



User-Experience-Based Visual Design Study for Carrier Optical Landing-Aid System

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Abstract. The design idea of Improved Carrier Optical Landing-aid System (ICOLS) has an important impact on the research of carrier landing-aid system. At present, the research on ICOLS in China is mainly focused on the working principle of equipment and technology realization. Although the research on optical and laser application and safety protection technology are relatively mature, the practical application field has not clearly defined the guidance of carrier optics yet formed a complete set of guideline for the visual design. This paper is aimed to investigate the ICOLS systems according to the theory of visual ergonomics, and provide optimization recommendations on optical guidance system for the future development of aircraft carrier. The study gives a brief review of development on optical landing-aid. The optical signal cognitive theory and design principles are analyzed and summarized. A questionnaire survey, observation, and user interview methods were taken to explore the needs of the pilots by asking the information needed at the time of carrier landing. Then, design concept of user-experience-based visual design in line with the existing ICOLS system has been developed, which provides three sets of optical signals in different stages of different distances guided by the basic principles of recognition, and gives the physical properties and optical characteristics' definition. In addition, a simulation software based on PC and flight game consoles has been developed to simulate the optical signal and driving conditions following by a subjective satisfaction survey and a usability test.

Keywords: User experience · Optical landing-aid system · Visual perception Usability

1 Introduction

Landing, with problems such as instable navigation, narrow space to land, short runway, terrible environment, has been the core difficulty of aircraft carrier operation, which is far more difficult than normal airplanes and needs more technique to operate. Pilots in the returning carrier need to specifically control the glissade deviation, center deviation, angle of attack, speed and slope in a short period. According to statistics, the probability of failure of the carrier based aircraft landing at night to reach 15% to 22%,

during the day is 5%. More than half of the accident is mainly because pilots fail to make the right decision or not able to get the information on time while glissading down [1, 2]. Pilot's visual vision is heavily taken up while perceiving the displayed information from panels in a special channel. To solve the problems on lack of location guidance at night, designers usually consider to use the peripheral vision to guide the pilots [3].

The design idea of Improved Carrier Optical Landing-aid System (ICOLS) has an important impact on the research of carrier landing-aid system. At present, the research on ICOLS in China is mainly focused on the working principle of equipment and technology realization. Although the research on optical and laser application and safety protection technology are relatively mature, the practical application field has not clearly defined the guidance of carrier optics yet formed a complete set of guideline for the visual design. By improving optical signal, it may provide the pilot with more visual guidance information and help them with better an early decision-making, and makes the driving task subject to a certain interference.

Persistent light guidance can be taken as an alert task that catches persistent attention, increasing the constant load of the pilots' working memory, which will easily disturb the pilots while driving or making decisions [4]. However, the pilot's visual cognitive processing resources are limited. According to Wickens's multitasking resource allocation theory [5-7], for most optical assistive guidance information, the information specified instruction affects the difficulty of information recognition and processing, and the layout of the information will lead to the transfer of the pilot's visual resources. Therefore, the questions such as how to optimize the optical guidance signal, which kind of guidance should be chosen to improve the pilot's information recognition efficiency and driving performance, are great significance to the ICOLS.

However, currently, the user visual cognitive processing resources to the ICOLS are inadequate in China. The optical signal is the most intuitive and fastest guide mode for the high-speed aircraft when landing on the carrier. The key issues, such as methods for optimizing the optical guidance signal, guidance for improving the user information recognition efficiency and driving performance, are great significance to the contribution to the ICOLS. Designing an optimized visual design for carrier optical landing-aid system based on user experience, such as driving situation and driving needs, could provide safety landing at decision-making level, meanwhile to improve efficiency of landing training activity.

2 Research Method

This paper is aimed to investigate the ICOLS systems according to the theory of visual ergonomics, and provide optimization recommendations on optical guidance system for the future development of aircraft carrier. The study gives a brief review of development on optical landing-aid. The optical signal cognitive theory and design principles are analyzed and summarized. A questionnaire survey, observation, and user interview methods were taken to explore the needs of the pilots by asking the information needed at the time of carrier landing. Then, design concept of user-experience-based visual design in line with the existing ICOLS system has been

developed, which provides three sets of optical signals in different stages of different distances guided by the basic principles of recognition, and gives the physical properties and optical characteristics' definition. In addition, a simulation software based on PC and flight game consoles has been developed to simulate the optical signal and driving conditions following by a subjective satisfaction survey and a usability test.

3 Optical Landing-Aid

3.1 Human and Optical Signal Interaction

The process of the pilot using the landing-aid system is a process of information exchange, with the input and output devices used as an interactive media. While gliding, pilots tend to make use of the information outside of vision, such as runway, the nearby marking lines, and the trailing tail to determine the route to the carrier, during daytime and good weather. But only the optical signal can be utilized to guide the route in the night and bad weather. To take the trailer waiting for the route to serve as an example, the carrier-based aircraft in the carrier waiting for the landing instructions issued by the carrier, then leave the Marshall holding pattern for 10 n miles away from the back of the carrier, and continue to raise as high as 1200 feet, putting down landing gear, turning into the Carrier Landing configuration. Travel to 3–4 nautical miles to capture the gliding point, directly into the glide route [8]. The pilot determine their own coordinates and routes and other flight data into the down route by monitoring radar and ground signals, during which the aircraft is landing along a certain slope (usually 3.5° – 4°). The aircraft may hit the carrier if the slip slope were too low, and it may let the arresting cable fail to blocking leading the failure of go around, if the slippery slope were too high. When approaching about 0.75 nautical miles, the aircraft landing down to 375 ft, through the view of carrier form, the Fresnel light guide signal and the radio command to determine the landing time. If the landing failed, then go around again and get into the gliding route at 3–4 nautical of the go around route, as shown in Fig. 1.

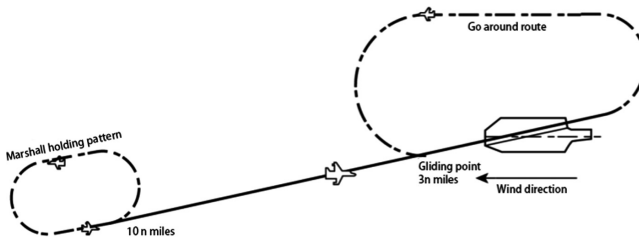


Fig. 1. Stern preparation arrival route.

The information input of whole interactive activity includes five parts: (1) digital information; (2) the external environment vision; (3) other visual information; (4), sound information; and (5) tactility information. The landing process involves visual range, auditory, and tactility, of which each stage is often occupied by more than one

channel. According to the Wickensdorf resource processing model [9], the user wants to call two or more channels in the same dimension at the same time. This will inevitably lead to the increase of cognitive load [10].

The pilot can reduce the cognitive load by following several design methods: (1) improving the sensitivity of the target signal, enhancing the user's ability to memorize the signal characteristics, therefore, the pilot can use the intuition to determine the meaning of the guide without accomplishing a complex thinking process; (2) improving the highlight of the target; (3) joining the transient hearing aid in a specific stage to the continuous visual presentation, and reducing the visual resource processing load; (4) reducing the number of propositions.

3.2 Cognitive Principle Based Optical Visual Elements

There are a number of deck lights on the aircraft carrier at night, landing-aid guidance light should align the pilots' cognitive knowledge and pay attention to specific differences of the light. The following parts illustrate factors that affect the identification of optical signals, i.e. lighting color, strobe, layout, and lighting intensity, of recognition optical signals based on the cognitive principle of "the high load or low sensitivity caused by weaken visual tasks", and put forward associated design rules.

Lighting Color. Colors, such as red, green, yellow, and white, are commonly used in the field of lighting color, of which values are based on General Requirements of Lighting Fixtures for Civil Airport (GB/T 7256-2005) or the International Association of Marine Aids to Navigation and Lighthouse Authorities Navigation Guide [11, 12]. In the airport navigation lighting system, the HAPI system for example, the green lights flash for high, while the aircraft is on the slide line, the green lights are steady; when the aircraft is slightly lower the red lights are on, whilst the red lights flash when the aircraft getting lower [13]. Optical guiding should be designed in line with pilots' cognitive habits, otherwise it will cause identification problems [14]. Semantic uniformity and prevent light color interference can improve the light color recognition: (1) in the same system, indicating an azimuth semantics corresponding to the light color should be formed into rules, where two or more light color should not be represented the same meaning; (2) white and yellow color are difficult to be identified from long distance, which should be avoided.

Strobe. Common azimuth lights, warning lights, and other lights' conventional flashing frequency are between 0.75 Hz and 2 Hz. NASA's research on the target light flashing frequency of eye-catching degree studies have shown that 2 Hz frequency is the most easily identified frequency, where fast flicker appropriate frequency is about 2 times as the slow flicker frequency, and 60–120 times/min flicker rate (1–2 times/s) for the highway and the channel can take into account people's ability to identify and available hardware restrictions [15, 16]. In the field of industrial applications, transportation, navigation aviation on the specific function of the light or different light quality of the light rhythm are provided. As a system, it is recommended to use a set of frequencies to distinguish the frequency of fast chatter, or to prefer a higher speed flash.

Layout. As shown in Fig. 2, pilot mainly use the glissading reference angle and the position of the Fresnel light as the reference of glissading of the slope, while use the runway tail line, the runway center line and the tail hanging light as the reference of centering. By visual focusing on the carrier stern and the left side of runway, guidance light is concentrated in the tail and runway edge on the left. The semantics of the “+” or “T” glyphs are the most matched with the mid-down, which is consistent with the basic order of the human eye’s search information, and the response mode of flight light. The “+” and “T” form distribution can effectively distribute the slope and centering signals in the range of 15° – 20° of the central zone of human eyes, where the human eyes rotates more efficiently [17].

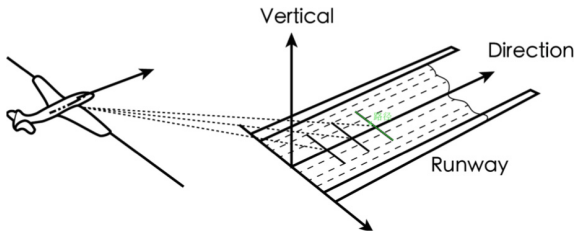


Fig. 2. Visual focus schematic.

The visibility of lighting layout is related to the distance and the human perspective. As the length of the light from the long distance will become shorter, and the larger spacing can form a clear linear effect. While from the distant distance, as the vertical column, horizontal row of the formation of the angle difference getting smaller, parallax changes for the vertical column will be a greater impact. Hence, the “graphical” guide only in a closer distance to play a more intuitive role, and point light can be used for remote guidance.

When the two adjacent lights need to be clearly distinguished, it is important to consider the angle of the view when designing the pitch. Based on the calculation, the deviation angle is very small when flying carrier-based aircraft to do a small increase and fall, which is, the light is not complete offset, resulting in difficulty of identifying the change. When the number of lights is increased, the range of light beams in each light room becomes smaller and the observed light drift is relatively complete when the aircraft is subjected to minor settling at a close range.

The design of the light pitch can be analyzed by referring to the principle of parallax angle that is to determine whether the configuration is theoretically reasonable. Transverse light with a distance of three meters when the theory of the maximum resolution of the line of sight is not more than five nautical miles. According to the analysis, it can be considered to increase the Fresnel lamp room offset slope and the number of lamp rooms, which can get farther resolution of the line of sight, as well as the guidance accuracy and horizontal row. Vertical column guide is limited to close precision guidance by distance. The increase in the guidance of the accuracy of the decline, will affect the observation of information, which the information on the

distribution of the two sides of the ship and the middle of the runway extension line area is conducive to the driver's observation.

Lighting Intensity. Light intensity is one of the important factors that affect signal discovery. If the light is too bright, it could hurt the pilot's vision, and consume more energy. Whereas the light is too weak, which will not conducive to the pilot observation. Thus, the lighting system design should consider following two issues:

- (1) The design of different lighting intensity system and light source should consider different visible distance. Remote light source should has 10 nautical miles for distance indication. It is difficult to achieve the light group graphics, which has to use monochrome, divergence, and penetrating laser light. Medium-range guidance system should follow the roles of 4 miles and light color recognition. The short-range guidance system is mainly on Fresnel lens light box.
- (2) Light intensity adjustment system should be well designed. "Airport lighting equipment configuration and performance requirements" specifies the edge line lights and midline light intensity adjustment range and has five levels: 1%, 3%, 10%, 30% and 100% [18]. Without special requirements, the short-range guide light group can be set to ten light intensity adjustable between 10% and 100%.

4 User Requirement Mining

The ICOLS system is deemed to be able to improve the landing efficiency to pilots. A study on the need of China pilots has been carried out. Figure 3 indicates that the most critical landing time is between 40 s–50 s, when the pilots' attention is mainly focused on angle of attack, the middle runway and Fresnel lights.

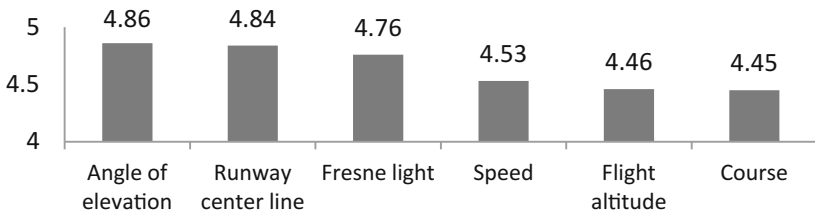


Fig. 3. Information requirement of pilots' attention.

As shown in Fig. 4, before moving into the carrier's route, the pilot mainly focuses on the descending point or the midline of the runway to find the course and determine the target through observing the current pitch attitude and slope, speed, and heading to adjust the flight attitude.

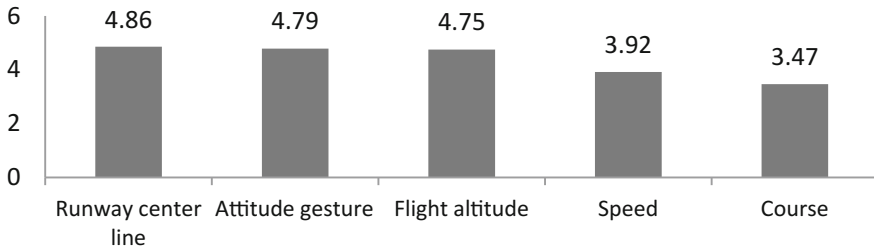


Fig. 4. Information requirements of pilots before entering the downside route.

Based on the analysis of cognitive principles and design principles, the following lessons has been learned for visual design of ICOLS:

- (1) Adjusting into the down route is needed when the aircraft carrier is in the range of 10 nautical miles, where instrumentation and radio are the main information sources to the aircraft; When the instrument and radio are failed, which cannot provide precise positioning, lights can guide the carrier to get into the appropriate range of decline.
- (2) While at range of 3–4 nautical miles, it can be considered to increase the middle of the guide in the tail, as the carrier is hard to identify. The guide light can help the pilot with successful landing into the appropriate area;
- (3) The current efficiency of FLOLS is inadequate, resulting in dangerous landing based on the pilots' own experience at the final landing stage, which causes a high mental load, and unstable operation. Therefore, to improve the efficiency of FLOLS is critical.

5 System Design and Simulation

5.1 System Design

Planning the installation position and scope of light group will be based on the actual situation of the development of optical assisting guidance system and the existing information [19, 20], the design analysis, and user study.

Light Installation Location

Fresnel Lens. IFLOLS and FLOLS are installed in the same location, located on the outer side of the flight deck of carrier, which is about two-thirds of the runway. The lens center is about 4.115 m away from the carrier's side, which uses inertial stability control system to reduce the impact of aircraft carrier roll.

Transverse Band. Installed in the bottom of the carrier below the slope, the center of the yellow and the middle of the runway are aligned, and paralleled to the runway entrance light. The central yellow light beam paralleled to the descending baseline.

Tail Hanging Lights. The lights are installed in the bottom of the carrier below the slope, and extended to the sea to avoid light color interference, which go perpendicular

to the runway center line, where the top lights are away from Crossbar center yellow light about 1.5 m–3 m.

The End of the Guide Index. It is installed on the left side of the carrier's runway, paralleled to the runway centerline. One on the runway deck side of the Fresnel lens is in the front of about 76.2 m, the other in the rear of the lens 76.2 m. In order to avoid the runway edge, the distance is greater than 3 m. The specific location can be adjusted according to the carrier model, which is needed to ensure that the beam is paralleled to the descending baseline.

Laser Alignment Indicator. Installed in the center of the transverse light center under the yellow light, the central yellow beam is paralleled to the descending baseline.

Laser Slope Indicator. Installed in the middle of the rear edge of the left side of the beveled deck, the central yellow beam is paralleled to the descending datum.

Light Composition and Scope of Action

Fresnel Lens. The specification of the Fresnel lens design is shown in Table 1. Based on the US military improved light box using 12 light room design, the overall size increased to 72 inches. According to the Fresnel lens parameters, the theoretical Fresnel lens offset can be observed at the theoretical 0.125 nautical miles, and the distance between the Fresnel lens edge and the edge of the reference arm should be over 0.8–0.9 m.

Table 1. The specification of the Fresnel lens design.

Specification item	Fresnel lens
System composition	Aiming lights: a total of 12, the top 10 yellow light room, the following 2 red light room, red light flash 50 times/min (or 60 times/min)
	Auxiliary lights: 7 × 2 base lights, 2 × 2 cut off lights, 4 × 2 flare lights, 3 × 2 auxiliary flare lights, auxiliary light flash frequency 60–80 times (base on the original number)
Size	6.2 m in length
	Aiming light boxes about 1.8 m high, 0.152 m high, 0.152 m wide per light
	Auxiliary light diameter about 0.152 m, spacing 0.152 m (base on the original number, size according to light regulations)
The maximum action distance at night	1 nmi–1.25 nmi
Angle of aiming light emitted beam	Total horizontal viewing angle: ±20°
	Total longitudinal viewing angle: 1.7° (±0.85°) (Yellow light viewing angle 0.13° × 10; red light viewing angle 0.2° × 2)

Transverse and Tail Hanging Lights. The specification of the transverse and tail hanging lights design is stated in Table 2. Transverse light band is a string of bright one-way constant light red spotlight, with the height of 13 m to 19 m. Since the lights are close to the sea, they are easy to damage. It is ensured that the number of lights unremittingly intensive, and also to avoid the impact of individual lighting longitudinal length.

Table 2. The specification of the transverse and tail hanging lights design.

Specification item	Transverse and tail hanging light
System composition	Transverse band: a total of 11 spot lights higher than the runway light intensity
	Tail hanging lights: 1–13 spotlights, always red light
	Yellow light, central, marked as No. 0 light, flash 60 times/min. Never bright out; Green light, right, flicker tail hanging lights flash 60 times/min; Red light, left, flicker lights flash 60 times/min
Size	Transverse light diameter about 0.203 m, light spacing ≥ 3.05 m
	Tail hanging light size: 0.203 m, light spacing: 1 m (light size should be based on light regulations)
The maximum action distance at night	3 nmi–4 nmi
Action range	Total longitudinal viewing angle: 5°
	Central yellow flicker light horizontal viewing angle: 0.5° ($\pm 0.25^\circ$)
	Single green or red light horizontal viewing angle: 0.1°

Horizontal light with the middle of the indicator yellow light are always bright and flashing, of which the left side placed five red lights, and five green lights on the right. According to the ICOLS program requirements, 11 lights light up in a continuous manner, theoretically five miles away from the carrier, and the ideal state of the distance between the light edges is 10 feet to form the minimum parallax angle of about 1 arc points. If the view within four nautical miles, the edge of the light should not be less than eight feet.

The End-to-end Slippage Guide Light. The specification of end-to-end slippage guide light is illustrated in Table 3. According to United States end of the slide slope guide light reference to the land-based decline guide way, there is no light when the aircraft is on the decline route. Two lights turn white when the aircraft is slightly higher. As it continue to be higher, the lights begin to flicker. When the aircraft is low, the two lights turn red and blink. However, this red-white lighting color semantic system is inconsistent. The use of red and green strobe lighting system could potentially benefit the lighting color semantic system.

Laser Alignment Indicator. The specification of laser alignment indicator is as shown in Table 4. The LCL is located on the underside of the trailing edge and on the midline extension of the runway. It is a low-intensity pulsed-coded laser that provides an optical sector centered on the slip datum, with a transverse beam angle of about 20° and a beam thickness of 5°. Outside the sector has no lighting zone. The system provides seven modes: red light flashing - red light slow flashing - stable red light - stable yellow light - stable green light - green light slow flash - green light flash. When the pilot is in a signal sector, the falling slope deviation of the baseline $\pm 2.5^\circ$ (1°–6°) are visible to the signal.

Table 3. The specification of end-to-end slippage guide light.

Specification item	End-to-end slippage guide light
System composition	Color-changed blinking spotlights: 2 (red - green)
	Slowly flash 60 times/min, fast flash 120 times/min
Size	Light size: 0.203 m, light spacing: 152.4 m (Lighting spacing and size should be based on carrier size and light regulations)
The maximum action distance at night	3 nmi–4 nmi
Action range	Total longitudinal viewing angle: 20° ($\pm 10^\circ$)
	No light zone: Offset falls within 0.3° ($\pm 0.15^\circ$)
	Red light longitudinal viewing angle: 1°
	White fixed light longitudinal viewing angle: 0.4°
	White flicker light longitudinal viewing angle: 1°

Table 4. The specification of laser alignment indicator.

Specification item	Laser alignment indicator
System composition	Yellow light, central, marked as No. 0 light, fixed light
	Green light, right, from left to right marked as No. 1 lights, fixed light; No. 2 lights, flash 60 times/min; No. 3 lights, flash 120 times/min
	Red light, the left side, from right to left marked as No. 1 lights, fixed light; No. 2 lights, flash 60 times/min; No. 3 lights, flash 120 times/min
Size	Laser launcher: 0.97 m long, 0.92 m wide and 0.125 m high, signal source averaging 0.12 m, horizontal distribution; (based on laser line corporation specifications)
The maximum action distance at night	10 nmi
Action range	Total longitudinal viewing angle: 5°
	Total horizontal viewing angle: 20° ($\pm 10^\circ$)
	Yellow light horizontal viewing angle within 0.5° ($\pm 0.25^\circ$)
	Red/green fixed light horizontal viewing angle: 0.8°
	Red/green slow flash beam horizontal view angle: 3°
Red/green flash beam longitudinal viewing angle: 6°	

Laser Slide Slope Indicator. The specification of laser slide slope indicator is as shown in Table 5. The laser slippage indicator is located on the left side of the carrier and is a low-intensity pulse-coded laser that provides remote slippage information. Indicator signal has five modes: red light slow flashing - stable red light - stable yellow light - stable green light - green light slow flash. There are five modes need to be reduced, such as red flash - lower to rise, red fixed light source - low, amber yellow - on the down route, green fixed light source - high, green flash - higher. When the pilot is in a signal sector, the offset center line within -3° – 2° are visible to the signal.

Table 5. The specification of laser slide slope indicator.

Specification item	Laser slide slope indicator
System composition	Yellow lights, the middle, recorded as 0 lights, fixed light
	Green light, right side, from left to right 1 lights, fixed light; 2 lights, flash 60 times/min
	Red light, the left side, from right to left 1 lights, fixed light; 2 lights, flash 60 times/min
Size	Laser launcher: 0.64 m long, 0.92 m wide and 0.2 m high, signal source averaging 0.12 m, the upper left → lower right diagonal distribution; (based on laser line corporation specifications)
The maximum action distance at night	10 nmi
Action range	Total horizontal viewing angle: 5° (-3°-2°)
	Total longitudinal viewing angle: 5°
	Yellow light beam longitudinal viewing angle 0.3° (±0.15°)
	Red fixed light beam longitudinal viewing angle: 0.4°
	Red slow flash beam longitudinal viewing angle of 0.6°
	Green fixed light beam longitudinal viewing angle: 0.4°
	Green slow flash beam longitudinal viewing angle: 1°

5.2 Simulation System

The simulation system is designed to simulate performance of new signal of aircraft landing system to the carrier by restoring the different flight conditions on the current form of signal, which can be recognized by pilots for their cognitive efficiency. The system provides the pilot with visual and dynamic inputs. The software provides the static object model, such as the carrier, the runway mark, the lamp, and the natural landscape. The experimenter can configure the scene element and parameters of driving tasks aligning the needs. In this paper, the virtual simulation environment required for night landing with tasks has three landing phase scenes, i.e. far, medium, and close, as shown in Fig. 5.

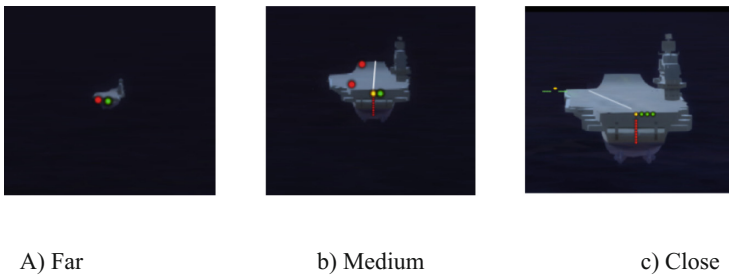


Fig. 5. Three landing phase scenes during the night in virtual simulation environment.

The experimental simulation data contains the control data during driving task, which is recorded by computer while the pilot is operating, including simulation calculated values, such as driving distance, flight real-time coordinates, pitching operation and tilt angle operation of the original volume, the guidance signal. The performance is determined by factors, such as the completion time of the driving task, and the completion of the situation.

6 Usability Evaluation

6.1 Evaluation Objective and Method

The objective of this section is to evaluate the pilot's perception of the design elements and psychological satisfaction, and to investigate whether the pilot can successfully descend by using the guidance of the optical signal, which guidance has been voted with higher satisfaction. As such the following sections are divided into two parts: (1) Experiment 1: Cognitive tests and interviews to obtain the pilot's presentation of the subjective attitude and understanding, and (2) Experiment 2: Driving task of measurement for obtaining the task of completing the driving process.

A total of six participants (pilots) were selected for driving task test and cognitive investigation test. The participants are about at the same age, and have never participated in such research. They are able to operate the simulation system and equipment after explanation. The test process is designed to encourage them to express their own opinions. Before the start of the test, the participants were told about the general situation of participating in the experiments, and signed an experimental agreement of voluntary participation.

6.2 Evaluation Experiment 1: Cognitive Tests and Interviews

Evaluation Experiment 1: Cognitive Tests and Interviews, is designed for evaluation of signal satisfaction and the use of intention research, which is to find out whether the presentation of the light point is intuitive and easy to read. The experiment process records the signal meaning, subjective attitude value and intention of the participants through the scene presentation and interviews that are focused on their subjective feelings of presented signals.

The LVLA, Crossbar, Fore-After, Droplights and Fresnel lenses are arranged in each system with different presenting approaches. Based on a combination of light color identification, position resolution and frequency comparison, a total of 23 screens for the experiment are in one set.

In order to study whether the guidance of the light array is easy to identify or not, a 1–5 scale has been adopted as following: 1 = Hard to understand, 2 = Not easy to understand, 3 = Moderate, 4 = Clear, 5 = Very clear. The results of the evaluation of satisfaction and use intention evaluation are as shown in Table 6 and Fig. 6.

Table 6. Mean value of experiment 1 results for visual identification level and use intention of LVLA(10 km), Crossbar(5 km), F&A(5 km), Crossbar & LGI(5 km), Crossbar & F&A(5 km), and LCL & LGI(5 km).

	LVLA (10 km)	Crossbar (5 km)	F&A (5 km)		Crossbar & LGI (5 km)	Crossbar & F&A (5 km)	LCL & LGI (5 km)
Identification level	3.50	3.67	2.71 (Red& White)	2.75 (Red& Green)	3.17	2.67	3.33
Use intention	3.0	3.0	0		4.0	0	3.0

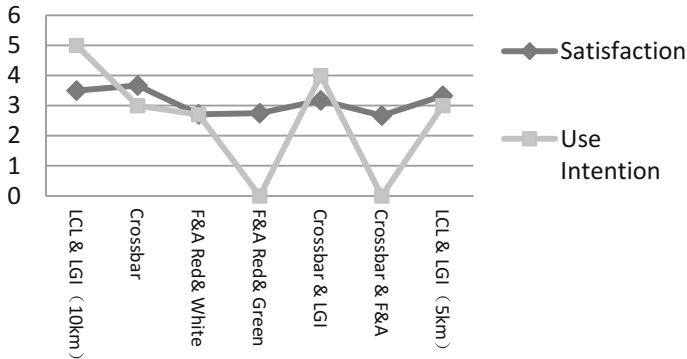


Fig. 6. Mean value of experiment 1 results for user satisfaction and use intention of LVLA, Crossbar, F&A, Crossbar & LGI, Crossbar & F&A, and LCL & LGI (5 km and 10 km).

The results of cognitive tests and interviews indicate:

More than 5 km Away From the LVLA, the LVLA Average Recognition of Satisfaction is Higher, and the Use of Intentions are Relatively High

- Color and flash frequency of the form for performance is relatively simple. The cognitive is no longer a problem, once the pilot is getting familiar with the rules.
- Easy to learn. After the initial explanation, the user is able to quickly and accurately explain the meaning of the signal represented.

The existing problems could be:

- The light perception of the point source is relatively poor. The participants is convinced that the instrument and the radio are more than 10 km, and more brain resources are allocated to the instrument.
- The degree of excursion of the flicker frequency is unclear. Especially during the fast and slow flashing, the pilot has to recall three sets of characteristics of “color” “frequency”, and “position”, which will negatively affect cognitive efficiency.
- Some pilots thought that the two signals could easily cause confusion without training and memorization.
- The signal should be simple.

Crossbar's Performance is the Highest, but the Participants' Intention is Relatively Little

- Graphical performance is more intuitive than the relatively single signal, which is easy to identify.
- Most of the participants believed that Crossbar is a kind of expression as “vertical Fresnel lights, which is not only has a directivity, but also through the length of the array to determine the”.

The existing problems could be:

- A number of visual stimuli are presented more likely to interfere with a line of sight, which waste energy;
- The guide is mainly used for guiding to align the middle of the runway, when a number of lights are hard to be distinguished in a long-distance;
- Some participants suggested that the memory load is too high for identify lights during the landing. However, other participants believed that the problem is due to the color of the light staying same when flashing.

F-A's form of Performance is the Most Recognizable, and the Participants' Intention to Use is the Least

- Instead of using white color, green color is considered to be suitable to represent height, as white color has never used as slope or height.
- Light-free mode could cause confusion of the participants, interrupting cognitive process, and worried about those lights will disturbed the operation.
- Long distance displayed in the vertical column of the display is unclear. It is easy to be confused in the runway with sideline lights in a short distance. One of participant suggested that “lights should be placed as minimum as possible on the deck, as lights can easily interfere and has an impact on judgment of pilot during the night”.
- There are too many lights with Crossbar, which will has interference with sight.

The LVLA Medium-Range Guidance is the Most Preferred Approach Followed by Crossbar & LGI

- LVLA guide form is relatively simple and clear. During the actual operation, Crossbar is thought to be too difficult to distinguish.
- The signal of the guide form is constant and stable.

6.3 Evaluation Experiment 2: Driving Task

Evaluation Experiment 2: Driving Task is designed to compare the completion of the driving task and the real-time coordinate measurement for verifying whether the success of the light is guided by the optical signal. The 10-nautical-miles test route has

been adopted for waiting for incoming route, since it reduces the impact of flight route on signal identification and can cover all the signals across stages.

Based on the starting speed and distance between the landing route node and each light group during the night, the route for the experiment has three sections, i.e. 180s, 120s and 90s. The experiment takes the utilization of lights as an independent variable, provides fundamental HUD parameters, such as altimeter, speedometer, heading table, pitch scale and distance warning information. As the simulation hardware equipment and the actual aircraft flight facilities could have some discrepancy, the scope of the design range is larger than the light security range. The task flow and scenario scene of simulation for the experiment are shown in Figs. 7 and 8.

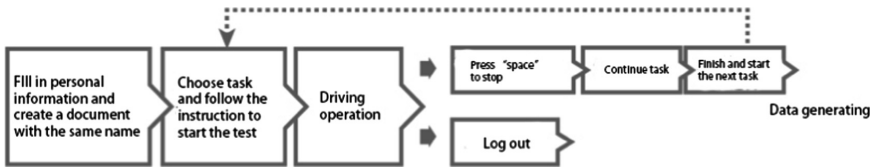


Fig. 7. Task flow chat for Experiment 2.

The results indicate that, when the runway has no auxiliary tips, the participants can complete 58.3% of the tasks by the use of the far and medium light for guiding.

The Situation of Remote Centering and Glissading Task. In the same task range, the optical signal-guided flight can successfully reach the target area in a short time, and the mean value of the completion time is about the same, which indicates that the pilot has a reasonable level of cognition of the optical signal and can understand the meaning of the signal. Most of the participants found the flicker feature during the task, but their tensions make them fail to recognize the difference in frequency, resulting in a light signal that did not give the pilot a clear “quantity” concept like a digital signal.

The Situation of Medium-Range Centering and Glissading Task. The success rate of LVLA mid-range guidance and Crossbar as well as LGI combination could reach 83.3%, while the success rate of Crossbar and Fore & Aft (red and green) is 50%. The finish time of the high success rate are nearly the same. But with the guidance of the LVLA manipulation, the performance is more stable. Crossbar has a good centering effect on close range, but it does exist the problem that it cannot be well known at long distances.

The Situation of FLOLS Glissading Task. The success rate of FLOLS is 67%, and raise to 83% with the number of light rooms increased. The improved Fresnel lights, to a certain extent, do fix the performance of the glissading manipulation.

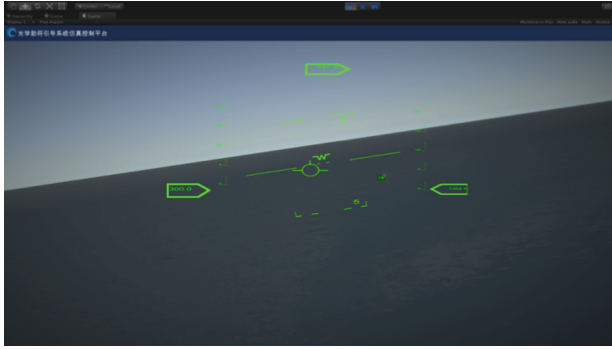


Fig. 8. The scenario scene of simulation for Experiment 2.

6.4 Discussion

Through the two experiments of optical signal form and the task test of guide manipulation for usability evaluation, there are some issues highlighted from the experiments:

- LVLA can be used for assisting the users to complete most of the tasks in far and medium ranges with high efficiency, which achieved a high satisfaction and intention of use from the participants. In theory, the rapid flash can enhance the signal characteristics, however, it did not cause the user's attention, and the processing of the flash frequency occupies the user's cognitive resources.
- Crossbar and LGI combination can facilitate the users completing most of the tasks with high satisfaction of identify. However, under the guidance of Crossbar, its control stability is slightly worse. The users believed that although this kind of display benefits their intuition, but a number of lights interrupt their cognitive process.
- Improved Fresnel lights, to a certain extent, could obtain a better manipulation of performance, which is what the users expected.

Moreover, the results of the experiments help with verifying the hypothesis of this paper, and supporting cognitive principles and design principles:

- Optical signal design should improve the user's ability of memorizing the signal characteristics, unify light color guide rules, and make the design layout reasonable to meet the user's cognitive habits. By the use of a number of colors for lighting, optical signals in different scenes represent their own meanings. Using color scheme for the optical signal and location, can reduce the user's cognitive difficulty.
- The user's cognitive ability and habits should be considered for providing appropriate guidance based on certain stages of the actions. Although Crossbar's performance is aimed at improving the users' intuition, it seems that it has not been proved to be the best method. Users have higher acceptance with pre-use of the guidance, and the habit of using forming into a stable memory, which can facilitate a better results.

Furthermore, the results of the experiments provide insights and challenges to design principles:

- It is wildly believed that signal differences can be improved by implementing proper design method resulting in visibility improvement. Interestingly, the user's cognitive ability and actual situation of the use could be ignored to that.
- The form of the signal should be simplified by minimizing signal features and dimensions. Crossbar factor has not been evaluated for improvement of guidance efficiency due to the lack of time, which follow-up study should cover this issue.

7 Conclusion

This paper presents the general design principle of light color, frequency, layout and light intensity in the design for optical signal, carries on the concept simulation, and obtains the concept of the ICOLS optical guidance system through the exploration of the data survey and the user research. The results indicate that the users can get a better cognitive level and satisfaction in the condition of the color and flashing of the light performed on the glide-slope and centerline guidance in remote and medium distance, especially when the radar communication is disturbed or too difficult to identify landing runway context. Moreover, it would help the pilots with successfully landing in safe area. At the same time, in spite of the pilots could nose down according to the rows of lights on some level, which causes worse satisfaction. Furthermore, the optimized Fresnel lens can improve the satisfaction and the handling stability of drivers. The result can benefit future design iteration and in-depth research.

With the gradual development of China's carrier and maritime aviation field, it is necessary to increase the content and methods for navigation. The development of photoelectric automatic auxiliary equipment is the trend for future development. However, the optical signal guidance, as a kind of application in the specific environment is still essential. It is the direction of the future development to study the optical-aid guidance coping with other related equipment and methods.

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