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INTERIOR AND CREW REST LIGHTING
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LED Reading Light Study

presented by

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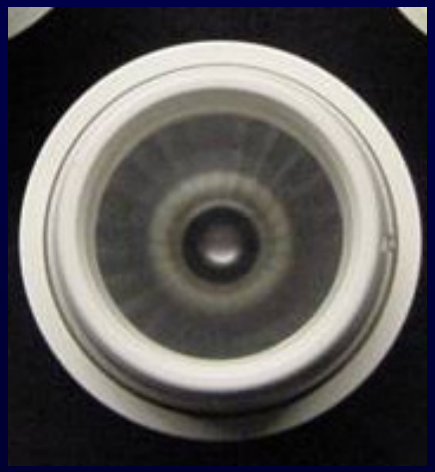
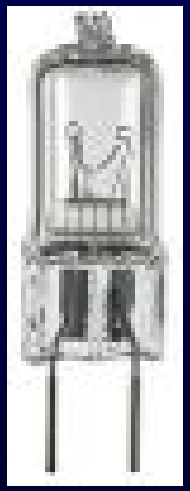
Introduction

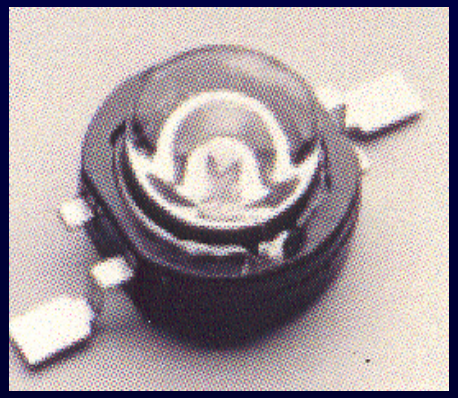
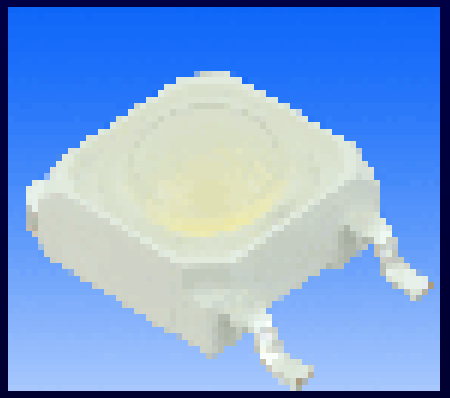
- Commonly used light source in aircraft passenger reading light is incandescent / halogen





Introduction

- LED is an evolving new technology that may have better characteristics for use in aircraft passenger reading lights

Why LEDs for reading lights?

- Longer life
  - greater than 30,000 hours, further improving
- Lower power requirements
  - 25 lm/W and continuously increasing
- More rugged
  - no filament or glass envelope to break

Reading light studies

- During the period 2003 – 2005, LRC conducted two studies to understand
  - Status of LED technology
  - How people react to LED reading lights
  - Develop guidelines for improved passenger aircraft reading lights

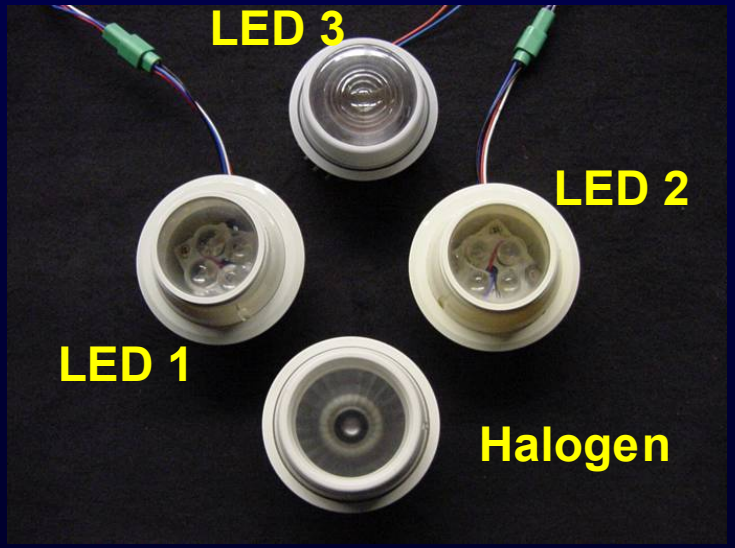
Study 1: Objectives
October 2003 to January 2004

- To test prototype LED reading lights for SAE ARP378 compliance and compare them to halogen systems

- To gather passenger opinions on several prototype LED and halogen reading lights

SAE compliance test

- Lamp type — Number of samples
  - Halogen — 12 (standard reading lights)
  - LED — 3 (prototypes, LED1, LED2, LED3)

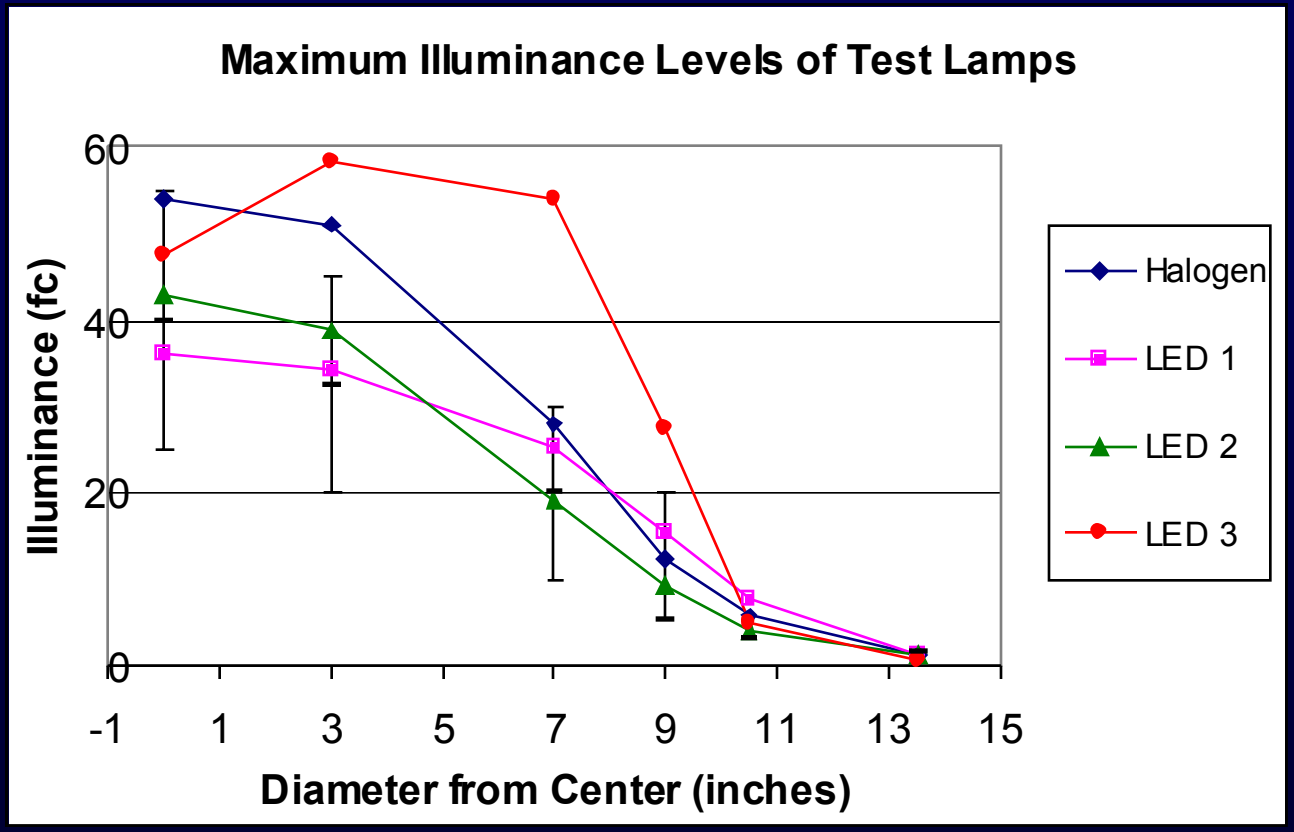


Results – Illuminance

(Measurements taken at 44 inches)

SAE ARP378 Guidelines Illumination Levels (fc)	Halogen (fc)	LED 1 (fc)	LED 2 (fc)	LED 3 (fc)
25 – 55 @ center point	54.7 ± 4.9 47.0 – 62.3	35.9 ± 0.0 35.8 – 36.0	42.9 ± 0.6 42.0 – 43.5	45.7 ± 1.2 42.7 – 47.5
20 – 45 @ 3” radius	46.2 ± 6.0 32.5 – 54.9	32.2 ± 1.4 30.8 – 34.4	33.4 ± 5.0 25.6 – 40.6	49.1 ± 6.1 40.0 – 58.1
10 – 30 @ 7” radius	19.8 ± 5.9 10.1 – 31.8	20.9 ± 3.1 16.9 – 25.4	14.7 ± 4.4 7.8 – 22.5	28.2 ± 16.3 10.5 – 53.9
5 (minimum average) 20 (maximum) @ 9” radius	7.5 ± 3.1 3.5 – 17.3	10.9 ± 2.8 7.5 – 15.6	6.1 ± 2.8 2.2 – 12.3	12.1 ± 7.7 4.6 - 27.3
3 (maximum) @ 10.5” radius	3.3 ± 1.5 1.7 -8.9	4.8 ± 1.7 2.7 – 7.9	2.58 ± 1.2 1.3 – 6.6	1.0 ± 0.2 0.7 – 1.4
1.5 (maximum) @ 13.5” radius	0.9 ± 0.2 0.6 – 1.8	1.0 ± 0.1 0.8 – 1.2	0.9 ± 0.1 0.7 – 1.3	0.5 ± 0.1 0.5 – 0.7

Results – Illuminance Patterns



LED 3 had higher light levels on the task even though it had the lowest power

Results – Flux / Color

Integrating sphere measurements

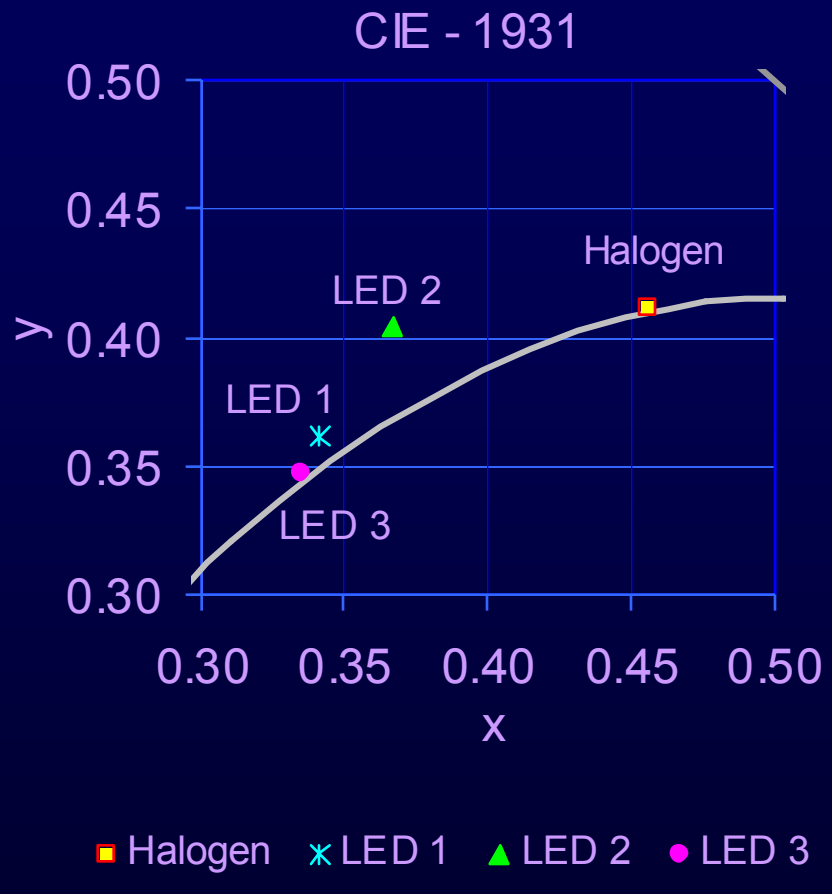
Temperature inside the sphere = 25°C

Lamp	Power (Watts)	Flux (lumens)	Efficacy (Lm/W)	CCT (K)	CRI
Halogen	10.0	49	4.9	2747	99
LED 1	6.1	53	8.7	5165	67
LED 2	6.3	47	7.7	4517	68
LED 3	5.0	63	12.6	5396	70

LEDs consumed 40% to 50% less energy than the halogen

Results – Color

Lamp	CIE x	CIE y	CCT (K)	CRI
Halogen	0.4567	0.4109	2747	99
LED 1	0.3415	0.3619	5165	67
LED 2	0.3674	0.4046	4517	68
LED 3	0.3350	0.3478	5396	70



CCT values for LED systems were much higher than halogen

Summary – SAE Compliance test

- For the most part, all reading lights met SAE specifications.
  - Beam pattern varied significantly
  - Non-uniform beam patterns
- All LED light sources had significantly higher CCT values than halogen.
- LEDs consumed 40% to 50% less energy compared to the halogen.

Part II: Passenger Opinion Study

Objective: To gather passenger opinions on several prototype LED and halogen reading lights so that improvements can be made in the future.

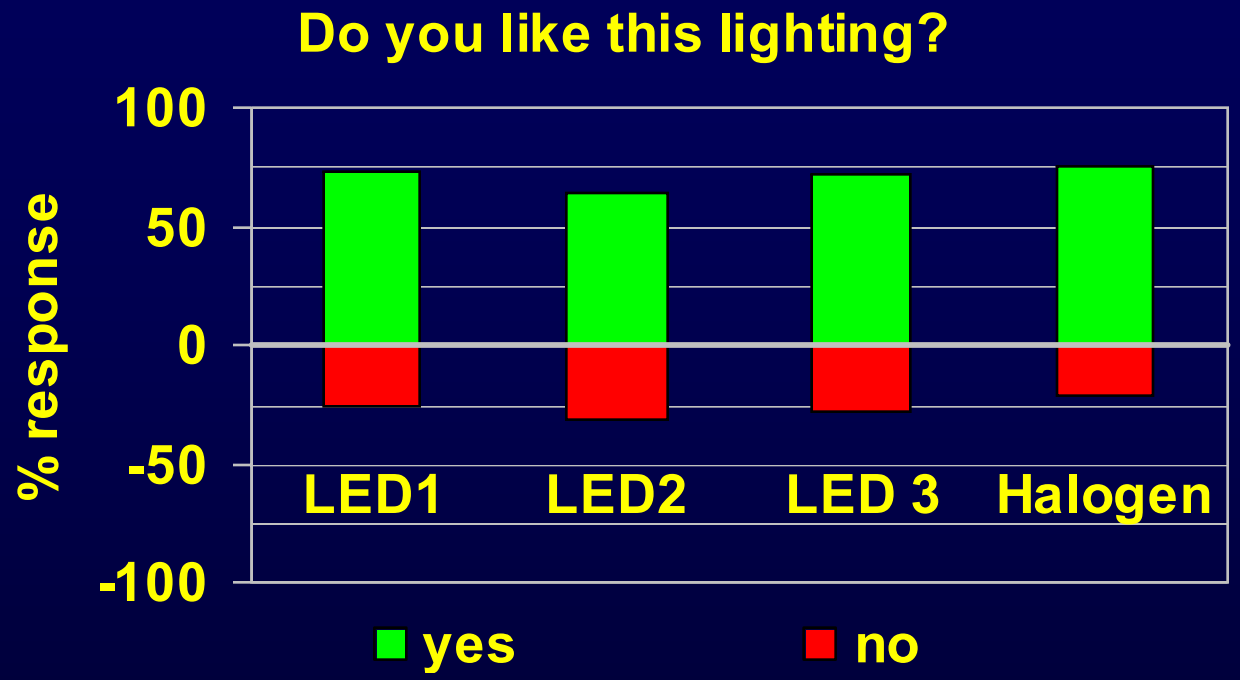
Test setup

- A mock aircraft cabin was set up with a 2x2 seating arrangement. All light sources were mounted at 44”.
- The test lamps were positioned 8” in front of the seat. The beam from each test lamp was aimed at the center of the passenger tray.
- All reading lights remained on during subject experiment.
- Ambient light levels in the test room: 0.2 – 0.8 fc
- 60 subjects: different age groups, mixed ethnicity, and all subjects have traveled at least once per year on an aircraft

Experiment Procedure

- Subjects performed the following tasks:
  - Computer (typing)
  - Reading (number verification)
  - Color discrimination (compared color samples)
- Completed surveys at the end of each task
- The light sources were presented in random order
- Task performance was also in random order

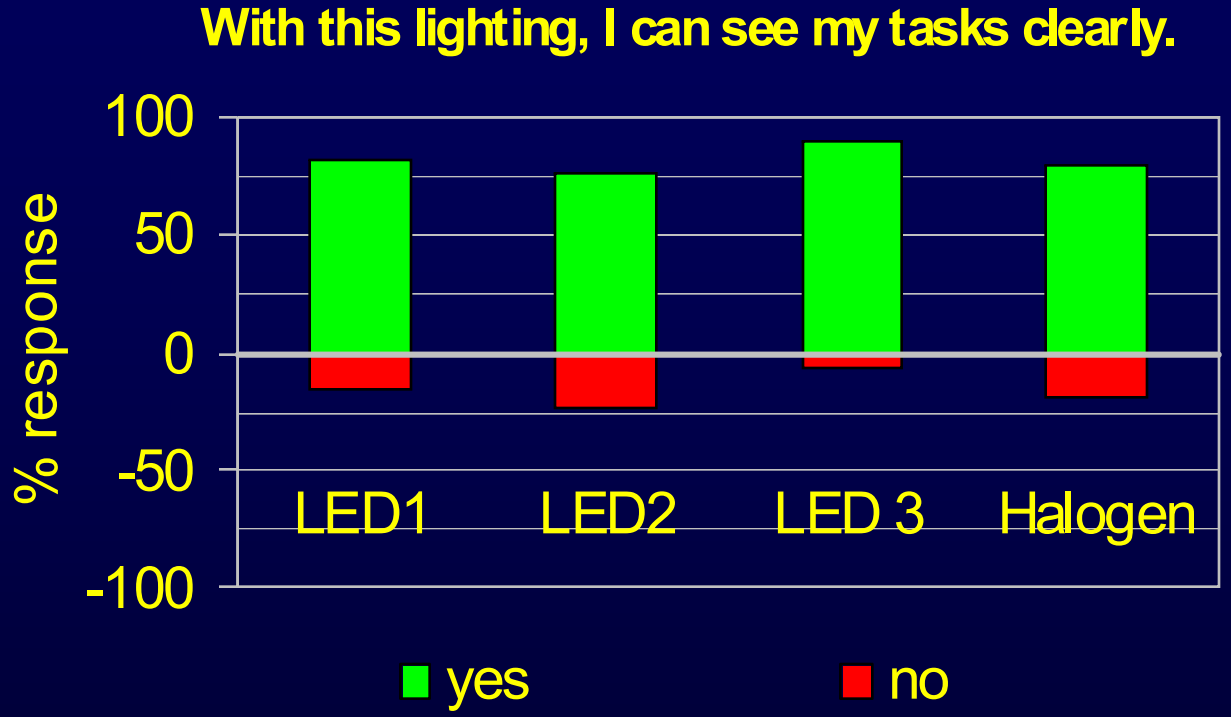
Results



None of the light sources can be considered perfect

- about 25% negative responses for all systems
- very small differences between them

Results

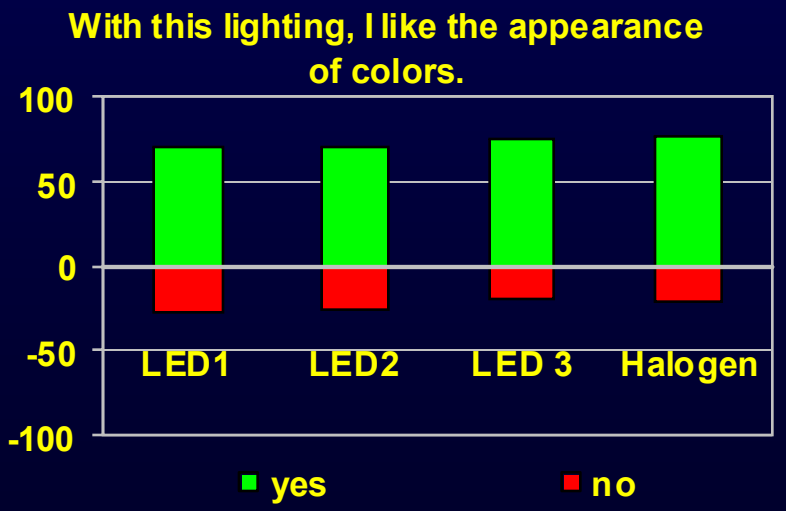


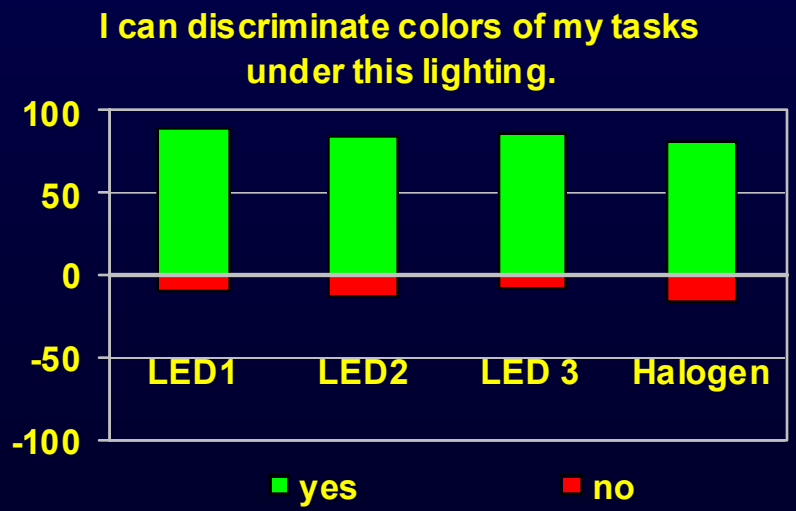
There is some relationship to illuminance:

LED3 with highest overall illuminance shows the least number of negative responses.

Results – Color

- Negative responses are not negligible, but little difference exists between all the reading lights.
  - Color rendering is not a critical problem for these reading lights.
- Comments
  - Poor skin tone rendering for LED reading lights
  - LEDs too blue or green; halogen too yellow





Results – CCT

- As CCT increases, the percentage saying the light is too blue increases; and as CCT decreases the percentage saying the light is too yellow increases. These data suggest that the optimum CCT would be around 4000 K

Summary – Passenger Opinion Study

- Light level at the reading task influenced rating
- Color appearance and rendering were a problem with all fixtures
  - Poor skin tone rendering for LED reading lights
  - LEDs too blue or green; halogen too yellow

Conclusions

- LEDs are more energy efficient (40-50%) than halogens for reading light application.
- LED reading lights and halogen reading lights perform very similar in terms of passenger response.
  - Color appearance was a problem with all fixtures
    - LEDs too blue or green; halogen too yellow
  - Skin color rendering was a problem with LED fixtures
    - Poor skin tone rendering for LED reading lights
  - Light level at the reading task influenced rating
- By fine-tuning the LED reading lights, they can be made to perform better than halogens in terms of passenger response.

Study 2: Objectives
January – March 2005

Identify appropriate

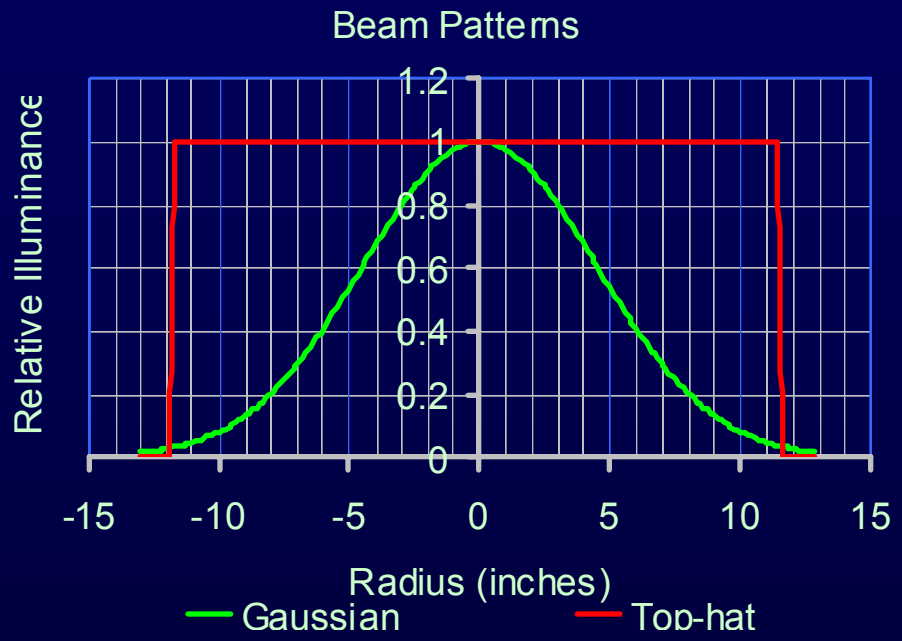
- Correlated color temperature (CCT)
- Illuminance level
- Beam distribution

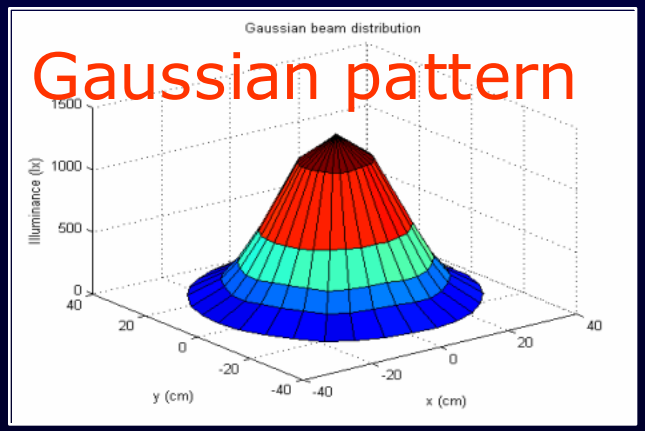
for aircraft reading lights.

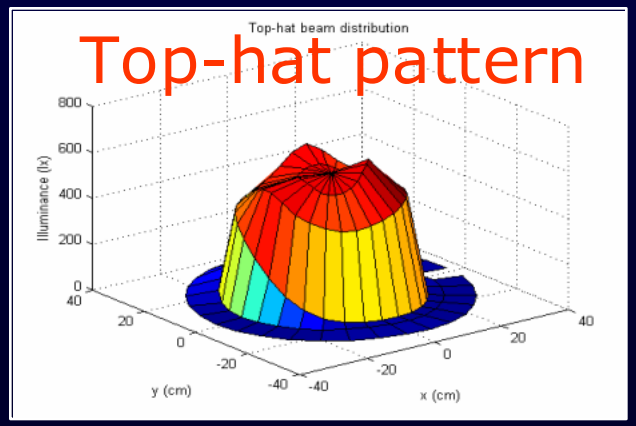
Experiment

- Room: 9.5 ft x 7.5ft x 11.5ft high
- A mock cabin: 4ft 11in x 7.5 ft
- Room temperature: 72°F
- Seats: 2 seats in 2 rows
- Subjects: 15 F / 14 M, various ethnic backgrounds and ages
- Other requirements: At least ten commercial flights in their lives and at least one flight within the last two years

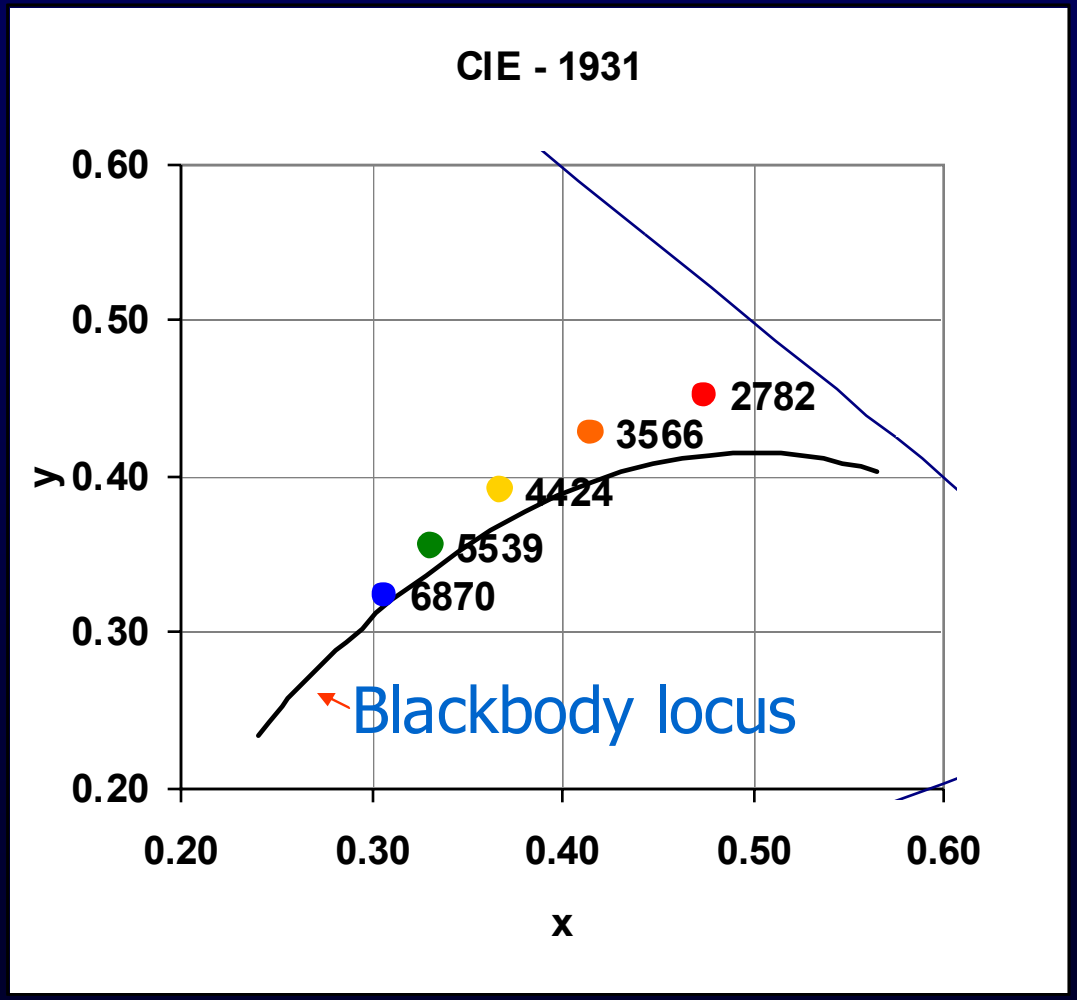
Beam patterns: Gaussian vs. Top-hat







Test reading light CCTs



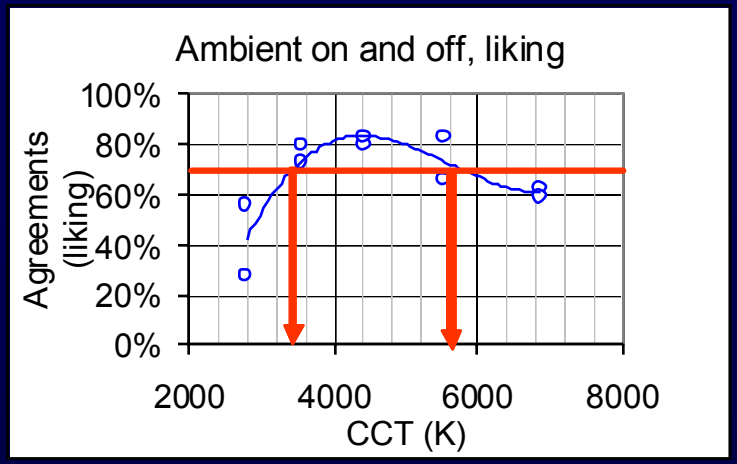
CCT Study: Variables and conditions

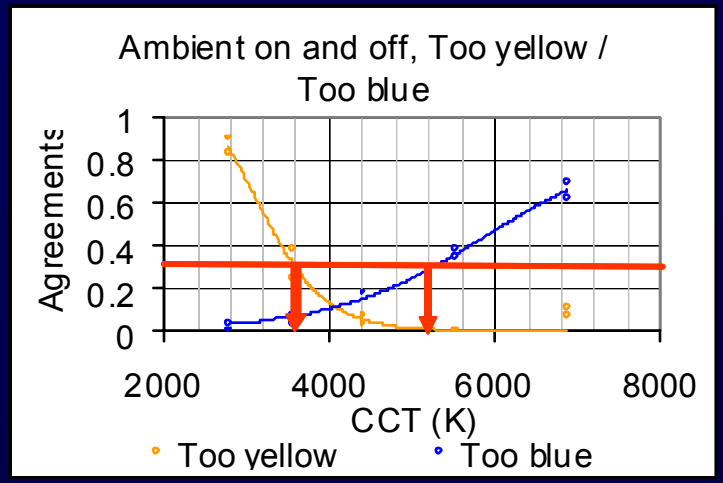
- Independent variables
  - Task CCT: 2780 K, 3570 K, 4420 K, 5540 K, and 6870 K
  - Task illuminance due to ambient lights: 0 lx (off), 150 lx (on)
- Dependent variables
  - Subjective evaluations: 13 questions using a 5-point scale
- Controlled parameters
  - Task illuminance due to reading light: 400 lx
  - Beam distribution: Gaussian pattern
  - Ambient light CCT: 3500 K

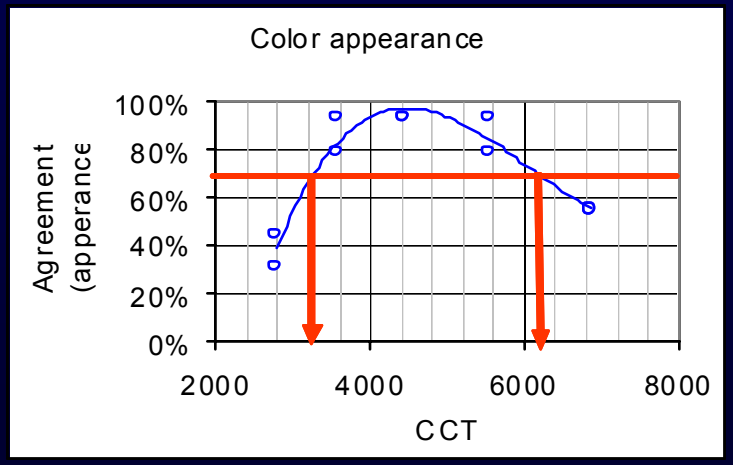
Analysis focused on:

- Liking
- Color appearance
  - beam
  - objects

Recommended range for CCT







Based on 70% criterion

	CCT range
Liking	3400 - 5600 K
Not too yellow or too blue	3600 - 5200K
Color appearance	3200 - 6200K

A CCT range of 3600-5200 K is recommended

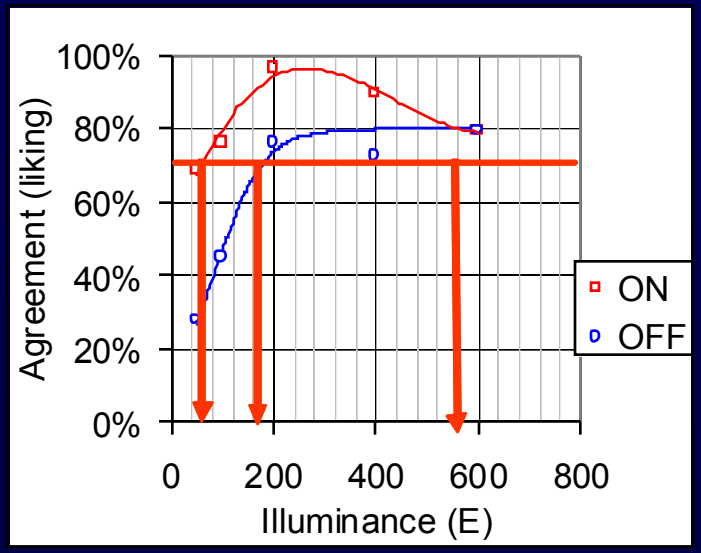
Light Level Study: Variables and conditions

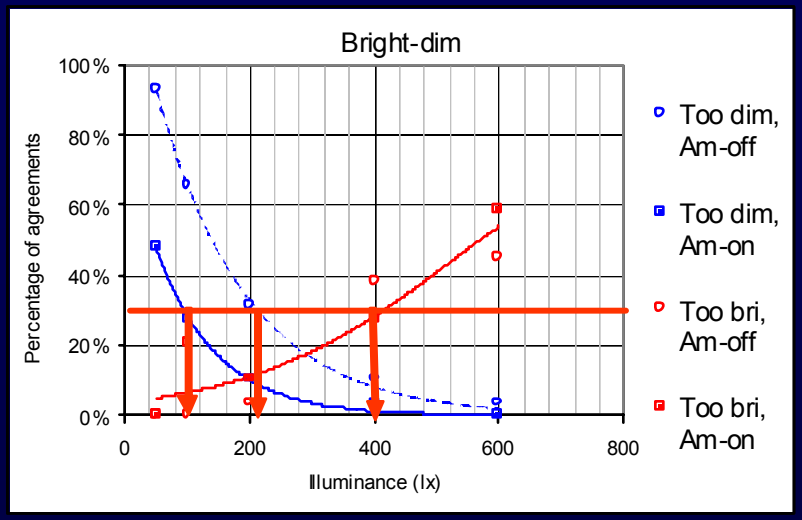
- **Independent variables**
  - Beam patterns: Gaussian, Top-hat
  - Task illuminance: 50 lx, 100 lx, 200 lx, 400 lx, and 600 lx
  - Ambient illuminance: 0 lx (off) and 150 lx (on)
- **Dependent variables**
  - Subjective evaluations: 13 questions using a 5-point scale
- **Controlled variables**
  - CCT: 4420 K

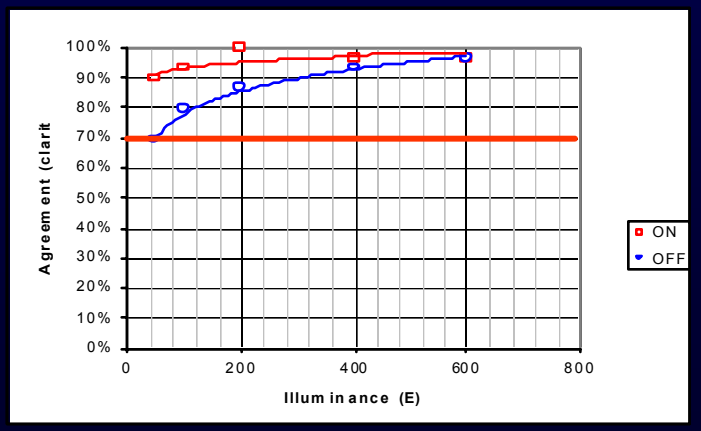
Analysis focused on:

- **Liking**
- **Visual clarity**
- **Brightness**

Gaussian: Recommended illuminance range



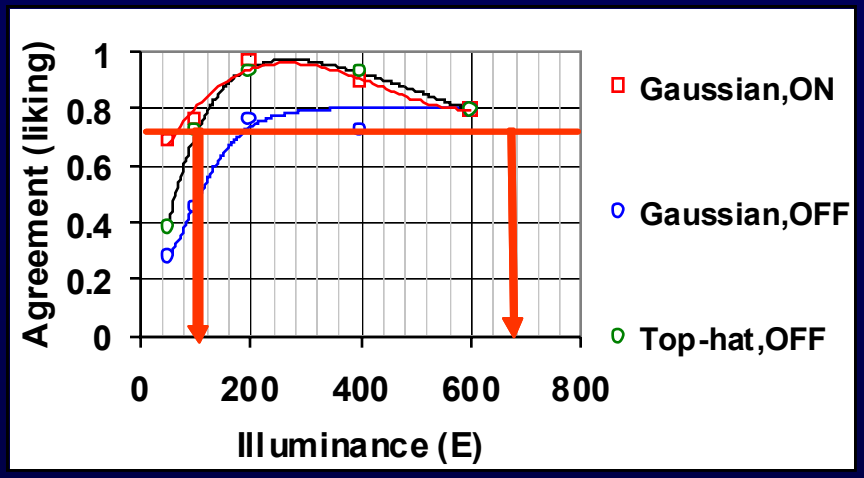


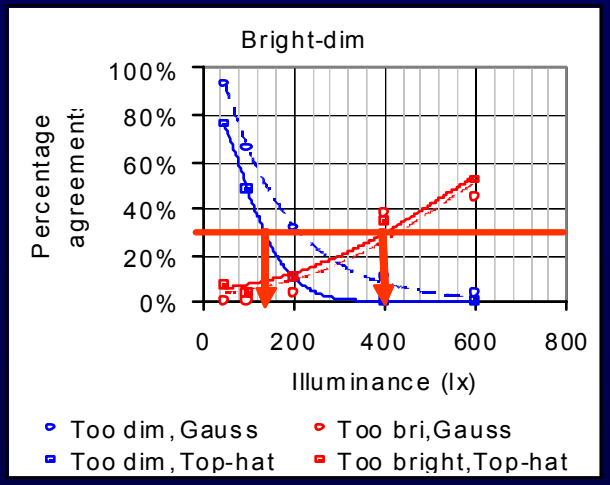


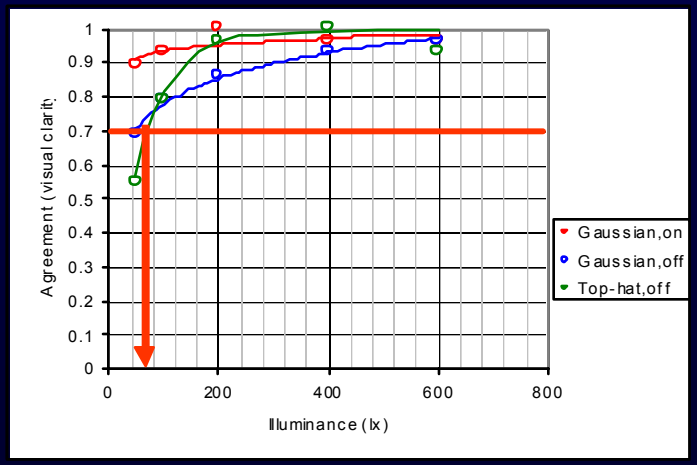
Ambient	ON	OFF
Liking	> 60 lx	> 160 lx
Not too bright/dim	100 - 400 lx	220 - 400 lx
Visual clarity		> 60 lx

220 - 400 lx for beam center

Top-hat: Recommended illuminance range





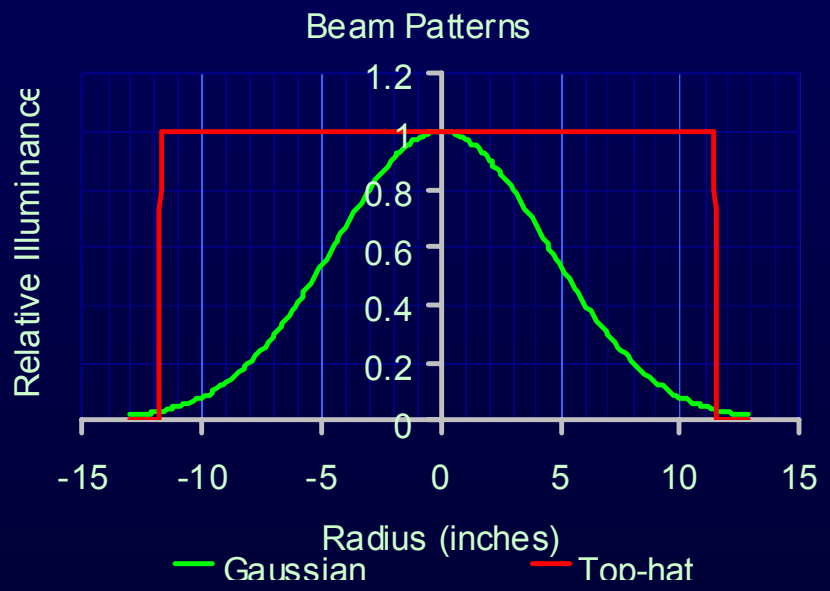


	Range
Liking	100 - 680 lx
Not too bright/dim	160 - 400 lx
Visual clarity	> 60 lx

An illuminance range of 160 - 400 lx is recommended

General Recommendations

- CCT: 3600 to 5200 K
- Illuminance at beam center:
  - Gaussian 220 to 400 lx
  - Top-hat 160 to 400 lx



- To ensure beam quality:
  - Tighter beam illuminance range at each radial position

Thank You