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AN OVERVIEW OF FLARE TECHNIQUES AND FLARE TRAINING METHODS

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Abstract

It seems there are almost as many flare techniques as there are flight instructors. A problem with most popular techniques is that they are presented as "every time right" "perfect landing" methods, without discussing their suitability or limitations regarding differences in airplane type, environmental factors, pilot capabilities, etc. Another problem is that some flare techniques are basically theories derived from geometrical relationships, and lack any human factors and aircraft dynamics considerations. Scientific research on flare techniques is scarce, and the available literature generally focuses on verifying the effectiveness of a specific method, rather than comparing benefits and limitations of several techniques.

In this paper we provide an overview of flare techniques found in literature and explain each technique's strengths and weaknesses. In addition, we will provide some suggestions for flare training and initial results of validation experiments of new training support tools.

Keywords: Landing flare, Round-out, Flight training, Manual flying skill, Human pilot control

1. Background

More than half of the civil aviation accidents (55%) are in the "Runway Safety" category, which includes runway excursions and incursions, undershoot/overshoot, tail strike and hard landing events [1]. The improper timing or execution of the flare maneuver can cause almost any of these events. Given that the flare is known to be one of the most difficult tasks that a pilot must routinely execute [2], it is likely that improving flare skills will lead to a significant reduction of accidents [3].

Unfortunately, the flare is notoriously difficult to learn, and to teach. There are at least three reasons for this. One is that the flare lasts only a few seconds of at least a few minutes of flight, making it very inefficient to train intensively. Another reason is that in this short time close to the ground, decisions and control should be based on mostly visual information, since there is no time to read and integrate information from the cockpit instruments, and the accuracy of instruments at such low heights is generally insufficient anyway. Explaining how to 'see' (or maybe better 'sense') ego-motion and the aircraft state from the rich out-of-the-window visual scene is difficult due to a lack of vocabulary, personal differences in perception, and the fact that most expert knowledge is acquired through extensive experience and mostly subconscious rather than explicit. A third complicating factor may be the perceived workload or stress, further fueled by the time pressure and the possibly severe consequences of mistakes.

With this paper we aim to create an overview of the various flare techniques and flare training methods found across training literature, research, and 'pilot talk'. We believe there is no one-size-fits-all solution for the flare, and that each technique has its strengths, weaknesses, and limitations. The real mastery of the flare therefore probably lies in understanding how multiple techniques can combined to achieve the best result given the behavior of the aircraft in its current configuration, in the current environment, with the current pilot. The more tools you have in your toolbox, the better you are equipped to solve a variety of problems.

On the other hand, having to learn how to use all those different tools at once may overload the trainee and be inefficient. This brings us to some questions like:

- What is the best order to teach the various flare techniques? Which are complementary and which are exclusive?
- When practicing flares during ab-initio training in a small single-engine airplane, should a trainee starting a career as a pilot for a major airline practice the same techniques as a trainee for who the private license is the final goal? (Techniques specific to small aircraft might need to be unlearned when transferring to multi-engine or jet aircraft, which would be inefficient.)
- Which personal differences could affect the suitability of certain techniques for certain pilots? (For example differences in perception, learning style preferences, or physical abilities.)
- How can the communication (instruction, discussion, feedback) between the instructor and the trainee be improved?
- Which training tools are available and how could they be applied to improve training efficiency?

We realize that with this paper we will only be able to provide a starting point to answer these questions and we hope researchers will pick up on this and collaborate to complete the picture.

2. Disclaimer

Although we do hope that actual trainees and pilots will find this paper useful, please thoroughly discuss with your instructor before trying out any of the techniques introduced in this paper. This is in the first place an academic publication to identify opportunities for further research. The authors are *NOT* certified flight instructors.

3. Flare Definition & Terminology

In the final approach to landing, the pilot tries to make the airplane descend along a straight line, called the glide slope or glide path (Fig. 1). We call this phase the **'Glide'** (which is consistent with the Airplane Flying Handbook of America's Federal Aviation Administration (FAA) [4], although others sometimes refer to it as the 'descent'.) If the pilot would maintain this path until hitting the runway, the sinkrate at touchdown would be too high and the pitch may be too low, causing a hard landing, nose wheel landing, or crash. Therefore, shortly before touchdown, the pilot pulls the control column to initiate the **'Flare'**. Pulling the column causes an increase of the pitch angle, resulting in an increase of lift and therefore a reduction of the sinkrate. If the timing, amount, and duration of the pulling action are coordinated perfectly, the resulting flare will be a fluent transition from the glide to a smooth but not too soft **touchdown**.

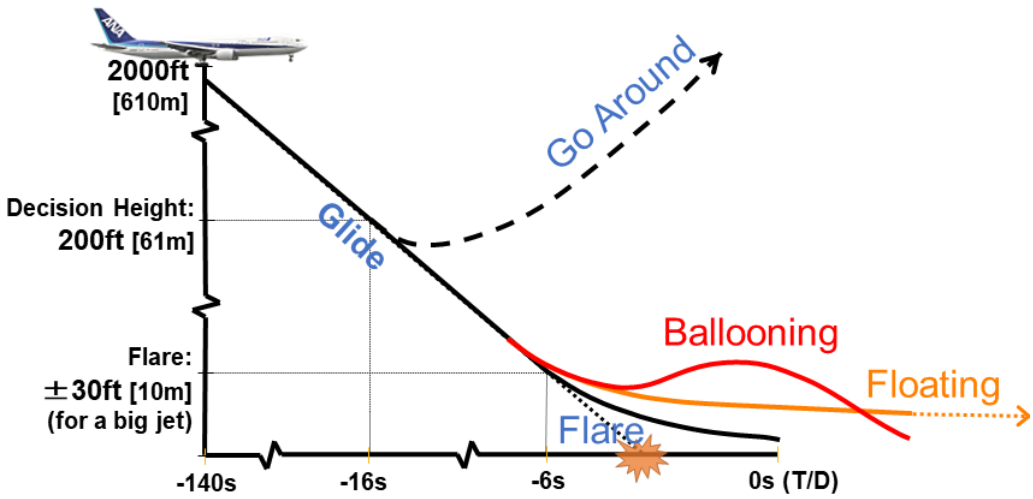

Figure 1 – Ballooning and Floating

A too early and/or too strong flare may result in **'floating'** or even **'ballooning'** (Fig. 1), increasing the risk of runway overrun and hard landing (in the case of ballooning). Even if the landing is smooth, a too soft landing is undesirable because the relatively high remaining lift and low pressure on the landing gear wheels may make it difficult to effectively brake and steer the aircraft, possibly leading

to runway excursions. A too late or to slight flare may lead to a hard landing, and a too late and to strong flare may lead to a hard landing or tail strike.

The flare maneuver is also called 'level-off' or 'round-out'. Although some make a distinction between these terms (e.g., [5]), the FAA uses the terms flare and round-out interchangeably [4]. We use the term flare to refer to the whole phase between the glide and touchdown. The distinction between flare, level-off, and round-out may be meaningful in a particular flare style where the flare phase is subdivided into 2 steps: an initial **level-off** phase which aims to change the flight path from the glide to a horizontal flight path just above the runway, and a subsequent **round-out** phase where the pitch attitude is further increased, eventually resulting in touchdown.

For simplicity, we have not included the change of power (thrust) during the flare phase in the discussion above. Obviously, the change of power will affect the total energy of the aircraft and therefore the speed and/or sinkrate. In addition, a change of power may result in a change of pitch due to the vertical position of the propeller(s)/engine(s) with respect to the center of gravity of the aircraft. The timing and speed of the power cut-off (change to idle), as well as the response delay of the propeller(s)/engine(s) may therefore be important to take into consideration as well.

4. Flare Techniques

Various techniques have been described in literature to guide the pilot in deciding when (where) to flare, and how to execute the flare. We first provide a list of the techniques we identified and then discuss each one in more detail in the following subsections.

This list should be not be considered as definitive, but rather as a work-in-progress. We may have missed some techniques or cues, and certainly more rigorous analysis will be needed to further identify strengths, weaknesses, and limitations for most items. For example, we did not evaluate the suitability of each method for special cases like crosswind landings, and we only just started to identify the floating/ballooning tendencies.

Phased Flares

Level-off & round-out / Holding-off (§4.1.1)
First reducing power to idle while pulling the column to change to a (nearly) horizontal flight path just above the runway, then pulling more to cause touchdown.

Sinking-sensation (§4.1.2)
Pull yoke at a specific altitude and obtain a constant pitch rate of ca. 5°/s, when the sinking sensation stops, keep the pitch constant and reduce the throttle to idle.

Cues for Initiation & Execution

Altitude (§4.2.1)
Flare at a specific height above the runway

Ground Effect (§4.2.2)
Flare when you start feeling the ground effect.

Jacobson Flare (§4.2.3)
Flare when a specific point along the runway passes the lower windscreen edge.

Runway Widening/Expansion (§4.2.4)
Flare when the runway zooms in size.

Aiming Point / Flight Path Vector (§4.2.5)
Pull the yoke so that center of expansion of optical flow changes from the aiming point markers to the far end of the runway.

Tau (τ) Flare (§4.2.6)
Flare at specific time to contact.

Theta-dot ($\dot{\theta}$) Flare (§4.2.7)
Flare at a specific speed of increase of the apparent angle between the runway sidelines (angular rate). This may also be observed as upward optical flow in peripheral vision.

Column movement

Smooth yoke movement (§4.3.1)
Pull the yoke once, smoothly.

2-step / 3-step flare (§4.3.2)
Pull the yoke in 2 or 3 steps, possibly relaxing it (partially) in between.

Fanning (§4.3.3)
Pulling and relaxing the yoke briefly many times.

4.1 Phased Flares

Although in general it is said that the ideal flare is a 'smooth transition', some methods explicitly specify sub-maneuvers.

4.1.1 Level-off & round-out / Holding-off

This seems to be the most commonly taught method for flaring light general-aviation aircraft. Unfortunately, there is no agreement on of the naming of the distinct sub-phases . For example, Machado [6] calls them Roundout & Flare, Langewiesche [7] calls them Level out & Holding off, and Benbassat et al. [5] call them Leveloff & Roundout. Note that 'Roundout' may refer either to the first or to the second sub-phase.

The first step is to reduce power to flight-idle and pull the column to reach a pitch angle of 0° (from a normally negative pitch angle during approach for light aircraft). Due to the lack of power, the aircraft will continue to sink, but much slower than during the glide phase. In the second step, the column is pulled more to further reduce speed and achieve a positive pitch angle, so that the aircraft will touch down on the main gear first.

Conditions

- Light aircraft

Issues

- Creates a 'floating' phase in between the two sub-maneuvers, excessive floating is not good.

Benefits

- Creates a 'floating' phase in between the two sub-maneuvers, which gives trainees or lesser experienced pilots time to asses the situation.
- May prevent ballooning (*"It is possible that many pilots simply skip the level off phase and attempt to immediately round out the aircraft. This tendency may lead to ballooning, especially because most trainee pilots approach at high velocity."*[5])

4.1.2 Sinking-Sensation based Flare

The Sinking-Sensation based flare consists of the following steps (values for a large jet airliner):

1. At 50 ft, prepare mentally & assure a stabilized approach (path, pitch, thrust)
2. At 30 ft, start pulling the column. Try to keep a constant pitch rate of ca. 0.5°/s
3. When the sinking sensation stops (no details provided on the cues used), keep pitch constant.
4. When managed to stabilize pitch at a constant angle, reduce the throttle to idle (and pull the column to maintain the pitch angle)
5. In windy/gusty conditions or low approach speed, one may keep some power on
6. Just before touchdown, reduce pitch a bit

This method results in a fixed flare initiation timing and fixed flare speed, but varies the flare amount (final pitch angle) and throttle idle timing.

Conditions

- Originally proposed for large jet aircraft. Not verified for light aircraft
- Manual throttle control

Issues

- Tendency to float/balloon (see §6.1), possibly due to the slow response of large aircraft to control inputs.
- Not clear which cues are used, in particular to assess the sinking sensation. (Possibly the automated radio-altitude call-outs are used for flare initiation and the height of the horizon for pitch and pitch rate.)

Benefits

- Fixed recipe simplifies decision making
- Late power-cut is good for jet aircraft (re-applying power in the case of a go-around will take time, so throttle should only be set idle if landing is certain)

4.2 Cues for Initiation & Execution

4.2.1 Altitude

The idea that there would be an 'ideal' flare initiation altitude is tenacious. Training literature and operation manuals generally mention a specific height above the runway at which the flare should be initiated [e.g., 8, 9], and researchers often evaluate subject performance based on it. As mentioned earlier, a slightly early flare may be compensated by executing it slower, or a somewhat late flare may be executed quicker.

The FAA provides a rough range and acknowledges the difficulty of actually *perceiving* altitude when they write: *"When the airplane, in a normal descent, approaches within what appears to be 10 to 20 ft above the ground, the round out or flare is started."* Other sources also acknowledge the flare should be initiated earlier or later than this 'ideal' altitude depending on various conditions like approach path, weight, wind speed, runway slope, etc., which basically all come down to variations in effective sinkrate. Airbus also mentions high airport elevation as a reason to initiate the flare earlier [8].

Use

- Flare initiation timing.

Conditions

- Calm wind conditions.
- Close to the ideal sinkrate and airspeed.

Issues

- Since altitude itself is not directly observed, it will have to be estimated from other visual cues like the apparent angle θ between the runway sidelines, the level of textural detail of the ground surface, whether objects of known height stick out above the horizon or not, etc. This will need to be learned and estimates are likely to remain quite inaccurate.
- If altitude is estimated from the apparent angle between the runway sidelines, estimates may be too high/low when approaching narrower/wider runways than usual (runway width illusion [10]).
- The eye height of the pilot is different from the gear height above the runway and depends on the pitch angle (if the cockpit is significantly ahead of the main gear).

Benefits

- Simple to understand and convey.
- May be useful as a rough indication, when used in combination with other cues.
- Automated altitude call-outs (as available in large jets) may be used as a cue for flare initiation. Actually, the time between subsequent callouts also gives a rough indication of sinkrate, so it could even be used during the flare execution. Freshmen jet pilots seem to use this [11].
- Does not depend on the glide path (works anywhere along the runway, not only when aiming at the aiming point markings).

4.2.2 Ground Effect / Boundary Layer Effect

This is a 'seat-of-the-pants' cue. It suggests to initiate the flare when you start feeling the ground effect [5, 12].

The Ground Effect occurs because the local airflow cannot have a vertical component at the ground plane. This restriction will alter the wing up wash, down wash, and tip vortices compared to free airflow conditions at higher altitude. More specifically, a reduction of the induced drag of the wing results in improved lift, which is noticeable from a height about half of the wingspan of the aircraft. It increases the tendency to 'float'.

A different effect, but somewhat similar in result, is the Boundary Layer Effect. This occurs in windy conditions. As the wind flow experiences some friction over the ground plane, wind speeds decrease at lower heights. When making a (headwind) approach to landing, the sudden reduction of headwind will cause a forward acceleration and therefore a tendency to float.

Whether these two effects can be used as a cue or not, they are important effects to understand and mitigate during the flare execution to ensure they don't adversely affect the resulting flare path but work with you instead [13, 14].

Use

- Flare initiation timing.

Conditions

- Both effects are more likely to be felt in low-wing light aircraft than in high-wing or larger aircraft.
- Steady wind (no gusts).
- No higher than usual sink rates (no steep approaches).

Issues

- Both effects are relatively small and may be hard to judge accurately, particularly in windy/turbulent weather.
- Both effect may occur too late to be actually useful as a cue.
- Ground effect will be different for low-wing and high-wing airplanes.
- Ground effect may be less over grass, water, or uneven surfaces than over a paved runway.

Benefits

- As a vestibular (motion) cue it can be perceived independent from most other flare initiation cues.

4.2.3 Jacobson Flare

Since the flight path angle is shallow in the final approach phase (e.g., 3°), the forward distance to the touchdown point is much larger than the vertical distance (about 20 times for a 3° path). Based on this fact, the Jacobsen Flare uses the forward distance as a cue for the flare initiation timing, rather than the vertical distance (altitude) [15].

In essence however, the Jacobson Flare is the same as the Altitude flare. From the supposedly 'ideal' flare initiation height, a specific point along the runway center line is calculated by triangulation in advance [16, 17]. The pilot initiates the flare when this point disappears below the lower edge of the windscreen (Fig. 2).

Although the way of timing the flare initiation is original to the Jacobson Flare, the flare execution part is simply the Aiming flare that is mentioned later (§4.2.5).

Use

- Flare initiation timing.

Conditions

- Assumes that forward distance and height above the runway are perceived with similar accuracy.
- The pilot has to calculate and comprehend the specific point in advance.
- Pitch must be stable.

Issues

- Sensitive to changes in the pilot's eye position w.r.t. the windscreen.
- Does not work with glide path offsets (i.e., when not actually moving toward the intended aiming point).

Benefits

- Based on simple triangulation and easy to calculate the point of flare initiation if the conditions changed.
- Does not depend on the width of runway.
- Relatively robust to changes in glide path angle.

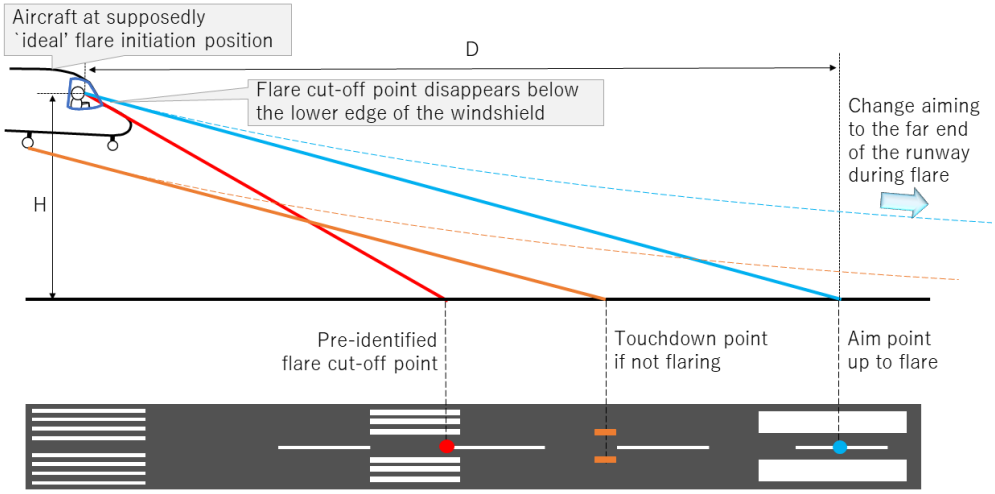

Figure 2 – The basic principle of the Jacobson Flare. Note that due to the shallow approach (glide) path of only a few degrees, distance D is much larger than height H. (Sizes and angles are not to scale. The indicated flare cut-off point and touchdown point are for illustrative purposes only, not for reference in actual flight.)

4.2.4 Runway Widening/Expansion

The apparent width of the runway increases when getting closer to it. The expansion rate isn't linear at all, and the 'Runway Expansion Effect' refers to the sudden increase in expansion rate that can be noticed short before impact (Fig. 3). It is also described as the sensation that *'the runway zooms in size'*. It is said that it can be used as a visual cue for flare initiation [6, 18]. During the flare execution phase, sinkrate should be decreased so as to keep the expansion rate constant.

Often the apparent width at the near runway end (threshold) is mentioned to quantify the runway expansion effect, but it should be kept in mind that for most approaches the aircraft will pass the runway threshold at ca. 50 ft height, so the threshold is typically not visible around the ideal timing for flare initiation. The apparent width at the position of the aiming point markings is therefore a more likely guideline. Rather than a perceived width, this cue is sometimes quantified as the visual angle Ψ between the points on each runway sideline beside the aiming point marker and the pilots' eyes [19].

The Runway Expansion Effect method is somewhat similar to the Tau Method (§4.2.6) and the Theta-dot Method (§4.2.7) in the sense that they all use time derivative information. The Runway Expansion Effect uses the differential of runway width, Tau uses the gap closure rate, and the Theta-dot Method uses the time derivative of the apparent angle between the runway sidelines.

Use

- Flare initiation timing.
- (Flare execution).

Conditions

- Light aircraft (because the effect is strong only close to the ground, whereas large jets flare at much higher altitudes).
- Close to ideal glide path and airspeed.

Issues

- Refers to a sensation, there is no clear quantitative indication of 'how fast is fast' (see Fig. 3). Although the method is often illustrated with an S-shaped curve [e.g. 6], both the apparent width and expansion rate actually get infinite when passing the reference point. The flattened top of the S-shape only results from the pilot's initiation of the flare.
- Not a general method but focuses on light aircraft (low flare altitude).
- Although often mentioned, it has been little researched.
- Available research suggests it is only effective when little scene detail is available [19].

Benefits

- The principle itself is relatively easy to understand and convey.

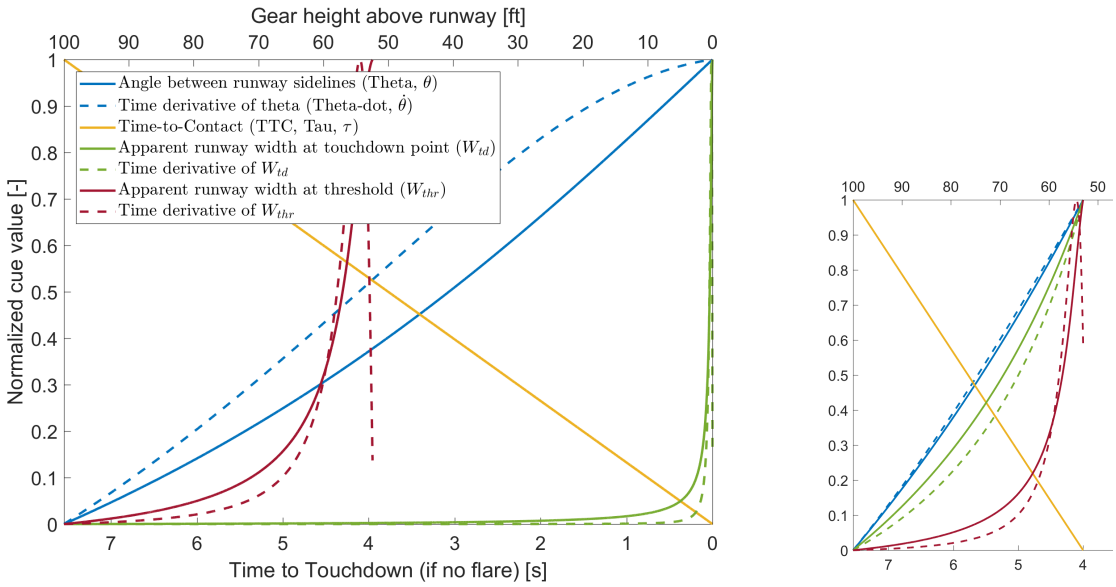

Figure 3 – **Left:** Comparison of several visual cues that may be used for flare initiation timing or flare execution. All values are normalized for easier comparison. Note that the apparent runway width at the threshold won't be visible below ca. 50 ft altitude. Also note that the same parameter measured at the touchdown zone will indeed 'suddenly increase sharply', but see how the image changes when normalizing to only the values up to 4 s before touchdown (**Right**).

4.2.5 Aiming / Flight Path Vector

The Aiming method cannot tell a pilot *when* to initiate the flare, but it can provide guidance throughout the flare. In this method, the pilot pulls the yoke to change center of expansion of optical flow from aiming point markers (the reference target during the glide phase) to the far end of the runway [10].

The center of expansion of the optical flow is the point one is moving towards (Flight Path Vector). If pitch, roll, and yaw are constant, this is the only point in the visual scene that remains in place. Although this may sound cryptic, the 'optical flow' will be immediately recognizable when moving through a (virtual) dot cloud. Learning to identify this center of expansion of the optical flow or 'aiming point' in naturalistic scenes requires a bit of practice, but can be trained (§6.2).

The 'Aiming' method is sometimes also referred to as the 'Gentle Touch' technique [20, 21], and used as the method of choice during the flare execution in the Jacobson Flare method [15].

Use

- Flare execution.

Conditions

- Stabilized pitch and yaw (and to a lesser extent roll).
- 'Sufficiently wide' field of view.

Issues

- Takes some practice to learn to find the aiming point in naturalistic scenes.
- Aiming flare doesn't tell you the when to initiate the flare.

Benefits

- Aiming skill will benefit maintaining a stabilized approach along a constant glide path as well.
- Simple to convey and relatively easy to execute.
- Less risk of floating and ballooning compared to the sinking-sensation method (§4.1.2 & §6.1).

4.2.6 Time-to-Contact / Tau (τ) Flare

The 'Time to Contact (TTC)' or τ can be calculated by dividing the remaining distance by the current speed (assuming constant speed). If we fly a straight path toward the aiming point markers, we can divide the height above the runway by the sinkrate, or equivalently the distance to the aiming point marker by our groundspeed. The TTC might be used as a cue for flare initiation [22] or flare execution [23].

Use

- Flare initiation timing.
- Flare execution.

Conditions

- Unclear (since it i unknown how the TTC is actually perceived).

Issues

- It assumes constant speed (no deceleration).
- It is not clear how the TTC could be observed, and therefore how its use could be trained. Research on Tau is academic and consistently focuses on measured aircraft state variables (distance to aiming markings, speed, and sinkrate) without considering practical visual information. It is supposedly an innate ability to detect the TTC from optical flow, which would imply that anyone could flare naturally without extensive practice.
- Although some research suggested that τ would be used by pilots during the flare execution [24, 25] the found relationship may as just well as well be the result of 'natural', smooth control based on some other cue or objective [26].
- Research showed that not exactly the TTC, but a similar combination of altitude and sinkrate information is used [27].

Benefits

- Conveniently integrates altitude and sinkrate information
- Sounds plausible (but may be hard to use in practice)
- Might be useful on grass-fields where no runway is clearly visible but detailed ground texture is.

4.2.7 Theta-dot ($\dot{\theta}$) Flare

As mentioned in §4.2.1 , the height above the runway can be estimated from the apparent angle between the runway sidelines θ (Fig. 4). Theta-dot ($\dot{\theta}$) is the time derivative of this angle [28]. It is the rate at which the apparent angle increases if you look at the far runway end or the horizon, or the angular velocity (rotation rate) of the sideline if you look to the side at either sideline. It may also be observed as an upward optical flow in the (far) visual periphery [11].

Similar to the Time-to-Contact parameter τ, Theta-dot conveniently integrates altitude and sinkrate information, so that a higher sinkrate will automatically lead to an earlier flare.

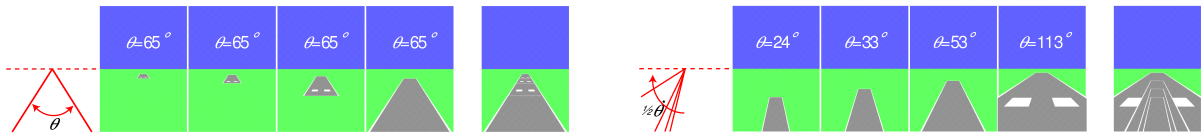

Figure 4 – **Left:** The apparent angle between the runway sidelines θ does not change with pure forward motion (level flight). **Right:** With (pure) vertical motion at a constant sinkrate, the angle changes at a faster and faster rate $\dot{\theta}$.

Use

- Flare initiation timing.
- Flare execution.

Conditions

- 'Sufficiently wide' field of view (if peripheral vision is used).

Issues

- Uses the runway sidelines, so estimates may be too high/low when approaching narrower/wider runways than usual (runway width illusion [10]).

Benefits

- Conveniently integrates altitude and sinkrate information.
- Does not depend on the glide path (works anywhere along the runway, not only when aiming at the aiming point markings).
- Multiple ways to visually perceive.
- Uses the runway sidelines, which are always clearly visible, even at night (although not on grass-fields).

4.3 Column movement

4.3.1 Smooth yoke movement

It is often suggested that the control column should be pulled 'smoothly', 'continuously' or 'gradually' in the flare [e.g., 4].

Conditions

- (none identified)

Issues

- Although a smooth fight path transition may be ideal, this does not necessarily mean the control input also needs to be smooth.
- Smooth and slow (low frequency) control inputs may lead to over-control (in particular in slowly responding large aircraft).

Benefits

- Possibly lower physical workload.
- Then intent of emphasizing smooth yoke movement might be to warn against *pushing* the column during the flare (as one might do in reaction to ballooning) but to *keep pulling*, although maybe slightly less.

4.3.2 2-step / 3-step Flare

This describes a pre-flare, main flare, and fine-tuning flare style. The level-off & round-out style is discussed in §4.1.1. Multi-step flares have been observed in landings of transport aircraft by various researchers [e.g., 11, 29, 30].

Conditions

- (none identified)

Issues

- Smooth control seems to be preferred in general.
- Effect when used in combination with fly-by-wire systems is unknown.

Benefits

- A pre-flare helps to judge the aircraft's response in the current configuration and environment.
- Fine-tuning the flare after initial execution can prevent hard landing, floating, and ballooning.
- Accepting updates may reduce the stress to get timing & strength correct from the start.

4.3.3 Fanning

Fanning *"involves pulling the yoke or joystick aft [(and release)] in small increments during the roundout and landing flare, giving the elevator surface the appearance of moving up and down just like a fan [6]."* This method is suggested only for initial training purposes, as it allows the trainee to see the discrete effect of each control input and learn the relationship between control inputs and aircraft state in the landing configuration.

With larger aircraft, in particular jet airliners, the aircraft response to the pilot's control inputs is so slow that a high-frequency control input like fanning or doublet control will smooth out naturally. This will allow pilots to achieve a quicker aircraft response by making a large initial control input, followed quickly by an opposite control input to prevent overshoot [31]. It must be noted however, that large control inputs during the flare are generally undesired, and may have unanticipated effects when used with fly-by-wire control systems.

Conditions

- Specific use for training.

Issues

- Increased pilot workload.
- May lead to over-control (including stall or ballooning) if too slow or too large amplitude.

Benefits

- Easier to try-and-error with many small increments, than to input the exact right amount of control from the start.
- Quicker response of the aircraft without overshooting (if executed properly).

5. Flare Training

Some literature discussing the effects of specific flare training aids or environments is available. This includes for example the effects of simulated motion (vestibular cues), additional or reinforced visual cues (including head-up-displays), scene detail, and providing specific (graphic or numerical) feedback. We will add some suggestions for exercises that may improve the recognition of various visual cues that can be used for the timing and/or execution of the flare.

5.1 Prolonged flare

There are (at least) two variations of this training method, but the common idea is that a prolonged flare gives the trainee more time to grasp the visual information and understand what the flare feels and looks like. This is particularly useful in real flight, since the time spent in the flare is typically less than 1% of a practice flight. One way to achieve a prolonged flare is by not reducing throttle before or during the flare [32]. Another is "Hepp's roundout-flare technique"[33], essentially a no-flap landing, which gives more time in the flare phase and less other taskload (like flap & speed changes).

Pros

- Can be used in real flight.
- Less distraction from other tasks and more time to focus on the look & feel of the flare .
- Transfer of skill to normal flares has been confirmed in practice.

- No-flap landings need to be taught anyway (to mitigate flap failure), but is normally taught at a later stage.

Cons

- No scientific evidence of effectiveness was found (but sample size was small and effects may have been confounded by other factors) [32].
- Higher sensitivity to pitch control.

Remarks

- The higher required pitch attitudes may obscure more of the runway. This means the trainee will need to rely more on peripheral vision. This may seem to be a con, but it could also be seen as a pro, since practicing the effective use of information from the visual periphery is also thought to benefit flare skill.

5.2 Simulator training

Although the common impression seems to be that simulators are not close enough to the real aircraft for effective flare training [e.g., 34], there is little research available to substantiate this claim. On the contrary, a study from almost half a century ago [35] already indicated training transfer ratios around 1 for landing training in general (including flare & touchdown) while this ratio dropped to less than 0.6 if the flare & touchdown were not part of the simulator training. A transfer ratio of 1 here means that 1 hour of simulator training saves 1 hour of real flight training to achieve the same proficiency. Considering that simulator time is cheaper and can be used more efficiently than real flight time, even transfer ratios significantly smaller than 1 may already be cost-effective. With the much improved visuals and large fields of view of today's simulators, it is likely that entry-level simulators can already be a useful training tool [25].

A side-note must be made that trainees might also develop simulator-specific flare techniques, which could negatively transfer to real landings [36] (i.e., it takes additional time to unlearn the undesired behavior). It is therefore important not to over-train to perfection in simulation. We suggest to reconsider research and simulator evaluations to clarify the suitability of modern simulators for flare training, and the right type and amount of simulator training to optimize skill transfer.

Pros

- Cheaper than training in a real aircraft.
- Training time can be used more efficiently than in a real aircraft by focusing only on a specific phase or maneuver.

Cons

- Not all cues are available (e.g., natural vestibular motion cues, binocular depth perception).
- Simulator time can often not be credited towards certification requirements.

Remarks

- The key is the training transfer ratio. If simulator use can reduce the number of real flight hours needed to reach a qualification, a cost-benefit analysis should be made. If trainees develop simulator-specific behavior, this may need to be unlearned in real flight and therefore prove counter-effective.

5.3 Aiming practice

Aiming is an important skill in the glide phase, where the center of expansion of the optical flow (the flight path vector) should coincide with the aiming point markings on the runway. During the flare, the aiming point should be shifted gradually to the far end of the runway in order to achieve a shallower flight path. To achieve this, the first step will be to learn to recognize the aiming point, because only after it is perceived it can be evaluated and used to generate corrective control inputs. In real flight training, the instructor may deviate from the glide path on purpose and ask the trainee to tell where the actual aiming point is (e.g., on the threshold, on the aiming point markings, on the 1500ft markings, etc.). Obviously, the same can be done in a flight simulator or flight training device

(FTD). Our research shows that even practicing glide phase aiming skills with a simple laptop 'game' has a positive effect on the amount of floating and ballooning in simulated landings (see §6.2).

Pros

- Can be practiced in real flight, in a simulator or FTD, or even on a laptop or tablet.
- Transfer of skill to simulator landings confirmed.
- Also useful to improve glide phase control / stabilized approach.

Cons

- Effectiveness not (yet) verified in real flight training.

Remarks

- The aiming point is easiest to see when the aircraft is stabilized.
- It may be beneficial to start practicing with scenes with rich detail (much optical flow) and gradually reduce scene detail, possibly even to the point where only the runway outline remains (night landing scene).

5.4 Peripheral awareness practice

The runway outline and peripheral vision are often mention as providing the most important visual information for the flare [e.g., 11, 37, 38]. Since our visual periphery is mostly sensitive to motion (optical flow), it is likely that sinkrate related visual information can be perceived well. However, it may also be used to judge height above the runway, since the front-to-back optical flow will be faster lower to the ground [38].

Optical flow in the visual periphery is not something you 'look at' but something you have to be 'aware of' or 'sense'. If we focus too much on what is straight in front of our eyes (foveal vision), we easily miss information from the visual periphery. This can be illustrated by looking at a peripheral drift illusion image [see e.g., 39]. The contrast-rich static image seems to show a motion pattern when viewed (at least partially) peripherally, but when you pick a specific point to focus on and concentrate very hard, the apparent motion can be stopped, only to return when you relax a bit.

It may require some training to develop a technique to allow peripheral information to come in while simultaneously judging for example pitch or aiming using foveal vision. *"By consciously denying the urge to fixate on our touchdown point, by consciously keeping our gentle scan going, we also allow the capabilities of our peripheral vision to apprehend and pass along information regarding height, relative motion and perspective in a useful form. This becomes particularly critical when faced with an up-sloping or down-sloping runway that gives us the illusion of either being too high or too low on approach. [40]"*

Pros

- Can be practiced anywhere (e.g., when walking through the house or riding a bicycle).
- Extra important in aircraft where the engine cowling blocks the straight-ahead view.
- There is some indication that lower touchdown sinkrates are achieved by trainees who show a faster pupil size increase during the flare, and the faster pupil size increase also seems to be related to the use of peripheral vision [41]. However, this effect is only noticeable after subjects have roughly mastered basic flare skill.

Cons

- There is no guidance on what is desirable, what should be 'sensed' and how. Effects cannot be quantified easily.
- Might distract from teaching other (foveally observed) information.

Remarks

- May be more difficult for older trainees or for trainees with corrective eyewear. Research is needed to see whether these groups could also benefit from practice.
- Can be used in conjunction with $\dot{\theta}$ practice (§5.5).

5.5 $\dot{\theta}$ practice

The principle of $\dot{\theta}$ can easily be understood by repeatedly squatting in a corridor, imagining the skirting boards are the runway sidelines. Although the increase of the apparent angle may be small, the upward optical flow in the outer visual periphery will be hard to miss (make sure there is some texture on the walls like bricks, posters, or even just a doorknob). Keeping one's gaze straight ahead at the end of the corridor, one can train the (foveal) perception of the angle's increase rate, while practicing the simultaneous (peripheral) awareness of the upward optical flow.

In order to make judgments based on $\dot{\theta}$, pilots will need to have a reference standard and receive feedback about their own performance. The first part could be achieved by just showing videos of 'good' landing flares or watching an instructor land, but in connection to the second part it seems desirable to quantify $\dot{\theta}$.

An example implementation of $\dot{\theta}$ training is outlined in §6.3.

Pros

- Visual cue strength can be quantified and reference values can be taught.
- Can be practiced in real flight or in a simulator (or maybe even on a laptop or tablet).

Cons

- Requires specially prepared footage and/or simulator flight replays.
- Reference values appropriate for the aircraft are needed. This may require evaluating flare data from a variety of 'good' and 'bad' landings.
- Effectiveness not (yet) verified, but see §6.3.

Remarks

- Can be used in conjunction with peripheral vision practice (§5.4).
- Field of view may influence the training transfer ratio (not investigated yet).

5.6 Cue Augmentation

Training with augmented cues may help trainees to gradually learn how to flare, instead of posing them for an overwhelming problem straight away. The key here seems to be that the augmented cue is only provided when strictly necessary, so that the trainee won't be able to rely on it [42]. In this regard, the addition of flare guidance cues to head-up display (HUD) devices [e.g., 43, 44] may be a worrisome development, as it could lead to further decay of basic flight skill.

Benbassat and Abramson [45] used an auditory cue at the 'ideal' flare altitude to help 26 undergraduate students without prior flight experience learn appropriate flare initiation timing. Auditory cues do not cause any additional visual workload and are processed faster by the brain than visual cues. Compared to a control group receiving 'traditional' instruction (instructor demonstrations and verbal descriptions of when to initiate the flare), students who trained with the auditory cue flared significantly lower and touched down with lower sink rates.

Ravestijn [46] investigated the effect of flare training with emphasized naturally present visual cues, as well as with visual situational-guidance augmentation in a study with 24 novice participants. He reported slightly better performance during approach, on touchdown location, as well as consistency in the throttle closing altitude for the group that had practiced with the situational-guidance augmentation.

Deldycke et al. [47] used off-target haptic cues through a side-stick (i.e., feedback is only felt when making a mistake) to help 16 students without prior flight experience learn both appropriate flare initiation timing and flare execution amount. The provided feedback indicated too early and too late flare initiation, as well as ballooning during the flare. Haptics is thought to be useful to enhance motor-memory followed by developing flare maneuver skill, because the flare maneuver is a perceptual-motor skill. Compared to a control group, students training with the haptic cues could initiate the flare at more correct altitude and no dependency on the haptic aid was found after it was removed.

More literature on cue augmentation for the flare is available [e.g., 17, 48, 49], but this research typically focuses on assistance for landings in degraded visual situations (e.g., rain or fog) during

actual operations, without considering the possible uses for training. We did not investigate these reports in depth, but they might contain interesting leads for further research.

Pros

- Can provide guidance or immediate feedback in the learning phase.

Cons

- Trainees may learn to depend on the augmentation (this risk can be reduced by providing the augmentation 'off-target', i.e., only when outside a nominal/acceptable range).

Remarks

- The usefulness depends on whether the chosen reference is meaningful or not.
- Care must be taken that the augmented cue does not distract from the naturally available cues and does not increase workload. In this sense, haptic and audio cues seem more appropriate than visual or vestibular cues.

6. Experiments & Preliminary Results

In this section we briefly introduce a few experiments we carried out to analyze the differences between flare techniques and to explore the possibilities simple and low cost tools may offer for flare training.

6.1 Aiming vs. Sinking Sensation Flares

6.1.1 Method

Apart from a theoretical analysis of the pros and contras of the different flare techniques, we also carried out some experiments with a veteran pilot in a fixed-base Boeing 747-400 flight training device (FTD). The pilot was comfortable with both techniques from his own flight experience and had also significant experience with both techniques in the FTD used. He was asked to fly 10 landing approaches with each technique.

6.1.2 Result and Discussion

Figure 5 shows a comparison of flight profiles of 'Aiming' and sinking sensation ('Shizumi') style flare control. It appears that the sinking sensation style flare control has a larger risk of floating and ballooning. Interestingly, the pilot had not noticed his floating/ballooning. It should be mentioned that the sinking sensation flare method might give better results in real aircraft, where vestibular (motion) cues are available as well.

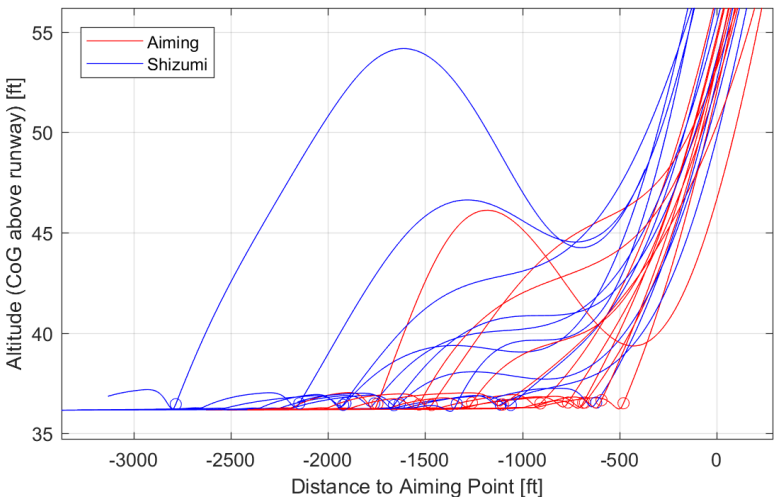

Figure 5 – Comparison of flight profiles of 'Aiming' and 'Sinking sensation' ('Shizumi') style flare control in by a veteran pilot in a fixed-base simulator.

6.2 Quasi-Transfer of Aiming Training Experiment

6.2.1 Method

20 students without flight experience were randomly assigned to a control group (A) who took a brief rest or group (B) who received aiming training. Before and after the rest/training, both groups flew 4 landing approaches to Tokyo Haneda runway 34R in a fixed base flight training device (FTD) with the simulated dynamics of a Boeing 747 and realistic scenery, starting at a height of 600 ft. All subjects were instructed to initiate the flare ('slightly pitch up by pulling the column') around the automatic altitude callouts of 40 ft or 30 ft. Subjects in group B received the additional instruction to change the aiming point from a -3° path to a -1° path (near the far end of the runway) with a visual illustration.

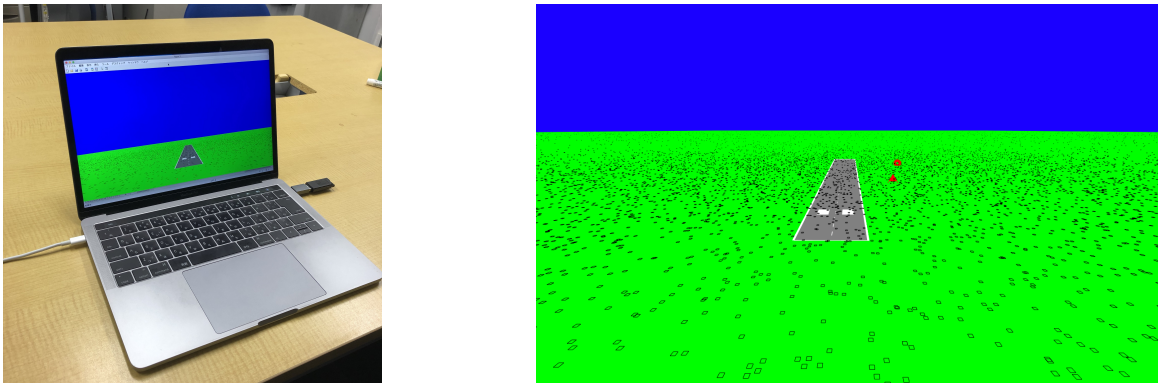

Figure 6 – Aiming training software running on a laptop and a closeup with the subject's guess (red circle) and actual aiming point (red triangle).

6.2.2 Training

The subjects in group B were shown optical flow animations with an abstracted landing scene on a laptop (Fig. 6. The animations represented the cockpit view of straight landing approaches (without flare) to a random aiming point within 2 degrees horizontally and vertically, centered around the runway aiming point markers. The subjects were instructed that they can recognize the aiming point of the aircraft as the center of expansion of optical flow. They were asked to move the mouse pointer across the scene while the animations were moving on and click once they felt confident that they had identified the actual aiming point.

- One set consisted of 20 trial estimations
- Each subjects completed 3 sets
- Subjects were left free in their trade-off between speed and accuracy.
- Each time the subject clicks the point (s)he identified, the correct answer appeared briefly on the display before starting the next trial.
- Subjects received feedback on their overall performance after each set. The feedback included speed, accuracy and bias, all in comparison to a reference data set collected previously from a variety of other subjects.

6.2.3 Result and Discussion

Although the training and experiment focused on the glide phase, we only discuss the effect on the flare phase here. Comparing the before/after flare evaluations of Group A (no training) and Group B (training), the aiming training seems to be effective for reduction of floating and ballooning occurrence (Fig.7).

However two notes must be made here. First, the gap of the before training results between groups A and B is large, indicating that the number of subjects was insufficient. Second, the improvement may have been caused by the improvement of glide path keeping skill, rather than by the

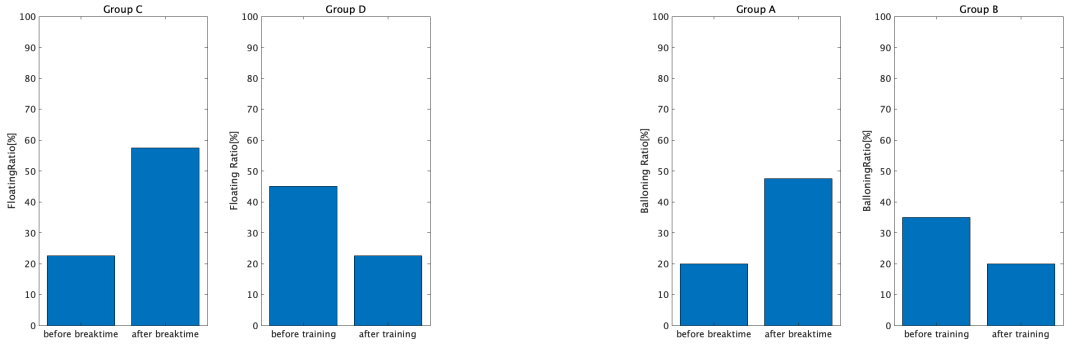

Figure 7 – Group B (training) could reduce the rate of floating and ballooning, while Group A (no training) actually got worse.

improvement of flare technique. Or as they say *"a good landing is usually preceded by a good approach [50]"*. In conclusion, this simple laptop-based software may be effective to the improve aiming flare skill, but more experiments are needed to substantiate this claim.

6.3 Theta-dot ($\dot{\theta}$) Peripheral Vision Training

6.3.1 Method

We developed a tool to train obtaining information for flare control ($\dot{\theta}$) from peripheral vision. Subjects see brief replays of a landing approach around 50 ft above the runway while their foveal vision is obscured. As a reference, they are shown replays representing $\dot{\theta}$= 1, 5, and 10°/s first. Then they have to estimate $\dot{\theta}$ in 20 replays where $\dot{\theta}$ is randomly varied between 1 and 10.

In an initial exploratory study, 2 naive students and 2 students with significant simulated flight experience in our FTD (but no $\dot{\theta}$ training) performed 1 set of 20 trials. A preparatory study with 10 naive subject was carried to verify on-task learning effects and to find an optimal number of sets to be used in a follow-up study. This follow-up study, which is currently being carried out, is a quasi-transfer of training experiment with 20 participants and an experimental design similar to the aiming training study (§6.2). In addition, trainees will see a graph showing how $\dot{\theta}$ changed over time during their landing, allowing them to fine-tune their perceptual-motor skills.

6.3.2 Result and Discussion

The results of an exploratory study show that more experienced pilot trainees perform better on the training task than freshmen (Fig. 8). With the preparatory study we could see on-task learning effects, although there was quite some variation among subjects. As we noticed signs of fatigue during the 4th practice set of 20 trials, we decided to use 3 sets in the upcoming follow-up experiment.

7. Discussion & Final thoughts

In this paper we reviewed a large number of flare techniques, cues, and training methods. Although the ways the information is perceived varies largely, most methods are based on altitude, and often complemented with sinkrate information. Some methods also depend on the longitudinal position along the runway (which may be good or bad, depending on the use case). The runway shape or sidelines and peripheral vision are often mentioned as important sources of information for the timing and execution of the flare [10, 37] and the importance of the runway has been verified in a recent study [51].

A danger of some geometric derivations of ideal flare paths or altitudes is that they do not consider how the pilot should accurately obtain the required information and cause timely actions. In particular for large jets, there may well be a 10 ft altitude drop between the moment the pilot starts pulling the column and moment the flight path starts to change noticeably. Another issue that should be factored in for larger aircraft is that the visual and vestibular cue information will be affected by the pitch, since the pilot's eye position is well in front of the center of gravity (and sometimes also well above it).

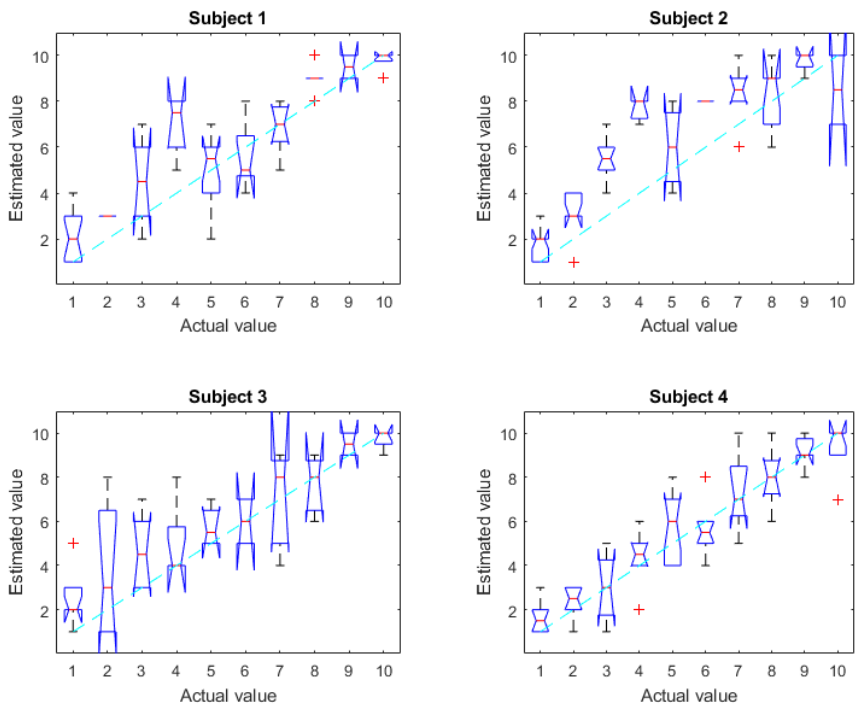

Figure 8 – Actual vs. estimated values of $\dot{\theta}$ from passive observation in peripheral vision of simulated flights around 50 ft above the runway. Upper 2 graphs: untrained subjects. Lower 2 graphs: trained subjects.

Although in this paper we focused on the flare, we should not forget the importance of the preceding phases on the (ease of) execution of the flare. *"A stabilized approach allows us to control and simplify the flow of visual information. [40]"*. Therefore, only training flare initiation without sufficient attention to glidepath corrections may not be effective.

We can conclude that the landing flare is maybe more an art than a science. It is very likely that experienced pilots use multiple cues or methods simultaneously and/or depending on the situation. As long as all parameters remain well within their acceptable ranges, trade-offs can be made between the timing and execution of the flare. The flare may be customized to a specific person's preferences or capabilities, and to the situation at hand. Not everyone perceives things the same way, not all aircraft behave the same way, and not all conditions allow/require the same operations. Still, with more scientific research, we may be able to identify the (safety) limitations of methods or the most efficient way of teaching/training flare skill.

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References

[1] *ICAO Safety Report*. International Civil Aviation Organization (ICAO), Montreal, Quebec, Canada, 2018 edition, 2018.

[2] D. Benbassat and C.I. Abramson. "Landing Flare Accident Reports and Pilot Perception Analysis". *International Journal of Aviation Psychology*, vol. 12, no. 2, pp. 137–152, 2002. ISSN 1050-8414. doi:10.1207/S15327108IJAP1202_3.

[3] L. Wang, Y. Ren, and C. Wu. "Effects of Flare Operation on Landing Safety: A Study Based on Anova of Real Flight Data". *Safety Science*, vol. 102, no. November, pp. 14–25, 2018. ISSN 18791042. doi:10.1016/j.ssci.2017.09.027.

[4] *Airplane Flying Handbook (FAA-H-8083)*. U.S. Department of Transportation, Federal Aviation Administration, Airman Testing Standards Branch, Oklahoma City, USA, 2016 edition, 2016. URL: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/airplane_handbook/media/airplane_flying_handbook.pdf.

[5] D. Benbassat, K.W. Williams, and C.I. Abramson. "General Aviation Leveloff, Roundout, and Accident Rate Analysis". *The International Journal of Aviation Psychology*, vol. 15, no. 2, pp. 189–203, 2005.

[6] R. Machado. *How to fly an airplane handbook*. The Aviation Speakers Bureau, San Clemente, CA, USA, first edition, Mar. 2020. ISBN 9780985932848.

[7] W. Langewiesche. *Stick and Rudder*. McGraw-Hill, 1972. ISBN 0070362408.

[8] R. Geuter, T. Lepagnot, S. Gupta, and M. Le-Lour. "A Focus on the Landing Flare". AIRBUS Safety first, Online, Sep. 2020. URL: https://safetyfirst.airbus.com/a-focus-on-the-landing-flare/, (Accessed 25 June 2021).

[9] Boeing. *747-400 Flight Crew Training Manual*. The Boeing Company, 6th (oct 31, 2007) edition, Oct. 2001. #FCT 747-400 (TM).

[10] J.O. Entzinger and S. Suzuki. "Modeling of the Human Pilot in Aircraft Landing Control". In *Proceedings of the 10th APRU Doctoral Students Conference*. 6-10 July 2009, Kyoto, Japan, Association of Pacific Rim Universities, Jul. 2009. URL: http://jorg.entzinger.nl/. Paper #460.

[11] J.O. Entzinger. *Analysis of Visual Cues for Human Pilot Control in the Final Approach and Landing*. PhD thesis, The University of Tokyo, Tokyo, Japan, Mar. 2010. URL: http://jorg.entzinger.nl/. [English, with abstract in Japanese].

[12] *C-172 Maneuver Description Guide*. Eastern Kentucky University (EKU) Aviation, 2020. URL: https://aviation.eku.edu/sites/aviation.eku.edu/files/files/SEL%20MDG%202020.pdf, (Accessed 25 June 2021). Online.

[13] E. Seckel. "The Landing Flare: An Analysis and Flight-Test Investigation". Contractor Report NASA CR-2517, Princeton University, May 1975. URL: https://core.ac.uk/download/pdf/42889077.pdf.

[14] C. Cutler. "Ground Effect: Why You Float During Landing". Online, Mar. 2021. URL: https://www.boldmethod.com/learn-to-fly/aerodynamics/what-happens-to-your-plane-in-ground-effect-float/?fb_comment_id=3708217942579712_3710152845719555, (Accessed 27 May 2021).

[15] D. Jacobson. "How to Land a Plane: The World's Best Landing Training Technique for Pilots". Online, 2021. URL: https://www.jacobsonflare.com/, (Accessed 21 May 2021).

[16] D.M. Jacobson. "Where to Flare?". In *The 1987 Australian Aviation Symposium*, Canberra, Australia, Nov. 1987. Institution of Engineers Australia. ISBN 0858253577. URL: https://www.jacobsonflare.com/wp-content/uploads/2015/02/1987-11-aust-aviation-symposium-article-optimised.pdf.

[17] L.L. Ngoc, C. Borst, M. Mulder, and R. Van Paassen. "The Effect of Synthetic Vision Enhancements on Landing Flare Performance". In *AIAA Guidance, Navigation, and Control Conference*, Toronto, Ontario, Canada, Aug. 2010. doi:10.2514/6.2010-8170. #AIAA 210-8170.

[18] C. Cutler. "How to Time Your Flare for a Perfect Landing". Online, Jul. 2018. URL: https://www.boldmethod.com/learn-to-fly/maneuvers/

how-to-time-your-flare-and-touchdown-for-a-perfect-landing-every-time/, (Accessed 27 May 2021).

[19] M. Mulder, J.M. Pleijsant, H. van der Vaart, and P. van Wieringen. "The Effects of Pictorial Detail on the Timing of the Landing Flare: Results of a Visual Simulation Experiment". *The International Journal of Aviation Psychology*, vol. 10, no. 3, pp. 291–315, 2000. doi: 10.1207/S15327108IJAP1003_05.

[20] D.P. Robson. "The Gentle Touch". *Aviation Safety Digest*no. ASD 134, Spring 1987. URL: https://www.atsb.gov.au/media/5774830/asd_134_spr_87.pdf.

[21] D.P. Robson. "The Gentle Touch – Landing an Aircraft Safely, Consistently and Well". In *Proceedings of the Australian Aviation Symposium, Canberra, Australia*, Nov. 1987.

[22] G. Ridgway and M. Jump. "Arresting a Descent: What Cues Do Pilots Use to Initiate a Flare Maneuver?". In *AIAA Guidance, Navigation, and Control Conference*, number August, pp. 1–13, 2011. ISBN 9781600869525.

[23] M. Jump and G. Padfield. "Development of a Nature-Inspired Flare Command Algorithm". In *AIAA Guidance, Navigation and Control Conference and Exhibit, 20-23 August 2007*, Hilton Head, South Carolina, USA, 2007. doi:10.2514/6.2007-6769. #AIAA-2007-6769.

[24] M. Jump and G.D. Padfield. "Tau Flare or Not Tau Flare: That Is the Question: Developing Guidelines for an Approach and Landing Sky Guide". In *AIAA Guidance, Control and Navigation Conference*, San Fransisco, 2005. doi:10.2514/6.2005-6404. #AIAA-2005-6404.

[25] S. Palmisano, S. Favelle, G. Prowse, R. Wadwell, and B. Sachtler. "Investigation of Visual Flight Cues for Timing the Initiation of the Landing Flare". Technical Report #B2005/02121, Australian Transport Safety Bureau, Jun. 2006.

[26] A.M. Brouwer, E. Brenner, and J.B.J. Smeets. "When Is Behavioral Data Evidence for a Control Theory? Tau-Coupling Revisited". *Motor control*, vol. 7, no. 2, pp. 103–110, 2003. ISSN 1087-1640.

[27] S. Advani, J. van der Vaart, R. Rysdyk, and J. Grosz. "What Optical Cues Do Pilots Use to Initiate the Landing Flare? Results of a Piloted Simulator Experiment". In *AIAA Flight Simulation and Technologies Conference*, 2012. doi:10.2514/6.1993-3561. #AIAA-93-3561-CP.

[28] J.O. Entzinger and S. Suzuki. "Inside the Pilot's Mind: Visual Information Use in Manual Aircraft Landings". In I. Grant (Eds.), *CD Proceedings of the 28th Congress of the International Council of the Aeronautical Sciences (ICAS2012)*, 23-28 Sept. 2012, Brisbane, Australia, Sep. 2012. Optimage Ltd. ISBN 978-0-9565333-1-9. URL: http://jorg.entzinger.nl/. Paper #173.

[29] R.K. Heffley, T.M. Schulman, R.J. Randle, Jr, and W.F. Clement. "An Analysis of Airline Landing Flare Data Based on Flight and Training Simulator Measurements". Technical Report TR 1172-1R, Systems Technology Inc. / NASA Ames Research Center, May 1982. URL: http://www.roberthefflley.com/pages/bib.htm.

[30] W.J.G. Pinsker. "The Landing Flare of Large Transport Aircraft". Reports and Memoranda 3602, Ministry of Technology Aeronautical Research Council, 1969.

[31] J.O. Entzinger, S. Kamo, T. Uemura, and S. Suzuki. "Objective Evaluation of Hand-Flying Skills and Styles in the Final Approach". In *The 7th Asia-Pacific International Symposium on Aerospace Technology (APISAT2015)*, 25-27 Nov. 2015, Cairns, Australia, Nov. 2015. URL: http://jorg.entzinger.nl/. Paper #534.

[32] W.R. Matson. "Comparative Effectiveness of a Prolonged Flare and Normal Flare on Student Pilot Achievement in the Landing Maneuver and on Time to Solo". Master's thesis, Oklahoma State University, USA, 1973. URL: https://hdl.handle.net/11244/31372.

[33] S. Deener. "Landing with Flair – For a Perfect Touchdown, Slow Down—slowly". *AOPA Flight Training Magazine*, Jun. 2017. URL: https://www.aopa.org/news-and-media/all-news/2017/june/flight-training-magazine/landing-with-flair.

[34] J. Harnagel. "3 Common Limitations of Flight Simulators". Online, 2021. URL: https://landing.redbirdflight.com/posts/3-common-limitations-of-flight-simulators, (Accessed 27 May 2021).

[35] L.E. Ryan, S.P. G., and R.F. Browning. "The Effects of Simulator Landing Practice and the Contribution of Motion Simulation to P-3 Pilot Training". Technical Report ADA061143, US Navy

training analysis and evaluation group, Sep. 1978. URL: https://apps.dtic.mil/sti/citations/ADA061143.

[36] A.G. Barnes and T.J. Yager. "Simulation of Aircraft Behavious and Close to the Ground". Technical Report AGARD-AG-285, North Atlantic Treaty Organization (NATO) Advisory Group for Aerospace Research and Development (AGARD), 1985. URL: https://apps.dtic.mil/sti/citations/ADA153320.

[37] D. Benbassat. "Perceived Importance of the Visual Cues to the Timing of the Landing Flare". *Journal of Aviation/Aerospace Education & Research*, vol. 15, no. 1, 2005. ISSN 2329258X. doi:10.15394/jaaer.2005.1512.

[38] A.H. Hasbrook. "Anatomy of a Landing – Cue by Cue". *Business and Commercial Aviation Magazine*, Aug. 1971. URL: http://avstop.com/ac/landing/anatomy.htm.

[39] S. Beukema, J.A. Olson, B.J. Jennings, and F.A.A. Kingdom. "Pupil Dilation to Illusory Motion in Peripheral Drift Images: Perception Versus Reality". *Journal of Vision*, vol. 17, no. 8, pp. 1–1, 07 2017. ISSN 1534-7362. doi:10.1167/17.8.1.

[40] Principal Air Ltd. Flight Training/Charter. "CFI Insights - The Landing: Part II, Visual Environment". Online, 2021. URL: http://www.principalair.ca/article%20-%20Landing%20Part%202.htm, (Accessed 27 May 2021).

[41] J.O. Entzinger. "Individualized Landing Flare Training Using Both Flight Performance and Psychophysiological Measures". In *20th International Symposium on Aviation Psychology (ISAP2019)*, pp. 19–24, 7-10 May 2019, Dayton, OH, USA, May 2019. URL: https://corescholar.libraries.wright.edu/isap_2019/3.

[42] G. Lintern. "Transfer of Landing Skill After Training with Supplementary Visual Cues". *Human Factors*, vol. 22, no. 1, pp. 81–88, 1980. doi:10.1177/001872088002200109. PMID: 7364448.

[43] M. Jenkins and R.F. Aaron, Jr. "Reducing Runway Landing Overruns". *Boeing Aero Quarterly*, vol. 12, no. 3, 2012. URL: https://www.boeing.com/BoeingEdge/aeromagazine.

[44] Rockwell Collins. "Head-up Guidance System™ (HGS) for Midsize and Light Business Aircraft". HGS-3500 White paper, Mar. 2016. URL: https://www.rockwellcollins.com/-/media/files/unsecure/products/product-brochures/displays/head-up-displays/hgs-3500-white-paper.pdf?lastupdate=20160301112801.

[45] D. Benbassat and C. Abramson. "Errorless Discrimination Learning in Simulated Landing Flares". *Human factors and aerospace safety*, vol. 2, no. 4, pp. 319–338, 2002. ISSN 1468-9456.

[46] C. Ravestijn. "Visually Augmented Simulator-Based Training of the Manual Landing Flare". Master's thesis, TU Delft, The Netherlands, 2016. URL: http://resolver.tudelft.nl/uuid:2339ce7d-73a0-4f68-b7ad-db1f23b7ceca. Embargo until 2021-12-21.

[47] P.J. Deldycke, D. van Baelen, D.M. Pool, M. van Paassen, and M. Mulder. "Design and Evaluation of a Haptic Aid for Training of the Manual Flare Manoeuvre". In *AIAA Modeling and Simulation Technologies Conference*, 2018. doi:10.2514/6.2018-0113.

[48] R.R.D. Arents, J. Groeneweg, C. Borst, M.M. van Paassen, and M. Mulder. "Predictive Landing Guidance in Synthetic Vision Displays". *The Open Aerospace Engineering Journal*, vol. 4, no. 1, pp. 11–25, sep 2011. ISSN 18741460. doi:10.2174/1874146001104010011.

[49] M. Jump and G.D. Padfield. "Progress in the Development of Guidance Strategies for the Landing Flare Manoeuvre Using Tau-Based Parameters". *Aircraft Engineering and Aerospace Technology*, vol. 78, no. 1, pp. 4–12, jan 2006. ISSN 0002-2667. doi:10.1108/17488840610639618.

[50] L. Bjork. *Piloting Basics Handbook*. McGraw-Hill, 2001. ISBN 0071361049.

[51] D. Benbassat, A. Konopasky, and T. Dong. "Ranking Pictorial Cues in Simulated Landing Flares". *Aviation Psychology and Applied Human Factors*, vol. 11, no. 1, pp. 23–32, 2021. doi:10.1027/2192-0923/a000205.