



Disorders from Rapid Changes in Altitude

- Decompression Illness (DCI)
 - Decompression Sickness (DCS)
 - Cerebral Arterial Gas Embolism (CAGE)

Cloudy is a myth, the Earth sucks.

The unsuitable environment

- Low Thermal
- Low Oxygen
- Low humidity

Decompression Illnesses

DCS vs. DCI

Reduction in ambient pressure causes formation of inert gas bubbles causing primary or secondary organ dysfunction. (Embolic vs. autochthonous)

Background

- U-2S Mission**
 - High altitude (+60,000 ft) reconnaissance
 - USAF's sole remaining *manned* high altitude platform
- Very High-Stress Physiological Profile**
 - High risk of DCS without preventative measures
- Standard DCS Prevention Measures**
 - Full pressure suit, 1-hour resting pre-breath, 100% O₂
- Historical DCS Incidence in U-2 Program (Prior to 1998)**
 - Many *unreported* cases of joint/skin DCS
 - No *recorded* cases of CNS-related DCS (neurological damage)
 - No *recorded* cases of permanent neurological damage

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Historical Background

- Robert Boyle – 1670 bubbles in snake eye
- 1845 – Caisson’s Disease
- 1878 – Paul Bert defines DCS
 - Snakes in vacuum
- Drs Smith (Eads) & Moir (Brooklyn)
 - Recompression chambers
- 1908 – JS Haldane
 - Royal Navy tables




Figure 10. French Caisson. The caisson could be raised over the work site and lowered to the bottom by raising the side tanks.



Tiny Bubbles... DCS

- Under pressure
 - Increased inert gas (nitrogen (N₂)) absorbed in solution
- Decreasing pressure
 - N₂ released into gas (Henry’s Law)
 - Bubbles deposit in joint fluid or block vessels
 - Spherical vs. conical
 - Endothelial effects
 - Leuk/plt adhesion
 - Complement cascade



Maybe true. Maybe not true. Better you believe. — Sherpa saying

DCS Symptom Recognition

- Type-1
 - Dizziness (not pain)
 - Itching of skin
- Type-2
 - Dry Cough
 - Dyspnea (altered breathing)
 - Substernal Chest Pain



CNS Presentations

- Fatigue (Commonly Discounted)
- Dull Persistent Headache
- Decreased Mentation
 - Confusion/Delirium
 - Poor Concentration
 - Personality Changes
 - Loss of Orientation
- Abnormal Neuro Exam
 - Often Spotty Sensory & Motor Signs
 - Migratory Symptoms
- Flashing/Flickering of Lights/Blind Spots
- Partial Paralysis
- Vertigo

History

Kelly Johnson – designer

- 1956 U-2/C-124C
- 1957 V-22/J57
- 1958 F-105/Boeing A-1E (0% flight success)
- 1959 F-4U/Boeing F-4U (100% success)
- 1960 J-79 turbojet – GE F-118 turbofan (1981) U-2/R/S
- H
- ER-2 (NASA)

Maintain (Keep the flyers flying)

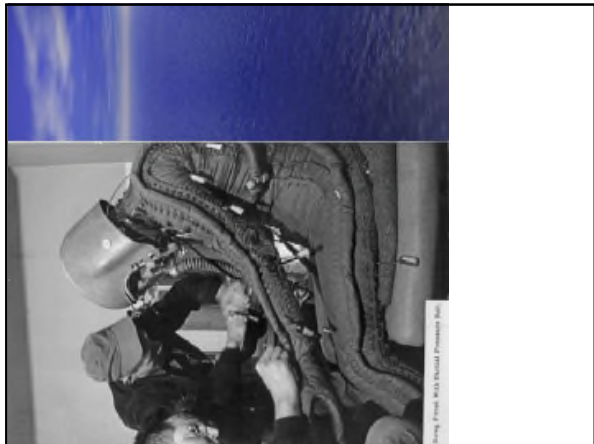
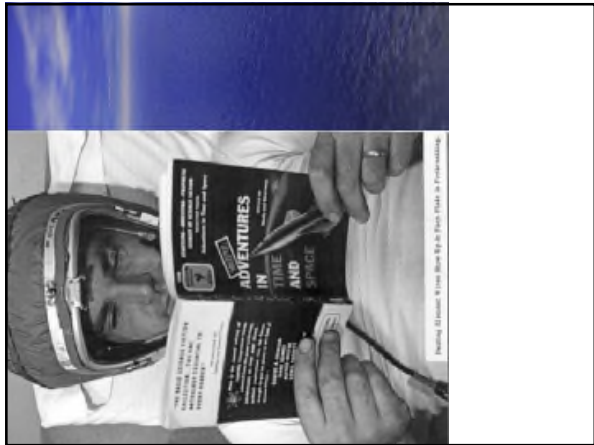



Intelligence, Surveillance, Reconnaissance (ISR)

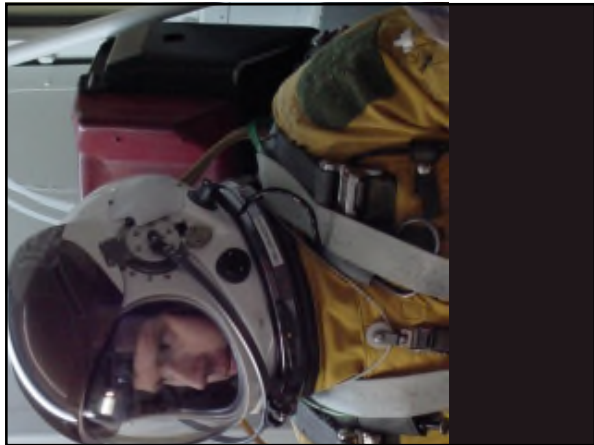




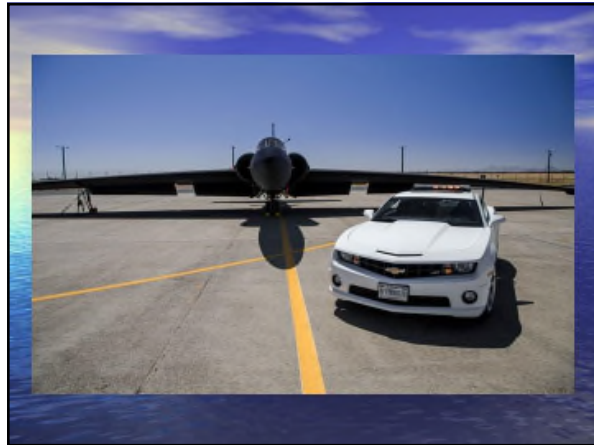
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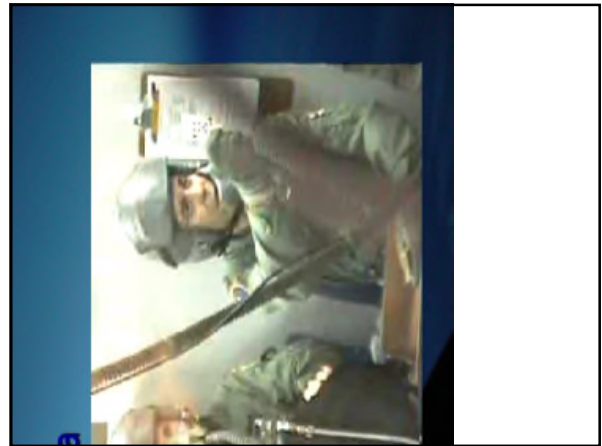
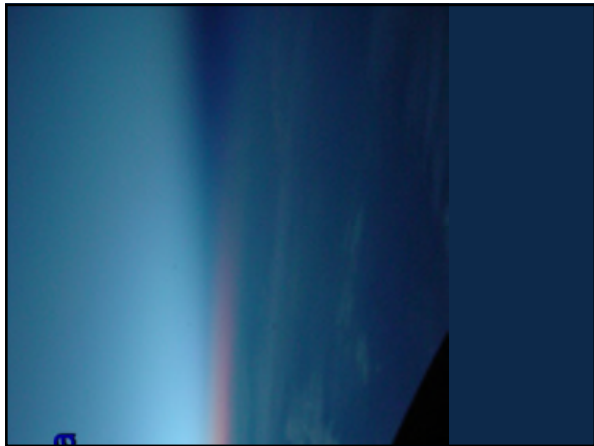
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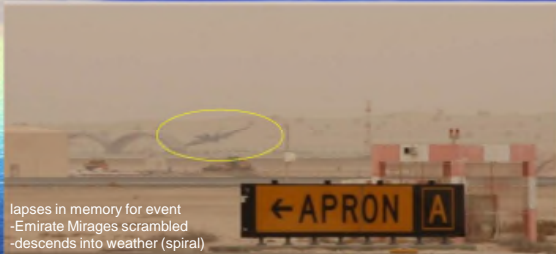


Hank's Wild Ride

- 2.5 hrs into flight, FL680, CP280
- Knee pain – dialed up suit
- Ankle pains
- a/c rolling – xck - ?vis illusion
- MFD task difficulty (5/10)
- frontal HA
- hot flashes (cabin temp 57°)
- hypoxia? – green apple
- weakness – pupils?
- second guessing "am I screwing up?"
- dehydrated?
- call MOCC? Head home?
- 5.5hrs into flight, MFD-confusion, can't transfer files
- "monkey on my chest"
- sudden vomiting – scared
- SFD only, diff seeing instruments
- "in my happy place" MOCC talking gibberish


Hank's Wild Ride



- lapses in memory for event
- Emirate Mirages scrambled
- descends into weather (spiral)
- next thing I know I'm at FL160
- faintly remembers AI
- sees concrete – Abu Dhabi IA at 2000ft
- "650ft over airfield is too low"



- banked turn over hangers – 5 ft AGL
- "bail out-bail out-bail out"
- "bailing out will get you to the medics quicker"
- "get it together or get out"
- no strength to pull handles
- 9.5 hrs into flight – gets it together

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Neurological Decompression Sickness In U-2 Pilots: A Case Series 2002-2009

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38

Disclaimers

- Approved for public release by 9RW/PA
- Research was approved by USAF David Grant Medical Center IRB (#FDG20100012H)
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- Views & opinions expressed in this presentation are solely those of the authors & do not represent official policy of the Department of the Air Force, Department of Defense, or the U.S. Government

CNS Neurological DCS (2002-2009)

- 45 recorded DCS incidents of ALL types (37 pilots)
- 16 confirmed cases neurological DCS (14 pilots)
 - Three (3) neurological + pulmonary DCS [2 at OL2]
 - Five (5) life and/or aircraft threatening [4 at OL2]
- 4 possible cases of neurological DCS (4 pilots)
- Observations:
 - Majority were men (one woman)
 - No correlation to age, body habitus, or GelDex use
 - No PFO detected among 6 pilots tested
 - One pilot with MRI lesions among 9 tested

CNS Neurological DCS Cases (1991-2001)

- 22 recorded DCS incidents of ALL types
- Two (2) confirmed chokes cases
- Three (3) confirmed neurological DCS cases
- Two possible cases of neuro DCS (1991, 2000)
- Five subjects*, all men
- Incomplete data on body habitus, age, & tests

* Cases don't add up to 5 because some subjects had multiple incidences and/or experienced multiple symptoms (i.e., chokes+neuro)

Unusual Symptoms for Aviation-Related DCS

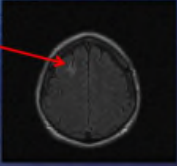
- **Late Onset of Neurological Symptoms**
 - 3 cases: sudden onset severe symptoms >4hrs in-flight
 - 7 cases: delayed recognition of symptoms after landing
- **Recurrent Symptoms After Indicated Treatment**
 - Temporal association with commercial airline flights
 - 2 cases flew home approximately 72hrs after treatment

Unusual Symptoms for Aviation-Related DCS (con't.)

- **Symptoms Persist Despite Indicated Treatment**
 - Subtle neuropsychological symptoms persist for years
 - One case of PTSD (one additional case possible)
- **Permanent Neurological Sequelae in 1 Case**
 - Correlating lesions on MRI
 - Severe case – clinical equivalent of ischemic stroke
- **Common in Diving-Related DCS, but Not Aviation**

Most Severe U-2 Neurological DCS Case

- Several prior (undisclosed) incidents of DCS
- 1-hour resting pre-breath, otherwise healthy male
- Cabin altitude 28,000 ft (8,534 m)
- Gradual onset of symptoms after 2.5 hrs flight
 - Joint pain progressing to fatigue, confusion, visual disturbances, difficulty breathing, chest pain, shock




Most Severe U-2 Neurological DCS Case

- Pilot required coaching for flying, periods of unconsciousness, nearly crashed on landing
- Most severe symptoms resolved with HBOT
- Brain lesions on MRI improved after HBOT
- Permanent symptoms, corresponding MRI lesions
 - Headaches, fatigue, personality changes, memory deficits, vision problems
- Permanently disqualified from flying

45

More Recent U-2 Neurological DCS Case

- ✓ No prior history of DCS
- ✓ 1-hour resting pre-breath, otherwise healthy male
- ✓ Cabin altitude 29,000 ft (8,839 m), 9.2hr flight
- ✓ Gradual onset of symptoms 5 hrs after landing
 - ✓ Bitemporal headache, partially resolved with NSAID
 - ✓ Overnight, headache recurred with worsening fatigue, dizziness, unsteady Romberg, blurred vision
 - ✓ Symptoms resolved with HBOT (USN TT-6)
- ✓ Symptoms recurred 48hrs later
 - ✓ Resolved with HBOT (USN TT-6 x2, TT-5)
- ✓ MRI lesion 05 Mar 10
 - ✓ Asymptomatic, normal neurological exam
- ✓ Should he fly again?



46

Possible Causes

- **Pilots More Willing to Report**
 - Classification barriers removed
 - No more “two strikes” penalty
 - Operational culture changed after 2006 incident
- **Normal Statistical Variation?**
 - True incidence unknown, relatively small numbers
- **Increased Operations Tempo**
 - Frequency & duration of flights unprecedented
 - Workload falling on fewer pilots (reduced manning)

Mission Duration & Frequency

	Previous Generation U-2 Pilots (1980's-1997)	Today's U-2 Pilots (1998-Present)	Percent Change
Number of Pilots Available	49	37	24% fewer pilots
Average Annual Hours	207	353	70% more hours
Average Annual Sorties per Pilot	42	92	122% more sorties
Time to Achieve "1,000-Hour" Status	7-10 years	3-5 years	They're ALL "1,000-Hour" pilots now!

Bottom Line:
 Increased duration & frequency of hypobaric exposure

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Other Causes Ruled Out by Investigation

- No correlation with aircraft tail number
- No mechanical failures in aircraft or life support systems
- No changes in equipment or integration/launch procedures
- No aircraft/LOX systems, LOX supply contamination
- No unique environmental contamination sources
- No correlation with amphetamine (GelDex 'go-pill') use
- No correlation with anthropomorphic variables or pre-existing medical conditions
- No evidence of malingering



Possible Risk Mitigation Measures

- Address Known Major Risk Factors for DCS:
 - Pre-breath, altitude, activity & exposure time at altitude
- Exercise Enhanced Pre-Breath
 - Risk reduction is population-based
- Reduce Time of Exposure (Sortie Length)
- Reduce Mission Operating Altitude
- Fly with Pressure Suit Partially Inflated at All Times
- Increase Rest Cycle Between Missions, Deployments
- Educate – Lower Threshold for Treatment Needed
- Return flights home with supplemental oxygen



Clinical Outcomes

Symptoms Similar to Traumatic Brain Injury (TBI)

- Normal imaging studies & neurological exam
- Persistent subtle symptoms, often overlooked initially
- Fatigue, headaches, irritability, sleep disturbances, difficulty focusing, memory problems
- Risk of concurrent PTSD
- Permanent deficits in most severely injured patient
- Suggests common final pathway of injury
- Window of increased susceptibility for re-injury?

Conclusions

- **Increased Number of Neuro DCS Incidents Among -2 U Pilots**
 - Coincident with persistent, increased tempo of operations
- **Unusual Symptoms for Aviation-Related DCS**
 - Onset of neurological DCS after >4 hours at altitude
 - Recurrence of symptoms after indicated treatment
 - Subtle, but persistent neuropsychological symptoms
 - Permanent injuries in some
 - Suggests common final pathway for brain injury
- **Implications for Aeromedical Management**
 - Should neuro DCS patients be managed as head injuries?
- **Implications for Treatment**
 - Immediate HBOT for ANY SUSPECTED neuro DCS
 - Operational patients at risk for concurrent PTSD
 - Could TBI treatments benefit neuro DCS patients (and vice versa)?



UCD/UCS



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