UTILIZING ECOLOGICAL PERCEPTION TO SUPPORT PRECISION LUNAR LANDING

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In this paper, we introduce the motivation for and design of and integrated flight instrument display component for use during vertical landing and hover operations of a future Lunar lander to support the vision to return to the Moon. A description of the human-system interface design approach to include a cognitive task analysis is outlined. The results of the analysis and the design of the resultant precision landing aid are discussed. The proposed integrated flight instrument display component, the Vertical Altitude and Velocity Indicator (VAVI), which leverages ecological perception through emergent features, is described in detail as well as the motivation and the rationale behind its design. The applicability of the precision landing aid to the aviation domain for use in V/STOL aircraft and rotorcraft is also discussed.

INTRODUCTION

In support of the vision to return humans to the Moon by 2012 and later on to Mars, the next generation lunar landing vehicle must be capable of achieving pinpoint, anytime, anywhere safe landing on the surface with high precision (10-100m). In addition, this vehicle should support both autonomous and manned lunar missions (NASA ASO-1160). Current studies indicate that future missions to the Moon will most likely also have the low-fidelity map constraints experienced in Apollo missions and will use a vertical landing procedure similar to that of Apollo with an emphasis on obstacle clearance (Fuhrman et al., 2005). The need for precision landings on the Moon or Mars is driven by the uncertainty in the terrain as well as the requirement to land near another vehicle or infrastructure.

A survey of the instruments and tools used to aid the astronauts in performing a vertical landing during Apollo missions indicated that few tools existed to assist the astronaut with such tasks as hovering and maintaining a safe vertical descent rate, while sustaining an accurate awareness of the present state of the vehicle. This shortcoming in vertical precision landing aids, still present in current technology, is addressed in this paper through the design of an integrated flight instrument display component that leverages ecological perception.

ANALYSIS APPROACH

The human systems engineering approach for designing the human-system interface for a return mission to the Moon and Mars included a cognitive task analysis which incorporated interviews, transcript analysis from the six moon landing missions, and the development of decision ladders to determine critical landing and hover task information requirements.

In addition, interviews were conducted with Apollo astronauts and NASA personnel such as ground controllers and engineers, as well as helicopter, Harrier, and Osprey pilots. The goal of the interviews was to capture the critical information required by crew in the cockpit and how it was used, specifically during the landing portion of flight. Another critical source of data was the Apollo lunar landing communication transcripts. Communications transcripts revealed that vehicle position was the primary focus during the final phase of flight. The cognitive task analysis led to the identification of three key decisions for the crew of the future lunar lander: 1) landing re-designation to avoid hazards or correct error, 2) the final decision to initiate an abort of the landing, and 3) the decision to resort to lower levels of automation during the landing phase, such as manual control.

Decision ladders were developed to further analyze and formalize data gathered through the interviews and transcript analysis. Decision ladders are tools that aid in capturing the states of knowledge and information-processing activities necessary to reach a decision (Rasmussen, Pejtersen, & Goodstein, 1994). A decision ladder was constructed for each of the three key decisions. The ladder created for re-designation of the landing site, shown in Figure 1, highlighted the need for a requirement to clearly display the vehicle state with

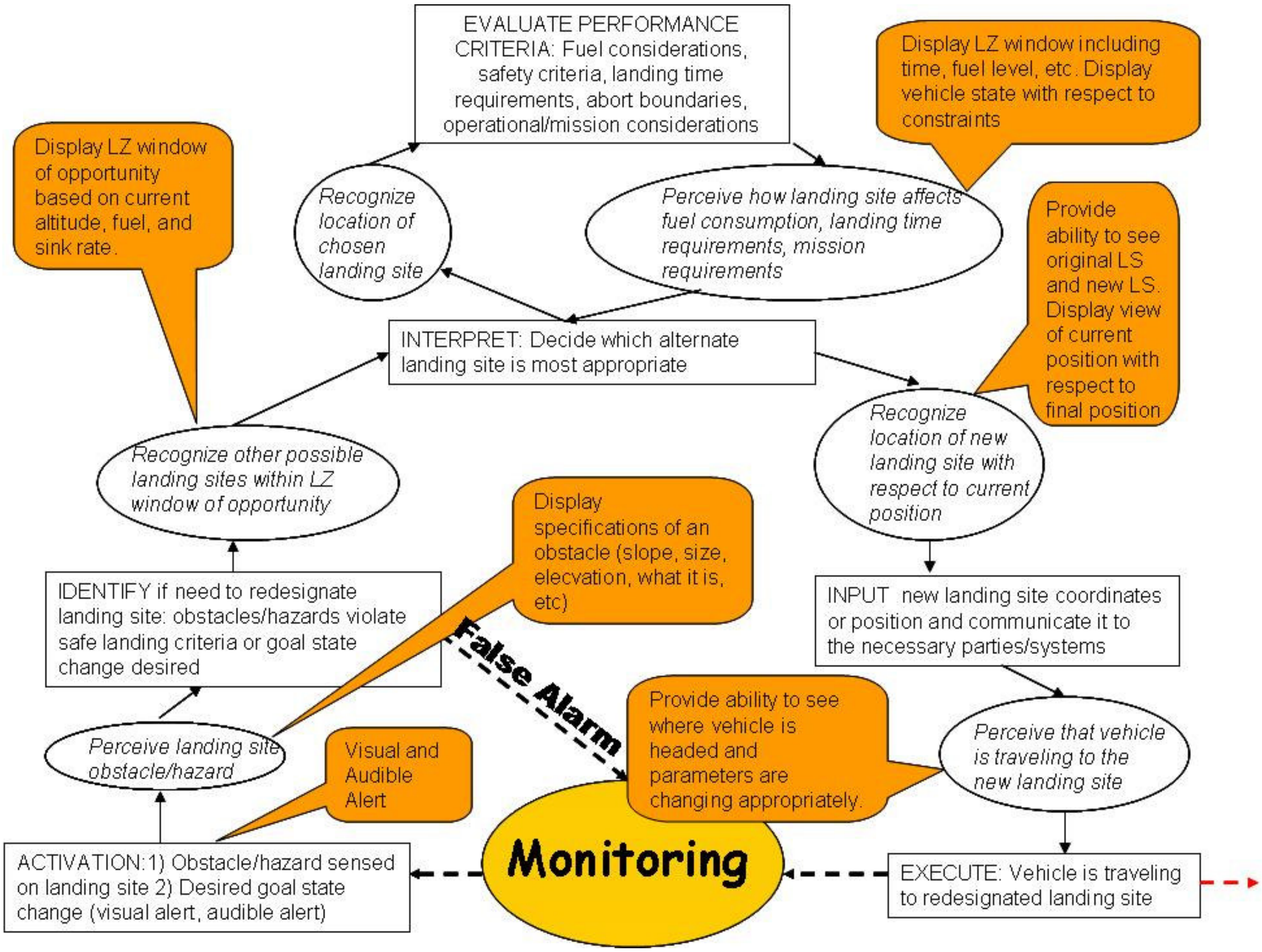


Figure 1: Landing Site Re-designation Decision Ladder

respect to operating envelopes and safety constraints. This paper focuses on an integrated flight instrument designed to support the re-designation and landing sequences. Specifically this vertical landing aid supports direct perception of a vehicle's current conformance to constraints and assists in the crew's monitoring and decision-making task.

The re-designation decision ladder analysis indicated that altitude, vertical speed, attitude, and time were the most critical parameters to ensure a safe and precise landing. The difficulty associated with integrating these pieces of information was also highlighted. For example, several Apollo astronauts reported that the approximate time to touchdown during the Apollo missions required the mental integration of current altitude and vertical speed. During the time and fuel-critical Moon landings, this was reported to be a cognitively demanding task compounded by the fact that the information the crew needed was available on gauges, distributed across various locations in the module.

Likewise, maintaining a safe descent rate was also reported as a cognitively demanding task that required the pilot or astronaut to recognize current altitude and vertical speed values, recall a learned heuristic or recall past experiences, compare current values to that heuristic, and finally understand how the vehicle state relates to the safety constraints.

A mismatch between the data provided by current instruments and the information needed by pilots to ensure a safe and precise landing became apparent through the interviews and decision ladders. Integration of these instruments, in a form that matches the mental model of the pilot, would likely significantly improve vertical landing operations.

The overall analysis of the data collected revealed the following design requirements for the design of future integrated flight instrument to assist in safer and more precise lunar landings.

1) *There shall be an unambiguous display of sink rate safety constraints and a means for*

attaining pilot attention when the constraints are violated. The display of maximum allowable rates of descent provides an indication of sink rate relative to the overarching goal of landing safely.

2) *Direct perception of the combination of vehicle altitude and vertical speed to assist in determining vehicle hover state shall be utilized in the display design*. The combination or integration of display parameters allows these to be observed as a single entity which addresses the difficulty in integrating dynamic vehicle parameters to gain position and rate information.

3) *Approximate time to touchdown shall be displayed.* The computation of time remaining during a vertical descent should be done by the automation to remove this mental calculation from the pilot and/or astronaut.

VERTICAL ALTITUDE AND VELOCITY INDICATOR

In accordance with the design requirements identified through the cognitive task analysis, we developed an integrated flight instrument to address the vertical portion of a lunar landing. The Vertical Altitude and Velocity Indicator (VAVI) is an integrated flight instrument display component intended for a heads-up-display (HUD). The VAVI is designed to aid astronauts and pilots with precision vertical landing and hover operations through reducing mental workload related to this cognitively demanding task. The VAVI conveys altitude and vertical velocity information to indicate unsafe situations and hover maneuvers in a condensed form.

Numerous studies show that performance can improve when displays utilize direct perception- action visual representations which allow the user to employ the more efficient perception processes rather than the cognitively demanding processes involved when relying on memory, integration, and inference (Bennett, 1992; Buttigieg & Sanderson, 1991; Lintern, 1999; Rasmussen & Vicente, 1989). Several design principles that capture this concept were applied to the design of the VAVI.

Gibson’s concept of ecological perception states that perception is a direct, non-inferential process (Gibson, 1979). This advantage makes ecological perception fast, effortless, and able to proceed in parallel unlike analytical cognition which is slow and error-prone (Vicente & Rasmussen, 1992).

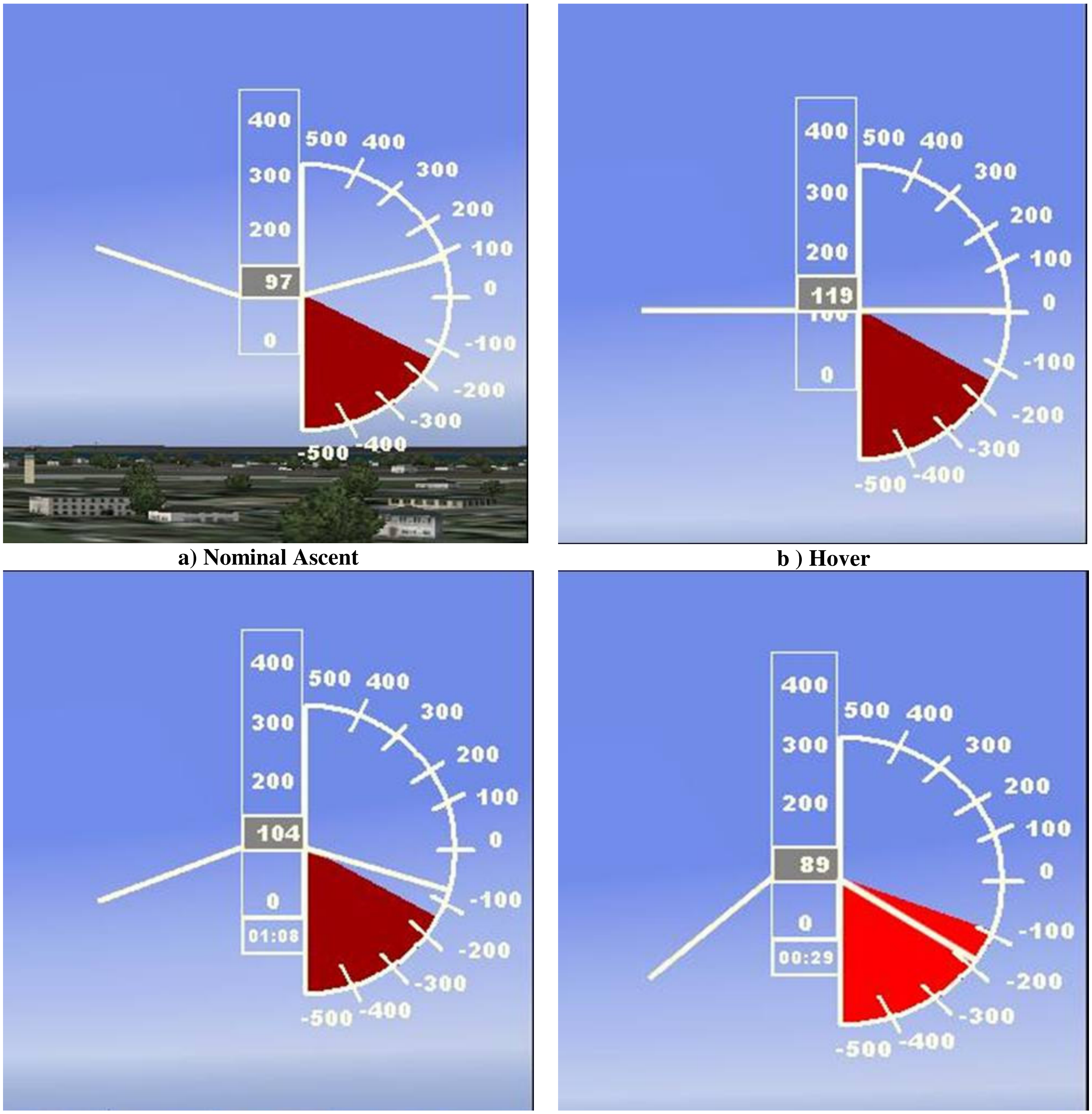
The concept of affordances facilitates the connection between ecological or direct perception and the design of user displays. The real value in direct perception comes not just from perceiving the environment, but from perceiving the affordances of the environment - the invariant attributes of the environment that are relevant to the human's purposes, and therefore specifies the possibility for action or demands appropriate behavior (Rasmussen & Vicente, 1989). Affordances directly relate perception to action, and thus allow for closing the information processing loop on cognitive processes without the need for analytical cognition which incurs higher processing costs.

One way to exploit the benefits of ecological perception is to include emergent features in a display design. Emergent features have been defined as "high-level, global perceptual features that are produced by the interaction among individual parts or graphical elements of a display" (Bennett & Woods, 1993). While each graphical element of the display maintains its perceptual identity, the emergent features evolve from the interaction between the multiple elements (Barnett & Wickens, 1988; Bennett, 1992).

The proximity compatibility principle (PCP) directly facilitates the creation of emergent features (Wickens & Carswell, 1995). Generally, the principle states that there is benefit in presenting information sources either close together in an object-like format, or by configuring them to create emergent features (Wickens, 2000).

The design of the VAVI leverages all of these design principles and the relationships between them by utilizing emergent features created by the interaction of individual parts of a display. The VAVI, illustrated in Figure 2, provides an intuitive integrated flight instrument display to be used during the vertical portion of flight.

The center shaft of the VAVI depicts altitude above ground level (AGL) in both an analog and digital representation. The VAVI is adjustable for appropriate hover or vertical operations. The half-circle on the right side of the altimeter tape depicts vertical speed over the range +/- 500 feet per minute. The "arms" that protrude from the altitude box represent the vertical speed indicator needle and illustrate ascents and descents (Figure 2a and c). The two arms, attached to the altitude bar, move up and down as one unit such that they always protrude from the current altitude. Level arms indicate a hover (Figure 2b). This emergent feature is accomplished through object integration and increased physical proximity of the two primary sources of information: altitude and vertical speed. Instead of mentally combining the altitude and vertical speed in an



a) Nominal Ascent

b) Hover

c) Nominal Descent

d) Unsafe Descent

Figure 2: Vertical Altitude and Velocity Indicator

effortful approach to determine the vehicle state, the operation can now be carried out by direct perception of the arms position. The red zone indicates an unsafe descent rate and is dynamic as a function of altitude, environmental, and vehicle factors. Rather than requiring operators to recall rules from memory to determine if their current vehicle state is safe, they can perceive it directly. When the unsafe sink rate is violated, the red becomes a brighter shade of red to indicate a change in vehicle safety state (Figure 2d).

The clock illustrated at the base of the altitude bar is a time to touchdown clock that is only present during a descent (i.e. negative vertical speed). It is the time to touchdown as a function of the current altitude and vertical speed.

DISCUSSION

The current instruments and displays used in vertically landing space and aircraft require integration across displays and complex data transformation for critical and time-pressured decision making. Therefore the VAVI has been designed to alleviate these additional steps, reducing the operator workload and opportunity for error. The VAVI specifically addresses the primary design requirements that were highlighted by the cognitive task analysis by displaying vehicle state relative to the constraints in an unambiguous and highly salient manner.

While the design of the VAVI resulted from the design of a Moon precision landing system, we believe it is applicable to the aviation domains as well. Vertical/short takeoff and landing (V/STOL) aircraft such as Harriers and Ospreys, and helicopters have the same requirements for vertical landing precision and face many of the same challenges. Several helicopter pilots who provided VAVI feedback commented on its utility and the ease with which flight critical information is gathered in one quick glance. As one experienced pilot stated, "the trick is to be able to see instantly, the position of things." In preliminary PC flight simulator tests, results indicate that the VAVI is an improvement over conventional gauges. Specifically, the VAVI helped reduce precision vertical speed control, maintain a constant hover altitude, and reduce perceived mental workload (Smith, 2006). Implementing and testing the effectiveness of the VAVI in a high fidelity simulator will be the next step in determining its effectiveness over conventional displays.

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