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PEER-REVIEWED ARTICLE

META-ANALYSIS OF COLOR CONSPICUITY FOR SMALL UNMANNED AIRCRAFT

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ABSTRACT

During the development of the Small Unmanned Aircraft Systems rule under Part 107 in Title 14 of the Code of Federal Regulations, the Federal Aviation Administration reported that they do not have any data that would indicate what color, if any, would enhance the conspicuity of small unmanned aircraft. By definition, conspicuity is the quality or state of being conspicuous or how easily it can be seen or noticed. A meta-analysis of archival data determined that fluorescent red-orange color schemes would most effectively increase the conspicuity of small unmanned aircraft to help establish and maintain unaided visual contact (other than corrective lenses and sunglasses) by ground operators/visual observers and pilots of manned aircraft under day visual meteorological conditions. The use of fluorescent paint schemes on airplane and rotorcraft type small unmanned aircraft, irrespective of their size, increased the visibility, detectability, range, and conspicuity. Fluorescent paint schemes were qualitatively ranked first and had a mean detection range of 2.16 miles versus a 1.0 mile range for non-fluorescent enamel paint schemes. Civil Aviation Authorities should consider the use of fluorescent colors in the development of future regulations and requirements.

Keywords: unmanned aircraft, color conspicuity, visual line-of-sight, detection range

Meta-Analysis of Color Conspicuity for Small Unmanned Aircraft

The rapid and escalating number of small unmanned aircraft being introduced into the National Airspace System (NAS), without any equipment providing a transponding capability to electronically indicate their position to other aircraft, has resulted in an increasing number of incidents between civil small unmanned aircraft and manned aircraft. A search of the Federal Aviation Administration (FAA) Near Mid-Air Collision System (NMACS) database, utilizing the keywords, drone and unmanned, revealed 65 pilot reported NMAC's between unmanned aircraft systems (UAS) and manned aircraft from January 2016 to August 2016 (Federal Aviation Administration, 2016). Out of the 65 reported incidents, seven incidents were evaluated and categorized as a critical incident (FAA, 2016). An incident is categorized as a critical when aircraft separation is less than 100 feet and a collision was avoided due to chance, rather than any actions taken by a pilot (Federal Aviation Administration, 2010, p. 5-5). These numbers can only be expected to rise as more unmanned aircraft begin to operate. The FAA also documents sightings from pilots, citizens and law enforcement in the UAS Sightings Report and recorded 1,346 events between November 2014 and January 2016 (FAA, 2016). For example, on January 1, 2016, a pilot reported that a "drone" passed below the aircraft between 10 or 15 feet, but could not give the color or type (FAA, 2016). Not only was the UAS dangerously close to the aircraft but the pilot was unable to identify the color of the system even within such close proximity. An evaluation of color conspicuity could help develop recommendations on the color or schemes that should be employed by UAS to reduce visual acquisition time by pilots of manned aircraft and enhance the small unmanned aircraft (sUA) to maintain visual line-of-sight contact with the platform under operation in order to remain well clear, see (sense)-and-avoid, and reduce collision hazards with manned aircraft.

The emergence of civil unmanned aircraft led to the passage of the Federal Aviation Administration Modernization and Reform Act of 2012. The FAA Modernization and Reform Act established a timeline of events and provided the authorization for developing unmanned aircraft regulations. The Modernization and Reform Act led to the FAA promulgating the Small Unmanned Aircraft Rule 14CFR Part 107 in June of 2016. The Part 107 ruling outlines regulations that apply to the operation of small unmanned aircraft within the National Airspace System (NAS). An unmanned aircraft that weighs less than 55 pounds is defined as a small unmanned aircraft system according to the FAA Modernization and Reform Act, 49 U.S.C 40101 (2012).

Operators of small unmanned aircraft must follow several key provisions of the Part 107 ruling. Unmanned aircraft are restricted to daylight-only operations, a maximum of 400 feet above ground level (AGL), a weather visibility of at least 3 miles, and must remain within visual line-of-sight (VLOS) from the pilot in command (PIC) or alternatively, the visual observer (VO) (Federal Aviation Administration, 2016, p. 42006). Maintaining visual contact between manned and unmanned aircraft and between sUA and the sUA PIC is an important aspect of ensuring safety within the NAS, and to comply with the regulatory requirements under 14CFR §§107.3, 107.31, 107.33, and 107.37 for sUA and 14CFR §§91.111, 91.113 and 91.181 for manned aircraft, which address see (sense) and avoid, remaining well clear of other aircraft, and collision avoidance (Federal Aviation Administration, 2016, p. 42006).

The allowable operational horizontal range of an unmanned system is limited by human vision capabilities because the remote PIC must be able to maintain unaided visual contact (other than corrective lenses and sunglasses) with the sUAS (Federal Aviation Administration, 2016, p. 42006). Human vision capabilities are affected by the external physical properties of the sUA (e.g. paint scheme, external lighting, dimensions) and the environment (e.g. general level of ambient natural and artificial illumination, sun angle, meteorological conditions, transparency of the atmosphere, terrain masking, background contrast).

Concerns over the ability to see small unmanned aircraft have been raised by commenters during the development of the Small Unmanned Aircraft Rule Part 107. Commenters asserted "that small unmanned aircraft may be difficult to see, from both the ground and from other aircraft operating in the NAS" (Federal Aviation Administration, 2016, p. 42114). The inability to easily see or identify unmanned aircraft could be due to the colors or schemes currently utilized in sUAS designs. The Air Line Pilots Association International (ALPA) commented that UAS's may be almost all black or all white and that they can be difficult to see against a non-contrasting background (Federal Aviation Administration, 2016, p. 42114).

Increasing platform conspicuity could enhance a remote PIC's ability to maintain visual line-of-sight. An increase in the ability to maintain VLOS could also result in a greater allowable operational horizontal range. While developing the Part 107 Rule the FAA acknowledged that they do not have any data that supports the use of any color, or colors, to enhance the conspicuity of small unmanned aircraft but previous research into color conspicuity has been beneficial in other fields. Hunter safety improved by increasing the conspicuity of hunting clothing. Researchers discovered that in more than 13,000 sightings observers preferred the use of fluorescent orange paint to increase hunter conspicuity (Federal Aviation Agency, 1961). A study by King and Solomon (1995) explored the influence color has on the number of accidents involving fire vehicles. Data collected from the Dallas Fire Department revealed that the likelihood of visibility related accidents was perhaps three times greater for fire vehicles painted in a red and white color scheme versus a lime-yellow and white color scheme. (King and Solomon, 1995). The lime-yellow and white color scheme resulted in drivers having greater situational awareness. Using the concepts presented in the two previous examples could increase the conspicuity of small unmanned aircraft.

Commenters suggested several options to help increase sUAS conspicuity during the development of the Part 107 ruling. Options suggested to the FAA include the use of alternating sections of aviation orange and white, a paint scheme of a black bottom with a mostly white top and at least two areas painted florescent/aviation orange, alternating aviation orange and red paint, and utilizing bright neon orange, red, or green (Federal Aviation Administration, 2016, p. 42114). The research presented focuses on determining if any colors or patterns could help increase small unmanned aircraft conspicuity.

Literature Review

Research into aircraft conspicuity has been largely focused on manned aircraft, but conspicuity has been studied in a variety of fields and applications. Many of the colors and schemes suggested by commenters during the 14CFR Part 107 rulemaking process have been previously studied.

Rasmussen, Vaughan, and Welsh (1978) studied the conspicuity of propeller and tail rotor paint schemes. Their research sought to identify a color scheme that would enhance personnel safety on the ground in the vicinity of an aircraft by increasing conspicuity. The study involved 30 volunteers rating three paint schemes for propellers and another two schemes for tail rotor blades. The color schemes employed for the study include; (a) asymmetrical black and white stripes; (b) yellow painted tip; (c) white painted tip with a red stripe; and (d) symmetrical stripes using red, black, and white. Table 1 depicts the mean rank order by viewing angle for the three propeller color schemes studied while Table 2 represents the distribution of the two tail rotor schemes.

Table 1

Mean rank order of propeller conspicuity by paint scheme

	Paint Scheme		
Viewing Angle	Black and White	Red and White	Yellow
Upward	1.53	1.80	2.67
Eye Level	1.27	2.0	2.73
Downward	1.27	1.93	2.80
Combined	1.36	1.91	2.73

Note. Adapted from “Conspicuity assessment of selected propeller and tail rotor paint schemes” by K.W. Welsh, J.A. Vaughan, and P.G. Rasmussen, 1978, No. FAA-AM-78-29, Federal Aviation Administration Washington DC Office of Aviation Medicine.

Table 2
Mean rank order of tail rotor conspicuity by paint scheme

	Paint Scheme		
Viewing Angle	Subjective Ranking	Black and White	Red and White
Upward	Most	26	4
Eye Level	Most	26	4
Downward	Most	29	1
Combined	Most	81	9

Note. Adapted from "Conspicuity assessment of selected propeller and tail rotor paint schemes" by K.W. Welsh, J.A. Vaughan, and P.G. Rasmussen, 1978, No. FAA-AM-78-29, Federal Aviation Administration Washington DC Office of Aviation Medicine.

Volunteers selected or ranked the black and white stripes scheme as most conspicuous for both propellers and tail rotors. The differences in Table 1 paints schemes were significant at the .001 level after researchers performed a two-way analysis of variance for ranked data. Rasmussen, Vaughn, and Welsh (1978) also performed a Chi-square analysis on the Table 2 tail rotor paints scheme. The perceived differences between paint schemes were determined to be statistically significant ($p < .01$). During the development of 14CFR Part 107 commenters suggested that alternating black and white paint could increase platform conspicuity.

The Applied Psychology Corporation (1961) prepared several reports on the role of paint in mid-air collision prevention for the Federal Aviation Agency. The reports focused on the use of exterior surface treatments to aid in visual collision avoidance. The report found firstly that some paint on the aircraft is better than the unpainted metal surface due to visual blending. Their research further revealed that an optimal paint scheme utilized positive and negative brightness contrast and color contrast. The report particularly recommended using dark colors on the bottom of the fuselage and wings while also using white or any bright color on the top. A color scheme suggested to the FAA used a black bottom, a mostly white top, and included at least two areas of fluorescent orange. The Applied Psychology Corporation also concluded that fluorescent orange and red paints are preferred over other fluorescent colors and enamels of all colors. Identification ranges for fluorescent red-orange, orange, and yellow-orange averaged 2.3 miles versus a 1.0-mile range average for non-fluorescent reds and oranges or other enamels of other color. Figure 1 provides a visual depiction of the average distances for each color scheme tested.

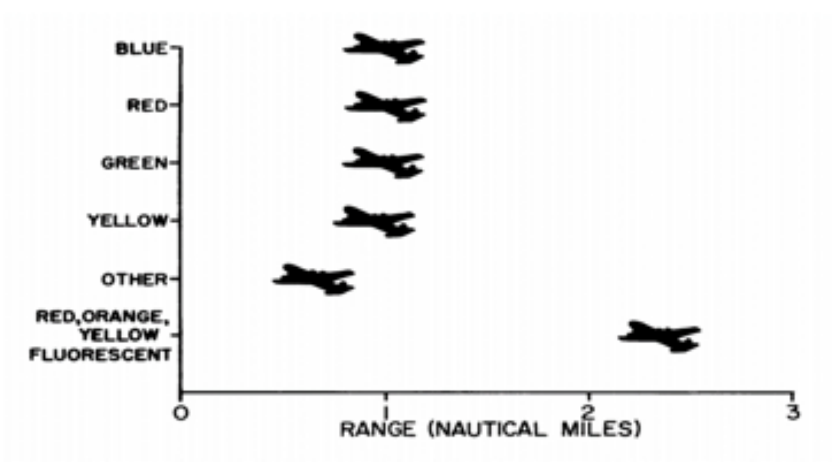

Figure 1. Average distance at which aircraft predominate color was identified. Adapted from "The Role of Paint in Mid-Air Collision Prevention" by the Federal Aviation Agency, 1961, Applied Psychology Corporation AD No. 273691.

The United States Air Force initiated a program to decrease mid-air collisions as reported by Baker (1960). The Air Force utilized fluorescent orange paint on the wing tips while also painting wide bands around the nose and aft sections of the fuselage. The Air Forces Air Training Command noted a consistent decline in mid-air collisions that closely followed the painting project and resulted in none of the painted aircraft being involved in any mid-air collisions. Most pilots commented that the painting technique contributed to the ease at which the aircraft was detected. Fluorescent orange paint was consistently recommended to the FAA to increase sUAS conspicuity.

The Applied Psychology Corporation (1961) conducted a field study on aircraft detection and color identification threshold ranges for the Federal Aviation Agency. Their research observed 541 operational aircraft from the ground to obtain approximate ranges. The research revealed that fluorescent colors could be identified twice as far away as non-fluorescent colors. While research concluded that size is the most important factor, fluorescent paint had a greater range no matter the size of the aircraft. Figure 2 presents threshold ranges of color based on aircraft size.

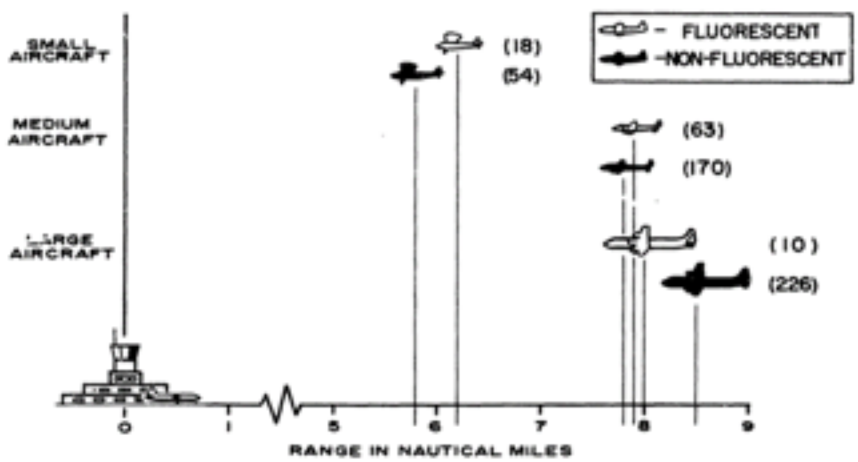

Figure 2. Average threshold ranges for fluorescent painted and non-fluorescent painted aircraft. Adapted from “Field Study of Threshold Ranges for Aircraft Detection and Color Identification” by the Federal Aviation Agency, 1961, Applied Psychology Corporation AD No. 727302.

Research conducted by Hodgson (1959) studied the use of paint to maximize the visibility of aircraft. Hodgson used ground observers, photographs, and three aircraft flying in formation, each painted a different color scheme. The study concluded that two basic principles exist to achieve a high-visibility design. To maximize contrast, black paint should be used in areas that are normally dark or shaded by the plane while areas that are normally bright should be painted white. The second principle to achieve high-visibility outlined in Hodgson’s research is the use of fluorescent red or orange paint in areas that are in direct sunlight. These principles are consistent with the Applied Psychology Corporations previous research and commenters suggestions.

Fletcher, Gifford, Lazo, and Siegel, (1969) developed a report on aircraft in-flight camouflage for the Department of the Navy. The report outlines various techniques that can be used to increase aircraft camouflage. One technique outlined in the report is the use of countershading. Countershading is using light paint in the areas that are normally in the shadow and darker paints in the normally highlighted areas. This technique is the opposite of the suggested methods and principles to increase aircraft conspicuity as previously discussed.

Siegel and Lanterman (1963) explored the use of fluorescent paint to increase aircraft detectability and conspicuity. The research centered around studies and pilot opinions on the use of fluorescent paint. Over 91 percent of the pilots interviewed expressed either a mildly positive or strongly positive opinion towards the use of fluorescent paint in increasing aircraft detectability and conspicuity. Table 3 presents the data concerning pilot opinions on the use of fluorescent paint. The research went further to suggest a possible high visibility paint scheme. Siegel and Lanterman (1963) suggested using either a glossy sea blue or white paint in conjunction with a red-orange or orange-red fluorescent paint to increase detectability and conspicuity. The research concluded that fluorescent paint might help increase detectability and conspicuity but more importantly, they concluded that fluorescent paint certainly would not create any harm.

Table 3

Pilot Opinion on the use of Fluorescent Paint

Squadron Type	Strongly Negative		Mildly Negative		Neutral		Mildly Positive		Strongly Positive	
	N	%	N	%	N	%	N	%	N	%
Helicopter	0	0	1	5	0	0	14	67	6	29
Reserve	0	0	0	0	1	3	25	76	7	21
Attack	0	0	1	5	0	0	14	64	7	32
Utility	1	10	2	20	2	20	5	50	0	0
Patrol	0	0	1	10	1	10	5	50	3	30
TOTAL	1	1	5	5	4	4	63	50	23	25

Note. Adapted from "Aircraft Detectability and Visibility: VI. A Qualitative Review and Analysis of the Utility of Fluorescent Paint for Increasing Aircraft Detectability and Conspicuity" by R.S. Lanterman, A.I. Siegel, 1963, AD No. 298331, Philadelphia, PA, U.S. Naval Air Material Center.

The Applied Psychology Corporation (1962) completed an outdoor evaluation of six paint patterns for the Federal Aviation Agency. Pilots viewed different size model aircraft with the six paint patterns on background panels under varying meteorological conditions. The researched concluded that any pattern was better than the aluminum/metallic color model, but none of the patterns were significantly more detectable than each other. The pattern that included white on top, gray on bottom, and a red-orange fluorescent empennage would offer the greatest reliability in a variety of environmental conditions as compared to the other five patterns. Similar patterns have been presented as potential solutions to increase conspicuity.

Research conducted by Bynum, Bailey, Crosley, and Nix (1967) considered paint schemes to improve helicopter conspicuity. The top of the helicopter rotors were painted in six different color schemes to evaluate their ability to increase conspicuity. Table 4 presents the mean first place rankings and *t*-Scores of the selected schemes. Data from Table 5 results in the white and fluorescent red-orange color scheme being statistically significant ($p \leq .05$) when compared to the other color schemes. The six schemes were also studied on two different days with varying amounts of light. Table 6 provides mean first place rankings and *t*-Scores on the two tested days. The white with FRO was consistently ranked first overall, with a mean score of .95 for day one and .98 for day two. Similar to many of the studies previously reviewed, researchers acknowledge that any paint scheme is recommended versus not using a scheme. Another important finding of their research was that they did not identify any significant differences in the rankings between pilots and non-pilots.

Table 4

Rankings of Helicopter Rotor Blade Paint Schemes

Scheme	Mean Proportion	*t*-Score
White – Fluorescent Red-Orange	.9650	68.1190
Black – Gloss White	.6650	54.2610
White – Orange-Yellow	.5400	51.0040
Black – Codit White	.4600	48.9960
Black Tip - White Tip	.3700	46.6810
Non-Painted	.0000	00.0000

Note. Adapted from "Development of a Paint Scheme for Increasing Helicopter Conspicuity" by J.A. Bynum, R.W. Bailey, J.K. Crosley, M.S. Nix 1967, USAARU Report No. 68-1, Fort Rucker, AL U.S. U.S. Army Aeromedical Research Unit.

Table 5

Significance Levels of Ranking of Helicopter Paint Schemes

	Paint Scheme					
	White, Fluorescent Red Orange	Black – Gloss White	White, Orange-Yellow	Black – Codit White	Black Tip – White Tip	Non-Painted
White, Fluorescent Red Orange	-	$p \leq .05$	$p \leq .05$	$p \leq .05$	$p \leq .05$	$p \leq .05$
Black – Gloss White	-	-	-	-	$p \leq .05$	$p \leq .05$
White, Orange- Yellow	-	-	-	-	-	$p \leq .05$
Black – Codit White	-	-	-	-	-	$p \leq .05$
Black Tip – White Tip	-	-	-	-	-	$p \leq .05$
Non-Painted	-	-	-	-	-	-

Note. Adapted from "Development of a Paint Scheme for Increasing Helicopter Conspicuity" by J.A. Bynum, R.W. Bailey, J.K. Crosley, M.S. Nix 1967, USAARU Report No. 68-1, Fort Rucker, AL U.S. U.S. Army Aeromedical Research Unit.

Table 6

Comparison of Rankngs for Helicopter Rotor Blade Paint Schemes on Consecutive Days

		Paint Scheme					
		White, Fluorescent Red Orange	Black – Gloss White	White, Orange Yellow	Black – Codit White	Black Tip – White Tip	Non-Painted
Day 1	Mean Pro-portion	.95	.74	.52	.44	.35	.00
	t-Scores	66.45	56.43	50.50	48.49	46.15	00.00
Day 2	Mean Pro-portion	.98	.59	.56	.48	.39	.00
	t-Scores	70.54	52.28	51.51	49.50	47.21	00.00

Note. Adapted from "Development of a Paint Scheme for Increasing Helicopter Conspicuity" by J.A. Bynum, R.W. Bailey, J.K. Crosley, M.S. Nix 1967, USAARU Report No. 68-1, Fort Rucker, AL U.S. U.S. Army Aeromedical Research Unit.

A FAA report developed by Williams and Gildea (2014) reviewed research related to UAS visual observers. The review revolved around the various human factors associated with the tasks performed by visual observers. The purpose of this review was to evaluate VO requirements to determine if any of these requirements needed to be strengthened or exceed the capabilities of a visual observer. Research highlighted several factors that affect see and avoid capabilities. One particular factor affecting see and avoid is poor contrast. Several suggestions to improve aircraft conspicuity would be achieved by increasing contrast. An increase in contrast can be achieved thru the use of light paint in areas that are normally illuminated and using dark paint in the normally shaded areas. A paint scheme that increases contrast has been suggested by several researchers and by commenters during the development of 14CFR Part 107.

Adamson (1959) reported on United States Coast Guard's efforts to mitigate mid-air collisions. The Coast Guard considered two methods, flight-crew discipline to ensure positive routine out-the-window visual scanning and the use of a high visibility paint scheme. The paint scheme employed by the Coast Guard utilized white paint with fluorescent orange trim. Alternating stripes of white and fluorescent orange paint is an option suggested to the FAA to increase conspicuity while the use of white and fluorescent orange has been suggested by other conspicuity studies.

Hall and Meeker (1995) explored the use of Multispectral Camouflage Appliques (MCAs). MCAs assist in camouflaging by manipulating the spectral characteristics of a high-value asset to disguise these assets as trees or parking lots while simultaneously reducing their thermal contrast. A key advantage associated with the use of MCAs is the ability to rapidly apply any camouflage technique or color scheme that may be required. The use of high visibility MCAs such as international orange, lime-yellow, and bright red have been successfully tested as landing and navigation makers.

Research conducted by Bauhmhardt, Blackwell, Fernandez, and Gaffney (2011) is concerned with the correlation between aircraft color and bird strikes. Their research sought to identify the impact aircraft fuselage might have on the number of bird strikes voluntarily reported. Researchers utilized a red, green, blue (RGB) additive color model as an index to measure the intensity of light in the RGB spectrums. A higher RGB score represents a higher level of intensity or a brighter color while a lower RGB score represents a darker color. The findings suggested that a correlation exists between the front and rear fuselage mean RGB value scores and the bird strike rate per 10,000 movements. Figure 3 illustrates that as the mean RGB value increases, the bird strike rate decreases.

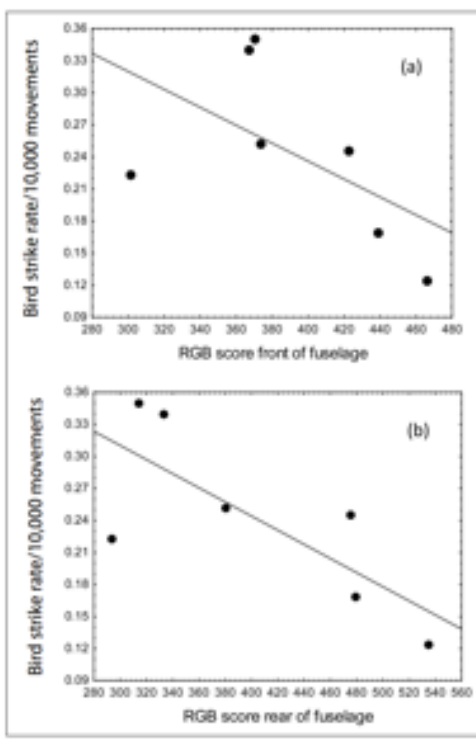

Figure 3. Relationship between bird-strikes and RGB score. Adapted from "Bird Strikes and Aircraft Fuselage Color: A Correlational Study" by P. Baumhardt, B.F. Blackwell, E. Fernandez-Juricic, and E.J. Gaffney, 1961, Human-Wildlife Interactions, 5, p. 224-234.

Their research concluded that bird-strike rates were negatively associated by the RGB score but not in a significant manner (*p = 0.192*). The researchers believe that their methodology could be used to measure avian responses to remote controlled aircraft that utilize different color schemes.

Barrett and Melkert (2005) studied the use of adaptive materials to achieve visual signature suppression to aid in UA camouflage. By tailoring the color and luminosity of a UA researchers were able to reduce the visual cross section of the aircraft to the point it was not detectable to the human eye from the ground. Decreasing the aircraft's illuminance under normal daylight conditions resulted in the darker aircraft standing out more against the white cloud background. The contrast between the dark aircraft and the light background made the UA easily identifiable to ground observers.

Federman and Siegel (1965) preformed five studies to determine what paint schemes would improve aircraft detectability and visibility. Federman and Siegel (1695) defined two thresholds, object and color, for obtaining measurements; (a) object threshold is the maximum distance at which the stimulus could be detected with certainty and (b) color threshold is the maximum distance at which the colors could be identified. The first study evaluated two sets of measurements, the outside limit (object threshold) and the inside limit (color threshold). Data concerning the inside limit measurements indicated that fluorescent blue had the largest visual field. While data on outside limits indicated that fluorescent colors have a larger visual field over ordinary colors. Vision fields of fluorescent and non-fluorescent colors yielded statistically significant differences at the .01 level of confidence. The second study utilized two luminance conditions, high and low, to determine object and color thresholds. Results of the second study indicated that fluorescent paints had a lower color threshold, but fluorescent colors had a higher object threshold as compared to their ordinary color counter parts. An analysis of variance for the data from the second study indicated a .01 level of confidence for colors and luminance levels for both object and color thresholds. Federman and Siegel (1965) conducted two field studies on the detectability of the selected stimuli. Table 7 provides object threshold ranking in field study two for the six different color schemes under varying meteorological conditions.

Table 7
Color Scheme Object Threshold Rank-Order

Rank Order	Sunny A.M.	Sunny P.M.	Cloudy
1	Fluorescent yellow-orange	Fluorescent yellow-orange	Fluorescent yellow-orange
2	Fluorescent red-orange	Fluorescent red-orange	Fluorescent red-orange
3	White	Ordinary orange	White
4	Fluorescent red-orange with a white medial stripe	Fluorescent red-orange with a white medial stripe	Fluorescent red-orange with a white medial stripe
5	White with a black medial stripe	White with a black medial stripe	Ordinary orange
6	Ordinary Orange	White	White with a black medial stripe

Note. Adapted from "Development of a Paint Scheme for Increasing Aircraft Detectability and Visibility" by P. Federman, and A. Siegel, 1965, Journal of Applied Psychology.

The data from the second study suggested that fluorescent yellow-orange and fluorescent red-orange had greater object threshold rankings as compared to the other stimuli. While fluorescent colors displayed relative superiority, there was no significant difference between fluorescent yellow-orange and fluorescent red-orange. Federman and Siegel (1965) recommended the use of unbroken fluorescent red-orange with a secondary area that provides color and brightness contrast. The suggestion of using a paint scheme involving at least two areas painted florescent/aviation orange along with black and white would be best color scheme based on this research.

The U.S Naval Research Laboratory Human Engineering Branch (1955) studied the detectability of colored targets at sea. Researchers painted aluminum spheres with different colors, to include four fluorescent colors. An aircraft flew the established search pattern while observers looked for the painted spheres from an altitude of 700 feet under varying conditions. Observers recorded the distances at which each of the spheres where recorded. Table 8 provides air to water detection distance comparison between the four selected fluorescent colors and the non-fluorescent colors. With the exception of Neon Red, fluorescent colors had a mean average of at least one mile or greater over non-fluorescents. Researchers concluded that fluorescent yellow-orange and red-orange had a greater air to water detection range when compared to non-fluorescent paints, which would be applicable for detecting a seaplane type sUA operating on the water.

Table 8

Air to Water Detection Distance in Miles

Color of Sphere	Number of Observations	Mean Detection Miles
Arc Yellow	24	2.6
Fire Orange	24	2.4
Saturn Yellow	24	2.0
Neon Red	24	1.4
Non-Fluorescent	24	1.0

Note. Adapted from “Field Study of Detectability of Colored Targets at Sea” by Human Engineering Branch, 1955, (Report No. 265). New London, CT: U.S. Naval Medical Research Laboratory

Methodology

A study of archival data is used to identify, gather, and evaluate color(s) or patterns that would help increase small unmanned aircraft conspicuity and assist in achieving and maintaining unaided visual contact by the sUA PIC and also by pilots of manned aircraft. Descriptive statistics including mean rank-order and visual detection range are used to develop a recommendation on the colors or schemes that can be employed by small unmanned aircraft.

Results

From the selected archival data, 11 out of the 16 studies recommended the use of some hue of fluorescent paint. Color schemes that included hues of fluorescent red, orange, or yellow had greater mean detection ranges than other fluorescent colors and enamels of any other color. Fluorescent oranges outperformed every tested color with a mean detection range of 2.35 miles. Color schemes that utilized hues of fluorescent yellow had a mean detection range of 2.3 miles while fluorescent reds had a mean detection range of 1.85 miles. Fluorescent colors had an overall mean detection range of 2.16 miles as compared to non-fluorescent colors mean detection range of 1.0 miles.
Other studies utilized a rank-order system to make determinations on the preferred color scheme to be employed. Fluorescent colors, in general, had a rank-order mean greater than that of non-fluorescents colors. A paint scheme containing elements of red and/or orange were recommended in 10 of the reviewed studies. A fluorescent red and/or orange have a mean rank order of 1.5. Federman and Siegel (1965) was the only study that included a fluorescent yellow-orange hue combination, which resulted in an overall first place rank order. Non-fluorescent yellow-orange or yellow hues were utilized in other studies and would reduce the rank-order to 2.03. Conversely, the addition of all red and/or orange combinations reduces the overall red/orange rank-order to 2.33. The combination of black and white, in various design schemes, resulted in an overall rank-order of 4.03. Of the reviewed archival data, the use of

black and white had the most data points, 14, followed by red and/or orange at nine.

Increasing contrast is another method that is recommended in the reviewed archival data. Six out of the 16 studies recommend maximizing contrast to increase conspicuity by utilizing light colors in normally bright areas and dark colors in normally dark areas. Four of these six studies recommended increasing the effects of contrast by also utilizing elements of fluorescent red-orange.

Analysis

Fluorescent colors outperformed non-fluorescent colors significantly in both rank-order and mean detection range. Fluorescent colors were recommended in 11 of the 16 reviewed studies with 10 of the fluorescents recommended being of red and/or orange hues.

Fluorescent color paint schemes may be a simpler, lighter, and less costly visual detection enabler for mitigating some of technological challenges of see-and-avoid equipage in manned aircraft. Manned aircraft operators are required by 14CFR §§91.225 to equip aircraft with ADS-B (Out) equipment by 2020 (Federal Register, 2015). Technologies including the Automatic Dependent Surveillance-Broadcast System (ADS-B) may be too costly, too heavy, or too difficult to integrate on to all unmanned aircraft. ADS-B uses Global Positioning Satellites (GPS) to report aircraft position and other data (ADS-B [Out]) receive aircraft data (ADS-B[In]) on a cockpit display for traffic information (CDTI) (FAA, 2016). Fluorescent color paint schemes are not an active means of reporting sUA location but could allow pilots of manned aircraft and sUA operators to detect and maintain visual contact with the sUA at a greater distance. An increased visual detection range could improve the ability of pilots of manned aircraft to see-and-avoid, remain well clear, and avoid collision hazards with sUA, as is done through electronic means with an ADS-B(In) CDTI, but at a shorter range.

Maintaining visual contact is one of the key provisions of 14CFR Part 107 and fluorescent colors could enhance a remote PIC's ability to meet these regulations. An example of where fluorescent colors could have an impact on future regulations is the current altitude limitations. Currently, unmanned aircraft have a maximum operating altitude of 400 feet AGL. It may be plausible for Civil Aviation Authorities (CAA) to increase the allowable operating altitude of unmanned aircraft if they are more readily visible. Remote PIC's also have the see-and avoid responsibilities at all times. Fluorescent colors could assist in extending the pilot's visual detection range, thereby increasing the allowable operating range.

The use of sUA in agricultural aerial spraying applications could benefit from the increased visual range associated with fluorescent colors. An operator maintaining a static control position could operate a sUA at a greater visual range and cover more area from one position, potentially removing the need for an operator to relocate to continue or complete spraying operations. In contrast, certain operators may wish to conceal, camouflage, or reduce the visual signature of a sUA. Local police may wish to reduce the conspicuity of sUA for applications requiring stealth and should avoid the use of fluorescent colors. Conversely, first responders may want to utilize fluorescent colors in search and rescue operations.

Fluorescent colors could reduce the potential of bird strikes and reduce any potential environmental impact potentially associated with increased unmanned aircraft operations. As previously highlighted, research conducted by Bauhmhardt et al. concluded that a brighter fuselage resulted in a lower number of bird strikes. Fluorescent colors could help birds identify unmanned aircraft in flight and prevent collisions that may result in the loss of a system and an overall reduction in avian populations.

Conclusions

The use of fluorescent paint schemes on airplane and rotorcraft type small unmanned aircraft, irrespective of their size, increases the visibility, detectability, range, and conspicuity, with fluorescent red-orange as the most desirable color. Fluorescent paint schemes of any color were in all cases an improvement over enamels or an unpainted metallic surface. An increase in sUA conspicuity not only improves the ability of pilots of manned aircraft to detect and avoid sUA's, but also extends the operating range in which the remote PIC and VO can maintain unaided visual line of sight. Although the overall size of a sUA is a factor that contributes towards increasing visual conspicuity, the most desirable color paint schemes were size agnostic.

Recommendations

When considering a paint scheme to increase sUA conspicuity fluorescent colors should be used instead of enamels or unpainted metallic surfaces. In particular, fluorescent red-orange paint schemes covering large sections of the aircraft and/or rotor blades should be utilized. Furthermore, the use of a paint scheme of a black bottom contrasting with a mostly white top and at least two large areas painted florescent red-orange should be considered. Figure 3 is an example of how the recommended paint scheme could be utilized to increase sUA conspicuity.

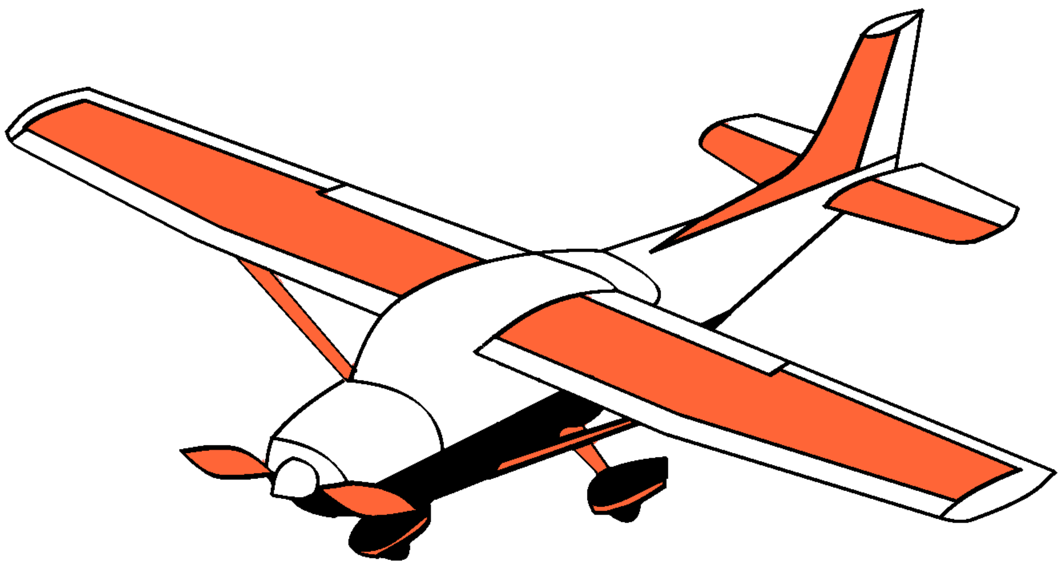

Figure 3. Example of the Recommend Paint Scheme for Small Unmanned Aircraft. A visual depiction of how the recommended paint scheme could be utilized and may vary depending on the UA. Image adapted from Clipart.org (2014).

For sUA mission applications that require occasional stealthy operations, such as law enforcement, fluorescent red-orange Multispectral Camouflage Appliques could be applied to a sUA when an increase in conspicuity is needed and removed when lower conspicuity may be needed. Civil Aviation Authorities should consider the use of fluorescent colors in the development of future regulations and requirements.

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