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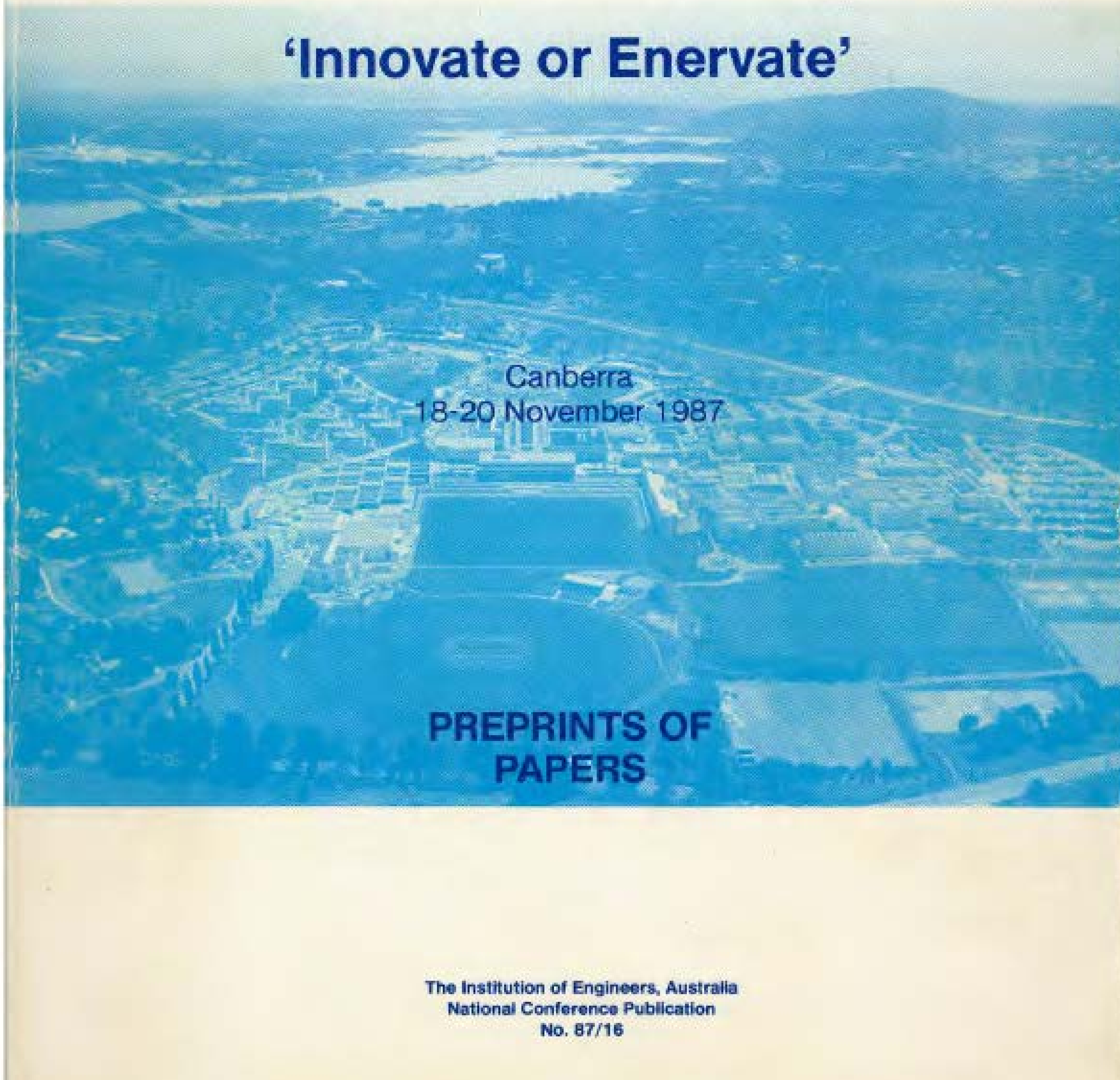

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WHERE TO FLARE?

KEYWORDS: Landing flare, visual cue, motion parallax, perception, pilot-portable training, consistency, safety.

ABSTRACT: In an age of technical precision, the critical landing flare manoeuvre remains imprecise. Existing flare techniques involve a critical estimation of height above the landing surface. This is very difficult to achieve *with consistency*, and is subject to a large number of variable factors, summarised as aircraft, pilot, and environmental.

This paper discusses the development of a practical technique for establishing a consistent flare point, which does *not* rely on the pilot's peripheral perception of vertical height. It embraces the physical principle of motion parallax to provide a simple cue for commencement of the flare. No device or modification is required and, therefore, no costs are incurred.

Major advantages over existing techniques are:
1. Most of the variables affecting perception may be discounted.
2. Elementary and advanced pilot training is simplified for student and instructor, reducing time and costs.
3. This technique is "pilot-portable" and may be developed and applied to successive aircraft conversions, when a pilot is usually, although temporarily, out of his "comfort zone".
4. Pilots who fly infrequently, such as private pilots and managerial pilots, are afforded increased confidence in their "next landing", due to an increased probability of success.
6. Safety is enhanced.

REFERENCE: JACOBSON, D. M. (1987) Where to Flare?

1 INTRODUCTION

Of all manoeuvres performed in fixed-wing aircraft, the landing flare is an enigma. It is critical to the safe and satisfactory conclusion of flight and yet, historically, has attracted little serious attention.

Student pilots and experienced pilots alike find it, at times, alternatively satisfying and frustrating, simple and complex, safe and hazardous. In Aviation Safety Digest Number 129 (Winter 1986) the Australian Bureau of Air Safety Investigation identified *improper landing flare* as the *third most significant* of 13 factors in instances where pilot factors were assigned to accidents involving private pilots.

In an age of technical precision, this critical manoeuvre remains imprecise. Existing flare techniques involve a critical estimation of height above the landing surface. This is very difficult to achieve *with consistency*, and is subject to a number of variable factors, summarised as aircraft, pilot, and environmental.

This paper discusses the development of a practical technique for establishing a consistent flare point, which does *not* rely on the pilot's perception of height. It embraces the physical principle of motion parallax to provide a simple cue for commencement of the flare. No device or modification is required and, therefore, no costs are incurred. Safety is enhanced and the technique is "pilot-portable".

2 NOMENCLATURE

2.1 Definitions

Touch point:	The pre-determined point of contact with the landing surface.
Aim point:	Intercept of pilot-eye path and landing surface; the visual centre of expansion (flow pattern); the origin of the X and Y axes.
Flare point:	The position where the approach to the aim point is discontinued and the flare commenced.
Cockpit cut-off angle:	The lower limit of pilot vision through the windshield.
Flare cut-off point:	The intercept on the landing surface of the cockpit cut-off angle projected from the flare point.
Eye path:	The locus of the pilot's eye.
Flight path:	The locus of the aircraft mass, here considered synonymous with eye path.
Landing surface:	A plane surface suitable for a landing.
ΔAim:	The distance on the landing surface from the touch point to the aim point.
ΔFlare:	The distance on the landing surface from the aim point to the flare cut-off point.
Main-wheel path:	The locus of the main wheels.
Impact point:	Intercept of main-wheel path and landing surface, assuming no flare.

2.2 Appendix Notation

X_e, Y_e:	Pilot-eye co-ordinates of flare point.
X_w, Y_w:	Main-wheel co-ordinates at flare point.
y_h:	Pilot-eye height above main-wheel on a stable approach in the landing configuration and attitude.
ΔX:	Distance on landing surface between the aim and impact points.
x_1, x_2:	Component lengths of ΔX.
γ (gamma):	Flight path angle, from horizontal.
κ (kappa):	Cockpit cut-off angle.

3 THE LANDING FLARE

3.1 Current Practice

The landing flare is one of the last critical phases of flight to which the term "seat of the pants" may still be applied. The vast majority of landings, world-wide, are practised by pilots utilising only their highly developed judgement, co-ordination, experience and skill.

Existing flare techniques, for a given aircraft, involve a critical estimation of height above the landing surface (Y_e), something very difficult to achieve *with consistency*. This estimate is subject to many variable factors including, but not limited to:

- aircraft type
- aircraft size
- aircraft configuration
- glide path angle
- pilot total experience
- pilot recent experience
- pilot experience on aircraft type
- pilot seating position
- pilot performance
- landing surface specification
- landing by day or night
- visibility and other weather considerations.

Historically, instruction in determining a suitable and consistent flare point has been inadequate, to say the least. We are attempting to recognise and extract one flare point from a fairly wide range of acceptable flare circumstances. The best that instructors have been able to manage, collectively, is to demonstrate a suitable flare point *for a particular aircraft* as being "about here"!

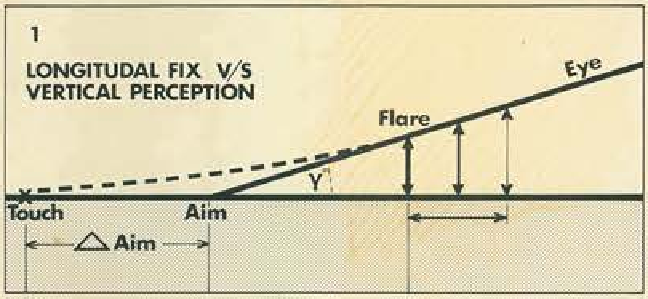
The student pilot has no proper model except in his memory, and that in itself is inconsistent. Trial and error is the arbiter in determining the soundness of his developing judgement. Unfortunately, even after the basic skills are mastered, the problem still exists, because every aircraft type requires a different flare height. As a pilot converts to successive aircraft types, he faces the same problem over and over. He has no proper model at the very time he needs one most, and there lies a clue.

Just as the student pilot consolidates his flare-height judgement, so does the experienced pilot after conversion to another aircraft type. After a time, he becomes comfortable with his aircraft (if he consolidates and flies regularly), and can land it as well as any flown previously. Probably, this is a subconscious recognition of something, visible to the pilot through his windshield, that is providing a vital cue for the flare. Obviously, to achieve consistency, some recognition and quantification is necessary.

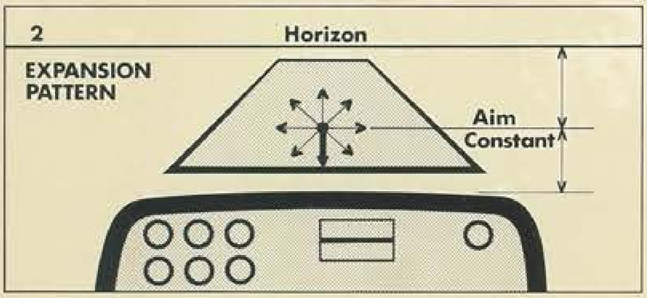
3.2 Another Way

When properly taught, pilots have little difficulty with the concept of selecting and flying an approach to a nominated aim point on the landing surface. With or without glide-slope guidance, pilots learn to fly a reasonably consistent and stable approach angle to the aim point.

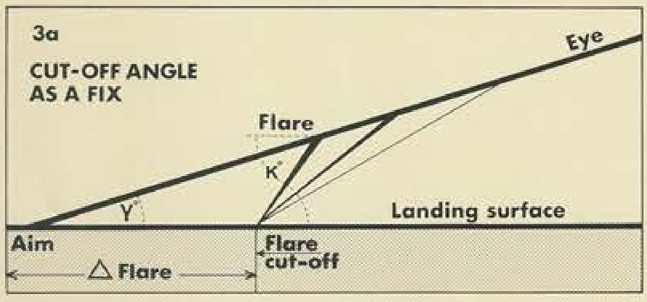
Accepting that the glide angle may be reasonably fixed within normal tolerances, it follows that any point located longitudinally on the approach path, short of the aim point, will correspond with a particular vertical height. Therefore, a flare-height fix of greater consistency than is possible using mere perception could be provided by a suitably chosen point along the approach path and overflown by the aircraft. See Figure 1.



Much has been written on the subject of the aim point being the centre of expansion of a flow pattern, providing the pilot with a visual illusion as points surrounding the aim point accelerate radially outwards as the aircraft approaches the ground (motion parallax). Points beyond the aim point will appear to move upward from the aim point, while points short of the aim point will appear to move downward. It is a point in this "six o'clock" sector of the pilots' view which has proven useful. See Figure 2.



If such a point were selected and could be simply identified, a consistent longitudinal fix for the flare point for a given aircraft could be obtained as this pre-selected point appeared to move down the windshield (due to increasing depression angle) to the point where it reached the lower cut-off angle (limit depression angle) of the cockpit. This angle is dictated by the geometry of the pilot's seating position in relation to the aircraft structure, where, within limits, some design consistencies exist between aircraft types. See Figure 3a.



Calculation of this distance from the aim point to the flare cut-off point, (△Flare), involves energy/geometry considerations, quickly determined in practice with experience, but complicated to derive by analysis.

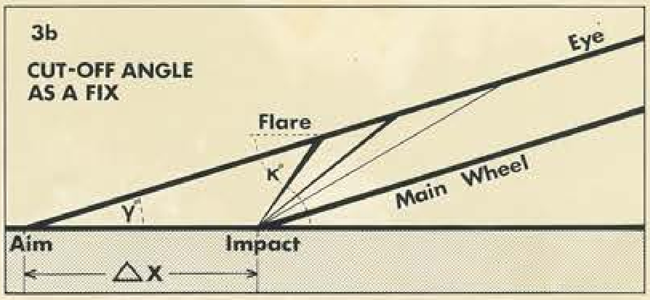
However, a suitable approximation, based on aircraft/approach geometry, and thorough practical testing, has provided a simple and effective alternative technique with near-universal application.

3.3 The Jacobson Flare

On final approach, the aircraft occupies space vertically, in practical terms, between the pilot's eye and the main wheels. Two parallel paths may be traced down the approach path: the upper pilot-eye path intersects the landing surface at the aim point; and assuming, for the moment, no flare, the lower main-wheel path would intersect the landing surface at a point called the impact point.

For a given aircraft type, the distance between the aim and impact points (△ X) has provided suitable quantification for the flare-point estimate. This distance accommodates the critical variables of glide angle (γ°), pilot-eye height above main wheels (y_h), and horizontal distance of main wheels from pilot-eye (x_2).

The flare is initiated when, on a stable approach, the pre-determined impact point, appearing to move downward from the aim point, reaches the cockpit cut-off angle (K°), and disappears from view under the aircraft. In practice, it is the simplest of tasks to notice the aircraft overtake the impact point while flying an approach using standard techniques. It does not detract from the pilot's attention, because the point in question is on the approach centre-line, in the pilot's *normal* field of view. See Figure 3b.



Appendix A details the simple geometry involved, together with mathematical derivations of relevant formulae. The distance between the aim and impact points (△X) is expressed as:

$$\Delta X = y_h \cot \gamma^\circ + x_2 \quad (1)$$

Or, as a practical rule-of-thumb:

$$\Delta X = (y_h \frac{60}{\gamma^\circ}) + x_2 \quad (2)$$

For aircraft types with the main wheels *forward* of the pilot:

$$\Delta X = (y_h \frac{60}{\gamma^\circ}) - x_2 \quad (3)$$

Note that for a standard glide path of 3°

$$\Delta X = (y_h \times 20) + x_2$$

Dimensions x_2 and y_h are noted in aircraft operations manuals or may be simply ascertained, mathematically.

In addition, adequate runway threshold clearance is assured.

Pilot-eye height at the flare point (Y_e) may be expressed:

$$Y_e = \frac{\Delta X}{(\cot \gamma^\circ - \cot K^\circ)} \quad (4)$$

The next important step is to locate the calculated impact point on the landing surface, short of the aim point. Many aviation authorities have developed runway surface markings as distance guides, often at 150, 300 and 450 metres from the approach threshold.

Simple interpolation of these markings by the pilot satisfies the practical requirements for a visual fix along the approach axis. Where distance markers do not exist on a landing surface, the pilot can estimate the position of the impact point using variations in surface colour or texture for identification. For night operations from these surfaces, calculations based on the longitudinal distance between runway-edge lights provide the pilot with a similar cue.

This flare-point concept is extremely tolerant when compared with traditional perception techniques. For a standard 3° glide path any error of judgement of flare height will, within limits, be magnified approximately 20 times, longitudinally. In marked contrast, any longitudinal inaccuracy will be reflected as only five per cent of that figure, vertically. The expanded scale of the approach axis (approximately 20 times the vertical dimension), together with a visual fix, provides a model that is *visible* and which provides unparalleled consistency of judgement for student and experienced pilot alike.

3.4 Non-standard Approaches

For larger aircraft types, the impact point calculated for a normal approach also serves for non-standard landing configurations, with their likely variations in aircraft attitude. An aircraft on approach at a higher attitude (body angle) than normal would require a higher flare point to accommodate the reduced main wheel clearance. The higher attitude self-compensates, because the lower cut-off angle is reached further back up the approach path, providing an earlier cue to flare, as would be expected. The converse also applies.

In the case of a full glide approach (e.g. forced landing), the normal approach impact point displacement, ΔX, applied from the steeper approach path, will once again schedule an earlier flare, as would be expected with the increased rate of descent.

If preferred, new impact points may be calculated.

3.5 In the Flare

Existing techniques provide generally (but subject to certain variations) for simultaneous reductions of rate of descent towards zero and of thrust/power to idle, positioning the aircraft just above the landing surface and converging slightly.

The actual *rate* of flare required depends on a number of variables including, but not limited to:

aircraft inertia
rate of descent
control effectiveness
density altitude
wind-shear effects
pilot reflexes.

Having commenced the flare at the point pre-determined in the above discussion, a further visual cue is available. In his paper, The Gentle Touch, David Robson, a qualified test pilot, has developed a technique to guide the pilot through the flare and on to the touchdown point. As the aircraft is rotated gradually in the flare, the pilot should raise his line of sight and select a new aim point, namely the centre of the far end of the landing surface. By endeavouring to "fly" his eyes towards this aim point, he will be guided to the rate of rotation required to hold off prior to touchdown, while accommodating the changing aircraft attitude.

Selection of *this* aim point has three distinct advantages:

(i) It aids in the prevention of over-rotation, and consequent climb.
(ii) It maintains the aircraft on a shallow angle of convergence with the landing surface, providing protection from too high a flare.
(iii) It promotes touch-down in a reasonable, proportionate distance, self-compensating particularly for reduced landing distances.

4 CONCLUSIONS

This technique is simple, practical and extremely effective. It was developed and tested over a period of three years in many aircraft types, ranging from single-engine light aircraft to large jet transports, by civil and military pilots of varied ages, abilities and experience.

The concept of universal application is not an over-simplification of obvious differences between aircraft; rather, it addresses those differences while consolidating the traditional argument of a basic system of flying which may be adapted as necessary to meet specific requirements.

Current techniques have not developed beyond the idea of an art form. Without taking anything away from a pilot's satisfaction, this flare technique offers the following major advantages:

1. Most of the variables affecting perception may be discounted (especially in poor visibility or at night).
2. Elementary *and* advanced pilot training is simplified for student and instuctor, reducing training time and costs.
3. This technique is "pilot-portable" and may be developed and applied to successive aircraft conversions, when a pilot is usually, although temporarily, out of his "comfort zone".
4. Pilots who fly infrequently, such as private pilots and managerial pilots, are afforded increased confidence in their "next landing", due to an increased probability of success.
5. Experienced pilots can better maintain consistency of standard.
6. Safety is enhanced.

While studies continue, support from all sections of the industry is most encouraging, suggesting far-reaching consequence for fixed-wing aviation.

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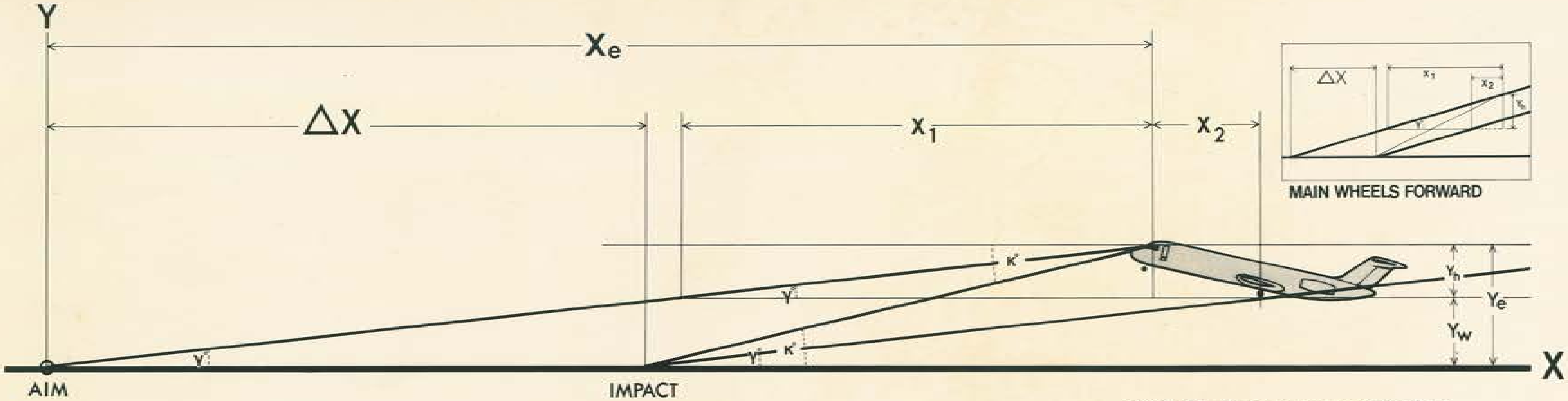

NOTE: Aircraft attitude exaggerated for clarity.

1. SOLVING FOR ΔX:

From above : $\Delta X = x_1 + x_2$

Solving for x_1 ; $\frac{x_1}{y_h} = \cot\gamma$

$\therefore x_1 = y_h \cot\gamma$

Then, $\Delta X = y_h \cot\gamma + x_2$ (1)

In practical terms, a simple rule of thumb may be developed:

Since (for small angles), $\cot\gamma \approx \frac{60}{\gamma}$

Then $\Delta X \approx (y_h \times \frac{60}{\gamma}) + x_2$ (2)

When main wheels are forward of pilot-eye, from above inset,

$\Delta X \approx (y_h \times \frac{60}{\gamma}) - x_2$ (3)

2. SOLVING FOR Y_e:

From above, since, $\cot\gamma = \frac{\Delta x + (X_e - \Delta x)}{Y_e}$

$\therefore Y_e \cot\gamma - \Delta X = (X_e - \Delta X)$ (i)

and, $\cot\kappa = \frac{X_e - \Delta X)}{Y_e}$

$\therefore Y_e \cot\kappa = (X_e - \Delta X)$ (ii)

from (i) and (ii) $Y_e \cot\gamma - \Delta X = Y_e \cot\kappa$

$\therefore Y_e \cot\gamma - Y_e \cot\kappa = \Delta X$

$\therefore Y_e (\cot\gamma - \cot\kappa) = \Delta X$

$\therefore Y_e = \frac{\Delta X}{\cot\gamma - \cot\kappa}$ (4)