Project 31 – Reevaluation of Effectiveness of Emergency Vehicle Colors in Safety and Identification

Presented by
John Lannutti, The Ohio State University

2019 PEGASAS Annual Meeting
The Team

• Keith Bagot (/Jonathon Torres), TPOC
• John Lannutti, OSU PI (Materials Science and Eng.)
  James Enders, Sloan Le, Makito Otsuka, Will Cites, Alex Houston (OSU Aerospace UG’s)
• Halil Ceylan, Iowa State U. PI (Civil Construction and Env. Eng.)
  Michael Dorneich, Yang Zhang (ISU Collaborating Faculty)
• Jacklin Stonewall (ISU GRA)
• H. Gene Hawkins, TAMU PI (Civil Engineering)
• TAMU UG’s TBD
Executive Summary

• What science dictates this color for airport operations?

• Advisory Circular AC 150/5210-5D states: “Yellowish-green is the vehicle color standard”

• What motivated this conclusion?

• Do we need to be as prescriptive as the tool implies?
Motivation / Need

- FAA Advisory Circular (AC) 150/5210-5D specifies standards for paint colors for ARFF vehicles.
- This AC defines the color that must be used on ARFF vehicles funded through the Airport Improvement Program (AIP).
- Recently, the age (33 years) of this guidance has lead to questions regarding the applicability of the color criteria in this AC and the manner in which it is used to select ARFF vehicle colors.
Motivation / Need

• Applicability of the AC color criteria (chromaticity and color difference) needs to be re-evaluated
• Many recent advances in emergency vehicle color schemes, paint materials, retroreflective materials, and lighting packages have taken place
• It is no longer clear what is ‘best’ in this context
• Review of research efforts that evaluate human factors effects and any literature in which equivalent methods in closely related fields have been created are desired
• Testing technologies have advanced rapidly and offer the opportunity to maintain adherence to any new standard
Research Objective(s)

• A definitive ‘genealogy’ of the currently proscribed yellow-green color
• Historical considerations of chromaticity and color difference and (ideally) information on the decision-making process that favored them
• Human factors (if available) research suggesting the selection and use of yellow-green
• A summary of recent advances in emergency vehicle color schemes, paint materials, retroreflective materials, and lighting packages
• A summary of relevant ARFF and non-ARFF research on paint color and lighting packages
• Comprehensive recommendations for future research in the area
Approach / Methods

- Co-ordinated literature review process ✓
- Establish a common web-based portal for submission of progress reports ✓
- Hire a local student or students to assist with the literature review process ✓
- Enable student interactions between universities ✓
- Interact with airport staff and industry to discuss their perspective ✓
- Use of tristimulus colorimetry to evaluate the optical characteristics of paint and lighting packages
Approach / Methods

- Initiate biweekly conference calls to discuss progress
- Monthly telecons with Keith and Jonathon
- Organize and submit the final report and summarizing powerpoint presentation
- Final group conference call with the FAA to discuss these findings and recommendations
A significant body of scientific research pertaining to visibility and color has been published:

- The human visual system is most sensitive to the band of colors between the wavelengths of 510 and 570 nm, which encompasses greenish-yellow (or lime-yellow) and yellow.

- Lateral peripheral vision for detecting yellows is 1.24 times greater than for red.

- Purkinje effect - the peak luminance eye sensitivity shifts to blue at low illumination levels; due to pooling of rod and cone output signals as a part of dark adaptation.
• Red or red-white was the most common ARFF color pre-1976
• The biomedical science suggested that lime-green might be more visible
• Data collected to date has shown that this is correct
  – Yellow-green gave rise to an automobile accident rate of 3.0/100,000 runs; for red-white the rate was 10.4/100,000 (Solomon & King, 1995)
  – “...a number of colours were associated with higher crash risk. These colours were black, blue, grey, green, red and silver.” (Newstead & D’Elia, 2010)
  – “Yellow cars induced a faster response time” (Díaz-Román et al, 2015)
  – Solomon et al are preparing an additional report involving 2.6M firetrucking runs that shows the same result as the 1995 study
• Color Perception: differential stimulation of photoreceptors by light entering the eye
• Fluorescent colors are easiest to see in daylight (APA, 2014)
• Airport weather conditions: fog, rain/sleet, snow, ice
  – Fog: causes color shift and reduction in contrast (Hagedorn & D’Zmura, 2000)
    • Yellow light appears brightest in dense fog (Takamatsu & Nakashima, 2001)
    • White, reflective pavement markings more subjectively visible than white during dense nighttime fog (Munehiro, Tokunaga & Asana, 2005)
    • Fluorescent colors combined with retroreflective sheeting are most visible during nighttime fog (Munehiro, Tokunago & Asana, 2005)
  – Fog has received the most study; what about other weather conditions?
b. **Aircraft Fire and Rescue Vehicles.** Solid red.

**SUBJECT: PAINTING, MARKING, AND LIGHTING OF VEHICLES USED ON AN AIRPORT**

1. **PURPOSE.** This advisory circular makes recommendations, in the interest of safety, efficiency, and uniformity, for the painting, marking, and lighting of vehicles used on the aircraft operational area of an airport. The criteria in this circular replaces that contained in TSO-N4; parallels actions recently taken by the Army, Air Force, and Navy; and is consistent with recommendations made by the International Civil Aviation Organization.

2. **CANCELLATION.** TSO-N4, Army-Navy Civil Uniform Requirements for the Marking of Vehicles Used on Landing Areas, dated July 2, 1947, is cancelled.
b. Aircraft Fire and Rescue Vehicles. Solid red.

1. PURPOSE. This advisory circular (AC) makes recommendations, in the interest of safety, efficiency, and uniformity, for the painting, marking, and lighting of vehicles used on the aircraft operational area of an airport. The criteria in this AC replaces that contained in TSO-N4; parallels actions recently taken by the Army, Air Force, and Navy; and is consistent with recommendations made by the International Civil Aviation Organization.

2. CANCELLATION. AC 150/5210-5, Painting, Marking, and Lighting of Vehicles Used on an Airport, dated August 31, 1966, is cancelled.

3. APPLICATION. The recommendations contained herein apply to all new vehicles which are to be operated in the aircraft movement area and other areas not intended for use by public vehicular traffic. At such time as existing vehicles used in these areas are to be refurbished, painting, marking, and lighting should conform to the recommendations.
b. Aircraft Rescue and Firefighting Vehicles. Yellowish-Green is the vehicle color standard. This color provides optimum visibility during all light levels encountered during a 24-hour day and under the variations of light as a result of weather and seasonal changes. Color specifications are in accordance with appendix 1.
b. Aircraft Rescue and Fire Fighting (ARFF) Vehicles. Yellowish-green is the vehicle color standard. Color specifications are per Appendix A.
(2) Aircraft Rescue and Fire Fighting (ARFF) Vehicles. Yellowish-green is the vehicle color standard. Color specifications are per Appendix A.
• Sought further information regarding the deliberations in the process
• References were made to the Airport Engineering Division (AAS-100) as a source of information
• Discussed origins of decision with Marc Tonnacliff
• Indicated that original FAA personnel - George Legarreta – had since retired
• We learned that work by Stephen S. Solomon had a considerable influence on the decision-making process
• Contacted Stephen Solomon via e-mail
• Solomon communicated with George Legarreta of the FAA
• George/FAA concerned with the problems of red letters – not short letters – and phone calls back and forth for ~2 years
• Data from a variety of sources was used
• Needed to reach a decision that could be accepted both above and below that committee
• Had to fight against tradition
• Conclusions eventually wound their way through the hierarchy and into 150/5210-5B
In CIELAB Space

CIE-L*a*b* coordinates
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Still in business?/location/website</th>
<th>Contact person – name/phone/e-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-ONE</td>
<td>Yes / 4760 Camp Rd Hamburg, NY 14075 / <a href="http://www.e-one.com/contact-us/">http://www.e-one.com/contact-us/</a></td>
<td>352-237-1122&lt;br&gt;<a href="mailto:info@e-one.com">info@e-one.com</a>&lt;br&gt;Matt Reda, <a href="mailto:mreda@e-one.com">mreda@e-one.com</a></td>
</tr>
<tr>
<td>Oshkosh Corp</td>
<td>Yes / Oshkosh Wisconsin / <a href="http://www.oshkoshairport.com/arfftrucks">http://www.oshkoshairport.com/arfftrucks</a></td>
<td>920-832-3000&lt;br&gt;<a href="mailto:jshively@airport.oshkoshcorp.com">jshively@airport.oshkoshcorp.com</a></td>
</tr>
<tr>
<td>Rosenbaur</td>
<td>Yes / P.O. Box 549, Wyoming, MN 55092 / <a href="https://www.rosenbaueramerica.com/fire-trucks/aircraft-rescue-fire-fighting">https://www.rosenbaueramerica.com/fire-trucks/aircraft-rescue-fire-fighting</a></td>
<td><a href="mailto:info@rosenbaueramerica.com">info@rosenbaueramerica.com</a>&lt;br&gt;(651)-462-1000&lt;br&gt;Tag Johnson</td>
</tr>
<tr>
<td>SIMON-CARMICHAEL</td>
<td>Yes / 5 Deabsway, Worcester, WR1 2JG. UK / <a href="http://www.simonigl.com/about.asp?id=199">http://www.simonigl.com/about.asp?id=199</a></td>
<td>+44 (0) 7984 149303&lt;br&gt;<a href="mailto:sig@simonigl.com">sig@simonigl.com</a></td>
</tr>
<tr>
<td>Unruh Fire</td>
<td>Yes / 100 Industrial Dr, Sedgwick, KS 67135 / <a href="https://unruhfire.com/contact/">https://unruhfire.com/contact/</a></td>
<td>1-800-856-7080</td>
</tr>
<tr>
<td>Sutphen</td>
<td>Yes / Dublin Ohio <em>Able to visit</em> / <a href="https://www.sutphen.com/contact-2/">https://www.sutphen.com/contact-2/</a></td>
<td>(800) 726-7030&lt;br&gt;List of individual’s emails on their website</td>
</tr>
<tr>
<td>PPG</td>
<td>Yes, US, Pittsburgh, <a href="https://www.ppgpaints.com/contact">https://www.ppgpaints.com/contact</a></td>
<td>Lou Milanovich&lt;br&gt;OEM Sales Manager, PPG&lt;br&gt;(612)-325-8501</td>
</tr>
<tr>
<td>Morita Group</td>
<td>Yes, Japan/Asia, Morita119.com</td>
<td>Form To Fill</td>
</tr>
<tr>
<td>Kronenburg</td>
<td>Yes, Netherlands, kronenburgfire.com</td>
<td>+31 (0) 485-476-290</td>
</tr>
<tr>
<td>Terburg DTS (UK)</td>
<td>Yes, UK, terbergdts.co.uk</td>
<td>+44 1422-257-100</td>
</tr>
<tr>
<td>Flamex</td>
<td>Yes, UAE, flamex.ae</td>
<td>+971 6 5442033</td>
</tr>
<tr>
<td>Volkan</td>
<td>Yes, Turkey, volkan.com.tr</td>
<td>+90 232 853 96 86</td>
</tr>
<tr>
<td>Airport Suppliers</td>
<td>Yes, UK, airport-suppliers.com</td>
<td><a href="mailto:Info@rbsglobalmedia.com">Info@rbsglobalmedia.com</a></td>
</tr>
<tr>
<td>Naffco FZCO</td>
<td>Yes, UAE, naffco.com</td>
<td>+971 4 815 1111</td>
</tr>
<tr>
<td>Magirus Group</td>
<td>Yes, Germany, magirusgroup.com</td>
<td>+49 731 408-0</td>
</tr>
<tr>
<td>Access Air</td>
<td>Yes, Canada, accessairsystems.com</td>
<td>450-638-5441</td>
</tr>
<tr>
<td>Ziegler</td>
<td>Yes, Netherlands, zieglerfirefighting.com</td>
<td>+31 (0) 597-456888</td>
</tr>
<tr>
<td>Sides</td>
<td>Yes, France, sides.fr</td>
<td>+33 (0) 2 40 17 18 00</td>
</tr>
<tr>
<td>Pierce MFG</td>
<td>Yes, US, piercemfg.com</td>
<td>920-832-3000</td>
</tr>
<tr>
<td>Hacknew EV</td>
<td>Yes, US, hackneyev.com</td>
<td>1-800-763-0700</td>
</tr>
<tr>
<td>Rev Group: KME</td>
<td>Yes, US, kmefire.com</td>
<td>1-800-328-1033</td>
</tr>
</tbody>
</table>
• Tag Johnson, Rosenbauer - Happy to hear about this study being funded; acceptable PPG paint codes (corners of quadrilateral?): 944873, 945258, 945246, 945247; thinks another color – Rosenbauer Hi-Vis (938207) – is better

• Lou Milanovich, PPG - does not have a strong opinion; sent me CIELAB numbers for the PPG codes; put us in touch with the PPG Commercial Color Lab (Delaware, OH) as they have a color library

• Joe Wiggens, Sutphen - fire department gives them the color or they scan a protected area to create a chip; original color code next to the driver’s side door; also the VIN number AND every fire truck should have a manual that lists the color codes.

• Neil Dickinson, Hackney - for reflective striping on trucks they follow NFPA 1901. For most orders they receive, they follow the paint code they are given. Each manufacturer uses a specific brand/color code
**Yellowish-greens**

<table>
<thead>
<tr>
<th>Color Code</th>
<th>Lightness (L)</th>
<th>a'</th>
<th>b'</th>
<th>Delta E</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDG 944873</td>
<td>77.58</td>
<td>-9.94</td>
<td>80.45</td>
<td>0.77</td>
</tr>
<tr>
<td>FDG 945246</td>
<td>80.26</td>
<td>-7.69</td>
<td>72.21</td>
<td>2.20</td>
</tr>
<tr>
<td>FDG 945247</td>
<td>78.48</td>
<td>-10.66</td>
<td>67.03</td>
<td>2.30</td>
</tr>
<tr>
<td>FDG 945248</td>
<td>79.37</td>
<td>-13.24</td>
<td>82.39</td>
<td>3.96</td>
</tr>
</tbody>
</table>
PPG Color Codes + CIELAB coordinates
“Visibility encompasses all of the processes involved in perceiving or seeing an object within a visual environment.” (Burns & Johnson, 1999)

Conspicuity (attention getting) – a function of visual contrast between object and background (Burns & Johnson, 1999)

- Large contrast = more attention
• Contrast can be achieved through differences in brightness (luminance) or differences in color
• While fluorescent yellow increases visibility, recognizing the vehicle is *believed* to be more important than paint color (FEMA, 2009)

The Battenburg pattern is immediately recognizable as an emergency vehicle in the UK

• Color is not the only factor – reflective striping increases nighttime visibility (FEMA, 2009)
• Retroreflection: Occurs when a surface is engineered to reflect light back to its origin (FEMA, 2009)

Reflectivity: Retroreflective optics added to materials greatly enhance visibility of objects when viewed under illumination (Burns & Johnson, 1999)
• Material placement
  – Contour markings enhance conspicuity (FEMA, 2009; Hildebrand & Fullarton, 1997) in both day and night (Cook, 1999)
  – Placing material lower on vehicle may optimize interaction of material with headlights (Sivak, 2006)
  – Consider light source when choosing material location

• What patterns of markings and emergency lighting are used in conjunction with ARFF vehicles?
  – both retroreflective and non-retroreflective materials
  – Includes types/styles/patterns/technologies for lighting
Retroreflection Issues

• What colors/grades/specifications of retroreflective and non-retroreflective sheeting/marking materials are used?
• What are the vehicles/light sources that should be used as the basis for determining the luminance of the retroreflective materials used on ARFF vehicles?
  – Luminance of a specific retroreflective sheeting is a function of the luminous intensity of the light source and the viewing geometry as defined by the relative position of the light source(s) of the viewing vehicle, driver/operator, and the target (ARFF) vehicle
Retroreflection Issues

• Contact ARFF vehicle manufacturers
  – Identify manufacturing specifications for vehicle markings and emergency lighting
    • Layout/arrangement, color, material type/grade
  – Determine headlamp performance specifications
    • Luminous intensity at various measurement geometries

• Contact retroreflective sheeting manufacturers
  – Identify retroreflective materials provided to ARFF manufacturers

• Contact airports
  – Acquire photographs of actual ARFF vehicles and purchasing specifications for retroreflective and non-retroreflective materials used
  – Identify trade organizations or other groups that may impact the selection of ARFF marking patterns and material/lighting selection
Conclusions

• We will establish a definitive ‘genealogy’ of the currently proscribed yellow-green color
  – Historical considerations of chromaticity and color difference
  – Information on the decision-making process
  – Human factors research needs to become more precise

• We will summarize recent advances in color schemes, retroreflective materials, and lighting packages
  – How do these effect tower control (if at all)?

• A summary of relevant ARFF and non-ARFF research on paint color and lighting packages will be created
  – Relevance?

• Recommendations for future research in the area
Expected Future Work

- Interact with airport staff to understand their needs for ARFF control in relevant contexts
- Establish an entirely new AC that improves upon current industry positions for both color and retroreflection
- Human factors studies that compare ranges of ‘better’ colors (i.e., within the yellow-green or orange ranges)
- Just over the horizon: new technologies that could couple machine vision with human detection to overcome our biological limitations; ‘roboticization’ of airports = additional demands on markings and their functionality;
• We are looking for individuals who are interested in the following:
  – History of lime-green as an ARFF vehicle color
  – Refinement of lime-green to improve vehicle visibility
  – Issues of fading that have caused problems
  – Technological advances outside of color (e.g., lighting) that should be considered
  – Providing commentary on experiences with lime green under specific weather conditions
  – Providing commentary on retroreflective striping and vehicular striping patterns