as "Rescue Suits." Thomas will discuss the success of the LEA suits and the consequences of eliminating their use or providing inadequate systems.

Biography: Kenneth S. Thomas is a second-generation space engineer who grew up with space exploration from Sputnik to Apollo. Thomas graduated cum laude with a bachelor's degree from Central Connecticut State University and worked over four decades in commercial, defense, and space industries. In 1989, he became a contractor engineer and task manager on the Shuttle Extravehicular Mobility Unit program. To develop his expertise in this area, he conducted hundreds of hours of unpaid research interviewing scores of individuals from many organizations who were directly involved in development of spacesuits, from the beginning to what was then current. Thomas also reviewed documents from that period to provide further insight and validate interview results. He became a consultant to the National Air and Space Museum's Space History Division starting in 1993. In supporting quests for information from national spacesuit historians, he gained access to even greater

documentation, interview information, and insights over the years. He additionally served as principal investigator or key technical support engineer on Lunar-Mars suit efforts for over 15 years. These experiences have culminated in a unique set of qualifications for this educational knowledge capture event.

EC5 Spacesuit Knowledge Capture POCs:

Cinda Chullen, Manager

cinda.chullen-1@nasa.gov

(281) 483-8384

Rose Bitterly, Administrator

rose.bitterly@nasa.gov

(281) 461-5795

Vladenka Oliva, Technical Editor (ESCG)

vladenka.r.oliva@nasa.gov

(281) 461-5681

U.S. Spacesuit Knowledge Capture Launch, Entry & Abort, Intra- Vehicular Spacesuits

Presented by Kenneth S. Thomas

April 10, 2013



Cover Illustration Courtesy of Dr. Pascal Lee SETI Institute

Use of illustrations in this presentation that were provided by outside organizations or parties as noted by "Courtesy of ..." does not constitute a relinquishing of ownership of the illustrations by those outside organizations or parties. Copy or reuse of such illustrations is forbidden except by written permission of the rightful owners of the illustrations.

Launch, Entry & Abort Suits

1. What Are LEA Suits?
2. Why Do We Need LEA Suits?
3. Russian Soyuz Suits
4. Non-LEA Intra-Vehicular Suits
5. U.S. Non-suit Approaches
6. U.S. IVA Suits Flown
7. U.S. 8 PSI IVA Prototypes
8. New U.S. LEA Suit Competitors
9. Chinese Shenzhou VI Suits
10. Insights & Considerations

What Are LEA Suits?

- Part of an overall vehicle crew escape and survival system
- Worn during the launch and reentry to enhance crew survival
- U.S. traditionally called these IVA spacesuits
- Russians (and, as of 2013, Chinese) call this type of spacesuit a “Rescue Suit”

Why Do We Need LEA Suits?

- Cabin depressurization
- Contaminated surrounding atmosphere
- Protection in a water splashdown – crewmember (CM) must remain buoyant until rescued:
 - During second Mercury flight, Gus Grissom almost drowned before being rescued
 - Russian and Chinese spacecraft can splashdown in water during off-nominal returns
 - Gemini and Shuttle Crew Escape Systems (CES) provided parachutes making water splashdown possible
- Off-nominal or emergency escape could leave CMs in harsh or remote areas

Why, cont.

- Space is hostile, unforgiving place
- Limited volume and mass allowances add to the safety challenges
- Murphy's law: What can go wrong, will go wrong – every possible escape from the normal process must be considered and every consequential risk mitigated

Russian LEA Suits - Past



The World's First Spacesuits, The Soviet SK-1 & SK-2 (1961-63) (Courtesy Zvezda)



The Soviet SOKOL-K Suit (Courtesy Vassili Petrovitch/Wikipedia)

Current Russian LEA: SOKOL-KV-2



Description:

- Soft garment w/a 2-layer enclosure (outer restraint layer is fabric and the internal pressure bladder is rubber or a rubberized material).
- RD&PE Zvezda of Tomilino Russia designed and manufactured this suit.
- Helmet has soft nape part and sliding visor; is an integral part of the suit enclosure.
- Differences between SOKOL-K and SOKOL-KV-2:
 - Lacing on front opening was replaced w/2 zippers
 - Helmet and visor dimensions increased
 - Pressure regulator was relocated on garment under helmet (it is located at the side on the SOKOL-K suit).
- If cockpit depressurization occurs, pure oxygen is supplied to the suit. The pressure regulator provides 2 suit pressure modes.

Chronology: Development and tests: 1973-1979. Nominal operations: 1980 to the present (as of 2013). Technical characteristics:

Suited crew stay in a pressurized cabin:	Up to 30 hrs
Suited stay in a depressurized cabin:	Up to 2 hrs
Nominal operating pressure:	5.9 psi (40.0 kPa)
Backup mode operating pressure:	3.9 psi (27.0 kPa)
Primary life support:	Vehicle-provided
Life support, backup:	PSA carried, 10 min.
Spacesuit mass:	22 lbs (10 kg)

Quantities manufactured (December 31, 2002): Test and training models = 63; flight models = 220.

SOKOL-KV-2, The Current Russian LEA Spacesuit
(Courtesy Gary Harris)

Non-LEA Intra-Vehicular Suits

- Has more experience in space than U.S:
 - The 18 humans w/the most time in space are all Russian
 - The 2 Russian cosmonauts have > twice the time in space as the most space-experienced U.S. astronaut
 - Russia's experience w/0-g produced 2 IVA suit systems exclusively for orbital use:
 - Penguin mechanical counter pressure suit
 - Chibis negative pressure suit

Non-LEA Intra-Vehicular Suits, Cont.

“Penguin” Suit:

- Earth’s gravity compresses spine and effort to overcome gravity or resistance to gravitational forces comprises the majority of human exercise.
- Prolonged periods in 0-g = substantial loss of muscle function, calcium loss in bones, and potential distress from spinal elongation (vestibular discomfort).
- In 1975, Zvezda’s Aeromedical Dept. started development of a Prophylactic Body-Loading or Penguin Suit.
- Penguin Suit started flight service on Salyut 6 in 1978. Improvements followed.
- In 1990-91, Penguin-3 configuration was tested on Salyut 7 and then was used on the Mir.

Non-LEA Intra-Vehicular Suits, Cont.

Penguin Suit, continued:

- Penguin-3 could load the body axially in compression to simulate gravity loads on a vertically oriented body and simulate gravitational loading on opposing pairs of flexor-extensor muscles.
- Suit's axial tension members are set to produce zero tension when the body is in the 0-g neutral position.
- Loads are induced when the spine is bent forward, backward, or sideways, but not when the shoulders are rotated in a plane perpendicular to the spine.
- Loads are induced in the legs when the thighs are rotated or legs are crossed.
- Calf muscles are loaded when the ankles are extended downward as in stepping forward.
- Penguin-3 had headgear to reduce vestibular discomfort encountered during first 3 days of space flight.



**Hamilton Standard's Dick Wilde
Demonstrating
The Penguin-3 Suit
(Courtesy HS)**

Non-LEA IVA Suits, Cont.

Penguin Suit, continued:

- Was worn on Mir continuously for all activities except exercise. For flights <31 days, no additional exercise w/exercise equipment was needed (according to Zvezda).
- For 1-3 months, normal movement in 0-g, plus light exercise (e.g., 5-10 minutes of simulated bicycle riding 6-8 times a day) produced bone and muscle loading to maintain calcium levels and muscle/cardiovascular conditioning.
- For \geq 6-month flights, ergometer exercise periods were added. Zvezda claimed cosmonauts in Penguin-3 returned to Earth in significantly better condition.
- Was worn over a full torso, 2-piece undergarment. The material was light and smooth like rayon. Lightweight socks were worn. In flight, underwear was changed every few days.
- It remained hygienically acceptable for > 1 month. Replacement clothing was provided on Progress resupply vehicle.

Non-LEA IVA Suits, Cont.

Chibis Negative Pressure Suit:

- Earth's gravity draws body fluids to the lower portions of the anatomy, specifically legs and feet. The heart pumps the blood back up and through the rest of the body as part of normal circulation.
- In 0- or micro-g of space, body fluids remain evenly distributed. The body's sensing mechanism for fluid control is in the head. Sensing the greater percentage of fluid in the upper portion of the body, the body rids fluid to adjust to 0-g. An increase in blood affluxion to the head and decrease in blood supply to the legs are natural under 0-g conditions and are normal in space.
- It is the opposite conditions in the human body in a vertical position in Earth gravity. Immediately after landing, such conditions can impair both function and judgment.
- For the Space Shuttle's short stays in space (7-10 days), U.S. astronauts drank fluids immediately before reentry. For longer stays (e.g., 6 months or more on Mir), the re-adjustment process is more difficult.

Non-LEA IVA Suits, Cont.

Chibis Suit, continued:

- Aeromedical Dept. at Zvezda developed it for Salyut 6 to prepare cosmonauts for optimal function immediately upon return.
- Has special lower-body negative-pressure that pools the blood in the lower body to simulate the ground conditions for the cardio-vascular system. A few weeks before return to Earth, usage of the Chibis on the orbiting space station allows crew to mitigate effects of months in 0-g and train the CM's cardio-vascular system for return to Earth.
- It is a half suit, comes in one size. It covers from the waist down and has an aluminum waist closure, two accordion-like leg assemblies, two aluminum boots, and a vacuum pump. Leg assemblies adjust in length. Vacuum pump connects to waist closure via a hose.
- In 1993, Hamilton Standard (HS) facilitated NASA acquisition of a Chibis.



The Chibis Negative Pressure Suit
at HS Before NASA Delivery
(Courtesy HS)

Non-suit Approaches



Personal Rescue Enclosure
(Development 1977-79, never flown)



Launch/Entry Helmets
(Flown 1982-86)

Personal Rescue Enclosure

Personal Rescue Enclosure (PRE): for rescue of non-suited CMs in stranded Orbiter:

- Used w/Portable Oxygen System
- 5 were to be carried as rescue kit
- Several configurations studied; 34” diameter spherical shape selected
- Time to get rescue orbiter launched was prohibitive given the nominal 7-10-day capacity of the original orbiter configuration
- PRE still used in astronaut screening
- Lesson learned: PRE capacity never validated

Launch/Entry Helmet

- Down to an ambient pressure of 3.3 psia (22.8 kPa), head enclosure of the Launch/Entry Helmet (LEH) provided an O₂ environment that had effective alternative to a pressure suit
- Below an ambient pressure of 3 psia, loss of function and loss of crew would result (could not support high altitude egress)
- Post-Challenger safety improvements replaced the LEH with a pressure suit system

U.S. Program IVA Suits



**X-15
Program
(1954-68)**



**Mercury
(1959-63)**



**Gemini VII ²
(1966)**



**Ejection
Escape
Suits ³
(1981-82)**



**Advanced
Crew
Escape
Suit ³
(1990-2011)**



**USAF X-20 ¹
(1958-63)**



**Gemini III
(1965)**



**Apollo Block I ²
(1965-67)**



**Launch Entry ³
Suit (1987-95)**

Courtesy: 1) Gary Harris, 2) Praxis/Springer Publications, 3) David Clark Company

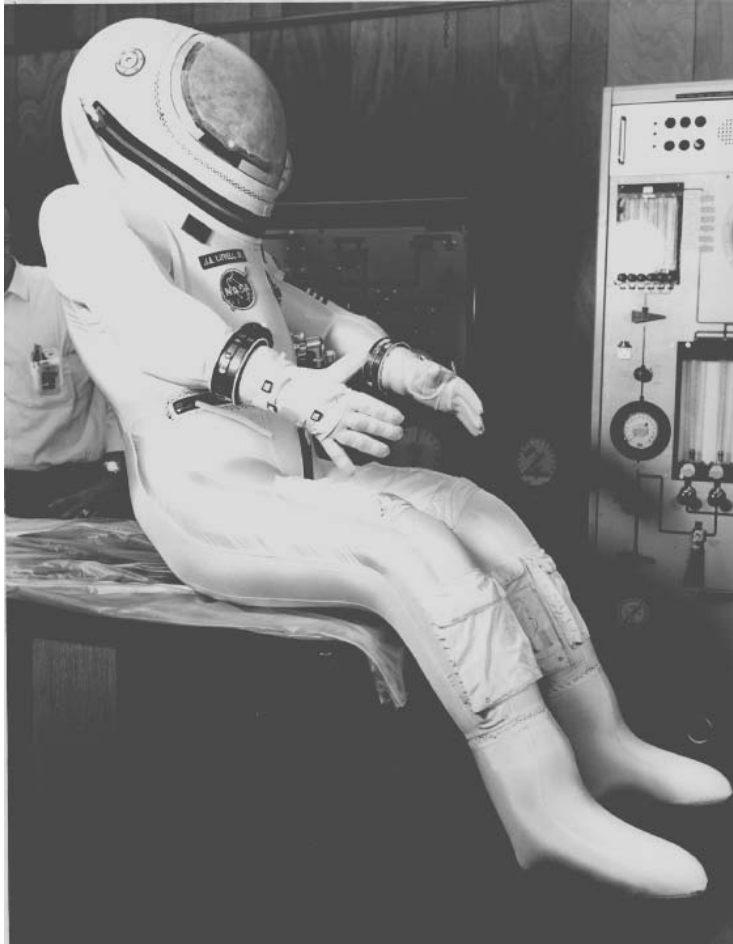
U.S. Characteristics

- Weight* Range: 16-55 lbs (27 lbs avg.)
Operating pressure: 2.7-3.5 psid
- High altitude pressure suits adapted for NASA use to minimize development time and cost
- Rescue Devices:
 - On-Suit Floatation Systems
 - Parachutes (Gemini & Shuttle)
 - On-suit flairs, dye markers, etc., (Shuttle)

*Weight is w/o rescue equipment

U.S. Lightest - Gemini G5C Suit

GEMINI VII G5C IVA SPACESUIT



**The Gemini Light-Weight G5C Suit
(Courtesy Gary Harris)**

Description:

- David Clark Company (DCC) designed and manufactured this spacesuit.
- It had a parachute/floatation harness system.
- It could provide atmosphere retention during vehicle decompression to enhance crew survivability.
- It was lightened w/as many hard parts removed as possible to enhance astronaut comfort for the Gemini VII 206 orbit/14-day mission.

Chronology: Development of this suit-system started April 1965 and was based on G4C. The system flew December 1965.

Technical Characteristics:

Operating Pressure (Nominal):	3.7 psi (25.5 kPa)
PGA Weight @ 1-g:	16 lbs (7.2 kg)
LSS, Primary:	Vehicle-provided
LSS, Backup:	Vehicle-provided

Quantities Manufactured: At least 11 G5C suits were manufactured. 2 were flown.

U.S. Lightest, Cont.

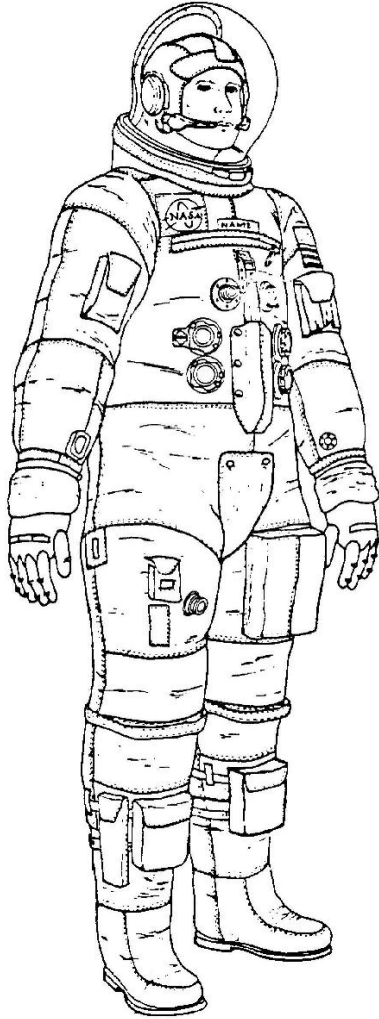
The David Clark Gemini G5C used a “Linknet” restraint system like the Gemini G3C shown below.



Linknet Restraint System
(Pictures Courtesy HS)



U.S. Heaviest LEA (IEVA Modified For IVA)



Apollo 7 & 8 (1968)



Apollo-Soyuz Test Project (ASTP) (1969-75)

Group Characteristics

- Weight* Range: 53-55 lbs
- Operating pressure: 3.7 psid
- IEVA pressure suits used for IVA applications by NASA to eliminate development time and cost

Rescue Devices:

- On-Suit Floatation Systems

*Weight is w/o rescue equipment.

Latest U.S. Flight System

Shuttle Crew Escape System with Advanced Crew Escape Suit

SHUTTLE ADVANCED CREW ESCAPE SUIT



Description:

- ACES Model S1035 began being delivered in 1994; used as part of the CES.
- Unlike the LES, ACES is a full-pressure system, lighter and more comfortable than the LES.
- ACES is an exclusively IVA spacesuit.
- Designed and manufactured by DCC, Worcester, Massachusetts.
- Suit-system has parachute and floatation systems to enhance crew survivability.

Chronology: Development and tests:

- Development started in 1990 as planned replacement of an expiring existing system and had the adaptation of U.S. Air Force Model S1034.
- ACES began flight service in 1994 becoming exclusive Shuttle IVA suit-system by end of 1995. Service ended w/Shuttle flights in 2011.

Technical Characteristics:

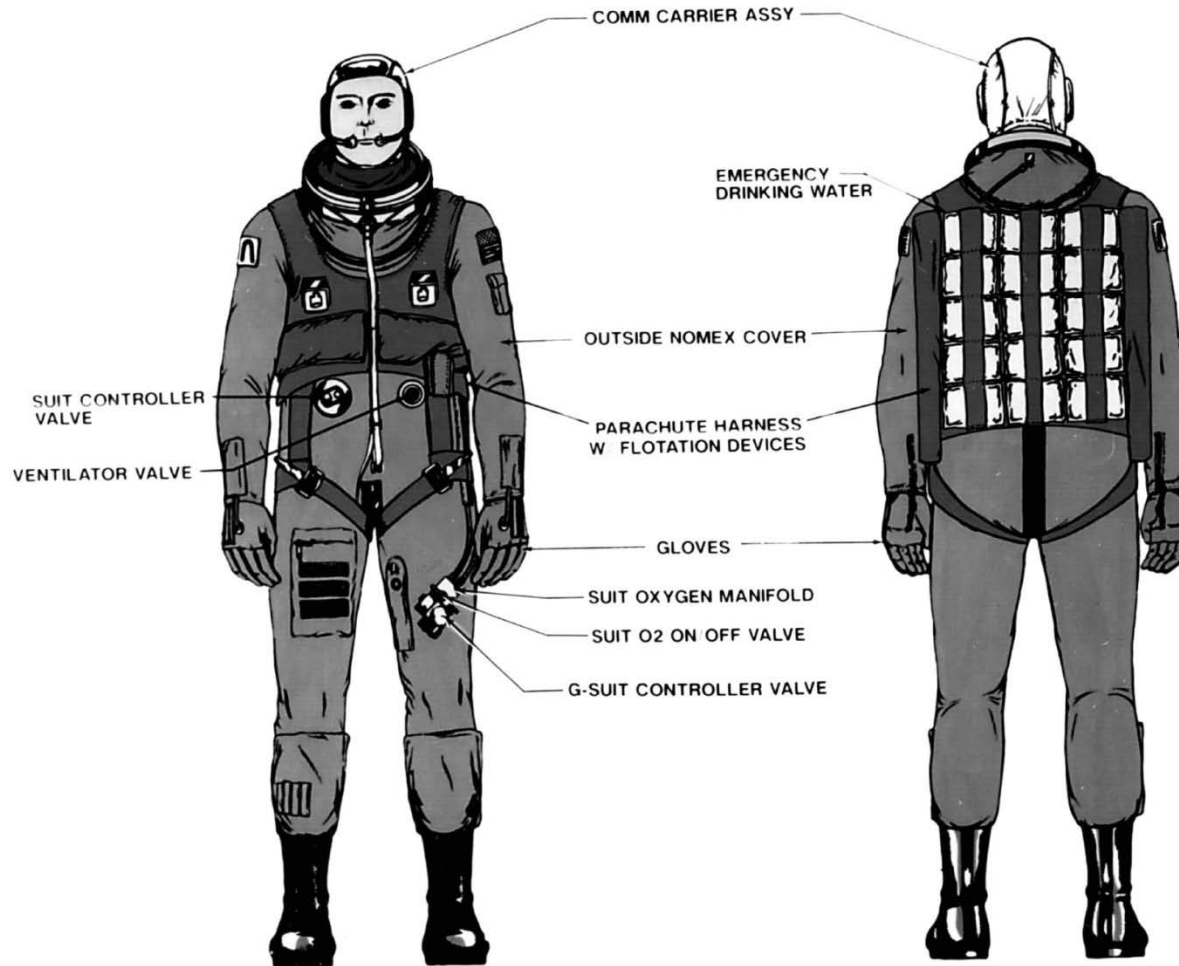
Operating Pressure (Nominal):	3.5 psi (24 kPa)
“Suit” Weight @ 1-g:	28 lbs (12.7 kg), approximately
Parachute & Survival Systems:	64 lbs (29 kg), approximately
Life Support, Primary:	Vehicle-provided
Life Support, Backup:	PSA carried, 10 min.

Quantities Manufactured: For the Shuttle Program, 70 ACES delivered.

**The ACES w/o Additional CES Items
(Courtesy DCC)**

Crew Escape System/Advanced Crew Escape Suit, Cont.

CREW ESCAPE EQUIPMENT

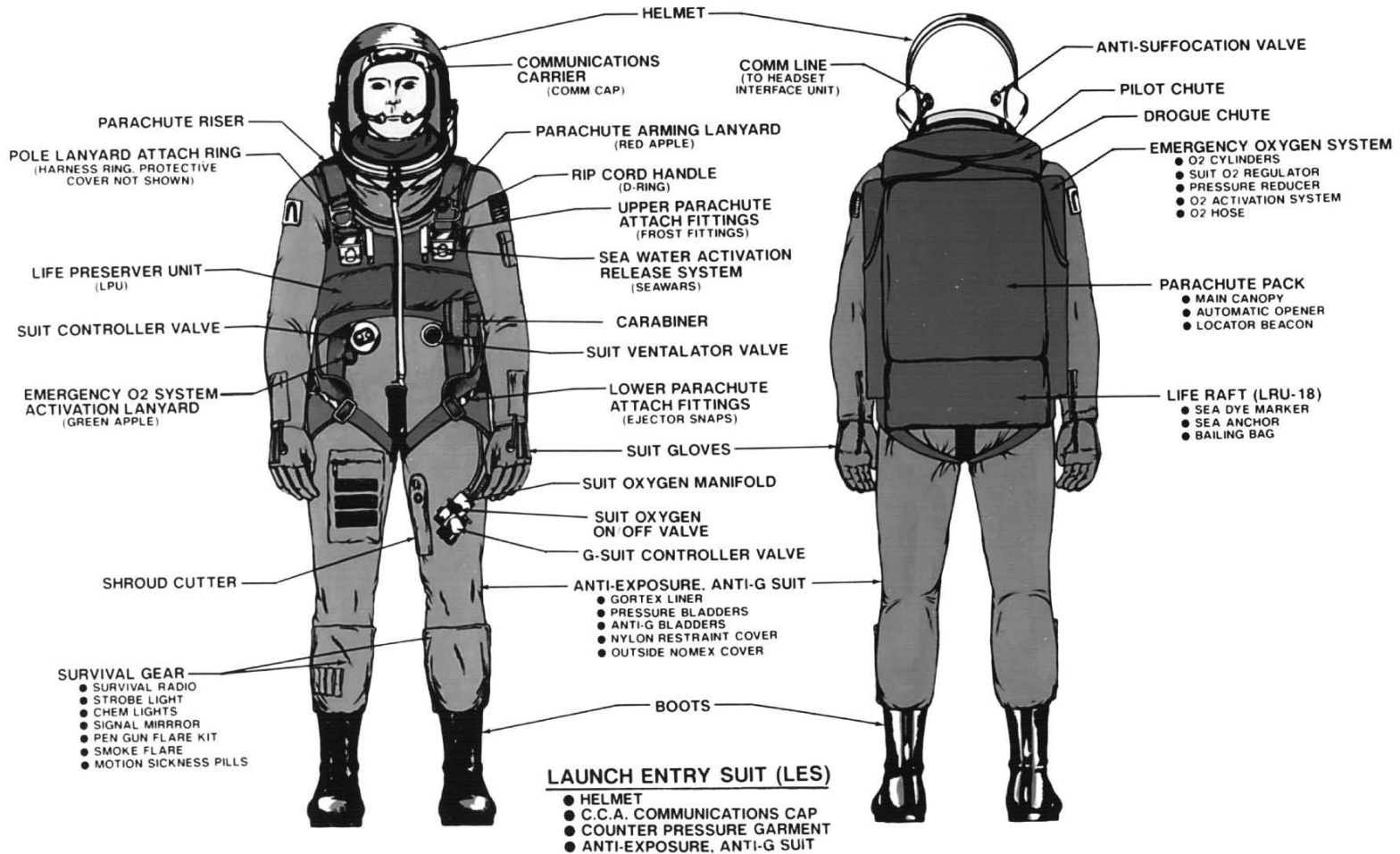


CES Harness & Floatation Devises

Note: Shown w/earlier Launch Entry Suit

Crew Escape System/Advanced Crew Escape Suit, Cont.

CREW ESCAPE EQUIPMENT



The Complete 1987-1995 Shuttle CES
 Note: Shown w/earlier Launch Entry Suit

Crew Escape System/Advanced Crew Escape Suit, Cont.



Above - ACES Continued the X-15/Gemini-Developed Linknet Restraint System in the Upper Torso (Courtesy DCC)

Right - ACES had the Parachute Interface Integrated into the Pressure Garment



Crew Escape System/Advanced Crew Escape Suit, Cont.



The ACES Pressure Garment had an Integrated "Mae West" Flootation System and Carried a Raft (Both Shown Deployed)

U.S. 8 PSI IVA Prototype



1972 ILC 8 psi Prototype
(Courtesy ILC Dover LP)

Characteristics

- Weight:* 21 lbs
- Operating pressure: 8 psid (55 kPa)
- During Apollo, U.S. research indicated 8 psi operating pressure was required to support reasonably rapid decompression from a 14.7 psi (1 atm) cabin pressure w/o risk of decompression sickness (DCS).
- In 1972, NASA funded ILC for an emergency IVA prototype w/reliable, fast closing, low leakage entry/closure system designed to operate at 8.0 psi (55 kPa).
- During 2008-2010 CSSS program, 8.0 psi was evaluated.

*Weight is w/o rescue equipment

New U.S. LEA Suit Competitors

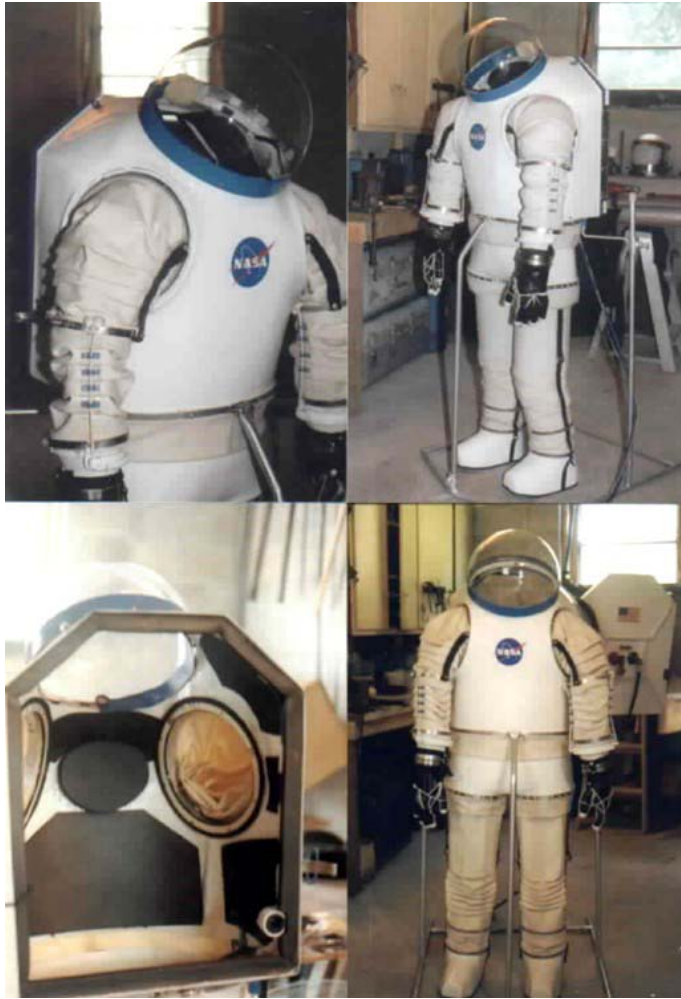
Chinese Shenzhou Rescue Suits

Three new, potential, IVA pressure suit suppliers have been part of the entrepreneurial movement within the space community over the last two decades:

- Harris, de León, & De Leon Technologies LLC (1994-Present [as of 2013])
- Gilman, Global Effects & Orbital Outfitters (2006-Present [as of 2013])
- Moisieff & Final Frontier Design (2007-Present [as of 2013])

Harris, de León, & De Leon Technologies

Chinese Shenzhou Rescue Suits



- Gary L. Harris built “test-bed” spacesuit analog in early 1990s to evaluate comparative EVA bearing and experimental fabric mobility joint configurations for a book.
- In 1994, Weaver Aerospace hired Harris to work on cryogenic pressure vessel structures, but reassigned him to spacesuit development.
- After achieving several aerial tests of the Roton vehicle, Rotary Rocket company went out of business and opportunities faded for all-civilian pressure suit development.
- Within a few years Lee Weaver died – Harris completed his book (published in 2001) and continued his hands-on research that led to a future collaboration (i.e., De Leon Technologies).

**1995 Circa Harris Testbed
(Courtesy Gary Harris)**

Harris, de León, & De Leon Technologies, Cont.

Chinese Shenzhou Rescue Suits



- Founded in 1987.
- Argentine Association for Space Technology (Asociación Argentina de Tecnología Espacial or AATE) is a private, non-governmental, non-profit organization based in Buenos Aires.
- Was formed by a coalition of academia (students and faculty), private individuals and corporations who promoted Argentina's participation and growth in peaceful space exploration and development.

AATE's chief designer, project manager, and primary spacesuit financial contributor was aerospace engineer Pablo de León. Under the auspices of the AATE, de León produced a neutral buoyancy spacesuit analog system.

**1996 Circa AATE/de León NBL Suit
(Courtesy Pablo de León)**

Harris, de León, & De Leon Technologies, Cont.

Chinese Shenzhou Rescue Suits



- In 2002, de León immigrated to the U.S. est. De Leon Technologies LLC in Cape Canaveral, Florida.
- De León and Harris met and collaborated on an IVA spacesuit project named the de León and Harris Prototype Number One (DL/H-1), started in 2004.
- The 4 psi DL/H-1 was created under the auspices of De Leon Technologies and reached testing at the University of North Dakota in 2008.

**2008 Harris, The DL/H1 Suit & de León
(Courtesy Gary Harris)**

Harris, de León, & De Leon Technologies, Cont.

Chinese Shenzhou Rescue Suits



- In 2009, de León and Harris modified their DL/H-1 prototype by adding an oval bubble helmet w/a lower aluminum base, an improved suit seal closure, and fabric pressure boots as a more comfortable and lighter alternative to the stiffer DL/H1 boot intended for parachute use.
- Configuration changes caused prototype to be renamed DL/H-1B.

**Harris in the 2009 DL/H1B Suit
(Courtesy Gary Harris)**

Gilman & Orbital Outfitters

Chinese Shenzhou Rescue Suits



- Chris Gilman, president and CEO of Global Effects (a movie prop and special-effects company) participated in real spacesuit development.
- In 1998, NASA funded global effect for a vent pressure, out-of-the-box thinking, small EMU HUT prototype.
- Gilman collaborated w/Dennis Gilliam.
- Gilliam was a spacesuit researcher and restorer, but brought experience as an aerospace engineer/manager.
- In 8 weeks, the Gilman/Gilliam team designed and manufactured a HUT prototype.
- Due to funding limitations, Global Effects lent NASA movie-quality arms, gloves, and a lower torso assembly to complete the concept prototype allowing evaluation of the prototype.

**1998 Gilman/Gilliam Small EMU Vent Pressure Prototype
(Courtesy Chris Gilman)**

Gilman & Orbital Outfitters, Cont.

Chinese Shenzhou Rescue Suits



- In 2006, Gilman helped found OO becoming their chief designer.
- OO provides suits for private space travelers – a major part of this was the 2007 debut of the OO “Industrial Suborbital Space Suit for Crew” (IS3C).
- Name of the suit morphed to Industrial Suborbital Space Suit (IS3) w/Gilliam joining OO as IS3 program manager.

As of January 2013, OO is developing their 2G LEA suit.

**2007 OO Industrial Suborbital Space Suit
(Courtesy Orbital Outfitters)**

Gilman & Orbital Outfitters, Cont.

Chinese Shenzhou Rescue Suits



**2007 The OO “A7IC” Shoulder
(Courtesy Orbital Outfitters)**

- In 2008 the Texas Engineering Experiment Station (TEES) of Texas A&M University teamed w/OO in the NASA-funded development of a “soft shoulder” concept for NASA's Constellation spacesuit program.
- TEES/OO brainstorming secession explored taking existing, proven architectures and updating them w/newer technologies and materials to develop lower effort mobility systems.
- The Apollo A7LB shoulder was selected for the exercise.
- The updated and improved shoulder was named the A7LC shoulder.

Moisiev & Final Frontier Design

Chinese Shenzhou Rescue Suits



**2009 Nik in His NAM Suit
(Courtesy Nikolay Moiseev)**

- Nik Moiseev was a spacesuit engineer for 20 years w/Zvezda, (organization that has made all the Russian spacesuits from Sputnik to present, as of 2013).
- His last 6 years were as Zvezda's lead designer and project manager.
- He has experience certifying suits and components to all requirements associated w/space use.
- He was temporarily an ex-spacesuit engineer in 2006.
- He went into business for himself and funded an intra-vehicular design.
- He constructed and internationally demonstrated 2 prototypes.
- Model was the NAM Suit (for Nikolay Alexandrovich Moiseev, his full name).

Moiseiev & Final Frontier Design, Cont.

Chinese Shenzhou Rescue Suits



- 2007 and 2009, Moiseiev partnered w/Americans to compete in NASA Astronaut Glove Competitions.
- 2009, Moiseiev joined Ted Southern to form FFD to pursue spacesuit development and production for commercial human spaceflight.
- July 16, 2010, FFD debuted their first complete space pressure-suit, the "Frontier Prime":
 - Weighed 13.4 lbs (6.5Kg).
 - Is intended to operate at 4 psi (27.6 kPa).
 - Can adjust to fit a person between 5'5" - 6'1" (1651-1854 mm).
 - Is a front-entry suit w/wrist and neck disconnects and features improvements over the NAM suit in the following areas:
 - New wrist disconnects
 - New helmet visor shape
 - More robust bladder design
 - Revised restraint system greater range of motion at reduced effort

2010 The FFD Frontier Prime
(Courtesy FFD)

Moisiev & Final Frontier Design, Cont.

Chinese Shenzhou Rescue Suits



- FFD's 2011 SBIR Phase I contract w/NASA JSC was for the development of an MCP glove design for EVA gloves.
- Final prototype glove delivered in Aug. 2011.
- Glove was developed for 4.3 psi (30 kPa) and made of a single layer, heat-sealed, urethane-coated airtight nylon.
- FFD further refined their reinforcement techniques to construct a more reliable glove.

As of Oct. 5, 2012, NASA was testing this glove w/a full ISS configuration EMU, and FFD was awaiting results. Southern was the PI for the contract and Moiseev was an advisor.

**FFD's SBIR Phase I Glove
(Courtesy FFD)**

Moisiev & Final Frontier Design, Cont.

Chinese Shenzhou Rescue Suits



**FFD's 2G Suit Prototype
(Courtesy FFD)**

Beyond Phase I SBIR, FFD completed a 2G pressure garment design in 2011 w/the following features:

- Single-layer integrated bladder and restraint for every designed body joint
- Adjustable straps in 11 locations
- Front entry
- Removable helmet and gloves
- All heat-sealed seams
- Under 14 lbs w/o life support
- Minimal metal parts

FFD burst-tested design components (elbow, knee) to >20 psi. By Oct. 8, 2012, the whole suit had been tested to +5 psid unmanned and +3 psid manned. The single-layer pressure garment is very comfortable both pressurized and unpressurized because it has very little bulk compared to traditional double layer designs.

Moisiev & Final Frontier Design, Cont.

- Design is affordable to produce.
- Takes fewer man hrs to manufacture and reduces pressurized torque.
- FFD estimates that the suit is currently at TRL 5-6.
- In 2012, FFD moved to the Brooklyn Navy Yard and became affiliated w/Brower Propulsion Lab.
- FFD currently (as of 2013) has ~1000 sq ft of lab and production space w/extensive patternmaking, heat sealing, assembly, machining, welding, and sewing capabilities.
- FFD's two-hand vacuum chamber glove box allows development testing and certification cycling activities.
- Through its affiliates, FFD has access to a 36" sq water jet cutting table and 18" X 36" lasercutter.
- FFD consults and works w/several part-time experts (technical staff total 6 including Southern and Moiseev).

Chinese Shenzhou Suits



China's Shenzhou 9 Crew Suited On Launch Day (Courtesy China News)

Shenzhou V “Rescue Suits”

Chinese Shenzhou Rescue Suits

Description:

The Chinese National Space Administration (CNSA) produced 2 configurations of Shenzhou “Rescue Suits” as of 2013 – it looks like an exact copy of the Zvezda Sokol-KV-2 Rescue Suit.



**Shenzhou V Chinese IVA Suit
(Courtesy CNSA)**

Chronology:

- China purchased 2 Sokol-KV-2 training suits in the mid-1990s from Zvezda.
- Shenzhou V configuration appeared immediately before first manned flight in 2003.
- Shenzhou VI type started service in 2004 and is the current CNSA IVA suit as of 2013.

Technical Characteristics:

Operating pressure:	5.9 psi (40.0 kPa)
Life support:	Vehicle-provided
Spacesuit mass:	22 lbs (10 kg) (est.)

Quantities Manufactured: Unknown, however, the Russian Sokol-KV-2 is made custom for each user.

Shenzhou VI & Subsequent Suits



**China's Shenzhou VI Rescue Suit
(Courtesy CNSA)**

Description:

- For Shenzhou VI, IVA design was revised by CNSA to include front cover and additional restrains.
- CNSA claims Shenzhou VI type is lighter and more comfortable than the preceding configuration.

Chronology:

- China purchased 2 Sokol-KV-2 suits in the mid-1990s.
- Shenzhou V configuration saw flight in 2003.
- Shenzhou VI started service in 2004 and is the current CNSA IVA suit as of 2013.

Technical Characteristics:

Operating pressure :	5.9 psi (40.0 kPa)
Life support:	Vehicle-provided
Spacesuit mass:	22 lbs (10 kg) approximately or less

Quantities Manufactured: Unknown, however, the Russian Sokol-KV-2 is made custom for each user.

Note: Shenzhou gloves are Chinese copies of the Russian Sokol gloves of 1970-90s, which were (w/minor tweaks) copies of 1965-69 ILC Apollo gloves.

Shenzhou VI, cont.



**Shenzhou Suit Visors Views
(left & above)
(Both Courtesy China News)**

Note: When opened, the visors of the Shenzhou Suits, like those of the Sokol KV-2, either hang behind the head (left) until the CM is cradled in his or her launch couch where the visor is cradled (right) for open-face operation, but ready to easily close in an emergency.

LEA Suit Insights & Considerations

- Part of an overall vehicle crew escape and survival system.
- Worn during the launch and reentry to enhance crew survival.
- Nominal use of LEA or IVA is unpressurized.
- Other uses are minimally pressurized above ambient and full pressure.

Insights, cont.

Launch and reentry impart multi-g loads:

- The torso assemblies of LEA spacesuits are designed to be w/o hard details to the extent possible – has associated penalty in full-pressurize mobility.
- LEA suits tend to be extremely light-weight (22-28 lbs) pressure suit systems w/minimum bulk to facilitate the extent possible egress from the spacecraft under emergency conditions.

Insights, cont.

Both Russian and U.S.:

- Discontinued providing LEA suits because their spacecraft were safe and reliable – LEA type spacesuits were no longer necessary.
- Resumed providing LEA suits after loss of entire crews.

Insights, cont.

Russian since 1973, and Chinese systems as of 2013:

- Manned spacecraft capable remaining operational for a fully controlled reentry return following rapid cabin decompression
- LEA suit operational pressure of 5.9 psi (40.0 kPa) providing reasonable protection for DCS or loss of life during rapid cabin decompression
- LEA suits typically carry no survival gear
- All survival gear is stowed in the spacecraft
- Russian and Chinese keep the CMs protected inside spacecraft and design spacecraft to survive emergencies

Insights, cont.

Since 1975, NASA manned spacecraft systems:

- Incapable of remaining fully operational during rapid cabin decompression.
- Cabin decompression would result in loss of vehicle electronics.
- Highest flight suit operating pressure has been 3.5 psi (24 kPa).
- Rapid cabin decompression would result in DCS and probable loss of life.
- Parachute and suit-born survival systems weighed approximately 64 lbs (29 kg). With the last and lightest LEA system, the shuttle CM could escape carrying a 92 lbs (41.7 kg) suit-system.

Insights, cont.

U.S. safety going forward:

- NASA is not clearly imposing a requirement that manned spacecraft and human occupants must remain safe and operational during cabin loss of pressure
- Loss of cabin pressure has happened before:
 - During the return re-entry on June 30, 1971, the Soyuz 11 capsule lost internal pressure and 3 CMs died from suffocation
- Loss of cabin pressure will happen again:
 - Orbital debris
 - Opportunity for human error
 - Short-term cost vs. human safety

Acronyms and Abbreviations

2G	Second Generation, a pressure suits assembly model from Final Frontier Design
AATE	Asociacion Argentina de Tecnología Espacial
ACES	Advanced Crew Escape Suit
ASTP	Apollo-Soyuz Test Project
atm	an atmosphere
CEO	chief executive officer
CES	Crew Escape System
CM	crewmember
CNSA	Chinese National Space Administration
CSSS	Constellation Space Suit System
DCC	David Clark Company Incorporated, Worcester, Massachusetts
DCS	decompression sickness
DL/H1	first LEA suit prototype by Pablo de León and (Gary) Harris of De Leon Technologies LLC, Cape Canaveral, FL
DL/H1B	second configuration of De Leon Technologies LEA suit
EMU	Extra-vehicular Mobility Unit
EVA	Extra Vehicular Activity
FFD	Final Frontier Design, pressure suit assembly manufacturer of Brooklyn, NY
ft	foot
HS	To 1969: Hamilton Standard Division of United Aircraft Corporation; 1969-1999: Hamilton Standard Division of United Technologies Corporation; 1999-2012: Hamilton Sundstrand Division of United Technologies Corporation
HUT	Hard Upper Torso, a Shuttle EMU subsystem
IEVA	Has two meanings: (1) Intra/Extra Vehicular Activity, a generic type of spacesuit (2) Integrated Extra Vehicular Activity, a specific HS advanced suit designed (1967-68)

Acronyms and Abbreviations (cont.)

ILC	To 1969: International Latex Corporation headquartered in New York City with space pressure suit facility located in Dover, DE. 1969 to Present: ILC Dover LP of Fredrica, DE.
IS3	Industrial Suborbital Space Suit
IS3C	Industrial Suborbital Space Suit-Crew, Pressure Suits Assembly model of Orbital Outfitters
ISS	International Space Station
IVA	Intra-Vehicular Activity
JSC	Johnson Space Center
kPa	kilopascal
lb	pound
LEA	launch, entry and abort, as of 2013, current alternative name to an IVA pressure suit assembly
LEH	Launch/Entry Helmet
LES	Launch/Entry Suit
LSS	Life Support Systems
MCP	metacarpal joint prototype
mm	millimeter
NAM	A model of pressure suit assembly privately produced by Nikolay Aleksandrovitch Moiseev
NASA	National Aeronautics and Space Administration
OO	Orbital Outfitters, a North Hollywood, CA-based pressure suit assembly manufacturer
PGA	Pressure Garment Assembly
PI	principle investigator
PRE	Personal Rescue Enclosure
PSA	pressure suit assembly
psi	pounds per square inch

Acronyms and Abbreviations (cont.)

psia	pounds per square inch absolute, differential pressure over an absolute vacuum
psid	pounds per square inch differential, differential pressure over ambient environment
SBIR	Small Business Innovation Research, a NASA research grant system
sq	square
TEES	Texas Engineering Experiment Station branch of the Texas A&M University
USAF	United States Air Force