SPACE CHALLENGES FOR WIRE HARNESS ASSEMBLIES

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SAIC / NASA Johnson Space Center

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WHMA Wiring Harness Manufacturer's Association
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The E-mail That Started The Conversation:

Hi Bob,

Do you know if NASA has bumped into any wire harness challenges over the years that might provide some guidance for the harness manufacturers?

I am exploring speakers for the WHMA 2020 conference in February.

Best regards,
Dave
David W. Bergman
Vice President Standards & Technology IPC
Executive Director – Wiring Harness Manufacturer's Association

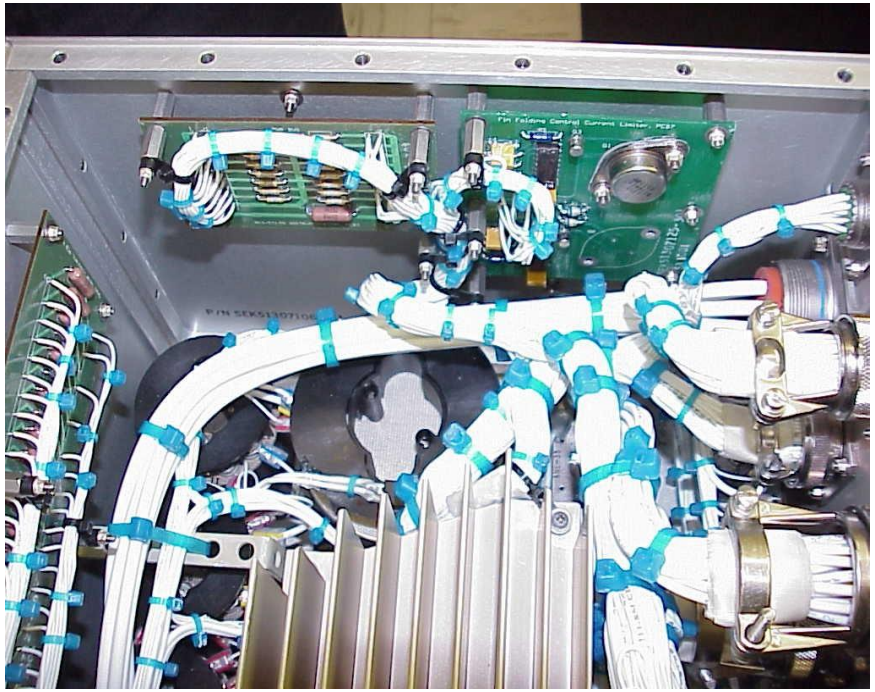
#1: What works down here doesn't always work "up there".

While we are rapidly moving to the commercialization of space (especially vehicles and hardware), what works down here on planet Earth doesn't always work "up there".

- Contamination and Foreign Object Debris (FOD) are constant issues.
- Material compatibility issues are a constant headache.
- Outgassing of volatiles from cable and harness assembly components (e.g. insulation, potting materials, connectors / hoods, thread adhesives, etc.) can range from a mild irritant to the crew to contamination of life critical environmental systems.
- Flammability is a serious issue. We have fire extinguishers, but we can't open a window to vent smoke or toxic residues. Even the smell of something getting hot causes great concern.

#2: Treat Cable & Wire Harness Assemblies With Respect!

- **We need to start treating cables and wiring harnesses as a critical component of the system.**
  - ❑ Often the most overlooked, ignored, and “taken for granted” component in a design.
  - ❑ Equivalent to the human circulatory and nervous system.
  - ❑ They deliver energy, transmit command and control instructions, and collect and distribute sensory data describing not only the environment external to the system, but the health and status of the system itself.
- **Having a highly advanced design with bleeding edge technology and A.I. capability is nice, but nothing works if the cables / wiring harnesses don’t fit, or don’t transmit / transfer power and signals as intended.**



Wiring Harness Installation
Image Credit: IPC-D-620, Figure 3-1

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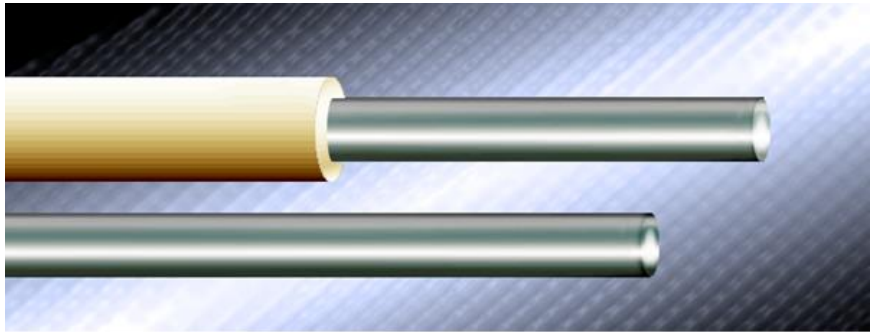
#3: Wire & Cable Shortages – Supply & Demand

Shortages of fluoropolymer-insulated wire and cable were reported in the second / third quarter or 2018 and may be tied to tariffs on fluoropolymer imports - and a number of factors all coming together at the same relative time:

- Increased worldwide demand for fluoropolymer resins
- Reduction in worldwide production capacity
- Reduction in the supply of fluorspar (calcium fluoride)
- Anti-dumping duties and tariffs
- Extended plant shutdowns at two major global fluoropolymer suppliers in 2018
- Environmental litigation against US manufacturers of Teflon



Insulated Solid Conductor
Image Courtesy of NASA

Insulated LITZ Wire
Image Courtesy of NASA

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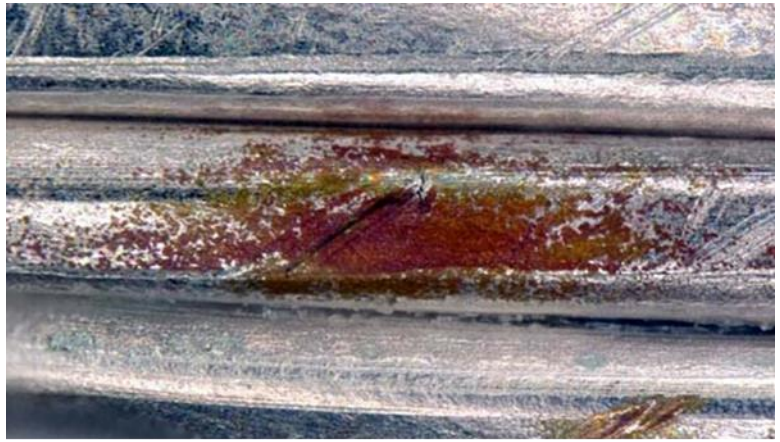
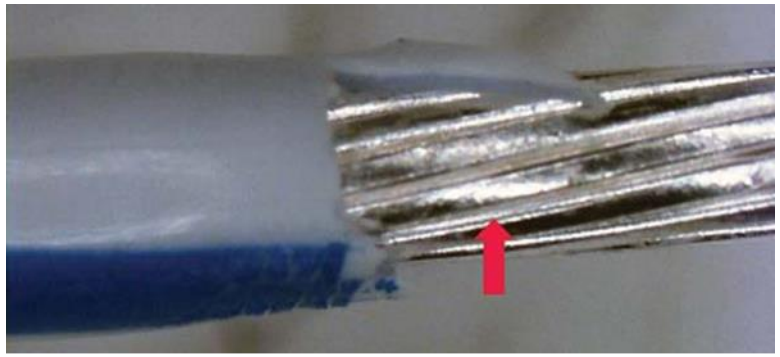
#4: Corrosion – Red Plague & White Plague

Red Plague (galvanic corrosion) continues to be an issue, and we are seeing an increase in questions about White Plague (fluorine attack).

- Red Plague (cuprous oxide corrosion) can develop in silver-coated soft or annealed copper conductors (component leads, single and multi-stranded wires and PCB conductors) when a galvanic cell forms between the copper base metal and the silver coating in the presence of moisture (H_2O) and oxygen (O_2).
- White Plague (Fluorine Attack) can develop in fluoropolymer-insulated wires and cables when carbonyl fluoride (COF_2), an extremely reactive compound, is released.



Red Plague (Cuprous Oxide Corrosion)
Photo Courtesy of NASA



White Plague (Fluorine Attack)
Note white frosted section on silver coating
Photo Courtesy of NASA

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#5: Green Contamination / Corrosion

Four (4) types of unusual contamination / green residue have been found in wiring:

- Copper Abietate [$Cu(C_{20}H_{29}O_2)_2$]
- Copper (II) Chloride [$CuCl_2$]
- Copper II Fluoride [CuF_2]
- Copper Phthalate [$C_8H_4CuO_4$]

- **Copper Abietate [$Cu(C_{20}H_{29}O_2)_2$]**

  The formation of copper abietate is readily noticeable on wire with clear Teflon insulation, but can appear on any copper-base wire contaminated with flux residue.

  - Electrically non-conductive, non-corrosive, forms a green, insulating coating on copper. May contaminate nearby optics, switch mechanisms, and surfaces.

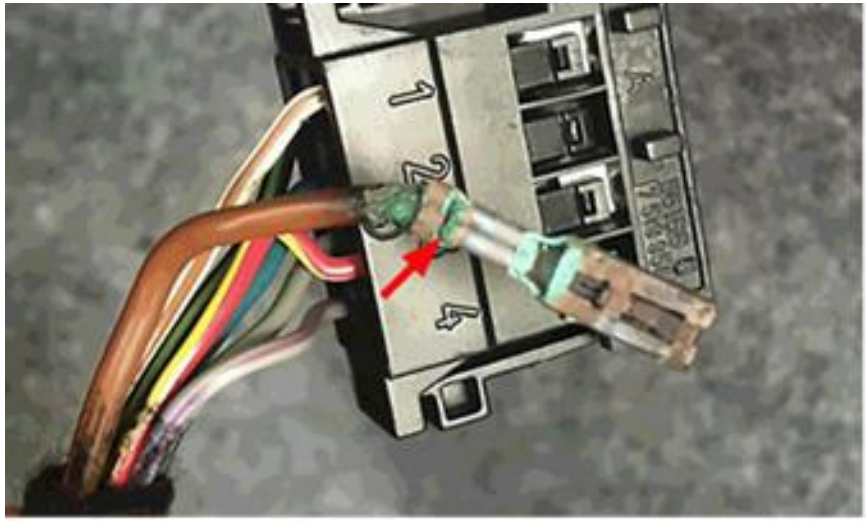
Copper Abietate (Green Specks) on Shield Braid
Photo Credit: NASA-TM-2008-215577, Long-Term Effects of Soldering By-Products on Nickel-Coated Copper Wire, Fig. 3b

#5: Green Contamination / Corrosion (cont.)

- **Copper (II) *Chloride [$CuCl_2$]***

  Copper (II) chloride is an unwanted, corrosive contaminant created by reaction of copper with chloride compounds and moisture.

  - It is para-magnetic (susceptible to magnetic fields), can be toxic if ingested, and is used in pyrotechnics as a blue/green coloring agent.
  - Health Concerns: The full toxicological risks of this material have not been fully investigated.
    - Inhalation of fumes may cause severe respiratory tract irritation, burns, and metal-fume fever.
    - Ingestion may cause severe digestive tract irritation with possible burns.
    - Direct skin and eye contact may cause burns.



Copper (II) Chloride
Image Credit: IPC-HDBK-620, Fig. 8-3

#5: Green Contamination / Corrosion (cont.)

- **Copper (II) Fluoride [CuF_2]**

  Copper(II) Fluoride (cupric fluoride) is described as a white or green, crystalline, solid, hygroscopic, inorganic compound.

  - ❑ Typically used in ceramics, and in brazing and soldering fluxes.
  - ❑ Identified as one of the contamination by-products associated with Fluorine Attack (White Plague).
  - ❑ Health Concern(s): Identified as an acute and chronic health concern in prolonged exposure.
    - ➢ Direct skin and eye contact may cause irritation and/or burns.
    - ➢ Ingestion / inhalation may cause severe irritation with possible burns / organ damage.

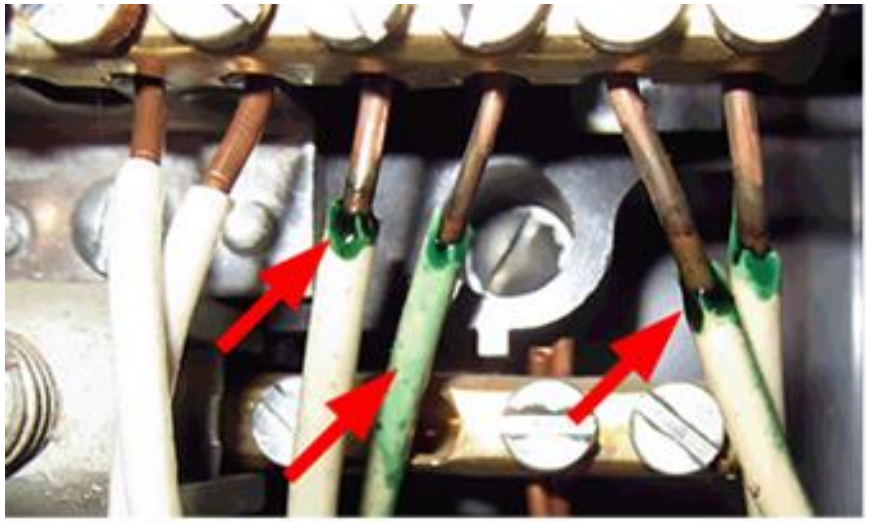
Fluorine Attack (White Plague)
Photo Courtesy of NASA

#5: Green Contamination / Corrosion (cont.)

- **Copper Phthalate [$C_8H_4CuO_4$]**

  Copper Phthalate (a.k.a.: Green Gunge / Green Goo) is described as a sticky blue/green liquid or gel that is typically observed oozing out of the end of an insulated wire or cable.

  - ❑ Generally only seen in PVC-insulated wiring and sheathed cables manufactured in the 1960-1970 era when subjected to high thermal cycling or over-heating.
  - ❑ May be found in other thermoplastic / fluoroelastomer insulated wiring if the extruder processes were contaminated.
  - ❑ Not considered corrosive, but may be electrically conductive and may contaminate nearby optics, switch mechanisms, and surfaces – plus, it's really sticky!

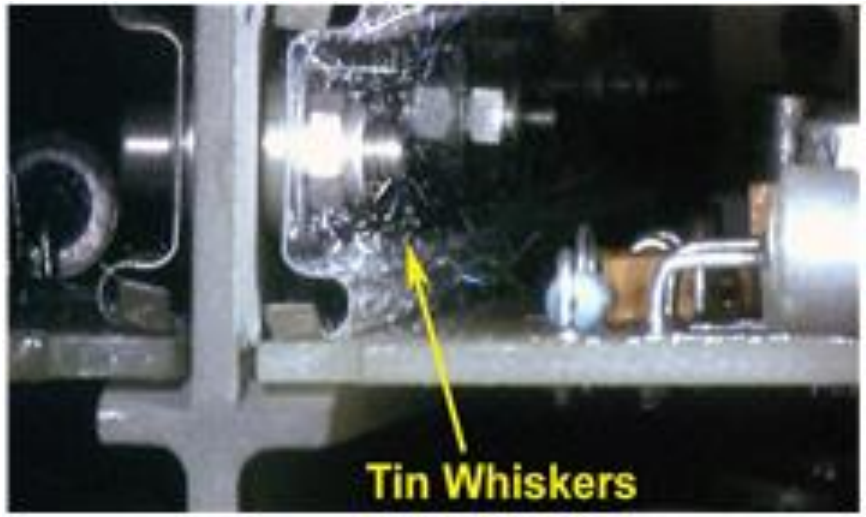


Copper Phthalate (Green Gunge / Green Goo)
Image credit: IPC-HDBK-620, Fig. 8-1

#6: “Green” Materials – Design & Material Compatability

THE CONTINUED MOVE TO “GREEN” MATERIALS IS CAUSING DESIGN AND MATERIALS COMPATIBILITY ISSUES.

- Connectors with coatings such as “White Bronze” or “Black Zinc-Nickel” may be acceptable for commercial or military applications, but must be carefully analyzed for use in manned space flight applications to ensure we don’t compromise the safety of the crew or adversely impact the performance / reliability of the vehicle.
- Green materials and manufacturing processes may not be suitable for spaceflight hardware. (e.g., lead-free technology, “no-clean” fluxes, biodegradables, etc.).



Tin Whiskers
Photo credit: NASA Electronics Parts & Packaging (NEPP) Program

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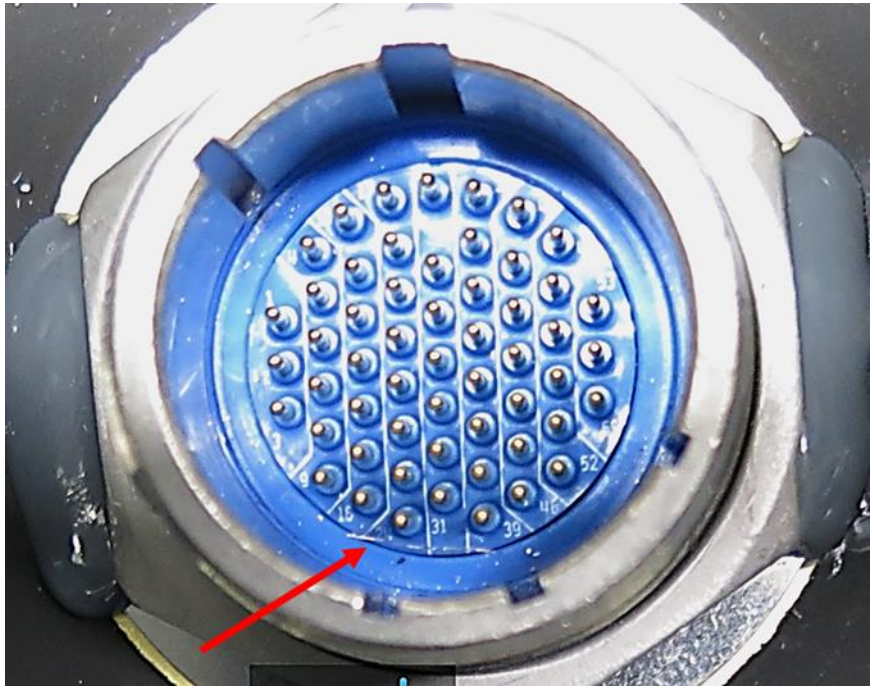
#7: Connector Mating Compatability

The incompatibility of mating connectors from different manufacturers has been an issue recently. The connectors were of the same MIL specification, shell size, keying, pin count, etc., but experienced a serious interference fit issue during testing.

- Projects are always cautioned to mate connectors from the same manufacturer and material to avoid this issue, but they often don't listen – then blame one or both of the connector manufacturers for the problem.
- In this specific instance there were also differences in the hardness of the connector shells (one soft and one hard) and a plating quality issue.
- Plating quality was identified as the problem, but the real issues were material and mating compatibility.



Conductive FOD in Connector Body Generated as the connector is mated

Image credit: NASA

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#8: Contamination Of The Harness – Metallic Braid

Contamination of hardware by the over-braid shielding is often an issue.

- Most commercially available braided shielding (tubing) comes in with a light oil coating that was applied during the braiding process.
- This lubricant can be a significant contamination source if not removed by washing the tubing in solvent and drying prior to installation on the wiring harness.
- Most design engineers and technicians are not aware of the contamination issue, and the harness cannot be washed after it is assembled.

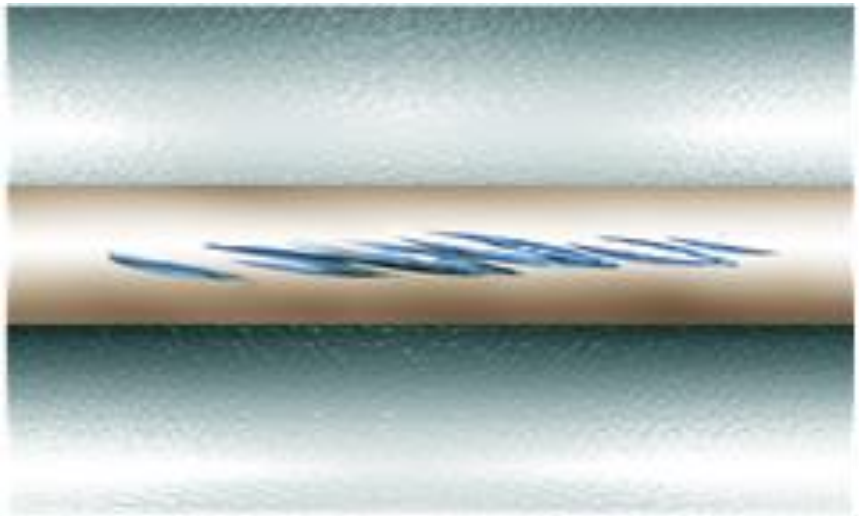
Flat / Tubular Metal Braid

Photo Credit: IPC- HDBK-620

#9: Use of ETFE-Insulated Wiring

Use of ethylene-tetrafluoroethylene (ETFE or Tefzel®) insulated wire to avoid the potential problem of insulation coldflow (NAST Damage) commonly seen with Teflon® insulated wiring, and to reduce the weight of the cable / harness assembly.

- The problem is that the ETFE-insulated wiring (especially the double-insulated XL-ETFE wiring) has a known issue with the outgassing of fluorine if the polymer is not properly doped and cured during the extrusion process.
- The fluorine attacks the silver coating on the wire, producing a frosty / fluffy white finish that makes the surface non-solderable.
  - ➢ Addressed in IPC-WP-114, but most design engineers only become aware of the issue after hardware is built).



Non-AST (NAST) Induced Damage
(Insulation Thinning Due to Coldflow)
Image credit: IPC-HDBK-620

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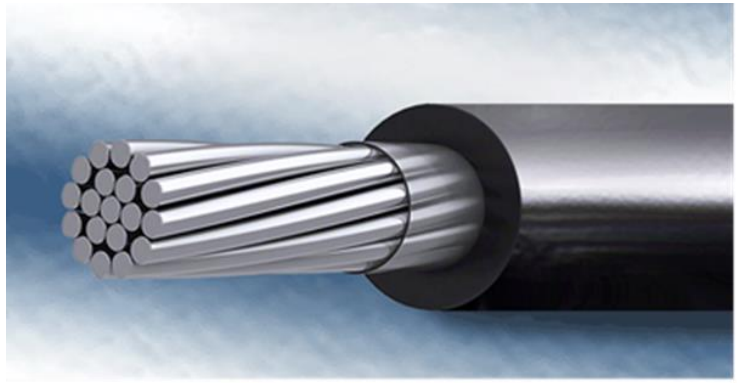
#10: Other Issues

Other issues include:

- The lack of proper power derating analysis to account for thermal issues and voltage drop.
  - Not taken seriously until the test integration team determines that the voltage drop in the harness wiring is preventing sufficient power to ensure reliable operation from being delivered to the next module.
- The increasing disconnect between separate design activities involved in the design and manufacture of wiring harnesses that must interconnect (e.g., there is often very little systems engineering oversight).
  - Doesn't seem to be taken seriously until you try to mate a harness assembly with 14 AWG conductors and contacts to a harness with 18 AWG conductors and contacts.
- The lack of effective communication between designers and manufacturers.
- The expected evolution of cable and wiring harnesses into functional systems in their own right, by integration of embedded components or modules, allowing the cable or harness assembly to reactively adapt to changing load demands, and report status to supervisory systems.

#10: Other Issues (cont.)

- The increasing integration of optical fiber into the harness assembly (e.g., hybrid).
- The increasing use of hyper-flex stranding designs.
- The increasing use of Litz wire for extremely high power applications.
- The increasing use of multi-color wiring in wiring harnesses, when use of a common insulation color would suffice and the colors serve no technical purpose other than “they look pretty”.
- The increasing use of aluminum wiring.
- The lack of awareness of IPC-D-620 and IPC-HDBK-620.



Aluminum Wire
Image Credit: IPC-HDBK-620, Fig. 7-1

Multi-Color Wiring in Harness Assemblies
Image Credit: IPC-HDBK-620, Fig. 7-19

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Conclusions

- **While we are rapidly moving to the commercialization of space (especially vehicles and hardware), what works down here on planet Earth doesn't always work "up there".**
  - Flying in space is easy – getting to space is hard!
  - No "up" or "down" in microgravity. Heated air doesn't "rise" in space, it just envelopes the hardware.
    - Convective cooling capability usually not unavailable in the habitable section of the vehicle – even though that portion of the vehicle has air. Most flight equipment doesn't have fans to cool.
  - Minor odors from materials used in wiring and harness assembly become really annoying in space. Even the smell of something getting hot causes great concern.

- **Use mating connectors from the same manufacturer, shell material, and plating.**
  - Having two MIL-38999 connectors from different manufacturers means they will mate (the specification requires that they do) – but there may be issues (e.g., tolerance stack-up, hard versus soft materials, differing platings, etc.).

Conclusions (cont.)

- **Standardize on a single color wiring insulation in harness builds whenever possible.**
  - Some harness designs require wire color-coding, especially if different wire sizes, voltages, or critical function circuits are present, or if field service is anticipated - but most do not.
  - Harnesses constructed with all nine wire insulation colors look pretty, but the electrons don't care what the insulation color is.
    - Running out of a specific insulation color in the middle of the build either stops the build or requires an Engineering Change Note (ECN) to allow the use of a different color. **> $$$**
    - Standardization of wire insulation color reduces procurement, test, and storage cost. **< $$$**

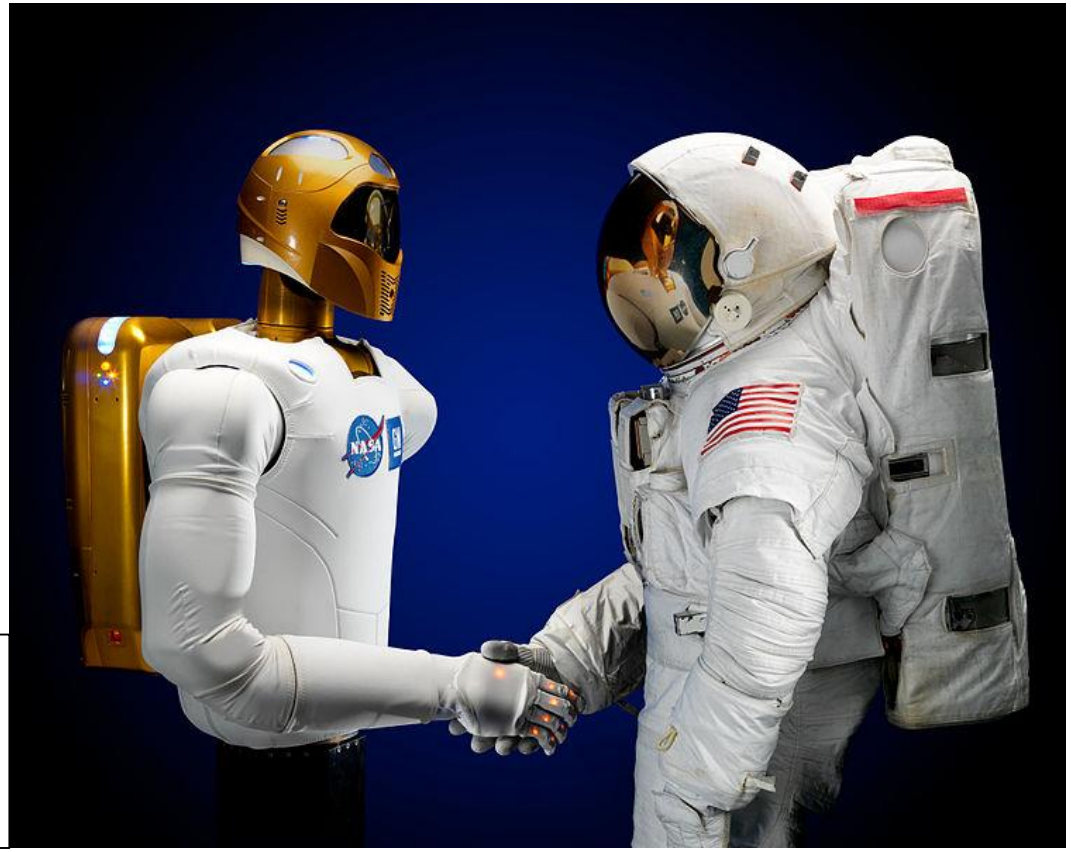
- **Treat wiring, cables, and harnesses with the respect the technology deserves.**
  - Cables and wiring harnesses are often the most overlooked, ignored, and "taken for granted" component in a design.
  - Not just a "wire". High quality cables and wiring harnesses are essential to the performance and reliability of any electrical / electronic system.

Conclusions (cont.)

Finally –

As we advance the use of A.I. and robotics, the “box” may still be considered a box with wires, cables, and harness assemblies inside – but it may eventually look and behave like a living organism.

It’s important that the wiring technology works as intended, especially if our intent is to mimic the human response and achieve a “human presence” in difficult environments and demanding missions - either here on Earth, in space, or on a different planet.



Robonaut 2, a dexterous, humanoid astronaut helper, flew to the International Space Station aboard space shuttle Discovery on the STS-133 mission. Although it only participated in operational tests, upgrades could eventually allow the robot to realize its true purpose -- helping spacewalking astronauts with tasks outside the space station.
Image Credit: NASA
http://www.nasa.gov/mission_pages/station/multimedia/robonaut_photos.html

Thank You For Listening

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