



## Altitude Estimation in the UH-60 Flight Simulator

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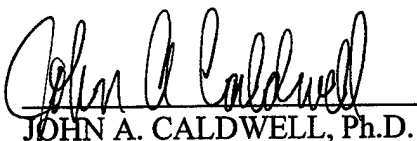


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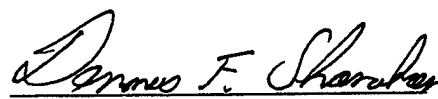
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## Introduction

The correct perception of self-altitude above the earth is an essential task for aviators. This is particularly true of those flying helicopters in the tactical, nap-of-the-earth (NOE) environment, where a few feet may mean the difference between a routine flight and disaster.

Indeed, faulty altitude perception is a frequent accident cause. A review of U.S. Army helicopter accidents from 1980-1991 revealed 30 accidents in which the pilot crashed after incorrectly estimating his/her height above the terrain (Table 1) (U.S. Army Safety Center, 1992). More recently, a review of 202 U.S. Army aviation accidents occurring between 1990-1992 found 40 mishaps that were related to misjudgement of altitude, rate of closure, or aircraft clearance (Durnford et al., 1995).

Table 1.

### Altitude perception accidents (1980-1992)

Mechanism	#
Controlled flight into terrain/water	10
Excessive rate of descent	7
Flared too high	5
Failed to flare	3
Landed short	3
Perceived wrong height	<u>2</u>
Total	30

Since faulty altitude perception is a frequent cause of accidents, it might be desirable to train aviators to perform this task more accurately. Although there is evidence that distance estimation ability can be improved with training (Gibson and Bergman, 1954; Reising and Martin, 1995), it is not known whether this is true for distance/altitude estimation in flight, real or simulated. If aviators can be trained to estimate self-altitude accurately, this could be a useful addition to the flight training curriculum.

Modern Army helicopter pilots receive much of their training in flight simulators that utilize computer-generated imagery. However, it is unclear how realistically these displays perceptually replicate the real-world visual environment (Kleiss and Hubbard, 1993). The resolution and detail of computer generated imagery found in training flight simulators is inferior to real world visual cues, but many believe that the fidelity of the out-the-window visuals is secondary to cockpit realism (Finlayson, 1991).

Operationally, it is important to know whether the perceptual cues learned in the simulator actually transfer to the real world flight environment. It would be unfortunate if, despite providing excellent emergency procedures training, the simulator taught aviators to rely on sensory cues that were not available while flying the actual aircraft. This question has not been addressed satisfactorily in the training literature.

In this simulator study, we assessed the accuracy of Army aviators at estimating self-altitude while flying a custom flight profile in a UH-60 Blackhawk flight simulator. The subjects were tested before and after feedback to assess any benefit of training.

## Methods

### Subjects

Eleven current and qualified U.S. Army aviators with vision correctable to 20/20 in each eye at distance and near were accepted into this study.

### Flight simulator

Subjects flew the U.S. Army Aeromedical Research Laboratory (USAARL) UH-60 Blackhawk flight simulator, which incorporates a six degrees-of-freedom motion base, an operational crew station with computer-generated visual displays, and a multi-channel data acquisition system. The computer graphics system utilized in this simulator is the Army Tactical Digital Image Generation Visual System (ATACDIG) developed by the U.S. Army and Link Flight Simulation (Figure 1).

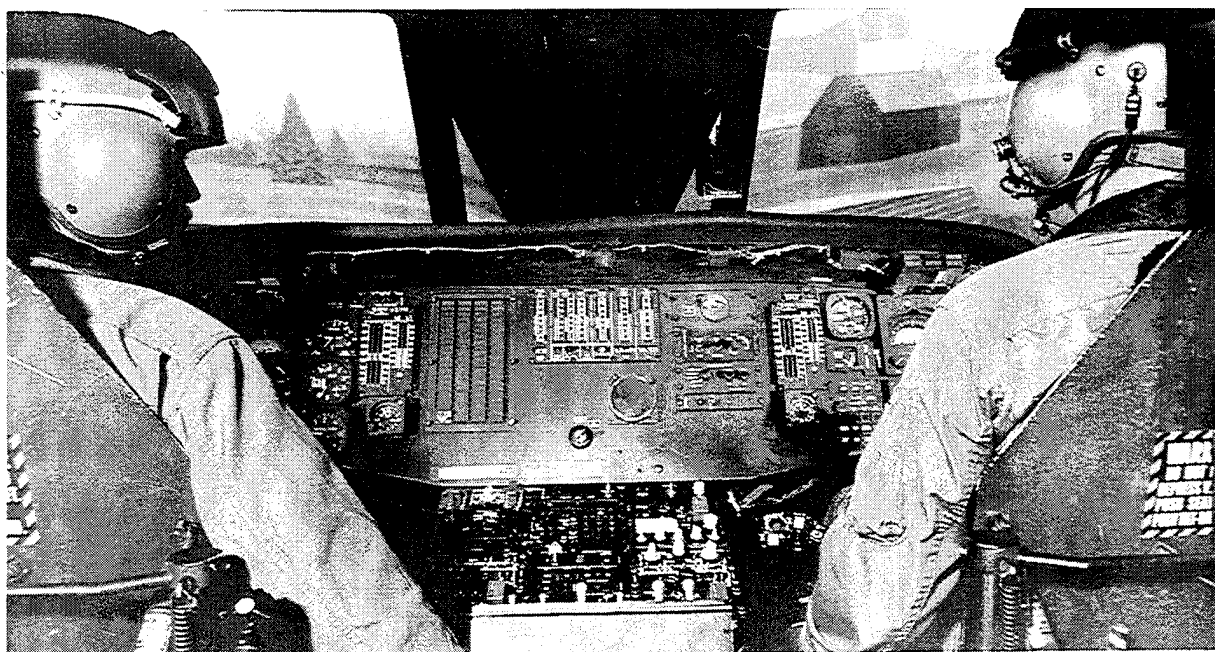


Figure 1. Typical scenery from the Army Tactical Digital Image Generator Visual System (ATACDIG) (photograph by Link Flight Simulation).



## Flight profile

A 30-minute custom flight profile (Appendix A) simulated a routine flight over farmland terrain (land), a large lake (water), and an airport runway. The flight consisted of an en route cruise segment, a hover segment, and an approach segment (Table 2) over both the land and water phases of the flight. The runway segment consisted of an approach phase only. At various times during the flight, the subject was asked either to guess the current aircraft altitude (above ground level[AGL]) or to fly the aircraft to a specified altitude (Appendix B). Details of the flight tasks are provided in Table 3. Other than the computer-generated scenery, no altitude cues were provided to the subject (altimeters, vertical speed indicator, and torque gauges were covered). Subjects were not informed of the starting altitudes for any of the flight maneuvers.

Table 2.

### Flight profile sequence

=====

#### Land

1. En route phase
2. Hover phase
3. Approach phase

#### Water

1. En route phase
2. Hover phase
3. Approach phase

#### Runway

1. Approach

=====

Table 3.

Details of flight tasks		
Phase of flight	Task	Conditions
En route	30 sec to fly to target altitude from 500 ft AGL	Targets: 500, 250, 100, 50 ft (random order)
Hover	30 sec to hover to target altitude from 50 ft AGL	Targets: 50, 25, 10, 5 ft. (random order)
Approach	During approach to truck, estimate altitude at 5 points along approach	Estimate altitude when 1400, 1000, 600, 200 & 100 M from truck

#### Procedure

After giving their informed consent and demonstrating 20/20 vision in each eye, acceptable subject-pilots received a short briefing on the flight profile from the simulator operator. The subject was then escorted to the simulator, where each of the flight maneuvers was practiced once. After a break, the subject completed a baseline iteration of the flight profile (Table 4). Following the break, the subject flew a training profile, which was identical to the first flight except that feedback was provided to the subject. Feedback consisted of the simulator operator informing the subject of the correctly achieved or actual altitude after each response. Following another break, the subject completed the post-training flight identical to the baseline flight. After a short debriefing, the subject was released.

Table 4.

Sample daily study schedule

Time	Activity
0800	Informed consent, eye exam
0830	Flight profile brief
0900	Practice flight, familiarization
0930	Break
0935	Baseline flight
1005	Break
1010	Training flight
1040	Break
1045	Post-training flight
1115	Debriefing
1130	Subject release

Data analysis

The altitude estimation data were analyzed in three separate three-way repeated measures analyses of variance, using BMDP 4V (Dixon et al., 1990) with all three factors repeated. For the en route and hover phases, flight (pre- and post-training), condition (over land and over water), and altitude (4 altitudes) were analyzed. For the approach phase, flight (pre- and post-training), condition (over land, over water, and runway), and distance from target (5 distances) were analyzed. Only the pre- and post-training sessions were subjected to analysis. A regression technique was used to estimate altitude error values for trials in which subjects crashed.

Each variable was corrected for departures from normality and sphericity violations using appropriate transformations and the Greenhouse-Geisser adjusted degrees of freedom, respectively. Analysis of simple effects was used to determine which post hoc comparisons could be made. Newman-Keuls analysis was used to compare differences among means.

## Results

### Sample

The mean age of the 11 subjects was 30.1 years (range 22-46) and 10/11 were male. Two were rated UH-60 pilots, while only 3/11 had more than 10 hours of experience in flight simulators equipped with computer-generated imagery (CGI). One of the subjects was excluded from analyses of the approach data due to equipment malfunction during this phase of testing.

### Simulated crashes

Table 5 contains the breakdown of simulated crashes and flight phase during the study. Eight of 9 crashes occurred while flying over water and 6/9 happened during the baseline flight.

Table 5.

Number of crashes during study		
Phase	Baseline	Post-training
En route		
land	0	0
water	0	0
Hover		
land	0	0
water	4	0
Approach		
land	1	0
water	1	3
runway	0	0
TOTAL:	6	3

### En route phase

A significant main effect was found for terrain ( $p=0.0461$ ) showing greater absolute error over water compared to over land (Figure 2). A significant main effect was also found for session ( $p=0.0026$ ), in which training resulted in a 64 percent reduction in absolute altitude estimation error. Finally, a significant main effect for altitude highlighted the fact that the absolute magnitude of the error increases with increasing altitude ( $p=0.0003$ , Greenhouse-Geisser correction).

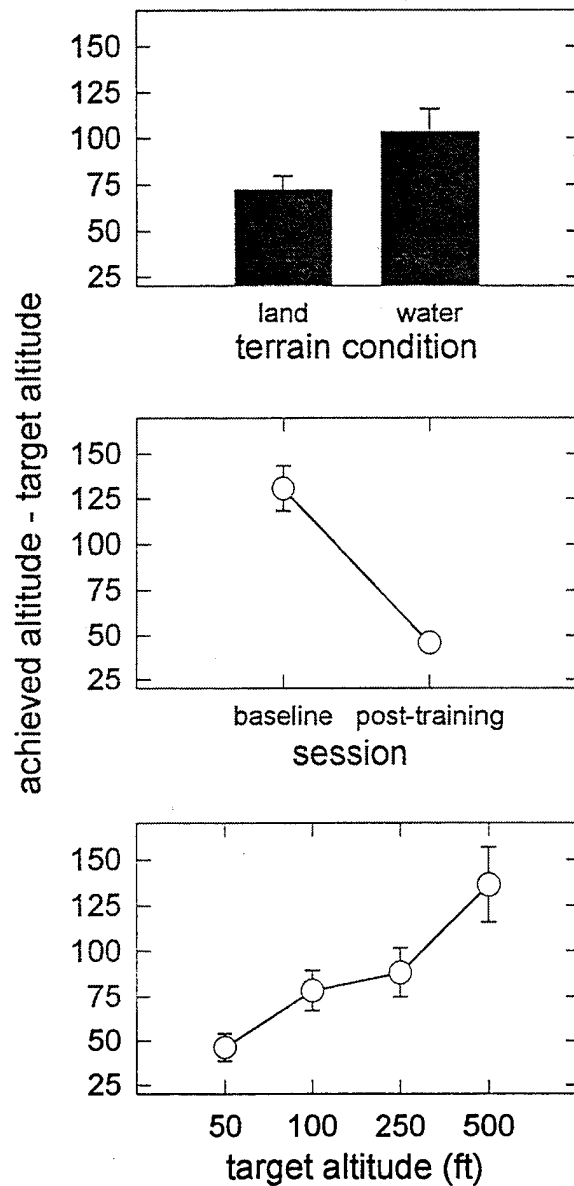


Figure 2. Significant results of en route phase ANOVA.

### Hover phase

A significant main effect was found for terrain ( $p=0.0191$ ), showing a smaller absolute error over water than over land (Figure 3). There was a borderline interaction between session and terrain in which the improvement in altitude estimation occurred more over land than over water ( $p=0.054$ ).

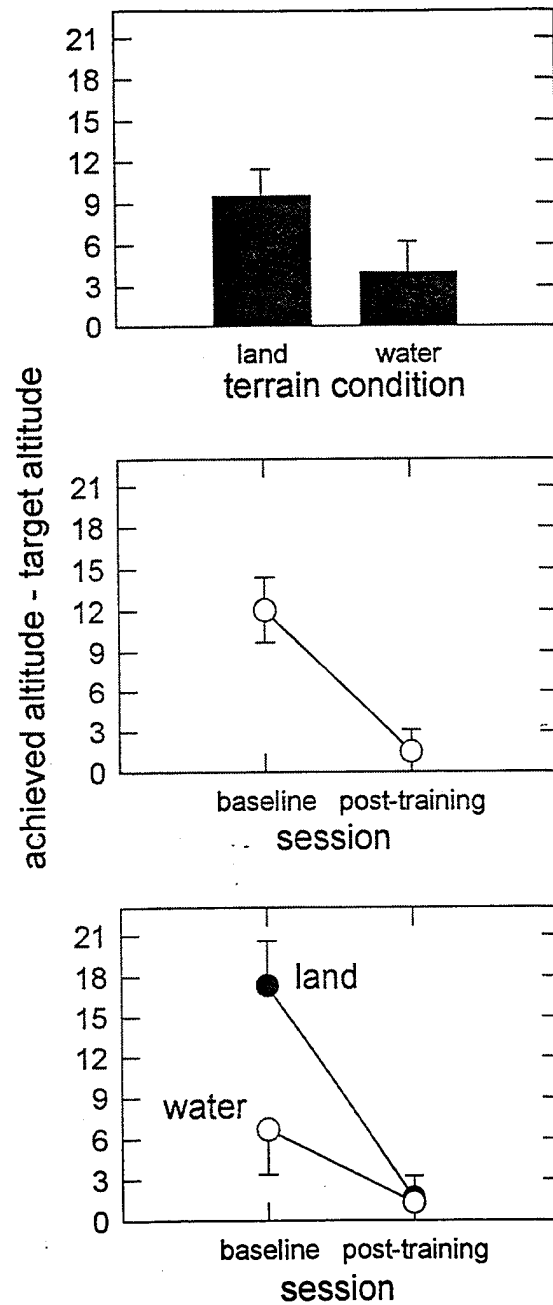


Figure 3. Significant results of hover phase ANOVA.

### Approach phase

Repeated measures analysis of variance of the absolute value of estimate error revealed a session by altitude interaction ( $p=0.0092$ , Greenhouse-Geisser correction). Figure 4 shows that this interaction was due to proportionally greater improvements in estimation at the three highest altitudes (600, 1000, and 1400

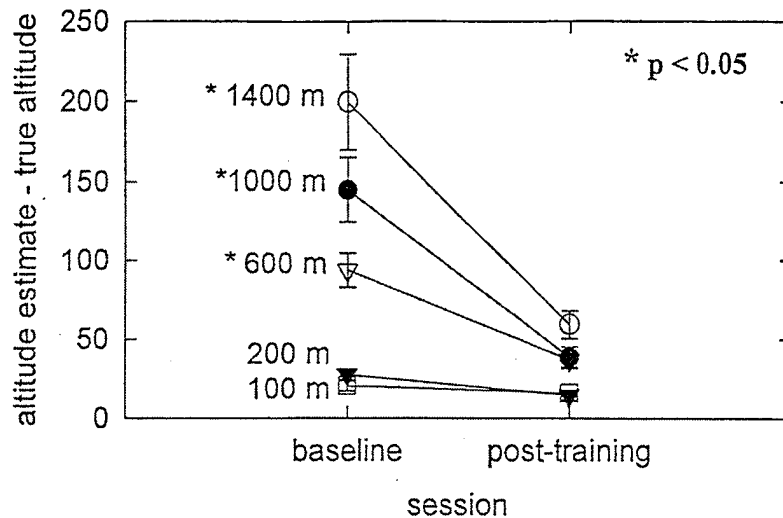


Figure 4. Effect of training on altitude estimation during approach.

The differences between actual and estimated altitude are shown in two ways: first, by plotting distance from touchdown against the mean raw error (Figure 5) and second, by plotting distance against the mean absolute value of the error (Figure 6). (Raw error can provide indication of the direction of errors while the absolute value indicates error magnitude.) Prior to training, the subjects tended to overestimate altitude in most conditions except at the higher altitudes over land (see note; also Figure 5). Estimates shifted to a slight underestimation after training. The magnitude of estimate error was uniformly reduced by training, an effect most prominent at higher altitudes (Figure 4).

NOTE: To standardize definitions, to "overestimate" altitude is to think one is higher than truth --- an error in the unsafe direction. Conversely, to "underestimate" altitude is to believe that one is lower than truth --- an error in the safe direction.

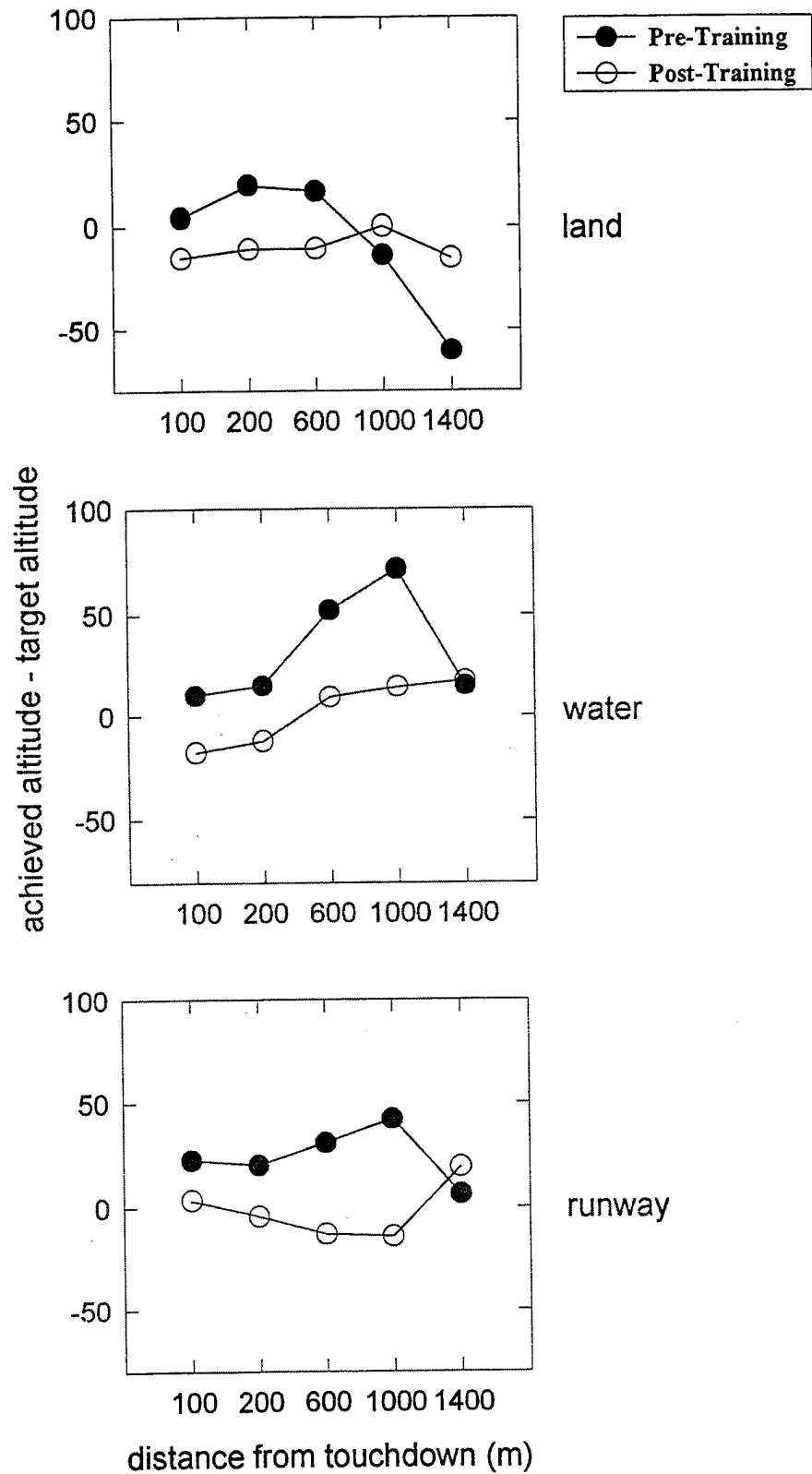


Figure 5. Changes in direction of altitude estimation error during approach.



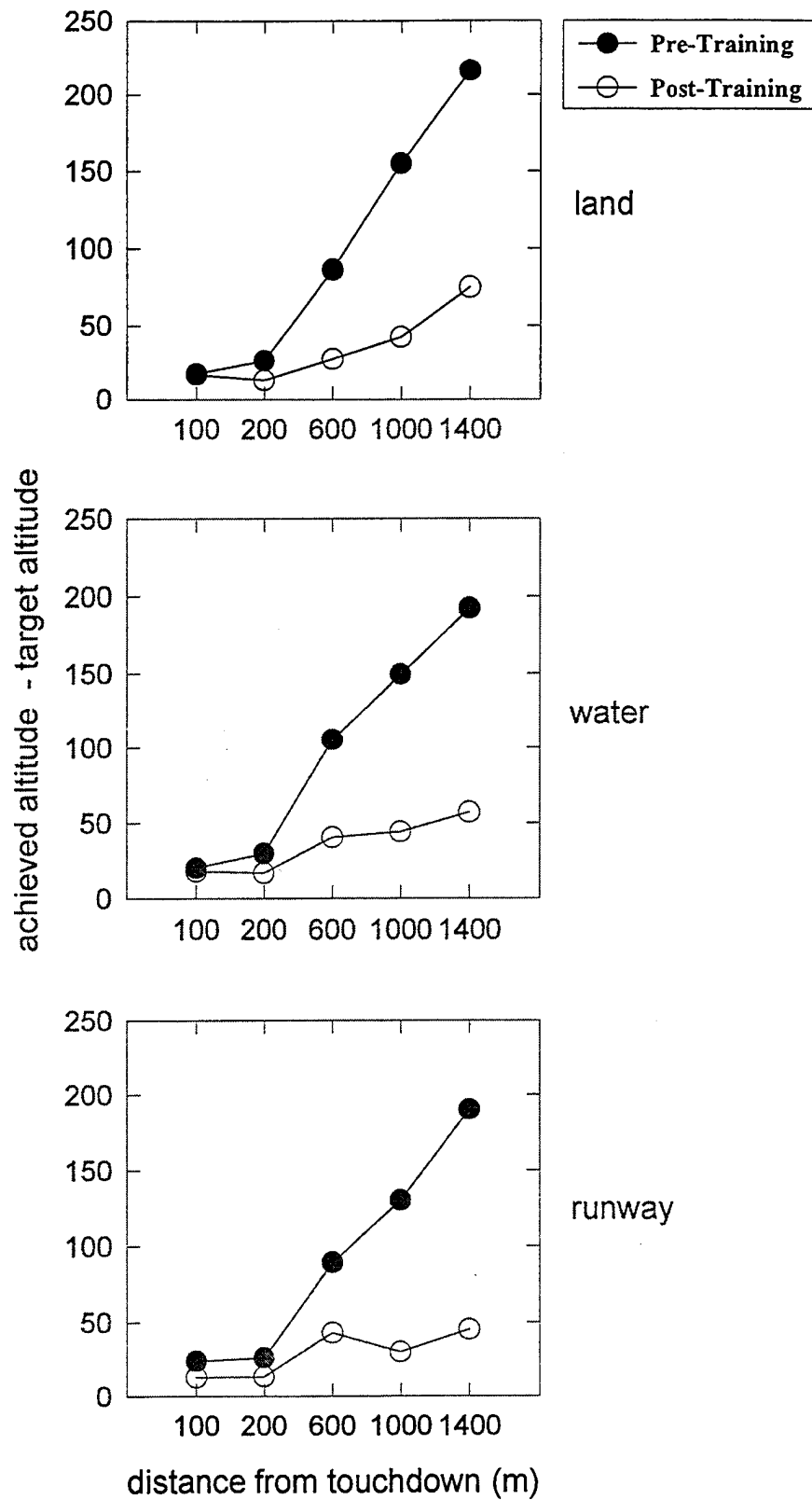


Figure 6. Changes in magnitude of altitude estimation error during approach.

The mean simulated aircraft flight path was reconstructed using the true altitude data from the first five data points (Figures 7 and 8). Flight path tendencies at baseline were preserved during the post-training flight although subjects flew slightly lower. Differences among the terrain conditions were not generally of operational significance. There was a tendency to fly higher during the first few minutes of the over-water approach and during the final 200 m of the approach to the runway.

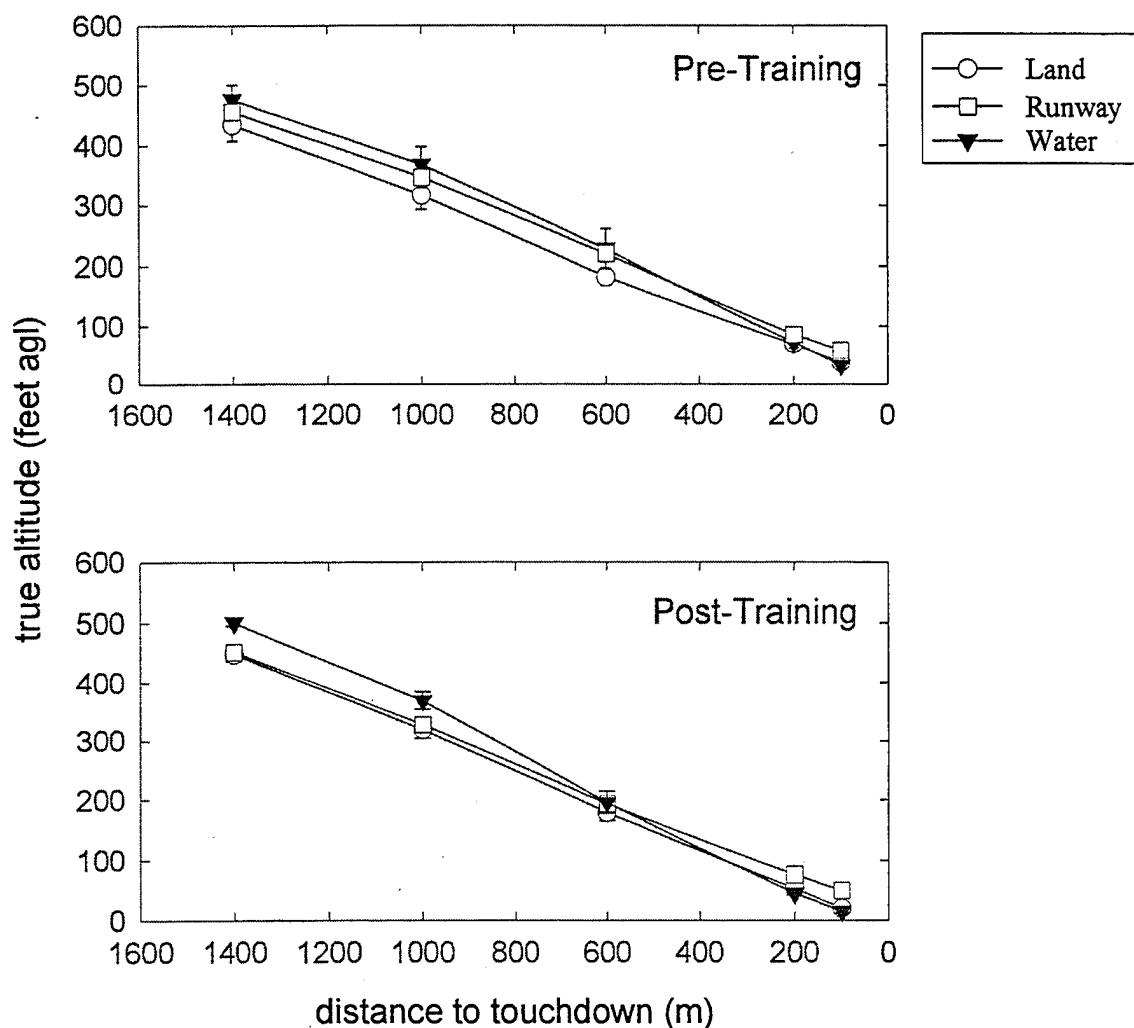


Figure 7. Effect of terrain on approach flight path.

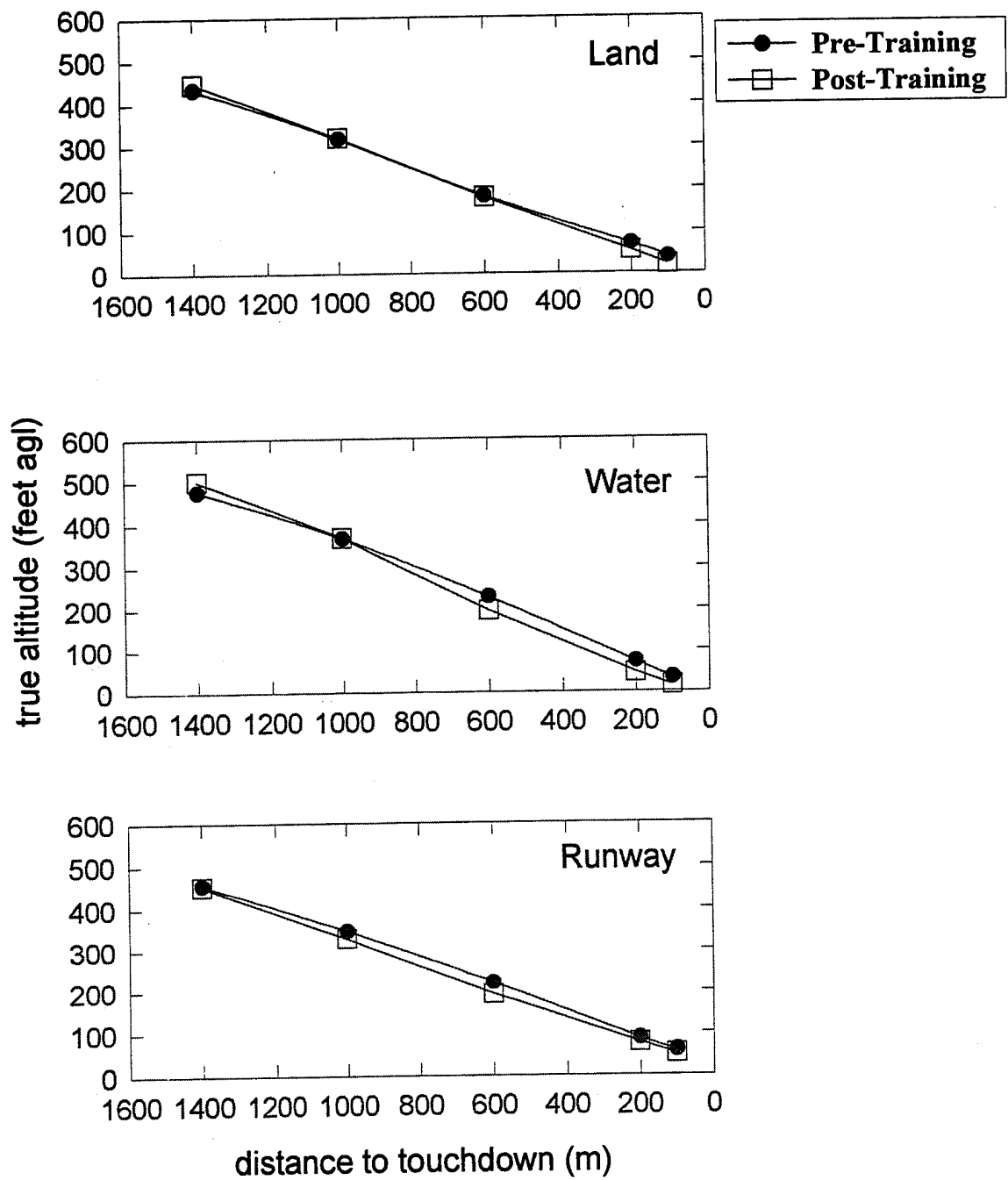


Figure 8. Effect of training on approach flight path.

### Altitude cues used

After testing, subjects were queried about cues that they used to estimate altitude. Subjects reported that they tended to rely on programmed simulator cues for altitude information (Table 6).

Table 6.

Altitude cues cited by subjects		
Land	Water	Runway
tree size	wave visibility	trees
tree height	rotorwash	runway size
silo height	counted waves	runway number markings

### Discussion

The growing importance of simulation in aviation training is indisputable. Today, Army aviators can complete transition training in some aircraft without ever leaving the ground. It would be useful to ensure that the visual cues learned in these flight simulators transfer to the real aircraft--at a minimum, they must not adversely impact flight safety. The present study represents a small step toward these answers, although no comparison yet can be drawn between simulator and aircraft.

In this investigation, significant interactions were found between simulated terrain type and the accuracy of altitude estimation. These findings are compatible with the observations of Kleiss and Hubbard (1993), who reported that the density of vertical objects is positively related to altitude awareness. Thus, it is not surprising that our subjects' estimation error over land was significantly better than over water. Additionally, crashes occurred more frequently over water than

over land (8:1). In ATACDIG computer-generated imagery (and the real world), typical "land terrain" is populated with vertical objects (e.g., trees, silos, buildings), while the surface of "water terrain" is flat and devoid of texture. Unless there are ships in the vicinity, water provides few altitude cues until the aviator is close enough to the surface to resolve waves.

Within terrain conditions, altitude estimation was more accurate over land while cruising at higher altitudes (>50 ft agl), and over water while hovering at lower altitudes. The unexpected advantage seen when hovering over water may be attributable to the artificial and highly predictable rotorwash cue generated by the ATACDIG software, in which rings of turbulence and spray suddenly become visible when the helicopter descends below a programmed height. However, another important difference between the hover and en route phases of the experiment was airspeed which may have contributed to these findings.

A dramatic improvement after the feedback session was seen in most experimental conditions, especially at higher altitudes and airspeeds (i.e., during en route phase and approach). This corroborates recent work by Reising and Martin (1995), although their experiments dealt with horizontal distance estimation. While this suggests that altitude estimation could be taught in the real world, it would probably be counterproductive (and actually unsafe) to teach aircrew to accurately interpret the unrealistic cues provided in the flight simulator.

It is important to note that the perceptual effects of one computer-generated imagery system may not apply to other more or less detailed display packages. Since this study was completed, there have been software upgrades to the USAARL UH-60 simulator visual database; whether these results could be replicated today is unknown.

In-flight research is currently underway using a modified AH-1 Cobra helicopter and methods similar to the present study. These results should facilitate a comparison between simulated and real altitude cues.

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Appendix A.

Altitude estimation simulator flight profile

1. GENERAL: This flight profile for the UH-60 AEROMED flight simulator has been designed to assess accuracy of altitude estimation using simulator graphics. It simulates a VFR flight around an airfield in the countryside with a lake. Subjects, flying from the right seat, will be asked to estimate their altitude over the terrain at various times during the profile by an investigator, while all instruments providing altitude cues (barometric/radar altimeter, and VSI) are covered (or deactivated). Subjects will not receive any altitude cues during the flight from any instrument or from personnel in the simulator. The entire profile should take about 30 minutes to fly.

## 2. MISSION PROFILE:

A. MISSION START: The mission begins with the aircraft located on the airfield helipad, heading 290 (Scenery 1). The subject performs a takeoff, turning immediately to a heading of 021 while climbing to 500 ft. After reaching approximately 500 ft AGL, the simulator operator will instruct the subject to level off.

B. EN ROUTE OVER LAND: After crossing the road and flying straight and level at approximately 500 ft/80 kts, the simulator operator will instruct the subject to close his eyes.

The simulator operator will freeze the flight and load Scenery 2, which is identical to the present route of flight and airspeed, at 500 ft AGL. The operator will then unfreeze the flight and instruct the subject to open his eyes and take the controls.

The operator will instruct the subject to fly the aircraft to 50, 100, 250, or 500 ft AGL, keeping the airspeed at 80 kts (the order of altitudes will be randomized and counterbalanced across subjects). The subject will have 30 seconds to complete the task. When the subject believes he has achieved the target altitude, he will state "50 feet" or whatever the assigned target altitude was. The operator (or researcher) will record on the scoresheet the true altitude AGL at that instant. The operator will instruct the subject to close his eyes, freeze the simulator, reload Scenery 2, and repeat the cycle for each of the 4 target altitudes.



C. APPROACH OVER LAND: After the en route phase, the operator will instruct the subject to close his eyes, freeze the simulator, and load Scenery 3, which is identical to the Scenery 2 flight parameters except that the aircraft is located 1 km farther along the flight path and is at 750 ft AGL.

The operator will instruct the subject to look for a truck on the ground in the distance; the truck will be located about 2 kilometers ahead of the aircraft. The subject will fly straight and level until the truck is sighted and will then begin a normal approach to the truck terminating to a hover over it. When the aircraft is 1.40, 1.00, 0.60, 0.20, and 0.10 km from the target, the operator will ask the subject to give an immediate estimate of aircraft altitude AGL upon his "mark." The operator will use the GPS system to cue himself for these distances. Actual aircraft altitude and the subject's estimate will be recorded simultaneously on the scoresheet.

D. HOVER OVER LAND: The simulator operator will instruct the subject to close his eyes, freeze the flight, and load Scenery 4, which is a stable hover with the same scenery, except the truck is removed, at 50 ft AGL. Operator unfreezes the flight and instructs subject to open his eyes, take the controls, and hover.

The operator will instruct the subject to hover the aircraft to 5, 10, 25, or 50 ft AGL, maintaining a stable hover and a specified heading (the order of altitudes will be randomized and counterbalanced across subjects). The subject will have 30 seconds to complete the task. When the subject believes he has achieved the target altitude, he will state "50 feet" or whatever the assigned target altitude was. The operator (or researcher) will record the true altitude AGL at that instant on the scoresheet. The operator will instruct the subject to close his eyes, freeze the simulator, reload Scenery 4, and repeat the cycle for each of the 4 target altitudes.

E. EN ROUTE OVER WATER: After the final hovering altitude test condition, the operator will instruct the pilot to take off and begin a climb straight ahead. After a few seconds, the simulator operator will instruct the subject to close his eyes. The simulator operator will freeze the flight and load Scenery 5, which is over water, 500 ft AGL, 80 kts, with no land in sight.

The operator will unfreeze the flight, and instruct the subject to open his eyes and take the controls.

The operator will instruct the subject to fly the aircraft to 50, 100, 250, or 500 ft AGL, keeping the airspeed at 80 kts (the order of altitudes will be randomized and counterbalanced across subjects). The subject will have 30 seconds to complete the task. When the subject believes he has achieved the target altitude, he will state "50 feet" or whatever the assigned target altitude was. The operator (or researcher) will record the true altitude AGL at that instant on the scoresheet. The operator will instruct the subject to close his eyes, freeze the simulator, reload Scenery 5, and repeat the cycle for each of the 4 target altitudes.

G. APPROACH OVER WATER: After the en route phase, the operator will instruct the subject to close his eyes, freeze the simulator, and load Scenery 6, which is over water, with no land in sight, and 750 ft AGL.

The operator will instruct the subject to look for a truck floating on the surface of the water in the distance. The truck will be approximately 2 kilometers away. The subject will fly straight and level until the truck is sighted and will then begin a normal approach to the truck, terminating to a hover over it. When the aircraft is 1.40, 1.00, 0.60, 0.20, and 0.10 km from the target, the operator (again using the GPS system) will ask the subject to give an immediate estimate of aircraft altitude AGL. Actual aircraft altitude and the subject's estimate will be recorded simultaneously on the scoresheet.

H. HOVER OVER WATER: The simulator operator will instruct the subject to close his eyes, freeze the flight, and load Scenery 7, which is a stable hover with the same scenery, except the truck is removed, at 50 ft AGL. Operator unfreezes the flight and instructs subject to open his eyes and take the controls.

The operator will instruct the subject to hover the aircraft to 5, 10, 25, or 50 ft AGL, maintaining a stable hover (the order of altitudes will be randomized and counterbalanced across subjects). The subject will have 30 seconds to complete the task. When the subject believes he has achieved the target

altitude, he will state "50 feet" or the assigned target altitude. The operator (or researcher) will record the true altitude AGL at that instant on the scoresheet. The operator will instruct the subject to close his eyes, freeze the simulator, reload Scenery 8, and repeat the cycle for each of the 4 target altitudes.

I. RUNWAY APPROACH AND LANDING: After the final hovering altitude test condition, the operator will instruct the pilot to take off and begin a climb straight ahead. After a few seconds, the simulator operator will instruct the subject to close his eyes. The simulator operator will freeze the flight and load Scenery 8, which is lined up with the airfield runway, 750 ft AGL, at approximately 1 km DME.

The operator will instruct the subject to fly a visual approach to the runway, terminating in a hover over the end of the runway (over the numbers). When the aircraft is 1.40, 1.00, 0.60, 0.20, and 0.10 km from the target, the operator (again using the GPS system) will ask the subject to give an immediate estimate of aircraft altitude AGL. Actual aircraft altitude and the subject's estimate will be recorded simultaneously on the scoresheet. Upon accomplishing a stable hover, the flight profile is ended.

Appendix B.

Data collection sheet

# ALTITUDE PERCEPTION STUDY

## OVER-LAND SCENARIO

### En Route

Order Tested	Target Altitude	Flown Altitude	diff.
	500		
	250		
	100		
	50		

### Approach

Distance to go	True Altitude	Altitude Guess	diff.
1400			
1000			
600			
200			
100			

### Hover

Order Tested	Target Altitude	Flown Altitude	diff.
	50		
	25		
	10		
	5		

## OVER-WATER SCENARIO

### En Route

Order Tested	Target Altitude	Flown Altitude	diff.
	500		
	250		
	100		
	50		

### Approach

Distance to go	True Altitude	Altitude Guess	diff.
1400			
1000			
600			
200			
100			

### Hover

Order Tested	Target Altitude	Flown Altitude	diff.
	50		
	25		
	10		
	5		

Altitudes are given in feet AGL.  
Distances are given in KM.

## SUBJECT INFORMATION

Name \_\_\_\_\_  
 Subject # \_\_\_\_\_  
 Date \_\_\_\_\_  
 Start time: \_\_\_\_\_  
 Stop time \_\_\_\_\_  
 Comments:

## RUNWAY SCENARIO

### Approach

Distance to go	True Altitude	Altitude Guess	diff.
1400			
1000			
600			
200			
100			

## RESEARCH INFO

Session: Baseline  
 Training  
 Post-training  
(circle one)

Simulator \_\_\_\_\_  
 Operator \_\_\_\_\_  
 Researcher \_\_\_\_\_

### Simulator Function:

OK?  
 Visuals: yes no  
 Audio: yes no  
 GPS: yes no  
 Trucks: yes no  
(circle one)

**DEPARTMENT OF THE ARMY**  
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**Research Laboratory**  
**Fort Rucker, Alabama 36362-0577**

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