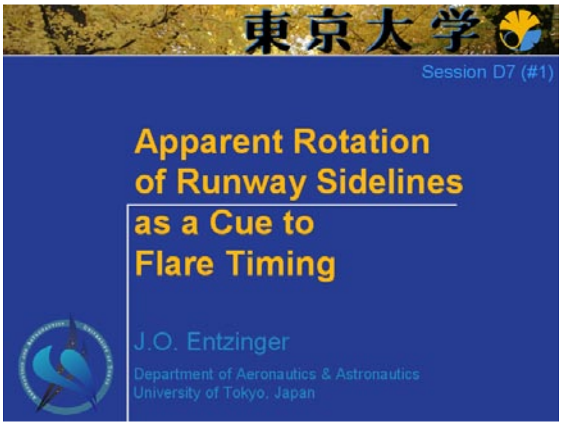
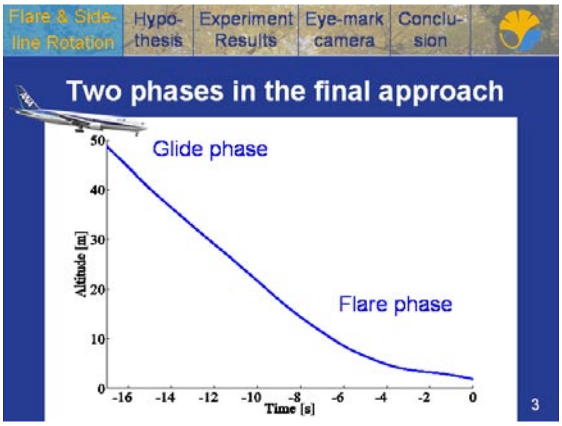
1 

Presentation for APISAT, Gifu, Japan
Thursday November 5th 2009 – Session D.7 (15:10-15:30)
(Feel free to contact me with comments/questions on this content; e-mail: jorg – at – entzinger – dot – nl)

This paper (and presentation) builds further on the work presented at the KSAS-JSASS symposium last year at Jeju island, South Korea, so some of you may be familiar with part of what I explain here today.

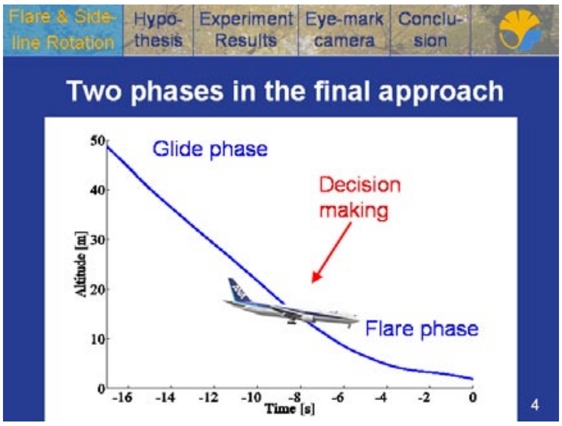
2 

[video shows: 1) plane from outside; 2) cockpit window view; 3) control column deflection; 4) combined videos]
This shows the final approach to landing (last part of glide and flare)
The question is: what is the pilot looking at and how does he decide the proper control inputs

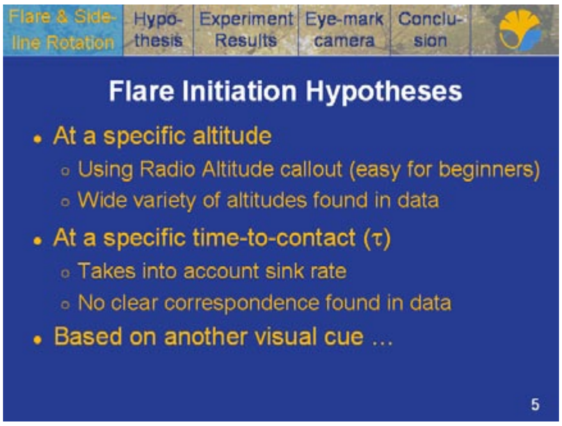
3 

The final approach to landing consists of 2 phases
[Animation]

1) The glide phase, where the pilot should track a straight path with about 3deg slope in the vertical plane
2) The flare phase, where the pilot should pitch up to reduce sink rate

4 

In my paper and in this presentation, I focus on the decision making regarding the initiation of the flare.

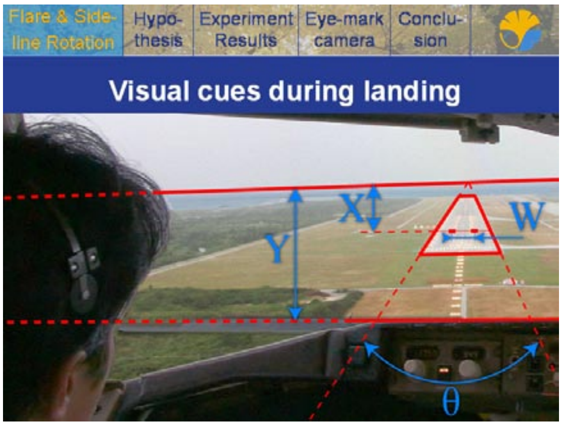
5 

In pilot modeling and pilot training literature, several cues have been suggested for judging the proper moment of flare initiation.

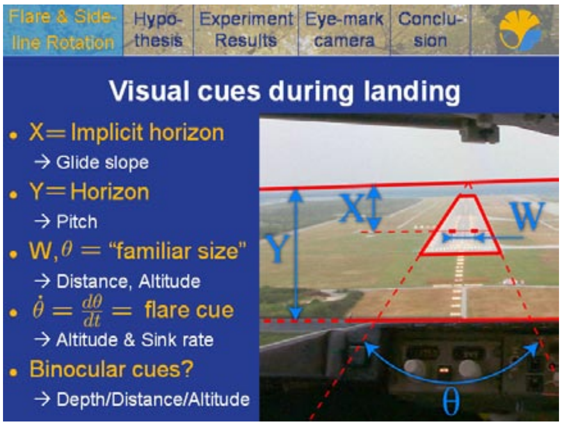
Often it is said that the flare should be started at a specific altitude above the runway. For beginning pilots, the radio altitude callouts would help to know when to flare. However, our data show a wide variety in flare altitudes, and experienced pilots confirm that they have developed a more "refined" sense of what is the right moment to flare.

Another cue put forward is the time-to-contact (for instance altitude divided by sink rate), sometimes expressed as "flare altitude is 10% of the sinkrate in ft\min". Although this method takes into account the important variable "sinkrate", this cue also doesn't match very well with our data.

It is thought that the pilots use another VISUAL cue to decide the proper moment to flare. I will now discuss visual cues in general and come to propose a cue for flare timing.

6 

I will now explain some visual cues
There are many cues which a pilot might use. I just show a few simple ones here

7 

The implicit horizon is the distance between the horizon and the aimpoint. If you follow a straight line to the aim point, this distance will be constant.
The distance from the bottom of the windshield (or any aircraft part for that matter) to the horizon provides information about the aircraft's pitch angle
Familiar size cues (also including the apparent size of trees, roads, buildings…) give distance information.
Stereoscopic cues could provide depth information, but for big aircraft it is probably not useful (for small aircraft and helicopters it might be)

I will focus on the flare (timing) cue dθ/dt now

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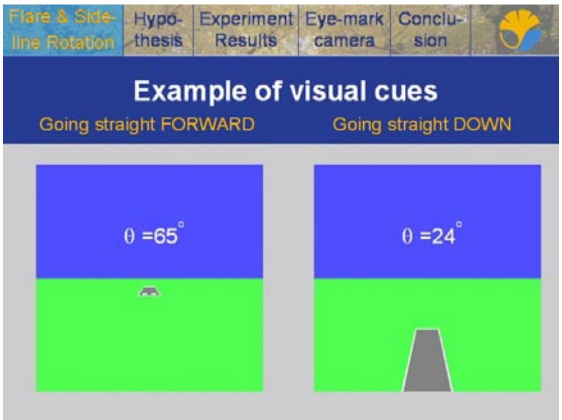

[animations] When moving straight forward, at constant speed, the runway sidelines will make a constant angle When going down, however, the angle increases. Even with constant sink rate, the angle grows faster and faster (i.e. not only **θ** , bust also **dθ/dt** increases when altitude decreases)

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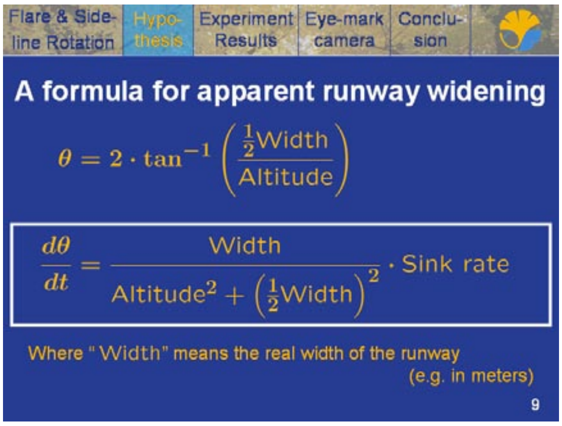

I further investigated the **dθ/dt** cue and derived these formulas
It is important to note that **dθ/dt** (the change of runway angle) includes both the altitude and the sink rate. These state variables were found to be important for de decision of flare timing. Therefore, **dθ/dt** cue is a suitable candidate cue.

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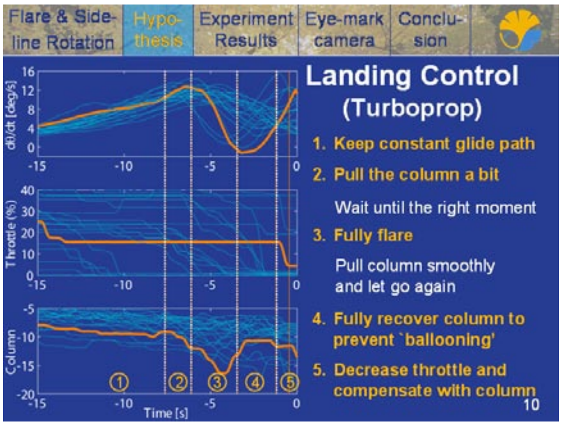

From the research I presented last year, I found that column control is closely related to the **dθ/dt** cue. It seems that the pilot typically controls the aircraft like this.
Not only for the Turboprop (JAXA's MuPal-alpha, a Dornier 228-200), but also for a Boeing 767, the pilots seem to fully flare at a certain value of **dθ/dt**

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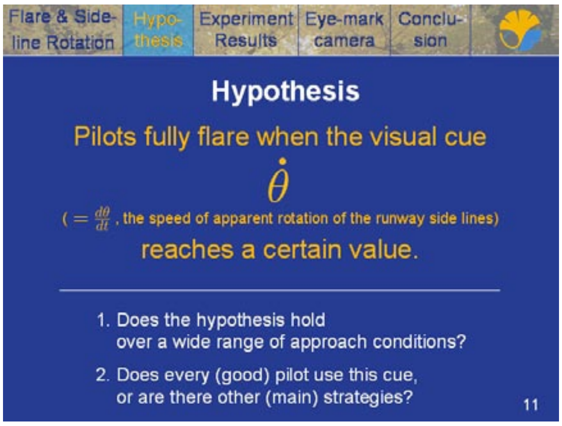
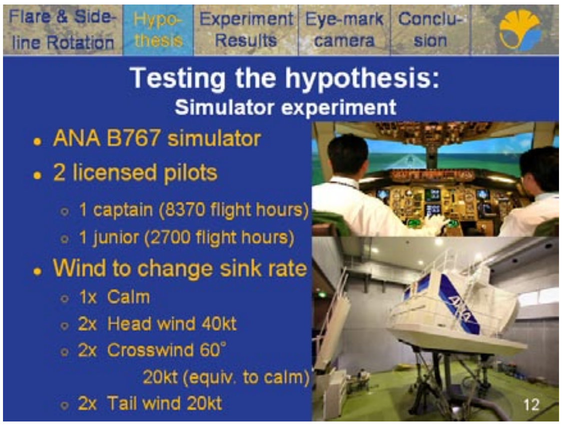
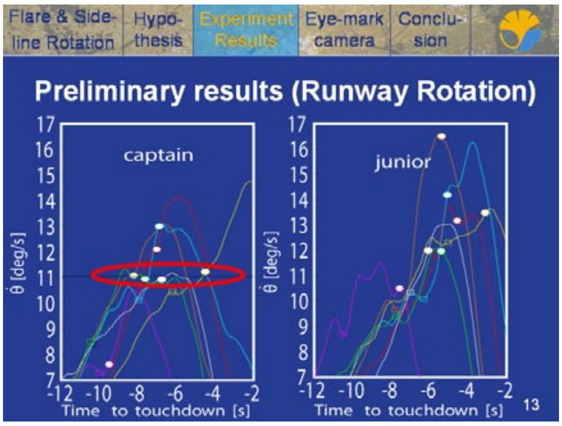


This lead me to the hypothesis that "pilots use the **dθ/dt** cue to time the (full) flare initiation"

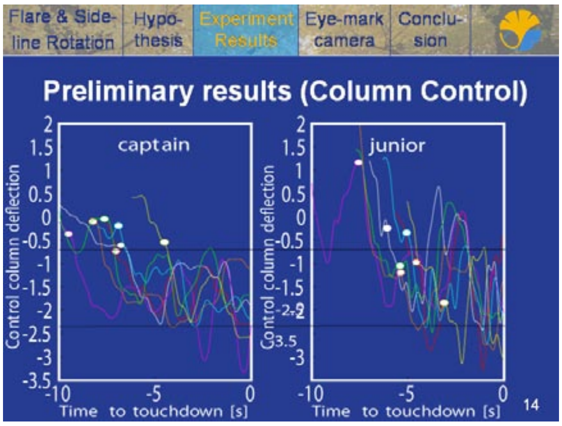
This raised 2 questions that require further investigation

12 

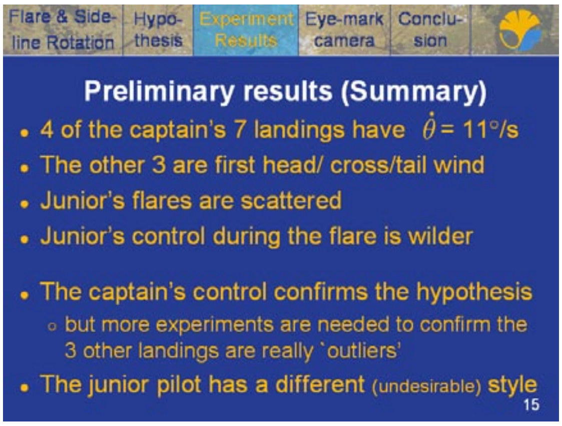
I designed a special experiment for the ANA B767 simulator with 2 pilots.
To create various conditions, we need different (nominal) sink rates, because these influence the cue value.
Most researchers use different glide slope angels in their experiments to get different sink rates, but professional pilots only use angles of about 3 degrees, so having very different angles will not give "natural" data.
Therefore I decided to use wind (another option would be aircraft weight) to get different sink rates

13 

4 full flares of the captain are initiated tat the same **dθ/dt**. The other 3 of the captain's landings have outlier **dθ/dt** values at flare initiation. These 3 times were the first headwind landing, the first crosswind landing, and the first tailwind landing. The junior pilot's flares are initiated at seemingly arbitrary **dθ/dt** values

14 

The captain's control during the flare (lower graphs) is more sophisticated, while the junior pilot's control is a bit wild (high frequency adjustments, high amplitudes)
I also did several statistical analyses, see the accompanying paper.
These are only few data sets ◊ more experiments needed

15 

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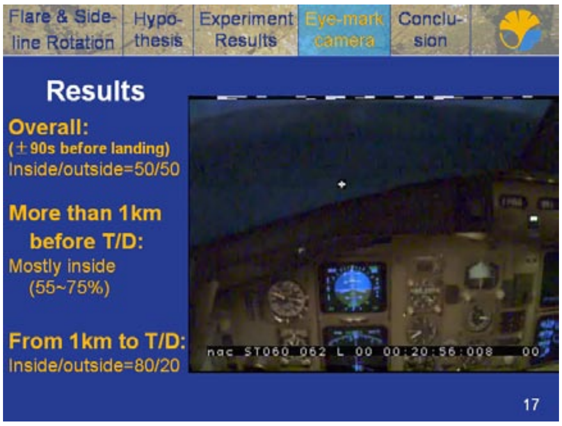
We also did a few simulator landings with an eye-mark camera, to find out where the pilot is looking during the final approach. From literature we know that the last 200ft (60m) altitude, the pilot mostly uses visual cues, and not instruments. Training manuals also state that the pilot should look at the aimpoint markers first, and in the last 200ft (vertical) shift his gaze to the end of the runway, for proper pitch control.

We did the eye-mark recording sessions without motion simulation to have a more stable image. However, in the de-breefing pilots noted that the landing without motion felt very different than with motion. They also said the use the instrument panel more if motion lacks, and even with motion simulation, they still use it more than in the real plane, because the simulated motion lacks proper g-forces.

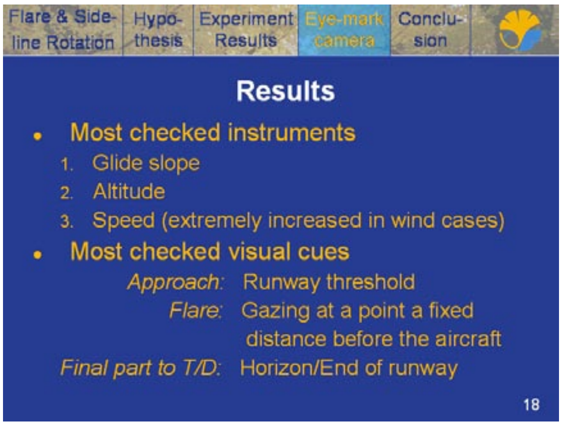
17



Results of the eye-mark camera experiments:
About 1km the touchdown point, the aircraft passes the "Middle Marker" beacon, a light flashes and there is an audio warning.
(This point 1km before the touch down point is passed at ca. 50m altitude = 150ft altitude.) I used this to split the "early" and "late" phase of the landing. For the "early" phase, 50s is analyzed.

Inside/Outside refers to the pilot focusing inside or outside the cockpit, that is, whether he watches the instruments or the visual scene (cues)

18



The most checked were glide slope, altitude and airspeed, all combined in the EFIS/Flight Director display. Attitude (pitch, roll) was also checked quite often using the Flight Director display. Especially in the cases with head and tail wind, the pilot checked airspeed very often and for long times, while altitude and glide slope were checked much less.

In the time before and during the flare, the pilot is not changing his gaze and even doesn't blink for a long time. His gaze fixed relative to the aircraft, and thus "travels along the runway".

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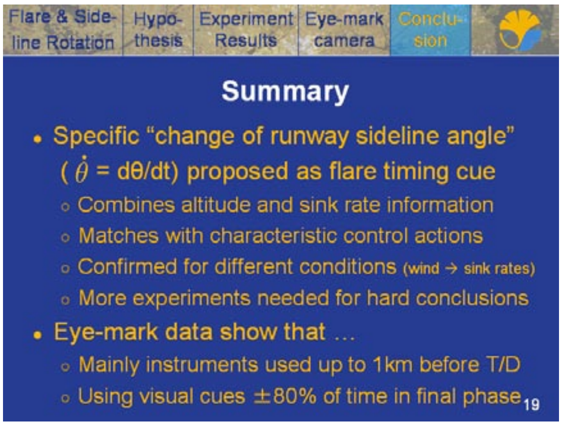

Mainly instruments used up to 1km before Touch Down (Extreme instrument use in wind cases, esp airspeed)
Using visual cues ±80% of time in final phase (Even when no motion is available and the pilot needs to get more info from instruments)

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Future work

- Another experiment has been done recently
  - ANA B767, different (captain) pilot
  - Wind and aircraft weight varied across cases
  - →This data has to be analyzed
- More data is needed because the above mentioned data is only a few landings.
- Write my thesis…

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東京大学

Session D.7 (#1)

Thank you
for your attention

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